

Spares Optimisation A Key to Supportability Analysis

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Attachment 1. Some computer tools

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0. SUMMARY

In order to achieve efficient Logistics Support good and early control over the supportability is necessary. This means both cost and effectiveness measures have to be regarded as supportability measures.

A necessary tool to understand, improve and control supportability is a multi-echelon, multi-indenture level spares optimising program. The paper will:

- o Present such a tool - OPUS10
- o Present its use in a number of successful Life Cycle Cost acquisitions covering
 - A Low-Coverage Radar
 - An Air Traffic Control Centre
 - The JAS39 Gripen Aircraft
 - Rapid Trains
- o Present its use in system level Logistic Support Analysis covering:
 - An Air Traffic Control Centre
 - An Offshore Process Control Equipment
 - A Power Control Equipment
- o Present its use for Spares Optimisation and the significant savings that are achieved
- o Present a new program for simultaneous optimisation of test equipment *location* and spares optimisation

1. BACKGROUND

1.1 General

In Sweden a number of significant steps forward within Logistic Support and its practical applications were taken during the 70-ies. The methods were developed within various projects and directly applied in those projects. In particular the development aimed at improving the acquisition process in order to get the Logistic Support problems highlighted. A version of LCC technique specially aiming at being an ILS tool was developed and successfully applied. Some of the applications have been documented - see ref [EbÖ 74], [EbW 75], [Kaw 81] and [PåW 82].

1.2 The OPUS10 Logistic Support and Spares Optimising Program

The development of the Logistic Support applications went hand in hand with the development of the OPUS suite of programs - present version is OPUS10. The reasons for this mutual beneficial situation are

- a) OPUS provided a necessary tool for the applications
- b) The applications provided the cases (and thereby the necessary push for improvements) as well as - in the beginning - some funding

The key characteristic with OPUS was that it provided the necessary bridge, not only between

- Technical system and the Logistic Support Organisation but also between
- Requirements fulfilment and Cost

This can be illustrated by the following figure.

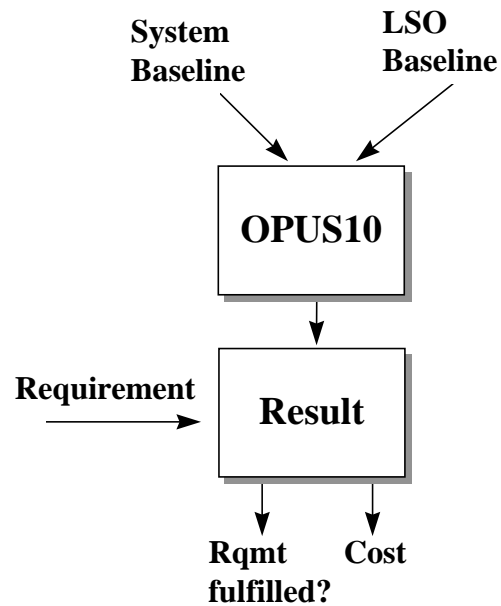


Figure 1.1

This can be illustrated further by an example of one of the OPUS10 outputs - the C/E-curve.

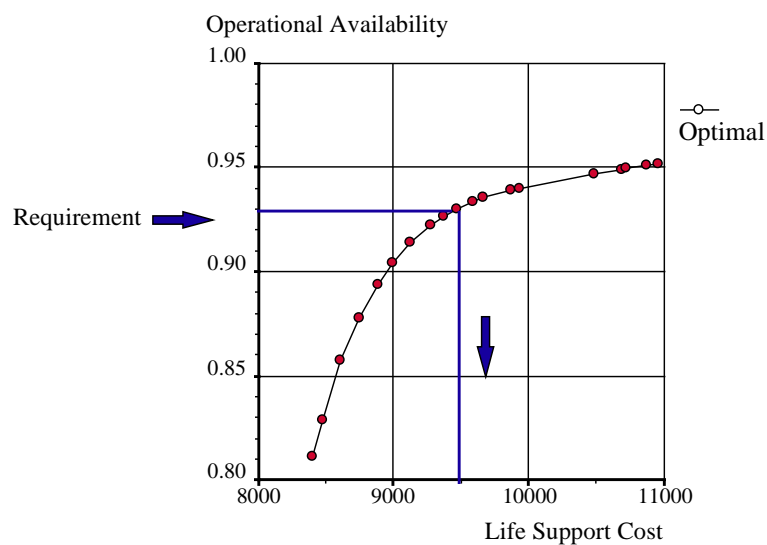


Figure 1.2

OPUS10 is a member of a class of programs denominated *multi-echelon, multi-indenture level spares optimisation programs*. An excellent description of this class of programs is given in [She 92].

Multi-echelon means that the spares are stored on more than 1 echelon. The support organisation can look as below.

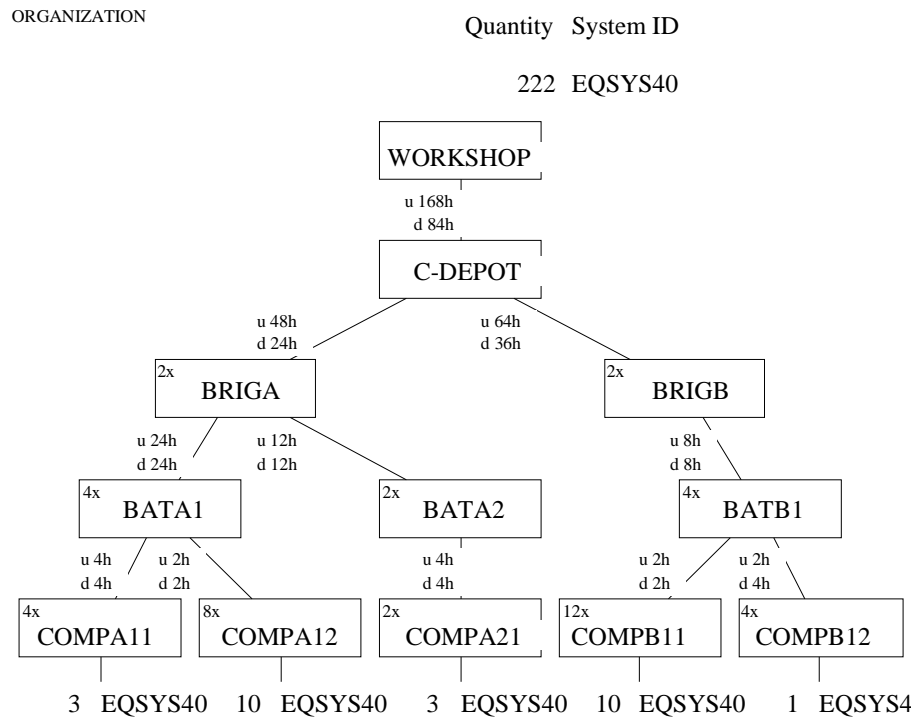


Figure 1.3. A multi-echelon organisation

A number of complicating factors pop up like *unsymmetrical* (stores on the same level are not identical), *item-individual* turn-around times and transportation times, *forbidden* stocks, minimum/maximum stocks, direct routes etc.

