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# **System Supportability and Life Cycle Cost based Decisions**



Molde University College

**PhD theses in Logistics 2008:4**



# System Supportability and Life Cycle Cost based Decisions

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System Supportability and Life Cycle Cost based decisions

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## **Preface**

This thesis is a result of my PhD study at Molde University College, Norway. I started my study in June 2004, and this thesis is written in the period up until November 2008. The main supervisor for the thesis is Professor Øyvind Halskau, Molde University College, Norway.

At the moment I am a Chief Consultant at Logiteam Consulting AS in Bergen, Norway, and I have a part time position as senior lecturer in logistics at the Royal Norwegian Naval Academy in Bergen, Norway.

My PhD has been financed by the Royal Norwegian Naval Academy in Bergen, Norway where I have been employed as a senior lecturer in logistics and head of the Logistics and Management Department from May 2003 until September 2008, holding the rank of Commander Senior Grade.

The main subject of my thesis is system supportability with a special focus on spare parts and life cycle cost based procurement decisions. The thesis contains four papers and a synthesis presenting why and what to research, the theoretical foundation of the thesis as well as how to research. The synthesis includes chapters on research design, validity and reliability, theoretical framework and paper abstracts. The synthesis further reports on the main research conclusions. Finally the synthesis gives the main research contribution along with self criticism and suggestions for future research.

All four papers in the thesis have been published (or accepted for publishing) in peer reviewed journals or peer reviewed conference proceedings or both.

## Acknowledgements

First of all I am grateful to my supervisor, Professor Øyvind Halskau at the Molde University College in Molde, Norway. Initially Professor Halskau constructed the study program consisting of 60 ECTS leading to fulfilment of the first part of my PhD study. In this part, Professor Halskau was always willing to discuss what different masters and PhD courses that should make up this first part of the PhD process. Further, Professor Halskau has throughout my studies encouraged me in my research and always been open for discussions on the topic(s) of the research projects finally making the total project.

Secondly I am grateful to the Royal Norwegian Naval Academy for making it possible for me to conduct this research as a part of my work at the academy. I would like to mention my colleagues at the Logistics and Management Department, Commander Lars Petter Holm, Lieutenant Commander Hans Georg Hygen, Lieutenant Commander Odd Alver and Captain (Air Force) René Erichsen for putting up with me being away at data collection and buried in writing and presentations many times throughout my study. Further I would like to thank the two commanding officers of the Naval Academy during my research period, namely Captain (Navy) Tor Vestli and Captain (Navy) Thomas Wedervang for letting me go through with my research. Further I would like to especially mention two persons at the academy that have meant a little bit more in each of their special contribution. First of all my thanks goes to Commander Karl Gunnar Nornes, because he was the king pin in the process of bringing me to the Naval Academy in the first place and for being the main negotiator with the leaders of the academy when I wanted to be able to study for a PhD as part of my contract with the institution. Without Karl Gunnar, this study would not have started in the first place. Secondly I want to mention the Dean of Studies Harald Rikstad. Harald has been one of the driving forces in making it possible for employees at the Naval Academy to pursuit a PhD as part of their job at the institution and in this respect he is an important part of making my study possible.

Further I am especially thankful to all the informants in the separate parts of the Norwegian Defence organization as well as the few contributing informants from the Norwegian Red Cross, that have willingly and interestingly contributed to the result of the research by answering questions in lengthy interviews in connection with two of the projects within this total research project. Further I would like to say thank you to all the project leaders in the Norwegian Defence Logistics Organization that took valuable time out of their schedules to answer my questionnaire connected to another part of the total research project.

Finally I wish to express my sincere gratitude to my family, with my two daughters Amalie and Johanne and my son Lars Kristian who have seen their father less than they should have in this time period and not least to my wife Anne-Britt who has taken more than her fair share of the work needed to make the family work.

I dedicate this thesis to my family.

Molde, Norway  
October 2008

Bernt E. Tysseland

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# 1. Introduction

In December 2003 the Norwegian Chief of Defence (CHOD) Sigurd Frisvold published a Defence Study where he said:

*The defence budget appropriations increase a little every year, but our Armed Forces constantly get a smaller share of the national budget. We cannot expect this situation to change to any considerable degree. Our challenge is therefore to adapt to the economic situation and to achieve more defence for the available money, and to adjust our activity accordingly<sup>1</sup>.*

The Norwegian Government Proposition number 42<sup>2</sup> published in June 2004, followed up CHOD's study. The proposition was accepted by the parliament and included a specific target of reducing logistic support spending by at least two billion Norwegian Kroner<sup>3</sup> by 2008. According to the proposition, the reduction in logistic support spending should result in a relative increase in defence materiel investment and military operations.

However as early as in 1998, General Steinar Jøssund, at that time Head of the Norwegian Army Material Command said:

*The Norwegian Defence's ongoing and future organizational change demands that the present focus on costs associated with material procurement is changed from only considering the initial procurement cost to looking at the material systems total life cycle cost. Procurement of state of the art technological equipment yields a high pressure on the operating budget and experience shows that operating and support costs are much higher than the initial acquisition cost. It is the material command's responsibility to make sure that user demands in terms of material reliability and operational readiness/availability is achieved, in the same time as total life cycle cost (LCC) is minimized. The art and science of integrated logistics support (ILS) is supposed to make sure that this balance is achieved by including analysis of needed logistics support and life cycle cost methods into the procurement process<sup>4</sup>.*

Blanchard (2004) states the following regarding Integrated Logistics Support (ILS):

*"ILS constitute a disciplined, unified, and iterative approach to the management and technical activities necessary to (1) integrate support considerations into system and equipment design; (2) develop support requirements that are related consistently to readiness objectives, to design,*

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<sup>1</sup> Translated from Norwegian by the author of this paper

<sup>2</sup> Stortingsproposisjon nr 42 2003-2004

<sup>3</sup> Measured in 2004 currency rate

<sup>4</sup> From the intranet of the Army material command – accessed June 2004.

and to each other; (3) acquire the required support; and (4) provide the required support during the operational phase at minimum cost.

Several other definitions of integrated logistics support can be found in articles, books and military standards regarding the matter. The British Ministry of Defence's Military Standard 00-60 (Def STD 00-60), states for example the following:

*“Integrated logistics support (ILS) is a disciplined management approach, affecting both customer and industry, aimed at optimising equipment life cycle costs (LCC). It includes elements for influencing equipment design and determining support requirements to achieve supportable and supported equipment<sup>5</sup>.”*

The definitions from Blanchard (2004) and Def STD 00-60 are basically the same. They both focus on achieving high system effectiveness at low life cycle cost.

According to Kumar et al. (2000), the integrated logistics support method was first developed by the US Department of Defense because their military material projects traditionally had been completed later than planned and at a higher cost than budgeted. When the systems became operational they failed to meet user's requirements and suffered from poor quality (Kumar et al., 2000). Hence the US Department of Defense developed a very detailed standard called MIL-STD 1388. This standard included a large amount of tasks to be carried out in order to get projects in on cost and time and within the given requirements (Kumar et al., 2000).

Blanchard (1998) is writing that the integrated logistics support method is a tool for making sure that the cost of operating, servicing and retiring equipment can be kept at a minimum (minimize LCC) in the same time as equipment performance requirements are met. In order to achieve this goal of “bigger bang for the buck”, integrated logistics support is divided into ten elements<sup>6</sup> that separate the logistic chain into manageable chunks (Farmer et al., 2003). The ten elements in question are:

1. Design interface
2. Maintenance planning
3. Supply support including spare parts
4. Technical data
5. Computer resources support
6. Manpower and personnel
7. Facilities
8. Support equipment
9. Packaging, handling, storage and transportation
10. Training and training support

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<sup>5</sup> From the intranet of the Norwegian Defence Logistic Organization (NDLO)

<sup>6</sup> The number of elements can be somewhat different in different publications and standards. Blanchard use nine element because he has consolidated technical data and information systems into one element (Blanchard 1998)

Since approximately 1993<sup>7</sup> the Norwegian Defence has through its material commands (Rødseth et al., 1995), and later Defence Logistic Organization's<sup>8</sup> material procurement programs/projects officially used integrated logistics support (ILS) in order to minimize the total cost of material procurements accounted over the materials total life cycle (minimize LCC).

At approximately the same time as The Norwegian Government Proposition number 42 was published in the summer of 2004 the importance of ILS and LCC was highlighted by the Norwegian Ministry of Defence (NoMoD) in their publication. "Konsept for fremskaffelse av materielle kapasiteter i forsvarssektoren" (Norwegian title). In this publication the NoMoD states that when investment decisions are made, solutions/systems that yield the lowest possible life cycle cost, given equal system effectiveness, must be preferred, even if this means that the initial investment cost becomes higher. This point was the same as the point made by CHOD in 2003, namely to achieve more defence for the available money taking into consideration the total life cycle of defence systems.

## 2. Objective of the research

Given the above short background a possible objective of a research project could have been to take on the big challenge of finding what challenges and effects reduced defence budgets have had on the Norwegian Defence organization in general, and in particular how the planned reduction in logistic spending is carried out on the large scale. However, to quote Remenyi et al. (1998, page 27):

*"It is important for the newcomer to research to understand that a relatively small project can lead to rich insight and thus make substantial contribution to the body of knowledge".*

Further Remenyi et al. (1998, page 27) say with regards to what to research:

*"It is frequently suggested that the best business research should lead to the development of guidelines by which individuals in positions of responsibility can manage their business responsibilities more efficiently and effectively".*

In order to narrow down the research into a project that could lead to rich insight and substantial contribution to the body of knowledge as well as being able to develop guidelines for individuals in position of responsibility within the Norwegian Defence, it was first necessary to establish what part of logistics to focus on.

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<sup>7</sup> Individuals within the Norwegian Defence have probably been working with ILS long before 1993, however according to an internal Navy Material Command report from 1995 (Rødseth et al.), the first ILS organization was established around 1993 in the Air Force Material Command.

<sup>8</sup> In 2003 the material commands of the Navy, Army and Airforce were merged into the Norwegian Defence Logistic Organization (NDLO). In the summer of 2004 the importance of ILS and LCC was highlighted by the Norwegian Ministry of Defence in their publication. "Konsept for fremskaffelse av materielle kapasiteter i forsvarssektoren" (Norwegian title).

Both Bjørnland et al. (2001), and later Jahre and Persson (2008) claim that logistics and hence logistics research can be categorized within three different schools of thought.

School of thought	Material Administration/Business Logistics	Logistics/Distribution Management	Logistics Engineering/Integrated logistics support
Unit of study	<i>Shipper or owner of the goods</i>	<i>Logistics service providers</i>	<i>Project</i>
Perspective	<i>From point of origin to end-user or disposal</i>	<i>From point of origin to end-user or disposal</i>	<i>From idea, through development, investment, operations and support to disposal</i>

**Table 1 Logistics schools of thought based om Jahre and Persson (2008, page 40)**

The first logistic school of thought is categorized as *Material Administration/Business Logistics*. According to Bjørnland et al. (2001) this school has its origin in Scandinavia in the early 1970s and is according to Jahre and Persson (2008) the dominating school of thought in the Nordic countries also today. This school has the shipper or owner of the goods in question as the main unit of study, and focuses on how to design and operate the flow of goods and associated information from point of origin to the end-user or rather disposal. This school has had a system approach to logistics in general and focused on using aspects from for example organization theory, strategy and marketing rather than operations research alone (Jahre and Persson, 2008).

The second school of thought is called *Logistics/Distribution Management*. This school of thought was not necessarily adapting a system approach to logistics, but rather focused on logistics service providers in order to optimize costs and performance within especially transportation and warehousing/inventory (Jahre and Persson, 2008). The perspective of this school of thought is still on the flow of goods and associated information from point of origin to the end-user or rather disposal, but the focus on optimization clearly put a greater emphasis on operation research and logistics in this perspective has been claimed be more segmented (Jahre and Persson, 2008).

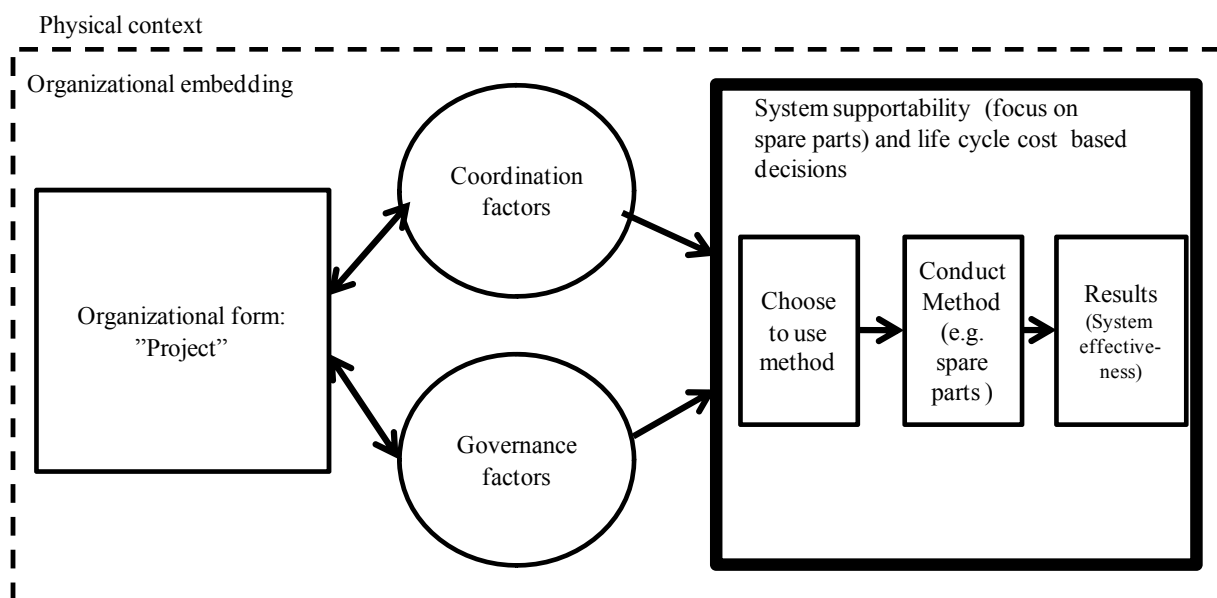
The third school of thought is called *Logistics engineering* or as used in this research *Integrated Logistics Support (ILS)*. In the words of Jahre and Persson (2008) the unit of study within this school is large-scale procurement projects. The perspective of this school of thought is from the conceptualization of an idea (the realization of a need for an equipment/system), through the development of the system, investment (procurement) and not at least the operation, support and disposal of the system.

All ten ILS elements (shortly presented in the introduction) affect supportability and thus support effectiveness of any equipment or system. All elements except the design interface will affect the support efficiency of the equipment or system in question. However, in reality the maintenance planning including supply support in terms of spare parts will normally be the driver for the other elements. According to Kumar et al. (2000) the supply support with a special focus on spare parts provisioning and management is probably the most challenging problems in the whole ILS process.

This research and thesis focuses on aspects from integrated logistics support (ILS), and more specifically on the concepts of system supportability and life cycle costing (LCC) based decisions.

In literature concerning ILS (and thus system supportability) and LCC (see for example Blanchard, 2004 or Kumar et al, 2000) the methods and tools described are very often based on mathematical assumptions and clearly originates from the field of operations research. This is especially true in the literature concerned with spare parts (see for example review papers by Guide and Srivastava (1997) and Kennedy et al. (2002)). However, the processes leading to the decision to use one of the ILS methods or tools in order to reduce LCC and how the method (for example spare parts optimization) is used must clearly be influenced by the organizational embedding and physical context facing the organization and/or project in question.

In figure 1, this is illustrated by placing the ILS method within a “black box” while at the same time showing that both whether one choose to use a ILS method in the first place, how it is used and the result from the use must be influenced by organizational factors such as coordination and governance as well as the organizational form and physical context of the user organization.



**Figure 1 Research frame**

The main objective of this research, and thesis, is:

- To show how factors from organization theory in general and economic approaches to organizations in particular can be used to explain differences in the approach to planning and use of system supportability methods and tools as well as how these factors can help to explain whether an ILS method is used or not in the first place.

The sub-objectives of the research are:

- To establish what and where the latest research is in connection with the system supportability element of spare parts inventory management.
- To study the planning process and set up of the ILS/system supportability elements of equipment maintenance and spare parts in connection with operations.
- To study the spare parts optimization process in procurement projects using “state of the art” ILS methods and tools within spare parts optimization.
- To evaluate the empirical results of spare parts optimization towards system availability and cost.

The research has primarily focused on how the Norwegian Defence utilize or not utilize concepts within system supportability (maintenance planning and spare parts optimization) and life cycle cost based decisions. However, in connection with the aim to study the planning process and set up of equipment maintenance and spare parts in connection with operations a non-governmental organization was also studied as a contradicting case study organization.

### **3. Research questions**

The main research objective as well as the sub-objectives has been transformed into research questions.

In connection with the main objective of the research, the research questions are:

1. Can physical context as well as well as organizational structure and governance factors explain why maintenance, spare parts inventory and spare part supply chain planning and set up towards operations are done differently in different organizations?
2. How has coordination issues affected the process and results of the spare parts optimization conducted in the Norwegian Defence procurement projects that has used OPUS10<sup>9</sup>?

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<sup>9</sup> OPUS10 is a so called multi-echelon, multi-item, multi-indenture spare parts optimization tool. OPUS10 is chosen as the preferred spare parts optimization tool by the Norwegian Defence (see appended paper III).

3. What can explain that some procurement projects are still carried out and reviewed based on initial procurement costs alone when the official policy is to apply the life cycle cost approach?

In connection with the sub-objectives of the research, the research questions are:

- a. What is the existing body of literature concerning the system supportability element of spare parts towards theory, models and applications?
- b. How does a small country's military force and a small country NGO plan for and set-up equipment maintenance, spare parts inventories and spare parts supply chains in connection with man-made humanitarian disasters?
- c. How has the spare parts optimization process been conducted in the Norwegian Defence procurement projects that have used the spare parts optimization tool OPUS10?
- d. Can empirical data show that the multi-echelon, multi-item, multi-indenture method solved through OPUS10, improves system availability and/or spares parts investment cost compared to the system supplier's suggestion?

#### **4. Structure of the thesis**

The first part of this research thesis is a synthesis of the research conducted. The synthesis starts with an introduction to the research topic, and continues with establishing the main research objective, as well as giving the sub-objectives. The objectives are then transformed into research questions. This first part of the synthesis is already shown in chapter one, two and three.

Here in chapter four of the synthesis, the structures of the total thesis as well as the rest of the synthesis structure is given.

Chapter five of the synthesis elaborates on the research design and the design used is justified based upon the research questions and thus research objectives.

In chapter six a discussion on research validity and reliability is given.

In chapter seven of the synthesis, the different theories used in order to answer the research questions are put into a theoretical framework. Theories used in order to answer the research questions and thus reach the research objectives are also shown in each of the appended research papers. However, here in the synthesis, each of the main perspectives used, namely integrated logistic support theory, life cycle cost theory and organization theory with a special focus on economic approaches to organizations are linked together and towards the research questions in a more holistic view.

Further the research paper abstracts are presented in chapter eight.

In chapter nine the main conclusions from the appended papers are given, while chapter ten focuses on the main research contributions and whether the main research objective and sub-objectives have been reached.

Finally self criticism is given in chapter eleven, suggestions for future research in chapter twelve and a listing of conference presentations in chapter 13.

The answers to the research questions are given in the four papers appended after the synthesis. The first paper is written together with the author's main PhD adviser, Professor Øyvind Halskau.

The last three papers are all researched and written solely by the author of this thesis.

All appended papers are either published or accepted for publishing in peer reviewed journals, conference proceedings or both.

**Paper I:** Tysseland, B.E. and Halskau H. (2007), "Spare parts inventory – A literature review with focus on initial provisioning and obsolescence management", *The 19<sup>th</sup> annual NOFOMA conference proceedings*, pp1075-1091.

**Paper II:** Tysseland, B.E. (2007/2009), "Maintenance and spare parts inventories in man-made humanitarian disasters", Published in the 2007 Cardiff/Cranfield Humanitarian Logistics Initiative (CCHLI) International Humanitarian Logistics Symposium Proceedings and accepted for publishing with small adjustments in *Management Research News*, In press to be published early 2009.

**Paper III:** Tysseland, B.E. (2008/2009), "Spare parts optimization process and results – OPUS10 cases in the Norwegian Defence", *The 20<sup>th</sup> annual NOFOMA conference proceedings*, pp 595-612 and accepted for publishing in *International Journal of Physical Distribution and Logistics Management*, Small adjustments based on feed-back at NOFOMA 2008, In press to be published early 2009.

**Paper IV:** Tysseland, B.E. (2008), "Life cycle cost based procurement decisions – A case study of Norwegian Defence Procurement projects", *International Journal of Project Management*, Volume 26, Issue 4, pp 366-375.

In addition to the appended paper, one paper has been written and published in a working paper series but not included in the thesis. However extracts of this paper is used in the synthesis. This paper is: Tysseland B. E. (2005), "A philosophical approach to Defence Material Procurement Project research", Working Paper No. 11/2005, Handelshøgskolen i Bodø, Norway.

The connection between the objectives, research questions and appended published papers can be seen in figure 2



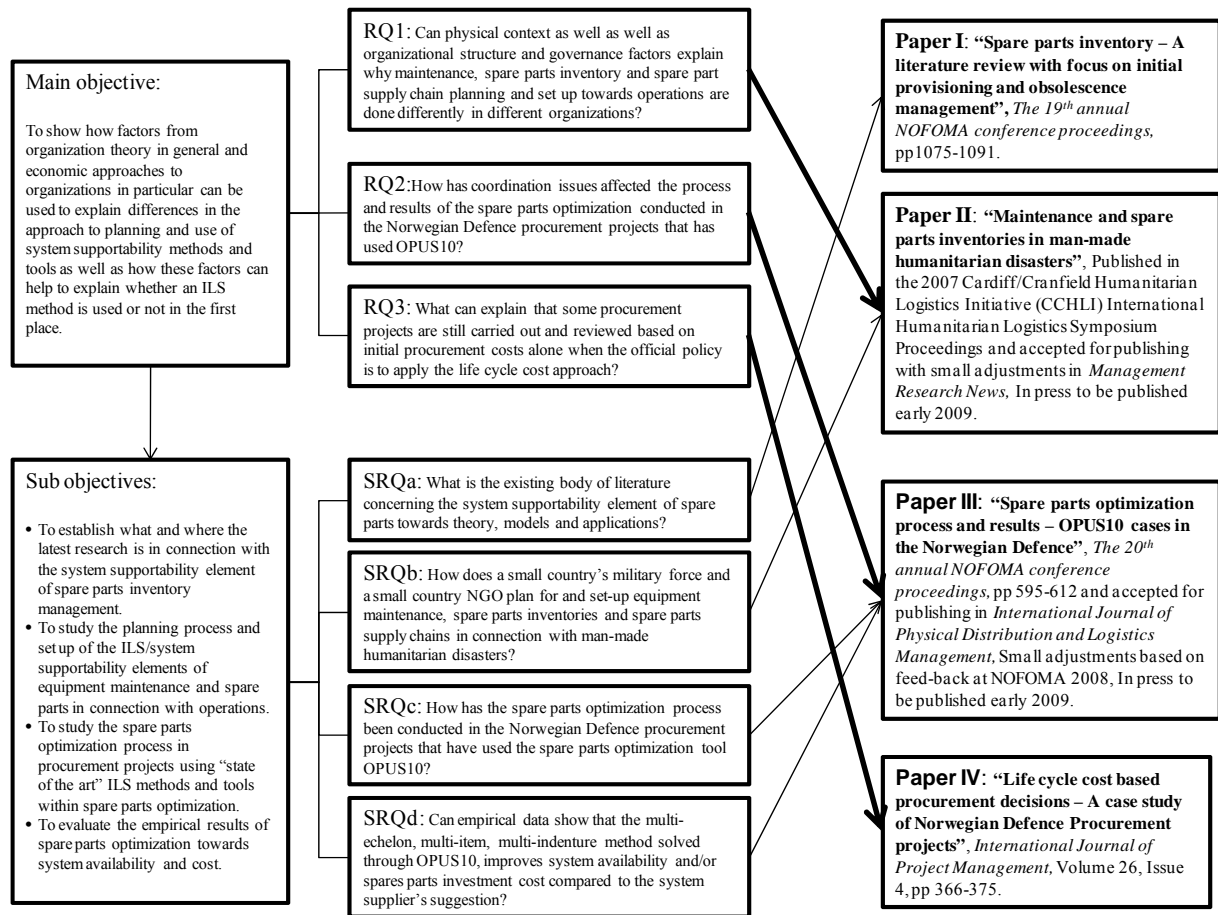
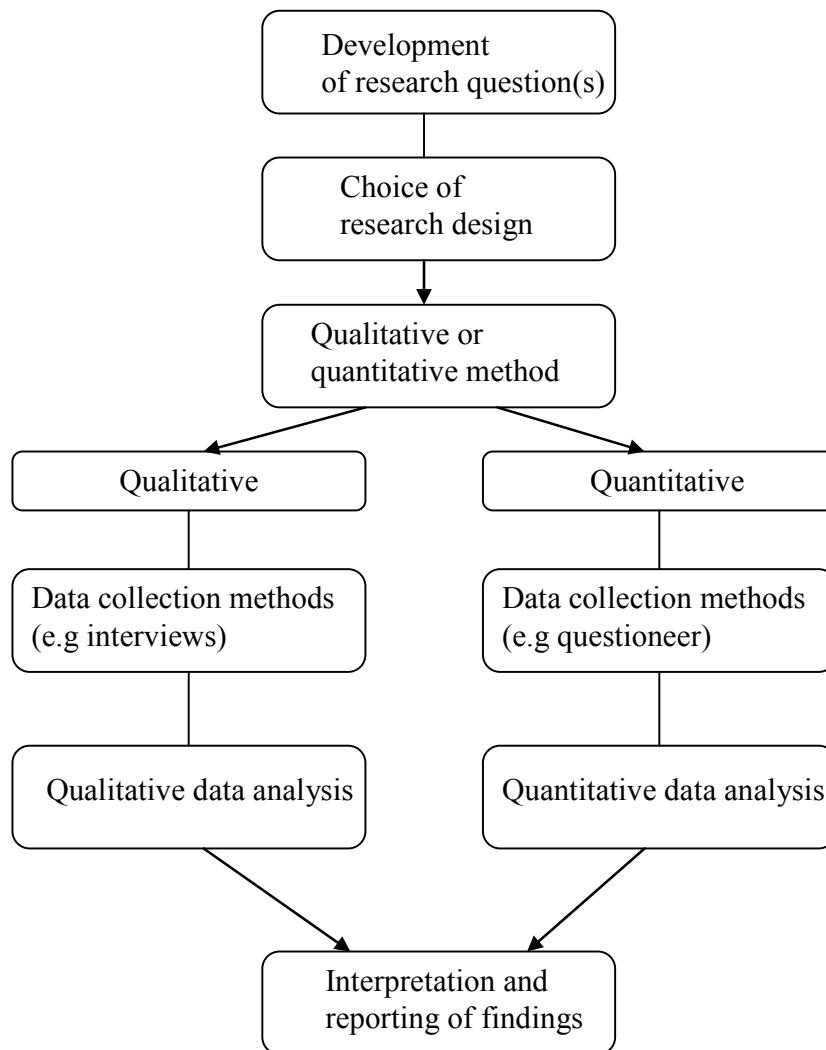


Figure 2 From objectives via research questions to the published results

## 5. Research design

This chapter will discuss the road from the main research objective and connected questions (RQs), as well as sub objective research questions (SRQs), to the findings published in the appended research papers.

Based on a model in Jacobsen (2000) the different phases in the research process of this project can be seen as follows:



**Figure 3 Phases in the research process based on Jacobsen (2000, page 10)**

The first phase in the total research project was to develop the research questions. The research questions are already reported in chapter three of this synthesis.

### **5.1 Ontological and epistemological view**

Some concepts are tightly connected to any research, whether the research is theoretical or grounded in “reality” (empirical). Two of the concepts in question are ontology and epistemology.

According to Jacobsen (2000), ontology has a Greek origin and means, “the way things really are”. Hence ontology is about how we can describe the world, how the world really is. As one might think this question has been central to philosophical discussions for many years. One ontological discussion that is very central to this research is the discussion on whether human interaction can be described as being governed by universal laws (positivism) or if all human interaction is unique (realism).

Positivism started with the work of Auguste Comte (1798-1857) in his “Course of Positive Philosophy” (Remenyi et al., 1998). Comte used the term positivism to describe his methodological procedures for attaining “positive” knowledge of theory-neutral empirical facts (Goulding 2002).

“Realism” or ontological realism, which might also be described as an existential-phenomenological perspective, provides a focus on everyday life and lived meaning of people (Lindberg 2003). According to Christina Goulding (2002) phenomenology, if looked upon as a philosophy, is based on the thinking of Martin Heidegger. Remenyi et al. (1998) on the other hand, claims that phenomenology started out with the work of Franz Brentano (1838-1917) and was developed by Edmund Husserl (1859-1938). Both however, agree that unlike the positivist, the phenomenologist does not consider the world to consist of an objective reality but instead focuses on the primacy of subjective consciousness. The phenomenologist place theory in second position compared to individuals, because according to this view theories cannot justify or explain experiences of a person.

The positivistic view and the existential-phenomenological view might be looked upon as extremes, realizing that there are several paths in-between. However the two extremes can be a good starting point for a discussion on what methodology to use in the case of this research.

Before starting the methodological discussion, the concept of epistemology should shortly be touched upon. Epistemology is very closely connected to ontology. According to Jacobsen (2000), epistemology is the “science of knowledge”, or how and to what degree we can gain knowledge about the reality (the world). Hence epistemology is connected to ontology, because if one wants to gain knowledge about the world, one first needs to agree upon a ontologically world view.

If one has a positivistic ontological view, there are three central tenets about how to gather knowledge/conduct research: First of all, there is an objective world out there. Hence the researcher and the problem of interest (the world) are two separate entities, and the problem can be researched with complete neutrality. Hence no prior experience will influence the study and findings of the researcher. Secondly the objective reality can be studied in an objective manner. Therefore, subjective studies as for example the voice of the individual (through for example interviews) should not be used; only objective observations (like for example measuring of blood pressure) should be used. Thirdly it is possible to gain a cumulative knowledge about the objective world. Hence, by ever improving the objective research one will eventually have a complete knowledge about the objective world.

If one has a phenomenological ontological view on the other hand, all tenets of the positivistic view will fall. In this view all prior experience will influence the study, each situation is seen as unique and its meaning will be a function of the circumstances and the individuals involved. The researcher is not independent of what is being researched, but is an included part of it. And finally phenomenological research is not readily conducive to generalizations. The phenomenologist place theory in second position compared to individuals, because according to this view theories cannot justify or explain experiences of a person.

## 5.2 Research purpose

The research purpose is closely connected to the objective of the research and hence the research questions that the objectives have been transformed into. According to Neuman (2006), the purpose or objective of research can be split into three groups, namely exploration, description and explanation.

The purpose of **exploration** is to explore a new topic or issue in order to learn about and report about it. This form of research is thus called exploratory research. According to Neuman (2006) exploratory research will not necessarily give definitive answers, but rather addresses the “**what**” questions.

With **descriptive** research the purpose is to present a more detailed picture of a subject or situation. Descriptive research typically focuses on the “**how**” and “**who**” questions of a research objective.

The purpose of **explanatory** research is **to explain** and thus answer the “**why**” questions. Explanatory research is called explanation and it typically builds on exploratory and descriptive research and the purpose is to find the reason or causes for why something is happening.

The different forms of research purpose or objective can be presented in the following format.

Goals of Research		
Exploratory	Descriptive	Explanatory
Become familiar with the basic facts, settings and concerns	Provide a detailed, highly accurate picture	Test a theory's predictions or principles
Create a general mental picture of condition	Locate new data that contradict past data	Elaborate and enrich a theory's explanation
Formulate and focus questions for future research	Create a set of categories or classify types	Extend a theory to new issues or topics
Generate new ideas, conjectures or hypotheses	Clarify a sequence of steps or stages	Support or refute an explanation or prediction
Determine the feasibility of conducting research	Document a causal process or mechanism	Link issues of topics with general principles
Develop techniques for measuring and locating future data	Report on the background or context of a situation	Determine which of several explanations is best

**Table 2 – Goals of research according to Neuman (2000, page 34)**

In the case of this research, it can be claimed that the three main research questions all are of an explanatory form used more or less in an exploratory setting.

In the first research question (called RQ1) connected to the main objective of the research, it was asked; *“Can physical context as well as well as organizational structure and governance factors explain why maintenance, spare parts inventory and spare part supply chain planning and set up towards operations are done differently in different organizations?”* To use factors from organization theory (structure and governance) as well as physical context in this connection is rather new and thus exploratory. The research question also has an explanatory goal because it aims at using the explorative factors to explain differences in maintenance, spare parts inventory and spare parts supply chain planning and set up towards operations in different organizations.

Research question number two (called RQ2) asked; *“How has coordination issues affected the process and results of the spare parts optimization conducted in the Norwegian Defence procurement projects that has used OPUS10?”* To use coordination factors to hypothesis about the spare parts optimization process as well as result in terms of use or no use of this ILS method is new and explorative, but in the same way as in connection with RQ1 the explorative use of coordination factors is done in order to conduct explanatory research based on accepting or rejecting the proposed hypotheses (reported in the appended paper III).

Finally towards the main objective of this research the following question (called RQ3) was asked. *“What can explain that some procurement projects are still carried out and reviewed based on initial procurement costs alone when the official policy is to apply the life cycle cost*

*approach?*” This question needs an explanatory research approach, in the same time as an exploratory strategy is utilized. This is because the idea to use governance constructs from agency theory to answer the question (as reported in the appended paper IV) is explorative. However the main research approach towards this question is explanatory.

The four research questions connected to the sub-objectives of the research all need a descriptive approach, with the addition of an explanatory goal connected to sub-objective question four (called SRQd).

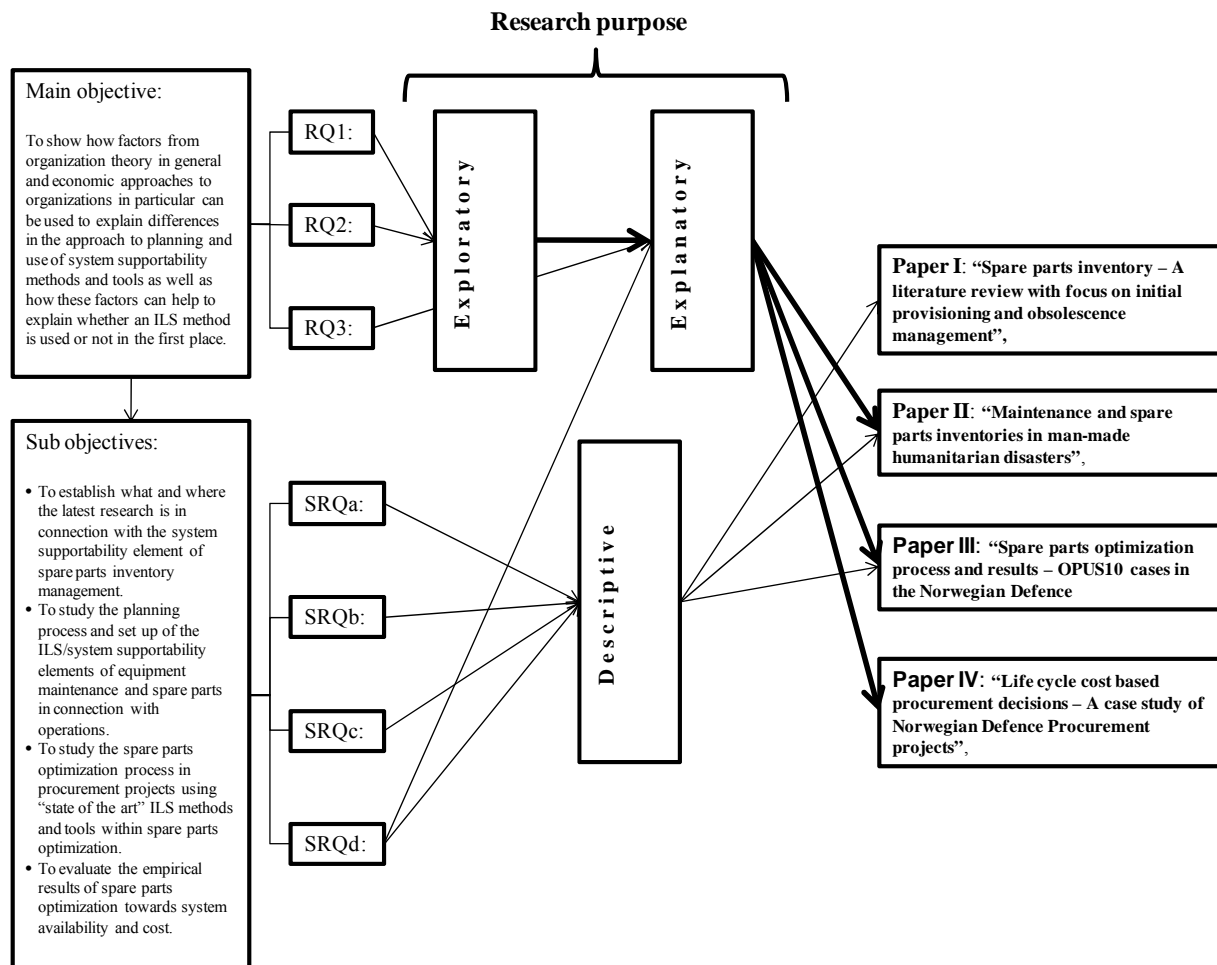
The first question (called SRQa) connected to the sub-objective was: *“What is the existing body of literature concerning the system supportability element of spare parts towards theory, models and applications?”* In line with table two’s overview of descriptive research, the aim is to provide a detailed and highly accurate picture of the latest research connected to spare parts theory.

The second question (called SRQb) was; *“How does a small country’s military force and a small country NGO plan for and set-up equipment maintenance, spare parts inventories and spare parts supply chains in connection with man-made humanitarian disasters?”* This question is raised in order to better answer the first main research question (RQ1) and warrants a descriptive approach.

In the same fashion sub-objective research question number three (called SRQc) asked: *“How has the spare parts optimization process been conducted in the Norwegian Defence procurement projects that have used the spare parts optimization tool OPUS10?”* The answer calls for a descriptive research approach.

Finally the fourth research question connected to the sub-objectives (called SRQd) calls for both a descriptive approach in the same time as it has an explanatory goal. The question was; *“Can empirical data show that the multi-echelon, multi-item, multi-indenture method solved through OPUS10, improves system availability and/or spares parts investment cost compared to the system supplier’s suggestion?”* It aims at documenting a causal process (descriptive) in terms of finding the empirical data, but also to use the data to test the theoretical claim (explanatory) that the multi-echelon, multi-item, multi-indenture method solved through OPUS10, will improve system availability and/or spares parts investment cost compared to a system supplier’s suggestion.

The chosen approaches are thus connected to the research questions transformed from the objectives in the following fashion:



**Figure 4 From objectives via research purpose to the published results**

### 5.3 Inductive or deductive approach

Using an inductive approach, one could start in the empirical world without a theory, and based on the findings a theory could be developed. An example of this approach, also called an inductive approach, is grounded theory (Glaser and Strauss 1967, Corbin and Strauss 1998). Philosophically, the origin, or roots of grounded theory can be traced to symbolic interactionism, which origins from the work of George Herbert Mead (1863-1931). Symbolic interactionism is both a theory of human behaviour and an approach to enquiry about human conduct and group behaviour. A principal tenet is that humans come to understand collective social definitions through the socialization process (Goulding, 2002). The original grounded theory approach was intended to develop all new theory through systematically collection and analysis of empirical data. Glaser and Strauss wrote, in their book *The Discovery of Grounded Theory* (1967):

*“We believe that the discovery of theory from data – which we call grounded theory – is a major task confronting sociology today, for, as we shall try to show, such theory fits empirical situations, and is understandable to sociologists and layman alike. Most important, it works – provides us with relevant predictions, explanations, interpretations and applications.”*

The original intent or discovery by Glaser and Strauss is that by going into research with an “open mind” you can through empirical gathering and thorough analysis of the data answer research questions and develop new knowledge or improve existing knowledge. Hence grounded theory is a general methodology for developing theory that is grounded in data systematically gathered and analysed (Corbin and Strauss 1998).

Even though the research questions connected to the sub-objectives of this research has a descriptive purpose it is not necessarily an inductive research. Initial work revealed early that existing theory can help to answer especially the research question connected to the main objective. Hence it can be argued that to start in the empirical world without a theory, and develop a theory based on the findings, would be very difficult and probably not appropriate at all.

According to Popper (referred to in Gilje and Grimen, 1993) an idea or hypotheses could not be regarded as scientific unless it was falsifiable. Popper’s point was that it is not possible to prove a scientific hypothesis, because no matter how much evidence one collected, one could not collect all relevant evidence. On the other hand, it is possible to disprove a scientific hypothesis. This idea can be explained through the famous swan example (Gilje and Grimen, 1993): One has the hypothesis that; “All swans are white”, at the moment one observes a black swan this theory must be rejected and abandoned. Popper’s view of scientific verification is by many thought to be naïve (Remenyi et al 1998). Lakatos came to believe that Popper’s thought ultimately was naïve, and he developed a methodology of scientific research programmes consisting of a “hard core” of propositions that cannot be questioned and a “protective belt” of auxiliary hypothesis that are flexible and can be used to scientifically develop the program (Lakatos and Musgrave editors 1970).

Scientific development based on the thoughts of Lakatos would most likely take on the concept of a deductive model. The concept of the deductive model is to derive a conclusion by logical reasoning in which the conclusion about particular issues follows from general or universal premises (Remenyi et al 1998). The deductive theory can be empirically tested after it has been set forward (Holme and Solvang 1991). The critic put forward against the deductive model is that the researcher will look for evidence that proves his preconceived attitude towards the problem. The researcher can become in danger of not including essential information about the problem, because it does not fit the theory basis of the research.

Regardless of the critic put forward, the research questions extracted from the main objective and the exploratory establishment of research hypothesis in this research, it can be concluded that this research clearly belong to the deductive research approach. The questions connected to the sub-objectives could have been approached without a prior knowledge to theory, but since they



were connected to the main objective questions they fell at least partly within the deductive tradition.

