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Department of Industrial Management & Logistics

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Framework for Evaluation of Strategies for Pooling of Repairable Spare Parts

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Preface

This Master's Thesis is a part of the examination of a Master's degree in Mechanical Engineering, finished at the Department of Industrial Management & Logistics at Lund University, Faculty of Engineering.

I would like to express my gratitude to all respondents that made time available to provide answers to my questions during the interviews. Among the respondents are various representatives from companies that may benefit from looking into the framework developed in this thesis, and also, consultants located at Systecon head office in Stockholm.

My special gratitude goes to my supervisors; Professor Hans Ahlmann, Håkan Borgström, and Pär Sandin. The primary value that Hans, Håkan and Pär have put in to this thesis is by providing; sharp analysis, new ideas in how to further proceed, and encouragements whenever needed.

I would like to conclude this preface by thanking all the colleagues at the Systecon office in Malmö, and also, to wish the reader a pleasant reading.

7th of May 2010, Lund

Driton Muhaxheri

Abstract

Title: Framework for Evaluation of Strategies for Pooling of Repairable Spare Parts

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Background: The ability to quickly provide parts for the supply of advanced technical systems in equipment-intensive industries (such as airlines and nuclear power plants) is critical to the systems overall performance. In order to maintain a targeted system availability large quantities of spare parts are often required which in turn results in excessive inventory costs. Seeing as inventory systems often account for a large proportion of a business' costs a tough issue faced by companies in these industries is how to reduce the total inventory cost without having a negative impact on the system availability. An approach that may successfully deal with such a problem is *pooling*. Pooling refers to an arrangement in which multiple owners of the same type of technical systems cooperate by sharing their inventories.

Purpose: The theoretical purpose of the thesis is to emphasize different pooling strategies and to identify and assess the characteristics of the strategies. The practical purpose of the thesis is to develop a robust method that facilitates a fair comparison of considered strategies. The objective is thus to develop a generic model that evaluates soft values (here, referred to as *soft aspects*) for each strategy, and also, to put the soft aspects in relation to the annual cost of a strategy in a final model.

Methodology: The initial phase of the thesis was dedicated to a desk study review of current literature within the field of study. Recently published scientific articles, papers authored by consultants at Systecon, and literature used in courses at the Faculty of Engineering at Lund University lay the basis for the theoretical framework. The framework developed is derived from discussions with the supervisors in connection with interviews carried out with; relevant Systecon customers and company representatives at two trade fairs, Offshore Wind 2009 and Nordic Rail 2009.

Conclusion: This thesis presents a framework for evaluation of strategies (stand alone, ad hoc cooperation, cooperative pooling, and commercial pooling) for pooling of repairable spare parts. Characteristics of all strategies are emphasized and assessed. From the characteristics, which are provided in Table 5.3, a model to evaluate soft values of each strategy is derived. The model, named *evaluation of soft values*, is provided in Table 5.4 and Table 5.5. Also, a methodical approach to derive a final strategy is provided in section 5.7. To make sure that a decision-maker is well aware of how the model should be applied, a fictitious case study is build up in where every step of the decision making process is thoroughly described. Furthermore, in the case study a *final model* that facilitates the derivation of a best strategy is presented. By means of a specified weighting coefficient and properly chosen set of scales, the final model provides with a final strategy. The outcome of the final model is based on the outcomes of the cost models and the outcomes of the evaluation of soft values model.

Keywords: MRO, pooling, spare parts strategies, incentives, evaluation, logistics, logistical expertise

Abbreviations

CSI : Customer Satisfaction Index

CW : Central Warehouse

DLT : Delayed Lateral Transshipment

EOQ : Economic Order Quantity

ERS : Equal Relative Savings

FFF : Form-Fit-Function

ILS : Integrated Logistic Support

IT : Information Technology

KPI : Key Performance Indicator

LCC : Life Cycle Cost

LCP : Life Cycle Profit

LSC : Life Support Cost

MDT : Mean Down Time

MLDT : Mean Logistics Delay Time

MoE : Measure of Effectiveness

MRO : Maintenance, Repair and Overhaul

MRUA : Maintenance Related Unavailability

MTBF : Mean Time Between Failure

MTTR : Mean Time To Repair

MWT : Mean Waiting Time

OMAX	: Objectives Matrix
PBTH	: Power-By-The-Hour
Q	: Quality
RoR	: Return on Investment
RPC	: Relative Pooling Contribution
VOL	: Annual Demand Volume
WS	: Work Shop

Contents

1 Introduction

1.1 Background

The ability to quickly provide parts for the supply of advanced technical systems in equipment-intensive industries (such as airlines and nuclear power plants) is critical to the systems overall performance. In order to maintain a targeted system availability large quantities of spare parts are often required which in turn results in excessive inventory costs. Seeing as inventory systems often account for a large proportion of a business' costs a tough issue faced by companies in these industries is how to reduce the total inventory cost without having a negative impact on the system availability. For that reason, a typical problem a decision-maker faces is to determine an optimal stocking level of spare parts. The downtime cost can be huge if stock on hand is not sufficient when demand occurs. On the other hand, the cost of tying up capital in non-revenue-generating spare parts inventories increases when maintaining an excessive number of spare parts.

An approach that may successfully deal with such a problem is *pooling*. Pooling refers to an arrangement in which multiple owners of the same type of technical systems cooperate by sharing their inventories. The aggregated demand volume from different locations in the network facilitates a more efficient supply of spares owing to the economies of scale. There are two distinctive ways of achieving a pooling strategy; one is if independent actors themselves organize a "virtual pool" where spare parts in the network are sent to a requesting location via a lateral transshipment from a location with a surplus of on-hand inventory, and the other way is if a niche company (a third party such as a maintenance company or a manufacturer) provide a commercial pool for the independent locations. The commercial pool is a physical central warehouse that satisfies demand from all participants of the pool.

Systecon AB is a consultancy and software company with world-leading expertise in system logistics, system reliability, maintenance, and Life Cycle Cost analysis. The company's core business is to provide customers with solutions that ensure higher productivity, better system availability, and higher system reliability at the lowest cost possible from a life cycle perspective. In the late 1960's Systecon started to develop the spares optimization software OPUS10. The software facilitates for the decision-maker to determine optimal stocking levels and also to allocate spare parts so a most efficient logistics solution in the network is obtained from a system perspective.

In addition to the *stand alone strategy*, this thesis specifies three different pooling strategies for the availability service of repairable spare parts; *ad hoc cooperation*, *cooperative pooling*, and *commercial pooling*, and finds out which factors contribute to the emergence of a particular strategy. The aim is to contribute to a situation where Systecon can enhance its service offering by not only optimizing the customer's spare parts strategy, but also in the best way to support costumers in the selection, realization and management of a pooling concept.

1.2 Purpose

The theoretical purpose of the thesis is to emphasize different pooling strategies and to identify and assess the characteristics of all four strategies.

The practical purpose of the thesis is to develop a robust method that facilitates a fair comparison of considered strategies. The objective is thus to develop a generic model that evaluates soft values (here, referred to as *soft aspects*) for each strategy, and also, to put the soft aspects in relation to the annual cost of a strategy in a final model.

The models ought to be used by people with logistical expertise, and yet, be comprehensible to people who are not familiar with the area. The output derived from the models should be clear and distinct.

1.3 Delimitations

The thesis is limited to analyze and evaluate four strategies for the availability service of repairable spare parts. In particular, a thorough description of the cooperative and commercial pooling strategy is provided. The focal point of the thesis is the design of two models; a model to numerically translate soft aspects for each strategy respectively, and also, inspired by the *objectives matrix* an additional model is developed that enables the derivation of a final strategy.

Key performance indicators as regards the cost allocation in spares inventory pooling are discussed, however, seeing as it is very time consuming it is outside the delimitations of the thesis to design a cost model for each strategy. Relative costs used in the case study are derived from OPUS10 analysis, while the inputs in the optimization software are based on information obtained from interviews with customers of Systecon. Furthermore; an early purpose of the thesis was to design contractual agreements containing the right incentives for all cooperating parties. Though, difficulties in the initial phase of the thesis in investigating in this area led to the choice of keeping the design of contractual agreements outside the delimitations. Nevertheless, the latter factor in connection with spares optimization software (such as OPUS10) supplement the other factors mentioned above, and thus, makes way for the complete design of an organizational and business model to most efficiently realize and manage a selected pooling strategy.

2 Systecon AB

2.1 The Company

Founded in the late 1960's, Systecon is an independent and employee owned company that provides consulting services in Integrated Logistic Support (ILS) and software products for systems and logistics engineering.

Whilst Systecon has customers from all over the world in many different industries, a special experience level is developed in three particular sectors. The specified sectors below are chosen based on highest interest experienced over the years;

- Defense
- Rail
- Energy

Initially, Systecon's engagement was to work with defense-related ILS projects (i.e. with FMV: Swedish Defense Material Administration), but later expanded to include civil industries such as rail, aviation, and energy production. Systecon provides consulting services, software and training for customers from all over the world. The renewal rate on software upgrade and support agreements is over 95%. Some of the clients are; Alstom, Boeing, Bombardier, Deutsche Luftwaffe, E.ON, FMV, Italian Air Force, Royal Air Force, SAAB, SAS Components, Tetra Pak, Vattenfall, and Volvo Aero Cooperation.

Systecon head office is situated in Stockholm whereas additional two branch offices are situated in Göteborg and Malmö. Through the partly owned subsidiary, Systecon UK that is based in England, Systecon is present in following markets; The United Kingdom, Belgium, France, Luxemburg, The Netherlands, Portugal and Spain. Systecon is also present in other international markets through a global network of qualified representatives that cover parts of these regions; Europe, Asia Pacific & Australia, and Africa. The representatives are situated in, among other countries, Greece, Germany, Italy, Turkey, Australia, Japan, China, South Korea, Singapore, Taiwan, and South Africa.

2.2 The ILS Toolbox

2.2.1 OPUS10

OPUS10 is a world leading spares optimization software that has been developed for more than 40 years to meet existing demands and requirements within different branches, projects and phases of complex technical systems. The optimization algorithms available in OPUS10 make it possible for a customer to decrease stock and reduce the invested capital by as much as 30%. Also, by using OPUS10 customers gain valuable understanding of the support organization and how it affects the performance of the system.

OPUS10 is used throughout a product life cycle, such as in;

- *early logistics studies to:*
    - Calculate Life Support Costs
    - Identify cost effective design solutions
    - Analyze initial support concepts
- *the spares tendering phase to:*
    - Evaluate different proposals
    - Determine optimal initial assortment and allocation of spares
    - Calculate sustainability and endurance
- *the operational phase for:*
    - Optimal replenishment procurements (and stock reductions)
    - Reallocation of existing stock
    - Proactive analysis of logistics improvement.

Results from OPUS10 are illustrated in a cost/effectiveness graph where the effectiveness Key Performance Indicator (KPI) is plotted against the Life Support Cost (LSC).

2.2.2 SIMLOX

SIMLOX is a simulation tool that can be used as a stand alone tool or as a complement to OPUS10 (e.g. to extend and verify the OPUS10 model). By using SIMLOX customers get a good indication of how suggested support solutions of their technical systems will perform in different operational scenarios. Results from SIMLOX, e.g. the state of a system or a resource over time, are illustrated in graphs.

2.2.3 CATLOC

CATLOC is a powerful calculation tool that enables Life Cycle Cost (LCC) / Life Cycle Profit (LCP) analysis and cost estimations for the different phases of the technical systems; development, acquisition, operation, and support during the operative life. Owing to a high degree of flexibility, a CATLOC model is applicable to all different industries and areas. Results from a CATLOC model, the break down of various costs, are quickly provided and illustrated in graphs.

2.2.4 MaDCAT

MaDCAT (Maintenance Data Categorization and Analysis Tool) is a software tool that enables for analysis and categorization of large sets of maintenance data. The main objective of MaDCAT is to analyze a systems reliability development over time.

3 Methodology

3.1 Research Classification

An issue, which you aim to emphasize or solve, is always the starting point for a scientific or research work. There are various types of scientific approaches that are usually categorized depending on the knowledge available in the particular field before the study takes place (Patel et al. 2003). According to Wallén (1996), the level of ambition of a project depends on a high degree on the existing knowledge within the area of interest.

Explorative Research

The study will have an explorative approach when little knowledge in the field of study is available. The main purpose with this approach is to acquire as much knowledge and understanding as possible of a particular issue. The results obtained with the explorative approach often form the base for further studies. Many different techniques to gather information are often applied when the approach is of an explorative nature (Patel et al. 2003).

Descriptive Research

A descriptive approach is suitable when an amount of knowledge regarding the issue already exists. Using this approach one studies in detail a limited number of aspects of the issue. The approach can either describe each aspect separately or provide a description of the connection between all considered aspects (Patel et al. 2003). The approach will only lead to a description of the issue, and not try to further explain it (Lekvall et al. 2001).

Explanatory Research

The explanatory approach regards mapping out the causality between often predetermined factors that are central to the field of study (Lekvall et al. 2001). The "why-issues" are regarded when using an explanatory approach (Wallén 1996).

Normative Research

A normative research is referred to when the aim is to recommend solutions to a problem after predictions of future developments have been made. Thus, the researcher's objective is to illustrate the issue from different perspectives, suggest solutions and to show on the impact of the consequences the respective solution will have on all parties involved (Wallén 1996).

3.2 Research Methodology

Qualitative Method

The approach is of qualitative character when the gathering and analysis of information is focused on "soft" data, e.g. qualitative interviews and interpreting analysis (Patel et al. 2003). The qualitative approach has a holistic view that takes the entire situation into consideration. This approach acquires flexibility and closeness to the information source (Holme et al. 1997).

Quantitative Method

The approach is of quantitative character when the gathering and analysis of information can be expressed numerically. The data obtained will be converted into numbers which in turn will lay the base for statistical analysis to be performed (Holme et al. 1997).

Preparatory Study

When additional knowledge is required, next to knowledge in the existing literature, a preparatory study can be done. A preparatory study can for instance lead to the design of a questionnaire with firm answering options after conducting a small amount of interviews. One can also conclude what the best technique for gathering data is after doing preparatory studies (Patel et al. 2003).

Survey Study

Survey studies are often used to answer questions relating to what, when, where and how in interviews or questionnaires. The studies are performed on a delimited group and make it possible to gather causal information regarding many variables, as well as a vast amount of information regarding few variables. When conducting a survey study a frequent question regards the general applicability of the study: Will the results also apply for parties that did not take part in the study?

Case Study

When carrying out a case study the researcher work on the supposition of a holistic perspective and aims to cover as widespread amount of information as possible. Case studies are often used when the target is to study processes or changes, in which a “case” can refer to an individual, a group of individuals, an organization or a situation. It is common that different techniques, such as interviews, observations and surveys, are combined to collect information in a case study (Patel et al. 2003).

Experimental Study

In an experimental study a few variables are observed while the researcher simultaneously tries to gain control over other factors that might affect the variables of interest (Patel et al. 2003). The experimental study can be carried out in a laboratory, out on the field or as a simulation of a real-life scenario with the help of a computer. The latter calls for a thorough understanding of the scenario in question so a detailed model can serve as an input in the software (Lekvall et al. 2001).

3.3 The Theory-Empirics Relation

Patel et al. (2003) argues that the mission for a researcher consist of relating theory and reality to one another. The groundsheet for the theoretical frame will comprise of empirics, data concerning the field of study, and will provide with as genuine knowledge of the reality as possible. Alternative approaches to relate the theory and empirics are named *inductive*, *deductive* and *abductive*. The sources of information can be of *primary* or *secondary* nature.

Induction

A researcher with an inductive approach will study a phenomenon and so formulate a theory on the basis of gathered empirics, without anchoring the issue to a previous recognized theory. Since the gathered empirics are typical for a special situation, time or a group of people, there is a chance that the researcher will have difficulties in obtaining a theory that is applicable in general. The researcher’s personal ideas and conceptions will inevitably influence the formed theories, even though the approach is of an inductive nature (Patel et al. 2003).

Deduction

A researcher using general principles and already existing theories when studying a phenomenon is said to have a deductive approach. Hypothesis-deductive is an approach wherein hypothesis that will empirically be tested on the field of interest are derived from existing theories. A deductive approach is assumed to strengthen the objectivity in the study since existing theories lay the basis for further research. Existing theories will have an impact in the way the study is executed and can therefore lead to new findings not being discovered, which is considered a disadvantage (Patel et al. 2003).

Abduction

Abduction is described as a combination of induction and deduction. The inductive approach will lead to the formulation of a temporary theory on the base of a single case. Using a deductive approach the obtained theory will then be further developed and thereby more applicable in general after being tested on new cases. The advantage with the abductive approach lies in increased flexibility for the researcher compared to a strict deductive or inductive approach. A drawback could be that all researchers are influenced from former experience which means that no study will start unbiased (Patel et al. 2003).

Sources of Information

Gathered information is categorized in primary and secondary data. Raw data that is collected by the researcher direct from the origin source, e.g. through interviews, is referred to as primary data. Secondary data is existing data the researcher gathers from compiled reports in other contexts, e.g. available statistics or previous studies (Lekvall et al. 2001). Patel et al. (2003) argues that a researcher must critically analyze obtained documents in order to make a fair assessment regarding how likely facts or experiences are to be true. Of central interest for the criticism of the sources is to find out when and where the document is written. Moreover, the researcher must consider the credibility of the author and the purpose of the specific document.

3.4 Research Quality

Reliability

The thoroughness of the researcher when processing information will determine the reliability in the study. High reliability, which ought to be the aim for every researcher, is achieved if several independent measurements on the same observable fact present exactly or nearly exactly the same results. With regard to many factors involved, it is inevitable to avoid errors when gathering and processing information. For this reason, the researcher must aspire to decrease these errors in order for the research study to have an adequate reliability (Holme et al. 1997). In a qualitative study the concept of reliability has a new meaning in comparison with a quantitative study. If a respondent is interviewed on many occasions and the answer to the same question differs every time, then the reliability in a quantitative study is believed to be low. However, in the qualitative study the respondent might have new insights on every occasion, which could instead improve the study. The reliability should therefore be seen in the light of specific circumstances prevailing during the study time when conducting a qualitative study (Patel et al. 2003).

Validity

High validity is achieved if the researcher actually measures what is intended to be measured. Validity is consequently strongly connected to the formulation of the problem and the specific questions the researcher wishes to investigate in. Both reliability and validity have to be considered simultaneously in a research study since the two concepts stand in a certain relation to each other. The meaning of validity in a qualitative study differs in comparison with a quantitative study. High validity in a quantitative study is achieved by studying the right phenomenon, supporting it with a good theoretical framework and research methodology, and by carrying out accurate measurements. Validity in a qualitative study regards the whole research process, not only the gathering of data and is connected to the researcher's ability to interpret many perceptions, although some might be contradictory. Procedures and rules cannot be set to secure the validity since every qualitative study is unique (Patel et al. 2003).

3.5 Proposed Methodology

Literature Review

In order to get familiar with the mission of the thesis the initial phase was dedicated to gather *secondary data* by means of a desk study review of current literature within the field of study. A *deductive* approach is exercised in which the core fraction of the theoretical framework (concerning different pooling strategies) is found in various scientific articles. Remaining theory is primarily found in literature used in courses at the faculty of engineering at Lund University (LTH). Additional secondary data is also gathered from compiled reports authored by employees at Systecon AB.

Interview

Primary data was collected at two trade fairs, Offshore Wind 2009 and Nordic Rail 2009, in which a first round of interviews was conducted. The target was to get a holistic view of the two industries; who the actors are and their views along with attitudes regarding pooling of spare parts. The interviews followed a non-strict template with the aim of covering significant themes.

Further interviews were carried out with personnel at Systecon with the intention of gaining deeper knowledge in what aspects could be of particular importance in different industries. Of interest was also to understand how Systecon will Figure as a supposed third party in a potential implementation of a pooling strategy. For specific information regarding different industries, interviews were conducted with customers of Systecon.

Discussions were also held with personnel at the division of production management at the institute of technology in Lund. Their research is focused on production and inventory control and the intention with the discussions was to get a deeper understanding of the mathematical models used in diverse scientific articles.

Information obtained is mainly of *qualitative* character. *Quantitative data* gathered from interviews held with customers of Systecon (e.g. cost of reaching a targeted service level) that facilitated the structure of the case study are masked. By this means, only relative comparisons or relative numbers can be viewed in charts and graphs.

Framework Design

The framework for developing a model to evaluate spare parts strategies, which is developed from *explanatory* and *normative* reasoning, consists of two models that support a decision-maker to evaluate each of the four different spare parts strategies covered in the thesis.

By means of explanatory reasoning characteristics of all four strategies are assessed and compiled in Table 5.3. The input data is of *qualitative* nature and is mainly gathered from interviews held with representatives from companies at the two trade fairs and from consultants at Systecon, as well as from various sections in the *theoretical framework*. The first model, *evaluation of soft values*, is presented in Table 5.4 (Main aspects) and Table 5.5 (Soft aspects). The model is developed from normative reasoning and derived from the compiled characteristics in Table 5.3.

The *final model*, also developed form normative reasoning, is illustrated in the case study in chapter 6. The aim with the final model is to support the choice of a final strategy by putting the outcomes from the first model in relation to the outcomes from the cost models (not developed here).

Although the models in the thesis are developed by objective means, when used by a decision-maker there is a risk of getting subjective results due to the fact that various scales and weights need to be determined during the decision-making process (see chapter 6.5 Sensitivity Analysis). Hence, there is a need for personnel that possess logistical expertise when using the models in order to diminish the risk of obtaining subjective results.