Multi-indenture levels means that spares of different levels of indenture (or break-down) are studied at the same time like shown below.

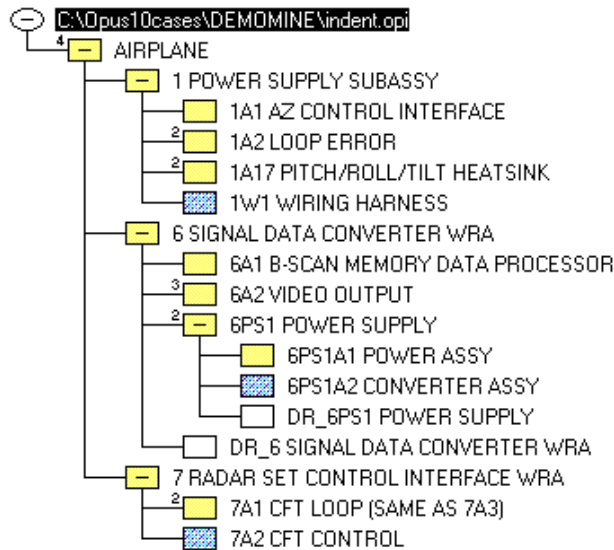


Figure 1.4. A multi-indenture system break-down (from OPSA)

Again, complications show up like commonality both in systems and on lower indenture items, repairables vs. non-repairables, partly repairables etc.

See also [Wååk98].

The magnitude of the curve problem is better understood when worded in the following way: For each point on the cost effectiveness OPUS10 has to decide upon a large number of variables namely how many of each items should be located to each store. If we have 1000 different items and 10 different stores we end up with 10000 variables that has to be solved in an optimum manner.

Problem types

When analysing spares one is frequently faced with fundamentally different *types of problems*.

- o Initial acquisition and distribution
- o Calculation of cost and effectiveness for a given assortment of spares with a given allocation between the stores. This mode is called *analysis*
- o Optimisation of the distribution of a given assortment, called *reallocation*
- o Optimisation of add on acquisition to a given distribution, called *replenishment*
- o Optimisation of add on to a reallocated distribution, in OPUS10 called *reallocation followed by replenishment*

The problem types are relevant in the following scenarios (as examples).

- a) Initial acquisition and distribution.
This is probably the most common problem type. In this scenario you start with a clear table i.e. no spares have been acquired in the actual project. ("Acquisition from scratch".)

- b) Calculation of cost and effectiveness for a given assortment with a given distribution between the stores- *analysis*.
This problem will appear when you do a calculation of the effectiveness of the existing maintenance support organisation for a certain project ("Existing stocks"). Another common situation occurs when you like to scrutinise a contractor spares recommendation.
- c) Optimisation of the distribution of a given assortment-*reallocation*.
This is a common problem in connection with the calculation as in b) above. The question is: "Is it possible to achieve improvements simply by distributing the spares materiel in a better way"? A similar question of course will come forward at different changes in the maintenance and support organisation some workshops are closed, new ones will be added etc.
- d) Optimum add on acquisition to a given distribution - *replenishment*. This is a less common problem but it may occur. See also point e).
- e) Optimum add on to a reallocated distribution - *reallocation* followed by *replenishment*.
This is a fairly common problem. The reason for e) to be more common than d) is the fact that you try to distribute the existing spares as efficient as possible before acquiring any new spares. In many projects the add on acquisition is pre-planned due to long series and it is not necessary to acquire all the spares upfront.

1.3 The acquisition process method

The acquisitions followed the classical sequence

- Need
- Requirement
- Commitment
- Verification
- Consequence

Methods have been developed in particular to permit

- Early studies
- Tender evaluation
- Contracting
- Verification

1.3.1 Early studies

A crucial activity here is to develop a baseline i.e. a description of a system that is estimated to fulfil the requirements. In particular it is important to develop a break-down description on the LRU level containing assessments on failure rates and item costs. To assist in this respect the Data Generator function in OPSA has been developed. See also Attachment 1. Other data are easier to estimate.

With those data available it is possible to perform LCC calculations and as a consequence the cost driving elements can be identified. This will start the improvement process as well as identifying the elements where higher accuracy might be needed. Normally the need for accuracy is overrated - it is far more vital to get going early than to wait for more accurate data to appear. The results are not that sensitive. The knowledge achieved in this way is carried over into the RFQ. See ref [Wååk 98]

1.3.2 Evaluation of Quotations

We can here identify in particular the following functions

- Materiel Data Handling
- Availability Performance Requirements
- Spares Optimisation
- LSC (or LCC calculation)

Materiel Data Handling

This is function takes care of the data at the LRU (sometimes SRU) break down level (like failure rates, unit cost, no of each, replacement times, workshop repair times etc. Furthermore OPSA summarised and ranks data as well as deliver to OPUS10. See also OPSA in attachment 1.

The Availability Performance

In some cases the Availability Performance requirements are formulated in such a way that a computer program is needed to analyse the possible requirements fulfilment.

Sample of programs: KRAVP, ARECA, MrP, ASTOR, SIDRIX, OpSSim.

The SIDRIX program is a comprehensive simulation program that simulates the operation of the Rapid Trains in the presence of faults and other disturbances together with limited repair resources. See also ref [PåK 92]

OpSSim is presented in Attachment 1,

Spares Optimisation (See previous chapter)

LCC programs

Although the LCC calculation is straight forward and simple (in particular in comparison with the Spares Optimisation) the sheer amount of alternative calculations make a computer program necessary. It will also permit a number of useful functions like sensitivity analysis, automatic plotting etc.