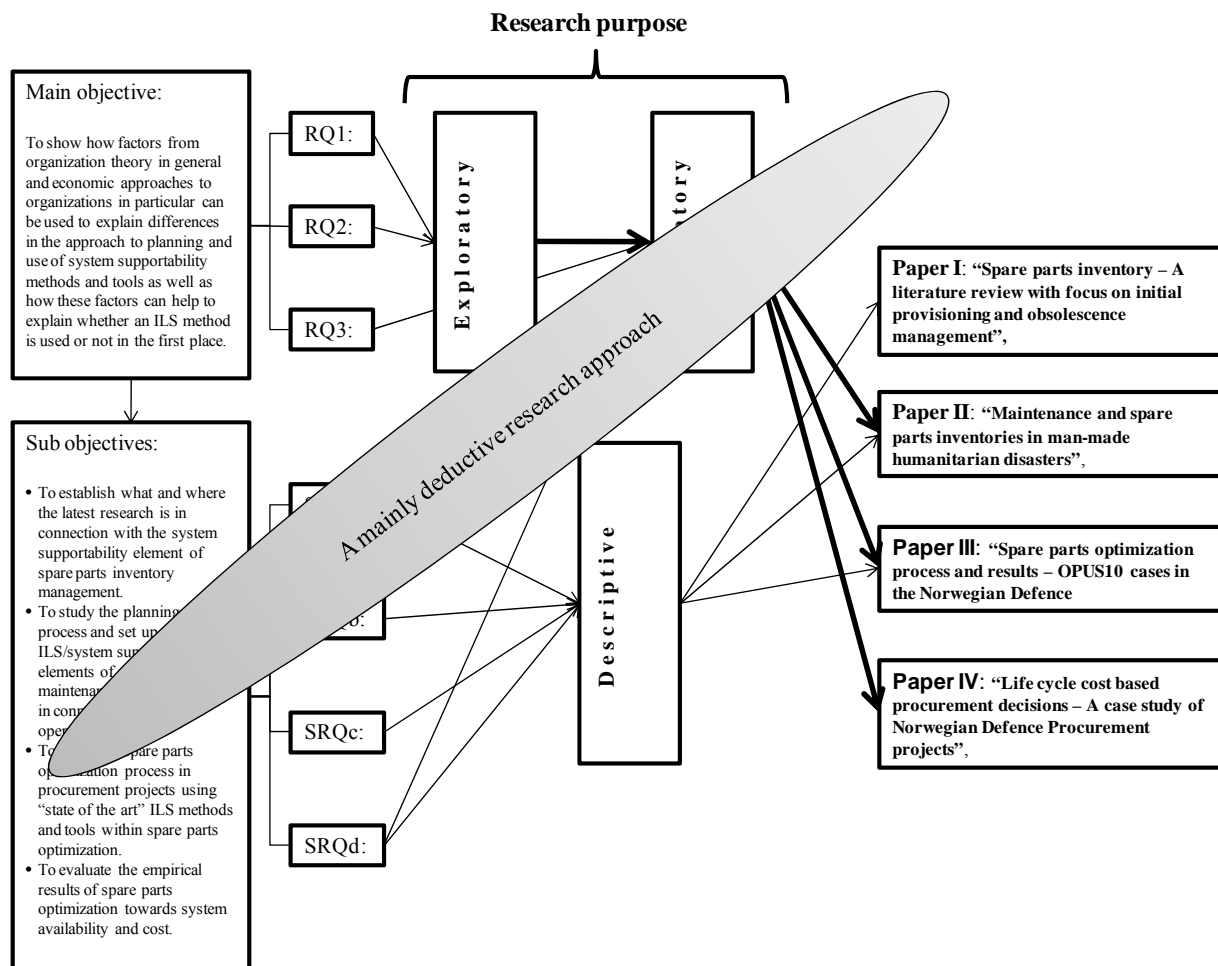


Figure 5 Focus on a deductive approach

### 5.4 Qualitative or quantitative research method, data collection methods and instruments

According to Jacobsen (2000) the basic assumption should be that qualitative and quantitative approaches to research are not different in principal. They are both method for collection of empirical data, but one method or approach will be better than the other according to the circumstances. Michael Quinn Patton is referred in Jacobsen (2000) to have stated (translated from Norwegian by the author of this thesis):

*“Because qualitative and quantitative methods have different strong and weak sides, they represent alternative, but not mutually exclusive research strategies. Both qualitative and quantitative data can be collected in the same research”*

This is the strategy pursued in this research project. According to Neuman (2006) an outcome of a comparison study on qualitative and quantitative research through the different stages of research from the definition of purpose until the outcome would probably lead to the following:

<b>Qualitative Style</b>	<b>Quantitative Style</b>
Construct social reality, cultural meaning	Measure objective facts
Focus on interactive processes, events	Focus on variables
Authenticity is key	Reliability is key
Values are present and explicit	Value-free
Theory and data are fused	Theory and data are separate
Situational constrained	Independent of context
Few cases, subjects	Many cases, subjects
Thematic analysis	Statistical analysis
Research is involved	Research is detached

**Table 3 – Qualitative style versus quantitative style according to Neuman (2006, page 13)**

With this as a starting point, each of the research questions were addressed towards choice of qualitative or quantitative research method, research strategy (e.g. case study, survey or archival), data collection method or methods as well as possible measuring instruments.

In connection with the first research question (RQ1); *“Can physical context as well as well as organizational structure and governance factors explain why maintenance, spare parts inventory and spare part supply chain planning and set up towards operations are done differently in different organizations?”* an intensive and qualitative research design was chosen. Linked together with RQ1 was also the second sub-objective question (SRQb), namely; *“How does a small country’s military force and a small country NGO plan for and set-up equipment maintenance, spare parts inventories and spare parts supply chains in connection with man-made humanitarian disasters?”* According to Yin (2003), the “why” and “how” questions of this type of study are likely to lead to the use of case studies as the preferred research strategy. Case studies are suitable when it is intended to understand contemporary complex social phenomena, such as maintenance and spare parts inventory planning and set up towards operations in different organizations. Yin (2003) states that first of all one has to make a choice between using only one case or several cases. The single-case has the advantage that a phenomenon can be studied very deeply, while the multiple-case approach looks at the phenomenon in a rougher way, but it offers the possibility to compare the findings of the different cases with each other. The rationale for a multiple-case design can be to produce contradicting results, which can be explained, based on predicted or hypothesized reasons (Yin, 2003). Data needed to answer these

two questions were collected through semi structured individual interviews, observations and collection of archival data. The interviews constitute, however, the main source of data. An interview guide<sup>10</sup> was developed based on the research model used in the study (the research model is presented in appended paper II). Each interview was taped and then partially transcribed to paper. Approximately 50 percent of the interviews were done face to face and 50 percent were done by telephone. The interviews together with observations and archival data were then analysed within the structure of the research model, serving to assist the researcher when forging the main conclusion. Findings and discussion of the findings can be found in detail in the appended paper II.

Main research question number two (RQ2) was: *“How has coordination issues affected the process and results of the spare parts optimization conducted in the Norwegian Defence procurement projects that has used OPUS10?”* In accordance with table three, the research question’s focus on processes made it natural to choose a qualitative approach. Further, the “how” setting of the question, lead the study in the direction of case studies as the preferred research strategy (Yin, 2003). The qualitative data were collected through semi structured individual interviews including sets of structured questions. An interview guide<sup>11</sup> was developed based on the research model (the model is presented in the appended paper III), containing 76 questions, where 36 questions were in a structured format. Each interview lasted approximately 90 minutes. Each interview was taped and main phrases transcribed to paper. The interviews together with archival data were then used to answer/explain predefined hypotheses (the hypothesis can be studied in the appended paper III). Two of the sub-objective research questions were also connected to RQ2. The first sub-objective question connected to RQ2 was SRQc, which asked; *“How has the spare parts optimization process been conducted in the Norwegian Defence procurement projects that have used the spare parts optimization tool OPUS10?”* In line with RQ2 the focus on process dictated qualitative research and the “how” question indicated a case study. The data were collected together with data needed to answer RQ2. Finally SRQd asked; *“Can empirical data show that the multi-echelon, multi-item, multi-indenture method solved through OPUS10, improves system availability and/or spares parts investment cost compared to the system supplier’s suggestion?”* The research question leads the study in the direction of a quantitative data analysis and hence the need for quantitative data. The quantitative data were collected by getting access to project databases and project files along with the management systems of the case study organizations (the Norwegian -Navy, -Army and -Defence Logistics Organization).

The last research question transformed from the main objective (RQ3) asked: *“What can explain that some procurement projects are still carried out and reviewed based on initial procurement costs alone when the official policy is to apply the life cycle cost approach?”* To answer this question, statistical verification became the preferred strategy, and this lead the research in a quantitative direction. In order to use statistics, data had to be collected from many subjects, specifically from project leaders. As presented in the appended paper IV, the study was focused

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<sup>10</sup> A translated version of the interview guide is included as an appendix to this thesis.

<sup>11</sup> A translated version of the interview guide used to answer the questions is included as an appendix to this thesis.

on the Norwegian Defence only and thus considered a case study, but researched through the use of a survey. The total number of projects and project leaders within the Norwegian Defence are shifting with the numbers of projects being started and/or terminated, but at the start of the data collection (December 2005) the number of projects were 252 with 98 project leaders<sup>12</sup>. It was decided to direct questions towards the different projects, and hence one person (the project leader) sometimes answered several times due to the fact that several project leaders lead more than one project. Since not all projects in the database are active, the initial number of 252 projects was reduced to 150 at the time of data collection. The measuring instrument of choice was a questionnaire (on-line survey)<sup>13</sup>. The main reason for choosing a questionnaire was to produce statistics and be able to quantitatively accept or reject the hypotheses put forward in the research model (reported in appended paper IV). The questionnaire was sent to the 150 potential respondents by including a link to the questionnaire database in an e-mail from the person in charge of all procurement projects in the Norwegian Defence Logistics Organization (NoDLO). In the summer of 2006, after two reminders, 87 informants (58 percent) returned answers to the questions. Out of the 87 answers, 9 responses had high levels of missing data and therefore they were deleted. The remaining 78 responses (52 percent) were all complete. Further description of how the collected data was analysed, findings and discussion of the findings can be read in full in the appended paper number IV.

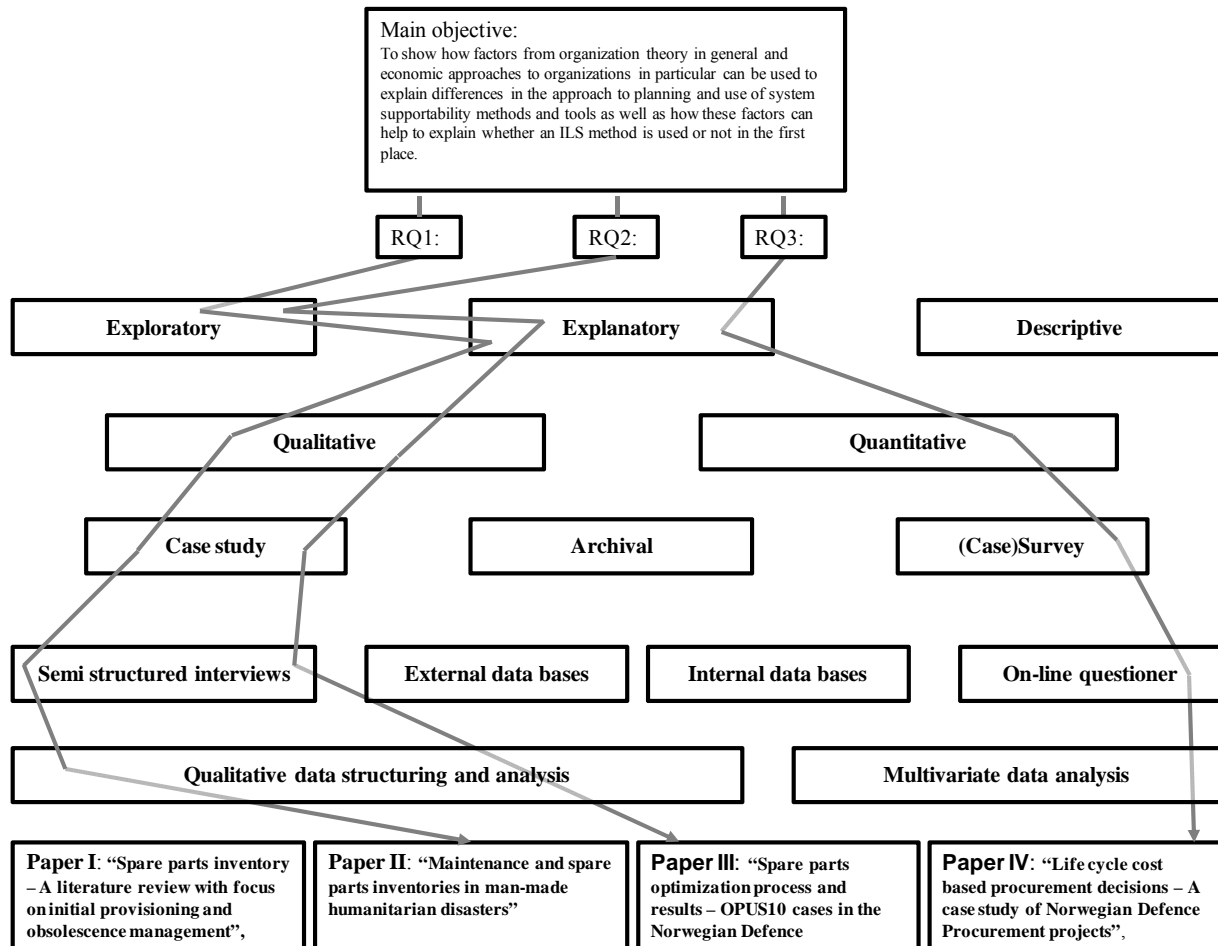
The last research question (SRQa) is connected to the sub-objectives. The question was: *“What is the existing body of literature concerning the system supportability element of spare parts towards theory, models and applications?”* To answer the research question a quantitative approach was needed in the form of an extensive literature search. Data bases like for example ProQuest and ScienceDirect were target and the search restricted to scientific papers found in well known international journals. However some papers found in proceedings from international conferences, a few relevant working papers, and some papers published in a military context, since armed forces are important operators of systems with long life cycles and a high degree of dependency on maintenance and spare parts, became a part of the study. Further data analysis and interpretations can be found in the appended paper number I.

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<sup>12</sup> The numbers are from The NoMoD’s project investment database called FID (“Forsvarets investeringsdatabase”).

<sup>13</sup> The questions from the survey that ended up in the final analysis are included as an appendix to the appended paper IV.

Figure 6 below depicts how the research design was set up for each of the main objective research questions (RQ1, RQ2 and RQ3).



**Figure 6 Research design connected to main objective and main research questions**

Figure 7 gives the same picture as figure 6 but connected to the sub-objective research questions (SRQa, SRQb, SRQc and SRQd).

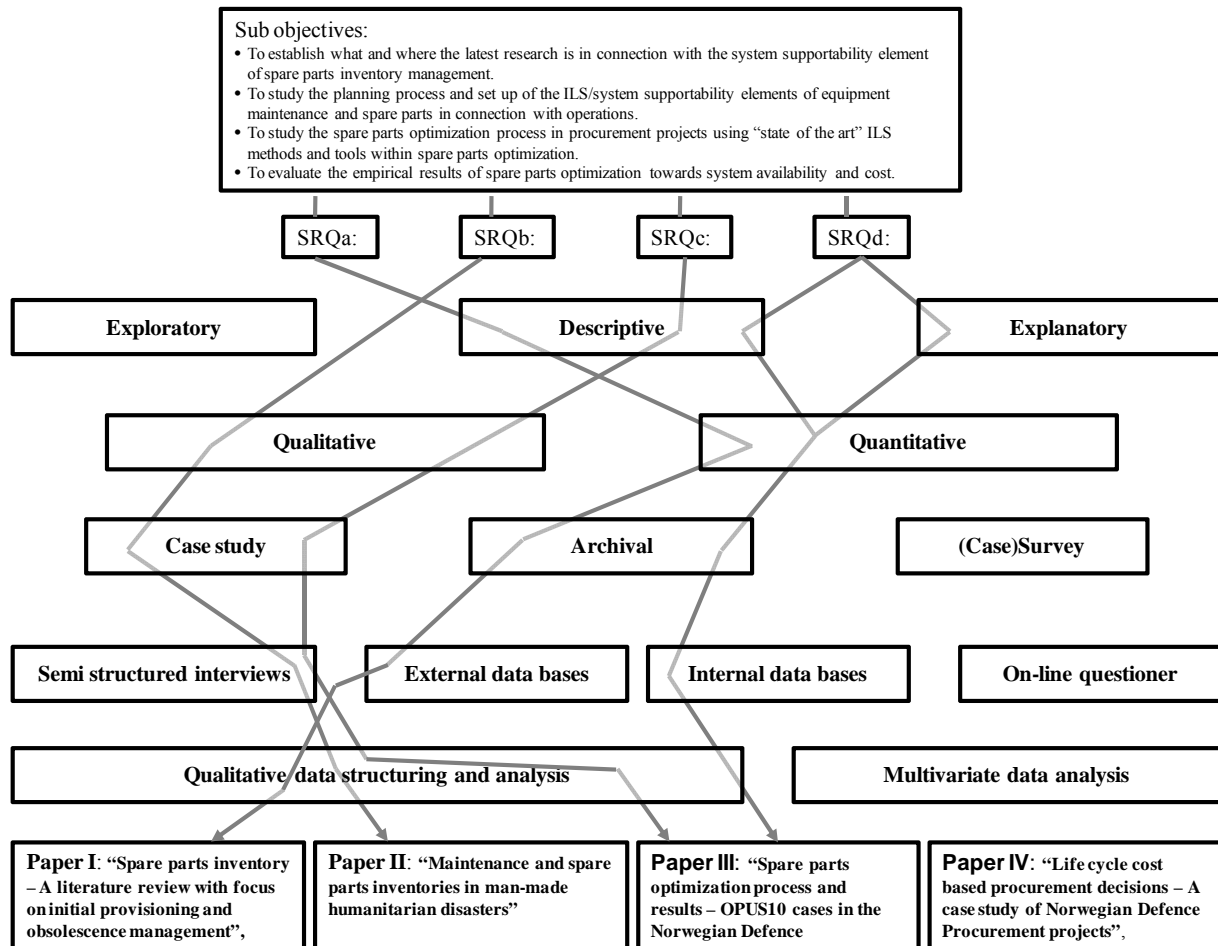


Figure 7 Research design connected to sub-objectives and sub-research questions

## 6. Validity and reliability

On the discussion of validity<sup>14</sup> and reliability<sup>15</sup> the intent in this research was to use the concept of triangulation. However it should be mentioned that when needed, such as when multivariate data analysis is used to answer main research question number three, content validity, unidimensionality, data reliability and scale validity are thoroughly discussed (see appended paper IV). Still the general concept of triangulation is used as the overall approach to validity and reliability. This is based on the notion that trustworthiness of research data is founded on triangulated empirical materials (Denzin et al., 1994).

Researchers have written about triangulation in several textbooks, and put forward that different types of triangulation exists and that they can be used in different ways. In this research five types identified by Miles and Huberman (1994) are evaluated:

1. Data source, use of multiple sources of data.
2. Researchers, implicating that several researchers work with the same data or research.
3. Methodology, the use of several methods (e.g interviews, surveys and archival records).
4. Data type, which may include linking qualitative and quantitative data.
5. Theory, implicating that a researcher applies different perspectives on the same data set.

Regarding data source triangulation, system supportability in general and spare parts planning and maintenance in particular has been researched by collecting data from two main organizations (the Norwegian Defence and the Norwegian Red cross) as well as from several projects within the Norwegian Defence. Data has been collected through archival material, data bases such as enterprise resource systems as well as from semi-structured individual interviews with many informants. In the research connected to life cycle cost based investment decisions the main data source was the respondents that answered the predefined structural questioner. However also in this part of the research archival data was used along with the researchers own experience from the field studied. Based on the above, it is claimed that data source triangulation is reached at its appropriate level towards trustworthiness.

On the second type of triangulation, the author of this thesis alone has conducted most of the research. Three out of four research papers making up the main part of this thesis is the sole work of the author of this thesis. However as this research is part of a doctoral study, an adviser has overlooked the work, as well as contributed to the appended paper I. The contribution consisted of input to the main idea behind the paper and final adjustments of the paper. Nevertheless, it is questionable whether researcher triangulation can be claimed to be fully met.

As explained above, both qualitative and quantitative methods are used in this research. It has been a goal of the research to use those methods found to best suit the research questions, but

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<sup>14</sup> The degree to which what is observed or measured is the same as what was purported to be observed or measured (Remenyi et al 1998).

<sup>15</sup> The degree to which observations or measures are consistent or stable.

also to better learn the different methods available for the (logistics) researcher. Hence methods from literature research, through qualitative semi structured interviews to multivariate data analysis in the form of regression analysis based on answers to a structured questionnaire (survey) is used in this total study. The concept of methodological triangulation should therefore be well covered.

The linking of qualitative and quantitative data is tried in connection with for example the research reported in the appended paper III. This type of linking is thus used in the research, but not consistently throughout the total study. This is because, as mentioned before, the research questions drives the method and data needed. However data type triangulation is used where appropriate to increase the trustworthiness of the research.

Finally, throughout the study a triangulation of aspects from integrated logistics support theory (e.g. spare parts optimization and life cycle costing), organization theory and economic organization theory in particular have been tried. Triangulation of these theories is as far as the author of this thesis know, not very common. However, this has been the driving force behind this research. This has hopefully made the research more trustworthy, in connection with validity and reliability of the research.

In the next chapter more details concerning the theoretical framework used in the research will be given.

## **7. Theoretical framework**

Huiskonen (2001) claims that surveys have shown that it has not been easy to transfer inventory research results into managerial practice. The author's own experience from the Norwegian Defence indicated in the beginning of this research that this also was a fact connected to integrated logistics support methods (e.g. spare parts optimization) and life cycle cost based decisions.

As mentioned in the introduction to the synthesis, ILS, system supportability and LCC methods and tools are very often based on mathematical assumptions and clearly originate from the field of operations research. This is especially true in the literature concerned with spare parts (see for example review papers by Guide and Srivastava (1997) and Kennedy et al. (2002)). However the processes leading to the decision to use one of the methods or tools in order to reduce LCC and how the method (for example spare parts optimization) is used must clearly be influenced by the organizational related factors.

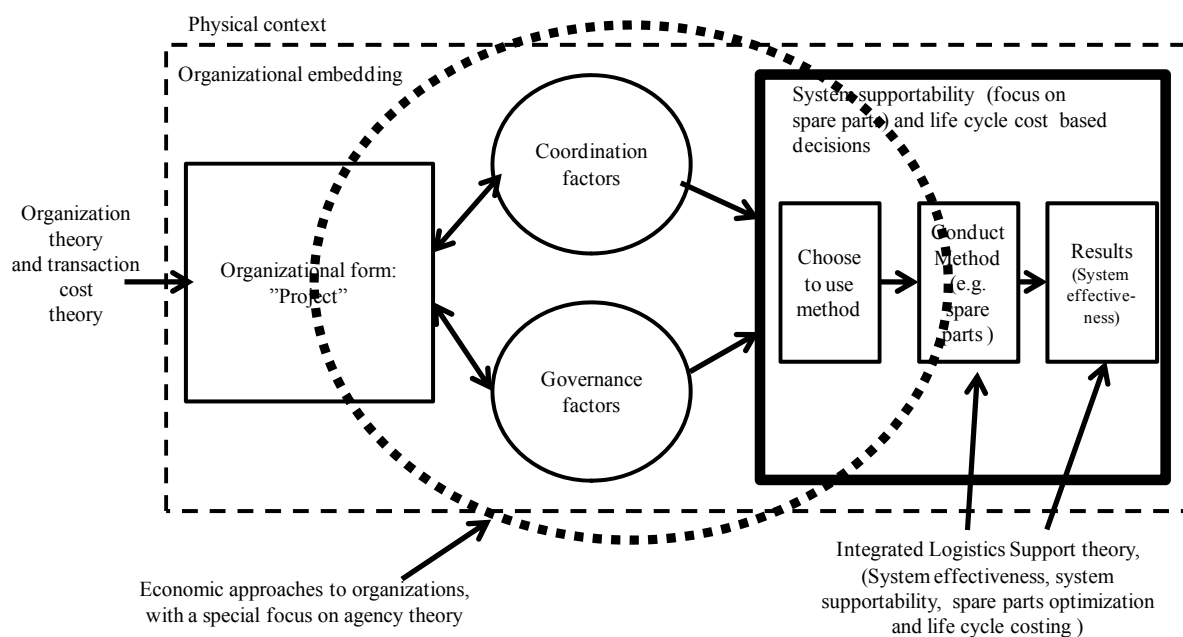
The main objective therefore became to show how factors from organization theory in general, and economic approaches to organizations in particular, can be used to explain differences in the approach to planning and use of system supportability methods and tools as well as how these factors can help to explain whether an ILS method is used or not in the first place.



However in order to reach the main objective it became necessary to establish what and where the latest research is in connection ILS theory, how the methods were conducted in organizations and the result they gave. This was thus constructed as sub-objectives of the research.

The theoretical framework used in the research is connected to the objectives of the research (both main objective and sub-objectives) and thus the research questions.

This can be depicted in the following manner:



**Figure 8 Theory connections**

The main research questions are as earlier stated:

1. Can physical context, as well as organizational structure and governance factors, explain why maintenance, spare parts inventory and spare part supply chain planning and set up towards operations are done differently in different organizations?
2. How has coordination issues affected the process and results of the spare parts optimization conducted in the Norwegian Defence procurement projects that has used OPUS10?
3. What can explain that some procurement projects are still carried out and reviewed based on initial procurement costs alone when the official policy is to apply the life cycle cost approach?

Based on the questions, the use of organization theory in connection with this study will be introduced in this chapter. The starting point is general organization theory which will be funnelled down to economic approaches to organizations. The main organizational form studied based on the questions is “project”, which is introduced through the use of general organization theory and transaction cost theory.

Further the factors used to answer the questions are introduced, discussed and the choice of factors justified. Generally speaking they can be categorized into coordination factors and governance factors as well as organizational embedding. In addition, physical context is touched upon in the research. The coordination factors are generated from organization theory, economic organization theory and operation management theory and based on a synthesis worked out by Wong et al. (2004). Governance factors are both based in organization theory and economic organization theory with a special focus on agency theory.

However before the organizational factors studied are more thoroughly introduced, a deeper introduction to system effectiveness, integrated logistics support, system supportability including spare parts as well as life cycle cost is given. This is because the research questions connected to the sub-objectives of the research are all concerned with research, processes, methods and tools connected to integrated logistics support and life cycle costing with a special focus on spare parts planning and optimization.

The sub-objective research questions are as earlier described:

- a. What is the existing body of literature concerning the system supportability element of spare parts towards theory, models and applications?
- b. How does a small country’s military force and a small country NGO plan for and set-up equipment maintenance, spare parts inventories and spare parts supply chains in connection with man-made humanitarian disasters?
- c. How has the spare parts optimization process been conducted in the Norwegian Defence procurement projects that have used the spare parts optimization tool OPUS10?
- d. Can empirical data show that the multi-echelon, multi-item, multi-indenture method solved through OPUS10, improves system availability and/or spares parts investment cost compared to the system supplier’s suggestion?

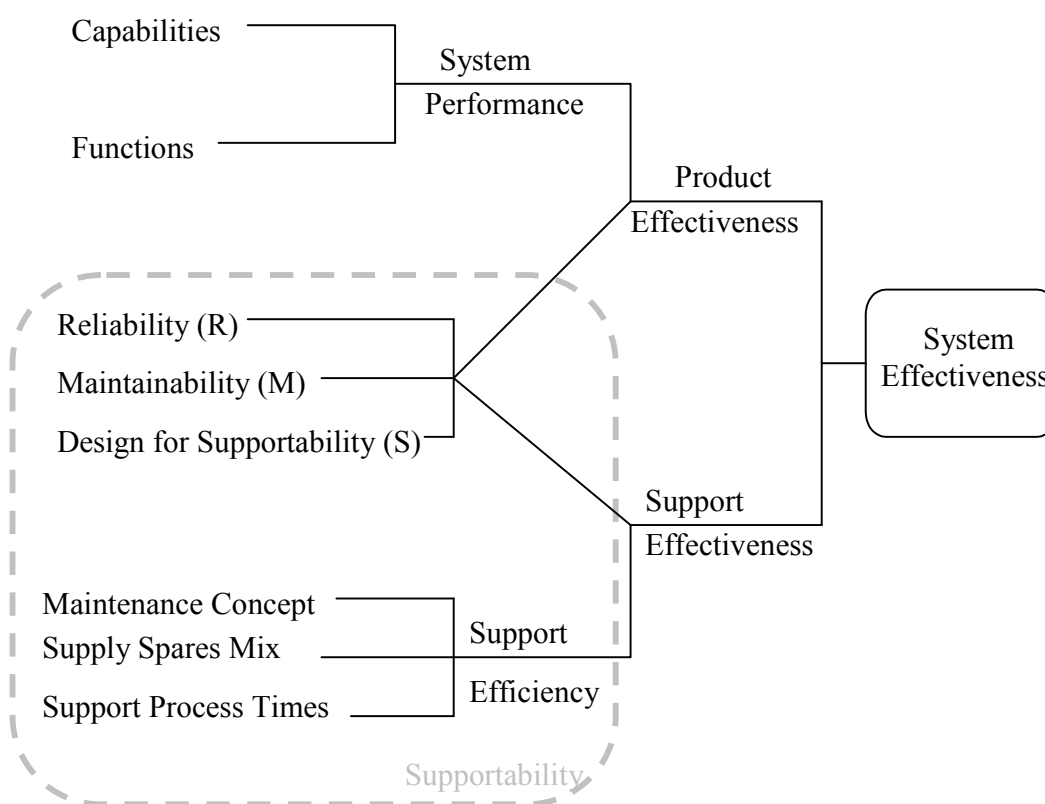
## **7.1 System effectiveness**

The success of any business, government or non governmental organization depends on the effectiveness of the process and/or products that they produce or operate (Kumar et al., 2000).

System effectiveness (SE) can be measured in several manners. Blanchard (2004) suggests that SE can be defined in terms of three main concepts; system performance parameters, point

availability (support efficiency) and dependability (reliability, maintainability and supportability).

System performance parameters can be defined as technical requirement (capabilities, functions and priorities) defining for example the accuracy of a radar capability, the capacity of a power plant. Point availability is the probability that an item or system is in a state of functioning at a given point in time, when operated, maintained and supported as prescribed (Kumar et al., 2000). Others have called the concept of point availability for support effectiveness (see e.g. DAU, 2008<sup>16</sup>).



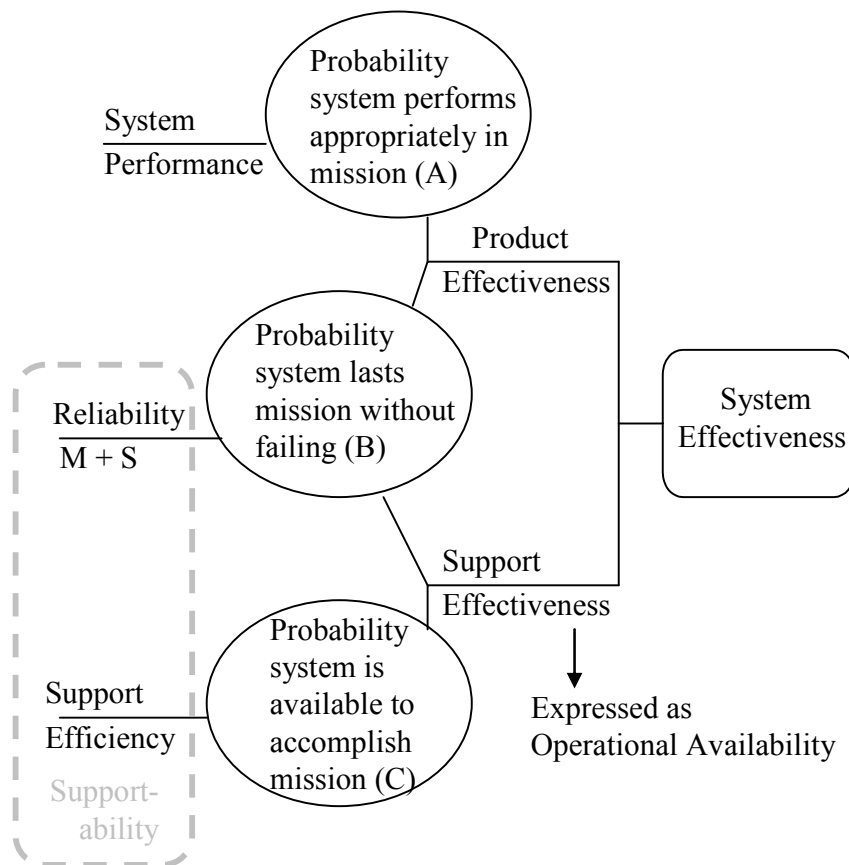
**Figure 9 System effectiveness, modified from a DAU (2008) presentation**

Figure nine gives an overview of what is defined within the concept of system effectiveness. In order to illustrate the concept, a diesel truck to be used in an operation in order to bring relief items to victims of a humanitarian disaster can be thought of. First of all, it is necessary to decide

<sup>16</sup> DAU = US Defense Acquisition University, The modified DAU figures used in this synthesis are collected from the online acquisition community connection practice center accessed in May 2008 through <https://acc.dau.mil/CommunityBrowser.aspx?id=22362&lang=en-US>

which performance the truck needs in terms of functionality or function. This can for example be the ability to carry goods. Further the truck's capability in terms of for example how many tons of goods it can carry, how much fuel it burns and so on should be described in the truck requirements. Capabilities and functions are technical performance factors that impact the system performance. If the truck has the right mixture of carrying capacity, fuel usage, ability to travel on bad roads and so on, it can be stated that in a hypothetical relief operation the truck would work appropriately.

In figure ten this concept has been placed within circle A, which is called the probability that the system performs appropriately in mission. If the system performance (capabilities and functions) match 100% to the needs the probability will be one, and then declining towards zero as needs and performance gets further apart.



**Figure 10 Probability connections, modified from a DAU (2008) presentation**

However, performance alone is not enough for the truck system to be effective in the planned operation or mission. If the truck cannot be used to transport relief items, in the imaginary humanitarian disaster relief operation, because something has failed on the truck or because the operator must perform a scheduled maintenance the system has downtime and the product effectiveness is reduced.

In particular the concept of reliability (R), maintainability (M) and supportability (S) are design factors that can, and will, influence the performance of the truck itself but also the support of the truck when in operations. Reliability can be defined as the probability that the system will perform in a satisfactory manner for a given period of time, when used under specified operating conditions (Blanchard, 2004).

Through design, a producer of systems can achieve high reliability by using high quality material, parallel configurations, monitoring sensors and so on. However, to gain high operational availability through design alone will in most cases result in a very high investment cost, and the balance between cost and performance might not be appropriate. Support in terms of maintenance is, based on this, needed throughout the life cycle of the system.

While maintenance is a result of a design already in place, maintainability is a design parameter like reliability. According to Blanchard (2004), maintainability, like reliability, is an inherent characteristic of the system/product design. It refers to how easy, safe and economic it is to perform maintenance actions on the system. If for example one needs to remove the engine in order to change the main light bulb of the truck used in the imaginary humanitarian relief mission, this will severely affect the effectiveness of that truck in the mission, and hence one might say that the system has bad maintainability.

Finally in figure nine the concept of design for supportability (S), which also can be termed supportability engineering (Kumar et al., 2000) is connected to both product and support effectiveness. According to Kumar et al. (2000), supportability engineering theory, as opposed to the total supportability within the dotted lines of figure nine, is concerned with designing the system so it can be supported at minimum (life cycle) cost. Hence in the design process one should according to theory establish what facilities, equipment and resources that will be needed to enable the system to be supported in the most cost effective manner. Within design for supportability, needed preventive maintenance can also be placed. As an example, if a specially trained technician with a very advanced tool and especially design depot is needed to change the main light bulb of the example truck, this will severely affect the effectiveness of that truck in the mission. Hence one might say that the system have bad supportability.

In figure ten the concept of reliability, maintainability and design for supportability has been placed within circle B. Circle B is called the probability that the system lasts mission without failing. Depending on the length of the mission in question, the reliability of the system and how easy the system is to support and maintain, the probability of lasting the mission without failing can vary from close to zero to close to one.

If one assumes that the truck both has a high probability of performing appropriately in the mission and initially has a high probability of lasting the mission without failure, further has good maintainability and is easy to support then product effectiveness is good. The question thus becomes whether this is enough to have an effective truck support system? According to theory, the answer is no. The maintainability and supportability of the product only relates to the easiness of supporting and maintaining the product. According to ILS theory, one should also plan for, and carry out, maintenance and other kinds of support in the operational phase as well as in the phase where the equipment is being phased out of use. In figure nine, support effectiveness is shown as a combination of reliability, maintainability and supportability factors combined with the system support efficiency.

Support efficiency has according to theory to do with how effectively (measured in time) a broken down product (e.g. the truck) can be brought back to a state of functioning based on the support process times, maintenance concept, available spare parts (supply spares mix) and the given maintainability and supportability of the product.

The chosen maintenance concept and spare parts mix determine which logistics chain response times will apply more frequently to impact support process efficiency. The amount of downtime, which includes maintainability and supportability, is influenced by the timeliness of support to restore equipment (support efficiency). In figure ten it is thus shown that support efficiency can be measured as the probability of the system/product being available to accomplish the mission in question (circle C). What is to be stressed here is the use of the term availability. According to Blanchard (2004) the term availability is used in a variety of contexts. Sometimes availability is termed as a measure for system readiness, which is the probability that the product/system is ready when called upon. This can be termed as point availability. Point availability is the probability that an item or system is in a state of functioning at a given point in time, when operated, maintained and supported as prescribed (Kumar et al., 2000). However, availability can also according to Blanchard (2004) be referred to as the probability that the product/system not only is ready when required, but will be able to complete its overall mission in a satisfactory manner. No matter whether one use the first or the second understanding of availability the measure of availability should be applied to a specific scenario or mission, such as for example the humanitarian relief example used above.

Again referring to both figure nine and especially figure ten, support effectiveness is impacted by the frequency of the equipment being down (B) and its associated downtime that prevents the system from performing in a mission (C). Another way to express the concept of support effectiveness is to use the well documented figure of merit called operational availability (Blanchard, 2004). Blanchard (2004) defines operational availability as follows:

$$A_o = \frac{MTBM}{MTBM + MDT}$$

Here MTBM is the mean time between maintenance and MDT is the mean maintenance downtime. The uptime of the system (MTBM) will be conditioned on the reliability of the system in terms of failures. Likewise, it will also be conditioned on how much preventive maintenance the system needs, defined within the design for supportability concept (refer to figure nine). The number of failures in any system has to do with the system's reliability.

Support in terms of maintenance is, as explained above, needed in connection with any type of operation or mission. Based on the research questions, the focus in this research has been on military operations and humanitarian relief operations. However the operation could just as well have been a commercial business operation utilizing equipment. The mean maintenance downtime (MDT) is made up of the mean active maintenance time ( $\bar{M}$ ), administrative delay time (ADT) and logistics delay time (LDT).

The system's active maintenance time is dependent on how easy the system is to maintain (expressed as maintainability and thus included in (B) of figure ten). ADT refers to that portion of MDT which maintenance is delayed due to administrative issues like for example lack of qualified technicians. Finally LDT refers to the part of MDT that is expended because of resource delays like test equipment, transportation and not least spare parts. Both ADT and LDT will be dependent upon the chosen maintenance concept, the support process times and the supply spares mix, and hence included in (C) of figure ten.

Operational availability can now be defined as:

$$A_o = \frac{MTBM}{MTBM + \bar{M} + ADT + LDT}$$

The combination of support effectiveness measured through operational availability together with product effectiveness gives the effectiveness of the system in question. Traditionally product effectiveness is 100% bought from the supplier of the product or system in question, while support effectiveness only partly can be bought, because much of the support efficiency making up a large portion of support effectiveness (especially logistics delay time (LDT)) is resting within the organization operating the product or system in question. LDT together with ADT are in figure nine expressed as support process times, and these times will be dependent upon the chosen maintenance concept, the spare parts concept and the attached supply chain and maintenance chain response times.

To sum up, when a product or system is designed it should theoretically be designed in order to perform appropriately in the operation or mission the system is to be used in. This is typically done by the system producer either directly based on customer requirement or by general demands. This is referred to as (A) in figure ten.

Secondly the support of the system needs to be designed. Again this is typically done by the producer of the system, and again either by direct customer requirements or by more general demands. This is referred to as (B) in figure ten.

Finally the chosen design has to be supported. This has traditionally been done by the organization that operates the system in question, which also is the case for the Norwegian Defence. However it can be possible to outsource either parts of the support or all of the support to other organizations, but this has not been a focus area in this research. In figure ten this part of system effectiveness is called (C).

## 7.2 Integrated logistics support, system supportability and spare parts

Referring back to the integrated logistics support (ILS) definition in the introduction of the synthesis, it can be seen that the definition fits the concept of system effectiveness by focusing on support considerations in the design, develop or design the support and support the chosen design. The ILS definition according to Blanchard (2004) was:

*“ILS constitute a disciplined, unified, and iterative approach to the management and technical activities necessary to (1) integrate support considerations into system and equipment design; (2) develop support requirements that are related consistently to readiness objectives, to design, and to each other; (3) acquire the required support; and (4) provide the required support during the operational phase at minimum cost.”*

Further it was stated in the introduction that ILS theory focused on ten logistic elements in order to minimize equipment or system life cycle cost (LCC). The ten elements were:

- Design interface
- Maintenance planning
- Supply support including spare parts
- Technical data
- Computer resources support
- Manpower and personnel
- Facilities
- Support equipment
- Packaging, handling, storage and transportation
- Training and training support

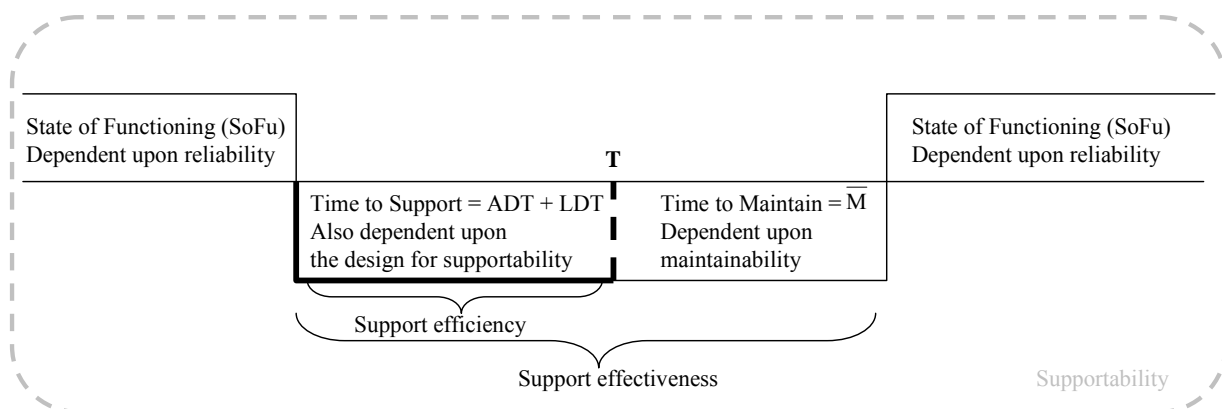
Out of the ten elements of integrated logistics support, only element number one (design interface) has impact on product effectiveness, the others have impact on support effectiveness in general and support efficiency in particular. The concept of supportability is in figure nine and ten marked within the dotted line, but what is the definition of supportability? According to Kumar et al. (2000) supportability can be defined as follows:



*“Supportability is the inherent characteristics of an item related to its ability to be supported by the required resources for the execution of the specified maintenance task.”*

According to Kumar et al. (2000), it is important to notice that supportability is inherent. Inherent in this context means that it is a consequence of the design. Hence either one has been able to affect design in terms of reliability, maintainability and supportability as referred to in ILS element one, or the design is already given. An example of an already given design could be the truck used in the imaginary humanitarian relief example. If this truck is a so called commercially of the shelf (COTS) product, the ability to influence the product will be zero or close to zero and the focus by the operating organization should thus in theory be on support efficiency.

Kumar et al. (2000) have developed a simple figure that helps explain the physical meaning of supportability. In figure eleven this figure has been developed further to better incorporate the definition of operational availability explained above and to link it to figure one and two of this synthesis.



**Figure 11 The concept of supportability based on Kumar et al. (2000, page 251)**

In figure eleven, the SoFu represents what is called MTBM in the operational availability formula, also referred to as the uptime of the system. The uptime of the system will, as explained before, be conditioned on the reliability of the system. When the system brakes down there will be a time period, called time to support, before the required maintenance task can be performed. In figure eleven, T represents the instant of time when required support resources have been made available. This time period is within the formula for operational availability called administrative delay time (ADT) and logistics delay time (LDT). ADT and LDT consists of waiting time for executing any of the nine reminding ILS elements; maintenance (plan), supply support including spare parts, technical data, computer resource support, manpower, facilities, support equipment, packaging, handling, storage and transportation as well as needed training.

To sum up, all ten ILS elements affect supportability and thus support effectiveness. All elements except the design interface will affect the support efficiency of the equipment or system in question. However in reality maintenance and supply support in terms of spare parts will normally be the driver for the other elements and according to Kumar et al. (2000) spare parts provisioning and management is maybe the most challenging problems in the whole ILS process. Based on this spare parts has been given a special focus in this research on system supportability.

Spare parts inventory theory in general and repairable inventory in particular now dates back more than 40 years (Kennedy et al., 2002). Repairable inventory theory is, unlike classic inventory theory, concerned with items which are repaired rather than discarded. According to Guide and Srivastava (1997) the classical repairable inventory problem and the so called multi-echelon models dates from the military, and they point out Sherbrooke's 1968 paper "*METRIC: A multi-echelon technique for recoverable item control*", as the starting point. In the military setting described by Sherbrook (1968) the problem is how to optimally stock repairable parts for aircraft at bases which are capable of repairing some, but not all broken parts, and a central depot which serves all bases.

For the spare parts that can not be repaired, the inventory levels are still largely a function of how equipment is used and how it is maintained, in comparison to work in progress (WIP) and final product inventories which is the focus of traditional business logistics. According to Kennedy et al. (2002) the main conditions that separate WIP and final product inventories from spare parts inventories are:

- Maintenance rather than customer usage dictate the need for spare parts inventories.
- System design in terms of for example redundancy (parallel configurations) in the system can increase reliability and hence operational availability, and in the same manner it can reduce the need for spare parts inventories because the redundancy makes it possible to replace non-working parts at a convenient time (e.g. after the ordering lead-time has elapsed). However, this requires that the system operator is aware of the part being broken, which is very often not the case even with redundant systems.
- Monitoring equipment can reduce the need for emergency spare parts inventories.
- Failure of one part is often dependent on the failure of another part.
- Demand can sometimes be met through cannibalism of equivalent systems.
- Many technologies, and hence spares based on these technologies, have life cycles that are shorter than the life cycle of the system they are in. Spares for possible obsolete systems must be managed, both in terms of deciding how many to stock if obsolescence is known, and in terms of how to replace a part that no longer is available from any source.
- When an expensive piece of equipment is bought, spare parts can often be bought at a reduced price. This can for example be due to the fact that the production line for the main equipment is running and hence no set-up cost is incurred for the spare part production.
- In addition to these points it will be shown in the next section that the counter balance to system effectiveness is cost effectiveness or what might be called life cycle costs. However, several cost elements are very difficult to assess, this can for example be costs associated

with the safety of personnel. One might for example decide to stock special spare parts for an engine onboard a ship in order to make sure the ship does not run aground due to engine failure, even if this is not economically optimal.

