Cut Maintenance and Logistics Support Cost with 50%. A Fantasy or a Feasibility?

SUMMARY: The purpose of this report is to

- Perform a limited literature study and to collect documentation of cases.
- Provide documentation for information about improvement methods.
- Provide documentation for training at various levels.
- Perform research aiming at understanding why certain methods that have shown to be very effective are not used as much as they ought to be.

This report has been funded as follows:

- The majority of the funds are internal from Systecon AB. (60-70%)
- The rest of the funding comes from the Foundation for Logistics and Maintenance development (UTC). Within UTC the split is equal shares between the:
  - Committee for Research
  - Committee for Information and Training

  The funds for Research comes from the Swedish National Board for Industrial and Technical Development. The funds for Information and Training comes from the sponsors of UTC.

The report reflects the split purpose in the following way.

Chapter 1 defines the problem and here the author’s strong belief that large improvements within the Logistics and Maintenance are possible is enlightened by examples from other branches.

Chapter 2 brings up various methods to be used for improvements and in particular
Life Cycle Cost (LCC)
Logistics Support Analysis (LSA)
Spares Optimisation

The main parts of this report consists of the chapters 3, 4 and 5. They have a similar layout. They start with a very simple case - although taken from the real world - just for illustration and to simplify the understanding. Then comes a more complex real world case to more in detail explain the methods used and the underlying rational. After that comes a number of cases to underline the broad potential of the methods as well as the success in applying them.

The comprehensive study of literature and other sources of information also has revealed a number of successful applications that do not lend themselves to the classification used. They are however, interesting from a number of points and they assist to cast light of the overall problem. These cases are reported in chapter 6.

In chapter 7 an attempt is made to describe factors that contribute to successful cases. The purpose here is to identify common factors (if any).

Chapter 8 brings up the questions about the reasons acting as obstacles for the use of systems oriented methods.

Chapter 9 finally brings up in short what could be done to improve the situation and a snapshot that illustrates a slow but hopefully, steady improvement.

About the author

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Education:
1961 M.Sc. Electronics Engineering
1968-1969 IFL, Business Management
1971-1972 University of California and US Naval Post Graduate School: extension courses in System Engineering and Program Management

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1961-1962 Military Service as Radar Engineer

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1965-1970 Swedish Defence Materiel Administration (FMV). Head of the Ground Based Radar Section. Program manager for three large radar programs involving industry in Europe and US

1970- Systecon AB Vice President and Partner. Main clients have been FMV, Swedish State Power Board and Swedish State Railways in the area of preparation of Request For Proposals and Life Cycle Cost evaluations. Wååk is a major point of reference in the Systecon's programs involving such tasks. He is a well recognised lecturer and involved in several training programs in Sweden and abroad regarding Systems Engineering, Program Management and Acquisition. He has published several papers at national and international conferences. He is in charge of the OPUS business area.

1996- Appointed Adjunct Professor in System Logistics at the University of Technology in Luleå.

1999- Appointed Adjunct Professor in Logistics at the Swedish National Defence College.

Recognition: At the Seventeenth Annual International Logistics Symposium Wååk was - as the 1st non-US citizen - awarded a Field Award "In appreciation for and recognition of his outstanding contributions in the area of Life Cycle Management”.

Other info: Wååk is a widower from his 1:st 30-year marriage with 3 children and 7 grandchildren. He is now remarried with 2 bonus children. His interests focus around Wine Tasting and Modern Jazz.

Contents

1. BACKGROUND

1.1 Examples from different branches

Significant improvements of the efficiency are made within a number of branches as results of improvements in technology - notably IT - as well as improvements in methods and procedures. Some examples can be mentioned.

Example 1.1: Passports
Last time I received a passport it took about 5 minutes. The first time I received a passport it took several weeks. This tremendous improvement is a result of a rearrangement in the process - all necessary information to clear the edit of a new passport can be picked out at one spot instead of having the draft passport to travel around and collect information from various sources (and wait on a number of desks). This is an effect of BPR - Business Process Reengineering. This is one example of how new methods and thinking give rise to improvements and more efficient ways of doing business. Other examples may be found in [Wil95]. Willoch also claims that the improvements from BPR should be dramatic and ”if you are looking for improvements in the order of 5-10% you can use other methods”.

Example 1.2: ABB T50 project
”Cut all turn-around-times with 50%”. This was the bold challenge within ABB. The sceptics were plenty - is it really possible to make improvements of this magnitude within activities that are already efficient? Today there are few sceptics. ABB has shown that it is possible to achieve this type of improvements.

Example 1.3: Volvo
The production time for a car in the Gent factory has decreased from 80 hrs to 47 hrs within a few years.

Example 1.4: Porsche
In an interview in SAS Scanorama Dr Wiedeling of Porsche states: ”Today it costs almost 40% less to produce a Porsche than it did when I began making changes”. Some other figures are given:
Lowered manufacturing flows: Down 50%
Inventories: Down over 10 MDMK
Assembly line: In 1992 the cars had to travel 416 meters, today only 109 meters.

1.2 Problem statement

The list of examples could be made much, much longer, all around in various branches.
The author’s opinion is - and that is the theme of this paper:
”If it is possible to make so large improvements within efficient branches like car manufacturing, should it not be possible to make at least equally large improvements within the maintenance and logistic support area? Admittingly the maintenance and logistic support is by no means nearly as efficient as car manufacturing or similar branches where efficiency has been a key element for decades”.
This opinion is being supported by a number of cases where it has been shown possible to make surprisingly large improvements. Some of those examples are being quoted in detail in this document since it is the authors belief that the best way to get acceptance for new methods is by showing good cases, cases illustrating improvements.

In particular methods applied early in the development process are very efficient. In spite of this they are not used that frequently. An important part of this study is to try to find out why and what could be done about it.

1.3 Cost for Maintenance and Logistics Support

The annual cost for maintenance and logistic support including production losses in Swedish industry is reported to be SEK190 billion (give or take a couple of billions) [Ahl96]. Another source [Tsc 97] reports 500-600 billion DM for Germany. The Japanese Institute of Plan Engineers [Jap 97] reports 160 billion USD for the Japanese industry and in this case losses due to losses of production and quality/goodwill are not included. The author does not claim that it is possible, overnight, to cut that figure in half but in the not too long run it should be possible to get it down by such a factor. In fact during this work the author is led to the belief that it is not only a feasibility, it is a ***necessity***. The challenge is tremendous - and so is the reward.

2. IMPROVEMENT METHODS

Many methods have been developed to assist in the improvement of maintenance and to decrease the support cost. Different ways can be used for classification of those methods. In this paper the following groups are being distinguished:

- Methods aiming at being used early in the project development cycle and applied at the system level.
- Methods to be used in detailed design.
- Methods to be used in the ongoing operation.

2.1 <u>Example on System level methods</u>

The following methods or techniques will be discussed in detail.

- LCC (Life Cycle Cost)/LCP (Life Cycle Profit) (System analysis methods) (see note)
- LSA (Logistic Support Analysis) (performed on System Level)
- Spares Optimisation

Note: There is no principle difference between the LCC and the LCP methods although it seems as if the LCP-methods tend to be closer to traditional investment calculus.
In this document the term LCC is used even when LCC/LCP might be more proper.

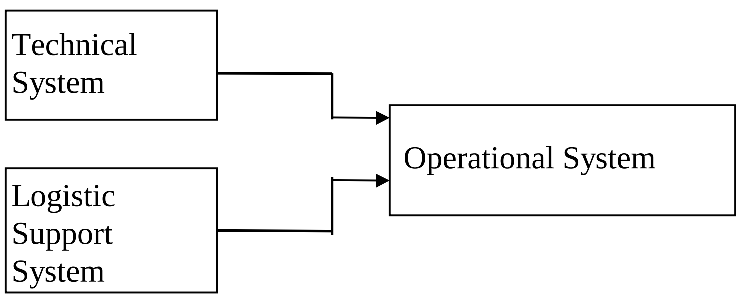

Fig 2.1

In order to get an Operational System it is necessary to have both a Technical System and a Logistic and Support System (i.e. Logistic Support Organisation).