Case Description

The case study in chapter 6 is fictitious. The commercial aviation industry is chosen due to the fact that the characteristics associated with the industry make way for the choice of one of the spare parts strategies covered in the thesis.

The aim with the study is to demonstrate the use of the models developed in chapter 5, *framework for developing a model to evaluate spare parts strategies*. The case study is developed from *descriptive* reasoning wherein a thorough review of the decision-making process at *Masters Airline* is provided. Qualitative and quantitative data used in the study are obtained from interviews.

Criticism of Sources and Credibility of the Thesis

Literature used in modeling the theoretical framework is authored by persons with substantial knowledge within their fields. Furthermore, the scientific articles are all recently published and some of them are doctoral dissertations. Results obtained in the articles mainly derive from simulation studies supported by advanced mathematical models. Additionally, the authors work in academic environments, e.g. universities, so the probability for distortion to occur due to external influence is supposed to be fairly low. The above-mentioned sources are consequently believed to be of high *reliability* and *validity*.

Interviews and discussions held with internal personnel at Systecon as well as with external parties involve a risk of misinterpreting information provided. An additional important issue regards the provider of information, the respondent. Seeing as pooling of spare parts is a relatively new concept in some industries; to what amount of valuable information does the provider possess and how reliable could the information be?

Most of the interviews were recorded in order to reduce the risk of misinterpretation. Interviews are also compared to each other so a holistic view of the answers from different actors is attained. This, in compliance with discussions with the supervisors at Systecon and LTH is believed to further lower the risk of misinterpreting information.

The second issue concerning the respondents and their possession of valuable information is dealt with by choosing respondents that are well aware of their line of business. Also, respondents from the two trade fairs, Offshore Wind 2009 and Nordic Rail 2009, were keener to provide with as good answers as possible on the interviews after I made them aware that I am a student doing my master's thesis.

Qualitative information obtained from interviews is matched with paragraphs from the theoretical framework with the intention of achieving as high validity and reliability as possible.

4 Theoretical Framework

4.1 Inventory Control

Axsäter (2006) points out that the strategic importance of *inventory control*, e.g. the control of material flow from suppliers of raw material to final customer, is today fully recognized by top management. Potential for improvements in this are high due to large total investment in inventories, and capital tied up in raw material, work-in-progress, and finished goods.

Besides keeping stock levels down to make capital available for other purposes, another objective of inventory control is often to balance conflicting goals amongst functions in the organization. Consequently, inventories should not be decoupled from other functions, e.g. from purchasing, production and marketing.

Economies of scale and uncertainties are two main reasons for holding inventories (Axsäter 2006). Companies can reduce their transactions/set-ups and acquisition price if they order large quantities, owing to the benefits of economies of scale. Uncertainties, that often come in the form of demand uncertainty, variations in order lead-time, uncertain estimates of cost parameters, etc, are likely to influence companies to build up inventories. Conversely, reasons to not hold inventories are high inventory holding cost, in terms of investment cost, inventory service cost, storage space cost, and inventory risk cost. The challenge is therefore to find the optimum where benefits and downsides of holding inventories are balanced (Olsson 2007).

4.1.1 Distribution Inventory Systems

Olsson (2007) points out the structure of a system being one of the most important aspects of an inventory system. Figure 4.1 illustrates the most simple inventory system, a single-echelon, single-item inventory system.

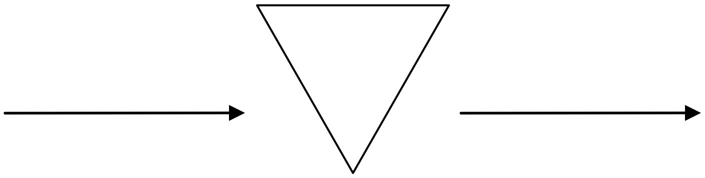


Figure 4.1: A single-echelon inventory system (Olsson 2007).

Coupling two single-echelon inventory systems together provide a *serial system*, where each installation has at most one immediate successor, shown in Figure 4.2. Customer demand takes place at installation 1, which is replenished from installation 2, which in turn replenishes from an outside supplier (Axsäter 2006).

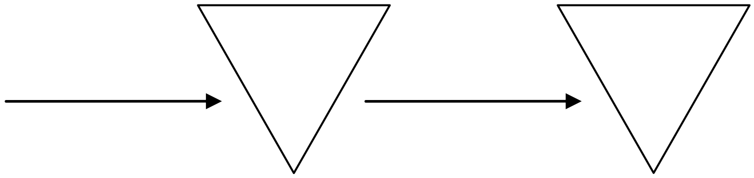


Figure 4.2: An inventory system with two coupled inventories (Axsäter 2006).

A very common physical structure in supply chain networks in connection with distribution of products is the one of *divergent* inventory system. The characteristic with the divergent system is that every installation has at most a single immediate predecessor, also illustrated in Figure 4.3. According to Axsäter (2006), factors such as the structure of the system, the demand variations, the transportation times, and the unit costs will determine the best distribution of the total system stock. In some cases it is more beneficial to keep relatively large stock at the central warehouse, but the optimal solution most often derives from having very low stock at the central warehouse.

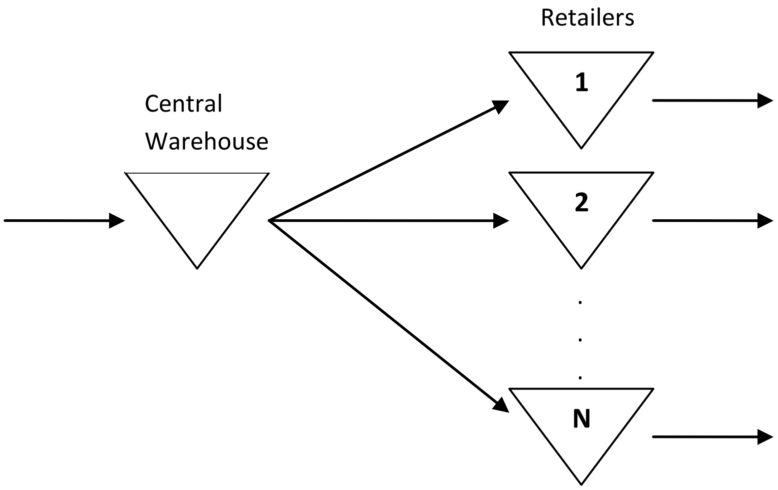


Figure 4.3: A divergent two-echelon inventory system (developed from Olsson, 2007).

The *assembly system* is another model often applied in production where parts are put together into a finished product. Consequently, the number of parallel stocking locations gets successively fewer later in the flow. It should also be noted that a serial system is a special case of an assembly system (Axsäter 2006).

4.1.2 Lateral Transshipments

A way to increase flexibility in a divergent distribution system is to allow stock movements between locations of the same echelon. A location unable to satisfy customer demand initiates an emergency shipment, a *lateral transshipment*, from another location with surplus stock. An illustration of a distribution system where lateral transshipments between three locations are applied can be seen in Figure 4.4.

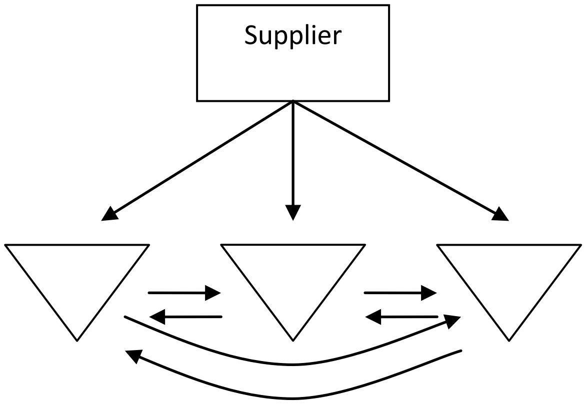


Figure 4.4: Lateral transshipments between three parallel locations (Olsson 2007).

Olsson (2007) states that on the expense of incurred transshipment costs, lateral transshipments will reduce the number of lost sales/backorders in the system. In so doing, better customer service can be achieved without increasing the total stock in the system. Conversely, the same customer service can be achieved with less total stock in the system. A prerequisite when modeling lateral transshipments in distribution systems is that the leadtime for a lateral transshipment should be considerably shorter than the normal supply leadtime.

A *reactive lateral transshipment*, also referred to as an emergency shipment discussed thus far, responds to a situation where a location faces a stock out (or the risk of a stock out). These types of shipments are most suitable in spare parts environment where transshipment costs are relatively low compared to costs associated with holding large amount of inventory and with failing to meet demands immediately, e.g. downtime costs.

Proactive lateral transshipment models are suitable in the retail sector, where handling costs are often dominant. These types of shipments redistribute stocks in predetermined moments in time amongst all locations in an echelon. In so doing, as low handling costs as possible can be achieved. (Paterson et al. 2009).

Alternative sourcing rules can be applied since it is possible to have two or more companies as the source of a lateral transshipment. Lee (1987) considers *maximum stock on hand* and *smallest number of outstanding orders* as two sourcing rules, while Axsäter (1990) applies *the random sourcing rule* in his model. An intuitively better rule applied by Kukreja et al. (2001) and Wong et al. (2005) is *the closest-neighbor sourcing rule*.

4.1.3 Inspection and Ordering Policies

Continuous review is referred to when the inventory position is continuously monitored in an inventory control system. *Periodic review* is referred to when the inventory position is monitored at certain given points in time, often constant time-periods. In both cases, an order is triggered if the inventory position is below a pre-specified amount of stock. Periodic review is a more appropriate inspection policy for items with high demand, while the advantages of continuous review are usually larger for items with low demand.

(R, Q) policy and *(s, S) policy* are the two most common policies in connection with inventory control. In the former policy a batch quantity of size Q is ordered when the inventory position declines to, or below, the reorder point R. Contrary to the case of continuous review, where a quantity Q is reordered exactly when the inventory position hit R, the inventory position will often be below R when time has come for inspection in a periodic review. Consequently, the inventory position R + Q will seldom be reached when ordering a quantity Q in case of periodic review, also illustrated in Figure 4.5. Using a (s, S) policy when placing an order, the order size is set that the inventory position always returns to S whenever the inventory position declines to, or below, the reorder point s. In case of continuous review and continuous demand the two ordering policies are equivalent, given s = R and S = R + Q.

Assuming discrete demand and setting s = S – 1 another ordering policy is attained, the *(S – 1, S) policy*. In spare parts environments where the items are expensive and slow moving, and where the ordering costs are considerably small compared to holding costs and backordering/lost sales costs, the (S – 1, S) policy is very appropriate (Axsäter 2006 and Olsson 2007).

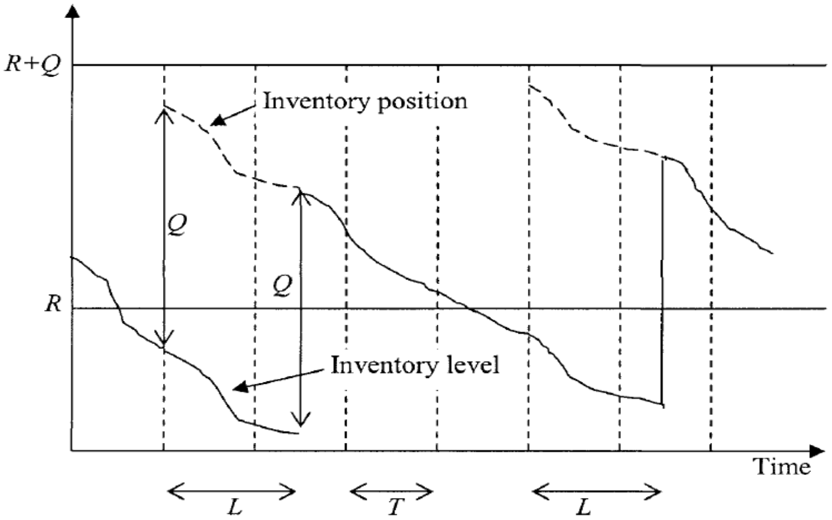


Figure 4.5: (R, Q) policy with periodic review. Continuous demand (Axsäter 2006).

4.1.4 Considered Costs

Axsäter (2006) argues that *inventory holding cost* cover all costs that are variable with the inventory level, e.g. capital cost, material handling, storage, damage and obsolescence, insurance and taxes. The holding cost per unit and time unit, which in general should be significantly higher than the interest rate charged by the bank, is often determined as a percentage of the unit value.

Costs that arise in connection with replenishment of stock are denoted *ordering costs*, which include administrative, material handling, and transportation costs.

Costs associated with inability to satisfy customer demand due to shortage is denoted *shortage cost*. In such case a customer either waits until the item is delivered, which induce a backorder cost for the company, or the customer chooses to buy the item from another supplier, which for the company is referred to as a lost sale. Backorders often lead to extra costs for administration, price discounts for compensating late deliveries, material handling and transportation. A lost sale does not only concern the lost contribution of that particular item but also concern loss of good will, which makes the potential loss of future revenues difficult to estimate. In cases when companies can get hold of the specific item, for example through an emergency shipment (or for example acquire it from the neighboring competitor), the additional cost is set equal to the shortage cost. Shortage costs are in general difficult to estimate in real-life situations and are therefore often replaced by a suitable service constraint.

In addition to the above-mentioned costs, Kilpi et al. (2008) identifies *interface costs* that represent the annual fixed costs of maintaining relationships between cooperating parties, e.g. in a decentralized system. The interface costs are assumed to be proportional to the complexity between cooperating parties.

4.2 Spares

Alfredsson et al. (2000) notes that large technical systems bring a problem that interests logistic managers responsible of MRO (Maintenance, Repair and Overhaul); the problem of spares support or supply. Spare parts are mainly divided into repairable and non-repairable (discardables/consumables). The latter are used in open-flow systems, such as wholesalers, and are mainly characterized by low price and high demand. Repairable spare parts on the other hand, having other properties compared with the non-repairable, are used in closed-loop systems. A simplistic model of repairable items in a closed-loop system, in which the technical system considered in this case is an aircraft, is illustrated in Figure 4.6.

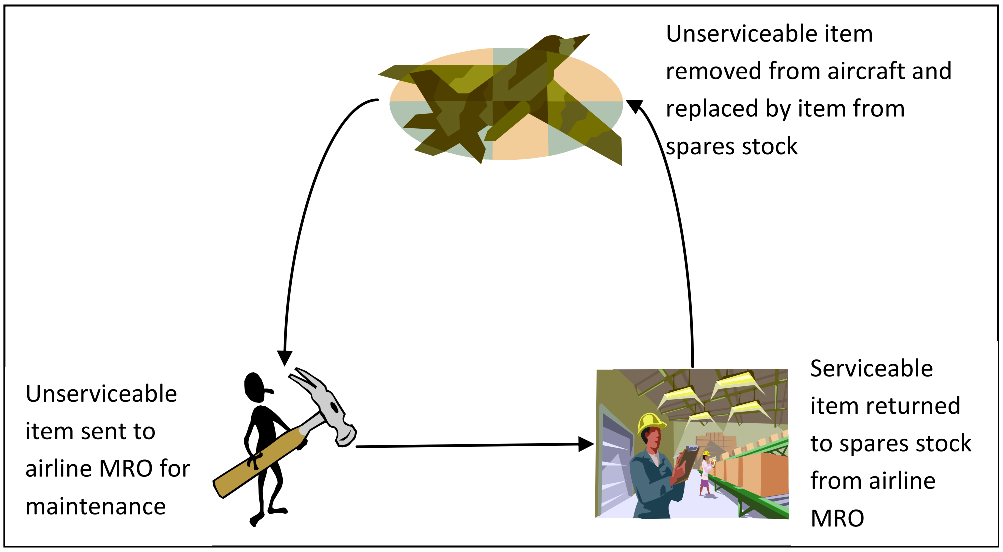


Figure 4.6: Repairable items in a closed-loop system.

Spares are often common in a range of commercial settings and in the military. Typical examples of repairable items are aircraft and warship engines, transportation equipment, and high cost electronics (Kim et al. 2006). Wååk et al. (-X-) discusses the frustration and confusion that spares causes in many organizations even though a large amount of money has been put into both the spares themselves and the spares management system. The lack of understanding of the difference between a traditional wholesaler stock and a spares stock is identified as a primary reason for the perceived frustration. Furthermore, characteristics of repairable spare parts are listed below to highlight typical differences between repairable and non-repairable spare parts:

- The demand rate is usually low. Expected demand for the very expensive items (e.g. aircraft engines) may be less than 1 during a 10 year period.
- For most items there are no methods or trends to forecast when demands occur.
- The demand rate is usually not affected by the item price, but essentially controlled by:
    - The items failure generation
    - The system configuration
    - The number of operating hours
    - The maintenance concept

- When stock-out occur (backorders), the cost per hour may for critical parts be >> item price. A wholesaler facing stock-out (lost sales) on the other hand might lose the sales profit and also some goodwill.
- The concept of repairing items does not exist in a wholesalers stock; therefore the traditional Wilson/Economic Order Quantity (EOQ) formula is not applicable for these items.
- The less demand – the better, thus, inventory investment is rather considered as ”fire insurance” than waste of money if spare parts are never used.
- The inventory level for a spare part mostly dependents on the lead time and the turn-around-time, while only to a minor extent on the reorder cost (which is a parameter that highly influences the inventory level for non-repairable items).

4.2.1 Spares Provisioning

Systems and items are in general repairable and therefore undergo several failure-repair cycles that include logistic delay while performing repairs. System unavailability reduces when availability of its subsystems increases, which in turn can be achieved by additional spares for each subsystem. In doing so, the cost of the total system also increases due to the added operational and maintenance costs (Amari et al. 2007). In order to fulfill availability requirements, the target of provisioning is to acquire and allocate a correct mix and amount of spares in the system. The system availability is defined as:

$$A = \frac{MTBF}{MTBF + MDT},$$

where MTBF is the Mean Time Between Failure and MDT is the Mean Down Time per failure (MDT = Mean Time To Repair (MTTR) + Mean Logistics Delay Time (MLDT) (Wååk -Y-).

4.2.2 Methods for Spares provisioning

Engineering judgments is referred to when a single employee, or a small group of employees, decides upon issues regarding spares inventory based on previous experience. The foremost advantages with this method are; the contributions to criticality assessments, and also a second opinion on the credibility of data predictions and assessments. Conversely, the drawbacks are related to the handling of the data since it provides with; no formal or robust method (e.g. two engineers will probably reach different results), and also no control over the effectiveness.

Item-by-item calculation is another method meaning that all spares will individually be calculated to a number to assure that a confidence interval against stock-out for a period of time will be obtained. This policy is rather common in practice, but not a very good one since the measure is directed towards the effectiveness of the stock and not towards the effectiveness of the total system.

Optimization is referred to when it is possible to find a combination of spares that is more efficient than all other combinations, for each cost level. This policy requires a system approach and an optimum curve is achieved if the results for each cost level are connected with each other (Wååk -Y-). Figure 4.7 illustrates an optimum curve attained with the help of the software OPUS10.

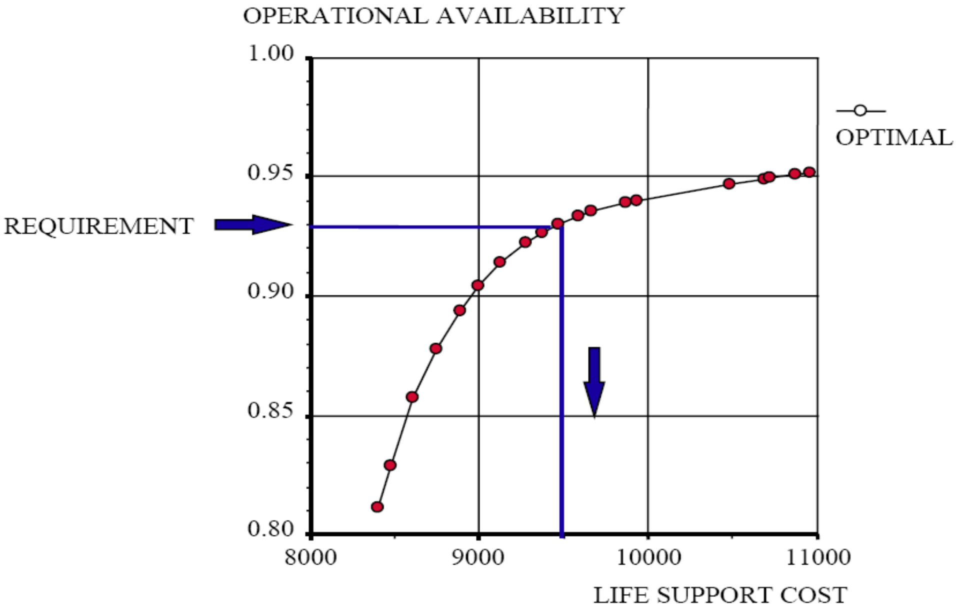


Figure 4.7: Operational availability as a function of LSC.

4.3 Pooling Strategies

Pooling of spare parts in a network system consisting of a number of different locations is the same as sharing spare parts in such a system. In doing so, the locations also pool their risk, reduce their inventory level or achieve higher availability in their technical systems. There are obviously vast benefits that can be derived from pooling, why the obstacles of attaining such a model need to be investigated and overcome.

Different strategies can be applied when companies choose to pool their inventory. Kilpi et al. (2008) specifies *cooperative strategies* for the availability service of repairable aircraft components. Another feasible strategy that can be applied is if a third party provides the pool. This strategy is referred to as *commercial pooling*, where the third party could for example be the manufacturer or a niche company. The above mentioned strategies are in general applied in centralized distribution systems, where decisions are made centrally to benefit the entire system.