Examples: PALSC, SYCAP, LCCDEMO.

These programs tend to be based on more or less tailored spread-sheets.

LCCDEMO is presented in Attachment 1.

When the results are available the potential for a very profitable dialogue with the tenderers open up and normally significant improvements show up. See chapter 2.

Finally the evaluation is over and a tenderer is selected. At this point he has made commitments that fulfils our requirements that (hopefully) meet the *needs* of our customer.

Those commitments are carried into the contract.

1.3.3 Contract

The contractor undertakes to deliver a system that fulfils a large number of requirements including:

- Reliability/Availability
- Life Support Cost limit

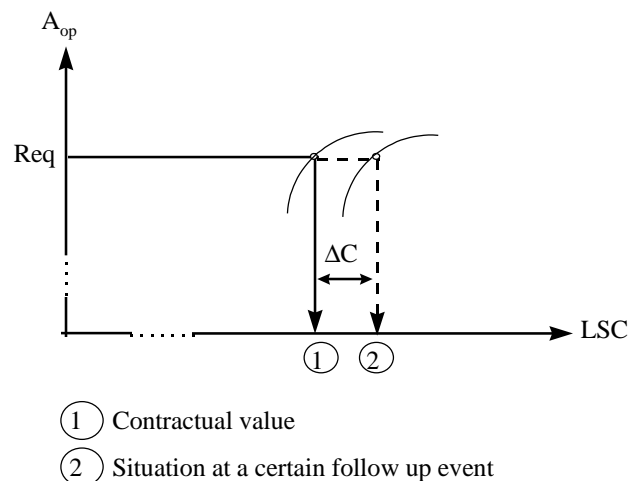
As a basis in the contract there are:

- A Life Support Cost model
- Customer input data
- Contractor input data including a *contractual baseline* (i.e. a system description in the form of a system break down with data at LRU/SRU level)

The system is subject to development. Hence the contractor can not undertake to deliver a system that in all details is identical to the contractual baseline. His undertaking is to deliver something that

- Fulfils the requirements
 - Has a LSC below the agreed limit
 - In time and at agreed price
- etc

Those deviations between the contractual baseline and the current baseline has to be taken care of by OPUS10 and the LSC model. This is illustrated below - the requirement and cost are tied together with the OPUS curve.



This is further illustrated by the following example.

$A_{op} = 0.95$	MTBF = 100 hrs	MTTR = 1 hr gives
	MTW = 4.263	
Assume it is necessary to add an LRU		
New data	MTBF = 98.7	MTTR = 1 hr gives
	MTW = 4.195	

Result:

- a) **Acquisition price: Fix price. No change**
(The contractor has to absorb the cost)
- b) **Investment in spares: Higher (lower MTW and a moved OPUS10 curve)**
- c) **Larger failure flow (more site repairs and more LRU repairs)**

The contractor has to compensate the customer.

1.3.4 Verification

It should be noted that in most cases it is not possible to verify a LSC commitment directly by looking at the real world cost. The reasons are:

- a) It will take much too long. The contract will have to be closed not too long after the final delivery - not when the systems fade out in a distant future.
- b) We do not have sufficient control of the of the environment over a long time. Utilisation and organisational changes will occur. Consequently the verification has to be done in a different way - the systems characteristics are verified (e.g. MTBF, MTTR etc.). (See also Ref. [Wååk 94].

Hence a lot of the verification has to rely to a large extent on calculations as illustrated below.

- o LSC value determined by
 - LSC model (= equations) (given by the customer)
 - Input data (to be verified)
- o Customer data do not have to be verified. The contractual LSO is a customer data set.
- o Verify the rest by
 - Normal invoicing procedure
 - Follow-up during installation etc.
 - MTBF test
 - Repair time test (will also cover many maintenance resources)
 - Special tests and analyses
 - Acceptance by convenience (the data element has a minor impact)
 - Acceptance after engineering judgement

2. LIFE CYCLE COST

In this chapter a number of successful LCC cases have been collected.

Ref [Wåå 98:2] contains some more aspects on the LCC methodology:

- o The method normally is not sensitive to poor accuracy in the input data
- o Only a few cost elements tend to dominate the cost profile
- o Only a few items in a complex equipment tend to dominate
- o The method is very good at pinpointing the weak points in the combination: Technical system/Logistic Support Organisation

2.1 Low Coverage Radar (LCR)

The details of the Low Coverage Radar acquisition can be found either in [PåW82] or [Wåå 98.2].

The LCR was used as a test case within the Swedish Defence Administration. The results were so good that the method applied became a standard for LCC acquisitions.

The overall sequence was:

- o Evaluation of the quotations
- o Feed back of results and suggestions for improvements to each tenderer
- o Modified quotations
- o New (2:nd) evaluation

The result after completion of the 2:nd evaluation for all tenders (and 3:rd for tenderer P) is given in figure 2.1.

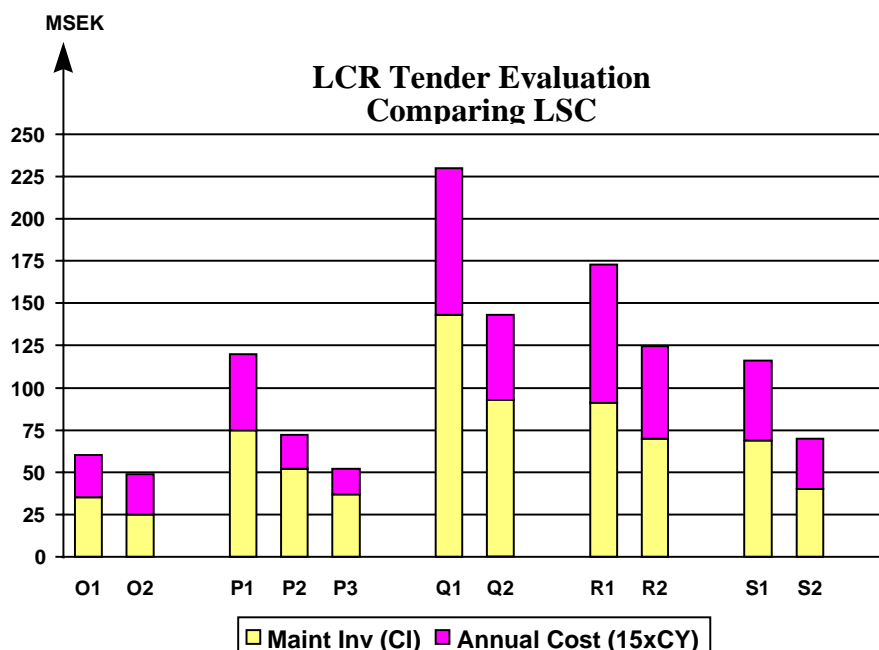


Figure 2.1

As can be seen improvements were made in all tenders. At this stage of the project a decision was taken only to go ahead with O and S (taking all aspects into account i.e. not only LSC - hence the exclusion of P). Since the model was slightly modified the further improvements made on O and S are not directly comparable but the overall picture was similar as for P.