A rough explanation of previous terms could be as follows:
System Analysis: ”Keep the Logistic Support Organisation constant and vary the System”.
Logistic Support Analysis: ”Keep the System constant and vary the Logistic Support Organisation”.
Spares Optimisation: Keep both the System and the Logistic Support Organisation constant and vary the Spares amount, assortment and allocation.

The reason why the author elects to go into detail on those methods is that they are so highly efficient for improvements and so little used.

2.2 <u>Methods used during later design</u>

FMEA	Failure Mode Effect Analysis
FMECA	Failure Mode Effect and Criticality Analysis
RCM	Reliability Centred Maintenance
MTA	Maintenance Task Analysis
LSA	Logistic Support Analysis (detailed level)

In this category we can also find improvements like:

- o Use of better material with respect to wear and tear
- o Building in various test methods e.g. vibration analysis, oil lubrication and other types of condition control and monitoring equipment

2.3 Methods used during ongoing operation

TPM Total Productive Maintenance
Efficient data collection, Efficient use of data collected
Improved technology and introduction of on-condition methods

2.4 No clear boarders

As can be seen the boarder between the various classes is by no means strict.
Examples

- o Design methods like RCM can be and has been used on equipment in operation.
- o LCC can be and has been used on modifications.
- o LSA and Spares Optimisation can be and has been performed on the operation.

This paper will mainly concentrate on **LCC, LSA and Spares Optimisation**

This should not be interpreted as downgrading of the other methods - each one of them has an important role to play but the large improvements have to be made early in the project cycle. This fact is illustrated by the following wellknown diagram illustrating Life Cycle Cost development:

Start working early, continue systematically through out the life cycle

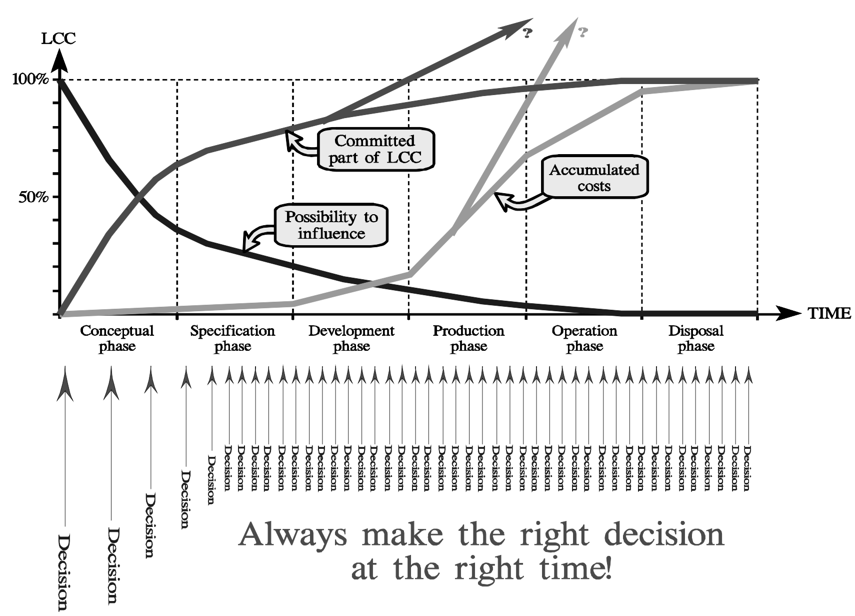

Figure 2.2

The figure is quoted from [Hel96]. The principle shown in the diagram is well known. To the best of the author's knowledge it was first illustrated by H Ebenfelt in the 60'ies.)

The necessity of getting into the project early is clear from the rapid decline of the "Possibility to influence" - curve. In particular it is important to start early with the System analysis - e.g. as LCC.

2.5 The data problem

In order to be able to perform various analyses data must be available. For obvious reasons good data are only available in later stages of the project. The key word here is ”good”. It is the authors opinion that far too frequently necessary analyses have been prevented by waiting for good data. Analyses can be performed with data of lower quality. It is far better to perform analysis with lower quality data than to wait for better data to be available.
Valuable results have been and will be achieved with rough estimated data. This aspect on data quality will be brought up in a number of the following chapters.

3. LIFE CYCLE COST

This - and the following two chapters - have a similar lay-out. First a simple case will be introduced to illustrate the method and then some real world cases will be given, in some cases to a fairly detailed level.

3.1 Headlights for buses

The background to this case - that over the years have been used in many presentations to explain the background for use of LCC - originally was given in a presentation by Gunnar Rehnström and Rolf Berg, both of them at that time employed by Stockholm Local Traffic Authority. The case has since then been used many, many times to explain the significance of LCC.

The cost for a light bulb for a bus depend on the source of delivery:
Low cost H4 SEK 15:-
High cost H4 SEK 50:-

So far it is simple and the solution to which bulb to select is simple - select the low cost one.
Let us add some information

o	Cost for a bus to be taken into the workshop	SEK 500:-
o	Cost for a bus to stop on the tour	SEK 1000:-
o	Number of replacements per bus and month for the low cost bulb	0.22
o	This high cost bulb has 50% longer life	

The calculation of a comparison cost (per bus and year) now could be made:

Low cost bulbs

0.22 x 12 x (15 + 500) = 1360:-

High cost bulbs

$$0.22 \text{ x } \frac{1}{1.5} \text{ x } 12 \text{ x } (50 + 500) = 968{:}-$$

We can now ask 3 questions:
- o Are the low cost bulbs really low cost - the overall cost is higher
- o Are the high cost bulbs really high cost - the overall cost is lower
- o Is it worth bothering?

Let us look at the third question first:
Stockholm Local Traffic Authority (at the time when preparing this example) had 1830 buses. The cost per year now becomes:
Low cost bulbs: 2.48 MSEK
High cost bulbs: 1.71”

There is a saving of MSEK 0.71 per year by simply selecting the high cost bulbs.
We can see how a simple calculation and a simple decision to switch from low cost bulbs to high cost bulbs will save a considerable amount of money.

We can also see - and we will come back to this problem - that it will be difficult to directly pinpoint the saving in follow-up systems.
The follow-up systems will show a slight decrease of unplanned workshop visits which in turn will lead to a slightly higher availability of the buses. Also - at least in principle - it will show a slightly lower cost at the workshop.

Further we can note - and we will come back to this question as well - that the accuracy of the calculation can be argued.

However we can see some of the basic characteristics of an LCC study:

- o There must at least be 2 alternatives (also a consequence of the need to take a decision)
- o Evaluation methods are given (in this case = the equations)
- o A decision criteria is given: The lower overall cost per bus and month is preferred.

3.2 Need of accuracy

It is obvious that the accuracy of the input data is not high. As a consequence the results can be faulty. What's the impact?

Let's take a look at the results of some data variations. Let us ***assume*** that:

a) The improvement by selecting the high cost bulb is only half as large as we assumed i.e. only 25%.
b) We have overestimated the cost for the visit to the workshop by a factor 2 - the cost is only SEK 250:-.
c) The source of delivery for the high cost bulbs take the opportunity to rise the price by a factor 2. Aside from the fact that we won't let him get away with it - what would be the impact of a price of SEK 100:- instead of SEK 50:-

We achieve the following results (in MSEK/year for 1830 buses):

Alternative		Low cost	High cost
o	Baseline	2.48	1.77
a)	Only +25%	2.48	2.13
b)	Only 250:-	1.28	0.97
c)	Expensive +50:-	2.48	1.93
a) + b)		1.28	1.16
a) + c)		2.48	2.32
b) + c)		1.28	1.13
a) + b) + c)		1.28	1.35

Some conclusions can be drawn:
Even large variations in the input data will ***not*** change the recommendation
In fact all 3 variations have to occur before the recommendation to select the high cost alternative becomes faulty and in that case the difference is small.

This lesson is general:
The recommendations tend to be fairly stable in its nature.
This of course is a very valuable asset connected to the LCC technique and it permits the use of early analysis.

A quote from Rolf Berg at the SL can be mentioned ”How come that the bulbs fail that frequent - and how come that we buy them”.
This illustrates the LCC technique of pinpointing the important characteristics for a component or a system. As a user of the bulbs Mr Berg was prepared to consider to pay more for bulbs with longer life.

Before leaving the bulbs a result from follow-up of subway trains and the most common causes for extra workshop visits can be given.