A three-stage supply chain is visualized in Figure 4.8, consisting of a supplier (e.g. a manufacturer), a central distribution center and N number of industry operators. The stock at the central warehouse (CW) is jointly held and owned by the cooperating operators. The target is to achieve overall optimization by means of the system approach.

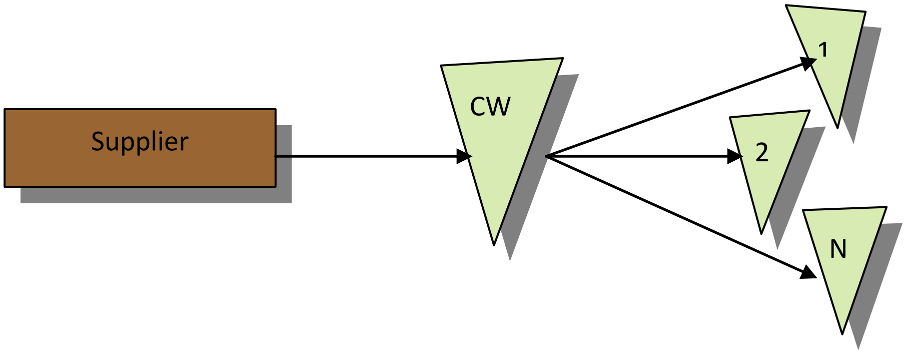


Figure 4.8: Centralized distribution system.

Advantages derived from pooling strategies, e.g. cost savings, are compared to the option of acting alone, referred to as the *solo strategy*. An industry operator in a decentralized system, wherein the solo strategy is normally applied, performs the availability service in-house so the service is provided for its own fleet only. Cooperative strategies applied in decentralized systems are often analyzed by game theoretical approaches (Olsson 2007).

Figure 4.9 shows a two-stage supply chain consisting of a supplier and N number of industry operators. In a decentralized distribution system stocks are held locally by the industry operators and all decisions concerning the inventory are made with no regard to other operators. Hence, every operator will try to optimize their own operation.

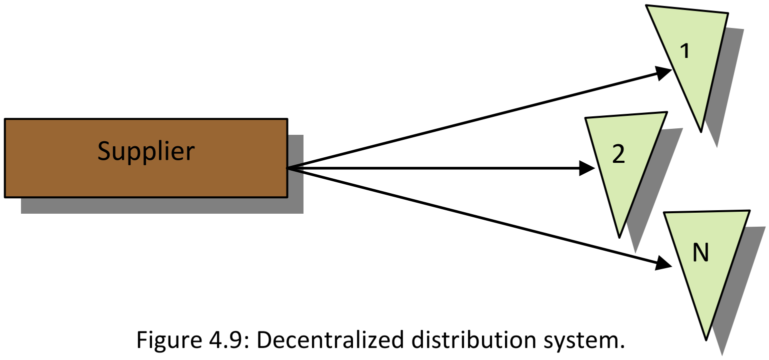
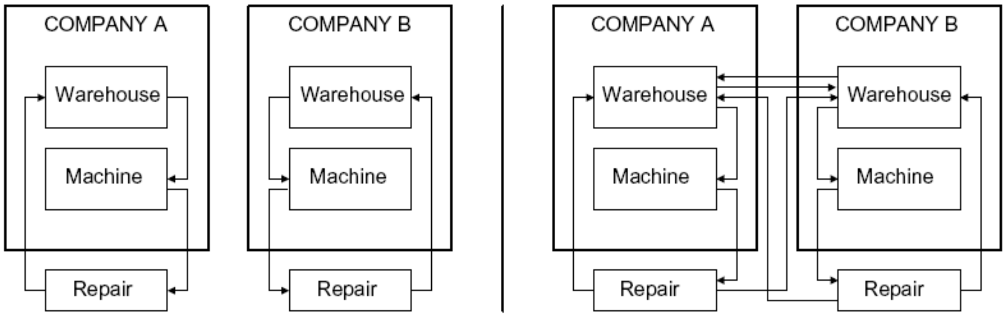


Figure 4.9: Decentralized distribution system.

4.4 Ad Hoc Cooperation

Two nearby operators with some fleet commonality can enter into a loose form of cooperation with no (or a low degree of) contractual integration, called *ad hoc cooperation*. The operators will provide each other with a loan unit against a standard fee when either of them is in need of a particular unit. Relying on loans from the other party enables the operators to lower their local stocks, assuming that there are efficient logistic connections between their bases and that they are almost equal in demand volume.

A strong relationship built on trust between two parties is a basic condition in order to form a successful ad hoc cooperation (Kilpi et al. 2008).



without loans with loans

Figure 4.10: The cycle of a repairable component (developed from Wong et al. 2004.)

4.5 Cooperative Pooling

Two or more industry operators with fleet commonality can formally agree upon a set of rules to share their spares inventories. This type of arrangement is called *cooperative pooling* where matters such as; benefit sharing principles, response times to spares needs, logistics arrangements between the parties, inventory distribution between the affected bases, and the priorities in the stock-out situations are determined within the set of rules.

When failure occurs, the faulty unit is replaced with a spare unit from the pool, making each member responsible to repair the failed unit before delivering it back to the pool (Kilpi et al. 2008).

There are many ways to model a cooperative pool. In addition to costs associated with pooling, e.g. transportation cost, one must also bear in mind the competitiveness between potential members of a pool when choosing a specific model. In the next section a comprehensive description of some of the foremost pooling models is carried out.

4.5.1 Complete- and Partial Pooling

When an item failure at a location occurs a replacement is ordered from the pool. The location is then responsible for repairing the faulty item and putting it back in the pool. Sherbrooke (1968) developed a basic model, called METRIC, where individual locations are supplied with repaired items from a central base-depot. The organizational structure is illustrated in Figure 4.11.

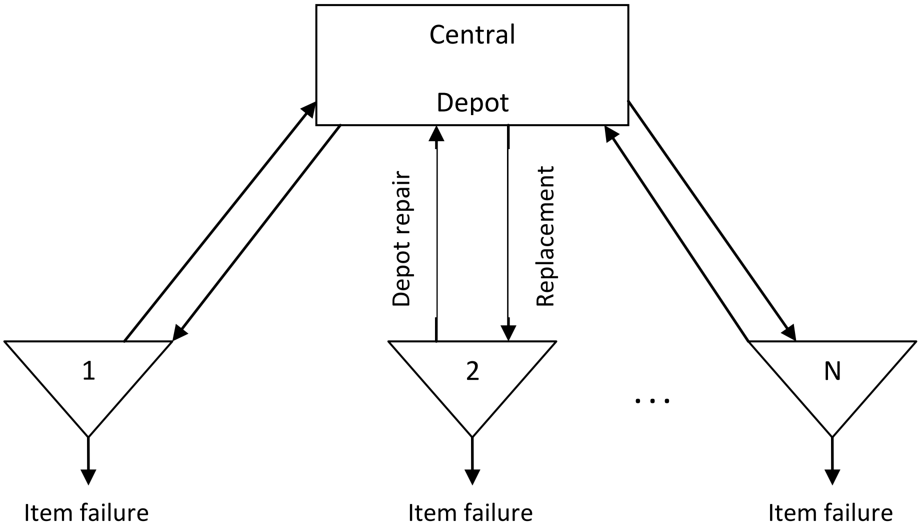


Figure 4.11: A two echelon system (developed from Sherbrooke, 1982).

Sherbrooke considered a two echelon system while other authors consider a single echelon system wherein a ”virtual pool” is applied, meaning that locations by means of lateral transshipments share their inventory. Normally, a distribution system is applied e.g. a two echelon system where all stocks are jointly owned by the locations. The majority of the inventory in the system will be kept at a central depot but each location can have a small amount of spares on hand to satisfy demand during the lead time from either the central depot or the lead time from a neighboring location.

In a pure *cooperative* setting decisions are made centrally to benefit the overall system. Conversely, when *competition* exists among locations, *game theoretical* approaches are made use of so all locations are better off taking part of the pool than acting alone.

Regardless of how the model is established, when locations do share their entire inventory in the system, *complete pooling* is realized. In mainly decentralized systems items can be reserved for future local demand, thus, a location may not automatically send an item to satisfy demand from e.g. a neighboring location. This concept is denoted *partial pooling* and due to additional managerial decision of how much inventory to reserve, such a system is more difficult to control and optimize than systems with complete pooling (Paterson et al. 2009).

4.5.2 Unidirectional Lateral Transshipments

To establish bidirectional transshipment links in an inventory system (e.g. as in complete pooling models where a location can both send to and receive from all other locations in the system) is not always feasible or cost efficient. Difficulties in establishing contracts between locations regarding the design of the transshipment policy, along with the cost and effort of implementing information systems are some of the arguments for not allowing transshipments among all locations. From a modeling perspective, the more complex a system is the more difficult it is to analyze analytically. Hence, the complexity of the inventory model is reduced when ”unnecessary” transshipment links are not established.

Locations at an echelon are usually non-identical and can therefore have very different backorder/lost sales cost. Seeing that a cost is associated with each transshipment, it is more reasonable to permit transshipments from a location with a low backorder/lost sales cost to the location with the higher backorder/lost sales cost. Transshipments allowed only in one direction are referred to as *unidirectional lateral transshipments* (Olsson 2009). Figure 4.12 illustrates unidirectional policies applied at the lower echelon in a two-echelon distribution system.

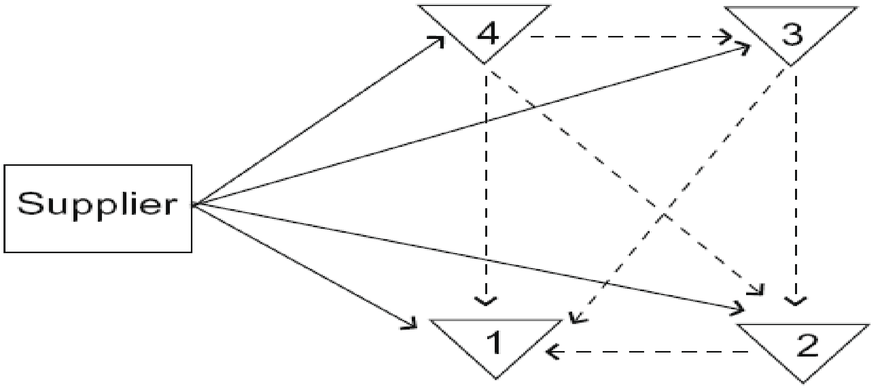


Figure 4.12: Inventory system when n = 4. Filled arrows represent the flow of regular replenishments while dashed arrows represent the transshipment flow (Olsson 2009).

4.5.3 Main- and Regular Local Warehouses

Motivated by real life scenarios Kranenburg and Houtum (2009) introduced a network structure in where they distinguish two types of local warehouses: main and *regular* local warehouses. Lateral transshipments are allowed from main local warehouses only, while both main and regular local warehouses can receive lateral transshipments.

Provided that the network structure only consists of regular local warehouses, the solo strategy (no pooling) is applied. On the other hand, when only main local warehouses exist in the network structure, full pooling is achieved. Thus, the model covers both the special cases of *no pooling* and *full pooling* and also a type of *partial pooling* that mostly resembles the model with unidirectional lateral transshipments, where only some of the warehouses are allowed to provide lateral transshipments.

In real life differences exist between local warehouses. Some warehouses are physically larger and thus having more inventory in order to satisfy higher customer demand rates. Some warehouses are strategically better positioned, for example close to airports, and are therefore able to provide a lateral transshipment faster than others. Further, some warehouses operate during the night also, hence having longer operating hours. Warehouses having the characteristics described above are suitable candidates to be main local warehouses. Kranenburg and Houtum (2009) show that only a few well chosen warehouses need to be equipped to provide lateral transshipment in order to obtain a major part of the full pooling benefits. Figure 4.13 illustrates a network structure with main and regular local warehouses.

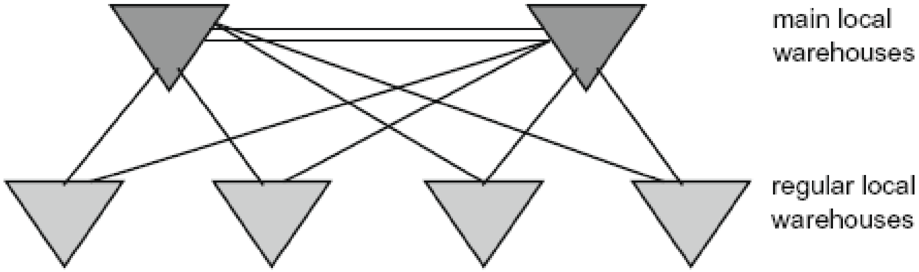


Figure 4.13: Graphical representation of pooling structure with main and regular local warehouses (Kranenburg and Houtum 2009).

4.6 Commercial Pooling

In commercial pooling there are several customers that buy availability services from one service provider. The service provider can supposedly be the manufacturer of the technical system or a niche company. A customer gets demand satisfied from the service provider against a fixed annual fee. In addition to the general clauses covered by the cooperative pooling agreements in section 4.5 (Cooperative Pooling), a formal agreement exists between the service provider and the customer which covers service fees, delivery lead times and liability in delay situations.

Every participant in a commercial pool has a connection only to the service provider, which in turn has a connection to all participants in that pool. Accordingly, in a pool with *n* participants, there are *2*n* connections. Conversely, in a cooperative pool with *n* participants, where every participant has connections to all other participants in the pool, there are *n*(n-1)* connections in total (Kilpi et al. 2008).

Zhao et al. (2005) state that there is an increasing number of manufacturers that are pursuing a strategy that promotes inventory sharing among the dealers in their decentralized distribution network. In a service-parts logistic system, the manufacturer provides an information system to its customers. This system generally contains inventory control software and in spite of costs associated in providing it the long-term returns come from a better customer performance, e.g. from a better after-sales service to the end-customers.

4.7 A Pooling Model

Dependent on existing restrictions, inventory sharing in a network consisting of independent locations can be modeled in different ways. Wong et al. (2006) embrace the *coopetitive framework* (a hybrid of cooperative – competitive), that was first introduced by Anupindi et al. (2001), for the decision-making in a decentralized setting. The main part of the problem formulation from Wong et al. (2006) will be presented below in order for the reader to get an understanding of how a decentralized setting can be modeled. For the full model, the reader is referred to read the article.

A continuous one-for-one replenishment (S – 1, S) policy is considered. *J* independent locations, indexed by $j = 1, 2, \ldots, J,$ keep spare parts for their systems (e.g. an aircraft, a train etc). Assumption is made that systems used by the locations are of the same type and that location *j* has N_j units of systems. Among the different items in the system, only a single type of repairable item is considered. In order to maintain generality in the model, it is assumed that one unit of the particular item is required for the system to be operable. When in use, the considered item is subject to failures, whereas the times between failures of an operating item are exponentially distributed with a mean $1/\lambda$.

S_j (integer) units of spare parts are stocked by location *j*. When failure occurs at location *j*, the faulty item is replaced by a ready-to-use item from the local warehouse. An item can be supplied via a lateral transshipment from another location if the required item is not available at the local warehouse. The reserve stock level set by location *j* is $c_j (0 \leq c_j \leq S_j)$. The only time location *j* agrees to supply a lateral transshipment is when its current inventory level is above its reserved stock level ($x_j > c_j$). Thus, complete pooling is realized when $c_j = 0$ for all j, while partial pooling is realized when at least one location sets a positive critical stock level. Conversely, no cooperation is realized if $c_j = S_j$ for all *j*. Since more than one location can be the supplier of a lateral transshipment, the closest-neighbor sourcing rule is applied. d_{jk} denotes the distance between location *j* and *k*, and it is assumed that $d_{jk} = d_{kj}$. In the case when a lateral transshipment is not possible the unit is backordered until a functional part is supplied to the location facing backorder. The part can either come from the repair facility or from one of the other locations that have a stock level above their critical stock level. If the part is sent from another location it is denoted as a *Delayed Lateral Transshipment (DLT)*. Assumption is made that the priority is given to the location with the largest number of backorders when there are two or more locations in need for a spare part. A location that supplies a lateral transshipment to another location will get back the failed item upon completion of its repair. This leads to that the stock on hand plus the number of parts in repair minus the number of backorders for location *j* always equals S_j.

When failure occurs the faulty item is directly sent into repair and will then be returned as a ready-for-use part after an exponential repair lead-time. μ denotes the repair rate. Since the modeling approach is based on Markov analysis it is required to assume that the repair lead-time is exponentially distributed. Even though the assumption is not very realistic, Alfredsson and Verrijdt (1999) have shown that the choice of lead-time distribution will barely affect the service performance of a system. Moreover it is assumed that there is an infinite repair capacity and that the repair lead-times of different items are independent and identically distributed random variables.

The analysis is based on the problem of determining two types of decision variables: one is the number of spare parts stocked at location *j*, S_j, whereas the second variable is the reserved stock level at location *j*, $c_j (0 \leq c_j \leq S_j)$. ($\underline{S}, \underline{c}$) is defined as a set of decisions applied in the system. The total cost corresponding to an arbitrary set of decisions is denoted Z($\underline{S}, \underline{c}$). A first situation considered in the model is games with full cooperation where a central decision maker set an optimal policy ($\underline{S}^*, \underline{c}^*$) in order to minimize the total cost for the whole system. A second situation considered is games with competition. In this setting every location chooses its own decision ($\underline{S}, \underline{c}$) with the aim to minimize its local cost given the decisions of the other locations.

Furthermore, a *J*-dimensional Markov process to model the behavior of the system is described. Possible states and transition rates are defined and as a result various logistical performance measures can be determined. The total cost comprise inventory holding cost, lateral transshipment cost, and downtime cost. The objective of the optimization problem, which is formulated as a cost model, is to minimize the total cost. The optimization problem can alternatively be formulated as a service model, in where some target service measures are put as constraints instead of considering the downtime cost.

4.8 Cost Allocation in Spares Inventory Pooling

This section covers some of the most common cost allocation policies in cooperative and competitive settings. If a certain policy is suitable or not greatly depends on how the network structure is modeled and what parameters are included in the cost model. In commercial pooling the main factor that determines whether or not a company should choose a commercial pool over a cooperative pool is the price set by the service provider.

4.8.1 Centralized System – Cooperative Setting

Gerchak and Gupta (1991) consider the cost allocation problem in a centralized continuous review inventory system with complete backordering. The cost model consist of a fixed ordering cost *A*, a holding cost per unit and time unit *h*, and a unit downtime cost π that is independent of the duration of the downtime. They look at four policies of how to allocate inventory costs among the members of a pool:

1. By demand volume
2. By individual safety stock requirements
3. By incremental contribution to joint costs
4. In proportion to stand-alone costs.

They then show that only the forth policy, cost allocation in proportion to each member's stand-alone costs, guarantees a reduction in costs allocated to it under centralization. The first three policies can easily lead to higher costs for particular members than their stand-alone costs.

With the intention of bringing out differences between the cooperative strategies (ad hoc cooperation and cooperative pooling) Kilpi et al. (2008) further develop the three cost elements in MRO inventory pooling that were identified by Carter and Monczka (1978): *inventory holding*, *ordering* and *backorder costs*. Ordering costs are divided into *handling* and *transfer costs* while backorder costs are divided into *loan-in* and *wait costs*. Additionally, the cost model also cover *interface costs* mentioned in section 4.1.4 (Considered Costs).

Kilpi et al. (2008) look at three typical benefit sharing criteria in cooperative pooling:

1. According to the annual demand volume (VOL)
2. According to equal relative savings from joining the pool (ERS)
3. According to relative incremental contribution to the pool (RPC)

Although the volume based criterion seems like an intuitive way of sharing pooling benefits it is shown that high demand members gain slightly more benefits compared to low demand members. Consequently, an incentive problem arises that encourages each individual member to pool with as small partner as possible. There is also a demarcation point associated with the volume based criterion, after which a large new member would take more benefit out of the pool than it would bring in the pool. The demarcation point may also create barriers to the pool growth since a dependency is identified between the number of participants and the maximum attractive size of a new pool. If the ERS criterion is applied the incentive problem still remains. The authors come to the conclusion that the relative incremental contribution to the pool is the most cost efficient setting and also the criterion that drives the pool arrangement towards a dynamic equilibrium.

By means of the *core concept* from the cooperative game theory Wong et al. (2006) solve the problem of how to fairly allocate the total system cost to each member (a definition of the core is found in the article). If a cost allocation belongs to the core (thus, the game have a non-empty core) then each member is better of joining the pool and no one is worse of when a new member joins up. A game can have an empty core in extreme situations (e.g. if the transportation cost of a lateral transshipment is too high) and pooling may in these cases not be beneficial. The network structure and the cost model are specified in section 4.7 (A Pooling Model). Further, Wong et al. (2006) evaluate four cost allocation policies and identify whether the cost allocations are in the core of the game:

Cost allocation policy 1:

- The inventory holding cost is allocated based on the number of spare parts stocked at each location.
- The downtime cost is allocated based on the local downtime at each location.
- The transportation cost for each lateral transshipment is always paid by the receiving location.

Cost allocation policy 2:

- The inventory holding cost and transportation cost are allocated based on the demand rate of each location.
- The downtime cost is allocated based on the local downtime for each location.

Cost allocation policy 3:

- The total cost is allocated based on the demand rate of each location.