2.2 Oslo Air Traffic Control Centre

A comprehensive description of this case is given in [Wååk 91]. Furthermore since the major improvements were made on cost elements related to the Logistic Support more details are given in the same reference.

Here we should concentrate on the overall improvements. The results of the evaluations are given below.

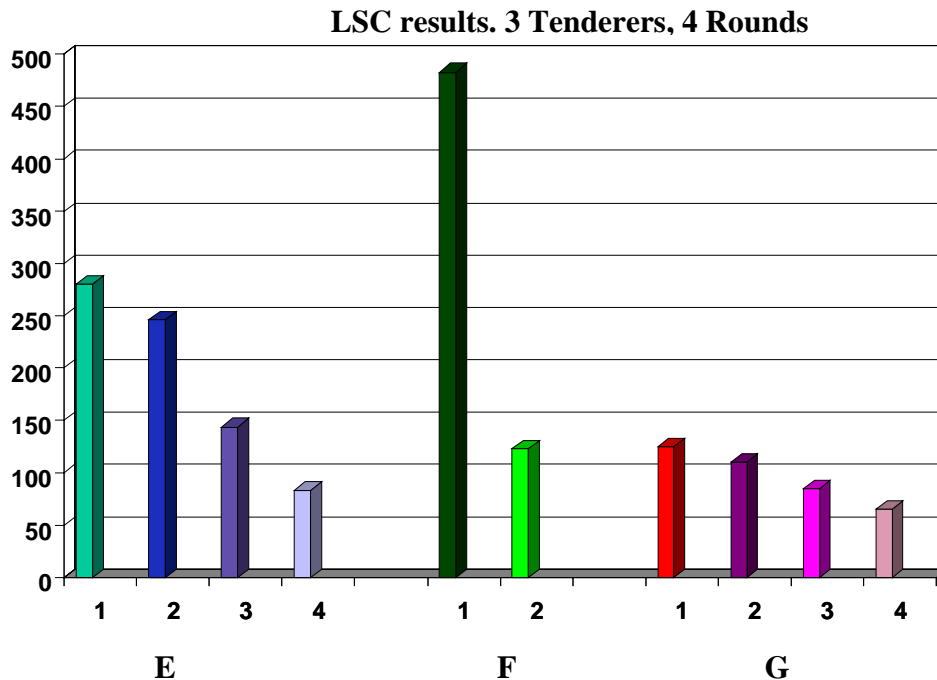


Figure 2.2

Significant improvements were for all, most impressing of course for tenderer F that was improved from 483 MNOK to 123 MNOK. However his quoted solution had a number of weaknesses and was screened out. The improvements for the other tenderers were not bad either. E is going from 280 MNOK to 83.5 MNOK and G is going from 125 to 65 MNOK. Again the savings are surprisingly large.

2.3 Rapid Trains

This case is interesting from several viewpoints notably:

- a) It is a civilian case thus showing that the LCC technique is not unique to military equipment.
- b) It concerns mainly mechanical equipment contrary to the misconception that the LCC technique can only handle electronics.

- c) It has been verified and the results from the verification have been made public.
- d) It is wellknown system, very successfully entered into full and expanding operation.

The method applied in the acquisition is the same as used for the low-coverage radar. The methods are detailed in a number of papers presented at various conferences (see [PAW 85] [PåK 92], [AkB 94]. The trains were acquired under intense competition and after a comprehensive negotiation period. There is no reason to believe that the contractor (ABB Traction - now Adtranz Sweden) was so assured about victory that he dared to keep large performance margins up his sleeve. Hence the contractual commitments regarding reliability, maintainability and LCC represent the project status at the time of the contract signing.

During the development both SJ and ABB put in considerable effort to make improvements - and they succeeded.

This resulted in the surprisingly large improvements that are shown below.

Swedish Railways' Rapid Train X2000

(from [AkB 94])

Requirement	Contract	Verified
Stopping failures (per 10 ⁶ km)	< 12	1.7
Unplanned workshop visits (per 10 ⁶ km)	< 750	100
Mean Time to Repair		45% better than the guaranteed value
LSC (Life Support Cost)		15% saving from the guaranteed value

The improvement regarding both stopping failures and unplanned failures is about a factor 7. Since the overall failure flow did not improve, the conclusion is that the design work put effort into designing in such way that the consequences of serious failures to a dominating degree were eliminated. Those failures as a result were "moved" to less serious failure categories that could be handled during regular planned maintenance periods.

Bearing in mind that the serious failures were reduced by a factor 7 and that the repair time was reduced by 45% it may seem surprising that the LCC improvement "only" is 15%.

This is partly due to the lay-out of the contractual LSC calculation method. Notably two factors should be observed:

- a) The model does not take "lost passenger time" into account. This type of saving comes over and above the 15% and it is of course significant. Furthermore the marketing benefits of the positive impact of good and recognised availability are not included.
- b) A considerable amount of preventive maintenance is performed and it is one of the dominating cost elements. The improvements made in this respect by phased or piecewise preventive maintenance is not included in the 15%.

The overall LSC saving thus is significantly larger than 15%. Having said that it should be recognised that those 15% represent a significant sum of money, in fact hundreds of millions of SEK.

2.4 Aircraft 39 Gripen

The Swedish Air Force maintenance and support budget is about 3000 MSEK per year. This corresponds to less than 3% of the capital stock (120 000 MSEK). This is a low figure in comparison with other Air Forces. One of the main reasons for the favourable figure is the fact the Swedish Air Force during a number of years has been very active and successful in decreasing the maintenance and support cost. There are other reasons: The close co-operation between the Air Force and Saab most likely has been a positive factor in this respect.