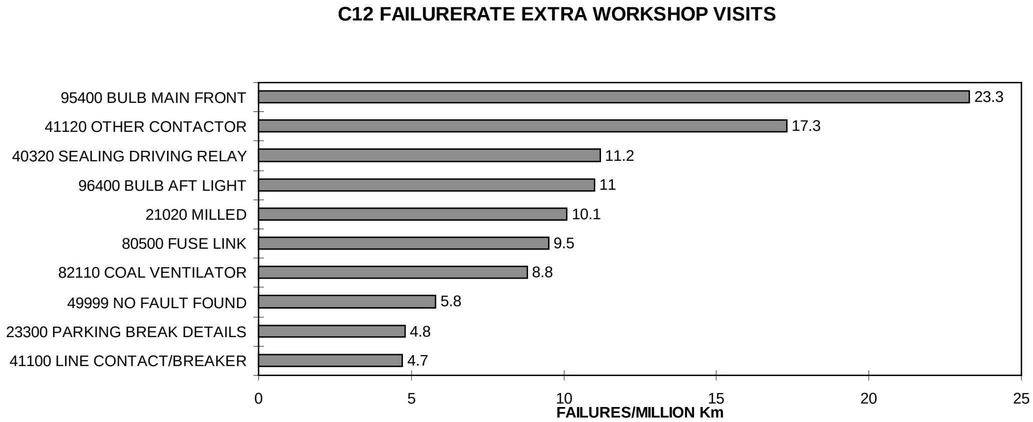

Figure 3.1: The most frequent failures covering 34% of the overall failures

The figure has been taken from an investigation for the Stockholm Local Traffic.

As can be seen the bulbs dominate and we can agree with the question above - ”How come that operators of complex and expensive systems like subway trains accept that simple components like bulbs limit the availability of their systems”.
We shall now take a look at another case - a Low Coverage Radar acquired by the Swedish Defence Administration (FMV) a number of years ago.

3.3 <u>The Low Coverage Radar Case</u>

The following description is taken from [PåW 82]. In this reference also the term LSC = Life Support Cost is used.

3.3.1 Results of the 1:st evaluation

Due to the good results of LCC, LSA and Spares Optimisation on a previous ground based radar project [KaW81] the FMV (FMV = The Swedish Defence Materiel Administration) decided to put analysis effort into the Low Coverage Radar acquisition.
This was done.

The analysis group developed, refined and computerised the methods developed in the previous projects, mainly the ground based radar one. Also methods were developed to study tentative results before sending out request for proposal (RFP). This way it was possible not only to have a reasonable opinion about the Reliability Performance requirements but also to have a clear view about the sensitivities of the different cost elements.
In fact, the results produced before sending out the RFP agreed surprisingly well with what was achieved for the best tenderer in the 1:st round.

This way the analysis team was very well prepared when the tenders were achieved and the initial work (scrutinising the quotation, checks for missing data, etc) went very smooth.

After 1.5 months the 1:st evaluation of the tenders was completed. The results are given in figure 3.2.

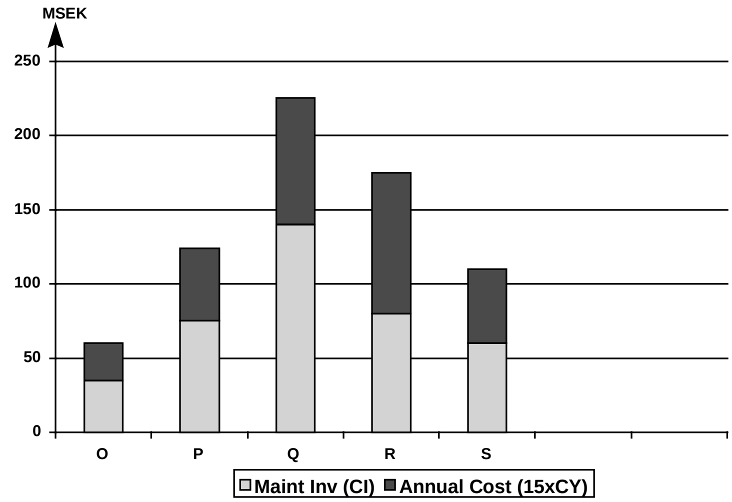

Figure 3.2

The most striking about this figure is the large differences - a factor of 1:4 between the best and the worst. It proves the opinion of the author ”There is virtually no limit on how poor a proposal can be from an LSC point of view if the tenderer has not performed a competent LSC analysis of his own”.

3.3.2 Methods for improvement

Tenderer P has been selected to illustrate the methods used by the team for improvements. It should be noted that this tenderer is not unique in any aspect - it is a large, capable and serious radar manufacturer - although somewhat untrained when it comes to LSC analysis. It should also be noted that it was possible to achieve considerable improvements for all tenderers - even for the best one.

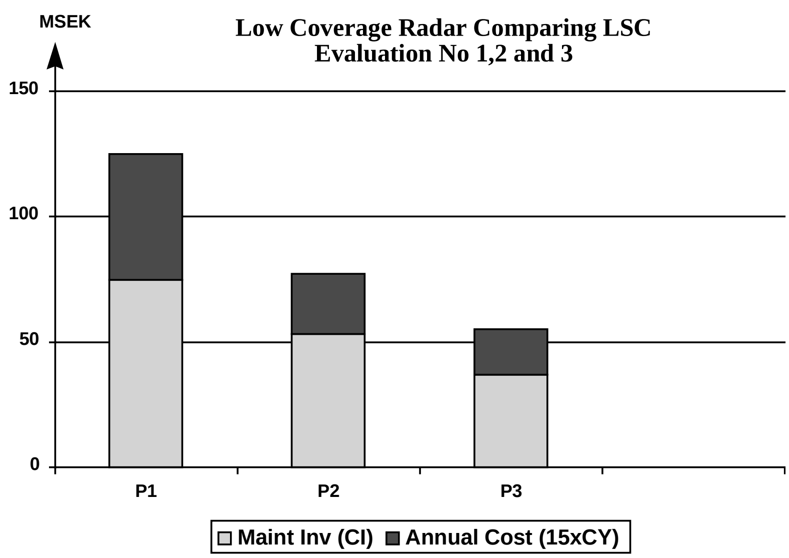

Figure 3.3

The improvement is considerable - from 120 MSEK down to 55 MSEK! A word of caution: The improvement does not represent a saving to the customer to 100% since some improvements are more adjustments of improper data than actual savings. A rough estimate however, indicates more than 50% of the improvement is actual savings to the customer - in case this tenderer is selected.

3.3.3 Feed-back to the tenderer

The basic feed-back took place at the tenderer's facility as a 2-days meeting. The customer made his presentation the 1:st day, the tenderer spent the evening (or perhaps part of the night) studying the documented results. The second day was spent on questions and answers. The tenderer was given a right to improve his proposal regarding LSC provided that the proposed changes reached the customer within one week. The response proved to lower the LSC with 45 MSEK and the tenderer was given the new results. He later came back - although not requested to do so - with a further set of improvement of 20 MSEK. In spite of those improvements, however, he did not reach the final field.

The customer part of the presentation is covered by the following menu:

- o Introduction
- o Purpose of the presentation
- o General principles
- o The models/programs
- o Results
    - oo Results in summary
    - oo Detailed cost drivers
    - oo Reliability performance

3.3.4 Cost drivers

Figure 3.4 (on cost element level) is a result from the high level sensitivity analysis function in the cost model applied on tenderer P's 1:st proposal.