One do see that maintenance is the prime driver for the spare parts assessment, and this is the case whether one is concerned with new equipment where reliability, maintainability and supportability can be influenced (through design) or whether one is planning for an operation or mission with existing equipment. Setting a side the question of cost, if the need is to have an effective system as explained earlier, it is easy to see that this can only be done by coupling product effectiveness (capabilities and functions) with as little downtime as possible.

The theoretical challenge thus becomes how to achieve as few systems as possible that are *Not Operational Ready* (NOR). NOR as a measure of effectiveness in spare parts optimization is according to literature not the best solution, and since access to spare parts will constitute a large part of the time to support and hence make sure that the system is operational ready another measure of effectiveness is needed. Thus in operation research literature<sup>17</sup> it has been shown by a chain of equivalence that minimizing NOR is equivalent to minimizing the *Number of Back Orders* (NBO). One could of course minimize NBO by buying an infinite amount of spare parts  $S$  at cost  $C$ . In most procurement projects and operations there will however be a budget restriction  $b$ . All systems consists of several sub systems, here denoted by  $k$  such that a system is a sum of  $k=1, \dots, K$ . In the simplest version with one indenture level and one site the problem can be defined as:

$$\min \sum_{k=1}^K NBO_k(S_k) \quad s.t. \sum_{k=1}^K C_k S_k \leq b \quad S_k \geq 0 \quad \text{and integer}$$

Looking at the minimization problem we see that it is not intuitively for anybody to decide which spare parts in what numbers are best to buy in order to minimize the number of back orders given the budget available.

The problem is called an integer knapsack problem, and this problem has been solved in theoretical models and spare parts optimization software by utilizing an algorithm called marginal allocation. In the models and software the complexity of several multi-indenture systems being supported by a multi-echelon support system is taken into consideration.

Through this section it has been shown that spare parts (also called supply spares mix) is a very important contributor to support efficiency, whether one is dealing with new equipment in a procurement project or putting together a package of equipment in order to solve an operation or mission. One of the most used measures of support efficiency in the literature connected with the matter has been shown to be operational availability. It has been shown that the downtime portion of operational availability is connected to support effectiveness in terms of administrative

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<sup>17</sup> See e.g. Alfredsson (1997).

and logistics delay time (ADT + LDT) and again spare parts is one of the most important factors in connection with delay time.

Further maintainability and design for supportability also governs the downtime of the system but is not connected to support efficiency. It has been shown how these factors together with reliability, capabilities and functions will govern system effectiveness. However the final point is that these factors (maintainability and design for supportability), in comparison to support efficiency factors in general and spare parts in particular to a less extent can be managed by the equipment owning or operating organization in order to achieve high system effectiveness. This is especially true if one is dealing with equipment that already is designed. Thus there needs to be a considerable focus on spare parts in order to achieve high system supportability.

It has been stated that optimization of spare parts has been solved in operation research literature with the use of the marginal allocation algorithm. The solution is often referred to as the multi-echelon, multi-item, multi-indenture method, also called the system approach. More knowledge regarding the latest research on these topics was to be established through the answer to the sub-objective research question a, (**SRQa**): *What is the existing body of literature concerning the system supportability element of spare parts towards theory, models and applications?*

According to Wong et al. (2005), it is well known within theoretical operation research literature and thus the operation research community that applying the multi-echelon, multi-item, multi-indenture method or system approach may lead to significant reduction in inventory cost compared to for example the single-item approach and definitely compared to bluntly accepting a system supplier's spare parts package suggestion.

It has earlier been shown that support efficiency consists of the maintenance concept, support process times and supply spares or spare parts mix. It was also shown that access to spare parts can contribute largely to the downtime and hence support effectiveness of any system. Further it has been shown that the spare parts optimization problem in an theoretical operation research analysis sense can be viewed as a so called knapsack problem. In many real life approaches to spare parts selection, some acknowledgement of the knapsack problem might be present, but solution chosen by the organization faced with such a problem need not be given by a system based optimization process.

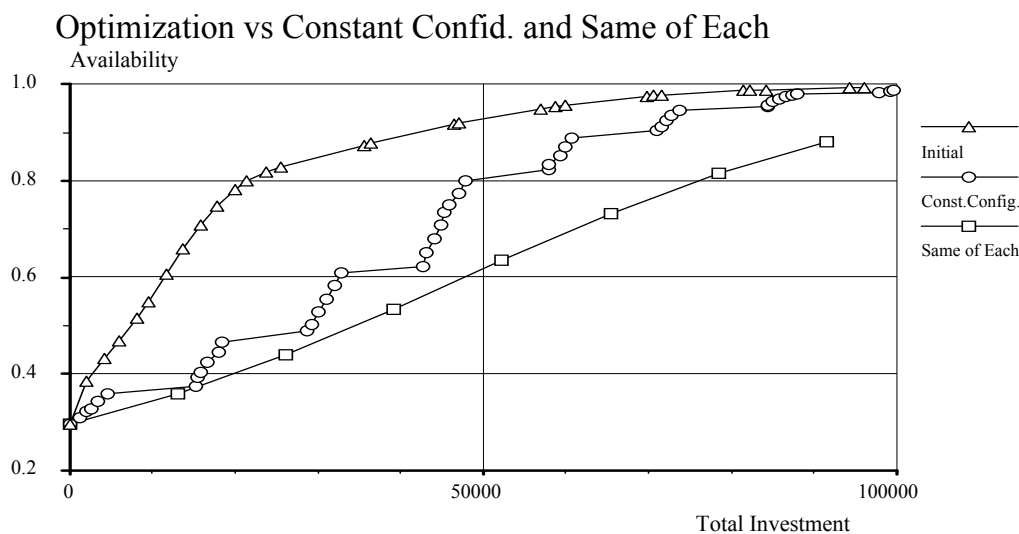
In a publication by Systecon (2002) a simple test case<sup>18</sup> is used to illustrate the challenge of deciding the number of spare parts to buy based on four different approaches. The four approaches are; random choice, same of each, constant confidence against stock out and the system approach.

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<sup>18</sup> The case consisted of 50 systems, one echelon, ten LRUs (one indenture level, 5 LRUs with two per system) with associated, system utilization, failure rates and turn-around times for LRU repair. One of the LRUs is more than ten times as expensive as the others.

In the random choice approach a random number of spares from 0 to 10 is chosen for each line replaceable unit (LRU), giving  $11^{10}$  possible combinations (hopefully not much used). The second approach basically means that you buy the same of each LRU (often one). The third method is more sophisticated because it takes into account the utilization factor, failure rate per LRU, number of LRUs per system and turn-around times (TAT) for repair of the LRU when the expected demand is calculated. All LRUs are then calculated to the quantity that meets a given confidence level (e.g. 95%) for not having a stock-out during a certain period of time. The main challenge with this method is that unit price of the LRU is not included in the calculation. If unit price for each LRU is the same then this method is close to optimal. We know however that in real life this is not the case, and the effect of unit price should be considered, especially since in most cases there is a limited budget for spare parts. Finally the fourth method is the system approach, solved in literature, models and spare parts optimization software by utilizing the algorithm, mentioned before, called marginal allocation. In the models and software using the system approach the complexity of several multi-indenture systems being supported by a multi-echelon support system is taken into consideration.

Below is a figure showing the results on availability and cost for different stocking alternatives for the three last methods (Systecon, 2002).



**Figure 12 Three alternative methods for spare parts dimensioning (source Systecon, 2002)**

As can be seen, the system based optimization method (indicated as “Initial” in figure twelve) is by far the best in this hypothetical case.

The point to make here, is that when focusing on maintenance and the associated spare parts, simple methods such as rule of thumb or same of each will not be the best way, at least theoretically, to reduce life cycle cost for the system in question and thus contribute to system

cost effectiveness. Neither will these methods (engineering choice and same of each) at least theoretically give the best operational availability.

However empirical data verifying the theoretical claims seems to be limited, thus leading to the sub-objective research question d (**SRQd**), asking: “*Can empirical data show that the multi-echelon, multi-item, multi-indenture method solved through OPUS10, improves system availability and/or spares parts investment cost compared to the system supplier’s suggestion?*”

### 7.3 Life cycle cost

So far the concept of life cycle cost has been touched upon without exactly defining life cycle cost. Life cycle cost refers to the life cycle of a system (for example the previous used truck example, including the truck’s support organization). The life cycle usually starts with the initial determination of system need, continues through design and development (also called research and development), production, deployment, operations and concludes with the system’s disposal.

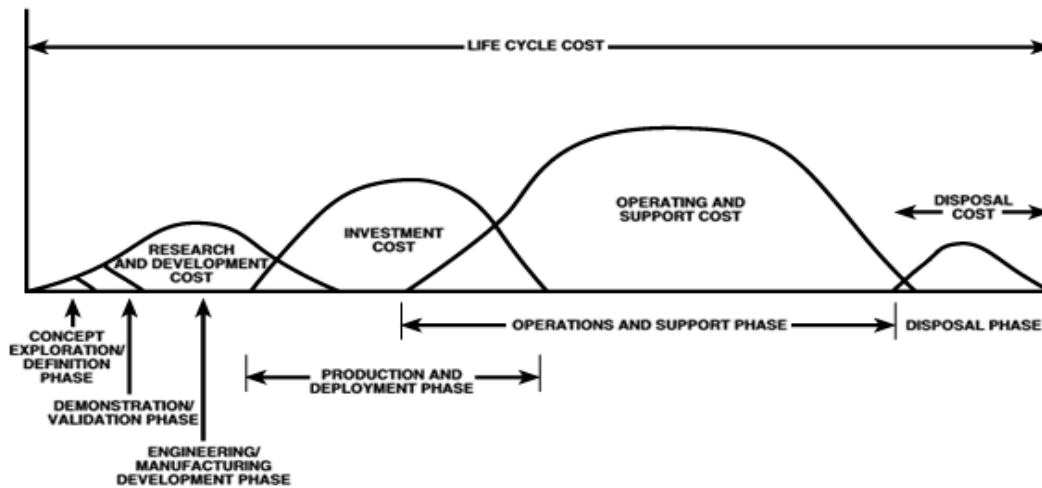
Office of the US Secretary of Defense, has in their Operating and Support Estimating Guide, separated the life cycle cost into four main areas<sup>19</sup>:

1. Research and Development: Includes costs of studies; analysis; design; test and evaluation; pre-production development; and documentation
2. Investment: Accounts for all production and deployment costs including any required training and infrastructure.
3. Operations and Support: Consists of all cost associated with usage and maintenance of the equipment/system.
4. Disposal: Although a relatively small percentage of LCC, and therefore often overlooked, this area accounts for demilitarization, destruction, or deactivation of the system.

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<sup>19</sup> Operating and Support Estimating Guide, <http://www.dtic.mil/pae>

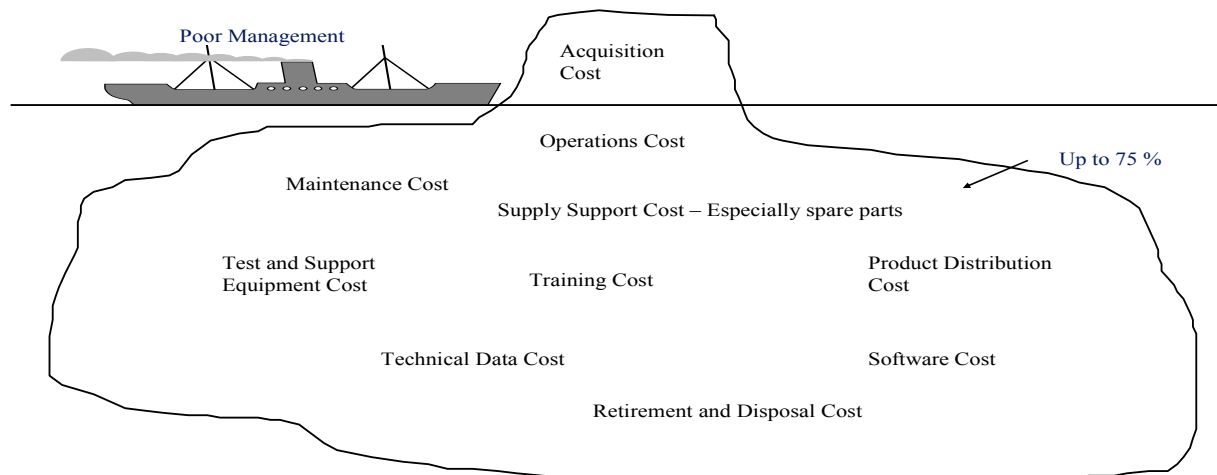
This has also been shown in the same guide, in the form of the following figure:



**Figure 13 The four main areas of life cycle cost (source see footnote 19)**

Figure 13 clearly indicates that the largest portion of the total cost of owning equipment is connected to the operation and support phase, at least for military equipment. Blanchard (2004) indicates that up to 75% of the total life cycle cost can be associated with the operation and support of the equipment or system in question.

The figure below depicts the total cost visibility needed to adopt the long-term perspective for buying valuation (adapted from Blanchard, 2004).

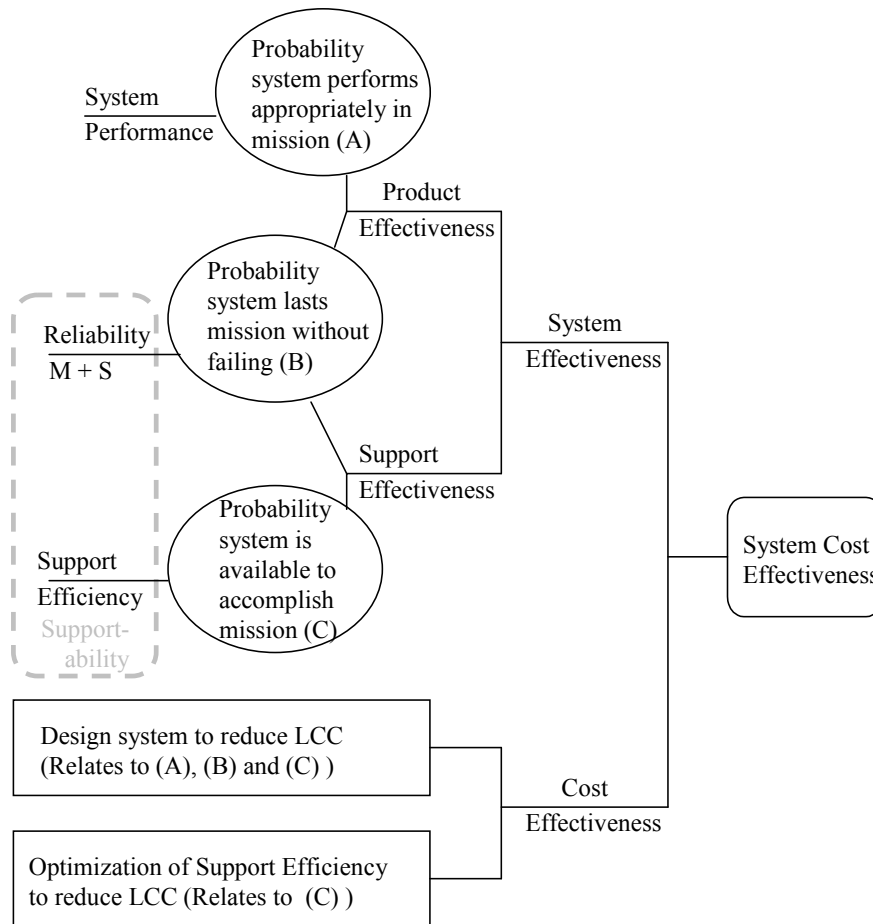


**Figure 14 Total cost visibility (modified from Blanchard, 2004 page 25)**

Life cycle cost may be categorized in many different ways, depending on the type of system and the sensitivities desired in cost-effectiveness measurement (Fabrycky and Blanchard, 1991). However the fundamental objective of LCC reduction analysis, as indicated by the total cost visibility figure, is to identify the cost drivers that most significantly contribute to LCC. This allows for trade off considerations with respect to different courses of action (Masiello, 2002). It is also very important to notice that LCC should not be used as a budgeting tool for the buying and operating organization, but as a tool for trying to identify cost drivers and to take into account the very important aspect of operating costs, support costs and disposal costs when making investment decisions. Naturally, and as shown through the section on system effectiveness and ILS, LCC will depend on the reliability, maintainability and design for supportability of the system in question. Further it will depend on how the system is used, maintained and supported and finally it will depend on support effectiveness and thus operational availability that is required out of the system. In a procurement situation or in a situation where an organization is planning for an operation/mission the cost of operating and supporting the equipment in question should thus in theory be evaluated in order to reduce the organization's life cycle costs.



The connection of system effectiveness to cost effectiveness can be shown in the following manner:

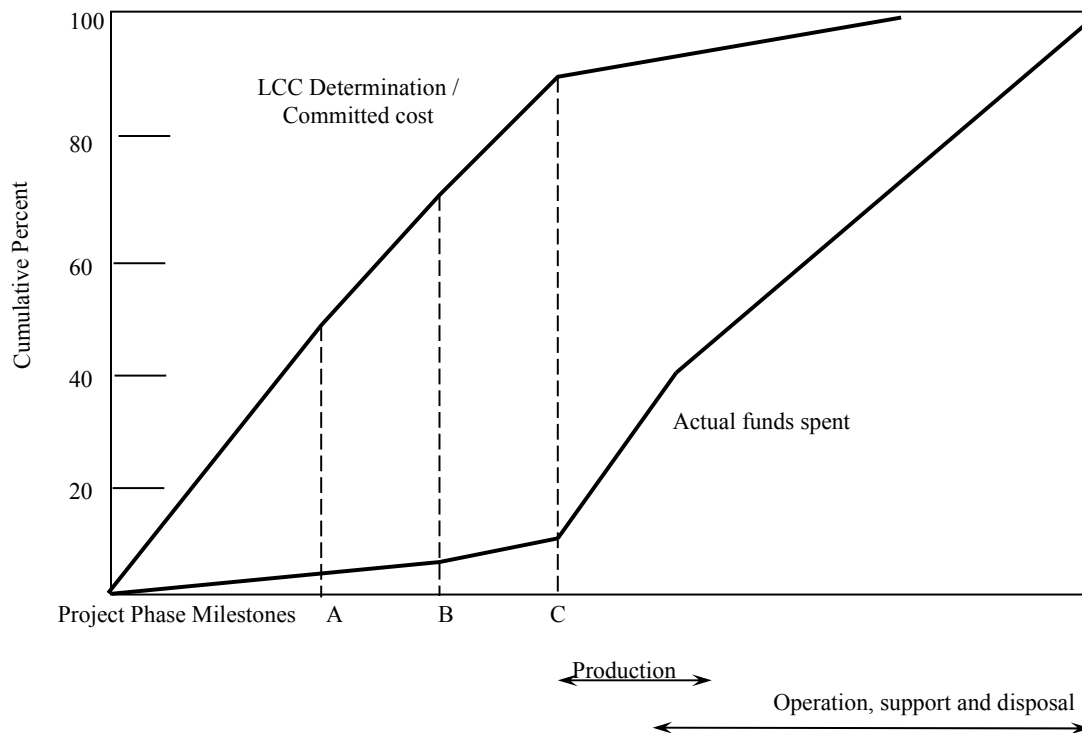


**Figure 15 Cost effectiveness and LCC modified from a DAU (2008) presentation**

The overall cost effectiveness goal is to reduce the system’s LCC. As shown in figure 15, cost effectiveness could be attacked in at least two manners according to theory.

First, designing the product to reduce LCC introduces product design tradeoffs with regards to system performance factors, reliability, maintainability and design for supportability as well as support efficiency. Hence the goal in theory is to make life cycle cost based procurement decisions in the research/development/investment phase of the equipment or system in question. The main reason for focusing on this early life cycle phase of the equipment, is that through design up to 90% of the systems life cycle cost might already be given, even if maybe as little as 10% of the total cost will actually have been spent when the system goes into operation.

This relationship is depicted in figure 16 below:



**Figure 16 Committed cost (LCC determination) versus actual funds spent (from a DAU (2008) presentation)**

According to theory, life cycle cost analysis should in connection with procurement of new system be used in basically two fashions:

1. Compare system effectiveness to cost effectiveness for several alternative solutions.
2. Compare system effectiveness to cost effectiveness for one single system in order to evaluate if the cost is appropriate and acceptable towards the returned value of the system.

If one is comparing several alternative solutions, the concept of net present value should be used because different systems/equipment will have different operating profiles for example due to the mean time between failures on sub-systems within the overall system, or simply due to the system supplier demanding different intervals between preventive maintenance.

However before the alternative cost profiles can be evaluated, these cost profiles must be captured in order to make an evaluation at all. According to Blanchard (2004) the process of developing a cost profile consists of seven steps:

1. Define system requirements – For example what functions and capabilities is required, what is the utilization rate, reliability factors, maintenance requirements and so on.
2. Describe the system life cycle and identify the activities in each phase.
3. Develop a Cost Breakdown Structure (CBS) – Here it is very important to cover all life cycles in accordance with for example figure 13.
4. Identify data input requirements.
5. Establish the costs for each category in the CBS.
6. Select a cost model for the purpose of analysis and evaluation.
7. Develop a cost profile and summary.

The steps above is described in a very broad manner, and for the interested reader more detailed description of the total process and tools can be found in for example Blanchard (2004). However, the main point is that if this exercise of developing cost profiles are done, the procurement project has a possibility of identifying high cost contributors and establishes cause and effect relationships. In this manner it will be possible for the system procurer in an early phase to influence design in such a way that either product effectiveness or support effectiveness or both can be achieved in a more cost effective manner. In this way better system cost effectiveness can be reached through reduction of life cycle costs.

Referring back to figure 15, the second way of reducing LCC and thus contributing to system cost effectiveness, is to optimize the support efficiency. Optimizing support efficiency can be done even if the system design no longer can be influenced. Optimizing support efficiency, should according to theory also be a focus in the procurement phase of the system, but also be conducted throughout the life cycles of the system in question. If for example several systems are put together in order to support a mission, an optimization of support efficiency ideally should be made in order to reduce the cost of the mission if possible while still gaining the same or better benefit.

To finish of the section concerning life cycle costing the final word of Blanchard (2004), in his sixth edition of the book “Logistics engineering and management “ is quintessential, here he says that:

*“To be successful in this area (read ILS and LCC) requires that the proper organizational environment be establish that will allow it to happen.”*

Unfortunately, not much more is said in Blanchard (2004) on how to establish this proper organizational environment.

## 7.4 Organization theory

In ILS/system supportability and LCC literature the methods and tools described are very often based on mathematical assumptions and clearly originate from the field of operations research. This is especially true in the literature concerned with spare parts (see for example review papers by Guide and Srivastava (1997) and Kennedy et al. (2002)). However, the processes leading to the decision to use one of the methods or tools in order to reduce LCC and how the method (for example spare parts optimization) is used must clearly be influenced by organizational factors and the physical context facing the organization and/or project in question.

This was the starting point for this research along with the authors own experience regarding for instance the fact that maintenance and spare parts inventory planning is done differently in different organizations and/or projects.

The first two main research questions are concerned with how organizational connected factors can help to explain differences in planning and use of system supportability issues of maintenance and spare parts. The questions asked were:

**(RQ1):** *“Can physical context as well as well as organizational structure and governance factors explain why maintenance, spare parts inventory and spare part supply chain planning and set up towards operations are done differently in different organizations?”*

**(RQ2):** *“How has coordination issues affected the process and results of the spare parts optimization conducted in the Norwegian Defence procurement projects that have used OPUS10?”*

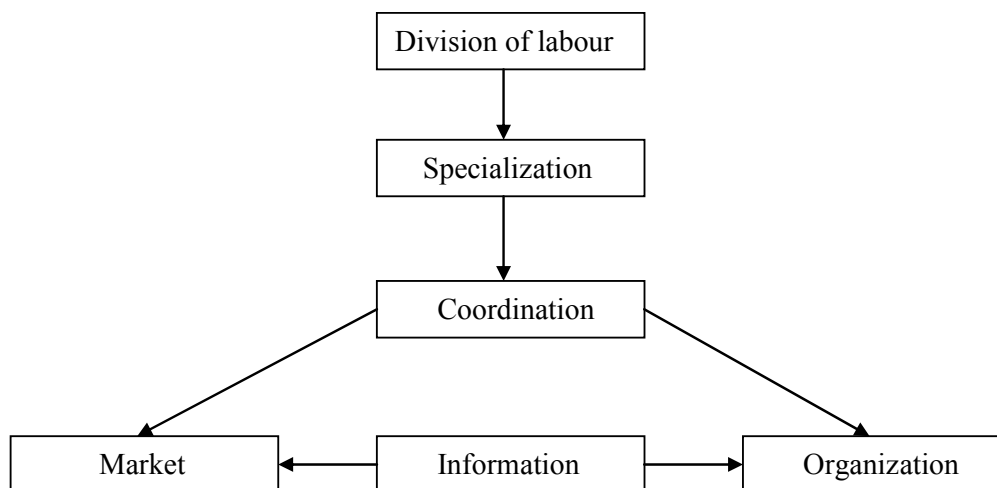
Further life cycle costing has been defined as a concept suggesting that managers should adopt a long-term perspective, for the accurate valuation of buying situations (Ferrin and Plank, 2002). This was probably the driving factor when the Norwegian Ministry of Defence (NoMoD) in 2004 published; “Konsept for fremskaffelse av materielle kapasiteter i forsvarssektoren” (Norwegian title). In this publication the NoMoD states that when investment decisions are made, solutions/systems that yield the lowest possible life cycle cost, given equal system effectiveness, must be preferred, even if this results in that the initial investment cost becomes higher. However, studies from for example the United Kingdom have concluded that buying decisions even in organizations that have implemented LCC, to a large extent is still based on acquisition cost alone (Kirkpatrick 2004). This was also the author of this thesis own experience from the Norwegian Defence.

Based on the previously described theoretical foundation and empirical observations main research question number three **(RQ3)** reflects on: *“What can explain that some procurement projects are still carried out and reviewed based on initial procurement costs alone when the official policy is to apply the life cycle cost approach?”*

According to Douma and Schreuder (2002) one will experience economic problems in any situation when needs are not fully met because of scarcity of resources. Hence the problem becomes how to best allocate the resources available in an optimal way and thus archive economic efficiency (“biggest bang for the buck”). Based on this, economic approaches to organizations focus specifically on the economic problem of optimal allocation of scarce resources and the economic contribution to the understanding of organizational problems. This focus addresses the challenge that equipment owners face when planning operations as well as equipment buying organizations (such as the Norwegian Defence).

Further, the economic contribution to the understanding of organizational problems or challenges increases as the economic problems forms a greater part of the organizational problem one is trying to understand (Douma and Schreuder, 2002). In this perspective the economic approach to the organizational challenge of how life cycle cost based decisions are made, or not made, as well as how scarce resources are optimized or not towards supportability issues in organizations procuring new equipment or planning operations becomes very interesting. Organization theory in general and the economic approach to organizations in particular thus becomes important in order to understand more of how the interesting and promising methods and tools within ILS and LCC are utilized or non-utilized within the organization in question, and “why things are done the way they are done”.

The basic concepts of the economic approaches to organizations are depicted as follows by Douma and Schreuder (2002):



**Figure 17** The basic concepts of the economic approaches to organizations (Douma and Schreuder, 2002 page 3).

The top box of figure 17 refers to division of labour which is the splitting of composite tasks into their component parts and having these performed separately. The more specialized and difficult the tasks become the more different components will they exist of. This is a fact for both issues concerning system supportability and life cycle cost based investment decisions.

The next step, or box in the basic concept of the economic approaches to organizations, is specialization. Specialization in terms of splitting tasks means that a greater amount of output can be produced with the same level of input than if each producer/worker performed all tasks. Thus according to Douma and Schreuder (2002) specialized production is more efficient than non-specialized production. Hence to gain the best possible system supportability through support efficiency specialization in terms of skills and knowledge is according to theory a good thing.

Due to division of labour and specialization, almost nobody will be self sufficient and hence exchange of goods and services have to take place in terms of transactions. According to theory exchange through transactions will require coordination. And according to Douma and Schreuder (2002), there are basically two types of coordination and that is transactions taking place across markets (e.g. between the Norwegian Defence and a supplier of standardized goods) or within organizations (e.g. between the Norwegian Ministry of Defence and the project leaders of the different procurement projects).

Since markets and organizations represent alternative ways of coordinating needed transactions (due to specialization and division of labour), there must be a reason for choosing either the market or the organizational form. In an ideal market only a price is needed to make decisions and in the opposite direction an ideal organization is a place where coordination of transactions will not use prices to communicate information between the transacting parties. However, in most organizations some type of prices (e.g. internal pricing mechanisms) will be used and in most markets other information than prices (e.g. frequency) are used in the decision process. As a reflection of this most transactions in the real world are governed by hybrid forms of coordination. Still the actual mix of coordination mechanisms that one can observe in any situation will according Douma and Schreuder (2002) depend mainly on the information requirements that are inherent in the situation in question. Thus it can be argued that information, or rather the cost of processing and transmitting information is the driving force for why activities or tasks are organized within firms/organizations rather than in open markets and with several hybrid forms in between.

Now, when the basic concept of the economic approaches to organizations is presented it is time to step back a little to see what the classic difference is between traditional economic theory and organization theory since factors from both these areas constitute part of the concept used in this research. According to Douma and Schreuder (2002), the main difference is the study objective. Economic theory on one hand is studying what is happening between markets, while traditional organization theory is concerned with what is happening within organizations. As explained above price is the prime coordinating mechanism in a market (at least in its perfect form). Within an organization however this is (at least in its traditional form) not the case. Mintzberg (1989)

has described six coordinating mechanisms that describe the fundamental ways in which organizations can coordinate their work:

1. *Mutual adjustment*, which achieves coordination by the simple process of informal communication.
2. *Direct supervision*, in which coordination is achieved by having one person issue orders or instructions to several others whose work interrelates (as when a boss tells others what is to be done, one step at a time).
3. *Standardization of work processes*, which achieves coordination by specifying the work process of people carrying out interrelated tasks (those standards usually being developed in the technostructure<sup>20</sup> to be carried out in the operating core, as in the case of standard operating procedures (SOPs) that come out of work studies (e.g. time and motion studies).
4. *Standardization of outputs*, which achieves coordination by specifying the results of different work (again usually developed in the technostructure, as in specifications that outline the dimensions of a product to be produced).
5. *Standardization of skills (as well as knowledge)*, in which different work is coordinated by virtue of the related training the workers have received (as in military specialists – say a pilot and his/her co-pilot in military fighter helicopter – responding almost automatically to each other’s standardized procedures).
6. *Standardization of norms*, in which it is the norms infusing the work that are controlled, usually for the entire organization, so that everyone functions according to the same set of beliefs (as in a religious order).

According to Mintzberg (1989), these coordinating mechanisms can be considered the most basic elements of structure and the glue that hold organizations together. When organizational work becomes more complicated the favoured means of coordination seems to shift from mutual adjustment (the simplest mechanism) to direct supervision, then to standardization, preferably of work processes or norms, otherwise of outputs or skills, finally reverting back to mutual adjustment (e.g. in very complex equipment projects including new technologies). Further, Mintzberg (1989) makes it clear that no organization can rely solely on one of these mechanisms, but that they can favour one mechanism over the others, at least at certain stages of their lives.

Again according to Mintzberg (1979, 1989) if each of these coordinating mechanisms is combined with certain key parts of the organization and a special type of decentralization a pull towards one of six organizational configurations will happen. The reason for bringing this up is not to go into detail on each of the configurations described by Mintzberg. The reason is to place the organization studied into a organization theory frame and configuration, and thus explain

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<sup>20</sup> Technostructure is according to Mintzberg (1979, 1989) the part of the organization where the analysts are located. The analysts plan and control the work of others. They are not part of the hierarchical line (operators – line managers – directors) and not part of the support staff (e.g. mailroom, legal council and so on). Examples of analysts are budgeters, operation researchers and for example the ILS support staff in paper three of this thesis.

why the focus have been on certain coordinating mechanisms from Mintzberg together with factors from economic approaches to organizations in general and agency theory in particular.

In this research project the use, or non-use, of system supportability issues have been asked in **RQ1** regarding organizations planning for operations in connection with man-made humanitarian operations as well as system supportability issues in terms of spare parts and life cycle cost based decisions within military procurement projects (**RQ2**). Hence the organizational unit of analysis in this research is a project, with the project defined as: A temporary organization, established by its base organization to carry out an assignment on its behalf (Vaagaasar and Andersen, 2007).

According to Kolltveit and Greve (1998), project as an organizational form is an extension of the organizational forms suggested by Mintzberg. Kolltveit and Greve (1998) claim that it is especially transaction cost theory (TCT) that drives what type of organizational form and governance structure that will be chosen in connection with transactions such as for example system procurement.

In classic economic theory it is assumed that perfect information, rationality, and perfect substitutability exist. Transaction cost theory was developed by Williamson (1979, 1991), as an answer to the classic economic theory's somewhat blurred notion of reality. Williamson was building on the work of Coase from the nineteen thirties, including disciplines of contract law, institutional economics and organizational behaviour (Hanna and Maltz, 1998). TCT replaces perfect rationality and complete information with bounded rationality and opportunism. The basic understanding is that some transactions are better done within the firm (or some hybrid mode of governance structure) than in the pure market (Reve, 1990). Transaction costs are hence costs associated with the transaction both ex post and ex ante.

Williamson is talking about two key dimensions of transactions – asset specificity and uncertainty (Williamson 1991). These two dimensions along with the third one - frequency of exchange - constitute the most important dimensions for choosing the “best” form of governance concerning transactions (Williamson, 1979 and 1991).

Further two main assumptions of human behaviour is included in the framework of TCT, namely bounded rationality and opportunism (Williamson 1979, 1991). In this research the concept of rationality is defined as a ratio between the cognitive capability of the decision maker and the complexity of the problem in question (Heiner, 1983 in Wong et al., 2004). The decision maker has absolute rationality when his/her cognitive capabilities completely match the complexity of the problem. Complete rationality rarely happens in an organization; instead rationality is bounded due to the complexity of the problem (Wong et al., 2004). Opportunism is in Williamson's word “self interest seeking with guild” (Williamson 1979). Hence one must expect that every party of a contractual agreement seeks to serve their self interest. In this context one could argue that, if it is in the interest of the armed forces of Norway to buy material equipment with high reliability in order to reduce maintenance cost it will be in the interest of the supplier to sell equipment with somewhat lower reliability in order to sell more spare parts.



Arnt Buvik (2001) is summing up the concept of TCT in this way:

*Specific assets (e.g. customization of products), the internal uncertainty surrounding the transaction (e.g. product complexity) and the frequency of exchange of activities and resources between the buyer and the seller (e.g. order scheduling) represent the core dimensions of the transaction. The composition of these dimensions is decisive for the way of assigning cost-efficient governance forms. Internal organization or the hybrid mode conceptualized as bilateral governance (e.g. long-term contracts or franchising) will replace market governance as asset specificity increases and bilateral dependency is deepened.*

Based on the TCT description above and the work of Kolltveit and Greve (1998), the following figure can be constructed regarding transactions.

		Uncertainty and asset specificity		
		Low	Medium	High
Frequency	Low	standard equipment	customer modified equipment	asset specific / special designed systems
	High	standard materials	customer modified materials	parts or equipment for special phases or operations

**Table 4 Different transactions translated from Kolltveit and Greve (1998, page 22)**

In table four transactions are separated into six boxes based on the frequency of exchange of activities and resources between the buyer and the seller from high (happening many times) to low (seldom) as well as uncertainty and asset specificity (from low, through medium to high).

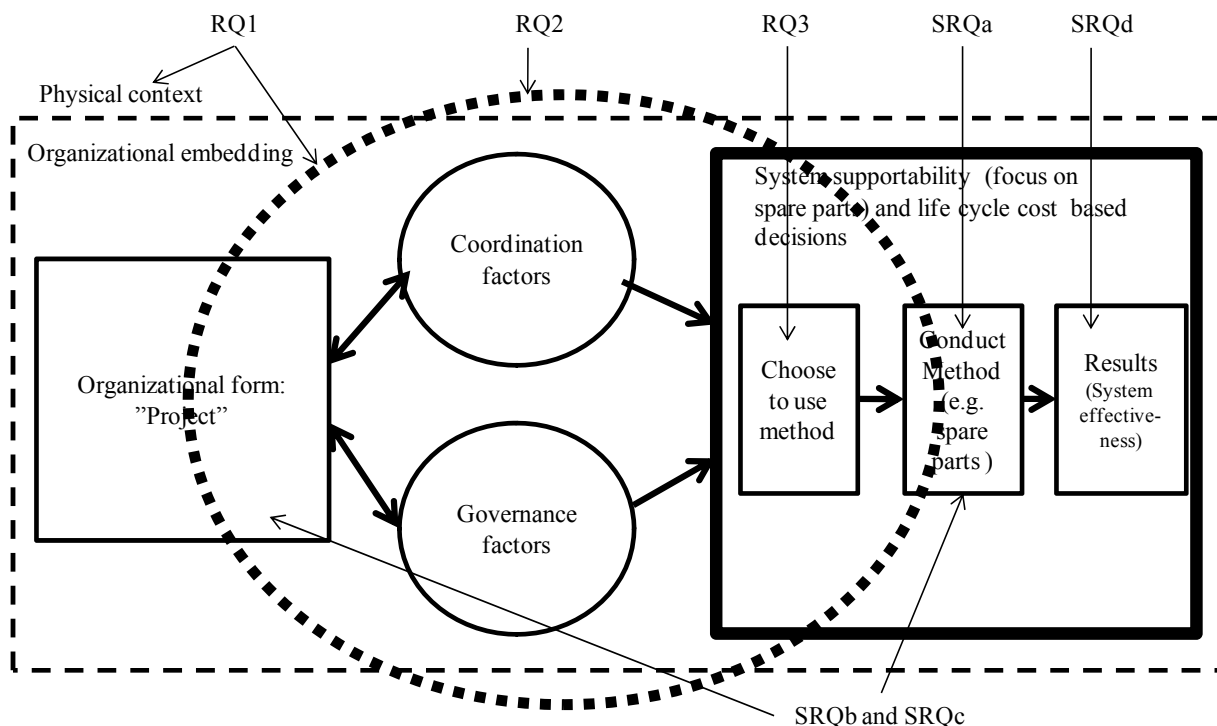
Kolltveit and Greve (1998) have in their work mapped the most cost efficient governance form onto the different transactions mentioned in table two in the following manner:

		Uncertainty and asset specificity		
		Low	Medium	High
Frequency	Low	Market	Project organization	
	High	Market	Alliances / Hybrid	Adhocracy

**Table 5 Transactions and governance form translated from Kolltveit and Greve (1998, page 25)**

Based on the research objectives, the focus in this research has been on system supportability issues in general and spare parts in particular and the study of life cycle cost based procurement decisions. The transactions have been connected to procurement of new equipment and systems to the Norwegian Defence through projects. Hence, the governance form here is already chosen to be project.

The connection between the research questions and the research frame can be depicted as follows:



**Figure 18 Connection between research questions and research frame.**

The governance factors in this research is thus not connected to the choice of organizational form, but to how the owners of the projects can/should govern the agents performing the work for them in connection with ILS methods, tools and decisions. Further the challenge connected to the objective of the research aims the focus at coordination both internally in the project in question as well as against the surroundings.

The first main objective research question (**RQ1**) has planning for, and setting up of, maintenance and spare parts for special operations are in focus. These types of operations (in this case humanitarian relief) will happen relatively often, at least in comparison to large and complex procurement projects and thus have higher frequency.

According to Kolltveit and Greve (1998) transactions in connection with both high frequency and high uncertainty are best governed within the organizational form called adhocracy by Mintzberg. According to Mintzberg (1979) the key coordinating mechanism within adhocracies is mutual adjustment. However, as Mintzberg (1989) points out for every operating adhocracy there is a corresponding professional bureaucracy. Standardization of skills (as well as knowledge), in which

different work is coordinated by virtue of the related training the workers have received is the key coordinating mechanism in the professional bureaucracy.

The main organization planning for the operations connected to **RQ1** (the Norwegian Defence and the NGO) can both be claimed to be more or less professional bureaucracies (the Norwegian Defence is probably closer to the professional bureaucracy than the NGO) and therefore standardization of skills and knowledge as a coordinating mechanism is important according to theory. Thus based on this, factors from Mintzberg's work should be used when trying to answer the research question. The factors from Mintzberg are: 1) The knowledge and skills possessed by the players in the organizations concerning spare parts inventory planning. 2) The formalization of behaviour (e.g. in terms of Standard Operating Procedures - SOPs) within the organizations connected to planning of maintenance and spare parts inventories. 3) The degree of specialization of the planning job.

Further, in order to answer **RQ1**, physical factors such as context of the organizations/projects in question along with organizational structure were targeted. In connection with organizational structure, the focus was on superstructure (Vries, 2005). Superstructure basically has to do with the number of organizational units involved in the planning.

Governance in this study concerns the relationship between the mandate group (understood as those who establish the projects in question) and the project leaders (PLs) on the one hand (connected to **RQ3**) and the maintenance- and logistic- planners on the other (connected to this question – **RQ1**). Organizations are established by owners and according to Greve (1995) it is the owners (the mandate group) who decide which goals and tasks the organization is going to have. In order to reach any preset goal, the mandate group must implement a governance system that makes sure that the leaders and employees of the organization implement actions to reach the goal. According to Greve (1995), one of the main theories that regulates the relationship between the mandate group and the organization leaders, is agency theory also referred to as positive theory of agency (Douma and Schreuder, 2002). According to Eisenhardt (1989), agency theory is directed at the ubiquitous agency relationship, in which one party delegates work to another, which performs that work. Agency theory will describe the relation between the parties (the principal and the agent) with the metaphor of a contract (Eisenhardt, 1989). Most empirical work towards agency relations are focused on the relationship found between firms, but agency theory can also be used to evaluate relations within the firm/organization, which is the case in this research (Bergen et al., 1992). According to agency theory two main problems can occur in agency relationships; the first problem concerns conflicting goals between the principal and the agent, and the second problem is that of risk preferences. The first problem will arise when the goals of the principal and the agent conflict, and it is difficult or expensive for the principal to verify what the agent is actually doing (Eisenhardt, 1989). The second problem, concerning risk preference arises when the principal and the agent have different risk preferences and hence will prefer different actions due to this. The assumption is that the principal will be risk neutral while the agent will be risk adverse.

The agency theory factors used in the research are; **uncertainty, attitude/behaviour and information symmetry**.

Uncertainty in the context of agency theory is connected to the basic risk assumptions of the theory. In agency theory the principal is assumed to be risk neutral, whereas the agents are assumed to be risk adverse (Bergen et al., 1992). The rationale behind this is that the principal most likely can spread his risk over several projects, whereas the agent will have to “succeed” in the one project he has. The problem arises when the goal of the principal conflicts with, or is not aligned with the preconception of the agents. Project leaders (connected to **RQ3**) or planners (connected to **RQ1** and **RQ2**) acting in what they think are their self-interest at the expense of the principal’s interest is called adverse selection. However it is hard to measure such behaviour by questions. Based on this, a substitute in terms of attitude towards the use of ILS methods and tools (maintenance planning and spare parts optimization) as well as LCC, is used as indicator. Negative attitude is not necessarily a sign of bad will, but can be the effect of prior experiences, lack of information and so on. In any case, project leaders and planners should base their work and decisions on the organization in question’s rules and regulations, and not to do this is strictly speaking adverse selection.

Information symmetry refers to the principal and agent possessing the same information. If the principal and agent possess different information one has information asymmetry, and this can lead to adverse selection. According to Eisenhardt (1989), information systems can curb adverse selection. The argument is that since information systems can inform the principal about what the agent is actually doing, the agent will realize that he cannot deceive the principal.