*Cost allocation policy 4 (**Shapley value)**:*

- Each member is allocated a cost equal to the average contribution it makes to each coalition to which it could belong. All coalitions are regarded as equally likely to emerge.

It is shown that in the centralized system all four cost allocation policies give cost allocations that are in the core of the game.

4.8.2 Decentralized System – Competitive Setting

The four cost allocation policies specified by Wong et al. (2006) are also tested in a setting where competition exists between the pooling members. In such a setting a different view of the decision process is required since each member will now make decisions as an optimal reaction to other members’ decisions. Regardless of what each member decides on their inventory and reserved stock levels, a certain level of agreement of how the total cost will be allocated must be reached by all members of the pool. For this reason a 'coopetitive' concept is recommended since members act both cooperatively and competitively.

A description of the game that cover the coopetitive setting is described as follows: All members first agree on a cost allocation policy. Each member then chooses its inventory and reserved stock levels with the aim to minimize its local total cost. The total cost of a location is however dependent on decisions made by other locations (because of the possibility to send and receive lateral transshipments). Each member acts rationally and will therefore not raise its own cost with the intention of raising cost of the other members. Finally, *perfect information* is assumed in the network system (all parameters are common knowledge for all members).

The concept of *Nash equilibrium* is employed in order to find a solution to the above described game. If no player can strictly benefit from solely changing its strategy while all other players stay fixed, then a pure strategy Nash equilibrium is obtained. Fudenberg and Tirole (1991) state that Nash equilibrium is a consistent prediction of how the game will be played in the sense that no player has an incentive to play differently if all players predict a Nash equilibrium.

In contrast to the cooperative setting, when competitive behavior is considered the decision to pool or not to pool is influenced by the chosen cost allocation policy. It is shown that the third and fourth cost allocation policies motivate the locations to join the pool, while the incentives to join the pool are not enough if either of the two first policies is chosen.

Games with *imperfect information* do reflect various real-life situations better in the sense that some parameters are only known privately. In a competitive environment it is questionable if members of a pool are willing to share their private information with the other members. Wong et al. (2006) analyses this kind of games in where the downtime cost is chosen as private information. The reason for choosing the downtime cost over the inventory holding cost or transportation cost is that the downtime cost is difficult to quantify and can therefore be subjective in comparison with the other costs mentioned. The main purpose of the analysis is to examine the possibility for members to make profits by telling false information. The fourth allocation policy is considered and is concluded by the following adjustment. Location *j* has to pay:

- the holding cost based on the number of spare parts stocked at location *j*,
- the downtime cost incurred by location *j*,

- the transportation cost for all lateral transshipments received by location *j*.

It is shown that locations (companies) are tempted to reveal untrue information regarding their downtime costs. In such situations, companies need to deal with the problem of balancing the risk and benefit from claiming a lower or higher (than the true) downtime cost. A company may benefit by marking up its payment in claiming a higher value than the true. On the other hand, a higher downtime cost means an increased contribution to the total cost in compliance with the Shapley value method.

Also shown is the importance to build mutual trust between all pooling members, which is done by means of all members agree on a common downtime cost or target service level. Issues in competitive settings make way for another pooling model; a model where an independent party is the provider of the pool.

4.8.3 Commercial Pool

In contrast to other strategies (e.g. ad hoc cooperation and cooperative pooling) where the costs are revealed afterwards, in commercial pooling the benefit sharing is based on service pricing. Therefore, from the perspective of a member, only commercial pooling offers foreseeable availability cost.

Kilpi et al. (2008) argues that an independent party (e.g. a service provider) has the opportunity to abuse its monopolistic market position by increasing prices for the members of the pool. The utilization of monopoly power of a service provider is however limited due to; threat of incursions by market entrance, the members may choose to set up a cooperative pool of their own, and by the possibility of establishment of another commercial pool.

The service provider’s pricing strategies are studied in a *pricing game*. If the prices are set high, the benefits for the members of the pool are low and vice versa. However, if the pooling members decide to set up a cooperative pool, then the service provider’s benefits are zero. Owing to lower interface costs for a commercial pool (than a cooperative pool), the costs for a commercial pool are always lower than if a cooperative pool is organized by the members, given the same demand. The total cost difference is also considered as the extra benefit of commercial pooling compared to cooperative pooling. This leads to the identification of two extreme cases; the first is a situation where the service provider acts in a highly competitive market that leads to the pooling members getting all the extra benefit, in the second case the service provider has total monopoly power and therefore get all the extra benefit by setting high prices. Pricing strategies where the extra benefit is divided more equally leads to situations in between the two extreme cases mentioned above. For specific details about the pricing game the reader is referred to the article Kilpi et al. (2008).

It is shown that the members of a pool should always set up a cooperative pool by their own, in agreement with the Nash equilibrium. However, a different equilibrium would exist if a repeated game with unknown number of forthcoming rounds is considered. Assuming a first round of pricing, instead of setting the prices high (e.g. as in the second extreme case) the service provider would in the long run benefit by setting prices so that the members of the pool would benefit more than they would benefit from setting up a cooperative pool. This leads to a win-win situation and calls for cooperation from the service provider. If the service provider chooses not to cooperate, the members of the pool then gets zero from one round and will as a result change to cooperative pooling. Thus, for the rounds thereafter the service provider would get zero profit. The authors state that as long as the benefits of the pooling members in the commercial pool are higher than it would be in a cooperative pool, the result of the repeated game is valid. Also, the required number of expected rounds increases by increasing the benefit of the pooling members in the commercial pool.

The pricing process is based on the demand; hence demand estimates have a significant effect on the benefit sharing. A slightly lower estimated demand (than the real) by the service provider equals to too high prices and therefore to a service offering not being competitive. A slightly higher estimated demand (than the real) will lower the prices and therefore lead to lost profits. As inaccurate demand estimations are likely, it is suggested that a service provider should pursue a strategy where the prices are set somewhat low in order to attract more demand, and later on raise the margins.

5 Framework for Developing a Model to Evaluate Spare Parts Strategies

5.1 Incentives for Pooling

In order for an independent company to pool its inventory the benefits from joining a pool must be larger than from acting alone. From joining a pool, the same availability on the technical systems can get obtained with a lower cost or a higher availability for the same amount of money spent can get achieved. The benefits mentioned above are derived from having lesser amount of spare parts in the total network system compared to the sum of spare parts of each company that act independently. Due to scale economies with a pool the investment cost can get reduced and owing to stochastic failure rates the probability for more than one item-failure at the same time is very low, leading to the ability for a pool to maintain high availability.

Smaller and newly founded companies may have limited financial resources and are thus dependent on joining a pool in order to keep the costs as low as possible in the beginning.

5.2 Prerequisites for Pooling

There are two main conditions that need to be met if a company (e.g. an owner or an operator) wishes to pool its spare parts; First, the necessity of having at least one more company using similar technical systems (e.g. aircrafts, rail vehicles etc) within a geographical area in where it is feasible to share spare parts. Although the systems can slightly differ between the companies, the spare parts considered to be used in a pool must be *compatible* with all systems.

The second condition regards the distribution between repairable spare parts and consumables in a system. The *value* of the spares a company chooses to repair must constitute the main part of the total value of all the components in the system. Intuitively, the second condition seems to always be met since spare parts in such technical systems do constitute the major part of the total value. However, due to various restrictions (e.g. high transportation cost in connection with a long lead time until the repaired unit is returned to the company) it is not always profitable for a company to repair a failed unit, as a consequence a new part is purchased and an open-loop supply chain is obtained.

5.3 Aspects of Interest

In all industries there are certain parameters that need to be accounted for when a company decide to pool its inventory or not. Carrying out a branch analysis in where; *the market*, *the actors*, *the technical systems*, and *the costs* are identified and mapped out provide a company with fundamental information in deciding whether to pool or not, and more specifically, what spare parts strategy to choose.

5.3.1 The Market

Kilpi et al. (2008) state that, from the viewpoint of availability service, the number of stocking bases and the distribution of the operational volume between these bases are the most important factors in the network complexity. The *complexity* of an industry is dependent on the number of different actors that interact together to deliver a product or a service to the final customer. There is a need to map out all relevant stakeholders in a market, such as; the manufacturers, the owners of the technical systems, the operators, and the companies that do the maintenance. In a *regulated market* only one (or a few) big actor (e.g. the government) is allowed to deliver a specific service. This actor usually buys spare parts packages from the manufacturer and does the MRO in-house. In such a case, the decisions regarding inventory optimization are made centrally and a less complex system is obtained. It is therefore not very lucrative to organize a pool of spare parts in a regulated market.

However, when a market is deregulated the *number of actors* that provide the same services grows, and as a consequence, the potential for a pool of spare parts between these actors increases. In a market consisting of multiple independent companies using similar technical systems there is often a need for assistance from a third party to supply the companies with services that are outside their core business. An activity that is often considered outside the core business is the MRO of spare parts. The more stakeholders in a distribution system the more complex the system gets. For example, an owner of the technical systems turns to another company (e.g. an operator) for operation and maintenance, which in turn contract sub-suppliers to do the maintenance on the systems. Although one can optimize logistics and material flows, the difficulties lie in creating a business model that satisfies all stakeholders involved.

The *distance* between the participants of a pool to the physical stock of spare parts is of vital importance when a company decides to pool or not. In a cooperative pool the distance of interest is the distance to a company's closest neighbors (considered as an appropriate sourcing rule) whereas the relevant distance in a commercial pool is the distance between the pooling participants and the physical stock held by the third party. Since a pool of spare parts incurs more transportations than if a company chooses to act alone, the transportation cost increases. A long distance also implies a longer leadtime for a spare part that is demanded to arrive. Of importance when modeling a cooperative pool, in section 4.1.2 (Lateral Transshipments) a prerequisite is stated where the leadtime for lateral transshipments in distribution systems should be considerably shorter than the normal supply leadtime.

Another important aspect that affects the decision to pool regards the *competitiveness* between companies in the market. Companies may either have designated geographical areas where they operate, hence, no competitive behaviors exist, or all companies may compete for the same final customers. In the latter case, companies are more reluctant to share spare parts or information with each other.

Furthermore, when a distribution network extends in a *transnational market* there is a need to investigate in the effects various jurisdictional regulations (e.g. customs regulations) may have on both the costs and the availability of the systems.

5.3.2 The Actors

The *size* and *resources* of a company affect the decision whether to pool or not. Moreover, the choice of a specific strategy is by some means dependent on the size and resources of a company. As regards the size, the factor of interest is the *demand per unit and time unit* (e.g. yearly demand per unit) of spare parts. The demand for spares is stochastic, and as mentioned in section 4.2 (Spares) there are no methods or trends to forecast when demand occurs for most items. Yet, in practice, facts regarding historical data and experiences from the past in connection with the number of systems a company operates provide an adequate amount of information to somehow forecast demand over a time unit (see *engineering judgments* in section 4.7.2 Methods for Spares Provisioning).

A further important issue to consider arises if there are *differences in customer demand* between participants of a pool. Two neighboring companies that provide each other with a loan unit against a standard fee need to be almost equal in demand volume (section 4.4 Ad Hoc Cooperation). However, as pointed out in section 4.8 (Cost Allocation in Spares Inventory Pooling) differences in customer demand in a cooperative pool strongly need to be considered and dealt with in order so no participant of the pool ends up with higher costs than if it had acted alone. Choice of cost allocation that is in the core of the game (alternatively, in a competitive environment a cost allocation that satisfies a Nash equilibrium solution) must be modeled so all participants benefit from joining the pool. A commercial pool is less sensitive to differences in customer demand between the participants of the pool. When a new actor joins the pool the service provider need to increase the inventory in proportion to the size of the new participant. The balance can however get disturbed if a customer with high demand volume in relation to existing inventory in the pool wants to join the pool.

In general, resources of interest are; financial resources, process resources, and human resources. A company that wishes to own spare part packages needs financial resources, while keeping the MRO maintenance in-house requires process resources (e.g. workshops that are strategically well positioned), and the human resources in the form of man-hours and expertise are called for in order to efficiently organize logistics so a high system availability as possibly can get obtained. Some companies have the choice to outsource its MRO to a third party in order concentrate on its core business, while others are forced to outsource the MRO due to limited resources in-house.

For some companies it is important not to reveal information regarding its business; (e.g. inventory levels, the downtime cost etc). There is a fear that insights from outside actors can backfire if the information is in the hand of the "wrong companies". The more stakeholders involved in a network the more open the information will be to outside parties. *Secrecy* is particularly important in competitive environments, but a way to circumvent that a competitor gets hold of private information is to involve a third party (a middleman). The third party is provided with all necessary information from the competitors in order to most efficiently solve the common issue without giving away private information to the competitive parties. The need of *contractual integration* gets tighter the more complex the network gets. A loose form of cooperation implies that the relation among the cooperative parties is built on *trust* rather than on tight contractual integration.

In order to prevent a supplier from utilizing its monopolistic power by increasing prices a company needs to not be dependent on one supplier only. The option to choose among more suppliers than one ensures an existence of balance of power in the market and consequently lowers the risk of monopolistic behavior.

5.3.3 The Technical Systems

Huge capital investments are associated with the technical systems that are often large and complex. *Safety requirements* are usually very high and in most industries only authorized actors are allowed to do MRO maintenance on the systems. In order for companies to get a high rate on return (RoR) the prominent requirement is to have the systems operating whenever customer demand exist. *System availability* is the most common measure of effectiveness (MoE) and the objective of the companies is to achieve a targeted availability level to a lowest cost possible. There is a need to identify existence of special safety requirements (e.g. various restrictions on approval of repaired items) that may directly affect availability of spare parts. Special requirements may thus complicate the option of joining a pool. MRO is a support function with the purpose of minimizing the downtime in case of system failure. Ready-to-use spares need to quickly replace a faulty unit while the faulty unit is sent to a workshop for repair.

To facilitate sharing of spare parts between companies the two main conditions mentioned in section 5.2 (Prerequisites for Pooling) need to be met: the components used in a pool must be compatible with all systems and the value of the repairable spare parts must constitute the major part of the total value of all components in the system.

A high degree of standardization of the technical systems makes it easier for companies to find potential components to pool and thus encourages inventory sharing between the companies. A high degree of standardization is evidently also of interest for the manufacturer owing to; a lower cost per system manufactured, a higher output given the same time period, and to a maintained high quality since less interruptions are needed. Figure 5.1 show the supply support cost as a function of design standardization. However, differences in customer requirements due to awareness that the technical systems will operate on dissimilar environments leads to the manufacturing of customer specific technical systems. A low degree of standardization does not make it possible for companies to share inventory.

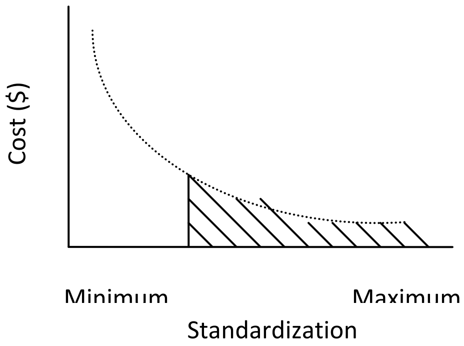


Figure 5.1: Supply support cost as a function of design standardization (Blanchard 2004).

An example is shown in Table 5.1 where a spare part has seven different FFF ("form-fit-function"), V1, V2, … , V7. A "form-fit-function" replacement is designed to match the "form" (shape, materials and interfaces), "fit" (size and all connectors), and "function" (delivering the same output from an appropriate input) of an original spare part (Storm 2006).

As can be seen, most customers (C1 – C4) can use many of the seven types in their systems but variation in customer demand complicates a pooling scenario. A possible solution to this particular problem is to group the various types of FFF and assign them to different groups of costumers. For example, a group of spares consisting of type V3-V5 is provided for customer C1 and C2 while type V4-V7 are grouped together and provided for customer C3 and C4. Alternatively, the demand of all four customers can be met by providing a single pool consisting of type V4 and V5.

Table 5.1: Seven FFF and four customers – complications when pooling.

V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**Customer**
*	*	*	*	*			***C1***
		*	*	*			***C2***
			*	*	*	*	***C3***
			*	*	*	*	***C4***

On the other hand, if customer demands are according to Table 5.2, where no replacement part is compatible with other systems, then no benefits can be gained from setting up a pool.

Table 5.2: Pooling not an option.

V1	V2	V3	V4	V5	V6	V7	Customer
*							***C1***
	*						***C2***
		*					***C3***
			*				***C4***

5.3.4 The Costs

Assuming that the technical systems operate continuously the most important cost usually is the *downtime cost*. A true downtime cost is very difficult to estimate, however, a rather simple example gives a good hint on what system unavailability can cost:

Consider a commercial airplane that does six trips per day. There are on average 100 passengers per trip and each passenger pays 100 EURO for a ticket. System unavailability means lost sales of 6 * 100 * 100 = 60 000 EURO per day for a commercial airline. In addition, due to Badwill and other important "non-tangible" factors (e.g. lost business opportunity costs because resources were allocated to rectify a downtime incident) that need to be taken into consideration the cost of downtime increase even more.

Spare parts packages require huge investments and are thus a cost that directly affect the choice to pool or not, and also, what strategy to choose. Companies aim to find an optimum inventory level so a targeted service level can get reached to the lowest cost possible. As mentioned in section 4.2 (Spares) the less demand the better since inventory investment is considered as "fire insurance" than waste of money if spare parts are never used. In the railway industry a trend is noticed in where smaller upcoming companies choose not to buy spare parts packages in order to keep the costs as low as possible during the first years of operation (Alstom, Nordic Rail 2009). The reason is obviously the high investments required in spare parts packages in relation to total investments in the technical system. It can be devastating for smaller companies to not have spare parts available in case of a system breakdown, still, it seem to be a risk they are willing to take.

Maintenance, Repair, and Overhaul services for the technical systems can either be done in-house or outsourced to a maintenance company. The technical systems are mainly driven by preventive maintenance that is usually done periodically based on operation time. Corrective maintenance of a spare part can cost around 20-30% of the purchasing price, which means that after five repairs a company spends the same amount of money as they would if they had purchased a new spare part. The remark is interesting and brings up an optimization problem: after how many repairs should the company purchase a new part instead of to keep on repairing the "old" one?

Ordering costs are in section 4.8.1 (Centralized System – Cooperative Setting) divided into *handling* and *transfer (/transportation) costs*. Inventory sharing requires more handling costs (e.g. administrative costs) than if a company chooses to act alone. In addition, *interface costs* increases as the network gets more complex. For instance, putting together a project team with representatives from all relevant stakeholders involved will not only be difficult to manage but the costs of interface will also increase significantly.

Inventory sharing promotes transportations and thereby increases the costs of transfer for the involved companies. The amount of money spent on transportation during a time period must be considered in relation to the value of the spares that are transported in that time period. In order for inventory sharing to be profitable the transportation cost should make up for a small proportion of the total cost of inventory for a company. For example, the cost of transfer may for a company increase to 30 000 EURO during a year, however, if the cost of inventory (/ the inventory value) is 300 000 EURO the transfer cost can then be justified. On the other hand, a smaller company having a 100 000 EURO inventory cannot justify increased transfer costs if they constitute 30% of the total cost of inventory.

The cost of holding stock that consists of high cost components is usually very low in relation to the stock value. Therefore, in most cost models regarding high cost components the *inventory holding cost* is often neglected. However, as pointed out in section 4.1.4 (Considered Costs) the inventory holding cost (which is mostly determined as a percentage of the unit value) should in general be significantly higher than the interest rate charged by the bank. Consider a case where a wholesaler (company A) takes a loan from the bank for a given interest rate and buys a big stock of spare parts. The stock is then sold to other companies but they choose to physically keep the stock at company A. In the agreement between company A and its customers it is stated that the customers account for the inventory holding cost. In order for company A to profit from keeping the stock in-house, the inventory holding cost charged by company A must thus be higher than the interest rate charged by the bank.

5.4 Soft Aspects

All aspects of interest stated above; the market, the actors, the technical systems, and the essential costs must be considered in a model. Different pooling strategies need to be compared to each other, and also to the strategy of acting alone (no pooling). Naturally, industries differ from one another even though characteristics of the technical systems and other environmental conditions can be very similar in many industries. As a consequence, the importance of the parameters discussed in every aspect of interest varies between the industries. In the same way, because of differences between companies (e.g. size, resources etc) the importance of the parameters varies between companies within an industry as well. Therefore, in order to obtain a fair conclusion on which one of the strategies is a best fit for an actor the parameters need to be weighted.

Characteristics of the different strategies (all aspects of interest mentioned thus far in relation to possible strategies an actor can choose) are presented in Table 5.3. The aim is to provide with an overview of how the assessment of the characteristics fit the different strategies, and thereby also work as a guideline to what strategies may be appropriate for an actor in a specific industry. The aspects are categorized according to the headlines in previous sections (the market, the actors, the technical systems, the costs). A decision-maker is encouraged to add, remove or/and modify current parameters according to specific circumstances in the industry and to the requirements of the individual company.