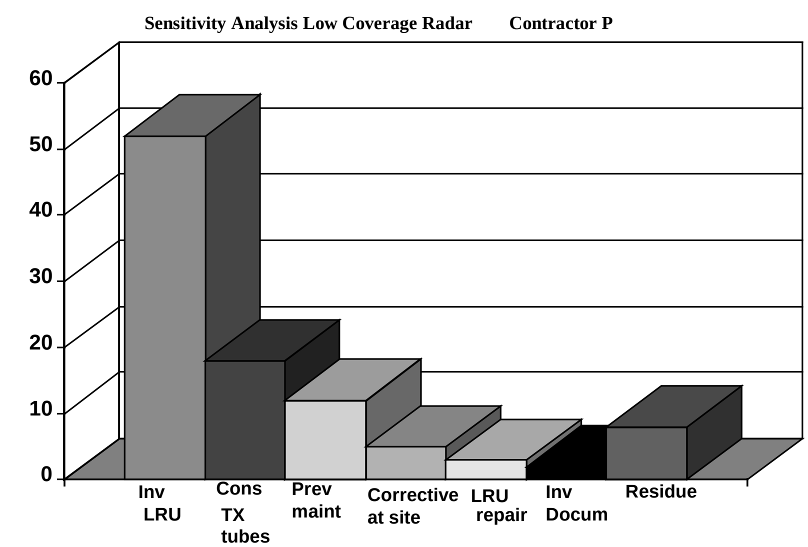

Figure 3.4

The dominating cost elements are:
The investment in LRU:s (CIRU) = 52% (see note 1)
The consumption of TX tubes (CYRT) = 18% (see note 2)
The cost for preventive maintenance (CYEO) = 11%

Note 1: LRU = Line Replaceable Unit is the denomination for a spare item that

a) Is replaceable in the system
b) is repairable e.g. at a special workshop.

A typical LRU could be a circuit board. The term CIRU is the denomination in the cost equations for Cost Investment (CI) LRU’s.

Note 2: TX = Transmitter Tube.
The term CYRT stands for Annual Cost for Transmitter Tube consumption.

These three elements (out of eleven) are responsible for 81% of the total cost. This is of course where we should look for possible improvements.

3.3.5 The investment in LRU:s

The critical part regarding the investment in LRU:s is the modularisation. Look out for items with both high failure rate and high unit cost. A high failure rate means that you have to buy many of the items as spares and a high unit cost will result in a high investment. A ranking based upon the product of failure flow and unit cost has proven to give good correlation to the LRU investment cost as well as a good visibility for the tenderers. The figure 3.5 shows the results.

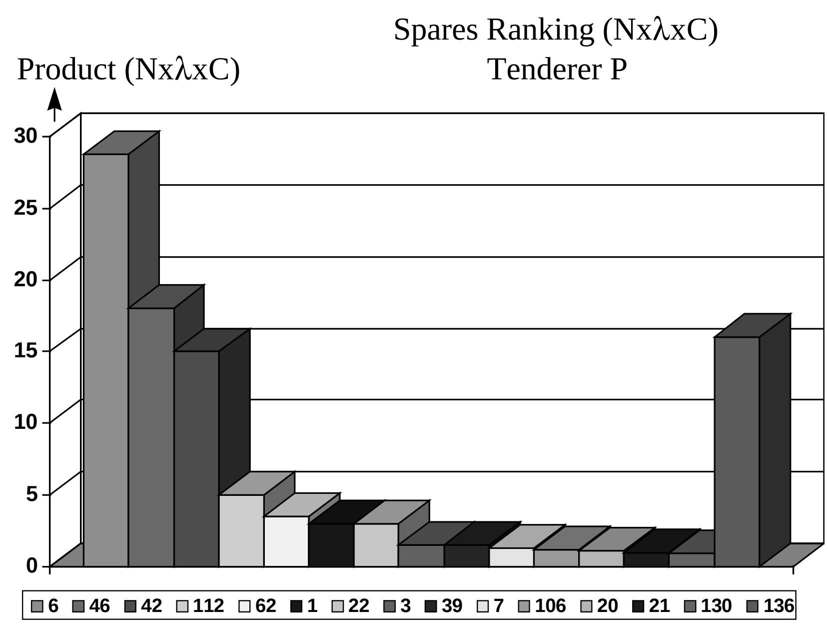

Figure 3.5

The message to the tenderer is quite clear: ”Do something (e.g. split) with the items 006, 046 and 042. If you have time do something with the next 4 too”. A good example of the way that LRU:s ought to be modularised is given in ref [KaW 81]. The 136 refer to the 136 remaining items, not the item number 136.

3.3.6 Consumption of TX tubes

The next cost driver is the consumption of the TX tubes. The figure below gives the input data possible to influence by the tenderer.

Annual Cost for TX Tube Consumption

CYRT = … x(NRT x CSRT x 1/LLTO)

NRT = No of tubes per equipment
CSRT = Cost for a new tube or the repair cost whichever is the lower
LLTO = Guaranteed life (years)

Again, the message to the tenderer is clear: ”If you have more than one TX tube try to make it one. Look into the possibilities to repair the tube and lower the related cost. Extend the warranted life of the tube”.

Here we can see a complication of the use of the LCC-technique. Is the ***warranted*** life the most accurate value to use in the equation? Most certainly no - the ***estimated*** life is a more accurate value. However, we have to look at the overall use of the LCC technique in this case. It is used to make a good evaluation and to ***make overall improvements*** - including commercial ones - for the customer. The warranted value has a contractual meaning - the estimated value has no penalties attached to it in the case it is not reached. In the case there is a large difference between a warranted value and an estimated value the customer has a very good argument to request a better warranted value (since otherwise the estimated value can be doubted).

The conclusion is that the LCC value is not necessary the best estimate of a true future cost. It is a ”figure - of - goodness” used to pinpoint possible improvements and negotiations. Hence - there is no such thing as a ”true” LCC value.

3.3.7 Preventive maintenance

The third cost driving element was the need for preventive maintenance (P.M.). The critical factor is the fact that the sites are un-manned in peace-time and frequent P.M. thus will cause a lot of travelling.

Annual Cost for Preventive Maintenance at Site

CYEO = NEO(1) x (..xCHBxTRB+..xDBAxCRM+..xCBAT)x..

NEO(1)	=	**Most frequent Preventive Maintenance action**
CHB	=	**Manhour Cost at Regional Level**
TRB	=	**Travelling time one way**
DBA	=	**Travelling distance one way in km**
CRM	=	**Cost imbursement for car per km**
CBAT	=	**Daily allowance at Regional Level**

Figure 3.6

The tenderer ought to do something about the most frequent action - and in this case he did after being made aware of the large impact.

3.3.8 Achieved improvements

The result of the tenderer's effort during one week is given in figure 3.7.

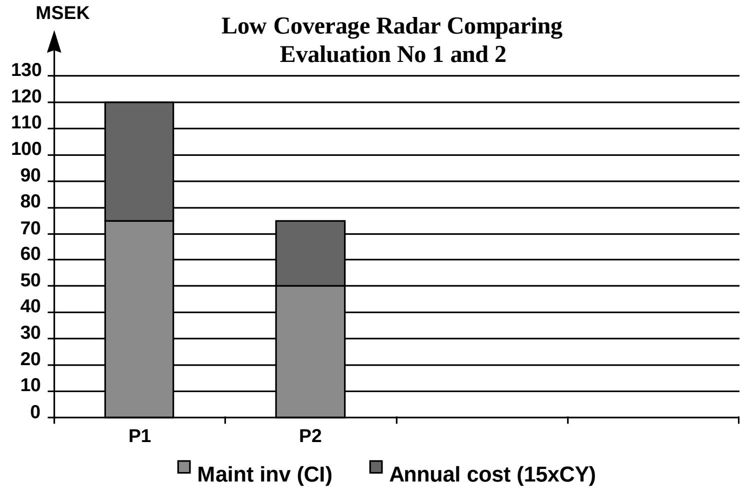

Figure 3.7

The improvement from 120 MSEK down to 75 MSEK has already been commented upon.
The improvement regarding the investment part is given in figure 3.8 below.