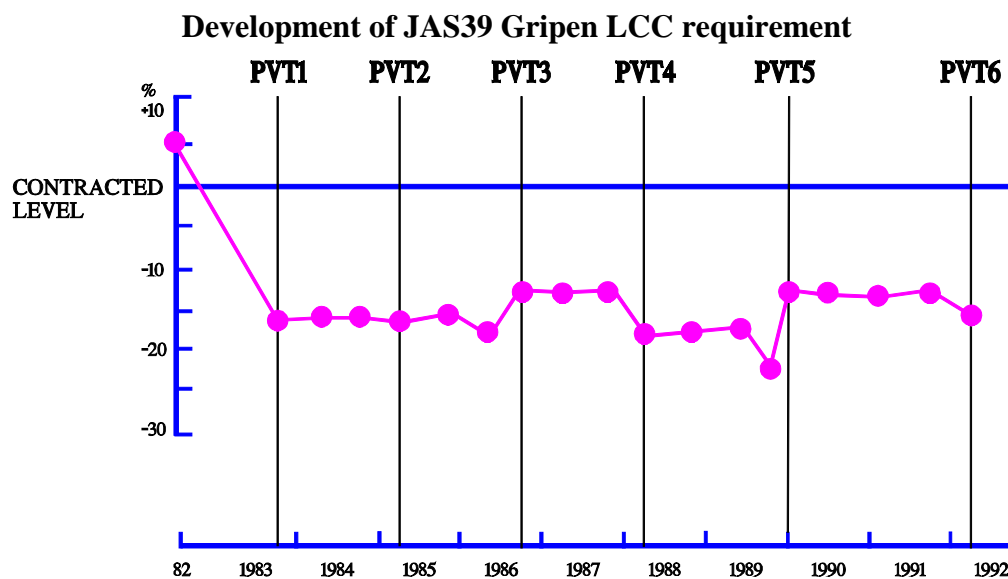


Figure 3.3 LSC estimates at a number of evaluation events
(PVT = Design Review Meeting)

The acquisition of JAS39 Gripen was made in very hard competition that assured that the best solution and conditions would be reached. The tender evaluation result for LSC was used as basis for the contractual value. However the customer, the FMV, insisted on having a better value. The argument was "We expect, that you - during the development - are able to make further improvements. Consequently we set the LSC limit 5% *below* the evaluated value". This was accepted (I guess one can assume that there were fairly hard negotiations about this). However the FMV were correct - the first evaluation event showed an improvement of 20% from the evaluation result and 15% below the contractual level. Basically it has stayed there - probably three factors influence here:

- a) 15% is judged by the contractor to be a satisfactory margin from contractual point of view - the intensity in the improvement work is lower.
- b) The design goes ahead - the possibilities for improvements go down.
- c) During design some negative factors pop up. The improvements are balanced by some subsystems that are not as good as they were expected to be. One such example is the

Auxiliary Power Unit (APU). It showed to have less favourable values than predicted. When adjusting the assumed values the LSC cost increased with approximately 10%. The work on an improved version is going on and it will again lead to better values. See also [Båå 95].

2.5 Summary

The table below shows some cases where OPUS10 is used not only in the evaluation, but contractually as well.

Summary LCC cases

	OPUS10 used	Degree of difficulty	Spares impact	OPUS10 contractual	See ref
Low Coverage Radar	Yes	Large	Large	Yes	PåW 82
Oslo ATCC	Yes	Medium	Medium	Yes	Wåå92
JAS Aircraft	Yes	Large-Medium	Medium	Yes	Båå95
Rapid Trains	Yes	Medium	Low	No	AkB94

Table 2.1. Some LCC cases

3. LOGISTIC SUPPORT ANALYSIS

3.1 General

As mentioned earlier the operational system consists of two parts

- o The Technical System
- o The Logistic Support System

As a consequence it is necessary to create the Logistic Support System in parallel with the development of the Technical System.

The *Logistic Support Analysis* is the analysis required to be able to compare alternative suggestions for the Logistic Support System.

The definition given above refer to the *system level*. The term Logistic Support Analysis is also used for the detailed level analysis when preparing the necessary manuals and maintenance procedures and instructions.

In this paper we refer to the system level analysis unless otherwise is stated.

3.1.1 Requirements on the Logistic Support System

The Logistic Support System shall

- a) Start its operation at the same time as the Technical System.
- b) Ensure that the Availability Performance requirements are met.

- c) Fulfil certain constraints e.g. laws, regulations, policies etc.

Some comments can be given.

- a) As soon as the Technical System starts to operate it will also start the process of generating demand for maintenance and support. Consequently the Logistic Support System must be ready to deliver the resources necessary to meet that demand. Unfortunately this simple fact frequently is neglected.
- b) The Logistic System has a crucial influence on the Operational Availability Performance. This also frequently is neglected with long down-times due to waiting times as result.
- c) It goes without saying that the Logistic Support System should be cost effective. In most cases however this is a neglected part.
- d) Total freedom from limiting constraints unfortunately never exist.

3.1.2 When to perform LSA?

We can start with some observations:

- o An important role for the LSA is to influence upon the design of the Technical System. (This role is also called Integrated Logistic Support (ILS).) In order to be effective such influence has to be *early* in the system design. As a consequence: the LSA must start early.
- o Good and accurate data are available late (if ever) in the system development. As a consequence the LSA also must be performed at later stages in the system development. The conclusion is that the LSA must be made a number of times and in parallel with the development of the Technical System. The early studies are characterised by:
 - oo Low ambition level
 - oo Rough and uncertain data
 - oo Goal: To influence upon the design of the Technical System.At later stages:
 - oo Higher ambition level
 - oo More accurate and detailed data
 - oo Goal: To design the overall lay-out of the Logistic Support System - to produce a Logistic Support Plan

3.2 Offshore Process Control Equipment

This part is a summary of a Masters Thesis (see ref [NiV 94]). The two students are associated with Statoil.

3.2.1 Support Organisation

The study concerns with the Process Control and Data Acquisition (PCDA) system for 4 different platforms.

The platforms are

- o Gullfaks A (GFA)
- o Gullfaks B (GFB)
- o Gullfaks C (GFC)

o Sleipner A (SLPA)

The PCDA system is slightly different between the platforms.