A red mark (with **-R** attached, in order for the qualifier to get noted even if the paper is printed in black and white) indicates a *qualifier* (an absolute requirement) that must be satisfied in order for an actor to even consider a specific strategy. For example, the market need to be deregulated if an actor considers a cooperative or a commercial pooling strategy. On the other hand, if an actor pursues the stand alone strategy then it needs to have the capacity to do the MRO maintenance in-house, hence, the qualifier high initial resources required need to be met. A green (with **-G** attached) mark emphasizes a high *importance* of the factor to be met in order for the specific strategy to turn out successful. For example, in an ad hoc cooperation the existence of mutual trust between cooperating parties is of great importance. Similarly, in a cooperative or a commercial pool it is very important that a required spare part is provided rapidly from the pool. Dependent on the criticality of the part that is required, different lead times can be accepted until the part reaches the requiring actor. However, it is of high importance that spare parts required are able to arrive within acceptable time periods. The colors highlight not just the importance of some parameters, but also serve as indicators to what an actor need to work on to achieve a successful strategy. For instance, actors that wish to form an ad hoc cooperation should in the beginning of the cooperation put much effort to build strong relationships between themselves.

Table 5.3: Matrix - assessment of characteristics for each strategy.

Aspects of Interest		**Pooling Strategies**		
	Stand alone	**Ad hoc**	**Cooperative**	**Commercial**
The Market	*Assessment*	*Assessment*	*Assessment*	*Assessment*
Regulated market	Possible	Possible/Not possible	Not possible **-R**	Not possible **-R**
Appropriate number of participants	1	2	~ 3-5	≥ 3
Sensitivity to competitive behavior	N/A (Low)	High	Average	Low
Complexity	Low	Low	High	Low
Lead time for stock to arrive	Low	Low	Acceptable **-G**	Acceptable **-G**
Number of transfers required	Low	Low	High	High
The Actors				
Total demand volume per year	Average/High	Low/Average/High	Low/Average/High	Low/Average/High
Sensitivity to variation in demand between pooling participants	N/A (Low)	High	Average	Low

Initial resources required	High **-R**	High	Average	Low
Sensitivity to disclosure of confidential information	Low	High	High	Low
Need for contractual integration	Low	Low	High	High
Level of trust necessary	Low	High **-G**	Low	Low
The Technical Systems				
Degree of standardization	Low/Average/High	Average/High **-G**	Average/High **-G**	High **-G**
The Costs				
Potential cost savings due to economies of scale	Low	Average	High	High
Initial investments required	High	High	Average	Low
Transportation	Low	Low	High	Average
Handling	Low	Low	High	Low
Interface	Low	Low	High	Average
Inventory holding	High	High	Average	Low

A model to evaluate soft values is derived from the characteristics in Table 5.3. The model, called *evaluation of soft values*, is further divided in two tables; Table 5.4 that covers main aspects of the strategies, and Table 5.5 that introduce an approach to convert the assessments of other relevant soft aspects into numbers. In so doing, the decision-making process is supported by numerical values.

A comprehensive reasoning regarding the assessments of the aspects in Table 5.4 is provided below.

As stated earlier it is required that the market is deregulated if an actor wishes to choose a cooperative or a commercial pooling strategy. The reason is obviously lack of other actors to cooperate with leaving only the stand alone strategy as an option. An ad hoc cooperation is still feasible though since a regulated market may still consist of more than one actor. Another possibility can be that two actors in neighboring countries choose to cooperate by pooling their spare parts in an ad hoc cooperation, provided that the actors are situated rather close to each other.

The optimum number of participants in a cooperative pool mostly depends on both the circumstances in the industry (e.g. existence of competitive behavior between potential cooperating parties) and on the degree of complexity in the network that increases as the number of participants increase. Supply chains in a network need to be transparent and not complex, therefore, it is desired to have a low number of actors that choose to pool their spare parts in a cooperative pool. In contrast to a cooperative pool, in a commercial pool the participants have connections with the service provider only and in so doing obtain a relatively low degree of network complexity. On the other hand, the responsibility of achieving an optimum logistic solution to efficiently satisfy all customers lies with the service provider. In Figure 5.2 below Kilpi et al. (2008) roughly illustrates the number of participants in relation to contractual integration necessary in pooling strategies.

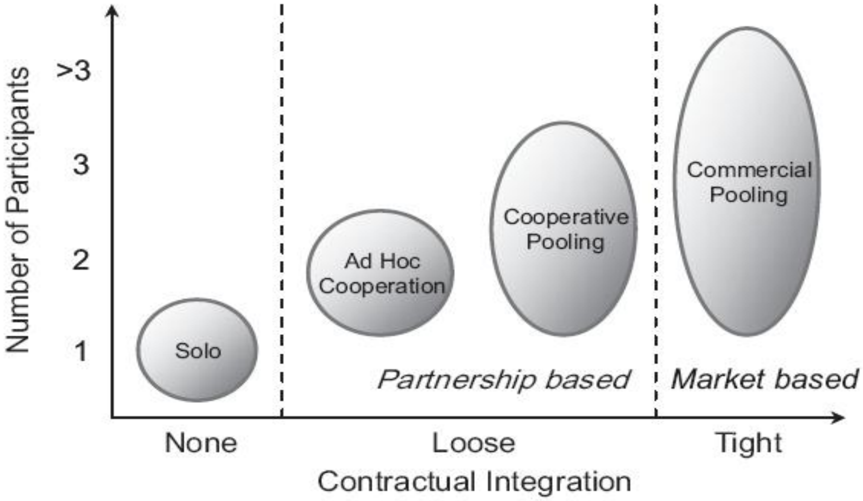


Figure 5.2: Number of participants in relation to contractual integration (Kilpi et al. 2008).

Table 5.4: The first part of the *evaluation of soft values* model. By studying the main aspects and their assessment for each strategy a decision-maker may exclude strategies, and hence, continue to evaluate remaining feasible strategies.

Evaluation of soft values – 1 **Main aspects**		**Pooling Strategies**		
	Stand alone	**Ad hoc**	**Cooperative**	**Commercial**
	Assessment	*Assessment*	*Assessment*	*Assessment*
Regulated market	Possible	Possible/Not possible	Not possible **-R**	Not possible **-R**
Appropriate number of participants	1	2	~ 3-5	≥ 3
Lead time for stock to arrive	Low	Low	Acceptable **-G**	Acceptable **-G**
Total demand volume per year	Average/High	Low/Average/High	Low/Average/High	Low/Average/High
Need for contractual integration	Low	Low	High	High
Level of trust necessary	Low	High **-G**	Low	Low

Degree of standardization	Low/Average/High	Average/High **-G**	Average/High **-G**	High **-G**
Potential cost savings due to economies of scale	Low	Average	High	High
Initial investments required	High	High	Average	Low

It is assumed that an independent actor buys spare part packages and have them available in-house, thus irrelevant to consider the lead time for stock to arrive in the stand alone strategy. Due to a short distance between two actors (alternatively, very efficient logistic solutions) in an ad hoc cooperation, the time until a required item arrives is therefore short. A cooperative pool can be likened to a number of ad hoc cooperation's that are linked to each other in the sense that the participants laterally share their inventory with their closest neighbors (an appropriate sourcing rule), but do also have the option of getting hold of a spare part from other participants. In that way, the participants also pool their risk together. Achieving a successful cooperative pool necessitates an acceptable lead time for a required unit to arrive otherwise the cost of downtime due to long waiting times may outweigh the benefits from a cooperation. In a commercial pool major pooling benefits are obtained when demand is accumulated and pooled from one location. However, to physically locate a central warehouse that satisfies the demand of all customers to an acceptable supply lead time is somewhat difficult since customers may be located far away from each other. Given that the customers are located far away from the central warehouse, a practical solution for the service provider is to hold a consignment stock that consists of the most critical spare parts near the customers' site. In so doing the lead time for stock to arrive is reduced to an acceptable level. A consignment stock is stock that is held by the customer but legally owned by the supplier. Only when the stock is used the customers need to pay for it. Seeing as the system downtime cost usually is the biggest cost the lead time for stock to arrive is one of the most important aspects no matter what strategy an actor choose.

To be able to successfully apply the stand alone strategy a high total demand volume is called for (in relation to its competitors or other actors providing the same services) in connection with high financial and process resources. The size of an actor is not of particular importance when considering the pooling strategies. Though, it is more favorable for smaller actors to choose the commercial pooling strategy since they may not have the resources or competence required to deal with MRO maintenance. In so doing, they can focus on their core business.

As stated in section 5.3.2 (The Actors), the more stakeholders involved in a network the more complex the network gets leading to the necessity of tight contractual integration. Conversely, a simple network with loose contractual integration between the actors calls for a high level of trust.

Another important aspect that highly influences the possibility of choosing a specific strategy is the degree of standardization of the technical systems. A service provider can only benefit if the accumulated demand volume from its customers is rather high. It may be that the accumulated demand volume is adequately high, but the customers are few. This situation can lead to customers wanting to do the MRO maintenance themselves, and thereby put the service provider of a commercial pool out of work. A high degree of standardization is almost a prerequisite for the existence of a commercial pool since it encourages smaller companies to enter a market, and in doing so, also balances the risks of the service provider since it no longer is dependent on a few big customers only. Naturally, to be able to obtain benefits with inventory sharing between independent actors (e.g. in an ad hoc or a cooperative pool) there is a need of an adequately degree of standardization of the technical systems.

Potential cost savings in relation to the stand alone strategy are high in a cooperative and a commercial pool. Consider a case where there are five independent actors using similar technical systems and are somewhat equal in demand volume. To be able to reach a service level of 95% each participant need to have three parts of a specific component in-house, leading to 15 components in the total system (a system consisting of five independent actors). If these actors choose to organize a cooperative pool between themselves the total required amount of the same component in the system can be reduced to 10 (due to a very low probability of having more than one customer demand at the same time) while the service level of 95% is maintained. The cooperation brings a cost saving opportunity since the actors only need to buy two components each, instead of three as they would have without cooperating. Cost savings are also high in a commercial pool since a service provider only needs to acquire and add a smaller amount of spare parts (compared to the amount of spare parts an individual actor need to acquire) to its existing pool in order to maintain the targeted service level. Also, a service provider has normally a higher purchasing power (due to scale economy) than an individual actor and can thus buy spare parts packages to a lower price from the supplier (e.g. the manufacturer). In so doing, the service provider attracts customers by offering them lower costs (e.g. the cost of service level) than they would have if the customers had purchased the components from the manufacturer directly.

A commercial pool is associated with a fixed *start-up cost* that is usually high. The main costs covered in this category are: purchasing of adequate amount of spare parts and the cost of setting up a warehouse where the stock is located. Therefore, the main barrier of entry for a third party that aims to provide with a commercial pool are the huge investments necessary during the start-up phase. Start-up costs are not considered in a cooperative pool because it is assumed that all actors already own their spare parts, and thus only need to pool them together. Also, due to lateral transshipments there is no need to set up an additional warehouse. High administrative costs in the initial phase are included in handling costs in a cooperative pool. In an ad hoc cooperation the extra administration costs that arise in connection with the initiating phase of the cooperation are often negligible.

Table 5.5: The second part of the *evaluation of soft values* model. The written assessments are given numerical values, and by this means, enables a decision-maker to assess the strategies numerically.

Evaluation of soft values – 2 **Soft aspects**				**Pooling Strategies**					
	Weight (%)	**Stand alone**		**Ad hoc**		**Cooperative**		**Commercial**	
		Assessment		*Assessment*		*Assessment*		*Assessment*	
Sensitivity to competitive behavior		Low	5	High	1	Average	3	Low	5
Complexity		Low	5	Low	4	High	1	Low	5
Number of transfers required		Low	5	Low	4	High	1	High	1
Initial resources required		High	1	High	2	Average	3	Low	5
Sensitivity to variation in demand between pooling participants		Low	5	High	2	Average	3	Low	4

Sensitivity to disclosure of confidential information		Low	5	High	2	High	2	Low	4
Value									

The second part of the *evaluation of soft values* model presented in Table 5.5 enables the decision maker to numerically assess specific characteristics of different strategies. Parsons (2001) state that two conditions ordinarily need to be met to make the aggregation of a number of items that are expressed in dissimilar units possible:

- A means to render items dimensionless
- A set of weights

In addition to the terms (e.g. Low, Average, and High) that notify the assessment of the aspects in all strategies, there are numbers from *1* to *5* next to the terms that stand for the written assessment. In so doing, the assessments are given dimensionless numerical values (a mark) which are then used to compare the strategies with each other. The reasoning behind the numerical translations is such that: *Low* can have the mark *4* or *5*; *Average* the mark *3*: and *High* the mark *1* or *2*. As pointed out earlier, different aspects are of different importance for the companies. In column *weight* the companies may by themselves decide on the importance of an aspect in relation to other aspects considered. The weighting factor ought to be expressed in percent. The reasoning regarding the assessments of the aspects in Table 5.5 is provided below.

Competition among actors is an aspect that can create barriers to a cooperating strategy although all parties may benefit from working together. An ad hoc cooperation is most sensitive to competitive behavior because of the lack of tight contractual agreements in the network. In a cooperative pool it is assumed that all relevant information (such as inventory levels) are shared between all participants in a common platform (e.g. software that is daily updated). While contractual agreements in a cooperative pool are tight the network is still sensitive to competitive behavior to a certain degree, due to the awareness that an actor can choose to make his spare part unavailable if he notice that his competitor will shortly be in need of that specific part. Therefore, every actor should thoroughly consider the consequences of joining a cooperative pool if competition exist (or may exist in the future) among the participants. Regardless of the existence of competitive behavior a commercial pool organized by a service provider will diminish the risk of sabotage from other participants, since all participants are in contact with the service provider only. The service provider has no incentives of revealing information regarding a specific customer to the other customers. However, in some industries (such as *defense*) a service provider may be restricted from having various customers due to national safety motives.

As previously mentioned, it is desired to obtain a transparent supply chain that is not complex. A minimum degree of complexity is obtained when the solo strategy is applied because of no other (excluding parties that are contracted to manage a business that is outside the core) parties directly involved in the decision making process regarding the inventory. The complexity increase as the number of participants in a cooperation increase, and therefore, a cooperative pooling strategy may turn out to be very complex if not managed properly from the beginning. The number of participants in a commercial pool is not of importance for a single actor that joins the pool. The actor has contractual agreement with the service provider only and thus expects the agreement to be respected regardless of the complications that may arise for the service provider. The degree of complexity in a commercial pooling strategy is equal to the corresponding degree in the stand alone strategy (if not lower). The service provider can obtain a complex situation as the number of participants increase (for example, due to difficulties in finding efficient logistic solutions) and should therefore find the demarcation point; the maximum number of participants in the pool until the benefits from providing a commercial pool decrease.

In the stand alone strategy spare parts packages are acquired and provided in-house, therefore, the number of transfers required is low. Due to loans in emergency situations in an ad hoc cooperation there is a slight increase in number of transfers required. A cooperative and a commercial pooling strategy lead to a high number of transfers required in the distribution network, and thereby, increasing the cost of transfer. In a cooperative pool, the cost of transfer is dependent on the locations of the participants and in the effectiveness of the existing logistics. In general, the further away they are located from each other, the more will a transfer cost, and also, the more time until a spare part reaches the requiring actor. A commercial pool need to be located within an acceptable reach to all its customers. A faulty item is returned to the pool while a functional replacement is sent the other way. The item is repaired by the service provider and then put back in the pool. Also of interest is the distance to the situated workshops where the faulty items are sent for repair. By simple means Figure 5.3 and Figure 5.4 illustrates the required flow of transfers in a cooperative and a commercial pool with four participants. As one would expect, participants are very seldom geographically located in a circle as illustrated in the figures, however, the approach is illustrative to comprehend the logic of transfers in the two pooling strategies. The solid lines represent the regular flows (both ways) while the dashed lines represent the flows in case of emergency (e.g. if the neighboring locations are out of stock). For example, location 1 sends to and receives from both locations 2 and 4, while location 1 will send to and receive from location 3 if locations 2 and 4 are out of stock.

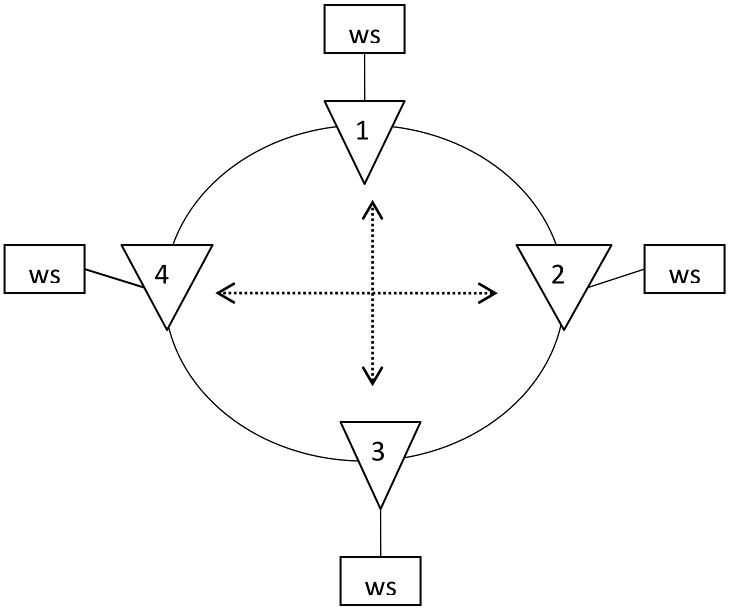


Figure 5.3: Flow of transfers required in a cooperative pool consisting of four participants. WS are the work-shops where the repair of faulty items takes place.

Figure 5.4 show the flow of transfers required in a commercial pool where the pool is strategically placed in the middle of all participants. Connections are established with the service provider only which in turn is in charge of repairing the faulty items and putting them back in the pool. Worth noticing, as illustrated with the dashed lines, the distance for an item to reach location 4 (after being repaired) from location 1 may be longer compared to the corresponding distance in a cooperative pool.

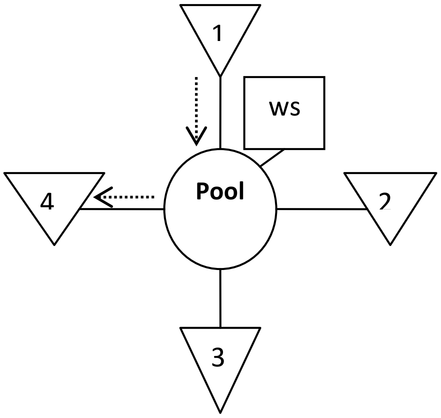


Figure 5.4: Flow of transfers in a commercial pool consisting of four participants.

An actor needs the resources; financial, process, and human resources in order for the stand alone strategy to be possible to choose. The financial resources to acquire spare parts packages, process resources to do the MRO maintenance in-house, and human resources to manage the supply chain. At the same time, the actor need to concentrate on its core business in order to maintain (or increase) its market share or reach other targeted goals. In a cooperating strategy, such as the ad hoc or cooperative pooling, the participants still need resources (process and human resources especially, since it is assumed that the participants have acquired spare parts packages in the past). However, it is not required for all participants to have the resources in-house seeing as an agreement can be made where the participant(/s) having the resources in-house are responsible of the MRO maintenance. Thus, a location without the necessary resources can, against a fee, let a neighboring actor that does have the resources in-house do the MRO maintenance. Another option that is very common in some industries is the option of outsourcing the entire MRO maintenance to a company outside the pool that is specialized in maintenance services. In so doing, all participants are responsible of putting a repaired item back into the (virtual) pool, but other parties are subcontracted to actually perform the MRO maintenance on the entire systems and the spare parts. An independent actor that chooses the stand alone strategy may also outsource its MRO maintenance to a third party, however, considered actors that choose the stand alone strategy in this thesis are those that do the MRO maintenance themselves. Neither process nor additional human resources are needed for an actor to join a commercial pool. A connection fee is necessary to join the pool and therefore require some financial resources in the beginning.

As stated in section 4.4 (Ad Hoc Cooperation) it is important for the two cooperating actors in an ad hoc cooperation to be almost equal in demand volume. For instance, a bigger party will not see any benefits from cooperating with a considerably smaller party because of the little amount of stock the smaller company has available in-house in case of emergency. The ad hoc strategy is therefore very sensitive to variation in demand between the cooperating parties. Correspondingly, a cooperative pool is also sensitive to variation in demand between the participants. Though, due to a higher number of participants the risk of imbalance between the actors decreases. Additionally, as stated in section 4.8 (Cost Allocation in Spares Inventory Pooling), the choice of cost allocation policy can render a situation where no actor, regardless of size, looses from joining the pool. Hence, a way to decrease the sensitivity to variation in demand between pooling participants in a cooperative pooling strategy is to choose an appropriate cost allocation policy. From the perspective of an actor the variation in demand between pooling participants in a commercial pool is almost irrelevant. The sensitiveness lies in the fact that smaller actors may be given lower priority be the service provider, and thereby not receives items according to contractual agreements. However, penalty fees stated in the contract are intended to reduce the risk of getting a lower priority by the service provider in the pool. On the other hand, from the perspective of a service provider there is a threat of customers wanting to organize an own pool (e.g. a cooperative pool between themselves) if the demand is uneven and the customers are few in the pool. Also, a service provider needs to keep track on the capacity restrictions before accepting a big customer in the pool. The existing customers must not obtain a lower service level due to the arrival of a new customer that may complicate the management of the pool for the service provider.

The sensitivity to disclosure of confidential information is mostly dependent on two factors; first, the more actors involved the more sensitive a network is. And second, the looser contractual agreements between cooperative parties the more tempting for a party to misuse information it gets hold of. The two cooperative strategies are therefore classed as sensitive to disclosure of confidential information. Information of interest that may easily leak is often regarding the technical systems and “the way work is done”. However, many industries are considered as open industries where all actors already very well know of the technical systems a competitor use and the way they work. For example, in the commercial airline industry the technical systems are out in the open (an actor knows what aircrafts its competitor got), the timetable lay out open on every actors website (an actor can thus calculate a competitors flying hours per year), and business is often done in a similar way in the same industry. So, often there is not much confidential information that is vulnerable of disclosure when an actor joins a cooperative pool. On the other hand, a commercial pooling strategy has a low degree of sensitivity to disclosure of confidential information since actors are connected to the service provider only which in turn has no incentives of revealing information about a customer to other customers. An actor must bear in mind that a service provider usually hold much information about every customer, therefore, dependent on the sensitiveness of the information extra precautions may need to be taken in case of the service provider happens to leak information to others.