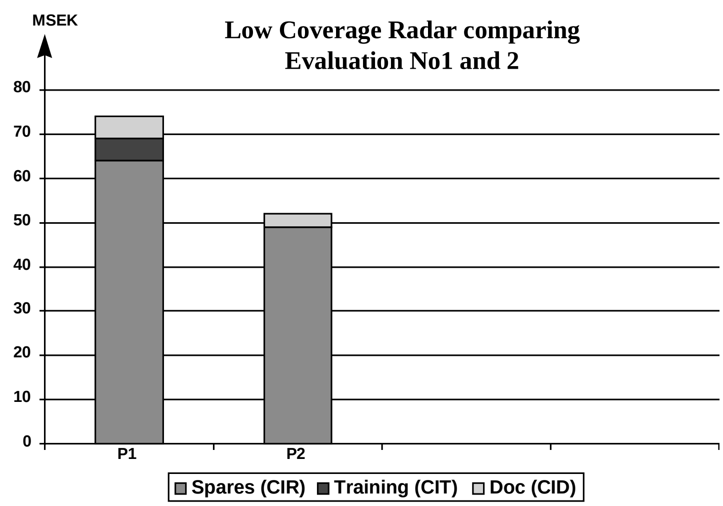

Figure 3.8

The major achievement (15 MSEK) is on the spares investment, as expected. The investment in training has also been lowered by proper selection between the tenderer's facility and the customer's facility for different training courses (short courses with many customer participants should be in Sweden).
The cost for documentation has disappeared from LSC and has become a part of the acquisition cost (not all ”improvements” are real savings).
The investment in instruments and tools is so small so it is not visible in the graph. Although the reduction in spares in principle led to more investment in instruments and tools it was fairly small.
The improvements on annual cost (over 15 years) is given in figure 3.9 below.

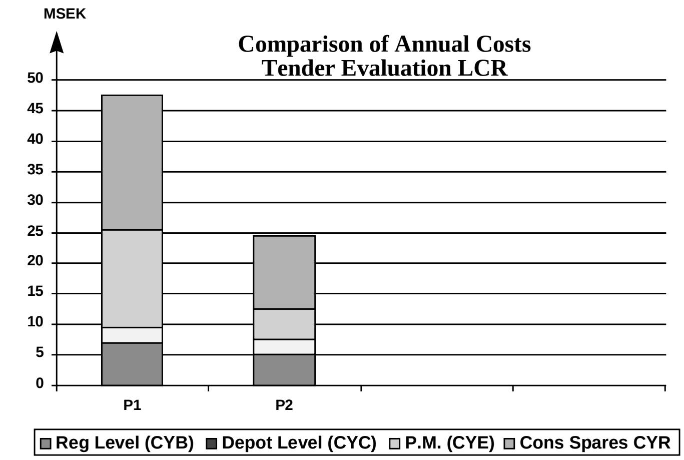

Figure 3.9

Both the cost for consumption of TX tubes and P.M. shows considerable improvements as expected - 9 MSEK for each.

3.3.9 Improvements for all tenderers

The result after completion of the 2:nd evaluation for all tenders (and 3:rd for tenderer P) are given in figure 3.10.

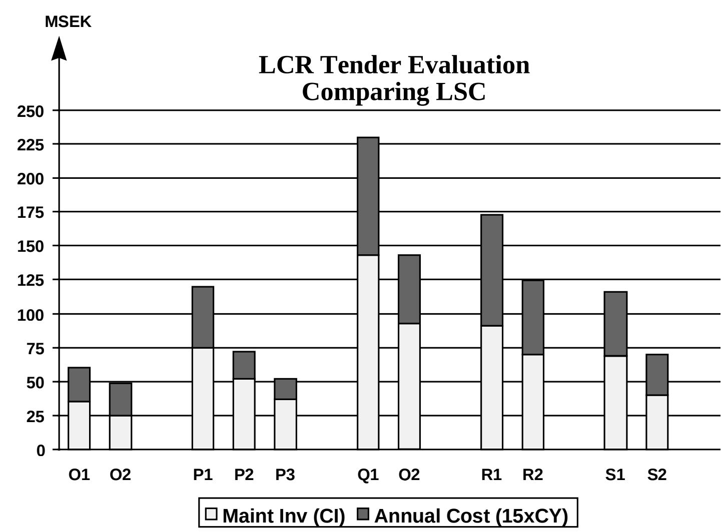

Figure 3.10

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. 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.

3.3.10 Conclusions

We can now leave the detailed case description and note some conclusions:

a) ***Only a minor fraction of the cost elements are of real importance. Concentrate on those.***

b) ***When looking at the system normally only a few items are of importance.***

We can then dwell on the question: How come that a large, qualified, advanced radar manufacturer submits proposals that can be improved to such a degree?

The answer is simple: Since he has not done any calculations of this kind of his system, he is not aware of the fact that there are a number of potential improvements.

This unfortunate situation is common although improving. It is obvious however that the initiative must come from the customer side. This can be achieved by various methods:

a) Request LCC calculations to be a part of the quotation.
b) Take the contract award decision based to a large extent on LCC thus forcing tenderers to have a good LCC to be competitive.

3.4 Oslo Air Traffic Control Centre

A comprehensive description of this case is given in [Wåå 91]. Furthermore since the major improvements were made on cost elements related to the Logistic Support more details are given in chapter 4.3.
Here we should concentrate on the overall improvements. The results of the evaluations are given below.

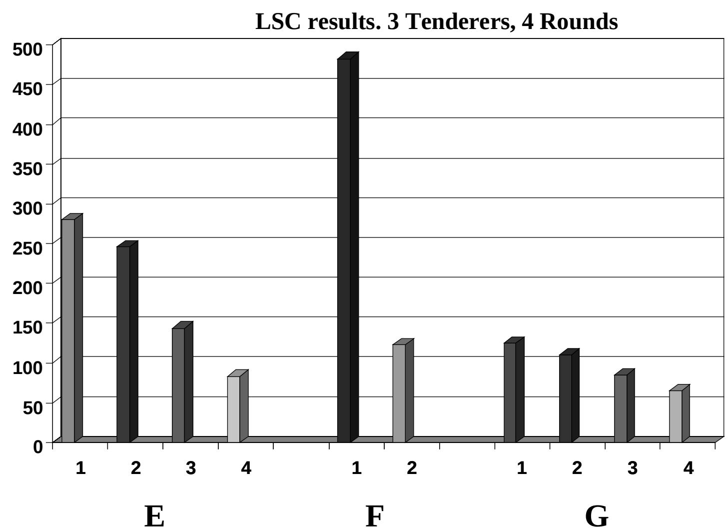

Figure 3.11

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 going from 280 MNOK to 83.5 MNOK and G going from 125 to 65 MNOK. Again, the savings are surprisingly large.

3.5 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 a 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. In fact personnel from the FMV (Defence Materiel Administration - Mr L Pålsson and Mr L Borghagen) were employed by the Swedish Railways (SJ) in order to initiate and advance the use of LCC and modern availability methods within the SJ. The methods are detailed in a number of papers presented at various conferences (see [PåK 92] [PAW 85] [BoB 84], [AkB94]).

The trains were acquired under intense competition and after a comprehensive negotiation period. There is no reason to believe that the contractor (ASEA Traction - now Adtranz Sweden) was so assured about victory that they 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.

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		Only 55% of guaranteed value
LSC (Life Support Cost)		Only 85% of guaranteed value (i.e. 15% saving)

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 failures 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 is 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.

3.6 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) which is a low figure in comparison with other Air Forces (a common figure is around 10%). 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.
The overall cost for advanced weapon systems keep on escalating (in fact: the LCC technique originally was developed to balance the ever increasing demands for higher performance at the expense of higher and higher cost - both acquisition and maintenance/support costs).

The problem can be illustrated as below. [Hel96]

Design to budget in an LCC project

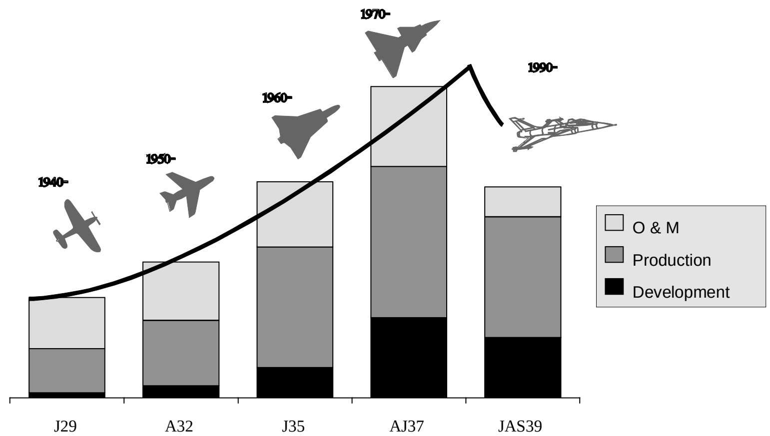

Figure 3.12: LCC for a number of Swedish Aircraft

It was clear that in order to afford the next generation of aircraft even more emphasis had to be put on the cost. So what has been done?