The present support organisation is given below ("The autonomous case - no co-operation between bases or platforms").

Autonomous Stores

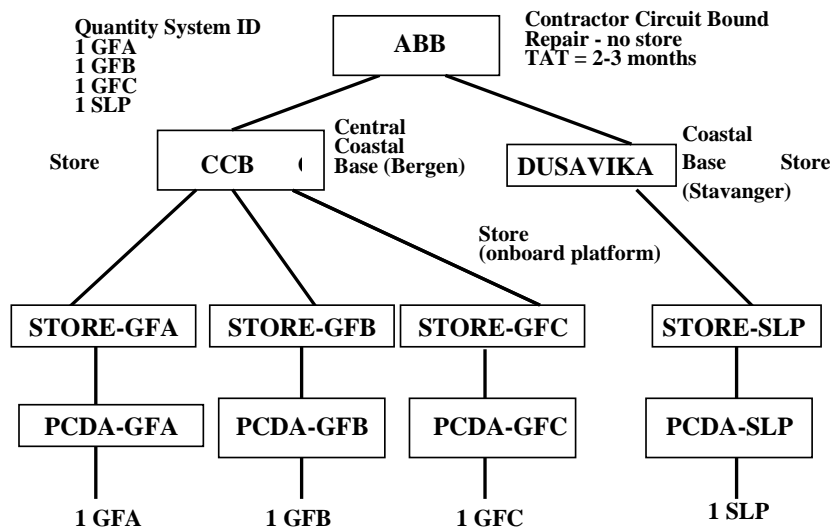


Figure 3.1

3.2.2 Some system data

The PCDA systems are partly common, partly unique. The spares item list contain 191 lines (= different items). The individual systems contain lines as follows

GFA	85	different items
GFB	88	- " -
GFC	111	- " -
SLP	111	- " -

SLP has 111 different items. 60 of them are unique to SLP, 51 are contained in one or more of the GF systems.

The items occur in large numbers. Total installed number is 15163 i.e. an average of about 80 of each. The spread is large: One digital input board is installed in 1413 positions over all GF systems. 8 items are only installed in 1 position.

The overall failure rate from the 4 systems is 26673×10^{-6} i.e. between 4 and 5 failures per week. The average failure rate per item is 1.76×10^{-6} . The overall installed value is 107 MNOK.

The value of "1 of each" is 2.34 MNOK i.e. the average price per item is NOK 12.261. The most expensive item has a price of NOK 108.000. Its installed value is about 4 MNOK. Another item has an installed value of 8 MNOK (400 boards and over 20.000 NOK per board).

3.2.3 Support structures

A number of different structures and scenarios were investigated.

- a) Joint on-shores bases.
The common items (i.e. the items that are used both on the GF platforms and on the SLP platform) are stored only on the Central Costal Base. Consequently SLP is supported both from CCB and Dusavika.
- b) 100% discard
- c) Contractor agreement (Support Contract)
No shore bases except the Contractor's store. He sends spares to the platforms when needed.

The result with existing stores and the autonomous case is given below.

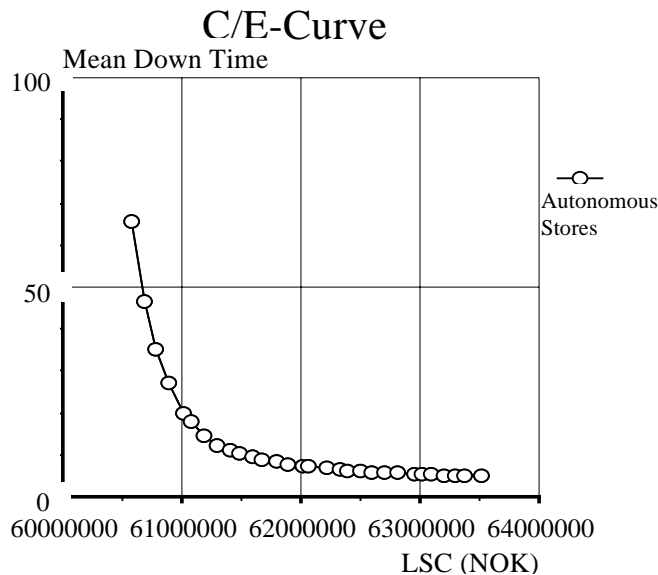


Figure 3.2

*Point Summary (POINT: 23)

Life Support Cost, LSC.....	62817216.0
Total Investment, CI.....	636591.4
PV Total Annual Cost, CN.....	62183112.0
Mean Waiting Time, WT.....	2.62
Expected Number of Backorders, NBO.....	0.07
Risk of Shortage, ROS.....	0.024
Availability, A.....	0.9640
Mean Down Time, MDT.....	5.62

Figure 3.3

*LSC Summary (POINT: 23)

Life Support Cost (LSC)	62817216.0	
Total Investment (CI)	636591.4	
Investment Repairables (CIR)		267138.3
Investment Discardables (CID)		369453.1
Investment Resources (CIX)		0.0
PV Total Annual Cost (CN)	62183112.0	
PV Consumption Spares		4956078.5
PV Reorder Cost (CNO)		1121938.8
PV Storage Cost (CNS)		32547588.0
PV Transport Cost (CNT)		6416088.0
PV Repair Manhours (CNC)		17141418.0
PV Resource Cost (CNX)		0.0

Figure 3.4

3.2.4 Results

Joint stores: Small saving.

Autonomous Organisation with discard: Certain saving.

Contractor agreement: Up to 10 -15 MNOK within reach.