In connection with main research objective question number two (**RQ2**), the focus on coordination factors were extended. Coordination of the spare parts optimization process focused through **RQ2**, is needed both within the organization itself (e.g. between project leader (PL) and the project’s ILS manager called Project Coordinator ILS (PC ILS)) but also with the project’s supplier(s). According to Van de Ven et al. (referred in Wong et al., 2004), coordination is defined as the integration or linking together of different parts of an organization to accomplish a collective set of tasks. Lack of coordination causes many problems, but primarily affects organizational or economic effectiveness and efficiency (Wong et al., 2004). Wong et al. (2004) have looked at the coordination problem from three different theoretical standpoints, namely organization theory, economic organization theory (economic approaches to organizations) and operation management theory. All three theories recognize the source of coordination problems as lack of **information symmetry, lack of centralized decision making, uncertainty and interdependency**. Further, especially within economic approaches to organizations **bounded rationality** and **behavioural issues (attitude)** are identified as important sources for coordination problems. Thus all these six aspects or sources for coordination problem are included in the research connected to this part of the total project.

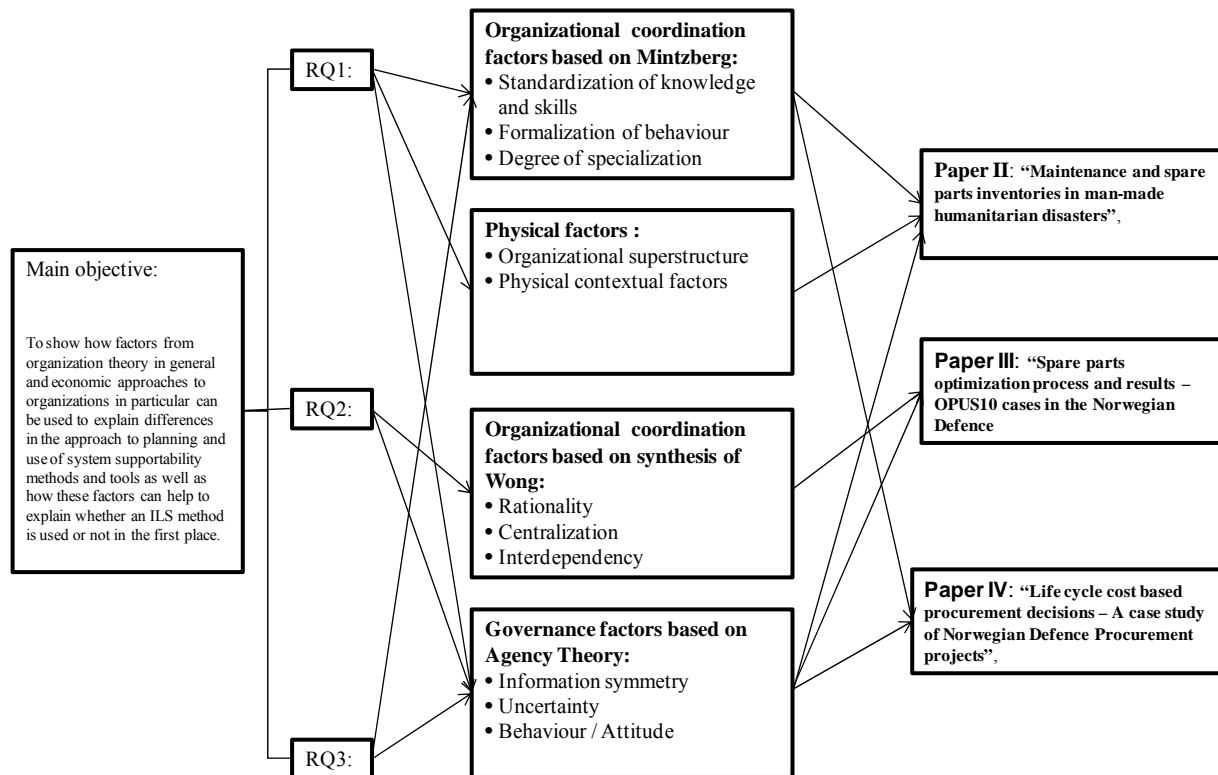
Information symmetry, uncertainty and attitude are introduced above. Coordination problems based on **interdependence** are due to scarcity of resources or scarcity of information or a combination of the two (Wong et al., 2004). In connection with spare parts optimization the project in question can either get access to all needed information (e.g failure rates) through open sources or they must rely on the system supplier. In the same direction the project can have access to needed resources, for example in terms of personnel with knowledge of spare parts

optimization, within their own organization or they must get this outside their own physical context.

According to theory **centralized decision making** will reduce coordination problems (Wong et al., 2004). In this context centralized decision making could be done through the utilization of a common concept for spare parts optimization, and followed up by key performance indicators (KPI). A decentralized version would be to let each PL decide how to perform the spare parts optimization process and setting of spare parts inventory control variables (e.g reorder points).

In this research the concept of **rationality** is defined as a ratio between the cognitive capability of the decision maker and the complexity of the problem in question (Heiner, 1983 in Wong et al., 2004). The decision maker has absolute rationality when his/her cognitive capabilities completely match the complexity of the problem. Complete rationality rarely happens in an organization; instead rationality is limited or bounded due to the complexity of the problem (Wong et al., 2004). Bounded rationality may lead to the use of rules of thumb in the decision making process, such as in the decision process of spare parts.

The connection between the main objective research question and the theoretical perspective used can be depicted in the following manner. Since the sub-objectives of the research do not focus on organization theory they are not included in the figure below.



**Figure 19 Connection between research questions and research factors**

This concludes the synthesis of organization theory and how aspects and factors from organization theory in general and economic approaches to organizations in particular are used to answer the research questions.

## 8. Paper abstracts and connection to research questions

This chapter includes the abstracts of each of the four appended papers as well as the connection to each of the research questions.

In **paper I**, the answer to sub-objective research question a (**SRQa**) is given. The question was; *“What is the existing body of literature concerning the system supportability element of spare parts towards theory, models and applications?”*

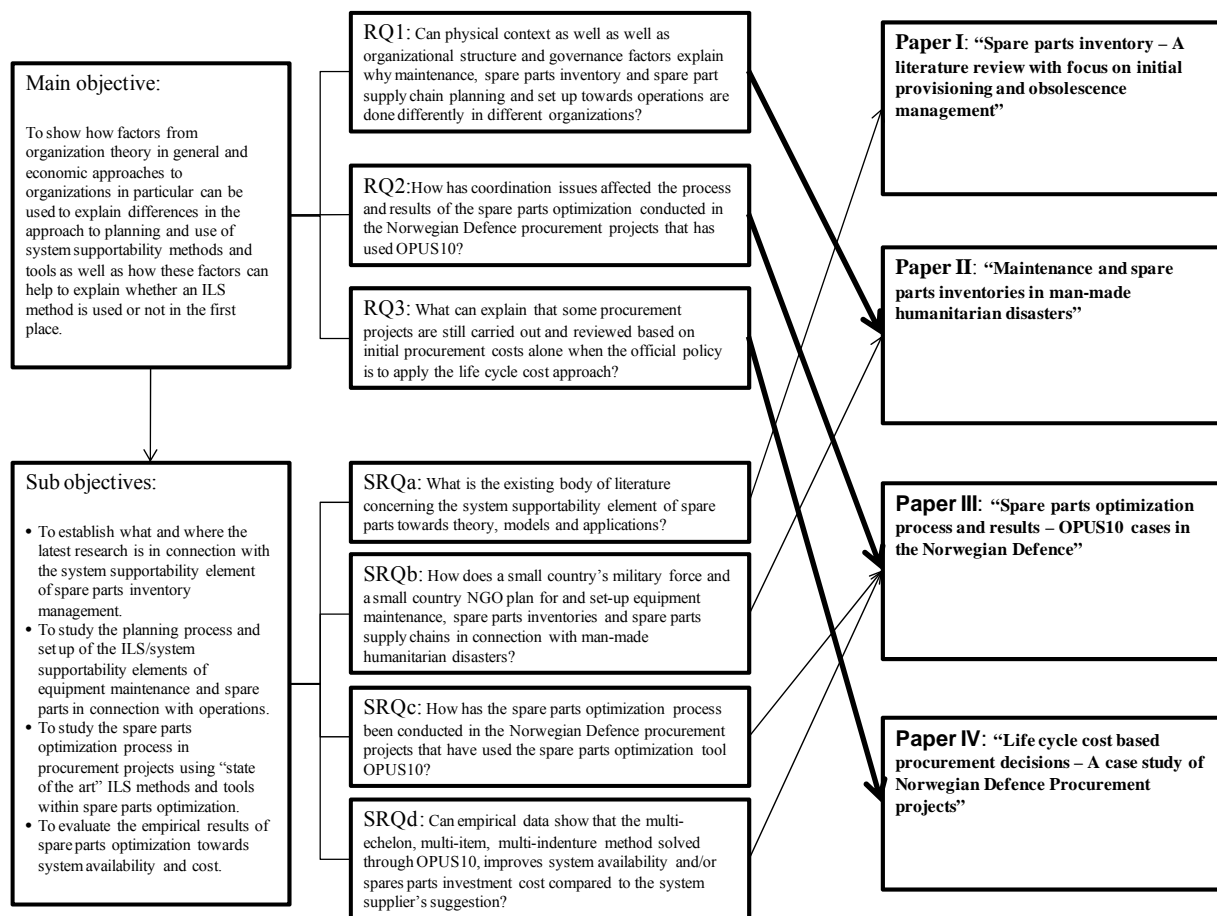
In **paper II**, the answer to main objective research question number one (**RQ1**) is given along with the answer to sub-objective research question b (**SRQb**). RQ 1 was; *“Can physical context as well as well as organizational structure and governance factors explain why maintenance, spare parts inventory and spare part supply chain planning and set up towards operations are done differently in different organizations?”* and SRQb was; *“How does a small country’s military force and a small country NGO plan for and set-up equipment maintenance, spare parts inventories and spare parts supply chains in connection with man-made humanitarian disasters?”*

In **paper III**, the answer to main objective research question number two (**RQ2**) is given. In addition answers to both sub-objective research question c (**SRQc**) and d (**SRQd**) are given. RQ2 asked; *“How has coordination issues affected the process and results of the spare parts optimization conducted in the Norwegian Defence procurement projects that has used OPUS10?”* SRQc asked; *“How has the spare parts optimization process been conducted in the Norwegian Defence procurement projects that have used the spare parts optimization tool OPUS10?”* and SRQd asked; *“Can empirical data show that the multi-echelon, multi-item, multi-indenture method solved through OPUS10, improves system availability and/or spares parts investment cost compared to the system supplier’s suggestion?”*

**Paper IV** answers main research question three (**RQ3**), which is; *“What can explain that some procurement projects are still carried out and reviewed based on initial procurement costs alone when the official policy is to apply the life cycle cost approach?”*

The connection between objectives, research questions and papers can be depicted in the following manner.





**Figure 20 From objectives to papers**

In the following the published abstract from each of the papers are given. Paper II and III have so called structured abstracts due to requirements from the journals the papers are published in. Paper I and paper IV have not structured abstracts.

### 8.1 Paper I

When systems with long life cycles are procured systems owners are often faced with the challenge of achieving high system effectiveness with low life cycle cost. Spare parts for maintenance operations will have an effect on both the operational availability and life cycle cost of the system.

When an expensive piece of equipment is bought, spare parts can often be bought at a reduced price and hence a decision must be made about the initial provisioning of spare parts. Further,

many technologies have life cycles that are shorter than the life cycle of the system they are in, and spares for possible obsolete systems must be managed.

This paper is an update and extension on earlier review papers and is based on the existing body of literature concerning spare parts inventory theory, models and applications. We focus especially on literature concerning initial provisioning and obsolescence management in a multi-echelon setting where the goal is to maximize system effectiveness / operational availability at minimum life cycle cost.

Our review shows that the multi-item, multi-echelon approach is superior to the single item approach regarding optimization of availability subject to life cycle costs.

Further, the review of forecasting showed that substantial savings can be achieved by using more accurate forecasting methods than most businesses use today. Within the niche of spare parts management research, the studies seem to be more empirically based, than what the case is regarding multi-echelon spare parts modelling.

## **8.2 Paper II**

Purpose: The main research question of this paper is to answer how a small country's military force and a small country non-governmental organization (NGO) plan for and set up equipment maintenance, spare parts inventories in connection with man-made humanitarian disasters. Additionally it answers how the physical context, organizational structure and governance affect the planning and set-up.

Methodology: A research model that combines organization theory with spare parts inventory theory is developed. Case study research methodology is used and observations and findings are discussed within the research model in order to answer predefined hypotheses.

Findings: Regarding planning procedures as well as how the maintenance concept and spare parts inventory are set up, the research concludes that the organizational structure and governance of the organization contributing to the humanitarian operation in question are more important than physical context of the operation itself. Further it is concluded that the maturity level, when it comes to inventory control issues, are different for the two cases in question. None of the cases, however, utilize modern optimization methods and tools.

Research implications/limitations: Qualitative data from the two case studies give the possibility for in depth analysis of the case study findings. Lack of quantitative data means that it has not been possible to statistically reject or accept the hypotheses.

Practical implications: By applying the research model developed in this study, organizations that contribute to humanitarian disasters could more easily assess their own possibility for effective maintenance and spare parts inventory planning and set up. More research is needed to present a template and/or processes based on the findings in the research.

What is original/paper value: The study of the planning and set up of maintenance and spare parts inventories for both military and NGO players in connection with a man-made humanitarian disaster is new. Further, the development of spare parts inventory theory into organization theory is relatively new. Limited research is available within this field. The paper should be of interest to both practitioners and researchers within the field of maintenance and spare parts inventories in general, and in connection with humanitarian disasters in particular.

### 8.3 Paper III

Purpose of this paper: The first research question focused on how the spare parts optimization process had been conducted in the Norwegian Defence procurement projects that had used the system approach based on OPUS10, and whether coordination issues affected the process and results. Secondly, empirical data were analysed in order to evaluate whether the theoretical claim of the system approach used through OPUS10, being better than other methods in terms of availability and spare parts investment cost holds up in reality.

Design/methodology/approach: Both qualitative and quantitative methods were used in order to answer the different questions of the study.

Findings: Very few Norwegian Defence projects have used the system approach through OPUS10. Empirical data however comply with the theoretical claims of potential large savings in spare parts investment cost and/or improvement in operational availability. Several organizational factors can explain the lack of use of OPUS10. The most important being lack of resources, lack of a centralized concept and a somewhat low project leader attitude towards the approach.

Research limitations/implications: The study of Norwegian Defence cases makes generalizations of findings not applicable. The research model could however easily be transferred and utilized in the study of other organizations' spare parts optimization processes.

Practical implications: The Norwegian Defence should alter their concept for project governance and management in order to gain the full potential of the system approach used through OPUS10.

What is original/value of paper: Few research papers have evaluated the promising theoretical findings of system based optimization based on empirical operational data. Even fewer, if any, studies have used a combination of factors from organization theory, economic organization theory and operation management theory in order to explain findings based on predefined hypotheses. This research should have value for both practitioners and researchers within the field spare parts optimization in general and systems management in particular.

## 8.4 Paper IV

A Norwegian Ministry of Defence publication states that when procurement decisions are made, systems that yield the lowest possible life cycle cost (LCC) for the Norwegian Defence must be procured, even if this means that initial procurement cost becomes higher.

However, several projects within the community are still carried out and reviewed based on initial procurement cost alone.

This study investigates four hypotheses, based on agency theory and earlier LCC work, in order to help explain why this is happening.

A questionnaire was administered to all projects currently running in the defence community.

Findings regarding project uncertainty, information symmetry, the project leader's attitude and knowledge about LCC, as well as control variables are discussed both towards theory and in terms of managerial implications.

## 9. Main research conclusions

The reader of the thesis should read each of the appended papers. This is because it is only by reading each of the papers that the complete answers to each of the research questions are given, the complete findings reported and discussed both towards theory where that is applicable as well as towards managerial implications. However in this chapter the main conclusions from each appended research paper are repeated.

### 9.1 Main conclusions reported in appended paper I

In paper I, the answer to sub-objective research question a (**SRQa**) is given. The question was; *“What is the existing body of literature concerning the system supportability element of spare parts towards theory, models and applications?”*

Through an intensive literature review it was found that maintenance effectiveness and access to spare parts will govern the availability of most systems. Further, life cycle cost will be dependent upon how spare parts inventories are procured and managed.

It was shown that this area of research can be divided into a qualitative and a quantitative research stream.

In the qualitative approach, the focus seemed to be aimed at developing work processes and templates for organizations interested in managing systems and spare parts inventories in a life cycle cost perspective.

In the quantitative stream, a more traditional operational research approach is used. Here the goal is to find optimal, or close to optimal, solutions with life cycle costs as the objective.

Based on the finding it was felt that empirical research, especially regarding processes, within this niche is limited and hence further empirical studies are needed. The recommendation of further empirical research regarding processes connected to spare parts inventories and life cycle costing was strengthened by the limited new research observed regarding management of spare parts inventories and initial provisioning of spare part.

The review of initial provisioning and follow on supply, based on spare parts optimization models in a multi-echelon setting established the impression regarding this stream of spare parts inventory research, namely that it is based on rather sophisticated mathematical modelling with stepwise development of established models. The review showed that the multi-item, multi-echelon approach is superior to the single item approach regarding optimization of availability subject to life cycle costs. Development of sound methods is also the focus of researchers within forecasting research. However, within this niche the studies seem to be more empirically based, than is the case for multi-echelon spare parts modelling.

The review of forecasting showed that substantial savings can be achieved by using more accurate forecasting methods than most businesses use today. However, the review showed that the results are not consistent with each other; in one case a specific forecasting method seem to work well and in another it does not. More research is needed in this field to sort out when to use which method(s).

As a part of the research the concept of obsolescence management was looked into. It was found that this area of research is rather new and hence more research both in terms of both theory and empirical research is needed.

Finally empirically based papers were reviewed, and the findings can to a large extent sum up the main impression, namely that most research within the field of spare parts inventories are based on theoretical and sophisticated mathematical models grounded within the fields of operation research, statistics and forecasting. Further, many of the promising findings from the above mentioned research areas are difficult to implement in real life organizations. In line with e.g. Zomerdijk and Vries (2003), it was therefore felt that in addition to the traditional methods, there is a need for more managerial approaches that are able to bridge the gap between the traditional mathematical methods and the practitioners' need for managerial methods. In addition more empirical data should be gathered both on processes and results connected to system supportability issues in general and spare parts inventories in particular.

## **9.2 Main conclusions reported in appended paper II**

In paper II, the answer to main objective research question number one (**RQ1**) is given along with the answer to sub-objective research question b (**SRQb**). **RQ 1** was; *“Can physical context as well as well as organizational structure and governance factors explain why maintenance, spare parts inventory and spare part supply chain planning and set up towards operations are*

*done differently in different organizations?” and SRQb was; “How does a small country’s military force and a small country NGO plan for and set-up equipment maintenance, spare parts inventories and spare parts supply chains in connection with man-made humanitarian disasters?”*

System supportability issues must be dealt with both when an equipment or system is procured as well as throughout the operations and support phase of the system. As a reflection of the need to study system supportability issues towards the operation and support phase as well as the initial procurement phase, supportability issues towards operations were first studied.

By answering sub-objective research question a (SRQa) – reported in paper I, it became evident that few researchers had tried to combine factors from organization theory such as organizational structure and governance as well as physical context with the more hard core operation research theories of system supportability.

It was concluded that the physical context of the operations studied clearly influenced how maintenance and spare parts inventories were planned, but also vice versa. Further the findings also showed that the organizational structure and governance in the organization in question are more important than physical context regarding how the maintenance concept, spare parts inventory and spare parts supply chain are planned for and set up.

The findings in connection with the harder core part of maintenance planning and spare parts inventories showed that the two organizations studied had what one might call different maturity levels when it comes to inventory control issues. The conclusion was that the logistics organization connected to the military case studied was more advanced when it came to maintenance planning and spare parts inventory planning than the logistics organization connected to the non-governmental humanitarian organization studied. Based on the findings connected to organizational setting and governance in each of the case organizations, this was not surprising.

The findings also clearly showed that the research model developed (shown in the appended paper II) is a helpful tool in the evaluation of maintenance and spare parts inventory planning in organizations.

The findings further revealed that all data for spare parts optimization, based on the multi-echelon, multi-item, multi-indenture method are available at least in the military case studied. However, these tools and methods are not used and actually almost unknown for those who are in charge of the planning for maintenance, spare parts inventories and spare parts supply chain in the two case studies. For the military case, this finding was somewhat puzzling, knowing that in the Norwegian Defence, which the case study organization is a part of, there exists an optimization tool based on the mentioned method. However, this finding was clearly in line with the claims of Huiskonen (2001), who alleges that it has not been easy to transfer research results into managerial practice and thus so called “rules-of-thumb” sparing decisions and management are still popular in managerial practice.

### 9.3 Main conclusions reported in appended paper III

In paper III, the answer to main objective research question number two (RQ2) is given. In addition answers to both sub-objective research question c (SRQc) and d (SRQd) are given.

RQ2 asked; *“How has coordination issues affected the process and results of the spare parts optimization conducted in the Norwegian Defence procurement projects that have used OPUS10?”*

SRQc asked; *“How has the spare parts optimization process been conducted in the Norwegian Defence procurement projects that have used the spare parts optimization tool OPUS10?”* and SRQd asked; *“Can empirical data show that the multi-echelon, multi-item, multi-indenture method solved through OPUS10, improves system availability and/or spares parts investment cost compared to the system supplier’s suggestion?”*

First of all it was early found that very few projects had actually used OPUS10 since it was decided to be the Norwegian Defence standard system for spare parts optimization back in 1995.

It is believed that this lack of usage is not due to the method and system it self but to how the different coordination factors are observed and solved by the procurement projects in question.

It was found that factors connected to organization theory and economic approaches to organizations have a major impact on the use of operational methods and tools. The research gave some interesting findings with managerial implications. If the Norwegian Defence really wants the system approach based on OPUS10 to be used completely, the project in question should be mapped out based on the research model of this study, in order to get as little coordination problems as possible. Three problem areas were identified to be the most challenging in the projects that have used OPUS10. These problem areas are probably even bigger in the vast majority of projects that have not used OPUS10. The three areas in question are; lack of resources; lack of centralized instructions and finally; the project leaders’ attitude.

All studied projects reported that they had limited resources in terms of personnel with the needed ILS competency. Further all case projects reported lack of one common concept for spare parts optimization as well as to little focus in PRINSIX on the subject. Along with an increase in resources, it is thus believed that a common concept should be developed, approved and implemented by the NDLO and sustained by PRINSIX. Further the research concluded that the concept must be followed up by key performance indicators (KPIs) primarily aimed at the project leaders. It is believed that use of KPIs to a certain degree will address the somewhat low attitude found from the project leaders towards system based optimization. Another way of addressing the attitude issue is to build knowledge within the procurement community concerning the topic. This finding was also a part of the finding based on the evaluation of the quantitative analysis done in part four of the total research projects (see paper four).

The quantitative empirical findings from this part of the total research project, clearly supported the theoretical claims of the multi-echelon, multi-item, multi-indenture method in this case based on the system called OPUS10, being better than other approaches (same of each and engineering choice) in terms of system availability and spare parts investment cost.

Out of the eight cases studied only two cases had operational data in terms of system availability or rather inventory fill rates. These two cases (called case NA and case AA) either performed as good as, or better than, comparable systems that had not been spared with the multi-echelon, multi-item, multi-indenture method.

In project NA and AA, cost saving was only an issue in project AA with 55.7 percent saving over the system supplier's suggestion. This saving in spare parts investment has not reduced availability of the system compared to systems spared with other approaches. If the availability of system AA is representative the large reduction in spare parts compared to the system supplier's suggestion clearly indicates that in the non OPUS10 based projects where the supplier's suggestion is accepted a considerable amount of spare parts are bought that actually are not needed. Further when the supplier's suggestion is reduced with an engineering choice approach by the Norwegian Defence such as in project NB, the chances of buying wrong spares and removing the ones they need are still very present.

The reduction in spare parts investment cost based on the use of OPUS10 identified in this study (on average 60.3 percent) was very interesting, especially since empirical operational data show that system availability is not reduced. This finding should warrant managerial action. With a conservative approximation of spare parts cost to 3.5 percent of the total Norwegian Defence procurement budget, and a reduction of the saving potential to 40 percent, the annual saving in procurement of not needed spare parts would still be 140 million NoK. Total life cycle cost of these not needed spare parts would be even higher considering the costs of holding unneeded inventory.

#### **9.4 Main conclusions reported in appended paper IV**

In main research question three (**RQ3**) it was asked; "What can explain that some procurement projects are still carried out and reviewed based on initial procurement costs alone when the official policy is to apply the life cycle cost approach?"

The Norwegian Ministry of Defence (NoMoD) decided in 2004 that when investment decisions are made, solutions/systems that yield the lowest possible life cycle cost, given equal system effectiveness, must be preferred, even if this means that the initial investment cost becomes higher. However, they were still experiencing in 2006 that procurement for example towards system supportability issues in terms of spare parts, in some projects were carried out and reviewed based on initial procurement costs alone.



To answer **RQ3** factors from agency theory in particular was used to hypothesis about the reasons why. As explained before a quantitative approach was used and multivariate data analysis of collected data conducted.

Eisenhardt (1989) claims that two main problems can occur in agency relationships, the first problem is that of conflicting goals between the principal and the agent, and the second problem is that of risk preferences.

It was assumed that the NoMoD would be risk neutral when it comes to evaluating projects based on life cycle cost, while the project leader was assumed to be risk adverse, especially if the project in question had high project uncertainty. The first hypothesis therefore stated that *“Project uncertainty will negatively affect the use of LCC- based procurement decisions”*. The data analysis showed that uncertainty correlated to the use of LCC, and in the direction that theory assumed (negative correlation). However, the correlation was weak and not statistically significant, and hence the hypothesis had to be rejected. There is not one single good explanation why the hypothesis is not supported, it is however interesting to notice that there is a statistical significant bivariate correlation between uncertainty and information symmetry (see paper four). This correlation indicates that the project board is more informed about the use of LCC if the uncertainty for the project is high. Information systems can curb adverse selection (Eisenhardt, 1989), and hence it can be argued that NoMoD through the project boards has made sure that less information asymmetry can occur when project uncertainty is high in order to reduce the possibility of adverse selection. It looks like the Norwegian Defence already uses the concept of information alignment in order to reduce the possibility of adverse selection more in projects with high uncertainty than in projects with low uncertainty, and due to this it could not be statistically concluded that project uncertainty negatively affected the use of LCC-based procurement decisions.

As stated above the first problem in agency relationships is that of conflicting goals between the principal and the agent (Eisenhardt, 1989). The research questions tried to capture the attitude of the project leaders towards the use of LCC, in order to answer hypothesis 2 (see paper four). The hypothesis was supported by the empirical data, and from a theoretical standpoint this means that less goal conflict exists between projects' leaders with a positive attitude towards LCC and the principle, than between the principle and project leaders with a less positive attitude towards LCC.

According to agency theory one of the most effective ways to avoid goal conflicts is to align the information between the principle and the agent (Eisenhardt, 1989). Statistically significant support, based on the 0.05 significant level, was not found towards the hypothesis regarding information symmetry between the principal and the agent (hypothesis 3 - see paper four). However, there is no more than eleven percent chance that the positive beta coefficient found in the empirical data (which supports the hypothesis), is due to chance. Further, since the sample size in the case of this part of the total research consists of more than 50 percent of the total population, it is very likely that information symmetry between the principal and the agent really makes a unique contribution to the

use of LCC based procurement decisions. Hence, even if not statistically supported, the data is in line with the agency theory proposition.

Regarding the proposition that when the agent, either by himself or through members within his own project, has thorough knowledge about life cycle costing, he will be more likely to understand and accept the position of the principle (NoMoD), and therefore use LCC (expressed in hypothesis 4 – see paper four) is supported by the data. This means that lack of knowledge, with regard to LCC, leading to less use is empirically supported.

At the start of this part of the total research project, control variables regarding what main type of procurement the project is dealing with (project-type), what NoDLO site the project works out (project-site) of and the size of the project in terms of personnel working with LCC (project-size) were included in the research model. The project leaders were asked to mark what subgroup within each of the three variables they belonged to. No hypotheses were made before the collection of data, and it was really not expected to be a statistically significant difference between the subgroups within each variables.

This was also the case regarding project-type and project-size. Somewhat surprisingly though, the data clearly showed that project leaders working in Bergen (the Navy site) are on average less likely to use LCC based procurement decisions than their colleagues working in the “Air Force site” and the “Army site”. The data collected can not verify why this is the case. It is however a fact that the Navy site (Bergen) is much further in physical distance from the NoMoD (the principal) situated in Oslo, than the Army site (Kolsås, just outside Oslo) and Air Force site (Kjeller, also just outside Oslo). Other explanations could be connected to organizational cultural differences between Navy, Army and Air Force regarding how closely the goals and tasks of the mandate group (the principal), are followed. These are however only speculations.

The data showed that high uncertainty projects have better information alignment between principal and agent than projects that are less uncertain. Hence one can see that uncertainty already is closely connected to information symmetry. In order for NoMoD to make sure that project leaders do use LCC in procurement decisions it becomes important that all projects are followed up by a project board. Further, this board must make sure that they and the project leader have the same information about how LCC is used. The data suggest that projects that have information symmetry regarding LCC decisions with the principal are more likely to use LCC than projects that do not.

Further the empirical data clearly show that NoMoD should do what they can to get a positive attitude from the project leaders towards the use of LCC, because this will assure more use of LCC based decisions. Answers to the items of the attitude construct, indicate that not all project leaders believe that NoMoD really mean what they are stating in the “LCC concept”. In this concept NoMoD clearly state that when investment decisions are made, they must favour solutions that yield the lowest possible life cycle cost, even if this means that the initial investment cost becomes higher. Project leaders that do not believe in the concept have a more negative attitude, and use LCC less than those that believe what NoMoD is saying. The bottom

line is that NoMoD must use every opportunity, to ensure the project community that they really mean what they are stating in the concept.

NoMoD together with the Norwegian Defence Material Agency and the Norwegian Defence College started a project leader certification program some years ago. The first fully certified project leaders graduated in the spring of 2005. In this program, use of LCC based procurement decisions is a part of the education. The data of this analysis clearly show that project leaders with good knowledge of LCC are more likely to use LCC in procurement decisions than those with less knowledge. It is therefore essential for the NoMoD to continue this program (and other programs/courses where LCC concepts can be learned), if they want the use of LCC to grow.

Finally, since the data show that project leaders working out of the old Navy Material Command site are less likely to use LCC based procurement decisions than their Army - and Air Force - site colleagues, NoMoD should probably focus first on this group of project leaders.

#### **10. Main research contributions – have the objectives been reached?**

The main theoretical contribution from this research is the extension of integrated logistics support theory with factors from organization theory.

Traditional literature concerning integrated logistics support theory including system supportability and LCC as seen in for example Kumar et al. (2000) or Blanchard (2004) are very much based on mathematical assumptions in describing the methods and tools within ILS. The theory clearly originates from the field of operations research. This is especially true regarding the methods concerning spare parts. As an example, 40 years have gone by since Sherbrook (1968) published his very important paper: “*METRIC: A multi-echelon technique for recoverable item control*”. In this paper he describes how to optimally stock repairable parts for aircraft at bases which are capable of repairing some, but not all broken parts, and a central depot which serves all bases. In the time span from 1968 up until now, the spare parts inventory theory as an important part of ILS theory has been theoretically advanced and is today a mature theoretical theory (see e.g. Kennedy et al., 2002). However in practice ILS methods and tools such as the advanced spare parts optimization seems to have a limited use among practitioners. This is in line with other inventory research, where for example Huiskonen (2001), claims that surveys have shown that it has not been easy to transfer promising theoretical research results into managerial practice. At the outset of the research it was hypothesized that the processes leading to the decision to use one of the methods or tools in order to reduce LCC and how the method (for example spare parts optimization) is used must be influenced by organizational factors (such as coordination) as well as governance factors and physical context facing the organization and/or project in question.

Based on this the main objective of the research was to extend the ILS theory by exploring and explaining how factors from organization theory in general and economic approaches to organizations in particular can be used to explain differences in the approach to planning and use

of system supportability methods and tools as well as how these factors can help to explain whether an ILS method is used or not in the first place.

This main objective was then transformed into three main research questions:

1. Can physical context as well as well as organizational structure and governance factors explain why maintenance, spare parts inventory and spare part supply chain planning and set up towards operations are done differently in different organizations? - called RQ1.
2. How has coordination issues affected the process and results of the spare parts optimization conducted in the Norwegian Defence procurement projects that has used OPUS10? – called RQ2.
3. What can explain that some procurement projects are still carried out and reviewed based on initial procurement costs alone when the official policy is to apply the life cycle cost approach? – called RQ3.

By answering the three main objective research questions the main objective of this research has been reached.

The research answering **RQ1** show that physical context as well as well as organizational structure (superstructure and structure of position) and governance factors can help to explain why maintenance, spare parts inventory and spare part supply chain planning and set up towards operations are done differently in different organizations (The Norwegian Defence versus The Norwegian Red Cross). It was for example clearly showed that the agency theory factor of information symmetry towards the ILS issues of maintenance and spare parts inventory planning could clearly help to explain differences in the approach.

Further, the research show how six causes for coordination problems extracted from organization theory, economic approaches to organizations as well as operation management theory can be used to explain why different Norwegian Defence procurement projects use methods and tools connected to spare parts optimization differently and not necessarily in accordance with the assumed current policy. Out of the six causes for coordination problems (interdependence, uncertainty, information symmetry, attitude, centralization and rationality) used in connection with **RQ2**, interdependence in terms of lack of resources (with necessary ILS knowledge), centralization (lack of centralized instructions) and attitude (project leaders attitude) proved to have the largest impact on the use of the ILS method in question (spare parts optimization).

Finally it is shown how constructs from agency theory can help to explain why some of the project leaders in Norwegian Defence procurement projects use life cycle cost based procurement decisions more than others. In the answer to **RQ3**, the agency theory factors statistically proved to have the largest impact was attitude and information symmetry. In addition the knowledge construct (referring to Mintzberg's organizational coordination factors) proved to be very important in line with the findings towards the answer to RQ2.

Remenyi et al. (1998) suggest that: *“The best business research should lead to the development of guidelines by which individuals in positions of responsibility can manage their business responsibilities more efficiently and effectively”*.

Thus based on this research, the transfer of ILS methods and tools (especially in terms of spare parts optimization and life cycle cost based decision) from theory to reality should focus on making sure that the “agents” in the organization (project leaders and planners) have the correct **knowledge, attitude and resources available** in the same time as the principal (in this case NoMoD or NDLO) develop **centralized instructions** on how to use the ILS and/or LCC methods as well as implement a information system to align the information regarding use of the ILS methods and decisions based on LCC (hence focus on **information symmetry**).

Further details regarding managerial implications are given in the appended paper III and IV (answering RQ2 and RQ3), as well as a more general conclusion regarding the implications of the findings connected to RQ 1 in the appended paper I.

In addition to the main research objective, this research also had several connected sub-objectives. These sub-objectives were:

- To establish what and where the latest research is in connection with the system supportability element of spare parts inventory management.
- To study the planning process and set up of the ILS/system supportability elements of equipment maintenance and spare parts in connection with operations.
- To study the spare parts optimization process in procurement projects using “state of the art” ILS methods and tools within spare parts optimization.
- To evaluate the empirical results of spare parts optimization towards system availability and cost.

The sub-objectives of the research were than transformed into the following research questions:

- a. What is the existing body of literature concerning the system supportability element of spare parts towards theory, models and applications?
- b. How does a small country’s military force and a small country NGO plan for and set-up equipment maintenance, spare parts inventories and spare parts supply chains in connection with man-made humanitarian disasters?
- c. How has the spare parts optimization process been conducted in the Norwegian Defence procurement projects that have used the spare parts optimization tool OPUS10?
- d. Can empirical data show that the multi-echelon, multi-item, multi-indenture method solved through OPUS10, improves system availability and/or spares parts investment cost compared to the system supplier’s suggestion?

The sub objectives have been reached trough answering the connected questions. **SRQa** was answered in the literature review paper (paper I). In this paper a synthesis of the latest research

within spare parts inventories has been given, thus contributing to the body of knowledge by consolidating the latest research. It was in this part of the study established that the multi-echelon, multi-item, multi-indenture approach (also called the system approach) to spare parts optimization is theoretically superior to the engineering choice method and the “same of each” method. Further it was established early that empirical research on system supportability issues in general and spare parts in particular need to be increased.

By answering sub-objective research question b (**SRQb**), the objective to study the planning process and set up of the ILS/system supportability elements of equipment maintenance and spare parts in connection with operations was reached. This is reported in the appended paper II. Thus an important contribution from this research is the increased knowledge of how maintenance and spare parts are planned for in connection with man-made humanitarian disasters by a small nation’s military force (the Norwegian Defence) and a small nations NGO (the Norwegian Red Cross).

The next sub-objective was to study the spare parts optimization process in procurement projects using “state of the art” ILS methods and tools within spare parts optimization. This was done by answering **SRQc**. The findings are reported in total in the appended paper III. It was established that the system approach (according to theory the best spare parts optimization approach) was not much used by procurement projects in the Norwegian Defence even if this method eligibly was chosen to be the preferred method a decade ago. However in the projects found to have used the method, the process was studied and the findings is included in the appended paper III and hence the sub-objective reached.

Finally the last sub-objective was to evaluate the empirical results of spare parts optimization towards system availability and cost and more specifically as asked in sub-objective research question d (**SRQd**): Can empirical data show that the multi-echelon, multi-item, multi-indenture method solved through OPUS10, improves system availability and/or spares parts investment cost compared to the system supplier’s suggestion? In the appended paper III it is shown that the objective also was reached. The empirical research on Norwegian Defence projects showed that the theoretical claim of the system approach (in this case solved through OPUS10) with a high probability holds true, both towards system availability and system life cycle cost.

## 11. Self criticism

In this chapter some thoughts on research limitations are given. The focus is on the main research objectives. Limitations towards the research connected to the sub-objectives can be found in the appended papers.

In connection with the main research question 1 (**RQ1**), which was the study of how small nation’s military and NGOs plan for and set up maintenance and spare parts inventories in connection with man-made humanitarian disasters, only two cases were researched. The two cases were evaluated against hypotheses put forward based on a research model developed (reported in the appended paper II). Studying more cases could have strengthened the research.

Further the research is based on qualitative data, and hence it was not possible to reject or accept the hypotheses based on statistically verified methods. However, it can be argued in the opposite direction that the use of qualitative data gave a more in-depth view which quantitative data from a questionnaire could not have given. The theoretical approach in terms of factors analysed has been firmly rooted in the economic approach to organizations and more specifically in agency theory. The main reason for choosing the agency theory approach is based in how the organizational form studied (in this case disaster relief projects) is established. The relief projects of this study are established by owners. It is the owners (the mandate group) who decide which goals and tasks the organization is going to have (Greve, 1995). In order to reach any preset goal, the mandate group must implement a governance system that makes sure that the leaders and employees of the organization implement actions to reach the goal. According to Greve (1995), the main theory that regulates the relationship between the mandate group and the organization leaders, is agency theory. However, also factors from more general organization theory based on the work of Mintzberg were used. The focused actors in this study were the project leaders and/or (logistics) planners (see more details in the appended paper II) and thus the agents in an agency theory perspective. The research leading to the answer to RQ1 could have taken on a broader perspective by including other stakeholders besides the principals and agents in the relief projects. If this approach had been chosen another theoretical perspective could have been used. Mitchell et al. (1997) agrees that agency theory is an important theory along with resource dependence theory and transaction cost theory in the study of what they call the stakeholder-manager relations. They claim however that the principals (owners) are not the only stakeholders the managers (in this case the project leaders and planners) have to pay attention to. Mitchell et al. (1997) claims that stakeholders can be identified by their possession or attributed possession of 1) **power** to influence the firm, 2) the **legitimacy** of the stakeholder's relationship with the firm and 3) the **urgency** of the stakeholder's claim on the firm. Further they claim that the stakeholder's salience, which is the degree to which managers give priority to competing stakeholder claims, will be dependent upon power, legitimacy and urgency. By using stakeholder theory, one could maybe have found even more explanations of why maintenance, spare parts inventory and spare parts supply chain planning and set up towards operations are done differently in different organizations. The same could be argued in connection with **RQ2**.

This is in line with the limitation that clearly applies to the findings connected to main research question three (**RQ3**). In the answer to RQ3, the three ordinal constructs (two agency theory constructs – attitude and information symmetry and the knowledge construct) and the dummy variables that ended up in the final analysis do not explain fully why some procurement projects are still carried out and reviewed based on initial procurement costs alone when the official policy is to apply the life cycle cost approach. Other factors or variables (from for example stakeholder theory), together with the ones already included in order to answer RQ3, must be examined in order to fully answer the question.

Not being able to statistically accept or reject the hypothesis presented in the data analysis used to answer how coordination issues have affected the process and results of the spare parts optimization conducted in the Norwegian Defence procurement projects that has used OPUS10, can be argued to be a limitation to the answer to **RQ2**. The same limitation can be argued against

the answer to **RQ1**. The research could have been developed by using a questionnaire to reach as many projects within the community as possible. However it can also here be argued that the use of qualitative data has presented more indebt knowledge then a questionnaire could have given. Further the cases are restricted within the Norwegian Defence and hence generalization of both qualitative and quantitative findings is at best questionable and probably not fruitful.

In the same direction, the answer to **RQ3**, the study of life cycle cost based procurement decisions is a case study from the Norwegian Defence, hence the findings can not be automatically transferred to other organizations.

## 12. Suggestions for future research

In future research the research model developed in connection with the answer to **RQ1**, hence the study of how small nation's military and NGOs plan for and set up maintenance and spare parts inventories in connection with man-made humanitarian disasters, could be developed into a genetic template. If such a genetic template could be developed, an organization that will contribute with equipment needing maintenance and spare parts for a humanitarian operation could map the physical context of the operation in question, together with their own organizational structure and governance in order to better estimate which methods and tools they both could and should utilize. Further one could also better evaluate if the organization could benefit from a change to their own organizational setting and governance in order to use the methods and tools (e.g. multi-echelon, multi-item, multi-indenture spare optimization) that gives the best possible equipment availability for the lowest possible amount of money. In other words, if combined with the best possible product effectiveness, maximum system cost effectiveness.

The research conducted to answer **RQ2** regarding system supportability in general and spare parts optimization processes and results in particular, should be of interest to other organizations and industries besides the Norwegian Defence. The research model developed in connection with this part of the total research project could easily be transferred and utilized in the study of other industries who utilize a structured approach to procurement including spare parts optimization. In this way a more general template or process map, based on the extension of spare parts theory into organization theory could be developed.

Finally in the study of study of life cycle cost based procurement decisions in the Norwegian Defence (answer to **RQ3**), the three ordinal constructs and the dummy variables that ended up in the final analysis do not explain fully why some procurement projects are still carried out and reviewed based on initial procurement costs alone when the official policy is to apply the life cycle cost approach. Other variables, together with the ones already included in this study, must be examined in order to fully answer the question. Further one of the findings were that projects' leaders working out of the Navy site are less likely to use LCC than their project leader colleagues in the Army- and Air Force- site, the empirical data however does not tell us why this is happening. In order to examine this finding, and other variables besides the ones hypothesised in this research, it is suggested that a more in depth qualitative case study of the use of LCC in Norwegian Defence Procurement projects could be conducted.



### 13. Conference presentations

In addition to the published papers several conference presentations have been held in order to present the research findings:

- The research reported in paper I was presented 8<sup>th</sup> June 2007 at the 19<sup>th</sup> annual NOFOMA Conference in Reykjavik, Iceland.
- The research reported in paper II was presented 20<sup>th</sup> November 2007 at the Cardiff/Cranfield Humanitarian Logistics Initiative (CCHLI) International Humanitarian Logistics Symposium in Faringdon, Oxfordshire, United Kingdom.
- The research reported in paper III was presented 5<sup>th</sup> June 2008 at the 20<sup>th</sup> annual NOFOMA Conference in Helsinki, Finland.
- A synthesis of the findings reported in paper IV and the quantitative findings of paper number three was presented 8<sup>th</sup> May 2008 at Norsk Militært Logistikkforum's conference at Sessvollmoen, Norway.