Note: Collegues of mine point out that J29 was a jet powered aircraft. That is true but we have to allow some artistic freedom to the artistry of the figure designer.
With respect to maintenance and support cost a very clear indication of the success can be given by the following figure. [Båå95]

Development of JAS39 LCC requirement

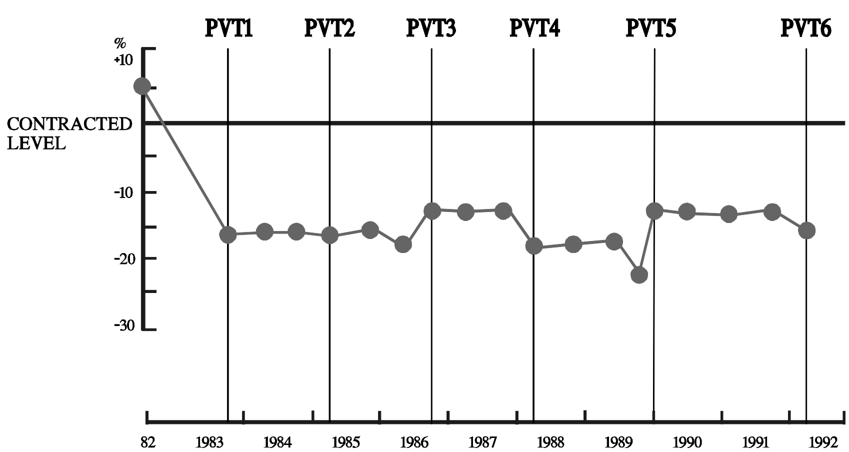

Figure 3.13: LSC estimates at a number of evaluation events
(PVT = Design Review Meeting)

The acquisition 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.

A further illustration of the possibilities for improvements is given below. [Hel95]

Maintenance man-hours per flight hour - Comparison between aircraft

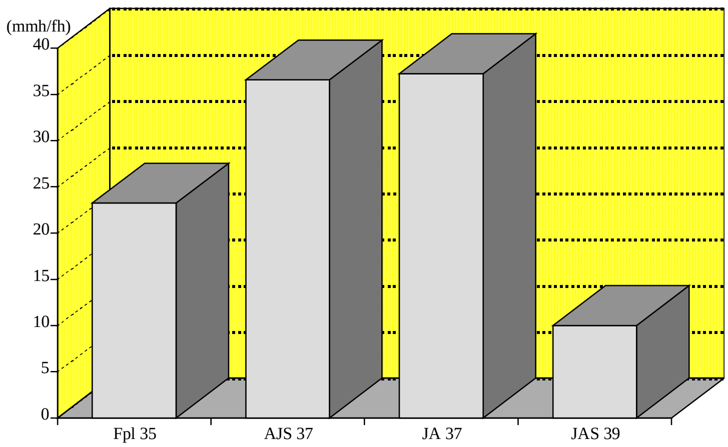

Figure 3.14: Comparison between aircraft

The man-hour consumption per flighthour for the JAS 39 is only 25% of the consumption for the Aircraft 37 and less than half of the consumption for Aircraft 35.
An anecdote can illustrate The value of LCC: I had the opportunity to visit the Republic of South Africa at the time when the SAAB JAS39 Gripen was announced as the preferred contractor. On a TV presentation LCC, its value and its importance for the selection of contractor was given broad coverage - music to an LCC advocate.

3.7 Offshore equipment

This case is from Statoils acquisition of Wellheads and X-mas trees for the following fields.

- Troll
- Sleipner
- Heidrun
- Gullfaks
- Veslefrikk (optional)
- Fenris (optional)

In total the acquisition covered

- 177 Wellheads/X-mas trees

- 46 in option
- Installation
- Maintenance and support

The budgeted frame for the acquisition + installation was MNOK 745.
The budgeted frame for the maintenance and support was MNOK 1400.
The acquisition was very successful and the following comparable figures were achieved:

Acquisition: MNOK 350 i.e. a saving of 53%
Maintenance and support: MNOK 338 i.e. a saving of 76%

The large savings can be explained by the following factors:

a) The budgets were pessimistic
It is normally true that budgets leave a certain margin for unexpected cost escalation. However these margins tend to be fairly small.

b) Field co-ordination
By co-ordinating a number of fields (which actually is relatively rare in the offshore business) volume was created and the competition became more fierce.

c) Functional requirements
Common practice within the offshore business is that the customer representative makes detailed design and the equipment contractor produces in accordance with the detailed design. By changing to functional requirements the equipment manufacturer’s knowledge could be exploited in an efficient manner.

d) Task clarification.
The maintenance and support tasks were clarified and specified thus eliminating uncertainties and possible costs attached to those uncertainties. Furthermore effort was made to co-ordinate and optimise the maintenance and support tasks (e.g. to minimise the number of trips to the platforms).

e) Working with cost drivers
The LCC technique was suitable to identify and improve on cost driving elements thus helping to focus the work on essential subjects.

4. LOGISTIC SUPPORT ANALYSIS

4.1 General

As mentioned earlier the operational system consists of two parts

- o The Technical System
- o The Logistic Support System

Both are necessary and it can be illustrated like this

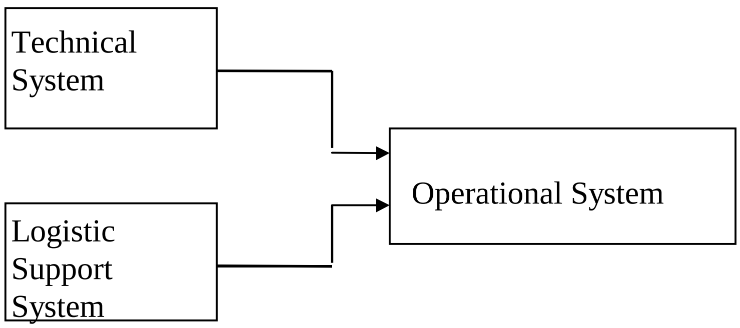

Figure 4.1

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.

4.1.1 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.

4.1.2 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

4.1.3 Data quality

This subject has been commented upon earlier and it deserves to be commented upon again (and then again).

Why should we accept to work with data of poor quality? There are a number of reasons for this:

a) The alternative is to do nothing - there are no better data available.
b) The classic saying: ”Garbage in, garbage out” is somewhat misleading in this case since the analysis will help us to refine the data. It will help us to understand which data elements that are critical (and where consequently some effort has to be made, in order to improve the quality).
c) The data quality normally is not as poor as one might think. The people making the estimates are experts.
d) As has been shown earlier the results tend to be surprisingly insensitive to data variations.

4.2 <u>A simple example</u>

In this example we shall look at a rough and simple Logistic Support analysis performed on an Intercom System for the Swedish State Power Board (SSPB). (The reader should keep in mind that the case is from 1973 hence some low figures like manpower cost - those were the days.)

4.2.1 Data

Aside from the cabling the system consist of 2 different items.
- o Exchange (1 of)
- o The individual telephones (1000 of)

The data achieved from the contractor were:

- o Exchange 0.47 failures/year
- o Telephones 59 failures/year

The data for the exchange are fairly uncertain. The data for the telephones are more accurate.

4.2.2 Alternatives

We can now identify the following repair alternatives.

a) The contractor takes care of everything.

b) The contractor takes care of everything for the exchange. The customer replaces a faulty telephone with a correct one taken from a local store. The contractor performs the repair of the faulty telephone.

c) The customer performs everything local. The contractor takes care of all workshop repair.

d) The customer performs everything. (This alternative immediately was rejected for policy reasons - The SSPB do not wish to spend the scarce technical resources on repairing intercom telephones.)

Some other information is:

The SSPB has their main office in a suburb to Stockholm. They also have technicians available that could be trained to perform the maintenance of the intercom. However, those technicians are dedicated to the SSPB electronic system for the surveillance and control of the power grid.
The contractor had the office and workshop for his technicians relatively central to Stockholm.