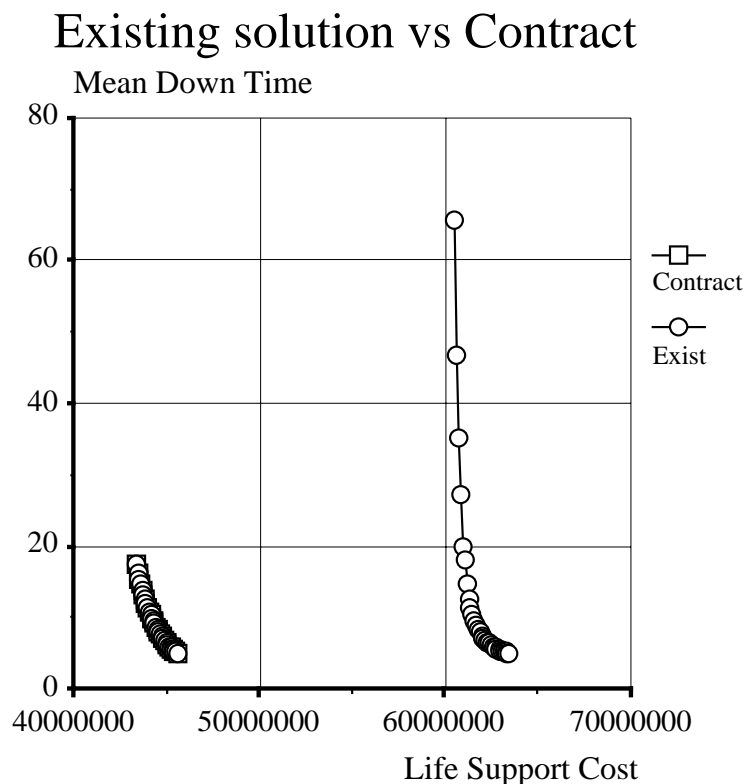


Figure 3.5

Considerable saving (although the contractor price is not included). It is however only a small fraction of the 20 MNOK difference between the alternatives.

3.2.5 Conclusions

The study shows the possibility of performing LSA also on complex equipment and in a complex support structure.

The results concerning the contractor depot store and repair gives excellent results to have up the sleeve in the negotiations with the contractor.

As will be shown in chapter 4 the study also revealed that the spares assortment ought to be changed drastically and a continuation of the study most likely would have shown that a combination of

- o Contractor central depot and repair
- o Possible sell back of certain items
- o Selective discard

would be the optimum strategy (although it would have been difficult to explain the wisdom of discarding a circuit board with a purchase price of about 100000:- NOK). These types of problems are developed further in ref [Isd 99].

On the other hand, what do you do when you have bought too many of those expensive circuit boards and

- o The repair also is expensive
- o You can not sell them back or onwards
- o You have many more than you could possibly consume over the expected lifetime

More reading on LSA is given in ref [Wål 92].

3.3 Use of computer tools

The tools basically are the same as the ones presented in chapter 1.3.2 in particular OPUS10. One addition could be made. When looking at Logistic Support Organisations it is very beneficial to be able to start with an optimised skeleton of test equipment (optimised together with the spares). This is done by the OPRAL program (see attachment 1).

4. SPARES PROVISIONING

4.1 Introduction

We will here consider different types of spares although the focus mainly will be on repairable, fairly expensive items. It must be admitted though that aircraft engines with their very high price represent - by far - the upper end of the scale.

4.1.1 Requirements on Spares Provisioning

The aim of the provisioning is to acquire and allocate the correct mix and amount of spares to fulfil availability requirements. In the military arena the requirement to endure a certain period of time also has to be observed. All this should be done at lowest cost.

The relation between availability of spares and the system availability could be illustrated by the following example.

The availability in this case is defined as

$$A = \frac{MTBF}{MTBF + MDT} \quad \text{and} \quad MDT = MTTR + MLDT$$

where

A	=	Availability
MTBF	=	Mean Time Between Failure
MDT	=	Mean Down Time (per failure)
MTTR	=	Mean Time To Repair the system
MLDT	=	Mean Logistic Delay Time

If we neglect the risk for shortage of various maintenance and support resources like waiting time for technicians, waiting time for spares etc., which means that $MLDT = 0$ the Mean Down Time will be = $MTTR$ i.e. the Mean Time To Repair for the system. It also - unfortunately - requires infinite investments.

Let us assume a system with $MTBF = 200$ hours and $MTTR = 0.5$ hours gives the availability =

$$A = \frac{200}{200 + 0.5} = 0.9975$$

This is definitely an excellent availability that will meet most requirements.

Now, let us assume that 2 times out of 5 we have to wait 4 hours for a technician and that 1 time out of 5 we have to wait 48 hours while a spare is sent from a central stock.

We will then achieve:

$$\begin{aligned} MLDT &= 2/5 \cdot 4 + 1/5 \cdot 48 = 1.6 + 9.6 = 11.2 \\ MDT &= 0.5 + 11.2 = 11.7 \end{aligned}$$

$$\text{Our availability will then be } A = \frac{200}{200 + 11.7} = 0.945$$

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This result may not be as satisfying as the one that we had earlier. As a consequence we can note that the availability is strongly dependent upon the probability for shortage of various types of maintenance and support resources of which spares form a vital part.

Note that the unavailability is dominated by the shortage of spares:

	Time	% of the unavailability
Active repair	0.5	4.3
Waiting for technician	1.6	13.7
Waiting for spares	<u>9.6</u>	<u>82.0</u>
	11.7	100.0

We can decrease the risk of shortage by acquiring more spares. If we decrease the risk of shortage of spares to 1 in 20 the availability will be 0.978. To summarise we have found that

- o The systems availability performance is strongly dependent upon the access of spares
- o The access of spares - and consequently the systems availability - can be controlled directly by investing more or less funds in the acquisition of spares

4.2 Methods for Spares provisioning

Basically there are three provisioning methods

- o Engineering judgements
- o Item-by-item calculation
- o Optimisation

Here we shall only look at optimising methods since they are by far superior. More details are given in [She 92], [Wååk 98.2] and [OPUS10].

Two cases are given to illustrate the saving by using optimisation.

4.3 Royal Air Force comparisons

When the Royal Air Force (RAF) changed method from item-by-item (the SIM computer program) to optimising (OPUS) they made comprehensive comparisons between the two methods.

The comparisons are made with the same availability for both alternatives. One of the results is given below. [Cla88]

Serial No	System No	SIM Investment (£)	OPUS10 Investment (£)	Saving	Saving % of SIM's value
1	15	1.262.736	859.523	403.213	31.9
2	16	3.065.550	2.766.124	299.426	9.8
3	17	427.000	403.000	24.000	6.7
4	19	1.914.832	1.638.734	276.098	14.4
5	20/21	1.160.674	691.608	469.066	40.4
6	24	78.326	66.732	11.594	14.8
7	25	234.975	210.008	24.967	10.6
8	26	370.300	192.178	178.1221	48.1
9	29	216.803	41.773	175.030	80.7
10	41	907.804	441.372	466.432	51.4
11	42	243.890	241.590	2.300	0.9
12	45	1.732	1.732	0	0.0
13	55	642.790	370.321	272.469	42.4
14	56	38.504	36.112	2.392	6.2
15	57	186.937	80.050	106.887	57.2
16	71	811.620	721.035	90.585	11.2
Total		11.663.473	8.761.892	2.801.581	24.2

Table 4.1

All in all the comparison gave a *saving potential on 4 projects of 12.6 M£ by using OPUS instead of SIM.*

A comment could be made on subsystem 12 where there is no improvement. The reason is very simple: This subsystem consist of only 1 LRU.