The second part of the *evaluation of soft values* model in Table 5.5 presents soft aspects of interest that facilitates a comparison between the different strategies. The aspects are often of different importance for different actors; therefore, an actor needs to weight every aspect in relation to the others. For every aspect, the weight (in percent) is multiplied by the numerical assessment in every strategy. The aggregated result is then provided in the final row *Value*. The reasoning is such that the higher the value the better the strategy. An example of how the model is used is provided in chapter 6 (Case Study – Commercial Aviation Industry).

5.5 Key Performance Indicators (KPI)

A number of different factors should be considered when the cost of organizing a pool is divided between the participants. Following factors are of interest when setting a key performance indicator that helps to divide the total cost between the pooling participants in a fair way:

1. The benefits from joining the pool
    - Risk reduction
    - Reduced downtime
    - Opportunity costs: e.g. acquisition of spare parts or loan-in
2. The current status of the spare parts each participant possess
    - Time left until next scheduled maintenance
    - Operational profile
    - Age
3. The content of the pool: available spare parts and their locations (/owners)
4. The total capital investment of the pool
5. Average interest and return requirements on restricted capital

A proposition to share the total cost of the cooperative pool between the participants is according to relative incremental contribution to the pool (RPC), which is derived from;

- For each participant the contribution to the pool is calculated: *Number of components x Price*
- This is then put in relation to the total value of the pool.

The cost allocation policy is fair over a long period of time, however, in the short run it can be sensitive to variations in component price.

As discussed in section 4.8.3 (Commercial Pool), the cost of service is only foreseeable in commercial pooling seeing as the strategy is based on service pricing. In a pool spares are often categorized based on demand. The *Failure rate* may therefore serve as a KPI that determines how the service provider sets prices. Smaller service providers are more reluctant of having high cost components with low failure rates in the pool owing to the high risk (e.g. stock on hand that may never be demanded by a customer) these components are associated with (ST Components, 2010). Nevertheless, the service provider may still offer to do the MRO maintenance on these components. On the other hand, components having higher failure rates are associated with a lower risk and are therefore more likely to be pooled. A brief discussion of various existing pricing methodologies follows below.

Power-By-The-Hour (PBTH) is considered as one of the most holistic pricing methodologies. Using this approach, a customer pays a set price for logistics support for each hour that a system operates. For example, on a locomotive engine contract, the service provider is paid a fixed amount of money for each engine-operating hour sustained by the customer. On the other hand, the service provider would be responsible of providing any parts required to support the engines within a negotiated lead time. Seeing as the service provider is paid the same regardless of the number of parts supplied, the Power-By-The-Hour pricing methodology provides significant incentives for the service provider to improve the reliability of its spare parts. In order for the service provider to benefit from organizing a pool, the customers are charged for a minimum amount of hours during a period (e.g. a year). For example, a helicopter operator may be charged for a minimum of 300 flight hours per helicopter and year, during a contract period. However, compensations are possible to specify in the contract. For instance, if the helicopter operator has only flown 250 hours the first year but flies 350 the next year then the operator can get compensated for the first year by only getting charged with 300 hours the next year. The methodology is beneficial for customers seeing as:

- The customers only need to concentrate on their core business, e.g. operating the technical systems
- Budgeting gets easier as customers are assured of an accurate cost projection
- Costs associated with unscheduled maintenance are avoided

Time and Material is another pricing methodology which suits a service provider that does not want to have a specific component in the pool. As mentioned above, smaller service providers may not want to risk having high cost components that may never be demanded due to low failure rates. The service provider will repair an item and send it back to the customer after repair completion. By means of Time and Material, the customers are charged for all of the hours of work performed, material purchased during repair completion, and a profit margin added by the service provider. The customers are thus responsible of the outcome in case of component failure for components covered with Time and Material. They can either have a spare part in-house, or choose to not have stock on hand and take the high cost (e.g. cost of downtime) when or if it comes.

Some customers may not own the technical systems (e.g. in a leasing agreement) and do therefore only need the systems for a specified amount of operating time. For these customers another pricing methodology can get derived;

- Fixed annual fee + Usage fee.

The annual fee is a fixed cost regardless of usage (similar to the principle of PBTH) while the usage fee is a variable cost depending on the operation of the technical system (e.g. number of operating hours, driven km etc). For example, if a spare part has only run 50% of its full potential, a customer could therefore pay a lower price on that returned part (or entire technical system). Figure 5.5 illustrate the remaining value of a spare part after usage.

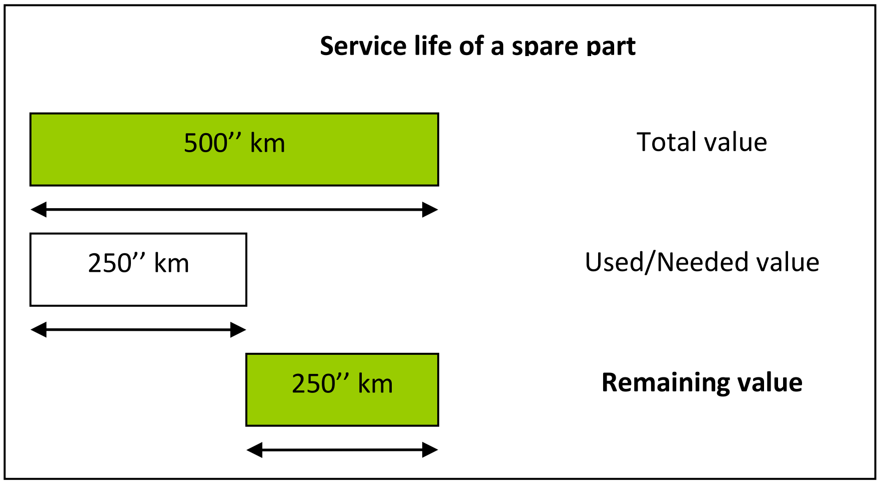


Figure 5.5: A spare part that is not required during its entire service life still holds a value that can be traded.

5.6 Diseconomies of Scale

Kilpi et al. (2008) recognize that the scale economies are strong in the availability service. The most efficient way of building scale is if companies pool their demand together and thereby form as large a pool as possible. Olhager et al. (2001) consider a manufacturing plant and the impacts an increase in scale of production has on a manufacturing company. They further state that building scale may reduce certain costs but can also cause other costs to increase. Olhager et al. (2001) refer to four different types of *diseconomies of scale* that affect a manufacturing company. Due to similarities of increasing the scale of production in a manufacturing company to increasing the scale of spare parts in a pool, the logic behind diseconomies of scale should be considered in a pooling strategy as well. Further on, a commercial pool is considered where the demands of several customers are pooled together by a service provider. Four types of *diseconomies of scale* will be discussed briefly.

Distribution Diseconomies: When a pool increases in size it most often also mean that items need to be shipped over a larger geographical area. Provided that a customer moves further away from the pool, the required costs to distribute items over an expanding region will probably increase a lot faster than the revenues. In cases where the customer incurs the transportation costs directly, the service provider may still have to pay "freight equalization charges" in order to prevent competitors nearer the customer from gaining cost advantages.

Diseconomies of Bureaucratization: The bigger the pool, the more workforce required to handle it. Additional personnel make way for the organization of the service provider to grow like pyramids. This leads to increased difficulties with communication and coordination. As a result, the management costs increase, the response time to both external forces and internal crisis deteriorates, and information that filters up or down the organization becomes more likely to get lost or deteriorate.

Diseconomies of Confusion: In situations where the number of products and/or processes increases, activities of dissimilar nature are often combined with the aim to reduce complexity. However, by doing so complexity is merely reduced and if not managed cautiously the organization can begin to work cross-purposely.

Diseconomies of Vulnerability to Risk: As the pool increases the service provider put more resources into the pool and thus becomes more dependent on the successful operation of the pool. Consequently, the performance of the service provider will seriously get damaged should the pool be struck by a natural disaster (e.g. fire, earthquake etc) or a human one (e.g. strike, mismanagement etc). This vulnerability can be reduced by the means of allocating items in more than one pool separated from each other.

5.7 Methodical Approach – The Decision Making Process

A decision-maker in a company that wishes to investigate in which of the four strategies may be a best fit needs to first study Table 5.3. A number of characteristics are lined up and categorized in four segments (The Market, The Actors, The Technical Systems, and The Costs) that give the decision-maker a holistic view of what the four different strategies might necessitate. Then, a thorough analysis of the main aspects in Table 5.4 is required (the first part of the *evaluation of soft values* model). The analysis will serve as an exclusion point, whereby, only feasible strategies will be further investigated.

Further on, in order for an actor to choose a right strategy the soft aspects in Table 5.5 (the second part of the *evaluation of soft values* model) need to supplemented by the cost to reach a targeted a service level. A model that covers all relevant costs needs to be designed for each strategy. The cost models need to be as precise as possible, and yet, in order for all participants to clearly understand the mathematical calculations in the models they also need to be simple. In so doing, actors will then obtain the total cost that comes with a specific strategy. In section 4.8 (Cost Allocation in Spares

Inventory Pooling) numerous cost allocation policies in pooling strategies are briefly discussed. The design of cost models is outside the delimitations of the thesis.

A straight cost comparison between strategies is not recommended. For every strategy, the outcome of a cost model must first be weighted with the outcome of the second part of the *evaluation of soft values* model. An approach according to the objectives matrix (OMAX) is proposed when weighting the outcome of the two models for each strategy. OMAX is a model where target levels for multiple indicators are combined and weighted (based on importance) into a single performance index. This index facilitates for the decision-maker to make a straight comparison between considered options (Borgström 2006).

For each criterion (e.g. MRUA, CSI, MWT, and Q in Figure 5.6) a scale is set up consisting of possible obtained measures. Further on, the scale of measures is then matched to a scale of scores from zero to ten. The score 10 corresponds to a best possible measure obtained while the score 0 corresponds to a worst possible measure obtained. Accordingly, for each criterion the actual measure obtained is matched with a corresponding score. A value is obtained as the product of a criterions score and weight. By aggregating the value of all criteria a single performance index is obtained.

Performance Measure					
MRUA	CSI	MWT	Q		
0.60%	91%	310 min	89%	Performance	
0	100.0	30	100	10	Scores
0.1	97.5	40	98	9	
0.05	95.0	60	95	8	
0.15	92.5	80	90	7	
0.20	90.0	100	85	6	
0.30	85.0	120	80	5	
0.40	80.0	180	75	4	
0.50	75.0	240	70	3	
1.00	50.0	300	50	2	
2.00	30.0	420	30	1	
3.00	20.0	540	20	0	
3	6	2	7	Score	
40	20	15	25	Weight (%)	
120	120	30	175	Value	

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Figure 5.6: Objectives matrix with four performance measures: Maintenance Related Unavailability (MRUA), Customer Satisfaction Index (CSI), Mean Waiting Time (MWT), Quality (Q) (Borgström 2006).

A decision-maker that wishes to evaluate its options using the objectives matrix will need to set up an appropriate scale of measures for each considered criterion. The scale does not need to be linear, but the measures must correspond to the scores in the most equitable manner possible so the values obtained will not be distorted. In chapter 6 (Case Study – Commercial Aviation Industry) two criteria (Soft aspects and Annual cost) are considered for each strategy when deriving a final performance index in accordance with the objectives matrix, consequently, a scale of measures is set up for each criterion. Two guidelines in how to set up a scale of measure are provided below:

Based on a predetermined set of scale: Actual values obtained are assigned scores according to a predetermined set of scale. For example, each criterion is assigned a score on a scale of one to five (could also get extended to a scale of one to ten) dependent on how the obtained values meets the predetermined requirements. In so doing, the strategies are not evaluated in relation to each other. The scores can be divided accordingly:

5	Much better than the requirement
4	Better than the requirement
3	Meets the requirement
2	Somewhat worse than the requirement
1	Much worse than the requirement

Based on the arithmetic mean (μ): The scale of measure (from either one to five or one to ten) is stretched out based on the arithmetic mean of values obtained from each criterion and strategy. The upper and lower boundaries of the scale are determined by adding/subtracting a percentage of the arithmetic mean, alternatively, by adding/subtracting the standard deviation (σ) of the values to the arithmetic mean. When based on the arithmetic mean the scale must be linear. A value that exceeds the upper or lower boundary of the scale will be assigned a score that equals the corresponding score of the closest boundary. Consequently, the scores can be divided accordingly:

10	$[\mu + 0.5\mu]$ *or* $[\mu + \sigma]$
5.5	μ

1 $[\mu - 0.5\mu]$ *or* $[\mu - \sigma]$

A thorough execution of all the steps in the process will provide a good basis for choosing a best strategy. Figure 5.7 outline the four focal steps in the decision making process.

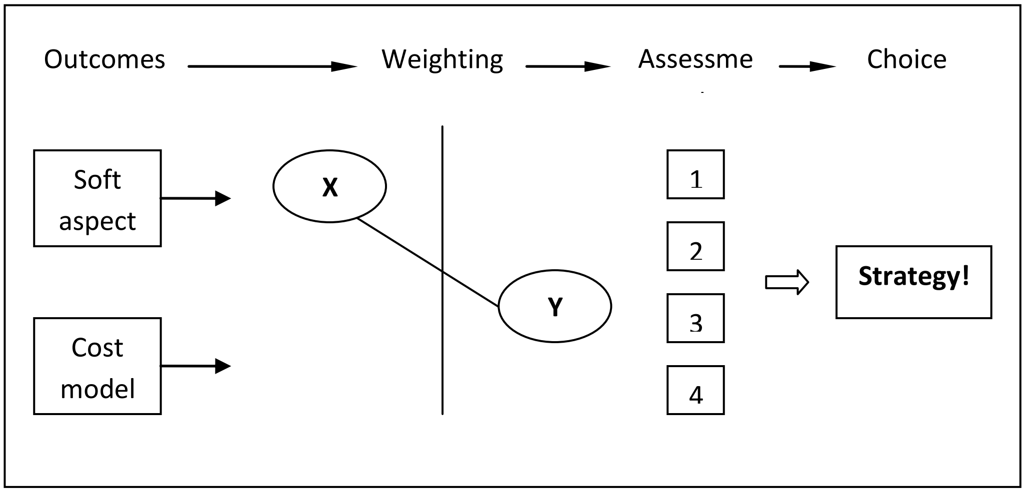


Figure 5.7: For each strategy, the outcomes of the two models are weighted and a best strategy is finally derived. X = Value soft aspects, Y = Value annual cost.

6 Case Study – Commercial Aviation Industry

The case presented in this chapter is fictitious.

6.1 Background

Masters Airline (M.A.) is a newly founded commercial airline having its home base in a big city in central Europe. M.A. completed a major business deal about a week ago as they acquired 22 new aircrafts of the same type. Upon purchasing, M.A. was also offered to buy spare parts packages that cover the 22 aircrafts. However, the CEO of Masters Airline was somewhat aware of the existence of different strategies regarding the management of MRO maintenance, and thus, succeeded in negotiating a new deadline for the decision to acquire spare parts packages or not. Since the completion of the deal last week it has been a primary focus for the seniors at M.A. to gather as much information as possible to support the decision whether to buy spare parts packages (and to what extent) or not. The deadline expires today and the CEO of M.A. is right now on his way to a meeting with the manufacturer of the aircrafts. The decision whether to buy or not is based on the compiled report below.

6.2 Aspects of Interest

In the commercial aviation industry the product that is offered; a seat to a number of locations at a specific time of day, is considered a perishable commodity. Once a plane with an empty product (en empty seat) departs there is no way to recapture that value. The airline cannot put the seat on a shelf waiting to be purchased the next day.

There are many commercial airlines acting in a deregulated global market. The market, which is considered mature, is also characterized by a high competitive behavior between the airlines. Huge capital investments are associated with purchasing of aircrafts and the cost of having airplanes on ground is vast (cost of downtime).

Masters Airline is a medium-sized company. The demand for spare parts that arises to cover 22 aircrafts is considered as average in relation to the corresponding demand for other airlines. The aircrafts acquired are common aircrafts in the market, and thus, facilitates for cooperation with other airlines for mutual benefit. Main affecting factors upon purchasing spares are; the price and the failure rate (the total demand) of each item. Once purchased, the spares are often categorized accordingly:

- **Class 1 – No go:** Critical items. In case of failure, the aircraft cannot leave ground until a working spare is installed.

- **Class 2 – Go if:** The aircraft can under certain conditions leave ground and the faulty item is repaired after the aircraft reaches its destination. These conditions are regulated by a variety of legislations that are set by the authorities.
- **Class 3 – Go:** The aircraft may leave ground and the failed spare part is repaired on the next occasion.

6.3 The Evaluation of Soft Values Model

After studying the characteristics in Table 5.3 and the first part of the evaluation model in Table 5.4, M.A. intuitively feel that all four strategies are within a reach. By entering into a pooling cooperation, M.A. is certain that confidential information will not be at risk to be disclosed. Hence, M.A. is not sensitive to disclosure of confidential information. However, M.A. does feel an urge to avoid partnering up with a competitor in a cooperative pool regardless of how tight the contractual integrations are. M.A. is aware of the huge capital investments required in both process and human resources if they choose to acquire spare parts packages and act independently. Nonetheless, if the stand alone strategy proves to be a best fit the investments in initial resources required will be provided immediately.

The second part of the evaluation model in Table 5.5 (Soft Aspects) is made use of in order to assess soft aspects for each strategy. M.A places great emphasis on the degree of complexity in the network. Equal importance is put on the robustness of a pooling cooperation consisting of competitors. M.A. feels that these two aspects are of main interest for a healthy long-term pooling strategy and therefore constitute 50% of the weighting in the model. The model is provided below and the value of each strategy is obtained by aggregating the weighted assessment of each row. The weighted assessment of a row is the product of the weight and the assessment mark. For example, the weighted assessment of the first row for the cooperative pooling strategy is *75* (25 x 3).

Table 6.1: Modeling soft aspects. All aspects are weighted based on perceived importance by M.A. A final value for each strategy is obtained. The higher the value the better fit might the strategy be. It can be seen that based on selected soft aspects only (costs excluded) the best strategy to choose would be the stand alone strategy followed by the commercial pooling strategy.

Evaluation of soft values – 2 **Soft aspects**				**Pooling Strategies**					
	Weight (%)	**Stand alone**		**Ad hoc**		**Cooperative**		**Commercial**	
		Assessment		*Assessment*		*Assessment*		*Assessment*	
Sensitivity to competitive behavior	*25*	Low	5	High	1	Average	3	Low	5
Complexity	*25*	Low	5	Low	4	High	1	Low	5
Number of transfers required	*10*	Low	5	Low	4	High	1	High	1
Initial resources required	*15*	High	1	High	2	Average	3	Low	5
Sensitivity to variation in demand between pooling members	*15*	Low	5	High	2	Average	3	Low	4

Sensitivity to disclosure of confidential information	*10*	Low	5	High	2	High	2	Low	4
Value		**440**		**245**		**220**		**435**	

6.4 Strategies

All strategies are investigated in detail by M.A. Specific conditions are analyzed and a total cost is obtained for each strategy. The total cost is spread over a time period in which the aircrafts are intended to be utilized. A summary of important analysis in connection with the annual cost of a strategy is provided below.

6.4.1 Stand Alone

Even though the stand alone strategy offers a minimum of network complexity, the strategy is associated with a high degree of complexity in the perspective that the independent actor must by himself manage the MRO maintenance of the technical systems. However, the lack of other stakeholders involved leads to a more transparent supply chain and to decisions being made faster due to shorter communication channels. The actor will gain a lot of knowledge of the spares and will be able to more efficiently optimize logistics.

M.A. assess that there are no obstacles with setting up workshops near its home base but have run into difficulties when investigating in the option to set up work-shops near the many of Masters Airline's destinations. Owing to the existing mature market, a variety of maintenance companies has already established work-shops near airports around the world. Nonetheless, if the stand alone strategy is to be chosen M.A. can circumvent that barrier by contracting the MRO maintenance to the established maintenance companies at the destinations.

M.A. sense that the main benefit from acting independently will be the high service level (e.g. availability) obtained of spare parts in case of system failure. Having spare parts in-house also diminishes a potential lead time that can be positive in other strategies (lead time for stock to arrive).

Derived from an OPUS10 analysis, the cost/efficiency – curve diagram is illustrated in Figure 6.1, the annual cost of choosing the stand alone strategy is estimated to be 13 million.