4.2.3 Cost comparison

Compare a) to b):

Cost separate to a)
Contractor man-hour rates: 1.5 hrs at 70:-/hour (note 1).

Cost for car: 10:- (20 km at 0.5 SEK per km).
Administration: 25:-.
Total: 140:-/failure.

59 failures per year at 140:- gives 8260:-/year.
The Net Present Value with 15% and 10 years is <u>41455:-</u>
Cost separate to b).
Investment: 25 telephones á 250:-/each = 6250:-
Training: 2500:-
4 transports/year (of faulty telephones) at 125:- = 500:-/year.
Total 11260:-
Select alternative b).

Note 1: The customer ***always*** must have a representative accompanying the contractor technician.

Compare b) and c)
What is the cost for the exchange failures?

0.47 x 140:- = 66:-/year (!!!).
This can not compensate any investments in training and spares.

Hence leave the exchange maintenance to the contractor.
It can be noted that we have made assumptions that will not be true when we see the cost for the maintenance contract since the contractor will have other costs as well. However we have established a ball park.

4.2.4 Effectiveness measure

When looking at logistic support alternatives the effectiveness also has to be considered. Since the travel time between the contractor shop and SSPB is fairly short it can be assumed that the better capability for the contractor technicians roughly compensates for this. Anyway the calculation of a suitable effectiveness measure can be illustrated.

We assume that a failure in the exchange will stop the whole intercom system. This is a slightly pessimistic assumption - certain failures will only prevent parts of the system. We further assume that a failure in a telephone will only stop that telephone. We now can calculate two extremes

a) Only failures in the exchange are taken into consideration.
b) All failures are taken into consideration independent upon whether they occur in the exchange or in a telephone.

Assuming 2 hrs downtime per failure we achieve

a) Downtime = 0.47 x 2 = 0.94 hrs/year
b) Downtime = 0.47 x 2 + 59 x 2 = 118.94 hrs/year

The spread in downtime is large - but so is the spread in failure definition. A reasonable compromise between those two failure definitions is to weight the downtime with the number of telephones that are inoperative.

$$Downtime = 1x0.47x2 + \frac{1}{1000}x59x2 = 0.94 + 0.12 = 1.06 hrs / year$$

As can be expected the downtime is dominated by the exchange downtimes. Since no alternative differed with respect to exchange maintenance the effectiveness considerations do not influence upon the decision.

4.3 <u>The Oslo Air Traffic Control Centre</u>

The overall results from this evaluation were given in para 3.4. Here we shall look at how the dominating cost driver was identified and how improvements were made within this area.
Initially 3 tenderers participated in the race. Tenderer F was excluded at an early stage due to reasons outside the scope for this paper. That left tenderers E and G. Both had 3:rd level maintenance as a dominating cost element. (The term 3rd level maintenance here is used for contractor workshop repair, e.g. circuit boards are sent to the contractor for repair in his facilities.)

Of course this was not unexpected. The fact that the system is very complex, containing a large amount of electronics naturally means that there will be a large need for workshop repair.
The cost was influenced upon in two ways.

- o Logistics Support Analysis to find the best repair mix of customer and contractor repair.
- o Lower failure flows especially for repair cost critical items. (Systems analysis)

4.3.1 Logistics Support Analysis

Both tenders suggested 100% 3rd level maintenance e.g. all workshop repair is sent to the contractor (or his subcontractors).

Already in Request for Quotation (RFQ) the possibility for customer repair was identified. There are a number of reasons for having a considerable customer involvement, i.e.:

- The customer has personnel available for the system site repair. In order to keep them well trained and motivated, challenging workshop repair tasks in addition to their site repair tasks fit extremely well. "Good personnel policy".
- The nature of their prime task - site repair - is such that a considerable under-utilisation is unavoidable. Addition of work tasks consequently is cost effective.
- The turn-around-times are shorter for the customer repair due to absence of transportation time and shorter queuing times. "Smaller spares investment needed".
- Less sensitivity for long term contractor escalation of 3rd level maintenance cost. "Safer".

Unfortunately there are some drawbacks, the most important one being the need for advanced test equipment. Consequently careful analysis has to be performed with respect to the possibility for the customer personnel to perform workshop repair i.e. find the "easy" items. The LSA really paid off. Significant savings were achieved due to better adopted support. Large improvements were also considered to have been made in areas that are important but not possible to quantify in money - like personnel satisfaction, long term stability etc.

4.3.2 Lower failure flows for repair cost critical items

The contractor repair can be quoted in different ways.

a) Fix price per year for the system.
b) Fix price per repair (independent upon which item is faulty).
c) Fix price per repair and per item (frequently this price is given as a percentage of the purchase price of the item).

In order to concentrate the effort to the right items various rankings were performed.

One ranking aiming at discussing failure flow is

$$N(i) \times Z(i)$$

where

N(i) = Number of item "i" in the total system
Z(i) = Failure rate for item "i"

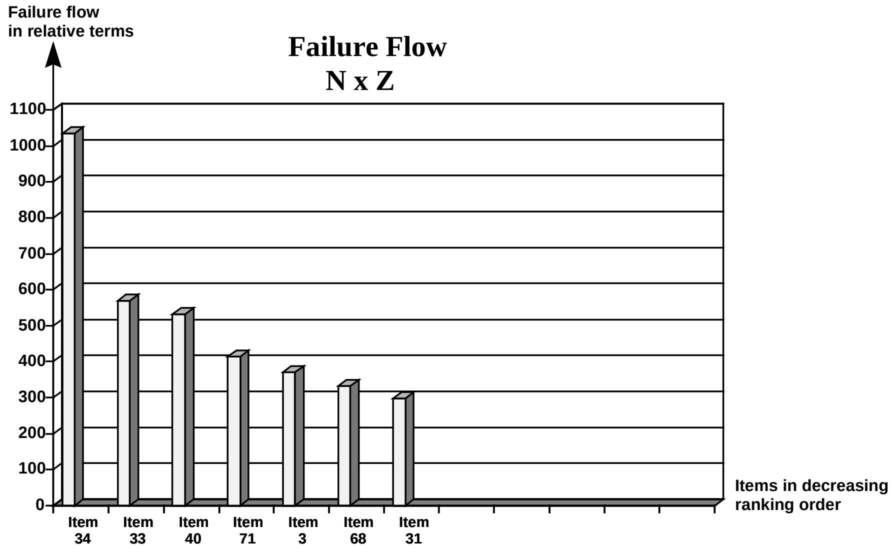

Figure 4.2

Another ranking aiming at discussing repair cost as c) above is

N(i) x Z(i) x C(i)

where
N(i) and Z(i) are defined above and
C(i) = Unit cost.

This ranking is in fact effective both when looking at repair cost and spares investment.

Several other rankings were used all aiming at creating better understanding. The various rankings for each tenderer were presented at formal meetings with each tenderer. In some cases this was an eye-opener for various improvements.

4.3.3 3rd calculation

Significant improvements were achieved as can be seen below.

Comparison 2:nd and 3:rd round (MNOK)

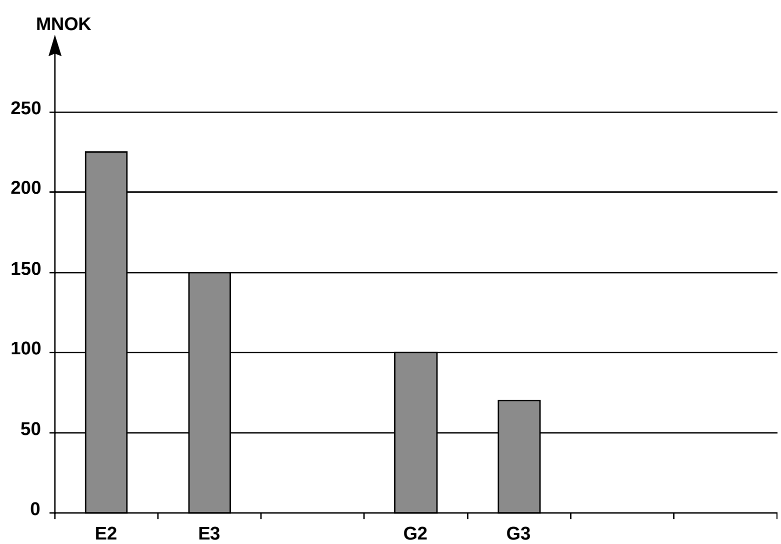

Figure 4.3

A comparison between the tenders (please note that all values have been modified for the sake of confidentiality).