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## **Paper I**

**Spare parts inventory – A literature review with focus on  
initial provisioning and obsolescence management**

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## PAPER I

# **Spare parts inventory – A literature review with focus on initial provisioning and obsolescence management**

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## Abstract

*When systems with long life cycles are procured systems owners are often faced with the challenge of achieving high system effectiveness with low life cycle cost. Spare parts for maintenance operations will have an effect on both the operational availability and life cycle cost of the system. When an expensive piece of equipment is bought, spare parts can often be bought at a reduced price and hence a decision must be made about the initial provisioning of spare parts. Further, many technologies have life cycles that are shorter than the life cycle of the system they are in, and spares for possible obsolete systems must be managed. This paper is an update and extension on earlier review papers and is based on the existing body of literature concerning spare parts inventory theory, models and applications. We focus especially on literature concerning initial provisioning and obsolescence management in a multi-echelon setting where the goal is to maximize system effectiveness / operational availability at minimum life cycle cost. Our review shows that the multi-item, multi-echelon approach is superior to the single item approach regarding optimization of availability subject to life cycle costs. Further, the review of forecasting shows that substantial savings can be achieved by using more accurate forecasting methods than most businesses use today. Within the niche of spare parts management research, the studies seem to be more empirically based, than what the case is regarding multi-echelon spare parts modeling.*

*Keywords: Forecasting; Initial provisioning; Inventory; Life cycle cost; Maintenance; METRIC; Obsolescence; Operational availability; Spare part.*

### 1. Introduction

Spare parts inventories is a field of increasing importance both from a cost focus and service focus perspective. When systems with long life cycles, e.g. ships, aircraft, military systems and oil platforms are procured, system owners are often faced with the challenge of achieving high system effectiveness (high performance and high availability) with low life cycle cost (LCC). If such a goal is obtained we can claim to have a cost-effective system, or in other words a system that in the best possible manner balances system effectiveness and life cycle cost.

#### 1.1 Life cycle cost and system effectiveness

LCC refers to the life cycle of a system, where the life cycle usually starts with the initial determination of its need, continues through design and development, production, deployment, operations and concludes with the system's disposal.



LCC may be categorized in many different ways, depending on the type of system and the sensitivities desired in cost-effectiveness measurement (Fabrycky and Blanchard 1991). However the fundamental objective of LCC reduction analysis is to identify the cost drivers that most significantly contribute to LCC. This allows for trade off considerations with respect to different courses of action (Masiello 2002).

If the goal was to obtain low LCC alone this could of course be done by spending little in research and development, having a small investment, operate the invested equipment as little as possible and so on. This is of course not a normal *modus operandi*. The success of any business, government or non governmental organization depends on the effectiveness of the process and/or products that they produce or operate (Kumar et al. 2000). System effectiveness (SE) can be measured in several manners. Blanchard (2004) suggests that SE can be defined in terms of three main concepts; system performance parameters, point availability and dependability. System performance parameters can be defined as technical requirement defining for example the accuracy of a radar capability, the capacity of a power plant and so on. Point availability is the probability that an item or system is in a state of functioning at a given point in time, when operated, maintained and supported as prescribed (Kumar et al. 2000). In comparison dependability is interval availability, or a measure of the system operating condition at several points during stated period of time (Blanchard 2004). In the following we will not make a distinction between point availability and dependability, but for simplicity rather use the concept of operational availability.

## **1.2 Operational availability and maintenance**

Blanchard (2004) defines operational availability as mean time between maintenance (MTBM) divided by MTBM plus the mean maintenance down time (MDT). MTBM expresses the uptime of the system and MDT is an expression for the downtime. The uptime of the system (MTBM) will be conditioned upon how reliable the system is in terms of failures and upon how much preventive maintenance the system needs. The number of failures in any system has to do with the systems reliability. Reliability can be defined as the probability that the system will perform in a satisfactory manner for a given period of time when used under specified operating conditions (Blanchard 2004). Through design, a producer of systems can achieve high reliability by using high quality material, parallel configurations, monitoring sensors and so on. However, to gain high operational availability through design alone will in most cases mean a very high investment cost, and the balance between cost and performance might not be appropriate. Support in terms of maintenance is, based on this, needed throughout the life cycle of the system. The MDT is made up of the mean active maintenance time, administrative delay time (ADT) and logistics delay time (LDT). The system's active maintenance time is dependent upon how easy the system is to maintain. ADT refers to that portion of MDT which maintenance is delayed due to administrative issues like for example lack of qualified technicians. LDT refers to the part of MDT that is expended due to lack of resources like test equipment, transportation and spare parts.

### 1.3 Research scope

From the definition of operational availability logistics delay time and hence access to spare part contributes to the availability of any system. We have also shown that the counter balance to system effectiveness is life cycle costs, and hence the concept of life cycle costing becomes closely connected to investment and management of spare parts inventories. When for example an expensive piece of equipment is bought, spare parts can often be bought at a reduced price and hence a decision must be made about the initial provisioning of spare parts. Further many technologies have life cycles that are shorter than the life cycle of the system they are in, and spares for possible obsolete systems must be managed.

This paper is an update and extension on earlier review papers *on these topics* and is based on the existing body of literature concerning spare parts inventory theory, models and applications. However, as shown in this introduction we focus on settings where the goal is to maximize system effectiveness / operational availability at minimum life cycle cost and hence literature concerning initial provisioning and obsolescence management in a multi-echelon setting.

The rest of this paper is organised as follows: in section 2 an overview of earlier studies is performed. In section 3 different categories of more recent papers are discussed and related to earlier findings. In section 4 some conclusions are done.

## 2. Earlier studies within the field

At the start of this research we set out to find the most recent review studies within the field, and came up with Guide and Srivastava's (1997) review paper on repairable inventory theory and Kennedy et al.'s (2002) review paper regarding spare parts inventories. Spare parts inventory theory in general and repairable inventory in particular now dates back more than 40 years Kennedy et al. (2002).

Guide and Srivastava (1997) focus on literature dating back from the early 1960s concerning repairable inventory theory. They claim that repairable inventory theory is, unlike classic inventory theory, concerned with items which are repaired rather than discarded. In their paper they classify the body of literature by several criteria, such as solution methodology, inventory policy (e.g.  $(S-I,S)$ ) and modeling levels. However, the most important criterion and final classification of the papers reviewed is modeling level (multi-echelon or single-echelon) and application/implementation.

According to Guide and Srivastava the classical repairable inventory problem and the multi-echelon models dates from the military, and they point out Sherbrooke's 1968 paper "*METRIC: A multi-echelon technique for recoverable item control*". In the military setting described by Sherbrook (1968) the problem is how to optimally stock repairable parts for aircraft at bases which are capable of repairing some, but not all broken parts, and a central depot which serves all bases.

In line with what we have outlined in our introduction, the objective in these models is typically to maximize availability of the system which the repairable parts are meant for, subject to a budget constraint. In these models maximization of availability is typically measured by minimizing the expected number of backorders at the base level. A comprehensive description of the METRIC model can be found in Guide and Srivastava. Guide and Srivastava review 42 papers regarding multi-echelon models, covering the timeframe from 1967 to 1996.

Since multi-echelon models are complex, and since some problems can be solved by only modeling one echelon, several papers in the Guide and Shrivastava's review have this focus. According to Guide and Shrivastava, the single-echelon problem focuses on optimal replacement quantities for repairable parts that are worn beyond recovery, have been lost from the system, or on optimal batch size for repair lots. They review 18 papers, with the oldest one published in 1967 and the newest one in 1994.

In the final classification section, Guide and Shrivastava review papers regarding the implementation and use of repairable inventory models. It is interesting that they can only find a very limited number of studies regarding this topic. However, they have included eight papers, covering the timeframe from 1980 to 1996.

Kennedy et al. (2001) claim in their introduction that spare parts inventory levels, are largely a function of how equipment is used and how it is maintained, in comparison to WIP and final product inventories.

In the introduction section they refer to an earlier review paper by Pierskalla and Voelker from 1976 called "*A survey of Maintenance Models: the control and surveillance of deteriorating systems*" and Nahmias' review paper from 1981 called "*Managing repairable item inventory systems: A review*".

Kennedy et al. (2001) do not refer to Guide and Shrivastava and hence claim that the newest review paper is from 1981 and that it therefore warrants a new look at the literature of spare parts inventories. Kennedy et al. have a reference list of 61 papers out of which three papers are used in the introduction. To address different aspects within spare parts inventories, they have divided the papers under review into seven categories. Most of the papers are from the period 1981 to 2000, but some older papers are included.

The first category they review is called general papers. In this section they include six papers regarding the maintenance function and some of the main issues that have to be addressed need in determining spare parts inventories. In the next section they include papers regarding management issues such as methods of organizing and reducing spares. In this section twelve papers are referenced. Further they review three papers regarding age based replacement, 13 papers regarding multi-echelon problems, eleven papers on problems involving obsolescence, 15 papers dealing with repairable spare parts and finally six papers on what they classify as special cases.

A fairly recent overview with a somewhat different perspective is Farris et al. (2005). They review 18 articles from the period 1992 to 2002. The main focus is on supply chain management, strategic alliances, after sales services. The content of the articles used are mostly related the aerospace industry. The main findings from the review as far as aftermarket is concerned, are key variables like technology, need for visibility, traceability, and collaborative product commerce. The authors underline that there can be substantial opportunities for incremental profits in after market support.

In section 1.3 we stated that access to spare parts, and hence availability and system effectiveness can to a large extent be controlled by how we invest in spare parts inventories. Both Guide and Srivastava (1997) and Kennedy et al. (2002) clearly acknowledge this fact and they both distinguishes spare parts inventories from work in process (WIP) inventories and final products inventories. Inventory demand related to spare parts inventories is driven by maintenance (both corrective and preventive) rather than “customer usage”.

In Kennedy et al. (2002) the interested reader can also find conditions that separate WIP and final product inventories from spare parts inventories. We will only list the main points from Kennedy et al., and extend the list in some areas:

- Maintenance rather than customer usage dictate the need for spare parts inventories.
- We mentioned in section 1.2 that system design in terms of redundancy (parallel configurations) in the system can increase operational availability, and in the same manner it can reduce the need for spare parts inventories because the redundancy makes it possible to replace non-working parts at a convenient time (e.g. after the ordering lead-time has elapsed). However, this requires that the system operator is aware of the part being broken, which is very often not the case with redundant systems.
- Monitoring equipment can reduce the need for emergency spare parts inventories.
- Failure of one part is often dependent on the failure of another part.
- Demand can sometimes be met through cannibalism of equivalent systems.
- Many technologies, and hence spares based on these technologies, have life cycles that are shorter than the life cycle of the system they are in. Spares for possible obsolete systems must be managed, both in terms of deciding how many to stock if obsolescence is known, and in terms of how to replace a part that no longer is available from any source.
- When an expensive piece of equipment is bought, spare parts can often be bought at a reduced price. This can for example be due to the fact that the production line for the main equipment is running and hence no set-up cost is incurred for the spare part production.
- In section 1.3 we stated that the counter balance to system effectiveness is life cycle costs. However, several cost elements are very difficult to assess, this can for example be costs associated with the safety of personnel. One might for example decide to stock special spare parts for an engine onboard a ship in order to make sure the ship does not run aground due to engine failure, even if this is not economically optimal.

## 2 Classification of papers

Kennedy et al's (2002) paper was accepted for publication in 2001 and is – to the best of our knowledge – the most recent paper reviewing this field.

By searching different data bases like ProQuest and ScienceDirect we found that a fairly large number of papers have been published since then. In addition, we found that neither Guide and Srivastava's (1997) nor Kennedy et al.'s (2002) exactly matched what we set out to cover. Hence, we found it desirable to make the present review. We have restricted our search to scientific papers found in well known international journals, but have added some papers found in proceedings from international conferences, a few relevant working papers, and some papers published in a military context, since armed forces are important operators of systems with long life cycles and a high degree of dependency on maintenance and spare parts.

In order to cover the different areas we introduced in section 1, and to update the existing review papers covered in section 2, we have classified and reviewed 42 new papers, categorized in seven different categories as shown in the table below.

*Table 1. Categories for the reviewed papers.*

<b>General content of the papers</b>	<b>Number of papers</b>	<b>Section</b>
Papers on spare parts inventories closely connected to the concept of life cycle costing and maintenance.	8	3.1
Papers regarding classification and management of spare parts inventories.	6	3.2
Papers regarding initial provisioning of spare parts – general papers not based on multi-echelon spare parts modeling	2	3.3
Papers regarding initial provisioning and follow on supply, based on multi echelon spare parts optimization models.	12	3.4
Papers regarding forecasting of spare part needs	4	3.5
Obsolescence management papers.	5	3.6
Case based and organizational connected spare parts management papers.	5	3.7

## 2.1 Spare parts inventories and the concept of life cycle costing and maintenance

In this section we have reviewed eight papers regarding the topic. The first five papers are closely connected to the concept of life cycle costing, while the last three papers are more connected to spare parts and maintenance but not in the traditional METRIC modeling.

The first paper connected to LCC is Pallas and Novak (2000). They describe how to reduce the cost of ownership of military systems in the United States Department of Defense (US DoD). They do not present a single solution, but rather show how 30 pilot programs are initiated in the US DoD.

In the second paper, the question is how to design and develop support for products in order to minimize LCC. The authors are Markeset and Kumar (2003-1) and in this paper they use a case study to come up with a process solution. They focus on how a company can sell total support of a product throughout the product's life cycle rather than only sell the product itself. In their second paper, Markeset and Kumar (2003-2) look into how to integrate reliability, availability, maintainability and supportability (RAMS) and risk analysis in the design and development of products. They develop new templates for how to include RAMS and risk analysis in design, and show how this is closely connected to spare parts inventory assessment.

Gurvitz et al. (2005) study how costing of spares (in a LCC setting), needed to sustain a number of aircrafts under different operational scenarios, can be done. They develop a software decision support system based on Monte Carlo techniques to simulate operations and METRIC approximation on spare part settings. The software solution gives cost versus availability graphs of different scenarios.

Finally, product support strategy is the focus of Markeset and Kumar (2005). They see product support as an income opportunity for the system producer, rather than cost for the buyer. They examine different scenarios for product support and discuss approaches for development of strategy.

In the second stream of papers classified in this section we have included three papers that are especially concerned with maintenance and spare parts. In the first paper, Kumar and Knezevic (1998), ask what the effect of supportability (in terms of the number of repair facilities) is on operational availability in a multi-echelon setting. They answer the question by utilizing Markov models under different assumptions, and by using complex mathematical models. They develop three models that can be used to determine the number of repair facilities needed given an availability requirement.

Vaughan (2003) addresses the question of how to find a spare part ordering policy that takes into account both preventive and corrective maintenance. He uses dynamic programming where the objective is to minimize the total cost function. He looks at a one site solution, and none of the spare parts in his setting is repairable, which of course make the solution easier.

In the last paper, Giri et al. (2005) study optimal spare part order-replacement policy for a high cost single unit complex system. They use discrete optimization, where the objective function is to minimize total discounted cost and they present one model for preventive maintenance and a separate model for corrective maintenance.

## **2.2 Classification and management of spare parts inventories**

In this section we have included two papers regarding what we have called classification of spare parts. Further, we have reviewed four papers which are more focused on general management of spare parts inventories.

Of the two papers we found published after 2002, connected to classification of spare parts, the first paper studies how to differentiate spare parts policies between different types of spare parts. In this article by Huisken (2001), a spare parts policy matrix is developed, with different policies for different squares in the matrix. The matrix categorizes spare parts based on high and low criticality and standard or user-specific parts.

How to use attributes that are not quantifiable (such as safety) in spare parts management is the focus of Braglia et al. (2004). Development of a multi attribute spare tree analysis (MASTA) is one of the results they come up with. The spare part classification based on MASTA is linked to different inventory policies in a policy matrix.

In addition to the two papers already mentioned in this section we include a paper published before 2002 but not treated in the earlier review papers. Cook (1990) looks at the US Department of Defense which is accused of buying overpriced spare parts. Implementation of additional administrative requirements gave mixed results. Increased requirements meant reduced spare part prices, but on the other hand longer lead times.

In the next paper Deshpande et al. (2003) look at the conflict between minimization of cost and maximization of system availability through the use of priority codes. They assign fill rate objectives to the different priority codes in order to include this in the stocking models as constraints. When fill rate percentage is higher for high priority spare parts one acknowledges the challenge of setting the correct priority code.

Kalchschmidt et al (2003) study how to design a spare parts solution in order to manage uncertain and extremely variable demand. Four alternatives/scenarios with orders based on differentiating forecasting and inventory management, based upon whether the part has stable or unstable demand are presented. Cost versus availability/service level graphs for different scenarios is one of the results.

Finally, Razi and Tarn (2003) look at how to implement an inventory management model for spare parts in an enterprise resource planning (ERP) environment. Simulation of the proposed model is compared to simulation of a standard ERP inventory management model. The proposed

model uses pooled distribution of parts instead of statistical distributions and performs better than the ERP solution.

### **2.3 Initial provisioning of spare parts – general papers**

Haneveld and Teunter (1997) study how many spare parts should be ordered for the initial part of a system's life time. Further, they look into how many parts should be ordered after the initial period is over to cover the rest of the life time. The objective they use is to minimize the expected discounted total cost for the system's life time. Algorithms for deciding the number of spare to buy initially and for when to re-buy or not (the cut of point) are developed.

Kumar and Hinds (2005) study how to deal with the problem of lack of reliable in-service data when conducting initial spare parts provisioning. They develop a system for collection of expert opinion in order to estimate parameters for exponential, normal and log-normal distributions. This system also gives spares needed to cover accident-, wear- and design- brake downs based on the expert opinion and fill rate calculations.

### **2.4 Initial provisioning and follow on supply based on spare parts optimization models in a multi-item multi-echelon setting.**

According to Wong et al. (2005), it is well known from literature that applying the multi-item approach, also called the system approach, may lead to significant reduction in inventory cost compared to the single-item approach. Under the multi-item approach all parts in the system are considered when making inventory level decisions, while under the single item approach fill rates are set for each individual part independently. All papers under review utilize the system approach. All papers are also within the multi-echelon setting thoroughly described in e.g. Guide and Srivastava (1997). In this review we have lumped papers into two buckets.

In the first bucket we have included papers which are based on the METRIC solution and later extensions to the METRIC solution as shown in Guide and Srivastava (1997) and Kenndey et al (2002).

The first paper covered is Rustenburg et al. (2000). The authors have as their objective the optimization of the initial inventory and then deciding the re-supply under limited budgets where no repair of spare parts is possible. Initial procurement in this paper is based on a modified METRIC solution using a non-linear integer programming model in a single-echelon, single-indenture setting. For the re-supply periods the solution is based on an extension of the single-period, constrained multi-item problem to an infinite horizon problem with budget for each period to find order quantities.

Rustenburg et al. (2001) look at the use of METRIC based optimization in an initial procurement phase and the re-supply problem in technology-based organizations. In this paper the authors use the Royal Netherlands Navy as a case for evaluation of METRIC based optimization of spare parts both in terms of initial procurement and re-supply. They show how METRIC assumptions



regarding capacity restriction, criticality of parts, commonality, redundancy and condemnations needs to be addressed in spare parts modeling research.

Thonemann et al. (2002) have a slightly different approach. They show how to quantify the improvement of system approach in inventory management by approximating the system approach from an item approach standing. In comparison to the system approach, the item approach does not vary the fill rate over different items. The authors show how a small amount of data (cost and demand parameters) can be used to approximate the relative improvements of a system approach over the item approach as a function of unit cost- and demand-skewness. The authors clearly show how the system approach is superior towards the item approach.

Wong et al. (2005-1) research stocking decisions for repairable spare parts pooling in a multi-hub system. The authors describe the two main approaches to spare parts modeling in what they call a multi hub environment, namely the METRIC approach and the more exact queuing models. Their solution is building on the METRIC approach where they develop a two stage model with a first step algorithm to find the aggregate demand for all hubs. In the second step the stocking decision is modeled by minimizing all relevant costs including downtime cost, transportation cost and transshipment cost.

In Wong et al. (2005-2), the authors combine the spare parts problem applied in the multi-item (system approach) versus single item research and the multi-location systems with lateral transshipments (inventory pooling) research. The objective is to determine close-to-optimal stocking policies by minimizing the total cost for inventory holding, lateral transshipments and emergency shipments subject to a target level for the average waiting times at all locations. Since the problem is quite complex, several assumptions are made by the authors where the most important assumptions are that; failures occur according to Poisson processes, all parts are repairable, there is no condemnation, lateral transshipments are faster and cheaper than emergency supplies, inventory levels are kept at a constant level in all companies, repair lead-times are exponential, complete pooling is applied and inventory holding cost dominates. They structure the optimization problem as a combinatorial problem, develop and test four different heuristics, where the greedy-type heuristic has the best performance in terms of total cost and computation time.

Nickel et al. (2006) describe an algorithm used to solve a very large, nonlinear, integer optimization problem associated with developing aviation sparing policies for US Navy aircraft carriers. This problem is a multi-echelon, multi-indenture problem, where the objective is to find a minimum-cost sparing policy that meets the readiness requirements of the carrier embarked aircraft. They compare their algorithm to the model already in use in the US Navy with four test cases. In three of the four cases the algorithm they developed came out with lower cost (up to 18 percent lower) than the cost from the solution given by the model already in use.

Finally Adan et al. (2006) claim that in most system approach models, a first come first serve (FCFS) policy regarding repair of failed SKUs is used and that this will mean that high cost items will have the same turn around time (TAT) as lower cost stock keeping units (SKUs).

Hence, by implementing priority codes to high cost SKUs, the TAT on these items can be reduced and thus reducing the total amount of spare SKUs needed for the high cost items (in the same manner one might need more low cost repairable SKUs). In the paper they show that substantial savings (up to 40%) can be made with priority codes over FCFS policies.

In the second bucket of papers in this section we have included more exact models and optimization models based on queuing theory. The first paper in this bucket is Cochran and Lewis (2002), where they study the optimization of a spare part package for a limited operational time frame with redundancy and no re-supply. With a small number of systems, such as in this problem, the METRIC's Palm theorem is violated. Extension of existing finite queuing spares models is therefore used in their solution.

Houtum et al. (2003), study how to relate overall system availability to budgets via optimal stock allocation policies. Compared to the approximate analysis of the METRIC model this is an exact evaluation. This exact evaluation is closely connected to base stock policies ( $s-I,s$ ) regarding consumable items, but they extend the model with repair capacities and commonality.

In Sleptchenko et al. (2003) trade off between inventory levels and repair capacity in a multi-echelon, multi-indenture system is researched. The authors simultaneously optimize the availability of spares and repair capacity in the system. For the inventory problem the VARI-METRIC model is used and for the repair capacity problem a multi-class, multi-server queuing model is used. In order to do the trade off analysis, prices for different repairs are used in order to compare two spare part prices. An algorithm is developed in order to give an exact evaluation of a given base stock policy.

Lau et al. (2004) look at how the demand for spare parts is affected by passivation of systems due to brake downs and how the lack of Palm theorem assumptions affects availability. When the number of working systems is small, the failure rate is high and/or the repair time is long, like in the problem covered in their paper, standard METRIC optimization underestimates availability. Further, when passivation of systems happen (due to e.g. "turning-off" systems due to failure), the demand rate will change over time. This can be modeled with the use of "utilization" rates. The authors consider a multi-echelon, single-indenture repairable system with time-varying demand and with passivation. They show how their model performs "better" than standard METRIC.

The last paper in this bucket is Spanjers et al. (2005). In the paper the authors utilize queuing theory to consider a closed loop two-echelon repairable item system with repair facilities both at a number of local centers and at a depot. The goal of the system is to maintain a number of production facilities in operational conditions. Machines at the local center can be repaired at the center or at the depot. Spare machines are kept at the depot and the centers. An optimal allocation of spares in the system is the objective, and the problem is formulated by trying to maximize system availability subject to a maximal stocking cost and a fixed configuration of machines and servers.

## 2.5 Forecasting of spare part needs

Forecasting needs for spare parts is often based on failure rates and breakdowns. According to Kumar et al. (2000) failure rate is by definition only appropriate to use when the time to failure for the part in question is exponentially distributed. We have not studied further the use of failure rate in spare parts inventory modeling, but we have looked at papers concerned with forecasting of spare parts needs, published after 2002.

In the first paper reviewed, Ghobbar and Friend (2003-1) looked at how the need for aviation spare parts should be forecasted. It is difficult to predict the need for aircraft maintenance repair parts owing to the sporadic nature of demand (breakdowns). The authors use real life maintenance data from an airline operator in order to evaluate 13 different forecasting methods including mean time between repair/replacement (MTBR), single exponential smoothing (SES) and the Croston's method. In the study a general linear regression analysis with four forecasting factors, and six interactions between the four factors, were used as an evaluation tool. The dependent variable of the regression is the mean absolute percentage error (MAPE). The estimated forecasting error is given by taking the natural logarithm of MAPE found. The analysis shows that the two forecasting methods most often used, namely MTBR and single exponential smoothing (SES), actually perform far worse than the forecasting method found to be most accurate. The method in question is the simple weighted moving average.

In line with Ghobbar and Friend (2003-1), Willemain et al. (2003) also evaluate exponential smoothing and the Croston's method regarding forecasting of intermittent demand for spare parts. Ghobbar and Friend (2003-1) did not however include the bootstrap method in their analysis. In Ghobbar and Friend (2003-2) the authors have surveyed airline operators and airline maintenance organizations regarding the way they control their spare parts, especially whether they use reorder point (ROP) technique or material requirement planning (MRP) techniques in their inventory control. Of 175 respondents, 152 were using ROP and only 23 (eight operators and 15 maintenance organizations) were using MRP. Hence MRP as a forecasting tool is not widely used within the airline community at the moment. The authors claim however that about half of the 152 companies that use ROP are dissatisfied with ROP and are considering implementing the MRP system.

Willemain et al. (2003) compared the accuracy of the forecasting methods by applying them to over 28000 items provided by nine industrial companies. They show that the bootstrapping method produces more accurate forecasts of the distribution of demand over a fixed lead time than do exponential smoothing and Croston's method. It is also interesting to notice that the authors at the beginning of the research thought that some modification of a Poisson process would be a good way to forecast intermittent demand, but they were not able to find a robust, flexible and estimable model and hence switched their attention to bootstrapping.

Eaves and Kingsman's (2004) paper regarding forecasting for the ordering and stock-holding of spare parts also evaluates different forecasting methods using MAPE, but also other measures of accuracy. In comparison to the other papers under review in this section, not only intermittent

demand is looked upon, but also other inventory classes such as items with smooth- and irregular-demand. Moving average is found to perform badly, while even if both exponential smoothing and the Croston's method are found to be far better than moving average they are worse than the recommended method. The recommended method is what they call the approximation method. This method is a modification of the Croston's method, and it allows the lowest stock-holdings across all demand patterns including smooth, irregular, slow moving and intermittent. The authors point out that substantial savings can be achieved by using more accurate forecasting methods and cutting safety stock with no appreciable reduction in service levels.

## 2.6 Obsolescence management

We stated in the introduction that many technologies have life cycles that are shorter than the life cycle of the system they are in, and spares for possible obsolete systems must be managed. We have reviewed five papers regarding this topic. The topic is mainly seen from the viewpoint of the holder of spare parts inventories, but the producer aspect is also touched upon.

The first paper we include is published before 2002, but is not included in earlier reviews of spare parts inventories. The paper by Teunter and Fortuin (1998), reports on a case study at Philips' central service organization in The Netherlands. This service organization is responsible for providing spare parts for equipment that Philips has produced, many years after the production period is over. In order to do this, the service organization must place a large final order at the end of the production run such that they can fulfill the service obligation set by Philips' management. The service organization knows exactly for how long the service period is for the equipment, because this is set by Philips' management. The result of the paper is a newsvendor based formula that the researchers have developed, where the goal is to minimize the total expected discounted cost in the service period subject to meeting the service demand.

The other papers we have reviewed are seen from the viewpoint of a spare parts inventory holder. In the paper by Hamilton and Chin (2001), the period for when to support the equipment in question is not known as in Teunter and Fortuin's (1998) problem. In this paper the authors report on the problem of aging military electronics within the US DoD. This coupled with the fact that electronics, once being driven by military development, now is totally dominated by the civilian market means that especially electronic spare parts very often become obsolete (unavailable for the military systems). The paper reports on different actions started by US DoD to meet this challenge. These actions include tools to predict which components that will become obsolete, a so-called diminishing manufacturing sources management system database, end of life buys (newsvendor problem) and remanufacturing.

Cattani and Souza (2003) look at end of life buys when both the buyer and the seller are more equal players than in the case with US DoD electronics. The authors show that the two parties have directly opposite interests with respect to delaying the end-of-life purchase. The buyer will benefit from delaying as much as possible and opposite for the seller. For the delay decision to be implemented, it is necessary that the buyer compensates the supplier for their loss incurred.

Baca's (2005) article is focusing on US DoD management of the obsolescence problem. He claims that currently only two dimensions of information support are utilized in DoD, while there should be three. The first dimension is the use of pro-active component lifecycle projections during component selection for a new design. The second dimension is concerning the same diminishing manufacturing sources management system reported by Hamilton and Chin (2001). The third dimension is access to obsolescence information. If only two or three individuals are capable of using the existing systems, the information age's promise of empowerment is empty, is the claim he makes.

Singh and Sandborn (2006) build their work on Cattani and Souza's (2003) paper. They focus on obsolescence driven design refreshment planning for sustainment-dominated systems. In the paper, they develop what they call "The mitigation of obsolescence cost analysis (MOCA) methodology". The methodology is used to perform optimum design refreshment planning for sustainment-dominated electronic systems based on forecasted technology obsolescence and a mix of obsolescence mitigation approaches ranging from lifetime buys to part substitution.

## **2.7 Case based - and organizational connected - spare parts management papers**

Much work within spare parts inventories is based on mathematical assumptions, models and simplification of what might be called real life interference. Due to this we wanted to see if we could find case studies connected to implementation, use and management of spare parts inventories.

Case based papers received limited attention in earlier reviews; hence we have included papers from before 2002. The first paper is a case study by Cohen et al. (1999), done at a major manufacturer of electronic testing equipment used in semiconductor and electronics assembly plants throughout the world. The service-parts logistics network of the company in question has a two-echelon structure with a single parts-repair and inventory-stocking depot in the USA and seven non-US inventory centers in Asia and Europe. The authors applied, together with the company, two basic inventory models, one for the consumable parts (a periodic order-up-to policy) and one for repairable parts (based on METRIC). The consumable model showed that the company could reduce late shipments to customers by over 90 percent, with less than three percent increase in inventory investments. The repairable model indicated that it could reduce inventory investment by as much as 37 percent, while improving customer service by around four percent. According to Cohen et al. basic models used in complex logistic systems can be very effective for both operational control and strategic analysis because the policies these models recommend can dominate the decision rules used in practice. Further, even these basic models can be very hard to implement in real life scenarios because one needs a thorough understanding of both model theory and the underlying logistics processes. This kind of understanding is not always present in a company. However, the simplicity of the basic models and the policies they generate enhances the likelihood of implementation because managers at all levels in the company can understand and embrace the policies generated.

Ghodrati and Kumar (2005) claim that estimation and calculation of required number of spare parts for storage to guarantee systems availability when required with respect to techno-economical issues has rarely been considered and studied. In the little research available on spare parts' calculations based on reliability characteristics, the operating environment conditions (temperature, humidity, dust, etc) have not been considered even if we know that the reliability is a function of the operating environment (and other issues). In the paper, the authors have used data from a case study of load-haul-dump (LHD) machines in a mine in Kiruna, Sweden. They found that the manufacturers recommended number of spare parts were lower than needed because the hard operational environment of the LHDs were not taken into consideration when optimizing the number of spare parts needed to avoid downtime of the mine.

Cunha et al. 2005 claim in their article that most recent models regarding multi-echelon inventory models have restrictions to their successful application. They have therefore defined a methodology based on simulations that can be applied to all multi-echelon problems. The model developed permits modelling of different systems with a different number of echelon, repair times, transportation times and so on. Real life data from a case study of a three echelon operation and maintenance system for a single type of locomotives within a railway company was used to evaluate the simulation model. By doing this they could clearly show that one point in the operation and maintenance system (the central repair shop) was a bottleneck and hence reduced the availability of the locomotives.

In Huiskonen (2001), the author claims that the advances in inventory research have made it possible to take more realistic assumptions into consideration in inventory modeling. Further he states that surveys have shown that it has not been easy to transfer these results into managerial practice. In the paper, Huiskonen suggests a classification of spare parts based on criticality, specificity, demand pattern and value of the part in question. Different inventory management policies are suggested for the different squares of the matrix generated. For example if the spare part in question is a low criticality, low value, standard part, an automated order processing system with fairly high ROP is suggested. On the other hand if the part in question is a high criticality, high value, standard part, pooling of stock with other users is suggested. Finally, the author suggests that one should work with the understanding of spare part managers towards inventory theory, because lack of understanding might be the reason why so called rules-of-thumb still are so popular in managerial practice.

Finally we include the only paper we found that suggests how to extend spare parts inventory management into organizational management. Zomerdijsk and Vries (2003) claim that the vast majority of research within spare parts inventories originates from the fields of operation research, and thus the concepts and techniques are mainly based on mathematical assumptions. They further claim that despite the value of the available concepts, this common background in operation research has its limitations especially in implementation, management and practical control of spare parts inventories. Based on this, the authors develop a perspective on inventory control that includes four organizational perspectives or factors. The four factors in question are task allocation (e.g. allocation of responsibilities and authorities regarding inventory management), decision making processes (e.g. the amount of available information and the

number of decision makers), communication processes (e.g. the amount of feedback and the quality of information) and behaviour (e.g. uncertainty, power games and incompetence). These four contextual factors as well as the traditional factors are mapped out and integrated into a framework to be used in solving practical inventory control problems. The authors use the developed perspective on a case study, and show how the perspective is very helpful in dealing with inventory control problems.

#### **4. Conclusions and recommendations for future research**

We have showed that maintenance effectiveness and access to spare parts will govern the availability of most systems. Further, life cycle cost will be dependent upon how spare parts inventories are procured and managed. Based on this we have reviewed the most recent research connected to spare parts inventories, life cycle costing and maintenance (section 3.1). We showed that this area can be divided into a qualitative and a quantitative research stream.

In the qualitative approach, the focus seems to be aimed at developing work processes and templates for organizations interested in managing systems and spare parts inventories in a life cycle cost perspective.

In the quantitative stream, a more traditional operational research approach is used. Here the goal is to find optimal, or close to optimal, solutions with life cycle costs as the objective. We feel that the empirical research, especially regarding processes, within this niche is limited and hence further empirical studies are needed.

Our recommendation of further empirical research regarding processes connected to spare parts inventories and life cycle costing, is in our view strengthened by the limited new research we observed regarding classification and management of spare parts inventories (section 3.2) and general initial provisioning (section 3.3). The review of initial provisioning and follow on supply, based on spare parts optimization models in a multi-echelon setting (section 3.4) establishes our impression regarding this stream of spare parts inventory research, namely that it is based on rather sophisticated mathematical modeling with stepwise development of established models.

Our review shows that the multi-item, multi-echelon approach is superior to the single item approach regarding optimization of availability subject to life cycle costs. Development of sound methods is also the focus within forecasting research (see section 3.5). However, within this niche the studies seem to be more empirically based, than is the case for multi-echelon spare parts modeling.

The review of forecasting shows that substantial savings can be achieved by using more accurate forecasting methods than most businesses use today. However, the review shows the results are not consistent with each other, in one case a specific forecasting method seem to work good and in another it does not. More research is needed in this field to sort out when to use which method(s).

In section 3.6, we looked at the concept of obsolescence management. We found that this area of research is rather new and hence more research both in terms of both theory and empirical research is needed.

Finally we reviewed empirically based papers, and our findings in this section (section 3.7) can to a large extent sum up our main impression, namely that most research within the field of spare parts inventories are based on theoretical and sophisticated mathematical models grounded within the fields of operation research, statistics and forecasting.

However, many of the promising findings from the above mentioned research areas are difficult to implement in real life organizations. In line with e.g. Zomerdijk and Vries (2003), we feel that in addition to the traditional methods, there is a need for more managerial approaches that are able to bridge the gap between the traditional mathematical methods and the practitioners' need for managerial methods.



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## **Paper II**

### **Maintenance and spare parts inventories in man-made humanitarian disasters**

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## **PAPER II**

# **Maintenance and spare parts inventories in man-made humanitarian disasters**

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## Abstract

*Purpose:* The main research question of this paper is to answer how a small country's military force and a small country non-governmental organization (NGO) plan for and set up equipment maintenance, spare parts inventories in connection with man-made humanitarian disasters. Additionally it answers how the physical context, organizational structure and governance affect the planning and set-up.

*Methodology:* A research model that combines organization theory with spare parts inventory theory is developed. Case study research methodology is used and observations and findings are discussed within the research model in order to answer predefined hypotheses.

*Findings:* Regarding planning procedures as well as how the maintenance concept and spare parts inventory are set up, the research concludes that the organizational structure and governance of the organization contributing to the humanitarian operation in question are more important than physical context of the operation itself. Further it is concluded that the maturity level, when it comes to inventory control issues, are different for the two cases in question. None of the cases, however, utilize modern optimization methods and tools.

*Research implications/limitations:* Qualitative data from the two case studies give the possibility for in depth analysis of the case study findings. Lack of quantitative data means that it has not been possible to statistically reject or accept the hypotheses.

*Practical implications:* By applying the research model developed in this study, organizations that contribute to humanitarian disasters could more easily assess their own possibility for effective maintenance and spare parts inventory planning and set up. More research is needed to present a template and/or processes based on the findings in the research.

*What is original/paper value:* The study of the planning and set up of maintenance and spare parts inventories for both military and NGO players in connection with a man-made humanitarian disaster is new. Further, the development of spare parts inventory theory into organization theory is relatively new. Limited research is available within this field. The paper should be of interest to both practitioners and researchers within the field of maintenance and spare parts inventories in general, and in connection with humanitarian disasters in particular.

*Keywords:* Man-made humanitarian disaster, Humanitarian logistics, Operational availability, Maintenance, Spare parts inventories, Organization theory.

*Paper type:* Case study.



## 1. Introduction and main research question

Humanitarian disasters are either natural with sudden onset like for example earthquakes, natural with slow onset (e.g. famine), manmade with sudden onset (e.g. terrorist attacks) or man-made with slow onset like for example political crises (Tatham and Kovács, 2007).

Humanitarian aid models identify both military and non-military players (e.g. non-governmental organizations – NGOs) in the different stages of a disaster response. However, particularly in man-made disasters, military forces will often work alongside other governmental bodies as well as alongside NGOs. Experiences from both military organizations and NGOs have shown that in many cases few resources can be expected in the disaster area (e.g. Oloruntoba and Gray, 2006). Hence equipment, such as trucks needed to bring for example supplies into the disaster area, must be brought along.

One may hypothesize that equipment owners are faced with the challenge of maximizing operational availability of the support equipment, often with limited budgets. To gain high operational availability, maintenance will be needed throughout the operation (e.g. Blanchard, 2004). When a humanitarian aid operation is prepared, decisions must be made regarding the equipment maintenance, spare parts inventory and the spare parts supply chain. Spare parts inventories research has shown that the multi-echelon, multi-item, multi-indenture approach is superior regarding optimization of availability subject to costs (TysseLand and Halskau, 2007).

However, it is also claimed that it has not been easy to transfer research results into managerial practice. Subsequently so called “rules-of-thumb” sparing decisions and management are still popular in managerial practice (Huiskonen, 2001).

The main research question of this paper is to answer how a small country’s military force and a small country NGO plan for and set-up equipment maintenance, spare parts inventories and spare parts supply chains in connection with man-made humanitarian disasters. It further investigates how the physical context, organizational structure and governance affect this planning.

## 2. Literature review

The research started by conducting a literature search in several academic research databases, like ProQuest, JSTOR, ISI Web of Science, EBSCO Academic Search Elite and in conference proceedings. This research focuses on how organizations plan for maintenance and spare parts inventories in connection with humanitarian operations; hence the search words became “humanitarian” and “inventory” along with “humanitarian supply chains.” The search presented very few articles concerning the specific area of interest. However, some articles have mentioned the research subject.

Oloruntoba and Gray (2006) investigate the nature of the humanitarian aid supply chain and discuss whether more standard business supply chains and in particular so called supply chain agility are relevant to humanitarian aid.

In line with this article, both Tatham and Kovács (2007), Beresford and Pettit (2007) and Pettit and Taylor (2007) have studied different aspects of humanitarian supply chains, including players' roles and activities in the supply chain as well as the decision making process and the application of lean logistics techniques.

In the more specific problem of inventory management in connection with humanitarian disasters, Beamon and Kotleba (2006-1) address the question of inventory modelling for complex emergencies in humanitarian relief operations. In another article Beamon and Kotleba (2006-2) develop their work further in the direction of developing a strategic inventory management system for humanitarian relief.

All reviewed papers regarding supply chain management, and more specifically inventory management in connection with humanitarian aid, are concerned with the management of final products. In this research the main interest is on spare parts inventories and their extension into organizational embedding in a man-made humanitarian disaster context. Spare parts inventories can be distinguished from final products inventories in the manner that demand related to spare parts is driven by maintenance (both corrective and preventive) rather than "customer usage" (Kennedy et al. 2002).

Based on an earlier literature review, it was known that only a very limited number of papers deals with the extension of inventory management into organizational management (Tysse and Halskau, 2007). In order to answer the main research question, this extension became important. Zomerdijk and Vries (2003) claim that the vast majority of research within spare parts inventories originates from the fields of operation research. Thus the concepts and techniques are mainly based on mathematical assumptions. They further claim that despite the value of the available concepts, this common background in operation research has its limitations especially regarding implementation, management and practical control of spare parts inventories.

### **3. Theoretical framework**

The main objective is to perceive how a small country's military force and an NGO from the same country plan for equipment maintenance in general and spare parts inventory and spare parts supply chain in particular. It addresses how the physical context and their organizational structure and governance affect this planning. Hence the theoretical framework must be spare parts theory as well as organization theory.

The spare parts theory should be firmly anchored within organization theory because the utilization (or non-utilization) of the spare parts theory happens within organizations planning for a humanitarian operation.

Organizations, such as the organizations and projects of this case study, are established by owners. In economic organization theory, it is claimed that it is the owners (the mandate group) who decide which goals and tasks the organization is going to have (Greve, 1995). In order to reach any preset goal, the mandate group must implement a governance system that makes sure

that the leaders and employees of the organization (in this case the relief project) implement actions to reach this goal. According to Greve (1995), the main theories that regulate the relationship between the mandate group and the organization leaders, are agency theory, modern bureaucracy theory and stakeholder theory. Hence perspectives from these theories are used in the research.

Concerning spare parts theory, one could first of all claim that the success of any government (e.g. a military force) or NGO depends on the effectiveness of the systems that they operate (Kumar et al., 2000).

Blanchard (2004) suggests that system effectiveness SE can be defined in terms of three main concepts; system performance parameters, point availability and dependability. System performance parameters can be defined as technical requirement defining for example the capacity of a power plant and so on. For simplicity, point availability and dependability can be combined into the concept of operational availability. Blanchard (2004), defines operational availability as follows:

$$A_o = \frac{MTBM}{MTBM + MDT}$$

Here MTBM is the mean time between maintenance and MDT is the mean maintenance downtime. The uptime of the system (MTBM) will be conditioned on the reliability of the system in terms of failures. Likewise, it will also be conditioned on how much preventive maintenance the system needs. The number of failures in any system has to do with the system's reliability.

Reliability can be defined as the probability that the system will perform in a satisfactory manner for a given period of time when used under specified operating conditions (Blanchard, 2004).

Support in terms of maintenance is needed also in connection with humanitarian relief operations. The mean maintenance downtime (MDT) is made up of the mean active maintenance time ( $\bar{M}$ ), administrative delay time (ADT) and logistics delay time (LDT).

The system's active maintenance time is dependent on how easy the system is to maintain (expressed as maintainability). ADT refers to that portion of MDT which maintenance is delayed due to administrative issues like for example lack of qualified technicians. Finally LDT refers to the part of MDT that is expended because of resource delays like test equipment, transportation and not least spare parts. Operational availability can now be defined as:

$$A_o = \frac{MTBM}{MTBM + \bar{M} + ADT + LDT}$$

From the operational availability formula it is observed that logistics delay time (LDT) and hence access of spare parts contribute to the availability of any system. As a consequence, access to spare parts (often based on good utilization of spare parts theory) will to a large extent govern the availability and system effectiveness and thus imply how effective a humanitarian relief operation can be conducted if equipment is a part of the operation.

#### 4. Research model and hypotheses

The research model is based upon a model developed by Vries (2005). It is, however, somewhat simplified and adapted to the fact that this research focuses on how maintenance and spare parts inventories are planned for and set up in connection with humanitarian operations, differing here from Vries's study of management of end items inventories.