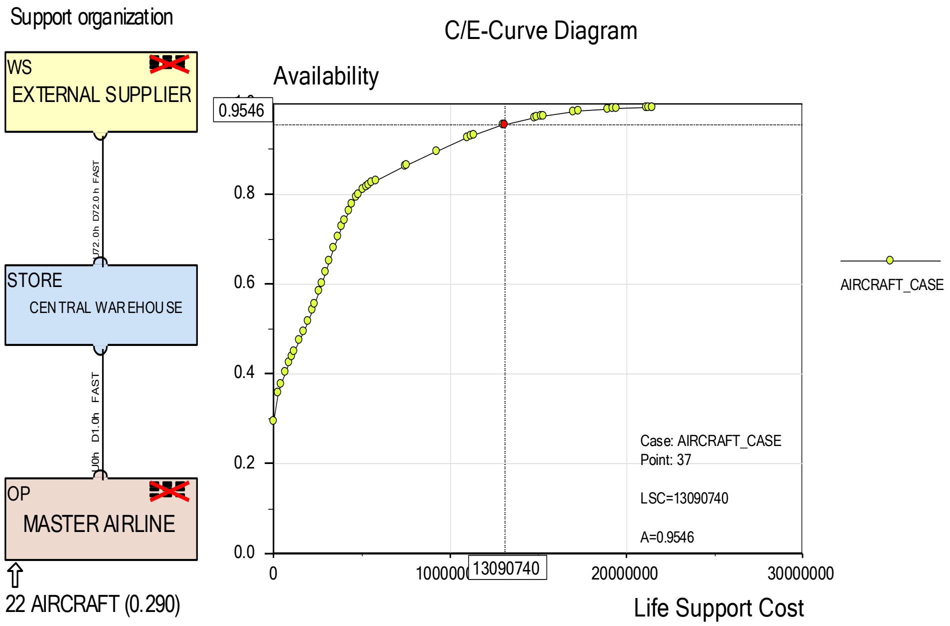


Figure 6.1: The figure is obtained from an OPUS10 analysis. The support organization is mapped out to the left of the figure. The central warehouse is situated only 1 hour from M.A. home base. To the right of the figure, we see that the cost of reaching the targeted service level of 95% is 13 millions.

6.4.2 Ad Hoc Cooperation

M.A. has identified a neighboring airline that may suit as a good partner in an ad hoc cooperation. The two airlines are somewhat equal in demand volume. In cooperating, the airlines may mutually save money compared to acting alone given that a lesser amount of high cost components are necessary in the network. For example, to satisfy a desired target level it is enough to have one aircraft engine in stock instead of each airline having its own engine. Also, the availability of other components increases due to the option of loaning from the other party when an airline is out of stock.

On the other hand, M.A. aspires to pursuit a long-term strategy and sense that an ad hoc cooperation will bring too much uncertainty that may cause issues in the forthcoming years. M.A. wishes to not rely on loans in case of system failure. In addition, seeing as the two airlines are competitors M.A. believes that achieving a necessary high level of trust will be difficult. Though in the short run, the idea of cutting costs temporarily is appealing.

Derived from an OPUS10 analysis, the annual cost of choosing the ad hoc cooperation strategy is estimated to be 11 million.

6.4.3 Cooperative Pooling

M.A. has located a cooperative pool and also received an offer to join the pool. At the moment, there are four participants in the pool whereas one of them is in charge of administrating the virtual pool. The pool is of a *coopetitive* nature, meaning that the participants have all agreed on a cost allocation policy but they independently set the reserved stock levels in order to optimize the benefits of their own location. Due to tight contractual integrations between the participants the pooling cooperation has yet not experienced any drawbacks because of existing competitive behavior.

The pool has existed for some years already and has proven to be both robust and successful. All participants are responsible of repairing components that fail in their systems and putting them back in the pool. Participants that do not have resources in-house contract maintenance companies to do the MRO maintenance. Until now, all participants contribute with more value in to the pool than they take out of the pool. M.A. having approximately same demand volume as most of the participants is definitely expected to contribute positively to the existing pool.

An illustration of the virtual pool is provided in Figure 6.2. Given that M.A. joins the pool, they will be geographically located to the east of all other participants (Masters Airline's central warehouse). Lead times for lateral transshipments between the airlines are specified in the figure. M.A. feel that an acceptable lead time for stock to arrive is within 24 hours, therefore, only airline number 4 satisfies the lead time requirement. Still, M.A. evaluates that by regulating the reserved stock levels a lead time of 30 hours can also be accepted. Since M.A. only need a proper connection to Airline number 4 (and to some extent also to Airline number 1), and owing to the fact that one of the other airlines is responsible for administrating the pool the network will not be as complex as one might first think.

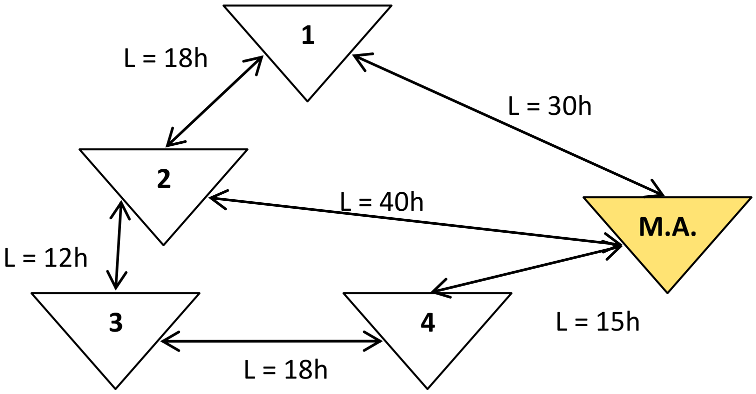


Figure 6.2: The network in a cooperative pooling strategy is mapped out. The virtual pool consists of five airlines. The lead time, L, for transshipments between neighboring airlines is specified.

There is a cost of initial investments (such as, acquiring spare parts and a fixed cost to join the pool) associated with joining a cooperative pool. Despite this onetime cost, M.A. makes out major cost benefits from joining the cooperative pool.

Derived from an OPUS10 analysis, the annual cost of choosing the cooperative pooling strategy is estimated to be 7 million.

6.4.4 Commercial Pooling

When investigating in the option of joining a commercial pool, M.A. has located two potential service providers (SP). However, only the larger of the two offers to pool all spare parts, including components that are very expensive and associated with low failure rates. Figure 6.3 illustrates the risk of keeping spare parts in stock in relation to the demand.

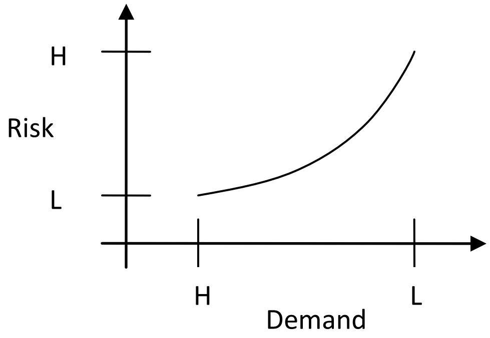


Figure 6.3: Higher frequency of component failure yields more accurate prognosis, and thus, lowers the risk of an item to become obsolete. High cost components have usually low failure rates and are considered high risk components. However, components with low failure rates but relatively low-priced are not categorized as high risk components.

M.A. reasoned that if they were going to choose a commercial pooling strategy they would prefer a service provider that manages all spare parts. For this reason, only the larger service provider is considered in the ongoing analysis.

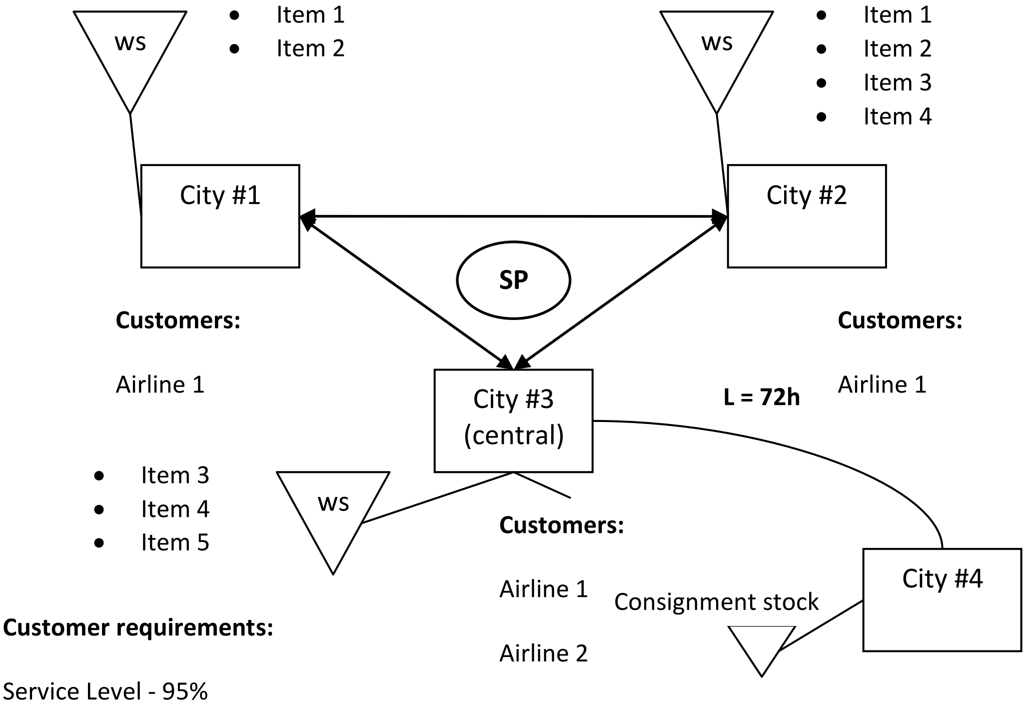


Figure 6.4: A mapping out of the service provider (SP).

Figure 6.4 shows the network structure of the commercial service provider. The SP has strategically established work-shops where MRO maintenance is carried out in connection with three major airports in different cities. Due to differences in work-shop capacities, all items need not to be repaired at all work-shops. For example, in case of failure of item 1 on an aircraft situated in City #3, the failed part (item 1) will be sent to either of the other two cities for repair. Since the SP has customers situated in City #4, there was a need to establish a consignment stock in order to maintain high availability on spare parts, on the critical parts in particular.

However, efficient logistic solutions are not issues that concern the participants of the commercial pool. The foremost aspect of interest for the customers is the ability for the SP to reach a targeted service level which is specified in the contractual agreements. Of course, the targeted service levels vary depending on how the items are classed; items in Class 1 having the highest service level.

At the moment, the commercial pool consists of spare parts that cover 200 aircrafts. If M.A. decides to join the pool, the service provider needs to acquire an addition amount of spares to maintain a targeted service level towards all customers in the pool. The SP is well aware that, in contrast to the scenario where M.A. themselves purchases spare parts packages, the SP need to acquire a smaller amount of spare parts to reach the same targeted service level. The latter conclusion is drawn owing to an already existing pool that only needs to get expanded by 11% (an addition of 22 aircrafts), compared to the other scenario where M.A. do not have other assets (e.g. existing spares) and will therefore be forced to acquire more spare parts (than the SP) if they wish to cover all 22 aircrafts. Before offering an annual cost to M.A. the SP looked into the cost of acquiring spare parts to maintain a targeted service level. The results provided in Table 6.2 are only known by the SP since M.A. does not have insights in the correct amount of spares the SP needs to acquire in order to maintain a certain availability level in the pool.

Table 6.2: If M.A. chooses to act independently, they need to acquire spare parts for a total cost of 154 millions to reach a targeted service level for the 22 aircrafts. On the other hand, to reach the same targeted service level the SP need to add spare parts to the commercial pool for a value of only 44 million.

	Total cost [mn]	**Cost per aircraft [mn]**
Masters Airline	154	7
Service provider	44	2
Potential benefit	**110**	**5**

The concept behind Table 6.2 is illustrated in Figure 6.4. Dependent on what party acquires the spare parts different states are obtained in the cost-availability relation.

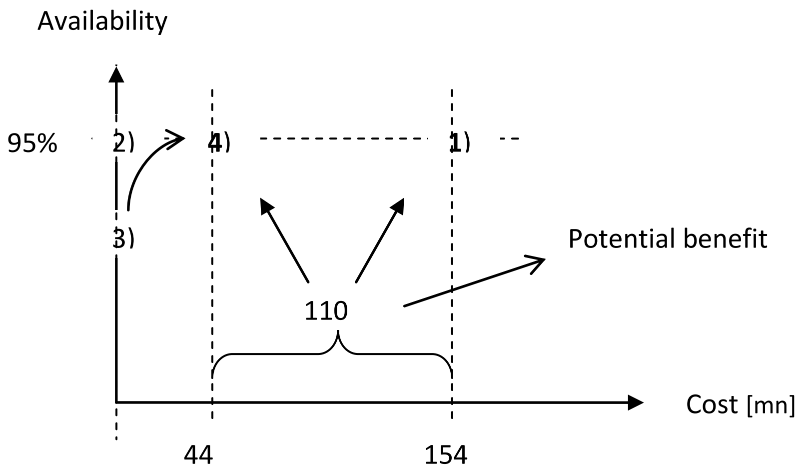


Figure 6.5: The cost of availability. Different states are presented and their cost to reach an availability of 95% (a targeted service level) respectively.

The reasoning of Figure 6.5 is as follows:

1. In the first state, M.A. decides to acquire spare parts packages (choosing the stand alone strategy)
2. State 2 represent the existing commercial pool
3. The third state illustrate the drop in service level as M.A. joins the commercial pool
4. In the fourth state the SP acquires additional spare parts in order to maintain a targeted service level after M.A. joins the pool

In a potential negotiation both parties will strive towards a cost agreement near the opposite endpoint. 110 millions are at stake and various aspects will affect how the benefit is shared between the parties.

Derived from an OPUS10 analysis, the annual cost of choosing the commercial pooling strategy is estimated to be 8 million.

6.5 The Final Model

The outcomes of the two models are summarized in Table 6.3.

Table 6.3: A summary of the outcomes of the two models.

Outcomes	Stand alone	Ad hoc	Cooperative	Commercial
Value	440	245	220	435
Annual cost [mn]	13	11	7	8

Using an approach according to OMAX, the outcomes of the two models are weighted and a *final index* is obtained for each strategy. In line with a linear scale the two outcomes are given a *score*. An index is obtained for each model respectively by multiplying the score with a given *weight* of a model. The final index of a strategy is calculated as the sum of the two *values*. Masters Airline evaluates that the choice of a strategy should mainly depend on the outcome of the cost model. By this means, the outcome of the cost model constitute 70% of the total weight. The results are provided in the final model in Table 6.4.

The scales of measure that are set up in the final model for the two criteria are based on the arithmetic mean, which is described in section 5.7 (Methodical Approach – The Decision Making Process). Though, it is preferable to assign scores according to a predetermined set of scale (which in turn is dependent on predetermined requirements for each criteria), since in so doing, one avoids to evaluate the strategies in relation to each other. Due to non-existence of specific requirements for the criteria that facilitates such a scale in connection with the awareness that one of the four strategies must be chosen, M.A. believes that a scale based on the arithmetic mean will prove to be satisfactory. The upper and lower boundaries are chosen accordingly;

- *Upper boundary:* $\mu + 1.5\sigma$
- *Lower boundary:* $\mu - 1.5\sigma$.

Table 6.4: *The final model*. The outcomes of the two models are weighted and a best strategy is thus derived. Based on the final index for each strategy, the commercial pooling strategy seems to be a best choice for Masters Airline.

Final model	**Stand alone**			**Ad hoc**			**Cooperative**			**Commercial**		
	Soft aspects	Annual cost [mn]	Final index	Soft aspects	Annual cost [mn]	Final index	Soft aspects	Annual cost [mn]	Final index	Soft aspects	Annual cost [mn]	**Final index**
	440	*13*		*245*	*11*		*220*	*7*		*435*	*8*	
Score												
10	513	5.6		513	5.6		513	5.6		513	5.6	
9	474	6.5		474	6.5		474	6.5		474	6.5	
8	434	7.5		434	7.5		434	7.5		434	7.5	
7	394	8.4		394	8.4		394	8.4		394	8.4	
6	355	9.3		355	9.3		355	9.3		355	9.3	
5	315	10.2		315	10.2		315	10.2		315	10.2	

4	276	11.1		276	11.1		276	11.1		276	11.1	
3	236	12.0		236	12.0		236	12.0		236	12.0	
2	196	13.0		196	13.0		196	13.0		196	13.0	
1	157	13.9		157	13.9		157	13.9		157	13.9	
Score	8.2	2.0		3.2	4.1		2.6	8.5		8.0	7.4	
Weight (%)	30	70		30	70		30	70		30	70	
Value	245	140	**385**	97	290	**387**	78	595	**673**	240	518	**758**

6.6 Sensitivity Analysis

The inputs in the final model (= the outcomes of the soft aspects model and the cost model respectively) are derived by means of somewhat subjective methods. In addition, since the decision-maker has relatively free rein in terms of setting up a scale of measure for each criterion, the subjectivity in the final model increases. Finally, a last mean of affecting the outcome of the final index is when determining the weighting coefficients of the two inputs in the final model. Having mentioned this it is obvious that there are reasons to question the output of the final model, and as a result, the need to carry out sensitivity analysis is strong.

The outcome of ***the soft aspects model*** varies based on the;

- *Relevance of the aspects included*: Is the included aspect relevant enough to be considered in the model? Are there any important aspects that are missing?
- *Assessment of the aspects*: Is each aspect assessed based on comprehensive understanding of the area of interest? Are the numerical translations (the marks) chosen with regard to the same reference point in all strategies?
- *Weighting of the aspects*: Is the decision-maker clear about the degree of importance of all aspects? Are the weights chosen in proportion to the actual difference in importance between the considered aspects in the model? Is the importance of the aspects considered with regard to the actual period when the decision is going to be implemented? Since the importance of some aspects change with time, the model needs to be up to date, and thus, weighted with regard to the period when the implementation of the decision will take place.

For all strategies, apart from the commercial pooling strategy, ***the cost model*** designed needs to be revised thoroughly. Are all relevant costs considered and are they estimated correctly? Since prices are known in advance (e.g. price of man-hour, price of acquiring spares etc), the reliability of a cost model greatly depends on the ability to forecast future demand (= item failure) of the technical systems. Moreover, it is of importance to catch the dynamics in the model due to changes in prices with time. In a commercial pooling strategy the costs are known in advance, therefore, an actor can affect the costs only during negotiations upon purchasing the service from the SP.

Before deciding what strategy to choose based on a first set of results obtained, an actor should aspire to carry out sensitivity analysis where the factors listed below are simultaneously varied for each strategy. In so doing, a decision-maker catches the sensitivity of the output (the final index) for a strategy from the final model, and can thus make a decision based on steadier basis.

- The *annual cost* derived from the cost model
- The *value* derived from the soft aspects model
- The *weighting coefficients* in the final model
- The *scale of measure* for each criterion

Masters Airlines is convinced that the three first factors are thoroughly considered and thereby chosen properly. For this reason, they wish to further investigate in how the final index is influenced when the scale of measure varies. In so doing, M.A. believes they will attain a scale of measure that will yield as accurate results as possible. Four different scales of measure are set up for each criterion. All of them are based on the arithmetic mean and the boundaries are stretched out accordingly;

- μ +/– σ
- μ +/– 1.5σ (made use of in the *Final model*)
- μ +/– 2σ
- μ +/– 0.5μ

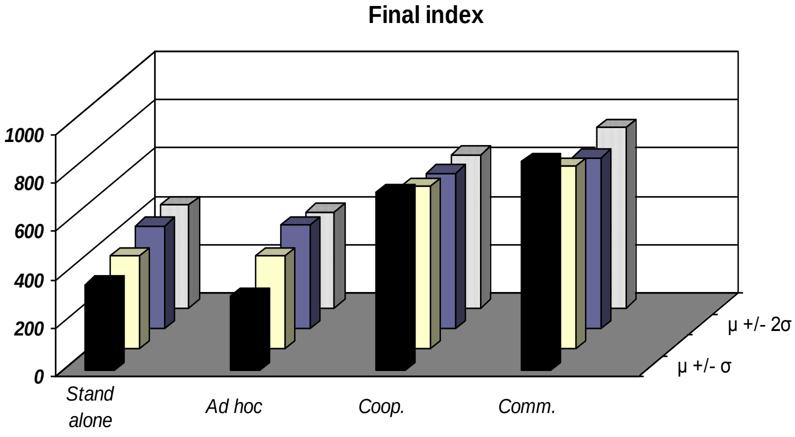
In this case, for each criterion there are only four values available (an obtained value for each strategy) to calculate an arithmetic mean. Depending on the spread of values (e.g. to what extent they differ from each other) the percentile of the fourth approach to set the boundaries (μ +/– 0.5μ) must be regulated. The closer the values are to the mean, the smaller percentile is needed when calculating the boundaries of the scales of measure. In Table 6.5 is illustrated how the boundaries for the two criteria vary between the four scales of measure. For every scale of measure, the score of each criterion and strategy is presented in Table 6.6. Different scales of measure yield different final indexes, and hence, the impact on the final index for each scale of measure is illustrated in Figure 6.6.

Table 6.5: Upper and lower boundaries for each criterion is calculated for each of the four scales of measure.

Boundaries	Soft aspects		Annual cost [mn]	
μ +/–	Upper	Lower	Upper	Lower
σ	454	216	7	12.5
1.5σ	513	157	5.6	13.9
2σ	573	97	4.2	15.3
50%	503	168	4.9	14.6

Table 6.6: The score of each criterion and strategy is calculated for each of the four scales of measure.

Score	Stand alone		Ad hoc		Cooperative		Commercial	
μ +/–	Soft	Cost	Soft	Cost	Soft	Cost	Soft	Cost
σ	9.5	1.0	2.1	3.5	1.1	10.0	9.3	8.4
1.5σ	8.2	2.0	3.2	4.1	2.6	8.5	8.0	7.4
2σ	7.5	2.8	3.8	4.5	3.3	7.7	7.4	6.9
50%	8.3	2.5	3.1	4.3	2.4	8.0	8.2	7.1



	Stand alone	Ad hoc	Coop.	Comm.
■ μ +/- σ	354	305	734	864
□ μ +/- 1.5σ	385	387	673	758
▨ μ +/- 2σ	424	427	642	707
□ μ +/- 50%	425	397	632	744

Figure 6.6: Different final indexes are attained depending on the choice of scale of measure.