4.4 Offshore Process Control Equipment

A study of the offshore Process Control system as mentioned in para 3.4 gave the following results. [NiV 94]

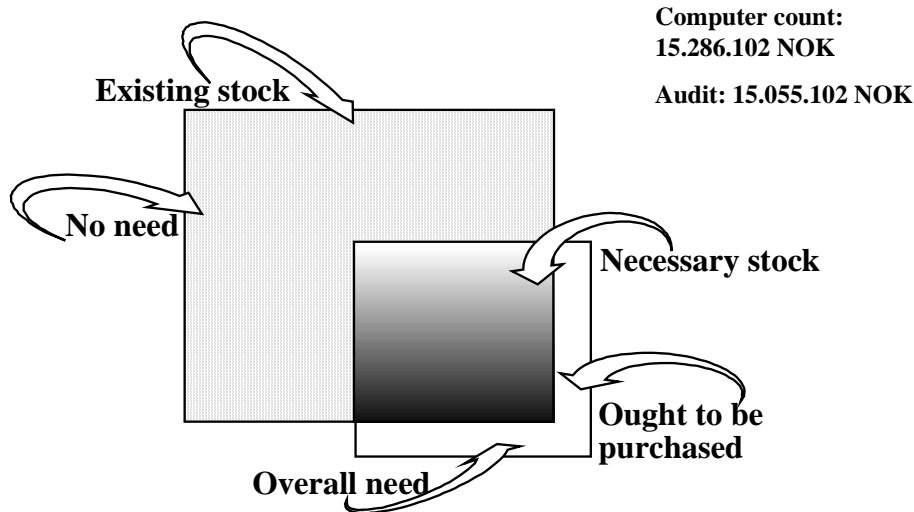


Figure 4.1

The results also can be summarised as:

Existing stock	MNOK	15.286
Necessary stock	MNOK	5.699
Ought to be acquired (<i>not</i> in stock)	MNOK	0.541
In stock and needed	MNOK	5.158
In stock and <i>not</i> needed	MNOK	10.130

Table 4.2

Two things should be noted:

- a) the small amount that ought to be acquired explains the small investment in the figure 3.4
- b) the large amount of unnecessary spares also causes the storage cost to be high as seen in figure 3.4.

4.5 Uncertain data

In order to perform a spares calculation, data are needed on the LRU level. Those data are uncertain, in particular in early project stages. If the input data are faulty the results are faulty. Then it is only natural to ask the question: "Is it effective to perform complex calculations and optimisation when the results most likely are faulty?" The answer is **yes** for two reasons:

- a) A decision regarding spares has to be taken early in the project since spares are needed when the system starts its operation. Normally it is not possible to wait for better data to materialise.
- b) It can be shown that the spare parts optimisation problem is robust with respect to uncertainty in input data [Alf 97:2]. This means that the assortment and allocations reached by OPUS10

tend to be optimal (or close to optimal) to a problem where uncertainty is explicitly taken into consideration. Furthermore, numerical studies with Monte Carlo simulation technique have shown the following: When the input data are different from the ones optimised against, the availability for the system will be different from the original expectation – normally the availability will be lower. The deviation is, however, *smaller* if the assortment and allocation was based on an optimising method rather than another method. These results are of course strong reasons for optimisation of spares.

4.6 Summary

The spares optimisation has the following advantages:

- o It connects the system characteristics with the logistic support organisation and consequently permits both LCC and LSA.
- o It gives a possibility to select a suitable ambition level for the availability.
- o It permits the study of other effectiveness measures.
- o It gives both the assortment and allocation for spares all in one run.
- o It saves money - typically 20-30%.
- o It gives more stable assortments and allocations.

5. CONCLUSION

A Multi-Echelon, Multi-Indenture Spares Optimising program is a necessary tool in every logisticians toll-box independent upon which special niche he is working in. It may be ILS, LCC, LSA or Spares Provisioning. That is definitely not the case today. Although it is tempting to speculate in the reason behind this sad fact it is no excuse for either side - the non-believers have failed by “doing as usual”, the believers have failed by not communicating well enough. Anyhow, it is time to improve.

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SOME COMPUTER TOOLS

OPUS10

The OPUS10 is the present version of the OPUS series of Logistic Support and Spares Optimisation programs. It is commercially available from Systecon AB and is presently installed with over 400 licenses with over 80 organisations including 8 Air Forces, 5 Armies, 3 Navies, several majors including Alenia, BAe, Boeing, Celsius, DASA, GEC Marconi, GIAT, GKN, Lockheed Martin, Northrop Grumman and Saab.

OPUS10 is a very flexible and fast multi-echelon, multi indenture level optimising analytical program working under Windows and giving a very comprehensive both output and cost effectiveness.

More information is available from <http://www.systecon.se>

OPSA

OPSA is a separate program but included in the OPUS10 package. the main functions are:

- o Handling and presenting system break down and item data
- o Generating approximate system data for early analysis
- o Generating OPUS10 input data

OpSSim

OpSSim is a simulation program developed by GKN-WSAL with Systecon as a major subcontractor. The program presently is installed with the RAF, BAe and Lockheed Martin. OpSSim is a powerful and flexible simulation program to analyse complex operational and logistic support scenarios. See also <http://www.gkn-wsal.com> and ref [Caf 97].

LCCDemo

This is a computer tool for LCC calculations. It contains the following functions:

- o Calculations
- o Graphics
- o Sensitivity analysis on different levels

Not commercially available.

OPRAL

This program optimises at the same time - the location of test equipment and spares to an organisation. By exploring ***location*** rather than ***level*** more alternatives are considered. OPRAL uses OPUS10 as engine and is a part of the OPUS suite of programs.