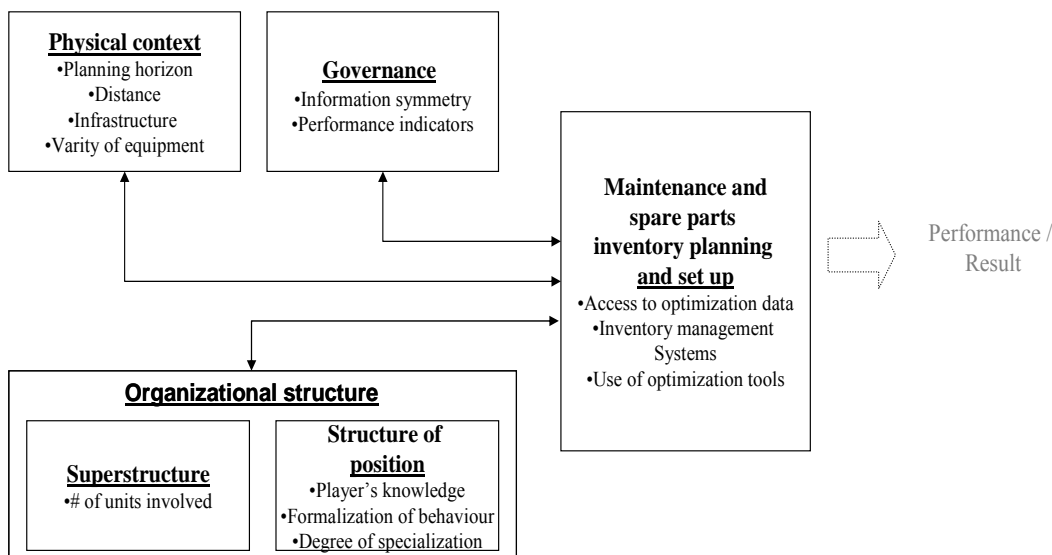


Figure 1. The research model

The main idea behind the research is close to the main idea behind the model developed by Vries (2005). It is believed that by studying the two different projects' physical context, organizational structure and governance, one will better understand and explain why the maintenance, spare parts inventory and spare part supply chain planning and set up is done the way it is done.

Further, it is believed that in the opposite direction, the maintenance and spare parts inventory planning of the two projects will influence their organizational structure and governance and maybe even the physical context.

The foci of this research was not on the performance and/or result of the chosen maintenance concept, spare parts inventory and supply chain, but rather as mentioned several times: on the

planning. Hence the performance aspect is toned down in the research model, and the connection has been drawn with a dotted line.

#### **4.1 Physical context**

In Vries's (2005) model, the physical context of inventories related to the way organizations produce goods and the way goods and materials are distributed from supplier all the way through to the customer.

The aim here, however, is to study the maintenance of equipment in man-made humanitarian disasters. Hence the physical context has to do with how the organization in question plans to organize its maintenance and spare parts inventories in the area of operation, and how the supply chain for spare parts is set up.

It is assumed that the planning horizon in terms of time available between call for help and deployment will affect the planning and set up of maintenance and spare parts inventory. Further, it is predicted that distance to the disaster response area will have an affect on how the spare parts inventory and supply chain are set up. It was also of interest to observe how the complexity and variety of equipment to be used in the operation area affected the planning process and set-up. Finally it was predicted that the operational plan and infrastructure in the disaster response area would affect the maintenance set-up and spare parts inventory setting.

Basically, it was hypothesised that the physical context of the operation in question will affect the planning and set-up. Further, in the opposite direction, the set-up of the chosen maintenance concept is hypothesised to affect at least the infrastructure needed in the disaster area.

#### **4.2 Organizational structure**

Organizational structure can be divided into two areas in connection with inventory planning according to Vries (2005).

The first area is that of superstructure. Superstructure basically has to do with the number of organizational units involved in the planning. It was hypothesised that the more units involved, the more complex planning and set-up of the maintenance and spare parts inventories. Also increased superstructure was predicted to give a less agile organization, at least in terms of response time.

The second area is that of structure of position. Vries (2005) refers to the work of Mintzberg when he divides this area into three aspects. In a somewhat simplified version, one might say that the three aspects in questions concern: 1) The knowledge and skills possessed by the players in the organizations concerning inventory planning. 2) The formalization of behaviour (e.g. in terms of Standard Operating Procedures - SOPs) within the organizations connected to planning of maintenance and spare parts inventories. 3) The degree of specialization of the planning job. Based on this, it was hypothesised that the better knowledge, formalization of behaviour and

degree of specialization that could be observed, the better focus would follow in the organization in question, regarding this part of the disaster response

### 4.3 Governance

Governance in this study concerns the relationship between the mandate group (understood as those who establish the projects in question): the project leaders (PLs) on the one hand and the maintenance- and logistic- planners on the other.

According to Greve (1995), agency theory is one of the main theories that regulates such a relationship. From agency theory, knowledge about maintenance and spare parts planning was naturally linked to studying the symmetry of information between leaders of the organization in question and the project leaders and logistic planners. According to Eisenhardt (1989), information symmetry refers to the principal (mandate group and PLs) and agent (planners) possessing the same information. Information symmetry can according to theory curb adverse selection (Eisenhardt, 1989). The argument is that since information systems will inform the principal about what the agent is actually doing, the agent will realize that he cannot deceive the principal. An important part of such an information system is assumed to be the use of key performance indicators (KPIs) used in connection with the planning for equipment maintenance and spare parts inventories. Based on the above, it was hypothesised that the better information symmetry that could be observed between project leaders and planners concerning the topic, the more focus the organization would have on the topic. Concerning use of key performance indicators (KPIs), the hypothesis was that the organization would focus mostly on those KPIs that would be expressed from the mandate group and PLs.

### 4.4 Maintenance and spare parts inventory set-up

Spare parts inventory levels in general and repairable spare parts in particular are largely a function of how equipment is used and how it is maintained.

In Sherbrooke's classical 1968 paper "*METRIC: A multi-echelon technique for recoverable item control*," a military setting is described where the problem is how to optimally stock repairable parts for aircraft at bases which are capable of repairing some, but not all broken parts, including a central depot which serves all bases.

It is important to notice that later extensions of the METRIC model include handling of non recoverable items and order quantity and reorder point questions (see e.g. Silver et al, 1998). Methods and tools based on the improved METRIC models are available through commercial software<sup>21</sup> that can typically help in the optimization of how many spares should be brought along in a humanitarian relief operation. Where they should be stored within the operation theatre, when replenishments should be made, stating how large these replenishment quantities should be.

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<sup>21</sup> See for example [www.systecon.se](http://www.systecon.se). Systecon AB sells OPUS 10, in their words a world leading software for spare parts optimization.

However, in order to use such models, certain input data are needed. First of all, one should know exactly what kind of equipment that are going to be needed in the operation. Further one should preferably have availability requirements connected to the equipment and knowledge of budget constrains connected to the set up-of the spare parts inventory if there were any. Assessment of what maintenance resources and infrastructure one could expect to find in the operation area is an important aspect as well as the operational scenario for the equipment planned to be used in the disaster area. Finally, access to equipment data and operational data along with spare part supply data (e.g. time to replenish from national stock to operational area) are important in order to conduct the best possible spare parts planning and set-up.

First of all it was hypothesised that the better the informants could answer questions connected to the above discussion, the better would their maintenance and spare parts inventory planning be. Further access and knowledge about the above mentioned data elements are needed to operate spare parts optimization tools based on the multi-echelon, multi-item, multi-indenture method. Hence it was hypothesised that the organization was more likely to use such methods if they had these data available.

Beside this, the availability and use of more standard inventory systems and communication systems used in connection with maintenance and spare parts inventories in the studied operation can be an important indicator of what system availability that the organization in question could obtain. One can hypothesis that an organization with high use of information technology (IT) also will have more formalization of behaviour and a higher degree of specialization than an organization with a lower IT utilization.

## **5. Methodology**

According to Yin (2003), the “how” questions of this study are likely to lead to the use of case studies as the preferred research strategy. Case studies are suitable when it is intended to understand contemporary complex social phenomena, such as how maintenance and spare parts planning are done in connection with man-made humanitarian disasters (Yin, 2003).

Yin (2003) states that first of all one has to make a choice between using only one case or several cases. The single-case has the advantage that a phenomenon can be studied very deeply, while the multiple-case approach looks at the phenomenon in a rougher way, but it offers the possibility to compare the findings of the different cases with each other. The rationale for a multiple-case design can be to produce contradicting results, which can be explained, based on predicted or hypothesized reasons (Yin, 2003).

Through the discussion of the different dimensions of the research model, several hypotheses are already put forward. The main research question has lead to the study of two different players in the man-made humanitarian disasters arena that might very well produce contradicting results. The players in question are a Norwegian-Swedish Engineering Battalion and the Norwegian Red Cross Transport Support Units (see section six).

Data were collected through semi structured individual interviews, observation and collection of archival data. The interviews constitute, however, the main source of data. An interview guide<sup>22</sup> was developed based on the research model and the questions presented in section four. The complete guide contained 45 questions. Each interview lasted from approximately 40 minutes to 90 minutes.

The intention was to interview approximately five to ten people from each organization, but due to the se-up of the two organizations in question (Norwegian Armed Forces and Norwegian Red Cross), the final research is based on eight interviews in the Norwegian Armed Forces and only two interviews in the Norwegian Red Cross. The reason for this is further explained in the description of the cases and in the analysis of organizational structure and governance. Each interview was taped and then partially transcribed to paper. Approximately 50 percent of the interviews were done face to face and 50 percent were done by telephone interview. The interviews together with observations and archival data were then analysed within the structure of the research model, serving to assist the when forging the main conclusion.

## **6. The cases**

According to Yin (2005), one of the most important components of a case study research is to define the unit of analysis early. The unit of analysis in this research is defined as a project, with the project defined as: A temporary organization, established by its base organization to carry out an assignment on its behalf (Vaagaasar and Andersen, 2007).

To be specific the two projects in question are a Norwegian-Swedish Engineering Battalion (after this called EngBat) planned to contribute to the United Nations peacekeeping force in Darfur and the Norwegian Red Cross Transport Support Units (after this called NoRC TSU).

### **6.1 The Norwegian-Swedish Engineering Battalion for Darfur**

The Darfur conflict is considered to be one of the world's worst humanitarian crises (UN, 2007-1). The last part of the conflict began in 2003 when a rebel group started attacking Government of Sudan targets, claiming that Khartoum was neglecting the region. Approximately 2.1 million people are believed to have left their homes, and up to 70,000 have been killed.

On 3 July 2004, the Government of Sudan and the United Nations signed a Joint Communiqué where the Government of Sudan commits to resolve the Darfur crisis and where UN commits to assist in this matter (UN, 2007-1). On 31 July 2007, in UN Security Council Resolution 1769 a plan was established for a joint force between UN and the African Union (AU) called UNAMID (UN, 2007-2). The UNAMID mandate authorizes up to 19,555 military personnel and an appropriate civilian component.

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<sup>22</sup> The guide is in Norwegian since all respondents were Norwegian. It is possible to get a copy of the interview guide by mailing the author.



The Norwegian Government together with the Swedish Government had plans to contribute a common Army Engineering Battalion to the UN Force, and through the establishment of the UNAMID mandate on 31 July 2007, these plans were highlighted (Regjeringen, 2007).

At the point of reviewing this paper (February 2008) the EngBat mission has been terminated due to political reasons<sup>23</sup>. However, the planning went all the way and the force was ready to deploy when the final cancellation came in January 2008.

The data collection was done when the planning was in its most hectic period in August and September 2007. Hence the termination of the EngBat mission has had no impact on the findings connected to this paper.

The following information has been gathered through interviews with eight officers who are working on the EngBat project. As some of the information is classified, details will not be given. In general the EngBat consisted of approximately 60% Norwegian personnel and 40 % Swedish personnel. The force was planned to operate in Darfur for twelve months. The EngBat organizationally consisted of two machine and construction companies, one maintenance company, one logistic company and one Staff Company.

The main mission for the EngBat was to build camps for the UNAMID and to contribute to the improvement of the infrastructure in Darfur in terms of for example roads. The equipment that the EngBat needed to plan maintenance and spare parts for in regard to the operation included armoured personnel vehicles, off-road vehicles, trailers, semi-trailers, standard dump trucks, off-road dump trucks, excavators, front loaders, motor graders, special tractors, bulldozers, drilling machinery, heavy lifters rescue trucks, gravel making machinery and so on. The informants presented detailed plans on what equipment which the force needed to bring along.

## **6.2 The Norwegian Red Cross Transport Support Units**

The operations in humanitarian disaster abroad are managed by the NoRC Head Office in Oslo, through its Emergency Department. The Emergency Department consists of four sections, where the Logistic Section will be responsible for planning for equipment maintenance and spare parts inventories for most material/systems used in projects/operations lead by the NoRC in a humanitarian disaster.

The Logistics Section is a small section consisting of only six persons (Section Head, three logistic coordinators and two warehouse workers). The following information has been collected through interviews with two of the logistic coordinators in the section and through archival material (Norges Røde Kors, 2007). Hence the information used in the analysis is based on the

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<sup>23</sup> The Government of Sudan refused to let the Norwegian-Swedish EngBat be a part of UNAMID, and hence the fully equipped and trained force could not be deployed.

informants' point of view and might not be 100% in line with the opinions of for example the International Red Cross.

The NoRC has specialized in setting up field hospitals and so called transport support units (TSU). A TSU is considered by the NoRC as a concept or project that delivers personnel and transport units in order to transport humanitarian aid items from a seaport or airport close to a humanitarian disaster area and into that area. The package can also be used to transport refugees out of a disaster area. Even though a TSU could theoretically consist of any type of vehicle, the vehicles used by NoRC are in reality the old ex- military M-621 Cargo Truck which have been donated in numbers of more than 1000 from the Norwegian Armed Forces<sup>24</sup>.

In the timeframe from 2004 until 2006 nine TSU projects have been planned, carried out and terminated. In these nine operations, 527 M6 trucks have been used, and according to NoRC they have transported 237,674 tons of food and other aid items, as well as transporting 48,000 refugees in connection with the Darfur conflict mentioned in the last section (Norges Røde Kors, 2007).

The next chapter focuses on one of these projects/operations, but the findings in regard to planning for maintenance and spare parts are more or less common for all operations.

## 7. Findings and discussion

In the following all sections start with a table that shortly sums up the main finding for every major research dimension connected to the variable in question. Then the implications of the findings are discussed in connection with the hypothesis put forward earlier in the paper.

### 7.1 Physical context

Table 1. Short summary of findings regarding physical context

	EngBat	NoRC - TSU
Planning horizon	Months	Days to weeks
Impact of distance to disaster response area	Large	Medium
Complexity and variety of equipment	Large variety – high complexity	Low variety – low complexity
Impact of operational plan and infrastructure	Bring along everything	Use of local resources

The planning horizon dimension gave significant differences between the two cases. This difference had, as hypothesised, an impact on how the maintenance and spare parts inventories and supply chains were planned for. The Norwegian defence started their planning in connection with EngBat in the fall of 2006, and as one of the informants working with procurement of new equipment for the operation said:

<sup>24</sup> The trucks were earlier partially given to Norway by the USA, and hence the gift to NoRC had to be approved.

*“At that time we were supposed to be in Darfur in January 2007, and at that time we wouldn’t even have had some of the main material ready to among other things, the procurement lead time for some of the engineering systems, so luckily for us this decision did not come.”*

The EngBat informants stated that the time needed from the political decision of deployment until the final deployment was approximately four months. Talking to NoRC regarding one of the TSU operations, where 50 M6 trucks were deployed to Kenya in 2006, the informant said that:

*“From the first request until we shipped the trucks, six weeks went by, but this is not the norm. Since this was a draft disaster we had more time available than if this had been sudden onset disaster.”*

Even though the Kenya operation is not in a man-made humanitarian disaster area, it can be compared because it has a slow onset in the same way as the Darfur operation of the EngBat. It is clear that the studied NGO case is used to responding much faster than the military organization studied, and in their eyes (the NGO) this reduces the possibility for spare parts inventory planning. However, it can also be argued that since the NoRC deploys the same type of TSU units every time, they could prepare a general concept well in advance that only needed a very short time to be set up for a specific context.

On the question of whether the distance to the disaster area and geographical location of the disaster area have had any impact on the planning and set up, the informants from the two organizations again had somewhat different views. In the EngBat case this was a major part of the planning. The EngBat plan was to be self-sufficient for the first 90 days in the operation area regarding technicians, maintenance equipment and spare parts for all systems. Nevertheless, they also planned the set up of a regular chartered flight from Norway once a week into the operation area. This flight would carry, among other things, spare parts and if needed, technical specialists. The NGO on the other hand had no plans for regular flights. This would, according to the informants, be done on a more ad hoc basis. In other words, distance does have an impact but not in a given direction.

The two cases more or less reacted in opposite directions even though the distance to the operation area was equivalent. It is believed that the complexity in terms of equipment brought along strongly influence this difference in planning and set up. The case descriptions in chapter six clearly show that there was a vast difference between the NoRC TSU and the EngBat. The latter had a wide variety of equipment, much of it new and complex in terms of both operations and maintenance. The M6 trucks used by the TSU on the other hand is as one of the NoRC informants expressed:

*“A very simple truck with almost no electronics at all, and therefore very suitable for local repair in the disaster area”.*

The findings are very clear examples of a combination of dimensions within the physical context, highly affecting the maintenance and spare parts inventory planning for the organization

in question. It is also interesting to observe how the infrastructure in the disaster response area affected the maintenance set up and spare parts inventory setting. Again the two cases studied attack this issue differently. The EngBat, as mentioned above, bring along almost all capacity needed within their own force. This can be illustrated by a comment from one of the informants when talking about a possible reduction in the number of personnel contributing to the force:

*“There is one thing we all agree on, and that is that we can not reduce the number of maintenance and logistics personnel and infrastructure that we are bringing along.”*

On the other hand, the NoRC TSU seems to have another approach, which they also need to possess because within logistics in general and maintenance in particular they have very limited resources. The concept they use is so called representatives. A representative is a volunteer within for example maintenance and/or logistics. In the Kenya operation the informant said:

*“We only sent out one maintenance representative together with the trucks, because the plan was to use local people whom this representative had to train.”*

The findings here clearly points to the fact that the maintenance concept and the spare parts inventory concept of the organization in question affects the physical context as well as visa versa.

## 7.2 Organizational structure

Table 2. Short summary of findings organizational structure

(Superstructure)	EngBat	NoRC - TSU
# of organizational units involved	Many	Few
(Structure of position)	EngBat	NoRC - TSU
Actors knowledge and skills	Medium to high	Medium
Degree of specialization	High	Low
Formalization of behaviour (e.g. SOP)	High	Low

The study of superstructure presented some interesting findings<sup>25</sup>. First off, the total structure of the armed forces in Norway cannot be introduced here, but simplified one can say that at the top level the Ministry of Defence (MoD) governs the political part and the Defence Staff governs the military part. The National Joint Headquarters (NJHQ) leads the operative branch of the Armed Forces. Further, the Norwegian Defence is divided into the following defence branches: The Army, the Navy and the Air Force. In addition, the Armed Forces have a number of joint departments that support the operative needs, and the Norwegian Defence Logistics Organisation (NDLO) is the largest one of these.

<sup>25</sup> The EngBat is set up by the Norwegian Government and the Swedish Government as a joint force, however only the Norwegian side of the force was researched in this study.

Most of these organizations are actually involved in the planning and set up of maintenance and spare parts inventories for the EngBat. In this case, the NJHQ dictated the operational requirements towards maintenance and spare parts together with the operational personnel who mostly originated from the Army. The MoD together with the NDLO have organized a separate material procurement project to procure new material including spare parts. Other parts of the NDLO planned the maintenance operation, planned and built the spare parts inventories and actually manned much of the logistic company of the battalion. A large and complex coordination- and meeting- activity was thus needed between the different Norwegian Defence organizations in order to establish the operation.

On the other side of the spectrum, the number of departments involved in the planning of maintenance and spare parts inventories in the NoRC TSU operation is rather limited. Most of the work is here executed within one or two sections of the Emergency Department. As one of the informants said when asked whether the leadership in the NoRC was interested in this type of logistics.

*“They are interested, but more in what I would call the political side, they are not that interested in the practical side of things”.*

The findings from the two cases clearly show that superstructure influences how the maintenance and spare parts inventories are planned and set up. The large number of departments involved in the planning in the EngBat case compared to the NoRC TSU case clearly increased the complexity of the planning process, but also made it possible to get a feasibly better result and at least a more complex and worked through maintenance and spare parts inventory concept.

In connection with structure of position, the two cases in the study also had rather large differences. When asked, all eight informants connected to the EngBat case and the two informants in the TSU case reported that they had some knowledge regarding maintenance and spare parts inventory planning. When asked about the formal education towards the subject only few of the informants within each case had higher university or college degrees, and only one of the informants (from the NoRC) actually had a master’s degree connected to logistics. The lack of higher degrees in logistics in the EngBat case seems to be possibly set off by the fact that the total organization involved in the planning is so much larger than in the TSU case, and thus somewhat offsets this negative fact. However, for both cases the lack of higher formal education in logistics may contribute to partially explain why not any of the organizations used optimizations methods and tools in the sparing process (see section 7.4).

Regarding the use of standard operating procedures (SOP), the EngBat possesses several procedures for how to plan for the operation and combine the force, but the informants reported on lacking procedures when it came to the question of building the spare parts packages. One of the informants said:

*“We built this spare parts package on a week-end using our own experience in what we think will be needed and a simple excel spread sheet”.*

In the NoRC TSU case the organization concluded in an internal report (Norges Røde Kors 2007) that they needed to improve their operating procedures. Moreover, one of the informants reported that they were not good enough at learning from those who operate and maintain the equipment in the disaster areas:

*“I have sometimes traveled into the disaster area in order to get information, because it seems like the challenges with maintenance and spare parts are forgotten when the representatives come back home”.*

Findings are in line with the hypothesis put forward in chapter four. Both superstructure and structure of position clearly influenced how the two case organizations humanitarian aid projects planned and set up their maintenance and spare parts inventories.

### 7.3 Governance

Table 3. Short summary of findings regarding governance

	EngBat	NoRC - TSU
Information symmetry between planners and leaders	Medium to high	Low to medium
Key performance indicators	Focus on “having enough”	Response time rather than sustainment

From the data collected in the two cases, the information symmetry between organizational leaders and maintenance- and logistic- planners and key performance indicators connected to maintenance and spare parts inventory planning seems different. The informants connected to the EngBat report that they are asked about this kind of information from every level in the organization. The focus is, however, more on “having enough” than on what this costs. As one informant put it;

*“We do have a budget, but this has not been an issue with how we build the spare parts packages for the equipment which we already operate in the organization. The reason being that we already have spare parts on the shelves here at home”.*

The informants in the NoRC TSU case reported that the management was more interested in how quickly they could respond to a call for a TSU unit rather than whether they had an efficient maintenance and spare parts concept ready. Again we apprehend clearly that governance in terms of information symmetry regarding maintenance and spare parts inventories, along with use of key performance indicators (KPIs) have a major impact on the planning and set up. However, the chosen KPIs impacted greatly on how the two project cases chose to solve the planning and set up issues. Based on this, one can claim that if system operational availability is important for the organization I question, this needs to be clearly communicated throughout the organization, and specific KPIs needs to be developed.

#### 7.4 Maintenance and spare parts inventory planning

Table 4. Short summary of findings on maintenance and spare parts inventory planning

	EngBat	NoRC - TSU
Operational availability -, maintenance – and infrastructure - requirements	High	Low
Structuring and set-up of spare parts supply chain	High focus – weekly flights	Ad hoc basis
Data available to use multi-echelon, multi-item, multi-indenture sparing	Yes	Maybe
Availability and use of standard inventory management systems	Yes	No
Use of optimization tools today	No	No

In order to plan for maintenance and decide which spare parts one need in a humanitarian operation, it is of course essential that the planners know exactly what equipment the organization is going to operate in the disaster area. In our two cases the TSU operation was rather straightforward in this respect, because the operation consisted of only one type of equipment, namely the M6 truck.

On the other hand, the EngBat case was far more complex when it regarding types of equipment. However, the planners still knew almost exactly what kind of equipment they were going to operate. According to the informants, the main challenge in the EngBat planning had to do with, equipment being procured specially for this operation. This challenge came about due to the fact that spare parts planning for the new equipment was not done by those who normally plan the spare parts package for the operation. One of the informants expressed this in the following way;

*“I am worrying a little about the procurement project set up for this operation, I think they might only buy the off-road lifters and not include the spare parts needed to operate the lifters in Darfur”.*

When the procurement project was confronted with this information, the informant said that due to short time frames they did not follow the Norwegian Defence’s normal procedure for material procurement, but that they still planned to buy spare parts. Hence the procedure for spare parts optimization based on the multi-echelon, multi-item, multi-indenture method, which at least officially, is part of the normal defence concept, was not followed.

Part of the research was to investigate whether the organizations had available data that would make it possible for them to perform spare parts optimization in line with the multi-echelon, multi-item, multi-indenture approach shown through 40 years of research to be very important in connection with building spare parts inventories (see e.g. Kennedy et al 2002). The finding clearly indicated that in the EngBat case, all data needed to conduct such an optimization analysis was available. In the NoRC TSU case on the other hand, one would lack data concerning both supply chain lead times, as well as equipment operational data. However, since the M6 truck used by the NoRC TSU are ex military trucks, operational data could probably be transferred from the military and used as a substitute.

Based on the research model's focus on especially structure of position, the earlier findings indicate that out of the two case organizations, the EngBat should probably have the best organizational embedding for optimal utilization of methods and tools in question. However,, when asked about whether optimization tools or software were used in connection with the planning of maintenance and spare parts inventories, all but one of the informants had never heard of these kinds of tools. The one informant that had heard of such tools was interviewed in connection with the EngBat project, and his comment was;

*“I know there is a tool called OPUS that the Norwegian Defence has, but I think this is only being used in some procurement projects and we have definitely not used it”.*

This indicates that an organizational possibility alone is not enough. Focus from the mandate group in terms of for example alignment of information, key performance indicators connected to the issue and increased knowledge at all levels of the organization is needed if the mandate group wants the organization to follow the goal of using spare parts optimization method and tools. It is emphasized that in the case of this research, focus has not been whether this is something the mandate group wants or not.

In order to collect information on for example mean time between failure, and maintain control over spare parts inventory in the operation area in terms of spares left, reorder points and so on, the organization operating in the disaster area needs an inventory system. The simplest form of inventory system would be a manual system without the use of information technology, while on the other side of the spectrum one could operate an integrated system with the mother organization integrated via for example satellite communication. It was discovered that the NoRC TSU operated in the disaster areas with no system or systems based on spreadsheets on stand alone portable computers. The EngBat on the other hand brought along a replicate version of the system used back home, and would either update the total system via file transfer or as one informant said;

*“If we are to stay longer than the twelve months initially planned, we might update with a satellite communication kit which makes it possible for us to be online on the systems back home just as if I were working in my office in Norway.”*

Again the findings are clearly in line with what was hypothesized in chapter four of this paper.

## **8. Conclusion, limitations and future research**

The physical context of the operations studied clearly influence how maintenance and spare parts inventories are planned, but also vice versa. However, the findings also show that the organizational structure and governance in the organization in question are more important than physical context regarding how the maintenance concept, spare parts inventory and spare parts supply chain are planned for and set up.



The findings in connection with the harder core part of maintenance planning and spare parts inventories showed that the two organizations studied had what one might call different maturity levels when it comes to inventory control issues. The conclusion is that the logistics organization connected to the EngBat case is more advanced when it comes to maintenance planning and spare parts inventory planning than the logistics organization connected to the NoRC TSU. Based on the findings connected to organizational setting and governance in each of the case organizations, this was not surprising. It also clearly shows that the research model is a helpful tool in the evaluation of maintenance and spare parts inventory planning.

The findings further revealed that all data for spare parts optimization, based on the multi-echelon, multi-item, multi-indenture method are available at least in the EngBat case. However, these tools and methods are not used and actually almost unknown for those who are in charge of the planning for maintenance, spare parts inventories and spare parts supply chain in the two case studies. For the EngBat case, this finding is somewhat puzzling, knowing that in the Norwegian Defence there exists an optimization tool based on the mentioned method. However, the finding is clearly in line with the claims of Huisken (2001), who alleges that it has not been easy to transfer research results into managerial practice and thus so called “rules-of-thumb” sparing decisions and management are still popular in managerial practice.

One could argue that there are limitations to this research. First of all only two cases have been researched and evaluated against the hypotheses put forward based on the research model. Studying more cases could strengthen the research. Further the research is based on qualitative data, and hence it has not been possible to reject or accept the hypotheses based on statistically verified methods. However, it can be argued in the opposite direction that the use of qualitative data might give us a more in depth view something quantitative data from a questionnaire could not have given.

In future research the research model could be developed into a template in such a way that an organization that will contribute with equipment needing maintenance and spare parts for a humanitarian operation can map the physical context of the operation in question, together with their own organizational structure and governance. This way the organization in question can better estimate which methods and tools they should utilize. Further one could also better evaluate if the organization could benefit from a change to their own organizational setting and governance in order to use the methods and tools (e.g. multi-echelon, multi-item, multi-indenture spare optimization) that at least theoretically gives the best possible equipment availability for the lowest possible amount of money.

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## **Paper III**

### **Spare Parts Optimization Process and Results**

#### **OPUS10 Cases in the Norwegian Defence**

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## **PAPER III**

# **Spare Parts Optimization Process and Results OPUS10 Cases in the Norwegian Defence**

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## Abstract

*Purpose of this paper: The first research question focused on how the spare parts optimization process had been conducted in the Norwegian Defence procurement projects that had used the system approach based on OPUS10, and whether coordination issues affected the process and results. Secondly, empirical data were analysed in order to evaluate whether the theoretical claim of the system approach used through OPUS10, being better than other methods in terms of availability and spare parts investment cost holds up in reality.*

*Design/methodology/approach: Both qualitative and quantitative methods were used in order to answer the different questions of the study.*

*Findings: Very few Norwegian Defence projects have used the system approach through OPUS10. Empirical data however comply with the theoretical claims of potential large savings in spare parts investment cost and/or improvement in operational availability. Several organizational factors can explain the lack of use of OPUS10. The most important being lack of resources, lack of a centralized concept and a somewhat low project leader attitude towards the approach.*

*Research limitations/implications: The study of Norwegian Defence cases makes generalizations of findings not applicable. The research model could however easily be transferred and utilized in the study of other organizations' spare parts optimization processes.*

*Practical implications: The Norwegian Defence should alter their concept for project governance and management in order to gain the full potential of the system approach used through OPUS10.*

*What is original/value of paper: Few research papers have evaluated the promising theoretical findings of system based optimization based on empirical operational data. Even fewer, if any, studies have used a combination of factors from organization theory, economic organization theory and operation management theory in order to explain findings based on predefined hypotheses. This research should have value for both practitioners and researchers within the field spare parts optimization in general and systems management in particular.*

*Keywords: Projects, Defence, Spare parts, Cost, Operational availability, Organizational coordination*



## 1. Introduction and research questions

Approximately 33 percent of the annual defence budget in Norway<sup>26</sup> is connected to investments (Prinsix, 2008). In an attempt to secure cost effective use of this large amount of money the Norwegian Defence has developed a concept for project governance and management called PRINSIX (Prinsix, 2008). PRINSIX was given authority as the official project management system in 1996. PRINSIX is now based upon the international acclaimed Project Management Body of Knowledge (PMBOK)<sup>27</sup> in addition to the unique Norwegian military experience.

PRINSIX consist of four main areas, with maybe the most important area being the methodological approach consisting of a decision model, a governance model, knowledge areas and document templates. One of the knowledge areas is integrated logistics support (ILS). ILS was first developed by the US Department of Defence because their military material projects had been completed later than planned and at a higher cost than budgeted (Kumar et al., 2000).

ILS is a tool for making sure that the cost of operating, servicing and retiring equipment can be kept at a minimum in the same time as equipment performance requirements are met (Blanchard, 2004). In order to achieve this goal of “bigger bang for the buck”, the ILS method is divided into ten elements<sup>28</sup> that separate the logistic chain into manageable chunks (Farmer et al., 2003). Spare parts provisioning and management is one of the most challenging problems in the whole ILS process (Kumar et al., 2000). Earlier Norwegian defence directives have stated that approximately five percent of total system investments should be used for spare parts covering approximately two years of operational needs (PS2000, 1995).

In a research project from 1995, it was shown that Norwegian Defence procurement projects have made investments in spare parts that are never used. The reason for this is, among other things, that they have accepted system suppliers’ spare parts suggestions without evaluating the suggestion based on the so called multi-echelon, multi-item, multi-indenture method (PS2000, 1995). In the same research, the Norwegian Defence was recommended to start using the multi-echelon, multi-item, multi-indenture optimization software tool called OPUS10<sup>29</sup> (PS2000, 1995).

More than ten years have gone by since the Norwegian Defence introduced PRINSIX as the official project management system and since OPUS10 was chosen as the spare parts optimization tool. In the same time period there has been a growing attention for management and organizational related issues both in academia and industry. Nevertheless the area of inventory management still seems to lack a clear linkage between planning and control issues on one hand and organizational issues on the other hand (Vries, 2005).

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<sup>26</sup> The total defence budget was plus 30 billion Norwegian Kroner (NoK) in 2007.

<sup>27</sup> See; [www.pmi.org](http://www.pmi.org)

<sup>28</sup> The ten elements in question are: maintenance planning; supply support (mainly spare parts provisioning and management); design interface; packaging, handling, storage and transportation; manpower and personnel; support equipment; technical data; training and training support; facilities and computer resources support.

<sup>29</sup> See [www.systecon.se](http://www.systecon.se)

It is believed that in the spare parts process of the different procurement projects, organizational issues such as coordination problems both within the organization and towards the supplier might affect both the process and the final result.

Based upon the above, the first research question becomes: How has the spare parts optimization process been conducted in the Norwegian Defence procurement projects that has used OPUS10, and has coordination issues affected the process and results? Secondly, does empirical data show that the multi-echelon, multi-item, multi-indenture method solved through OPUS10, improves system availability and/or spares parts investment cost compared to the system supplier's suggestion?

## **2. Literature review**

A large body of literature exists on spare parts inventory theory. Two major review papers are Guide and Srivastava's (1997) paper on repairable inventory theory and Kennedy et al.'s (2002) paper regarding general spare parts inventories.

According to Guide and Srivastava the classical repairable inventory problem and the multi-echelon models dates from the military. Guide and Srivastava reviewed 42 papers regarding multi-echelon models, covering the timeframe from 1968 to 1996. Kennedy et al. have a reference list of 61 papers included in their review.

Tysseland and Halskau (2007) have a literature review with a special focus on initial provisioning and obsolescence management. This paper pay respect to earlier review papers and focuses especially on the timeframe from 2001 to 2007. A new focus in this paper is the effort done in finding empirical studies connected to the use and implementation of spare parts inventories. The authors found only five papers on the topic even if papers from before 2001 were included. The last of these five papers, a paper by Zomerdijk and Vries (2003) extend inventory control into organizational management.

Zomerdijk and Vries (2003) claim that the vast majority of research within inventories originates from the fields of operation research, and thus the concepts and techniques are mainly based on mathematical assumptions. They further claim that despite the value of the available concepts, this common background in operation research has its limitations especially in implementation, management and practical control of spare parts inventories.

In this review, no further papers were found connecting the specific of spare parts inventory theory into organizational issues. One literature review paper by Wong et al. (2004) regarding general supply chain coordination problems proved however to be important for this research, and this will be further elaborated in the next chapter.

### 3. Theoretical framework

The research questions dictate that the theoretical framework must be both spare parts theory and organization theory. The spare parts theory should be firmly anchored within organization theory, because the utilization of the spare parts theory happens within an organizational setting.

Coordination of the spare parts optimization process is needed both within the organization itself (e.g. between project leader (PL) and the project's ILS manager called Project Coordinator ILS (PC ILS)) and with the project's supplier(s). According to Van de Ven et al. (referred in Wong et al., 2004), coordination is defined as the integration or linking together of different parts of an organization to accomplish a collective set of tasks. Lack of coordination causes many problems, but primarily affects organizational or economic effectiveness and efficiency (Wong et al., 2004).

In the case of this research it is believed that lack of coordination in the spare parts optimization process can lead to at least two main problems; First of all one can get less system effectiveness in terms of low system availability. Secondly one can get low system efficiency by spending more money than needed on spare parts in order to achieve a preset availability goal.

Wong et al. (2004) have looked at the coordination problem from three different theoretical standpoints, namely organization theory, economic organization theory and operation management theory. All three theories recognize the source of coordination problems as lack of information symmetry, lack of centralized decision making, uncertainty and interdependency. Further, especially within economic organization theory, limited rationality and behavioural issues are identified as important sources for coordination problems. Based on this, six causes for coordination problems are included in the research model.

It is assumed that when systems with long life cycles are procured, system owners are faced with the challenge of achieving high system effectiveness (high performance and high availability) with low life cycle cost (LCC).

If the performance measurement is acceptable, the challenge becomes how to achieve high availability in terms of having as few systems as possible that are *Not Operational Ready* (NOR). NOR as a measure of effectiveness in spare parts optimization is not the best solution. Thus in literature<sup>30</sup> it has been shown by a chain of equivalence that minimizing NOR is equivalent to minimizing the *Number of Back Orders* (NBO). One could of course minimize NBO by buying an infinite amount of spare parts  $S$  at cost  $C$ . In most procurement projects however there will be a budget restriction  $b$ . All systems consists of several sub systems, here denoted by  $k$  such that a system is a sum of  $k=1, \dots, K$ . In the simplest version with one indenture level and one site the problem can be defined as:

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<sup>30</sup> See e.g Alfredsson, 1997.

$$\min \sum_{k=1}^K NBO_k(S_k) \quad s.t. \sum_{k=1}^K C_k S_k \leq b \quad S_k \geq 0 \text{ and integer}$$

Looking at the minimization problem we see that it is not intuitively for anybody to decide which spare parts in what numbers are best to buy in order to minimize the number of back orders given the budget available.

The problem is called an integer knapsack problem, and this problem has been solved in literature and spare parts optimization software such as OPUS10, by utilizing an algorithm called marginal allocation. Further details of the marginal allocation solution and how the expected NBOs are calculated in OPUS10 will not be given here<sup>31</sup>.

In OPUS10 the complexity of several multi-indenture systems being supported by a multi-echelon support system is taken into consideration. In many real life approaches to spare parts selection, some acknowledgement of the knapsack problem is maybe present, but the solution need not be given by a system based optimization process.

In a publication by Systecon (2002) a simple test case<sup>32</sup> is used to illustrate the challenge of deciding the number of spare parts to buy based on four different approaches. The four approaches are; random choice, same of each, constant confidence against stock out and the system approach based on OPUS10.

In the random choice approach a random number of spares from 0 to 10 is chosen for each line replaceable unit (LRU), giving  $11^{10}$  possible combinations (hopefully not much used).

The second approach is known to be used in procurement projects in the Norwegian Defence. This approach basically means that you buy the same of each LRU (often one).

The third method is more sophisticated because it takes into account the utilization factor, failure rate per LRU, number of LRUs per system and turn-around times (TAT) for repair of the LRU when the expected demand is calculated. All LRUs are then calculated to the quantity that meets a given confidence level (e.g. 95%) for not having a stock out during a certain period of time. The main challenge with this method is that unit price of the LRU is not included in the calculation. If unit price for each LRU is the same then this method is close to optimal. We know however that in real life this is not the case, and the effect of unit price should be considered, especially since in most cases there is a limited budget for spare parts.

<sup>31</sup> The interested reader could e.g. consult Alfredsson (1997).

<sup>32</sup> The case consisted of 50 systems, one echelon, ten LRUs (one indenture level, 5 LRUs with two per system) with associated, system utilization, failure rates and turn-around times for LRU repair. One of the LRUs is more than ten times as expensive as the others.

Below is a figure showing the results on availability and cost for different stocking alternatives for the three last methods (Systecon, 2002).

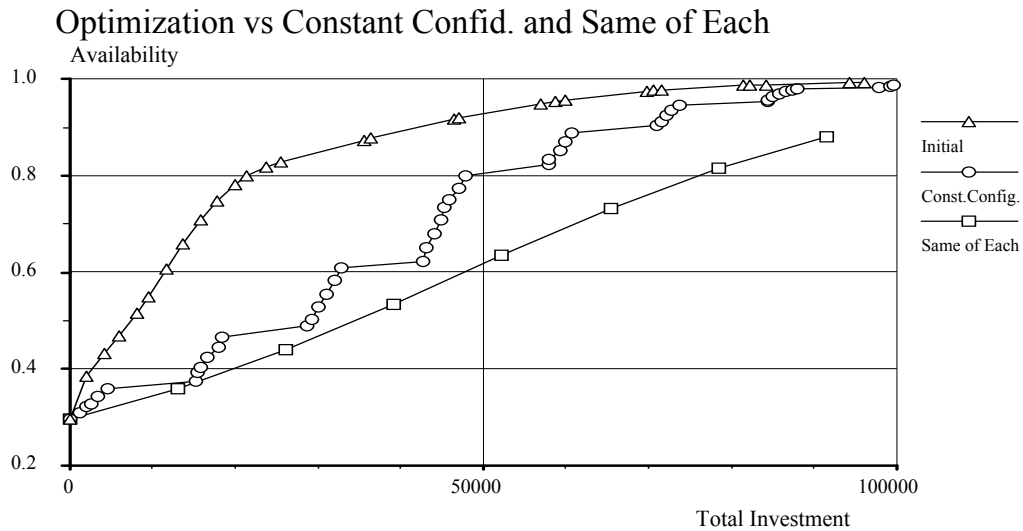


Figure 3.1 Three alternative methods for spare parts dimensioning

As can be seen, the system based optimization method based in OPUS10 (indicated as “Initial” in figure 3.1) is by far the best in this hypothetical case. Based on this the research questions stated in chapter one becomes very important.

#### 4. Research model and hypotheses

The research model is based upon the six causes for coordination problems (or coordination factors) extracted from organization theory, economic organization theory and operation management theory (Wong et al., 2004).

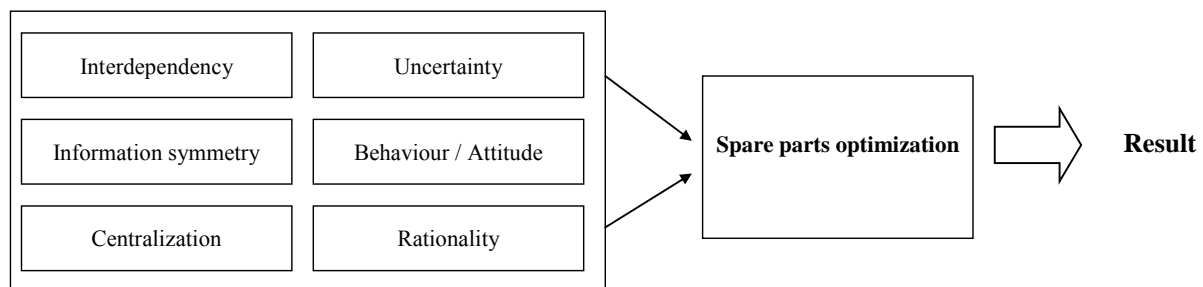


Figure 4.1 The research model

Addressing the first research question, it is believed that by studying the different projects' coordination factors one can better understand how the spare parts optimization process has been conducted and whether coordination issues have affected the process and results.

Project uncertainty and interdependency are defined within the physical context of the project in question. Project uncertainty can lead to coordination problems in the spare parts optimization process, resulting in less use and diminished results. Low uncertainty can lead to less coordination problems, which means better spare parts optimization. Project uncertainty could be studied by looking at the number of tasks in the project, and the uncertainty connected to the tasks. In this study, spare parts optimization is looked upon as one large task with associated sub tasks and uncertainty connected to it. In order to conduct a valid spare parts optimization, trustworthy input data in terms of for example validated failure rates are needed. Based on this, uncertainty is firstly defined as whether the system procured can be acquired so called "commercially off the shelf" (COTS), or whether it has to be developed specifically (high asset specificity). It is assumed that COTS systems indicate a better possibility for access to needed input data than asset specific systems. This is because COTS systems are most likely to be in use by others and validated operational data can more easily be acquired by the project. This will reduce the risk of data input error in the optimization. If the system is not in use by others, or failure rates can not be obtained, the risk of making incorrect calculations will increase. Further the size of the task including sub tasks will affect uncertainty. A small project with few LRUs connected to it will be less uncertain than a large and complex project. Regarding project uncertainty the following hypothesis is proposed:

*Hypothesis 1: High project uncertainty can lead to lower use of spare parts optimization based on OPUS10.*

Coordination problems based on interdependence are due to scarcity of resources or scarcity of information or a combination of the two (Wong et al., 2004). This dimension is placed within the frame of physical context because in terms of spare parts optimization the project in question can either get access to all needed information (e.g failure rates) through open sources or they must rely on the system supplier. In the same direction the project can have access to needed resources, for example in terms of personnel with knowledge of spare parts optimization, within their own organization or they must get this outside their own physical context.