6.7 Analysis

The results in the final model clearly indicate that the last two strategies are by far the better options among the four possible strategies. In a commercial pooling strategy the service provider is aware of the clear competitive advantage a commercial pool has against a cooperative pool as regards to the soft aspects. Based on Master Airline's preferences, the score of the soft aspects in a commercial pool is 8.0, whereas the corresponding score in a cooperative pool is 2.6. This competitive advantage justifies a somewhat higher cost in a commercial pool. By analyzing the results in the final model, the two latter strategies will obtain an almost equal final index if the SP increases the price by one million (an increase from 8 to 9 millions, which corresponds to a score of 6.3). The reason the SP has such low prices is the existing high competition among service providers in the market, however, even an increase to 9 million is still more lucrative to M.A. compared to joining the cooperative pool (given that there are no other service providers offering a better deal) since it is desirable for M.A. to be able to concentrate on their core business.

Seeing as Masters Airline is a newly founded company, they wish to keep the total costs as low as possible in the beginning. For this reason (in addition to the low final index obtained in the final model), the stand alone strategy is ruled out. An ad hoc cooperation is also ruled out at the moment due to same reasons as for the stand alone strategy; too expensive in connection to a relatively low final index obtained. However, M.A. is aware of that an ad hoc cooperation may be a lucrative option in a couple of years from now and will therefore aspire to develop strong relations with other airlines situated nearby regardless if they are competitors or not.

M.A. knows that the cooperative pooling strategy is definitely a tangible option. They feel that there is a potential improvement in soft aspects which in turn yields to an increase in the final index derived from the final model in Table 6.4. An advantage with the cooperative pooling strategy is the relatively high number of participants in the pool that contribute in making the pool more robust. The pool will not particularly get harmed if a participant decides to leave the cooperation. Of course, from the perspective of M.A. the risk lies in the possibility that Airline number 4 decides to leave the cooperation. Even if M.A. dismisses the choice of a cooperative pool, they are aware of the importance of the existence of a cooperative pool in order to counterbalance a potential monopolistic power abuse by a service provider of a commercial pool.

From the sensitivity analysis in the previous section we note that, regardless of the approach to set up a scale of measure, the final index in the commercial pooling strategy will always be higher than the corresponding final index in the cooperative pooling strategy. Regarding the ranking of the former two strategies (Stand alone & Ad hoc); dependent on which of the four approaches are chosen to set up the scale of measure for the two criteria, one strategy may prove to be a better than the other. Nonetheless, the distinguished difference is that the latter two strategies seem to be by far better options than the former two.

As stated earlier, different aspects are of different importance for different actors. Also, due to existence of dynamics in the market, preferences changes for each year (e.g. the importance of aspects varies with time). As a consequence, what might be a good deal this year may prove to be a bad deal the next year. Consequently, results obtained in accordance with the objectives matrix are very dependent on the weighting of the aspects of interest in Table 6.1 (which are based on importance), and also on the weighting of the outcome of the two models (the soft aspects model vs. the cost model).

6.8 The Choice of Strategy

Masters Airline has made a decision not to buy spare parts packages. Instead, M.A. will join the commercial pool, and in so doing, purchase service availability from a service provider. M.A. is confident that the commercial pooling strategy will be in line with a long-term strategy which brings the stability and prosperous continuity Masters Airline seeks. The decision is based on the final index (= 758) obtained from the model in Table 6.4 in connection with insights derived from the sensitivity analysis that has been carried out.

7 Logistical Expertise

In order to successfully implement a spare parts strategy an organization needs access to; reliable *software tools*, relevant *logistical information*, and *logistical know-how*. The main part of this chapter is derived from an interview that has been conducted with Håkan Borgström, consultant at Systecon AB.

7.1 Software Tools

The software tools necessary to effectively manage a company's assets comprise information technology (IT) and inventory management systems. An IT system facilitates a more transparent supply chain seeing as significant data about the spare parts are provided whenever needed. For example, for a specific item a company needs to know, amongst other important information; the price, the failure rate, the present location, to what location and when it will be transported etc.

Furthermore, in order to find an optimal inventory solution, e.g. to obtain a targeted system availability to the lowest cost possible over a specific time period, an inventory management system is required. Herein, various decision support tools for strategic and tactical analysis are included. For example, appropriate inventory positions and stock allocations can get obtained using a spares optimization tool. A traditionally approach to determine, e.g., inventory positions is having an employee that sets the inventory positions for every item based on experience (e.g. *engineering judgments*). The subjectivity of the approach is however drastically reduced seeing as a decision support tool (such as a spares optimization tool) provides with results based on established mathematical algorithms.

7.2 Logistical Information

An organization must strive to gain a deeper understanding and better knowledge of its technical systems. Valuable logistical information will then be used as input in decision support tools, and consequently, lead to more trustworthy analysis. For example, among other important data, an organization need to know; What components are included in the technical system? Which ones are considered as consumables and repairables respectively? How long does it take for the components to arrive when customer demand occur (the lead time)? What is the failure rate for the components? How often does preventive maintenance on the components (/technical systems) occur? How much does every component in the system cost?

Upon acquiring a technical system (e.g. a ship, an airplane, an oil platform, a train etc.) a basic condition is that an organization also ensures logistical information from the supplier.

When carrying out analysis with various decision support tools, an organization that acquires new technical systems must completely rely on logistical data provided by the supplier. However, if the technical systems have been running for some time and the organization has a working reporting system, historical data obtained from the IT system can be used to adjust the initial logistical data acquired from the supplier. For example, the failure rate for a specific component can prove to be twice as high or half as much as the initial value specified by the supplier. One must have in mind that a supplier may not always have full knowledge of the properties of every component in the system, and may consequently supply the acquiring organization with data derived from a standard table. Moreover, some logistical data are dependent on *how* and *where* (in what environment) the technical systems are operated. For instance, the failure rate of a component will probably differ if the technical systems are operated in two distinctly different environments. It is therefore always useful to supplement initial logistical data from the supplier with historical data obtained from the IT system.

7.3 Logistical Know-How

A common situation is that an organization does not hold resources in-house (software tools and logistical know-how) to carry out advanced optimization analysis. It will therefore need to acquire a service that covers both decision support tools and logistical expertise.

Upon acquiring a new technical system an organization must have the competence to set the right requirements on the supplier in order to ensure important logistical information is provided. Then, after the arrival of the technical systems an organization need to have the competence to: build a successful support organization; to ensure that it gets correct spare parts; to ensure that it uses reliable software tools (e.g. tools that uses good mathematical models); be able to gather experience data properly and to make use of this data competently so the analysis that are carried out are always updated. Logistical expertise yields improved analysis and makes way for a better decision-making in the organization.

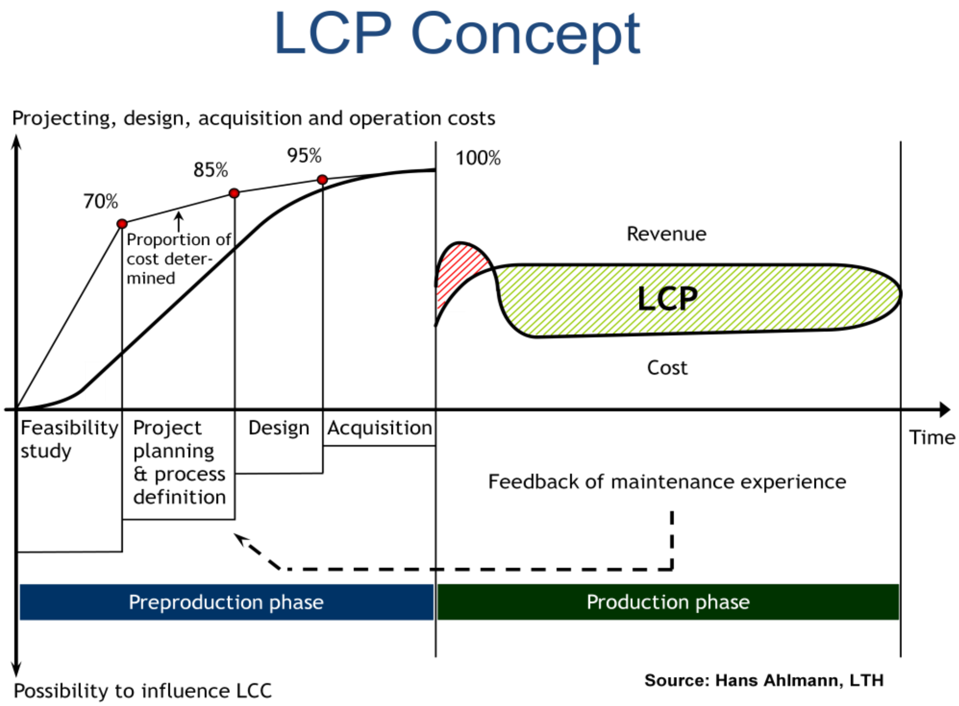
Logistical know-how is often acquired from consultants that are specialized in the line of business. Here, there are two main types of consultants considered; *software vendor consultants* and *third party (3P) consultants*. Both types possess the essential logistical know-how required while the main difference is that an organization acquires the decision support tools from the vendor consultancy firm (a firm that offer a service that includes both the software and the logistical expertise necessary). 3P consultants are likely familiar with the vendor's software tools and may therefore be important assets for an organization. Though, in the implementation stage of a new technical system, the role that the vendor consultants play is more important than 3P consultants or the internal organization team. The foremost reason is that, in addition to their advice on business processes, the vendor consultants are more capable of overcoming technical obstacles with either hardware or software due to the technical skills they hold. However, an organization should thoroughly examine the vendor's business process knowledge because a vendor consultant who lacks business process knowledge will severely increase implementation difficulties (Chuang et al. 2008).

An organization should avoid acquiring software tools from an IT consultancy firm. Even though the software offered by an IT consultancy firm may be reliable, the lack of logistical expertise associated with a pure IT consultant will cause difficulties in the implementation stage. Due to an existence of a high variety of logistical data, a high-quality consultant should have an understanding of the type of logistical information that is relevant for present and future analysis, and thus, select the right information required. Also, the organization should aspire to create a learning environment that encourages internal personnel to continue learning from the specialists during the change process.

If an organization does not hold necessary resources in-house when they are about to acquire technical systems worth hundreds of millions Swedish crowns, it should bring in special expertise from the very beginning (when they are about to define exactly *what* they are going to purchase). According to Figure 7.1, about 95% of the total costs are restricted before the technical systems are acquired. Furthermore, the organization should continue to either bring in the expertise from the outside or to acquire it in-house so the expertise is available through the entire lifetime of the technical system. The expertise is valuable not only in the pre-stages (before acquisition), but also after the arrival of the technical systems in order to build a robust support organization and to continuously improve the organization over time.

From Figure 7.1 Ahlmann et al. (2010) identifies four important facts for the investor and the owner of physical assets (e.g. complex technical systems);

- A majority of the running costs are linked to decisions taken at the definition and design stage.
- The cost of maintenance during the lifetime together with the cost of shut down often exceeds the initial investment cost.
- Maintenance costs at the operation stage are more easily avoided in the former stages than during full production, seeing as a significant part of those costs are already determined at the design and projecting stage.
- The existence of models and cost estimates developed (e.g. decision support tools) to handle, calculate, predict, and influence future operating and maintenance costs.



Source: Hans Ahlmann, LTH

Figure 7.1: The LCP Concept. We note that during the initial stages the majority of the capital will get restricted, and consequently, in these stages the possibility to influence the LCC is highest (Ahlmann et al. 2010).

7.4 Systecon's Engagement

Systecon AB is a vendor consultancy firm. Their services comprise; *decision support tools*, *logistical expertise*, and *training*.

Systecon has identified that organizations within defense, rail, energy, and offshore can benefit from Systecon's services. Organizations in these sectors have much capital tied up in technical equipment, spare parts, and also in the support organization around the technical systems. This motivates the organizations to acquire both decision support tools and logistical expertise from Systecon.

The training Systecon offer to their customers includes training in both systems logistics and training in connection with their software. However, logistical expertise is not only transferred to their customers through training. A customer may engage Systecon with the sole purpose of acquiring as much tacit knowledge as possible. For example, an approach in which a customer wants to use OPUS10 to work with spare parts estimations in their pool can have a set up like this: A project team is set up consisting of a couple of consultants from Systecon that possess logistical expertise in the specific sector and a couple of people from the company that are designed to work with these issues. The project will run for, e.g., one year and during that time period Systecon will try to pass on as much expertise as possible. After project completion, the company will be able to purchase an OPUS10 license and continue to work with spares estimations themselves.

Obviously, a cost is associated with acquiring services from a consultancy firm. Consequently, a question that arises is if it is worthwhile for an organization to acquire consultancy services compared to if internal personnel makes the decisions based on, e.g., experience only? Systecon argue that it is worthwhile, given that the technical systems are very complex and expensive. For example, a cost of 100 million SEK is associated to the supply of spare parts for 100 trains. Systecon state that by means of the systems optimization approach savings of between 30-50% are achieved compared to the two approaches; engineering judgments and item-by-item calculation. Acquiring services from Systecon for around 2 million SEK (e.g. an OPUS10 license and training) can lead to savings of 30 million SEK (30% of 100 million SEK). Thus, the savings are indisputable.

Acquiring specialist services is also beneficial in the long term seeing as the customer can make use of the decision support tools and the logistical expertise in other projects within the company. The costs are mainly about a one-time investment in software and logistical expertise, whereas a lesser amount of running costs may be incurred for updating logistical expertise in the future.

An organization must bear in mind that not only do savings in the supply of spare parts matter, but often a foremost aim is to achieve a highest effectiveness possible of its technical systems (e.g. high availability). However, a rule of thumb regarding the acquisition of services from consultancy firms is that; an organization should reach a considerable volume both in the management of spare parts and in the number of complex technical systems in order for it to be worthwhile to acquire software and logistical expertise.

8 Findings and Recommendations

8.1 The Framework

The framework developed in this thesis facilitates a fair comparison of four spare parts strategies. It is desirable to use the framework in the initial stages described in the LCP concept in Figure 7.1 (e.g. in *planning and process definition*), seeing as the possibility to influence LCC/LCP are still high. However, in practice the companies already have a rather clear idea of which spare parts strategy they want to pursue. In these cases, the targeted strategy is either based on; pure intuition, some basic reasoning and estimates of costs, or as a combination of pure intuition in connection with some reasoning and estimates of costs. In spite of the fact that the framework presented in this thesis ought to be considered from the very beginning in the LCP-model, the framework may still possess a value-adding effect even if it is applied at the later stages. For example, using the framework after a final strategy is chosen can benefit a company as follows;

- The company can confirm that the selected strategy derived by other means really seem to be the right strategy, seeing as the decision is supported based on further analysis.
- Seeing as many aspects of interests are considered in the thesis, the company has the opportunity to reflect on those aspects not taken into account in their model when a final strategy was selected. If necessary, there may still be time left for further modifications.
- Seeing as reflections are incredibly important when improving a model or a method, a thorough analysis carried out with the framework provided may lead to a rise in quality in the way the company carry out their own analysis.

As specified in section 1.2 (Purpose), a specialist ought to use the models while at the same time a non-specialist (e.g. a manager) should understand every step that is carried out in the models. The core concepts of the framework developed are believed to be of high quality, and thus, robust. Given that the analyses are performed by personnel that are well aware of their line of business, and if the assumptions made when using the models are objectively assessed, the outcomes of the framework should present the best logistical solution available. However, an aspect of improvement regards the user-friendliness of the framework. It is desired to visually improve the models in the framework in order to diminish a derivation of a non-optimal strategy which may have its root in a misunderstanding of the models.

8.2 Pooling

Benefits derived from pooling of repairable spare parts are in general higher when the component prices are relatively high compared to the handling costs, seeing as the benefits come from the ownership costs, not handling costs. Conversely, as stated in the thesis, a company may choose to increase its service level for the same amount of money spent when choosing to pool its inventory. Furthermore, pooling in a cooperative setting (e.g. ad hoc cooperation or cooperative pooling) necessitates a closer relation with the other participants of the pool. Seeing as it is of everybody's interest to optimize the total network system, the developed relations lead to environments in where sharing of experience between the participants is encouraged. Also, as time goes by, it will be easier for the participants to cooperate in future projects since the necessary relations are already established.

Some of the main disadvantages of pooling include; increased administration and management, difficulties in establishing relations and suitable contractual agreements with other participants (the more participants in the pool the more complex the network system gets), and increased transportation costs. Also, the participants of the pool must have in mind the diseconomies of scale described in section 5.6, when considering an expansion of the existing pool (the reasoning also applies the service provider in a commercial pool).

A practical issue that may arise in a pooling context is how the performance of the technical system during operation varies between the participants of the pool. For example, if the spare parts in the pool are used in different environments, a company that operates the technical systems gently (e.g. due to nearly ideal environmental circumstances) may not benefit from the pool as much as another participant (e.g. a company that yields a more frequent demand in spare parts due to the fact that its technical systems operates in a more rough environment). This issue must especially be regarded in a possible ad hoc cooperation.

In order for the inventory levels obtained from using a decision support tool to be optimal, it is preferred that the analyses are carried out in a pool that has a rather high level of demand. With low levels of demand, random fluctuation may appear due to the discontinuous nature of the size of the spares supply. For example, a pool can only have one unit or two units of a specific spare part, even if the optimal number would be 1.5 units. Consequently, this issue must be considered in an ad hoc cooperation.

In some industries it may be preferable to be the owner of the spare parts, rather than to just acquire the services from a service provider. Even though existing technical systems will not be of state of the art in a couple of years from now, there will still exist a customer demand for these systems in some markets (i.e. in the developing countries). Thus, the demand of spare parts for older technical systems will continue to exist in the future. While at the same time the absence of production of these "older" spares will bring up an opportunity for the owner of spare parts to raise prices. The idea of making profits in the future from owning the spares is an incentive for a company to invest in spare parts packages from the very beginning.

Another interesting matter that arises in spare parts management regards the decision whether to purchase a new spare part or to keep on repairing the same part, so that a most profitable solution is obtained. Seeing as every repair is associated with a cost and that after every repair the expected life time of the spare part decreases, a company must strive to find the demarcation point (e.g. after a number of repairs) until it is more worthwhile to purchase a new spare part rather to continue repairing the old one.

The cost of MRO maintenance usually constitute a low proportion of the total cost in an organization that supplies services with the help of large and complex technical systems. Traditionally, it was desirable for a company to have spare parts packages in-house and by themselves carry out the MRO maintenance. Nowadays, due to improvements in supply chains (e.g. suppliers that offer more reliable and accurate deliveries of spare parts), there is a smaller need from the companies to have stock on hand. A supplier of spare parts can either be a manufacturer, or a third party that is specialized in the line of business (e.g. a maintenance company). Seeing as a supplier most often profits when its customers (e.g. companies operating the technical systems) also profits, there is an incentive for a supplier to make sure that the customers targeted service levels are reached. If pooling of spare parts help customers to reach targeted service levels, a supplier can contribute with assistance to set up a spares pool (given that the supplier possess necessary resources).

Due to differences in maturity between the industries, it is not equally unproblematic to implement a spares pooling strategy even though all necessary conditions are met. For instance, the commercial aviation industry has embraced the concepts of pooling for some decades ago, and it therefore falls more natural for an airline to choose a pooling strategy. On the other hand, seeing as the railway industry has been regulated for such a long time (and still is in many countries) where the state has been dominating the market, to implement a pooling strategy in a recently deregulated market may thus require more effort. Consequently, following question need to be asked: Is the market ready for pooling?

An interesting remark regards a *trend* to pool. A big majority of the representatives that were interviewed at Nordic Rail (2009) experienced a trend that more and more companies seem to be willing to pool their inventories. However, as we all know it is not always profitable to hang on a whim of fashion. On the other hand, under ideal conditions the more a pool grows in scale the more do the participants profit.

8.3 Recommendations

A company that is the owner of large and complex technical systems should aspire to;

- Have different contracts for different spare parts.
- Cooperate with different actors. For example, for components having a higher failure rate the service may be acquired from a service provider of a commercial pool. At the same time, the company can join or set up a cooperative pool with other actors in the same market in where only the high cost components are pooled together. In so doing, a company makes use of different spare parts strategies for different items simultaneously.
- Look out for other actors that want to enter the same market (e.g. in a market with few players). If relations are established early, the probability for a smoother pooling cooperation in the future is higher.

8.4 Further Studies

To facilitate the derivation of an organizational and business model that strongly aids the decision-maker to realize and manage a selected pooling strategy, *contractual agreements* between the participants of a pool need to be designed appropriately. In expectation, all participants must benefit directly from the contract. Particularly, two contractual issues appear;

- How much should each participant purchase to inventory prior to demand realization?
- In case of shortages, how is the inventory allocated between the participants?

Additional issues that need to be accounted for when designing the contract in a pooling cooperation comprise; the financing of the pool (how the costs are allocated between the participants), what/which participant(/s) will operate the pooling system, what reporting systems will be used, and how the participants can assure compliance with legislations and contractual agreements.

Due to rising environmental awareness, another interesting subject for further research regards the possible negative/positive impacts a pooling strategy may have on the environment.

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