*Hypothesis 2: Low control over resources and information connected to spare parts optimization will negatively affect the use of OPUS10.*

Governance and organizational structure is closely connected to the research question on how the optimization based on the system approach has been conducted. Four possible reasons for coordination problems that can hamper the optimization process are included within this frame. The four dimensions in question are information symmetry, centralization, behavioural issues (attitude) and rationality. Symmetry of information between the PL and the PC ILS is of interest. According to Eisenhardt (1989) information symmetry refers to the principal and agent possessing the same information and information symmetry can thus curb adverse selection. The argument is that since information systems can inform the principal about what the agent is actually doing, the agent will realize that he cannot deceive the principal. In this case information symmetry can also be between the project and the main spare parts supplier. According to Wong et al. (2004) the more complete, timely, observable and verifiable information one has, the less possibility for coordination problems and the better result. Based on this the following two hypotheses are suggested:

*Hypothesis 3: Low information symmetry between PL and PC ILS regarding spare parts optimization will negatively affect the optimization. Hypothesis 4: Low information symmetry between spare parts provider and project regarding information needed for spare parts optimization will negatively affect the optimization.*

According to theory centralized decision making will reduce coordination problems. In this context centralized decision making could be done through the utilization of a common concept for spare parts optimization implemented through PRINSIX, and followed up by key performance indicators (KPI). A decentralized version would be to let each PL decide how to perform the spare parts optimization process and setting of spare parts inventory control variables (e.g reorder points).

*Hypothesis 5: Decentralization will negatively affect spare parts optimization based on OPUS10.*

In this research the concept of rationality is defined as a ratio between the cognitive capability of the decision maker and the complexity of the problem in question (Heiner, 1983 in Wong et al.,

2004). The decision maker has absolute rationality when his/her cognitive capabilities completely match the complexity of the problem. Complete rationality rarely happens in an organization; instead rationality is limited or bounded due to the complexity of the problem (Wong et al., 2004). Bounded rationality may lead to the use of rules of thumb in the decision making process, such as in the decision process of spare parts.

*Hypothesis 6: The more complex the system becomes compared to the decision maker cognitive capability, the more likely are the decision maker to use rule of thumb sparing.*

Traditionally project success is measured on the triple constraints; time, budget and overall quality (Gemünden et al., 2005). However the triple constraint has often only included the pure project phases, not the operation & support phase. If for example the PL and/or PC ILS think that their future (for example promotion) is based on the fact that the procurement project is finished on time and within the original investment budget, their attitude towards the use of spare parts optimization might be less positive. This is because the focus in spare parts optimization is on operation and support cost and availability in addition to the traditional triple constraint. PLs and PC ILS acting in what they think are their self-interest at the expense of the Norwegian Defence overall interest is called adverse selection (Eisenhardt, 1989). However it is hard to measure such behaviour by questions. Based on this, a substitute in terms of the PC ILS' general attitude towards the use of life cycle cost based methods (such as spare parts optimization based on OPUS10) is used as an indicator. Negative attitude is not necessarily a sign of bad will, but can be the effect of for example lack of information. The following hypothesis is proposed:

*Hypothesis 7: Positive attitude towards the use of LCC and spare parts optimization based on OPUS10 will positively affect the use.*

## **5. Methodology**

The second research questions regarding the result of OPUS10 based spare parts optimization leads us in the direction of a quantitative data analysis and hence the need for quantitative data.

The first research question (the how question) on the other hand leads us in the direction of case studies as the preferred research strategy (Yin, 2003). The qualitative data was collected through semi structured individual interviews including sets of structured questions and by obtaining archival data. An interview guide<sup>33</sup> was developed based on the research model, containing 76 questions, where 36 questions were in a structured format. Each interview lasted approximately 90 minutes.

The intention was to interview the main responsible for the spare parts optimization process in each of the projects where OPUS10 had been used since year 2000. As can be seen in the next chapter, the total number of projects was no more than nine. Some of the responsible persons in

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<sup>33</sup> The guide is in Norwegian since all informants were Norwegian. It is possible to get a copy of the interview guide by mailing the author.



these nine projects had left the Norwegian Defence, but it was still possible to get interviews with persons connected to the optimization process in eight out of the nine projects. Each interview was taped and main phrases transcribed to paper. Six interviews were done face to face and the last three interviews were done by speaker phone. Nine interviews in eight projects were conducted, because in one project two responsible persons, one from an earlier stage along with the one responsible today were interviewed. The interviews together with archival data were then used to answer/explain the predefined hypotheses.

The quantitative spare parts data was collected by getting access to project databases and files along with the management systems of the Navy, Army and Norwegian Defence Logistics Organisation (NDLO).

## 6. The cases and standard spare parts procedure

Since OPUS10 already in 1995 had been recommended as the main tool for spare parts optimization in the Norwegian Defence (PS2000, 1995) one should believe that there were many projects to get data from. In the Norwegian Defence Project Database there are currently several hundred projects, with an annual investment amount of approximately ten billion Norwegian Kroner (NoK).

In the search for cases, administrators for this database along with those responsible for the current contract with Systecon AB (OPUS10 provider) were contacted. This led to contacts with those very few (compared the total number of projects running) projects that in the later years have used OPUS10 in the spare parts optimization process. More specifically it was found that no more than approximately nine projects had used OPUS10 since the late nineties.

Since much of the information provided by the Norwegian Defence in their eyes are sensitive, all projects and informants are kept anonymous and given pseudonyms. Out of the nine projects identified to have used OPUS10 over the last ten years, data have been collected from eight of them.

Table 6.1 Case projects characterization

Project pseudonym	High cost project (> 500 million NoK)	Customer:	Life Cycle Phase	Operational data available
NA	No	Navy	Operational	Yes
NB	Yes	Navy	Procurement	No
NC	Yes	Navy	Procurement	No
AA	No	Army	Operational	Yes
AB	No	Army	Procurement/Operational	No/Little
AC	No	Army	Procurement/Operational	No/Little
FA	Yes	Air Force	Procurement	No
JA	No	All services	Procurement	No

As shown in table 6.1, only two projects had operational data available. Project NA was part of a large Navy procurement program that started in the eighties. The project developed and procured a weapon system in the late nineties to be used on a class of Navy vessels. NA was a system specially developed in cooperation between the Norwegian Navy and the Norwegian defence industry. The project had a total budget of more than 200 million NoK, and approximately 10 million (hence in accordance with the 5% estimate) were targeted for spare parts. Project AA delivered a main weapon system which in 2004 was considered for a spare parts update since more of the systems were to be used in international operations. OPUS10 optimization had also earlier been conducted on this system, but the focus of this analysis has been on the number of LRUs considered for increase in stock based on the 2004 analysis. The other case studies were not in the operational phase of their life cycle.

The standard procedure in the Norwegian Defence regarding spare parts dimensioning is that the main system supplier through contractual demands is obliged to provide NDLO with a suggested spare parts list. This spare parts list provided by the system supplier can in theory be based on any of the methods shortly presented in chapter three. Through a series of spare parts provisioning conferences the system supplier and NDLO will normally agree upon a final spare parts delivery.

It is in this process that the use of a multi-echelon, multi-item, multi-indenture spare parts optimization method is thought to be of high importance in order to achieve the best possible operational availability for the system at the lowest possible cost, or to achieve as much availability as possible for a given budget.

According to the informants, it is the organization within NDLO with technical responsibility for the system in question (NDLO Systems Management Division - NDSMD) that is supposed to lead the sparing process. The informants in this research confirmed that to the best of their knowledge the multi-echelon, multi-item, multi-indenture spare parts optimization method was only used through the system OPUS10 in Norwegian Defence procurement. They further confirmed that in the projects that have not used OPUS10, NDSMD representatives would work through the suggested parts list and maybe question some of the suggestions, but basically just draw a line when the budget no longer allowed NDLO to buy more.

Based on this one can say that the process in the vast majority of procurement projects thus far at best can be called an engineering choice process. The result will be affected by how the system supplier has constructed the spare parts proposal. If the supplier has taken into account the element described in chapter three under the system based method or used the constant confidence against stock-out method, the system availability will be better than if the supplier has used the same of each, engineering choice or random choice method.

Empirical data show that a lot of spare parts bought by the NDLO have no movement at all throughout the life time of the system they are bought to support. Hence it is likely to believe that system suppliers' spare parts suggestions and NDLO buying decisions not necessarily takes

into account system based criteria such as for example mean time between failures (failure rates). In the projects that use OPUS10 however, the system supplier's suggestion will be evaluated as explained in chapter three. After the final list of spares are decided, the project together with NDLO Supplies Management Division are supposed to make sure that all spare parts get a NATO Stock Number (for identification purposes) and associated inventory control measures (e.g. reorder points - ROPs).

## 7. Qualitative data analysis

Table 7.1 Summary of the qualitative data analysis

Project	Uncertainty		Interdependency		Info symmetry		Centralization	Rationality	Attitude		Use
	COTS	Task	Info	Resources	Internal	External	(Instruct./KPI)	(Complexity)	PL	PC ILS	
NA	High	Low	Low	Med/Low	High	High	Medium	Low	High	High	<b>Complete</b>
NB	High	High	Med/High	Med/High	Low	Medium	Low	High	Low	High	Partly
NC	High	High	Med/High	Med/High	Low	Medium	Low	High	Low	Med/High	Partly to none
AA	Medium	Low	Low	Med/Low	High	High	Low	Low	High	High	<b>Complete</b>
AB	Medium	Low	Low	Med/Low	Medium	High	Low	Low	Medium	High	<b>Complete</b>
AC	Low	Low	Low	Medium	Medium	High	Low	Low	Medium	High	<b>Complete</b>
FA	Medium	Low/Med	Medium	Medium	Medium	Med/High	Low	Medium	Medium	High	Partly
JA	Medium	Medium	Low	Med/Low	High	High	Low	Low	High	High	<b>Complete</b>
Ideal	Low	Low	Low	Low	High	High	High	Low	High	High	

Table 7.1 is a summary of the findings from the analysis of the qualitative data collected. In the following, analyses against the predefined hypotheses for each of the coordination factors are presented.

The use of OPUS10 in the nine case studies is divided into three categories. The first category is coded; complete – this means that the project has used OPUS10 to optimize the entire system when it comes to spare parts. Five out of nine project cases falls into this category, including both systems with operational data (system NA and AA). The second category is coded; partly – this means that only certain sub-systems within the total system have been optimized with OPUS10. Two systems NB and FA fall into this category. System NB for example consists of two major sub-systems and one of these has been optimized with OPUS10. The last category is; partly to none – this means that OPUS10 has been used at one stage in the project development but later dropped. This is the case of system NC.

The findings in the nine case studies to a certain degree support hypothesis one regarding uncertainty. Two of the three case studies that had not used OPUS10 completely had high uncertainty both in terms of being specially designed systems (non-COTS), and having a very high task complexity in terms of being large specially designed systems with a vast amount of sub-systems and LRUs attached to the systems. Both system NB and NC are systems for the Navy with very large investment budgets (multi billion projects) and a very high complexity. The last project that has not used OPUS10 completely is also a very complex system, but it has a somewhat lower uncertainty in terms of the COTS dimension because several nations is procuring this system together and because the type of industry (aircraft industry) delivering the

system has a long history of working with for example failure rates needed to do the spare parts optimization.

The projects with complete use of OPUS10, have all except one (JA) been identified to have low uncertainty in terms of the task dimension. This is because the complexity in terms of number of systems, LRUs, support organization and so on is not very large. The task complexity for system JA was identified to be somewhat higher than the others but still only low to medium. Compared to the hypothesis the finding of high uncertainty in terms of a very asset specific system in the case of project NA was somewhat surprising. However this high uncertainty is in this case offset by a low task uncertainty and almost ideal findings in four of the five other dimensions reducing coordination problems.

In connection with hypothesis two, it was found that scarcity of resources in terms of personnel with knowledge of spare parts optimization were evident in all projects. It is however important to notice that in the studied projects at least some resources are available while in the large amount of projects found to not have used OPUS10 one can predict that resources are almost non present. Seven out of the eight cases reported that no more than one person in the project had good knowledge of spare parts optimization based on the system approach. The NC project had at some times more than one person with this knowledge but this project is a very large project (one of the largest in the NDLO portfolio) with high complexity and a very high need for skilled ILS project members. All projects reported that they used resources from outside the project itself to run the OPUS10 software.

Before 2002 defence procurements were conducted by the different services (Army, Navy and Air Force) in their own material commands. From 2002 the three commands were organizationally joined in NDLO. However, the three physical sites<sup>34</sup> of the old commands were kept, and hence most Army projects are run from the old Army site, Navy projects from the Navy site and Air Force projects from the Air Force site. Before 2002 all three material commands had their own ILS community where spare parts optimization, at least theoretically, was a part of the portfolio. At the time of consolidation the organizational elements in Bergen (Navy) and Kjeller (Air Force) were terminated and a common community was established based in the old Army site at Kolsås.

One project of the eight studied was finished before the consolidation of the ILS communities (project NA). In this project, resources from the Navy ILS community together with resources from Systecon AB (the OPUS10 provider) ran the optimization. They also highly involved the organizations with technical and supply responsibilities towards the system in the optimization process as well as the system supplier. The informant in the NA project said that this was very important because such an iterative process removed misunderstandings and errors that otherwise would not have been detected. After 2002 the ILS community situated at the Army site have had limited amount of resources. Through the study it was found that three out of four projects with complete use of OPUS10 are ran out of the old Army site and thus have had physically closer access to the ILS community. The informant in the Air Force project (project FA) reported that he had not

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<sup>34</sup> The Army site is located at Kolsås just outside Oslo, the Navy site is located in Bergen and the Air Force site is at Kjeller north of Oslo.

heard of the new consolidated ILS community before 2006, and hence thought that such resources were not available after the termination of the Air Force command ILS community in 2002. However both project NC and JA which are both located in the old Navy site had used resources from the common ILS community and especially project JA reported that this was what they needed in their process.

It is interesting to see that all of the projects that have done a complete optimization reported that they had low scarcity of information, which is in accordance with the hypothesis. Project NB and NC reported that scarcity of information, especially for parts of the system made it impossible to conduct a complete optimization.

The informants in NB, NC and FA all reported that they experienced low information symmetry between the PL and PC ILS regarding spare parts optimization. All three reported that the leadership within the project had low knowledge and not to much interest in the spare parts optimization process and result, at least not early in the project. On the opposite spectrum the informant in project NA reported that the PL was very interested in the process and result because the PL had committed to delivering certain system availability in operations. Basically the findings from the cases studies are in line with hypothesis three.

For hypothesis four the findings from the case studies are very well aligned with the proposition. In those case study projects that have not used OPUS10 completely the informants reported that a major reason for this is the problem of getting reliable data from the system supplier regarding certain areas or sub-systems of the total delivery. For example in project NB, the informant stated that in the propulsion part of the project the supplier were not able to provide failure rates for the propulsion system. The informant in this project and in the NC project reported that some times the requirements against the system provider were not well enough stated in the contract. Hence if the system provider did not want to come up with the needed data there were no contractual way of making him do so. To sum up, finding from the case studies do support the two hypotheses put forward regarding information symmetry.

There is only one project of the eight cases studied that even come close to the theoretical concept of a centralized methodology and decisions reflected in hypothesis five. The project in question is the Navy project NA, which was completed, based in the old organization with a separate Navy ILS community deciding, or at least trying to decide how the Navy projects should conduct spare parts optimization. Talking to the informants from the other projects it is clear that a centralized decided process for how the spare parts optimization shall be done is not present. A proposed concept written by the ILS community situated at Kolsås was found<sup>35</sup>, but this concept is not approved by NDLO and hence not necessary for the different projects to follow. One could claim that support for the hypothesis is actually found because so few procurement projects actually use OPUS10.

In hypothesis six it was stated that the more complex the system becomes compared to the decision maker cognitive capability, the more likely are the decision maker to use rule of thumb sparing. Rule of thumb decision making in this context is that the projects accepts the systems

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<sup>35</sup> The concept is in Norwegian and a non approved version can be obtained from the author of the paper.

providers proposal either totally or by using engineering judgment on each of the spares suggested, and making corrections based upon this. In three of the eight cases studied the total complexity of the system delivery was very large (system NB, NC and FA). Nevertheless the rationality is coded as high in NB and NC but medium in FA. The reason for FA being coded medium has not to do with the complexity being lower but that finding that the cognitive capability of those involved in the project was found to be higher than in the other two projects. The FA project is a project where several nations work together on the procurement. In this way NDLO has been able to utilize specialists in spare parts optimization connected to one of the other nation's project team. In this way the ratio between the complexities of the problem compared to the cognitive capability of the project has been lowered compared to the large and complex NB and NC projects that are purely Norwegian. In the rest of the projects the ratio between complexity and cognitive capability is lower. Finding towards the concept of rationality seems to fit the hypothesis put forward.

The findings connected to hypothesis seven are divided into PLs attitude and PC ILS' attitude.

For the PC ILS informants the findings were that all were positive to spare parts optimization based on OPUS10. One of the informants in the NC project said that he had had some bad experience with OPUS10 optimization due to lack of reliable input data, and based on this he was somewhat reluctant to use the system.

All PC ILS informants were also asked structured questions regarding their attitude towards the use of LCC based procurement decisions (OPUS10 based spare parts optimization can be part of such an LCC analysis) identical to those given to all PLs in the Norwegian Defence in a research study from 2007 (Tysseland, 2007). Since items and summed scale regarding attitude was found to be both reliable and valid in the Tysseland's (2007) paper the exact same items and summed scale were used in order to test whether there was a statistical significant difference in the attitude towards LCC based procurement decisions between PLs and the PC ILS's included in this study. The mean for the PLs (sample size 78) was 3.24<sup>36</sup>, with a standard deviation of 0.95. The mean for the PC ILSs (sample size nine) was 4.56, with a standard deviation of 0.64. By using SPSS<sup>37</sup>, both the parametric t-test and the nonparametric Mann-Whitney test showed that there was a statistically significant difference in attitude between the two groups. This is clearly in line with the qualitative findings were the PC ILS informants reports on a general basis that their PLs are not that interested in LCC based decisions and spare parts optimization based on the system approach.

However the data also show that in those cases that the PL has what can be termed as a very good attitude such as in case study project, NA, AA and JA it is more likely that the project has used OPUS10 on all parts of the spare parts process. In the cases studied, the PC ILSs' attitude has not had an large impact on whether OPUS10 is used completely or not. This is not surprising, since they have chosen to use OPUS10 in the first place. If all projects not using

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<sup>36</sup> On a scale from one to five with end points "fits very badly" and "fits very well."

<sup>37</sup> SPSS is short for the Statistical Package for the Social Sciences, see [www.spss.com](http://www.spss.com)

OPUS10 had been included in the study this finding might have been different. However the attitude of the PL seems to affect the use of OPUS10 even in the projects were OPUS10 is used, and thus the hypothesis is partly supported.

## 8. Quantitative data analysis

In research question number two, the question was if empirical data could show that the multi-echelon, multi-item, multi-indenture method based in OPUS10 is better than other methods (e.g. engineering choice and same of each) in terms of system availability and spare parts investment cost.

It is important to notice that projects not using OPUS10 will, according to the informants, either accept the system supplier's suggestion as it is or make a more or less informed change. The supplier's suggestion could theoretically be based on a multi-echelon, multi-item, multi-indenture method, but according to the informants this normally is not the case. The informant reported that the suppliers' suggestions most likely were based on a same of each approach or an engineering choice approach. Again according to the informants, the main motivation for the system supplier is to sell as many spare parts as possible.

In order to get as close to the answer of the research question as possible with the available data, it was decided to look at the difference between system supplier suggestion and the case project's final decision based on OPUS10.

As stated before only two out of eight studied projects were in the operation phase of the life cycle, but several of the eight projects had some evaluation of cost and availability.

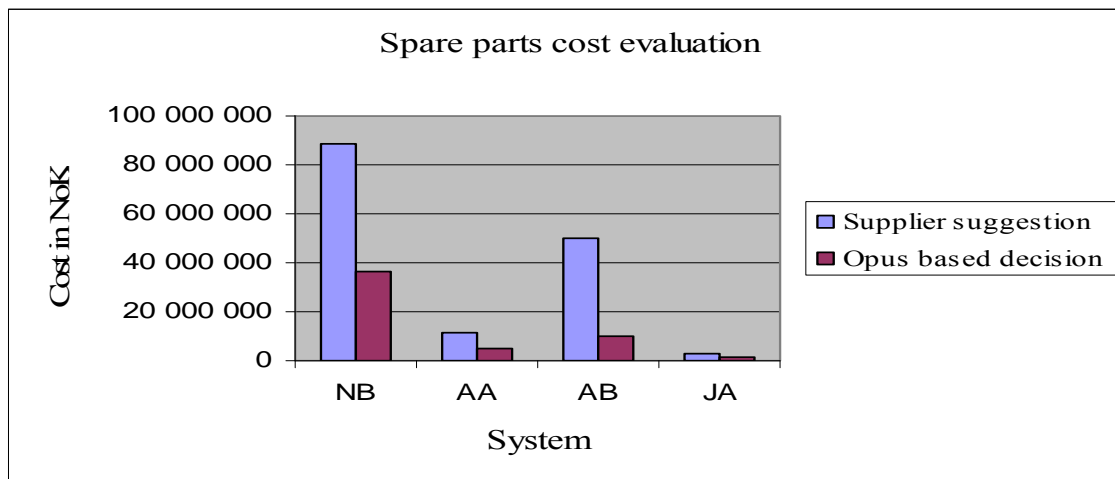


Figure 8.1 Supplier suggested spare parts investment cost versus OPUS10 based decision

In figure 8.1 the supplier suggested spare parts investment cost versus the OPUS10 based decision is shown for four out of eight case projects. The reason for not including project NA is that initial spare parts investment savings was not a part of the NA project. Project NA had received a spare parts proposal of approximately 10 million NoK. The supplier's suggestion was in this case a "same of each" (actually one of each) solution. In chapter three it has been shown that the same (one) of each solution will give lower system availability at the same cost compared to the system approach based on OPUS10. Project NA chose to use approximately 10 million NoK on spares and focused on increasing availability compared to what the system supplier's initial suggestion gave. Further case project AC is not included because in project AC, NDLO worked together with the supplier on the spare parts optimization and as such never received a separate spare parts suggestion form the supplier. Finally in the two large projects NC and FA it has not been possible to obtain detailed enough information to quantify the savings.

In project NB only the weapon part of the total system was optimized based on OPUS10. For the weapon system part of the project the initial supplier's suggestion for spare parts amounted to 88.4 million NoK. When this combination of spares was fed into OPUS10, the system returned an availability of 78%. Project NB then used OPUS10 to run an optimization without forcing a given combination of spares, but subject to a budget of 88.4 million NoK. This run gave a combination of spares which would according to OPUS10 increase availability to 96%. Project NB knew however that they did not have 88.4 million NoK to spend on an initial spare parts package. First they therefore tried to see what an engineering choice reduction (reducing the list based on experience alone by experts from NDSMD) of the OPUS10 optimal package with a budget of 88.4 million NoK would mean in terms of system availability. When reducing the package the engineers did not calculate the cost of the reduced list. The engineering choice list was then fed into OPUS10, which showed that the result would be a spare parts investment cost of 61 million NoK with an associated system availability of 55.4%. The total budget available was however only approximately 36 million NoK. Project NB rejected the NDSMD engineering choice suggestion and let OPUS10 run an optimization subject to the budget limit of 36 million. This final effort gave an availability of 62%. To sum up NDLO were able to reduce the cost of spares with 58.7% compared to the system supplier's initial suggestion still only losing 16 percentage points in availability.

In project AA the supplier's suggestion for increase in spares amounted to 11.5 million, which after the spare parts optimization with OPUS10 was reduced to 5.1 million NoK (saving 55.7%).

In project AB the supplier's suggestion was approximately 50 million for spare parts. The informant in the project said that after running OPUS10 they were able to get the desired availability with a spare parts cost of 5 million. However by increasing the failure rates given from the supplier with the concept of operator negligence, damage and misuse (NDM), the project ended up with spare parts buy of 10 million. A saving of 80% compared to the supplier's suggestion.



Project JA is a smaller project in terms of spare parts need, still the saving compared to the supplier's suggestion (thought to be based on an engineering choice solution) was reported to be 1.48 million or 46.8%.

The findings clearly indicates that suppliers do not necessarily take into account for example the mean time between failure (MTBF) on sub systems and turn around time on reparable parts when they suggest initial spare parts lists. The incentive seen from the system supplier's side is of course to sell as much spare parts as possible. The problem seen from the Norwegian Defence's side is that spare parts are bought that might not be used at all in the life time of the system it is bought for (due to MTBF being far higher than the life time of the system it is used within) or that they are bought in excess quantities.

As mentioned before, in a report from 1995 (PS2000) it was estimated that the Norwegian Defence at that time bought spare parts for 120 million NoK every year that would most likely not be used in the life time of the system they were bought to support. This analysis clearly indicates that this is still a problem.

The cost savings in the four projects that was possible to get detailed information from has, at least theoretically, been on the average 60.3 percent. In three out of four projects the availability percentage has been kept unchanged or improved even if the spare parts investment cost were this much reduced. In the last project (NB) the reduction in availability was minimal compared to the reduction in spare parts investment cost. Based on the informants claims that the suppliers' suggestions are most likely either put together randomly, by engineering choice or as a same of each solution the empirical findings in the cases where the multi-echelon, multi-item, multi-indenture method based on OPUS10 have been used clearly indicates that this method is better than other approaches in terms of spare parts investment cost and system availability.

The question now becomes whether real life operational data can sustain the claims and calculations done in the projects.

As mentioned before only two of the case projects had operational data, namely NA and AA. Data from these two projects have been evaluated over the period from the start of 2004 through the end of 2007.

Average fill rate for all Navy weapon system from 2004 through 2007 is 88.2 percent. The development in fill rate for the total group has been steadily declining from 93 percent in 2004 to 82 percent in 2007.

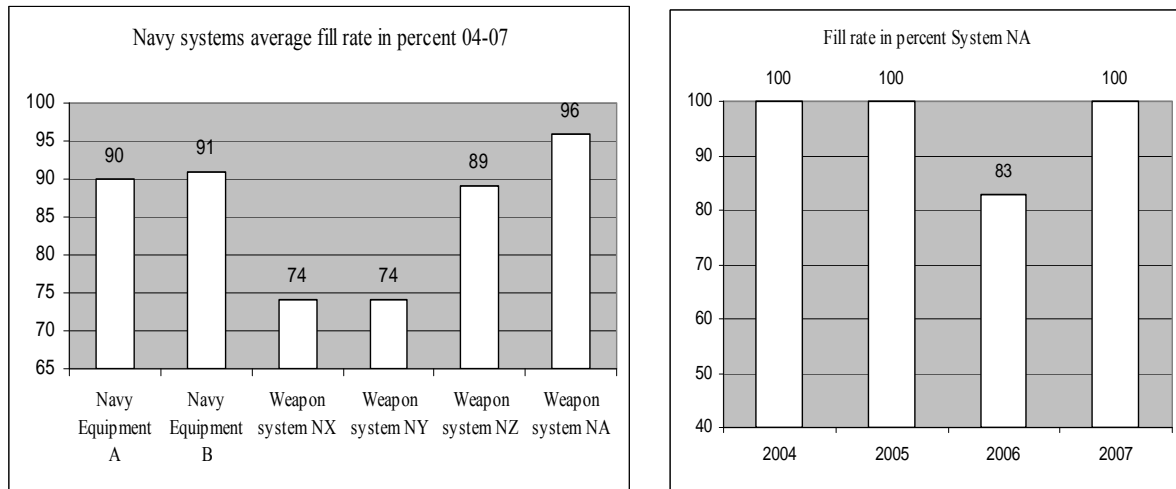


Figure 8.2 Navy systems average fill rate (2004-07) and system NA fill rate per year

Figure 8.2 first show a sample of Navy systems' average fill rates in the period, including system NA.

Secondly the figure shows the development in fill rate for system NA from 2004 through 2007. The total inventory for system NA today consists of 184 SKUs. The fill rate from central inventory has so far been very good with an average of 95.75 percent. Somewhat surprising is the fact that out of the 35 SKUs that have had demand, 13 (37%) has no longer stock. None of the 13 has so far had rest order, but of course with  $S=0$  for all 13, the chance for rest order and reduced system availability is definitely very present.

It is NDLO Supply Management Division (NDSuMD) who is responsible for inventory management and the NDSMD informants with technical responsibility for the NA system were very surprised by the finding when presented with it. According to standard procedure NDSuMD gets paid each time a customer (e.g. Navy) use a spare part. NDSuMD is supposed to use this payment to reset the inventory to the amount decided by NDSMD.

In the figure below the average fill rate for several Army systems including system AA from 2004 through 2007 is given in addition to the year by year fill rate for system AA. The availability requirement in project NA was 95 percent.

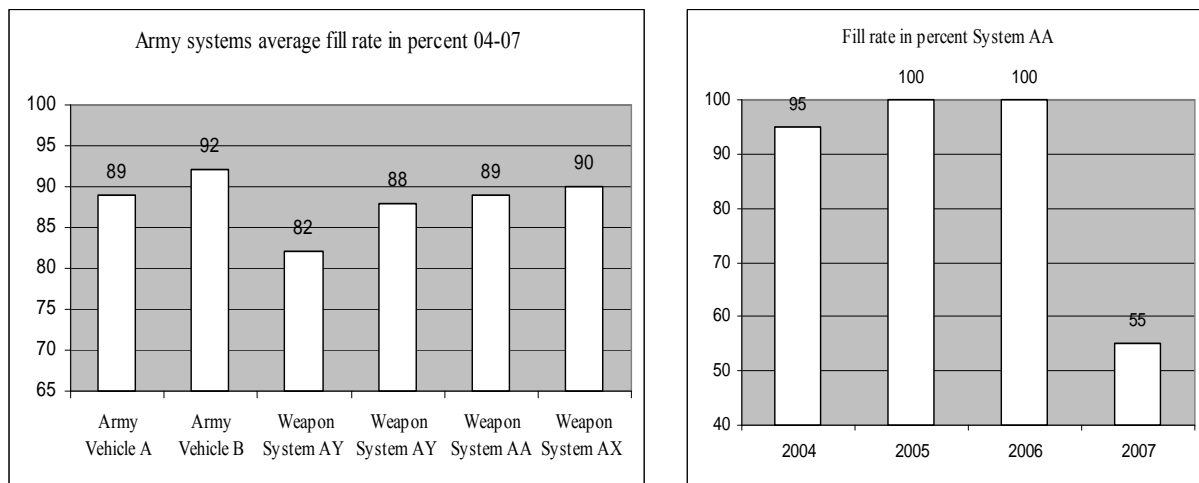


Figure 8.3 Army systems average fill rate (2004-07) and system AA fill rate per year

According to NDLOs Army inventory system, the number of SKUs connected to system AA is 1040. Out of these 1040 SKUs, 665 had stock at 3 March 2008. However only 479 SKUs had order points in the management system (a NDSuMD responsibility). Out of these, 90 had both the setting for maximum inventory position and order point (defined as minimum inventory position) set to zero.

The question becomes whether the zero setting for these 90 SKUs are real settings or just a system default. One can speculate that actually only  $479 - 90 = 389$  SKUs have real inventory settings.

The analysis showed that 697 SKUs have had orders in the period 2004-2007, and out of these 435 SKUs have had rest orders at least at one point. For the update job in 2004, 273 SKUs were considered for an update of settings (a change in the number of spare parts based on the new situation). Out of the supplier's suggestion of 273 items to be increased, the AA project based on the OPUS10 analysis removed 101 items.

By studying the development in fill rate an interesting development occurred. As can be seen in the figure 8.3 the fill rate for the first year after the optimization is very good with 95 percent, and than even better for year two and three with 100 percent fill rate for both years. In 2007 a dramatic change in fill rate is observed. The data analysis revealed the simple but still puzzling reason for this dramatic change in fill rate. For the SKUs included in the OPUS10 based optimization in 2004, NDLO have after the procurement of additional spares not sat order point or other decision variables (e.g maximum allowed stock) in the spare parts management system that System AA is managed by. The result became that no warning was given before the different SKUs reached a stock of zero with the given result of back orders.

To sum up the quantitative data analysis, the empirical findings clearly indicate that the multi-echelon, multi-item, multi-indenture method based on OPUS10 is better than other methods in

terms of both system availability and spare parts investment cost. However the data analysis also showed that poor follow on spare parts management can in the longer run ruin system availability.

## **9. Conclusion, limitation and future research**

The empirical findings clearly support the theoretical claims of the multi-echelon, multi-item, multi-indenture method based on OPUS10 being better than other approaches (same of each and engineering choice) in terms of system availability and spare parts investment cost.

The two cases with operational data (NA and AA) either performed as good as, or better than, comparable systems.

The dip in fill rate of system AA is an interesting observation in it self because this is due to an organizational inventory management issue rather than the result of a poor spare parts optimization. In project NA and AA, cost saving was only an issue in project AA with 55.7 percent saving over the system supplier's suggestion. This saving in spare parts investment has not reduced availability of the system compared to systems spared with other approaches. If the availability of system AA is representative the large reduction in spare parts compared to the system supplier's suggestion clearly indicates that in the non OPUS10 based projects where the supplier's suggestion is accepted a considerable amount of spare parts are bought that actually are not needed. Further when the supplier's suggestion is reduced with an engineering choice approach by the Norwegian Defence such as in project NB, the chances of buying wrong spares and removing the ones they need are still very present.

The reduction in spare parts investment cost based on the use of OPUS10 identified in this study (on average 60.3 percent) is very interesting, especially since empirical operational data show that system availability is not reduced. This finding should warrant managerial action. With a conservative approximation of spare parts cost to 3.5 percent of the total Norwegian Defence procurement budget, and a reduction of the saving potential to 40 percent, the annual saving in procurement of not needed spare parts would still be 140 million NoK. Total life cycle cost of these not needed spare parts would be even higher considering the costs of holding unneeded inventory.

Very few projects had actually used OPUS10 since it was decided to be the Norwegian Defence standard system for spare parts optimization back in 1995. It is believed that this lack of usage is not due to the method and system it self but to how the different coordination factors are observed and solved by the projects in question.

The findings from the qualitative part of the study gave some interesting findings with managerial implications. If the Norwegian Defence really wants the system approach based on OPUS10 to be used completely, the project in question should be mapped out based on the research model of this study, in order to get as little coordination problems as possible. Three problem areas were identified to be the most challenging in the projects that have used OPUS10.

These problem areas are probably even bigger in the vast majority of projects that have not used OPUS10. The three areas in question are; lack of resources; lack of centralized instructions and finally; the project leaders' attitude.

All studied projects reported that they had limited resources in terms of personnel with the needed ILS competency. Given the potential for savings identified, it is somewhat surprising that NDLO has not focused more on this area. Further all projects reported lack of one common concept for spare parts optimization as well as to little focus in PRINSIX on the subject. Along with an increase in resources, it is thus believed that a common concept should be developed, approved and implemented by the NDLO and sustained by PRINSIX. Further the concept must be followed up by KPIs primarily aimed at the PLs. It is believed that use of KPIs to a certain degree will address the somewhat low attitude found from the project leaders towards system based optimization. Another way of addressing the attitude issue is to build knowledge within the procurement community concerning the topic (e.g. Tysseland. 2007).

Not being able to statistically accept or reject the hypothesis presented in the data analysis can be argued to be a limitation to this research. The research could be developed by using a questionnaire to reach as many projects within the procurement community as possible. However it can be also be argued in the opposite direction that the use of quantitative data have presented more indebt data then a questionnaire could have given. Further the cases are restricted within the Norwegian Defence and hence generalization of both qualitative and quantitative findings is at best questionable and probably not fruitful. The area of research though should be of interest to other organizations and industries and the research model could easily be transferred and utilized in the study of other industries who utilize a structured approach to procurement including spare parts optimization. In this way a more general template or process map, based on the extension of spare parts theory into organization theory could be developed.

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**Paper IV**

**Life cycle cost based procurement decisions**

**A case study of Norwegian Defence Procurement Projects**

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# **PAPER IV**

## **Life cycle cost based procurement decisions**

### **A case study of Norwegian Defence Procurement Projects**

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## Abstract

*A Norwegian Ministry of Defence publication states that when procurement decisions are made, systems that yield the lowest possible life cycle cost (LCC) for the Norwegian Defence must be procured, even if this means that initial procurement cost becomes higher. However, several projects within the community are still carried out and reviewed based on initial procurement cost alone. This study investigates four hypotheses, based on agency theory and earlier LCC work, in order to help explain why this is happening. A questionnaire was administered to all projects currently running in the defence community. Findings regarding project uncertainty, information symmetry, the project leader's attitude and knowledge about LCC, as well as control variables are discussed both towards theory and in terms of managerial implications.*

*Keywords: Agency theory; Life cycle costing; Procurement decisions, Projects, Project leaders, Defence*

### 1. Introduction and research question

In 1998 General Steinar Jøssund, Head of the Norwegian Army Material Command said:

*The Norwegian Defence's ongoing and future organizational change, demands that the present focus on costs associated with material system procurement is changed from only considering the initial procurement cost to looking at the material systems' total life cycle cost.<sup>38</sup>*

Earlier research has presented cases where maintenance and logistics support costs for a system can be cut with up to 50 % by using integrated logistics support (ILS)<sup>39</sup> and life cycle cost (LCC) analysis [1]. The life cycle of a system usually starts with the initial determination of its need, continues through design and development, production, deployment, operations and concludes

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<sup>38</sup> From the intranet of the Army Material Command

<sup>39</sup> Integrated logistics support (ILS) is a disciplined management approach, affecting both customer and industry, aimed at optimising equipment life cycle costs (LCC). It includes elements for influencing equipment design and determining support requirements to achieve supportable and supported equipment (From the intranet of the Norwegian Army Material Command, 2002).

with the system's disposal. Life cycle cost may be categorized in many different ways, depending on the type of system and the sensitivities desired in cost-effectiveness measurement [2].

However, the fundamental objective of LCC analysis is to identify the cost drivers that most significantly contribute to LCC, since this allows for trade off considerations with respect to different courses of action [3]. Or as stated by Ferrin and Plank [4]; the concept suggests that managers adopt a long-term perspective, for the accurate valuation of buying situations.

Since approximately 1993<sup>40</sup> the Norwegian Defence has, used ILS in some projects in order to minimize the total cost of material procurements accounted over the materials' total life cycle.

In the summer of 2004 the importance of ILS and LCC was highlighted by the Norwegian Ministry of Defence (NoMoD) in their publication. "Konsept for fremskaffelse av materielle kapasiteter i forsvarssektoren" (Norwegian title). In this publication the NoMoD clearly states that when investment decisions are made, solutions/systems that yield the lowest possible life cycle cost, given equal system effectiveness, must be preferred, even if this means that the initial investment cost becomes higher.

However, approximately at the same time Commodore Morten Jacobsen, Chief of Procurement in the Norwegian Defence Logistic Organization (NoDLO), said in a speech that they are still experiencing that procurement in some projects are carried out and reviewed based on initial procurement costs alone. Reports from the United Kingdom are also concluding that the British experience is much the same [5].

Based on the information presented above the main question of this research is "What can explain that some procurement projects are still carried out and reviewed based on initial procurement costs alone when the official policy is to apply the life cycle cost approach?"

## 2. Theory framework

The concept of LCC, sometimes called Total Cost of Ownership (TCO) has been discussed, and examined empirically but with limited scope [4]. Literature review has not revealed many studies that could help answer the main research question raised in this study.

One study was found where the authors looked into the adoption of total cost of ownership for sourcing decisions [6]. The main difference between that study and this study is that in our case it is already decided by the mandate group that LCC should be used. The fact that the mandate group has decided that LCC should be used brings forward what is known as the mandate problem [7]. Organizations, such as the procurement projects of this study, are established by owners. It is the owners (the mandate group) who decide which goals and tasks the organization is going to have [7]. In order to reach any preset goal, the mandate group must implement a

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<sup>40</sup> Individuals within the Norwegian Defence has probably been working with Integrated logistics support (see footnote 7) long before 1993, however according to an internal Navy Material Command report from 1995 the first ILS organization was established around 1993 in the Air Force Material Command [19].

governance system that makes sure that the leaders and employees of the organization implement actions to reach the goal. According to Greve [7], one of the main theories that regulates the relationship between the mandate group and the organization leaders, is agency theory.

The main theoretical perspective of this study is therefore agency theory, used in an exploratory fashion. In addition to agency theory, one of the propositions put forward in a paper by Wååk [1] where he discusses why LCC is not more used, namely lack of knowledge, is also examined.

According to Eisenhardt [8], agency theory is directed at the ubiquitous agency relationship, in which one party delegates work to another, which performs that work. Agency theory will describe the relation between the parties (the principal and the agent) with the metaphor of a contract [8]. Most empirical work towards agency relations are focused on the relationship found between firms, but agency theory can also be used to evaluate relations within the firm/organization, which is the case in this study [9].

According to agency theory two main problems can occur in agency relationships; the first problem is that of conflicting goals between the principal and the agent, and the second problem is that of risk preferences.

The first problem will arise when the goals of the principal and the agent conflict, and it is difficult or expensive for the principal to verify what the agent is actually doing [8]. The second problem, concerning risk preference arises when the principal and the agent have different risk preferences and hence will prefer different actions due to this. The assumption is that the principal will be risk neutral while the agent will be risk adverse.

As mentioned before, agency theory describes the relation between the principal and the agent using the metaphor of a contract; hence the unit of analysis will be the contract governing the relationship between the two parties.

### **3. Research model and hypothesis**

The research model is based on the belief that agency theory constructs along with the knowledge construct<sup>41</sup> to a certain degree can explain why some procurement projects within the Norwegian Defence focus on life cycle costs while others do not.

In the research model the dependent construct is therefore the project leaders' use of life cycle costing in procurement decisions. The independent constructs are: project uncertainty, information symmetry, attitude towards LCC and knowledge about LCC. In addition to the independent constructs, some control variables were examined and in the final regression model independent dummy variables of the control variable found to be significant are included.

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<sup>41</sup> From Wååk [1]

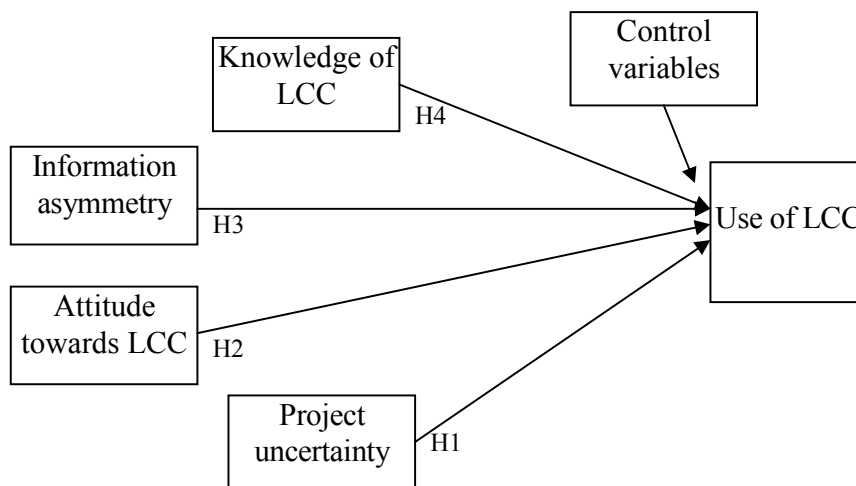


Figure 1: Research model

### 3.1 Project uncertainty

Uncertainty in the context of agency theory is connected to the basic risk assumptions of the theory. In agency theory the principal is assumed to be risk neutral, whereas the agents are assumed to be risk adverse [9]. The rationale behind this is that the principal most likely can spread his risk over several projects, whereas the agent will have to “succeed” in the one project he has.

Hence in the case of defence projects the NoMoD will have a portfolio of projects to govern, and even if one project comes out with higher costs than expected, another project might experience lower costs than expected. The project leader (agent) on the other hand, has only his one project, and he will therefore “play safe” in order to minimize potential failure.

In this case we look at uncertainty as whether the system procured can be acquired so called “commercially off the shelf” (COTS), or whether it has to be developed specifically (high asset specificity). We assume that COTS systems indicate lower risk for the project manager than asset specific systems. In the same direction, if a system is COTS, it is most likely already in use by others and it is therefore more likely that operational data can be acquired by the project, and hence reduces the risk associated with the system in terms of calculating life cycle cost. If the system is not in use by others, the risk of making incorrect calculations will increase. Based on the discussion of project uncertainty the following hypothesis is proposed:

*Hypothesis 1: Project uncertainty will negatively affect the use of LCC- based procurement decisions.*

### 3.2 Attitude towards LCC

According to Greve [7] it is the mandate group who decides which goals and tasks the organization is going to have. In this research, we look upon the Norwegian Ministry of Defence as the owner of the defence projects, and hence it is NoMoD's prerogative to decide that when project leaders make investment decisions they should favour solutions that yield the lowest possible life cycle cost for the system, even if this means that the initial investment cost becomes higher<sup>42</sup>.

The problem arises when this goal of the principal conflicts with, or is not aligned with the preconception of the agents. Traditionally project success is measured on the triple constraints; time, budget and overall quality [11]. However the triple constraint has often only included the research & development- and investment- phases of the project, not the operation & support and disposal- phases.

If the project leaders still think that their future (for example promotion) is based on the fact that the procurement projects are finished on time and within the original investment budget, their attitude towards the use of LCC based investment decisions will most likely be negative.

Project leaders acting in what they think are their self-interest at the expense of the principal's interest is called adverse selection [8]. However it is hard to measure such behaviour by questions. Based on this, a substitute in terms of the project leaders' general attitude towards the use of LCC, is used as an indicator. Negative attitude is not necessarily a sign of bad will, but can be the effect of prior experiences, lack of information and so on. In any case, based on the new concept from the NoMoD, project leaders should base their investment decisions on life cycle cost, and not to do this is strictly speaking adverse selection.

The following hypothesis is proposed on attitude towards the use of LCC:

*Hypothesis 2: Positive attitude towards the use of LCC by the project leader will positively affect the use of LCC- based procurement decisions.*

### 3.3 Information symmetry

Information symmetry refers to the principal and agent possessing the same information. In our case, the project leaders will most likely possess detailed information about the project that the NoMoD (represented by different project boards) cannot access easily. With different information we have information asymmetry, and this can lead to adverse selection.

According to Eisenhardt [8], information systems can curb adverse selection. The argument is that since information systems can inform the principal about what the agent is actually doing, the agent will realize that he cannot deceive the principal.

We assume that alignment of information is important regarding the use of LCC (making sure that the agent knows and believes in the intent of the principal). In the case of Norwegian

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<sup>42</sup> Konsept for fremskaffelse av materielle kapasiteter (Norwegian title), published on the Norwegian Defence intranet site 15 July 2004.

Defence projects the principal's maybe most important information system should be the project boards (or equivalent) that the different projects report to. If the project board clearly states that they want information on how the project leader uses life cycle cost when making investment decisions, the project leader will realize that this is what the project really is governed by. In this case we have a situation where information symmetry exists between principal and agent considering the use of LCC. On the other hand, if the board is not informed about life cycle cost questions, and/or is not interested in this information, it is less likely that the project leader will focus on LCC, and hence information asymmetry can be present.

Based on the above, the following hypothesis on information symmetry is proposed:

*Hypothesis 3: Information symmetry between principal (NoMOD) and agent (project leader) regarding the use of LCC will positively affect the project leader's use of LCC.*

### **3.4 Knowledge about life cycle costing**

There is no real consensus within science on what knowledge is, but in terms of this research we apply the following definition: "Knowledge is the confident understanding of a subject, potentially with the ability to use it for a specific purpose" [12]. Hence, knowledge about life cycle costing will refer to the common understanding of the concept and how it should be applied within procurement projects in the Norwegian defence.

Even though knowledge as such, is not a common agency theory construct, knowledge of LCC is proposed to help align the interest of the principle with that of the agents. The proposition is that when the agent, either by himself or through members within his own project, has thorough knowledge about life cycle costing, he will be more likely to understand and accept the position of the principle (NoMoD), and therefore use LCC. This is in line with Wååk [1], when he proposes that LCC is not used because:

*"In spite of considerable effort in training, a deep lack of knowledge exists with regard to LCC. This is both true with regard to effectiveness of the method and how it should be applied within the business at hand".*

Hence the following hypothesis is proposed regarding knowledge of LCC:

*Hypothesis 4: Better knowledge about life cycle costing will increase the use of LCC based procurement decisions.*

### **3.5 Control variables**

In order to control for non hypothesised variables that could influence the use of LCC based procurement decisions, variables like what main type of procurement the project is dealing with, what NoDLO site the project works out from and the size of the project in terms of personnel working with LCC were included in the study.



## 4. Method

### 4.1 Data collection and measuring instrument

The unit of analysis in this study is the “contract” governing the relationship between the NoMOD (the principal) and the project leaders (the agents) concerning life cycle costing. The contract is a metaphor regarding the relationship between the principal and the agent.

The relationship data was collected from project leaders within the Norwegian Defence project community. Most projects delivering to the Army are situated at a site in Kolsås outside Oslo, Navy projects from a site in Bergen and Air Force projects from a site at Kjeller outside Oslo.

The total number of projects and project leaders are shifting with the numbers of projects being started and/or terminated, but at the start of the data collection (December 2005) the number of projects were 252 with 98 project leaders<sup>43</sup>.

It was decided to direct questions towards the different projects, and hence one person (the project leader) sometimes answered several times due to the fact that several project leaders lead more than one project. Since not all projects in the database are active, the initial number of 252 projects was reduced to 150 at the time of data collection.

The measuring instrument of choice is a questionnaire. The main reason for choosing a questionnaire is to produce statistics and be able to quantitatively accept or reject the hypotheses put forward in the research model.

The questionnaire was sent to the 150 potential respondents by including a link to the questionnaire database in an e-mail from the person in charge of all procurement projects in the NoDLO. In the summer of 2006, after two reminders, 87 informants (58 percent) returned answers to the questions. Out of the 87 answers, 9 responses had high levels of missing data and therefore they were deleted. The remaining 78 responses (52 percent) were all complete.

### 4.2. Measures, validity and reliability

Constructs are all measured by multi item ordinal scales. All construct items use a five point Likert-type scale with end points “fits very badly” and “fits very well”.

The control variables were covered with nominal questions regarding the main type of procurement the project is dealing with (material, information technology or engineering), what NoDLO site the project works out of (Army, Navy or Air Force) and the size of the project in terms of personnel working full time with LCC in the project (1, 2-4 or 5 or more).

#### 4.2.1 Content validity

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<sup>43</sup> The numbers are from The NoMoD’s project investment database called FID (“Forsvarets investeringsdatabase”).

To minimize the possibility of the respondents not understanding the terminology and layout of the questions, the questionnaire was tested out on three respondents within the Norwegian Navy and two respondents within the NoDLO. Based on their feedback some alternations were done. Regarding the problem that respondents do not want to reply, validity is tried increased through guaranties of anonymity.

#### 4.2.2 Uni-dimensionality

An exploratory factor analysis in the form of principal component analysis (PCA) was conducted in SPSS<sup>44</sup>.

First the different original items in the summed scales of the study (TUseofLCC, TInfoSym, TKnowledge, TUncertainty and TAttitude), were assessed towards suitability for factor analysis. In accordance with general recommendations, the dependent scale (TUseofLCC) and the independent scales were measured separately. The assumption of minimum sample size in a PCA was met [13]. The initial correlation matrix of the independent construct variables and the dependent variable showed that from one to several items on each construct had to be removed due to low item to item correlation<sup>45</sup>. The correlation matrixes for the dependent and independent ordinal constructs can be seen in appendix 1.

The coefficient values for UseofLCC4 and UseofLCC5 were so close to 0.3 they were still kept in the analysis. Further it was found that sufficient correlations exist among the items with a Barlett's test of sphericity [13]. Finally the measure of sampling adequacy (MSA) came out with 0.792 for the dependent construct and 0.605 for the independent constructs [14]. Hence all tests justify that it is appropriate to apply factor analysis, and a Principal Component Analysis (PCA) was done in SPSS.

It is suggested that PCA should be done separately for the dependent and independent constructs. For the dependent construct the PCA gave an eigenvalue of 2.710 for one factor with a value of 0.729 for factor two (if two factors were to be retained), hence below the recommended cut-off value of 1 for the eigenvalue [13]. This is in accordance with the predetermined numbers of dependent factors. The percentage of variance explained with a one factor dependent solution is a little low (with 55%), but acceptable, and the factor loading of the five items to the construct are all above 0.6 (item 1 is 0.829, item 2 is 0.760, item 3 is 0.802, item 4 is 0.621 and item5 is 0.644). Based on this uni-dimensionallity for the dependent summed scale is met.

For the independent items a PCA with Varimax rotation was done in SPSS. The predicted numbers of factors should be four. The rotated component matrix is shown in table 1.

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<sup>44</sup> SPSS is short for the Statistical Package for the Social Sciences. The system was first developed in the 1960s, and has since gone through many updates [20]. The version used in this study is SPSS Release 13.

<sup>45</sup> Both Hair et al. [13] and Pallant [14] suggest that the cut of point for the correlation coefficient should be 0.3.

Table 1, rotated component matrix for the independent constructs' items

	Component			
	1	2	3	4
Knowledge3	<b>.919</b>	-.035	.126	.074
Knowledge4	<b>.892</b>	.087	.190	-.011
Knowledge1	<b>.727</b>	-.079	-.215	-.171
Uncertainty2	.066	<b>.900</b>	-.138	-.001
Uncertainty1	-.044	<b>.888</b>	-.151	.021
Uncertainty3	-.045	<b>.745</b>	-.113	-.159
Info symmetry2	-.123	-.165	<b>.830</b>	-.019
Info symmetry3	.112	-.075	<b>.796</b>	-.101
Info symmetry4	.103	-.164	<b>.712</b>	.162
Attitude LCC6	-.167	-.112	-.004	<b>.858</b>
Attitude LCC5	.071	-.012	.022	<b>.850</b>

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

Rotation converged in 5 iterations.

As can be seen in table 1, the items loaded against the factors as predicted, and with factors that are significant [13]. The total variance explained with the four factor solution is 73.1 % which is considered indicative of a well defined structure [13]. It can be concluded that it is statistically highly significant that uni-dimensionality is present in the summed scales making up the different constructs. All items (dependent and independent) included in the final model can be seen in appendix 2.

#### 4.2.3 Reliability and scale validity

Reliability on the collected data was checked through the use of item to total correlation and inter-item correlation on the items making up the scale and Cronbach's Alpha for the constructs themselves. Item to item correlation is already presented in the last section, and found to be acceptable.

Hair et al. [13] suggest that item-to-total correlation should exceed 0.50, however other researchers have advocated a cut-off threshold of 0.4, [15]. Finally, since this research is of an exploratory nature the accepted lower limit for Cronbach's Alpha (CA) is 0.60 [13].

As mentioned before, the PCA assigned all five items of the dependent construct to one factor. The correlation of each item to the summated scale score were; 0.67, 0.6, 0.63, 0.45 and 0.47 (from item 1 to item 5). This result indicates that each item is measuring the same as the summated scale [14]. Further a satisfactory internal consistency given by a CA value of 0.780 was found.

All independent items were, as shown in table 1, assigned to appropriate factors. The project uncertainty (TUncertainty) items had all item to total correlation above 0.5 and a Cronbach's Alpha of 0.82. This indicates a reliable scale.

Attitude towards the use of LCC by the project leaders (TAttitude) summed scale is made up of two items, both showing correlation of each to the summated scale of 0.5, this together with an alpha value of 0.67 indicate a reliable scale.

Information symmetry between the principle and the agent regarding the use of LCC (TInfoSym) got a summated scale that after the PCA was made up of three items. The items have an item to total correlation of 0.59, 0.54 and 0.5. Further the scale has a Cronbach's Alpha value of 0.72, and hence the scale should be reliable.

The last independent construct is the project leaders' (or his/her teams) knowledge about LCC (TKnowledge). After the PCA only one item was removed and the final scale has three items, with an item to total correlation of 0.72, 0.77 and 0.48. This together with an alpha value of 0.8 indicates internal consistency.

Scale validity was assessed with the use of discriminant validity. As can be seen in table 1, the final model demonstrated good discriminant validity with no cross construct loadings above 0.5.

## 5. Test of hypotheses

In order to test the hypotheses of the study, a multiple regression analysis was used. Before the regression equation was set up a one-way analysis of variance (ANOVA) for each of the three control variables (type of project, project size and project site) with use of LCC as factor was conducted in SPSS.

The analysis showed non-significant difference between the subgroups within project-type and project-size. Regarding project-site however (whether the project is run out of Kolsås (mostly Army), Bergen (mostly Navy) or Kjeller (mostly Air Force), the ANOVA test showed, somewhat surprisingly, that there was a statistically significant difference (0.003) somewhere among the mean score on the use of LCC for the three sites.

The descriptive data showed that projects lead out of Kjeller (N=22) had a mean of 3.93, projects based in Kolsås (N=33) had a mean of 3.78 and projects lead out of Bergen (N=23) had a mean of only 3.33. Due to the non-metric data of the site variable two indicator-coded dummy variables were made (ArmyCom and NavyCom), with projects based in the earlier Air Force Material Command as the comparison group.

The initial regression equation was set up as follows:

$$TUseofLCC = \beta_0 + \beta_{TInfoSym} + \beta_{TKnowledge} + \beta_{TUncertainty} + \beta_{TAttitude} + \beta_{ArmyCom} + \beta_{NavyCom} + \epsilon$$

A normality plot and scatter plot of the standardized residuals against their predicted value as well as histogram of the error term distribution were produced and tests showed acceptable results.

The significance level is set at the normal alpha level of 0.05. In the correlation and regression analysis one sided tests are used. This can be done because prior to the tests it was established through the hypothesis that the parameter will go in one particular direction.

The correlation matrix for the independent ordinal constructs (table 2) shows that multicollinearity initially is not a problem. However, there is a statistical significant bivariate correlation between the uncertainty construct and the information symmetry construct. This was expected, and the negative correlation indicates that the board is more informed about the use of LCC if the uncertainty for the project is high (more on this in the discussion section).

Table 2, correlations and descriptive statistics

	<i>TUseofLCC</i>	<i>TAttitude</i>	<i>TUncertainty</i>	<i>TKnowledge</i>	<i>TInfoSym</i>
<i>TUseofLCC</i>	1.0	0.284**	-0.005	0.169	0.257*
<i>TAttitude</i>		1.0	-0.121	-0.095	0.043
<i>TUncertainty</i>			1.0	-0.021	-0.313**
<i>TKnowledge</i>				1.0	0.066
<i>TInfoSym</i>					1.0
Mean values	3.69	3.23	2.93	3.36	2.74
Standard deviation	0.64	0.95	1.31	0.73	0.81

\*\* Correlation is significant at the 0.01 level (1-tailed).

\* Correlation is significant at the 0.05 level (1-tailed).

The correlation matrix further shows that *TAttitude* and *TInfoSym* have statistically significant correlation towards the dependent construct (Use of LCC). The knowledge construct has not a correlation that is statistically significant (significance of 0.069) towards *TUseofLCC* but was still kept in the analysis because of the bivariate nature of the correlation matrix and the closeness to the 0.05 level of significance.

Finally the uncertainty construct is correlated to the use of LCC but only weakly, and with no statistical significance. Based on this it was decided that the construct will not be included in the final regression analysis. We can conclude that no statistically significant support was found towards hypothesis 1: “*Project uncertainty will negatively affect the use of LCC- based procurement decisions*”.

The final regression formula became:

$$TUseofLCC = \beta_0 + \beta_{TInfoSym} + \beta_{TKnowledge} + \beta_{TAttitude} + \beta_{ArmyCom} + \beta_{NavyCom} + \epsilon$$

### 5.1 Regression analysis and results

Table 3, Regression model, dependant variable: Use of LCC

<i>Independent variable</i>	<i>Unstandardized Coefficient</i>	<i>Standard error</i>	<i>Standardized Coefficient Beta</i>	<i>t-value</i>	<i>VIF</i>
Constant	2.522	0.482		5.232**	
TInfoSym	0.108	0.087	0.137	1.241	1.150
TKnowledge	0.182	0.090	0.209	2.013*	1.025
TAttitude	0.144	0.075	0.215	1.936*	1.170
ArmyCom	-0.157	0.162	-0.123	-0.967	1.537
NavyCom	-0.470	0.188	-0.340	-2.502*	1.752

N=78; F = 4.578 (p<0.001); R<sup>2</sup>= 0.241; Standard error of the estimate = 0.572

\* Correlation is significant at the 0.05 level (1-tailed).

\*\* Correlation is significant at the 0.005 level (1-tailed).

The VIF values in table 3 shows that multicollinearity is not a problem. Hair et al. [13] estimate the minimum R square that can be found statistically significant with a Power of 0.80 with 5 independent constructs and a sample size of 78 to be approximately 17 percent. The total population in this study is 150, and hence a sample size of 78 is fairly large, it could therefore be argued that even a lower R Square would be significant. However, the final model gave a very acceptable result with an R square of 24.1 percent.

The residuals of the regression were checked for linearity and homoscedasticity with the help of SPSS' scatter plot, and normality with the help of the Normal Probability Plot. The findings did not indicate any nonlinear pattern to the residuals. Further no pattern of decreasing or increasing residuals can be seen, thus indicating homoscedasticity and finally no substantial or systematic departure is observed in the normal probability plot. Hence the regression variate is found to meet the assumption of normality [13].

Hypothesis 2 predicted that positive attitude towards the use of LCC by the project leader would positively affect the use of LCC- based procurement decisions. This is supported by the beta value for the standardized coefficient of the attitude construct ( $\beta_{TAttitude} = 0.215$ ). The coefficient is as expected positive and it is statistically significant with a one sided value of 0.0285 (P<0.05), meaning that the attitude of the project leader towards the use of LCC makes a significant unique contribution to the prediction of the use of LCC based procurement decisions.

In hypothesis 3, the prediction was that information symmetry between principal (Ministry of Defence) and agent (project leader) regarding the use of LCC would positively affect the project

leader's use of LCC. The empirical finding is that the relationship is as expected with a coefficient of  $\beta_{TInfoSym} = 0.137$ . However, this construct is not statistically significant (significance value of 0.11). There is in other words eleven percent probability that the result is due to chance, and thus the hypothesis is not statistically supported.

The last hypothesis (hypothesis 4) is supported empirically. It was initially hypothesized that better knowledge about life cycle costing would increase the use of LCC based procurement decisions. The findings indicate statistical significance with the one tail test of 0.024 ( $P < 0.05$ ) and a coefficient  $\beta_{TKnowledge} = 0.209$ .

Finally, the negative beta coefficients for the two dummy variables (ArmyCom and NavyCom) indicate that the intercepts for these two groups are lower than for the reference group (Air Force site). However the lower intercept of the Army site (ArmyCom) is not statistically significant, in comparison to the intercept of the Navy site (NavyCom), which is statistically significant (see table 3).

## 6. Discussion and conclusions

As stated in the theory section, Eisenhardt [8] claims that two main problems occur in agency relationships, the first problem is that of conflicting goals between the principal and the agent, and the second problem is that of risk preferences.

It was assumed that the NoMOD would be risk neutral when it comes to evaluating projects based on life cycle cost, while the project leader was assumed to be risk adverse, especially if the project in question had high project uncertainty. The first hypothesis therefore stated that "*Project uncertainty will negatively affect the use of LCC- based procurement decisions*". The data analysis showed that uncertainty correlated to the use of LCC, and in the direction that theory assumed (negative correlation). However, the correlation was weak and not statistically significant, and hence the hypothesis had to be rejected. There is not one single good explanation why the hypothesis is not supported, it is however interesting to notice that there is a statistical significant bivariate correlation between uncertainty and information symmetry (see table 2). This correlation indicates that the project board is more informed about the use of LCC if the uncertainty for the project is high (non COTS). Information systems can curb adverse selection [8], and hence it can be argued that NoMoD through the project boards has made sure that less information asymmetry can occur when project uncertainty is high (non COTS) in order to reduce the possibility of adverse selection. It looks like the Norwegian Defence already uses the agency theory concept of information alignment in order to reduce the possibility of adverse selection more in projects with high uncertainty than in projects with low uncertainty, and due to this we could not statistically conclude that project uncertainty negatively affects the use of LCC-based procurement decisions.

As stated above the first problem in agency relationships is that of conflicting goals between the principal and the agent [8]. The research questions tried to capture the attitude of the project leaders towards the use of LCC, in order to answer hypothesis 2. The hypothesis was supported by the empirical data, and from a theoretical standpoint this means that less goal conflict exists

between projects' leaders with a positive attitude towards LCC and the principle, than between the principle and project leaders with a less positive attitude towards LCC.

According to agency theory one of the most effective ways to avoid goal conflicts is to align the information between the principle and the agent [8]. Statistically significant support, based on the 0.05 significant level, was not found towards the hypothesis regarding information symmetry between the principal and the agent (hypothesis 3). However, there is no more than eleven percent chance that the positive beta coefficient found in the empirical data (which supports the hypothesis), is due to chance. Further, since the sample size in the case of this research consists of more than 50 percent of the total population, it is very likely that information symmetry between the principal and the agent really makes a unique contribution to the use of LCC based procurement decisions. Hence, even if not statistically supported, the data is in line with the agency theory proposition.

Regarding the proposition that when the agent, either by himself or through members within his own project, has thorough knowledge about life cycle costing, he will be more likely to understand and accept the position of the principle (NoMoD), and therefore use LCC (expressed in hypothesis 4) is supported by the data. This means that Wååk's [1] theory about lack of knowledge, with regard to LCC, leading to less use is empirically supported.

At the start of the research, control variables regarding what main type of procurement the project is dealing with (project-type), what NoDLO site the project works out (project-site) of and the size of the project in terms of personnel working with LCC (project-size) were included in the research model. The project leaders were asked to mark what subgroup within each of the three variables they belonged to. No hypotheses were made before the collection of data, and it was really not expected to be a statistically significant difference between the subgroups within each variables.

This was also the case regarding project-type and project-size. Somewhat surprisingly though, the data clearly show that project leaders working in Bergen (the Navy site) are on average less likely to use LCC based procurement decisions than their colleagues working in the "Air Force site" and the "Army site". The data collected can not verify why this is the case. It is however a fact that the Navy site (Bergen) is much further in physical distance from the NoMoD (the principal) situated in Oslo, than the Army site (Kolsås, just outside Oslo) and Air Force site (Kjeller, also just outside Oslo. Other explanations could be connected to organizational cultural differences between Navy, Army and Air Force regarding how closely the goals and tasks of the mandate group (the principal), are followed. These are however only speculations.

## 6.1 Managerial implications

The data show that high uncertainty in terms of projects with non COTS procurement, have better information alignment than projects that are less uncertain. Hence we see that uncertainty already is closely connected to information symmetry. In order for NoMoD to make sure that project leaders do use LCC in procurement decisions it becomes important that all projects are followed up by a project board. Further, this board must make sure that they and the project leader have the same information about how LCC is used. Our data suggest that projects that



have information symmetry regarding LCC decisions with the principal are more likely to use LCC than projects that do not.

Further the empirical data clearly show that NoMoD should do what they can to get a positive attitude from the project leaders towards the use of LCC, because this will assure more use of LCC based decisions. Answers to the items of the attitude construct, indicate that not all project leaders believe that NoMoD really mean what they are stating in the “LCC concept”. In this concept NoMoD clearly state that when investment decisions are made, they must favour solutions that yield the lowest possible life cycle cost, even if this means that the initial investment cost becomes higher. Project leaders that do not believe in the concept have a more negative attitude, and use LCC less than those that believe what NoMoD is saying. The bottom line is that NoMoD must use every opportunity, to ensure the project community that they really mean what they are stating in the concept.

NoMoD together with the Norwegian Defence Material Agency and the Norwegian Defence College started a project leader certification program some years ago. The first fully certified project leaders graduated in the spring of 2005<sup>46</sup>. In this program, use of LCC based procurement decisions is a part of the education. The data of this analysis clearly show that project leaders with good knowledge of LCC are more likely to use LCC in procurement decisions than those with less knowledge. It is therefore essential for the NoMoD to continue this program (and other programs/courses where LCC concepts can be learned), if they want the use of LCC to grow.

Finally, since the data show that project leaders working out of the old Navy Material Command site are less likely to use LCC based procurement decisions than their Army - and Air Force - site colleagues, NoMoD should probably focus first on this group of project leaders.

## **7. Limitations and future research**

Since this is a case study from the Norwegian defence, the findings can not be automatically transferred to other organizations considering the use of LCC based procurement decisions. We do however believe that our findings could be beneficial to most organizations.

The three ordinal constructs and the dummy variables that ended up in the final analysis do not explain fully why some procurement projects are still carried out and reviewed based on initial procurement costs alone when the official policy is to apply the life cycle cost approach. Other variables, together with the ones already included in this study, must be examined in order to fully answer the question. Further the empirical data does not tell us why the projects' leaders working out of the Navy site are less likely to use LCC than their project leader colleagues in the Army- and Air Force- site. In order to examine this finding, and other variables besides the ones hypothesised in this research, it is suggested that a more in depth qualitative case study of the use of LCC in Norwegian Defence Procurement projects could be conducted.

According to Yin [16], the most important application of a qualitative case study is to explain causal links in real-life interventions that might be too complex for a quantitative survey to fully

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<sup>46</sup> See, [http://www.prinsix.no/prinsix/nyheter/krav\\_til\\_sertifisering\\_av\\_prosjektlederkompetanse](http://www.prinsix.no/prinsix/nyheter/krav_til_sertifisering_av_prosjektlederkompetanse)

comprehend. Hence a possible future research into the main question of this study could utilize Yin's qualitative case study methodology.

Finally, other theoretical perspectives, like for example the administrative, political and actor-network perspective used in earlier studies of complex implementation processes [17] could also be addressed.

## APPENDIX 1

**Correlation matrix for the dependent construct items**

	Use of LCC1	Use of LCC2	Use of LCC3	Use of LCC4	Use of LCC5
Use of LCC1	1				
Use of LCC2	.528	1			
Use of LCC3	.668	.468	1		
Use of LCC4	.382	.381	.337	1	
Use of LCC5	.376	.388	.393	.288	1

**Correlation matrix for the independent constructs items**

	Uncer- tainty1	Uncer- tainty2	Uncer- tainty3	Atti- tude LCC5	Atti- tude LCC6	Info sym- metry2	Info sym- metry3	Info sym- metry4	Know- ledge1	Know- ledge3	Know- ledge4
Uncertainty1	1										
Uncertainty2	.792	1									
Uncertainty3	.495	.532	1								
Attitude LCC5	-.021	-.052	-.099	1							
Attitude LCC6	-.085	-.094	-.188	.503	1						
Info sym- metry2	-.258	-.238	-.239	.037	-.007	1					
Info sym- metry3	-.187	-.196	-.137	.005	-.075	.521	1				
Info sym- metry4	-.251	-.222	-.202	.066	.154	.459	.392	1			
Knowledge1	-.046	.051	-.033	-.040	-.233	-.208	-.001	-.012	1		
Knowledge3	-.085	-.004	-.097	.080	-.071	.043	.136	.149	.492	1	
Knowledge4	-.017	.081	.016	.015	-.155	.008	.217	.164	.416	.845	1

## APPENDIX 2

## Measure of constructs

UseofLCC1	In the project we evaluate how different system solutions will affect the operations- and maintenance- costs.
UseofLCC2	In my project we evaluate which technical solution will give the lowest operator training costs in the operational phase of the equipment/system.
UseofLCC3	In my project we evaluate which systems will give the lowest maintenance costs in the operation & support phase.
UseofLCC4	In a situation where two alternative systems yield the same benefit, I would recommend the system that gives the lowest possible life cycle cost, even if this means that the initial investment cost becomes higher.
UseofLCC5 (Reversed)	In my project we recommend/choose the system solution that gives the lowest initial procurement cost.
Knowledge1	All members of the project have knowledge about integrated logistics support and life cycle costing.
Knowledge3	I have good knowledge regarding integrated logistics support.
Knowledge4	I have good knowledge regarding life cycle costing.
Uncertainty1	In my project everything we procure is commercially available (commercially of the shelf).
Uncertainty2	In my project the main part of the procurement is commercially available.
Uncertainty3 (Reversed)	In my project very little or nothing of what we procure is commercially available.
Info symmetry2	My project board (or the one I report to) has the same information regarding operations- and support-cost for the alternative solutions/systems as I have.
Info symmetry3	My project board (or the one I report to) understands the concepts of life cycle costing.
Info symmetry4	Operations- and support- costs for the system I am procuring are on the agenda of the board meetings.
Attitude5 (Reversed)	There is no purpose in doing life cycle cost analysis, because the initial procurement cost will be the decisive factor anyway.
Attitude6 (Reversed)	Operating costs, support costs and disposal costs for the system/material my project is procuring are less important than initial procurement cost.

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## APPENDIX I

In this appendix the semi structured interview guide used in connection with paper II is included.

It is important to notice that in the interview situation both the interviewer and the person interviewed had a copy of the guide.

However, it was the interviewer that wrote on the guide used for analysis.

The interview guide was originally in Norwegian, and has been translated in order to be included in the thesis.

## Interview guide

Brief before the interview:

1. The statements and information collected through this interview will be used as part of the data foundation in a research project regarding maintenance and spare parts inventories in man-made humanitarian disasters.
2. Your person will be made anonymous as far as possible, but I might use direct statements in the published material without quoting who has said what.
3. I stress that this is no examination of your knowledge. I want you to tell me how you today do the things I ask about. I am in other words not interested in hearing what you think is “politically” correct to do, but what you really do or what you really think is going on.

### Part 1 Personal information:

1. What is your name?
2. What is the name of the organization that you work for and what is the name of the department that you work in.
3. What is your position (name of position and responsibility)
4. What is your responsibility in connection with (“the Darfur operation – if the informant is from the Norwegian Defence or TSU operation if NoRC)

### Part 2 Physical context:

1. What type of equipment will your organization operate in the operation area?
2. For how long time will the equipment be in the operation area?
3. Will you operate more than one operational base in the operation area?

4. What kind of maintenance infrastructure will you have in the operation area?
5. How long in terms of time is the supply lines to the next echelon in the supply chain and/or maintenance support chain?

**Part 3 Organizational structure: Superstructure (number of units involved) and Structure of position (knowledge, formalization of behaviour and degree of specialization)**

Number of units involved, degree of specialization and formalization of behaviour:

1. Who (organizational unit and role/person) has the responsibility to decide how the equipment you send into the operation area shall be maintained?
2. Who (organizational unit and role/person) has the responsibility to decide which spare parts are going to be sent into the operation area?
3. Who (organizational unit and role/person) really decide how maintenance of equipment shall be physically performed in the operation area?
4. Who (organizational unit and role/person) really decide which spare parts are going to be sent into the operation area?
5. How many organizational units or roles or persons must be a part of the decision process regarding spare parts in connection with the operation?
6. How will decisions regarding which spare parts to include in the set-up of the operation have on other decisions?



7. Are there many persons and or organizational units working with the planning and set-up of this operation that work with maintenance and spare parts? How are these organizational units and/or persons?
8. Are there formalized reports to those who have decided that the operation shall take place? If so, shall this report include aspects on maintenance and spare parts?
9. If there are formalized reports to those who have decided that the operation shall take place, are there asked for (life cycle) costs in connection with maintenance and the use of spare parts?

Player's knowledge:

10. What knowledge do you think that the different players involved in the planning and set-up of your operation have towards spare parts inventories?
11. Do you have good knowledge regarding maintenance and spare parts planning? Explain in more detail.
12. Do you think that maintenance and spare parts planning and set-up will be important in connection with the equipment used in the operation? If so, how?
13. Those persons responsible for the operation (in terms of leading positions in the "project" or in a project board), do they have knowledge and interest in maintenance and spare parts issues?

**Part 4 Governance: Information symmetry and performance indicators**

1. Is availability of equipment in the operation area an issue in meetings between the project management (e.g. the project leader) and the planner?

2. Are you governed and measured in terms of equipment availability in the operation area?
3. Are there other indicators that are measured and used in connection with project governance connected to maintenance and spare parts inventories?
4. Do you have a firm and fixed budget in connection with spare parts procurement connected to the operation?
5. Do you have a budget connected to procurement or re-supply of new spare parts when in the operation area, and during operations?
6. Are there other key performance indicators connected to maintenance and/or spare parts. Would you please elaborate on these and how the information is aligned between the planners and project management?

**Part 5 Maintenance and spare parts inventory planning and set up (access to optimization data, inventory management systems and optimization tools)**

1. What type of equipment will you probably conduct maintenance on in the operation area?
2. What is the maintenance philosophy or strategy regarding the equipment brought into the operation area (periodical maintenance, condition based maintenance, equipment cannibalization and so on)?
3. Do you consider a common equipment strategy (common with other organizations in the operation area) in connection with the planning of the operation?
4. Are you faced with requirement concerning operational availability on the total system (per equipment unit) or on sub systems?

5. Can you get access to operational data on spare parts that you send into the operation area? Operational data can be mean time between failure (MTBF), lead-times from external suppliers, turn-around time on parts repair and so on.
6. What kind of spare parts will you bring into the operation area?
7. When you plan in detail for which spare parts to bring along, do you take into account what kind of maintenance that will be performed in the area?
8. Is it other factors besides maintenance that govern which spare parts you take with you?
9. Have equipment reliability had impact on the decision on which equipment that will be used in the operation?
10. What is your view on equipment cannibalization? Do you include this in your planning?
11. How is the process in terms of setting up the spare parts package you bring into the operation area?
12. Do you decide on a minimum amount of each spare part?
13. Do you use spare parts optimization software such as for example OPUS10?
14. Do you use any type of spare parts inventory management system when in the operation area? If so, is this system:
  - A manual system
  - An information technology based system
  - Integrated with the spare parts inventory system you use back home in Norway via communication lines.

15. Have you decided on reorder quantities connected to re-supply? If so, how were these figures decided?
16. Is local re-supply or local sourcing of spare parts an option in connection with the operation?
17. How will you communicate spare parts needs back to the mother organization in Norway when you are in the operation area?
18. How will supply of spare parts be shipped when you are established in the operation area?
19. Are environmental issues a subject connected to the planning of maintenance and use of spare parts in connection with the operation?
20. Are there other issues that you would like to talk about regarding planning and set up of maintenance and spare parts inventories in connection with operations?

Debrief after the interview:

- Are there other persons in your organization/unit that I should interview in connection with this subject?
- Is it anything that you want to add or comment now when the recorder has been turned off?
- Thank you very much for your cooperation and help.<sup>3</sup>

## APPENDIX II

In this appendix the semi structured interview guide used in connection with paper III is included.

It is important to notice that in the interview situation both the interviewer and the person interviewed had a copy of the guide.

However, it was the interviewer that wrote down the answers on to the guide as well as marking answers to structured questions.

The interview guide was originally in Norwegian, and has been translated in order to be included in the thesis.

## **Research project connected to spare parts optimization in the Norwegian Defence**

Briefing before the interview:

From the early 1990s several projects within the Norwegian Defence have been working with so called integrated logistics support (ILS) and life cycle cost (LCC). According to ILS theory, the purpose or aim of ILS is to minimize the total life cycle cost for the procured system/material without this negatively reducing system performance or project procurement time. Life cycle costs include cost associated with research and development, direct investments, operation and support (including maintenance) as well as disposal. The Norwegian Defence procured the spare parts optimization software package called OPUS10 already in the 1990s in order to aid the ILS work. In the summer of 2004 the Norwegian Ministry of Defence highlighted the importance of ILS by deciding that all procurement projects within the Norwegian Defence shall use life cycle cost when based procurement decisions are made.

- The statements and information collected through this interview will be used as part of the data foundation in a research project connected to the process and results of spare parts optimization based on OPUS10 in Norwegian Defence projects.
- Your person will be made anonymous as far as possible, but I might use direct statements in the published material without quoting who has said what.
- I stress that this is no examination of your knowledge. I want you to tell me how you today do the things I ask about. I am in other words not interested in hearing what you think is “politically” correct to do, but what you really do or what you really think is going on.

General questions regarding the project including resources
---

1. What defence branch is the procurement aimed at?
  - Army*.....1
  - Navy* ..... 2
  - Air Force* ..... 3
  - Joint*..... 4
  - Other* ..... 5 *Please state*\_\_\_\_\_
  
2. Which PRINSIX phase is the project currently in?
  - Concept phase*.....1
  - Definition phase* ..... 2
  - Procurement phase* ..... 3
  - Operations*..... 4
  - Other* ..... 5 *Please state:*\_\_\_\_\_
  
- 3 How many man-years (including your own) is/was connected to the project?
  - Less than one..... a
  - 1..... b
  - 2-4 ..... c
  - 5-9 ..... d
  - 10-14 ..... e
  - 15 or more..... f
  
- 4 How many man-years (including your own) is/was used in ILS/LCC work in the project?
  - Less than one..... a
  - 1..... b
  - 2-4 ..... c
  - 5-9 ..... d
  - 10-14 ..... e
  - 15 or more..... f
  
- 5 How many meetings are there with the project leader each month ?
  - 1..... a
  - 2-5 ..... b
  - 6-10 ..... c
  - 11 or more..... d
  - Other* ..... f *Please state:*\_\_\_\_\_

6 How many persons are connected to the project management team?

- 1..... a  
 2-4 ..... b  
 5-7 ..... c  
 Who are they ..... d Please state: \_\_\_\_\_

7 How many persons in the project management team do you recon have knowledge regarding spare parts optimization?

- 1..... a  
 2-4 ..... b  
 5-7 ..... c  
 Other ..... d Please state: \_\_\_\_\_

8 How many persons in the project management team do you recon have experience with the use of spare parts optimization?.

- 1..... a  
 2-4 ..... b  
 5-7 ..... c  
 Other ..... d Please state: \_\_\_\_\_

General questions regarding you and your background
---

9 Are you?

- Male ..... 1  
 Female..... 2

10 Are you?

- Military employee ..... 1  
 Civil servant employed by Defence ..... 2  
 Consultant (external) ..... 3

**If the answer is 2 or 3 to question 10, move on to question 14**

11 What is your military occupational category?

- Operational ..... 1  
 Technical..... 2



*Logistics* ..... 3

12 What is your military rank?

*Lieutenant/lower* ..... 1

*Lieutenant Commander / Captain*..... 2

*Major/Commander*..... 3

*Lieutenant Colonel/Commander S.G.* .... 4

*Higher* ..... 5

13 Are you employed by?

*The Army*..... 1

*The Navy* ..... 2

*The Air Force*..... 3

**The rest of the questions must be answered by everyone**

14 Where is your work station?

*Kolsås*..... 1

*Kjeller*..... 2

*Bergen* ..... 3

*Other* ..... 4

15 What is your highest civilian education?

*Primary and secondary school* ..... 1

*High school* ..... 2

*Bachelor/Equivalent*..... 3

*Master/ Equivalent*..... 4

*Other* ..... 5 Please state: \_\_\_\_\_

16 What is your highest military education?

*Officer training school*..... 1

*Army/Navy/Air Force academy* ..... 2

*Defence college* ..... 3

*Higher* ..... 4

*None* ..... 5

Questions regarding physical context and uncertainty
--

1. What kind of equipment/system is it your project is procuring?
2. Is the project conducting spare parts optimization connected to everything the project is procuring?
3. How long is the planned operational phase in years for the equipment/system the project is procuring?
4. At what Defence base or bases will the equipment be stored / operated?

**Now some structured questions regarding project uncertainty – the focus in connection with uncertainty is wheter the project is procuring so called commersially of the shelf – COTS systems or not.**

	<i>Fits very bad</i>	<i>Fits bad</i>	<i>Fits neither well nor bad</i>	<i>Fits well</i>	<i>Fits very well</i>
5 In this project <b>everything</b> we procure is commercially available (commercially of the shelf):	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>
6 In my project <b>the main part</b> of the procurement is commercially available:	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>
7 In my project <b>very little or nothing</b> of what we procure is commercially available:	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>

Questions regarding access to data (interdependency)
--

1. How shall the equipment/system be maintained (periodic, condition based, etc)
2. Is availability requirement stated on the total system, sub-system and or part?

3. Can you get access to operational data such as:
  - a. Indenture data / Work breakdown structure or equivalent
  - b. Mean time between failure – failure rate
  - c. Lead time from spare parts provider
  - d. Lead times between repair echelons
4. Where do you get such data from?
5. Can you get access to price and cost data? If so where do you get it from?
6. Has reliability, common configuration with other systems in the Norwegian Defence or allies affected the choice of equipment?
7. What do you think about cannibalization of equipment? Is this part of the planning process?
8. Have you decided on a minimum of spare parts for the equipment before conducting the spare parts analysis/optimization?
9. Have you decided on reorder points in connection with resupply of spare parts – if so, how were the reorder points decided?
10. Are environmental factors a part of the spare parts planning?
11. What was/is the main challenge in connection with access to data and spare parts optimization the way you see it?
12. Are there other aspects of the spare part optimization process that we have not talked about?

**Questions regarding information symmetry, centralization and interdependency on resources**

1. Who is responsible for deciding how the equipment procured will be maintained?
2. Who is responsible for making the final decision on which spare parts to buy?
3. Who is responsible for deciding which spare parts will be stored at which echelons?
4. How many are working with maintenance planning and spare parts optimization in the project and in the supporting organization? Who are these persons?
5. How many has to be a part of the decisions regarding spare parts buys and who are these persons?
6. How will the decision regarding which spare parts to buy in which quantities affect other decisions in the project?
7. In status reporting to the project leader is spare parts a topic/issue?
8. In reports to the project board, or equivalent, is life cycle costs connected to maintenance and spare parts an issue?
9. Have the persons in leading positions in the project (e.g. project leader) interest in the subject of spare parts optimization?
10. Is equipment/system availability an issue in project management meetings?
11. Do you have a firm and fixed budget regarding procurement of spare parts?
12. Are there other key performance indicators connected to maintenance and spare parts?

**Now some structured questions regarding information symmetry between you and the project management (e.g. project leader)**

	<i>Fits very bad</i>	<i>Fits bad</i>	<i>Fits neither well nor bad</i>	<i>Fits well</i>	<i>Fits very well</i>
13 My project leader asks me to report on life cycle costs in connection with spare parts:	1	2	3	4	5
14 My project leader has the same information regarding estimated support costs connected to alternative spare parts packages that I have:	1	2	3	4	5
15 My project leader understands the concepts regarding spare parts optimization:	1	2	3	4	5
16 Operations- and support- costs for the system the project is procuring are on the agenda of the board meetings:	1	2	3	4	5
17 My project leader is more occupied with the investment budget than with the operations- and support costs of the system the projects are procuring:	1	2	3	4	5

18. Is it other aspects that you want to talk about regarding information symmetry, interdependency on resources or centralization in connection with spare parts optimization?

Questions regarding viewpoints/attitude towards spare parts planning and optimization and life cycle cost

	<i>Fits very bad</i>	<i>Fits bad</i>	<i>Fits neither well nor bad</i>	<i>Fits well</i>	<i>Fits very well</i>
1 Even if the Defence's concept for procurement of systems states that when investment decisions are made, systems that yield the lowest possible life cycle cost, should be preferred, it is the procurement cost alone that must be the deciding variable:	1	2	3	4	5

2 Decisions (regarding spare parts) based on life cycle costs does not happen in reality:	1	2	3	4	5
3 I focus on life cycle cost as an important indicator in connection with spare parts investment:	1	2	3	4	5
4 There is no purpose in doing life cycle cost analysis, because the initial procurement cost will be the decisive factor anyway	1	2	3	4	5
5 Operating costs, support costs and disposal costs for the system/material my project is procuring are less important than initial procurement cost:	1	2	3	4	5

6. Is it other issues that you would like to talk about regarding your own viewpoints on the importance of spare parts optimization?
7. Is it other issues that you would like to talk about regarding your project leaders' viewpoints on the importance of spare parts optimization?

Questions regarding knowledge (rationality) regarding spare parts optimization
--

1. What knowledge do you think the project members have regarding how to decide spare parts packages in connection with the procurement?
2. Do you have good knowledge regarding spare parts optimization yourself?
3. Do you have formal training, for example in terms of classes, in spare parts optimization?

**Some structured questions regarding knowledge or rationality defined as the ratio between the cognitive capability of the decision maker and the complexity of the problem in question**

	<i>Fits very bad</i>	<i>Fits bad</i>	<i>Fits neither well nor bad</i>	<i>Fits well</i>	<i>Fits very well</i>
4 Everybody that works with logistics in this project have knowledge regarding spare parts optimization:	1	2	3	4	5
5 I have good knowledge regarding spare parts optimization:	1	2	3	4	5
6 I know of the spare parts optimization system OPUS10:	1	2	3	4	5
7 I can use OPUS10:	1	2	3	4	5

8. Is it other issues that you would like to talk about regarding knowledge of spare parts optimization?

Questions regarding the use of spare parts optimization
---

	<i>Fits very bad</i>	<i>Fits bad</i>	<i>Fits neither well nor bad</i>	<i>Fits well</i>	<i>Fits very well</i>
1 In the project we evaluate how different spare parts solutions will affect the support and operation costs:	1	2	3	4	5
2 In the project we conduct spare parts optimization connected to all the equipment we procure:	1	2	3	4	5
3 In the project we conduct spare parts optimization for selected parts of the equipment we procure:	1	2	3	4	5
4 In the project we use OPUS10:	1	2	3	4	5

1. What would you say the results have been in connection with the spare parts optimization?
2. Have the system you have procured gone into operations?
3. If the system is in operations, how is the experience towards system availability?
4. Are there other issues that you would like to talk about regarding the specific use of spare parts optimization and the use of OPUS10?

Debrief after the interview:

- Is it anything that you want to add or comment now when the recorder has been turned off?
- Thank you very much for your cooperation and help.





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