	MNOK		
	E3	**G3**	**Difference**
LSC	150	68	72
Investment	28.0	13.6	14.4
Spares	14.0	4.5	9.5
Maint equipment	1.7	1.1	0.6
Training	6.6	5.9	0.7
Documentation	5.8	2.2	3.6
Future cost	122.4	54.4	68.0
Site maintenance	3.8	1.5	2.3
Customer workshop repair	1.5	1.9	-0.4
Prev Maintenance	0.6	5.1	-4.5
Spares Consumption	23.8	18.9	4.9
3rd level Maintenance	91.0	25.9	65.1
Maint on Maint Equipment	1.7	1.1	0.6

As can be seen tenderer G is superior on nearly all cost elements (exceptions being preventive maintenance and customer workshop repair).

The significant difference is in contractor repair. In fact, the difference in this element explains about 90% of the difference between the tenders.

When looking at improvements tenderer G's values are interesting.

We get the following table.

	MNOK		
	G2	**G3**	**D**
LSC	101	68	33
Investment	13.0	13.6	-0.6
Spares	6.0	4.5	1.5
Instruments	-	1.5	-1.5
Training	4.8	5.4	-0.6
Documentation	2.2	2.2	-
Future cost	88	54.4	33.6
Site	3.1	1.5	1.6
Cust workshop repair	-	1.9	-1.9
Prev Maint	5.3	5.1	-0.2
Spares Cons	16.9	18.9	-2.0
3rd level	63.0	25.9	37.1
Maint on Maint Eq	-	1.7	-1.7

As can be seen the saving in 3rd level maintenance leads to other elements being more expensive. Those are.

- Instruments 1.5
- Training 0.6
- Customer repair 1.9
- Maintenance on Maintenance Equipment 1.7

A bonus saving shows up in the spares investment due to shorter turn-around-time for certain LRU's.

4.4 Offshore Process Control Equipment

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

4.4.1 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 (note 1) (GFC)
- o Sleipner A (SLPA)

Note 1: The Gullfaks C platforms earns a certain reputation as being the largest object moved by man. (Although this is not verified by Guinness Book of Records).

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

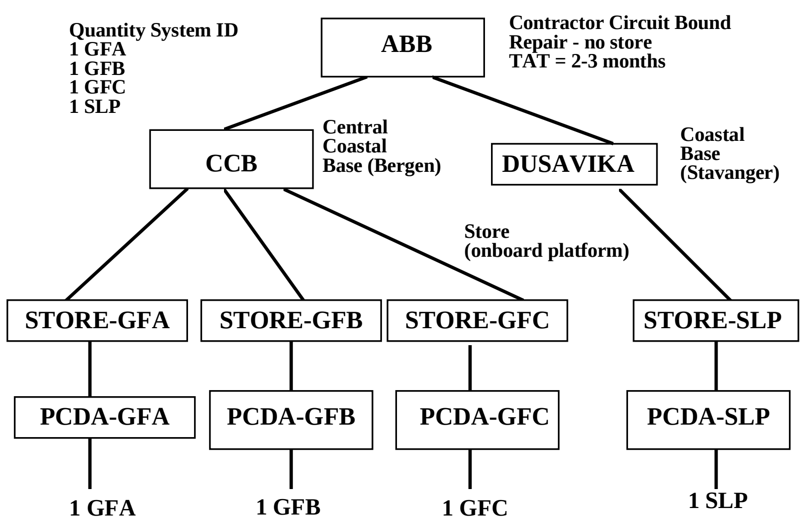

Figure 4.4

4.4.2 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 x 10^{-6} i.e. between 4 and 5 failures per week. The average failure rate per item is 1.76 x 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).

4.4.3 Support structures

A number of different structures and scenarios are investigated as shown below.

Joint on-shore bases

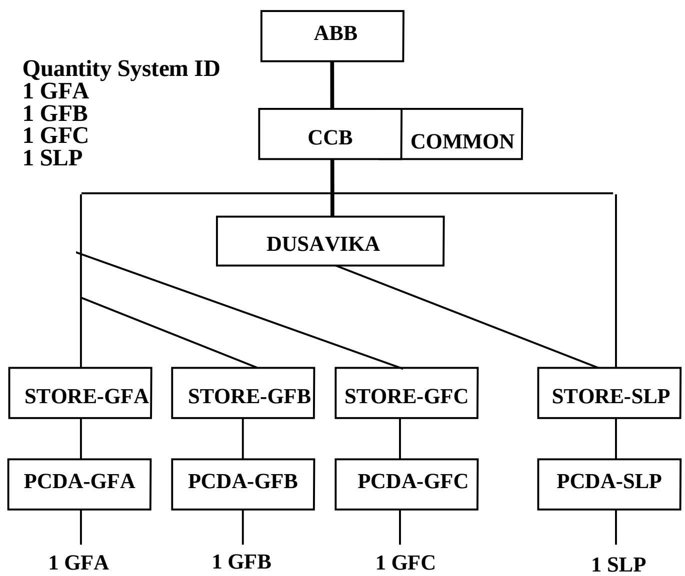

Figure 4.5

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.

Contractor agreement. (Support contract)

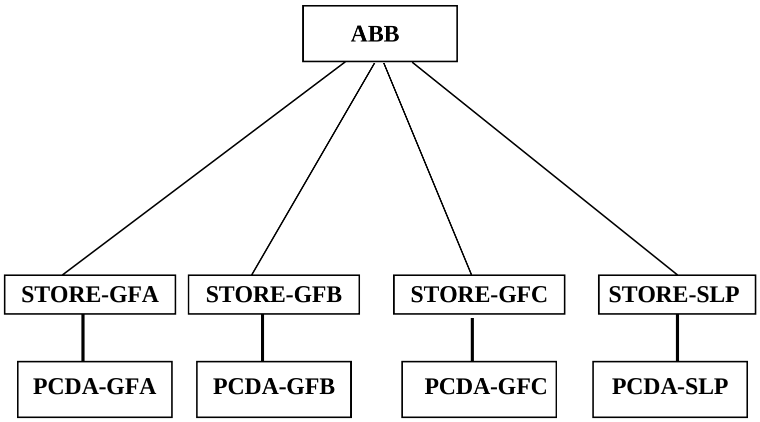

Figure 4.6

4.4.4 Basic results

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

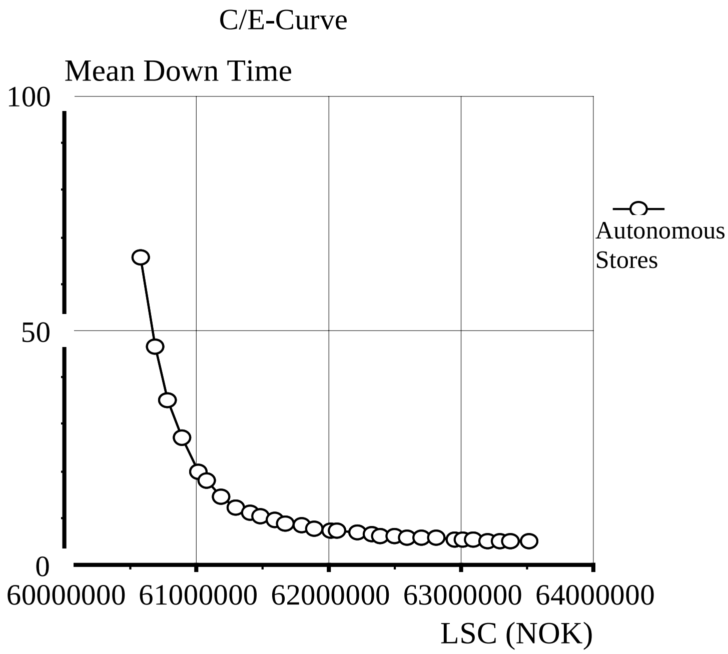

Figure 4.7

*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 4.8

*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 4.9

4.4.5 Joint stores

The results from joint stores compared with autonomous with start from existing stores.

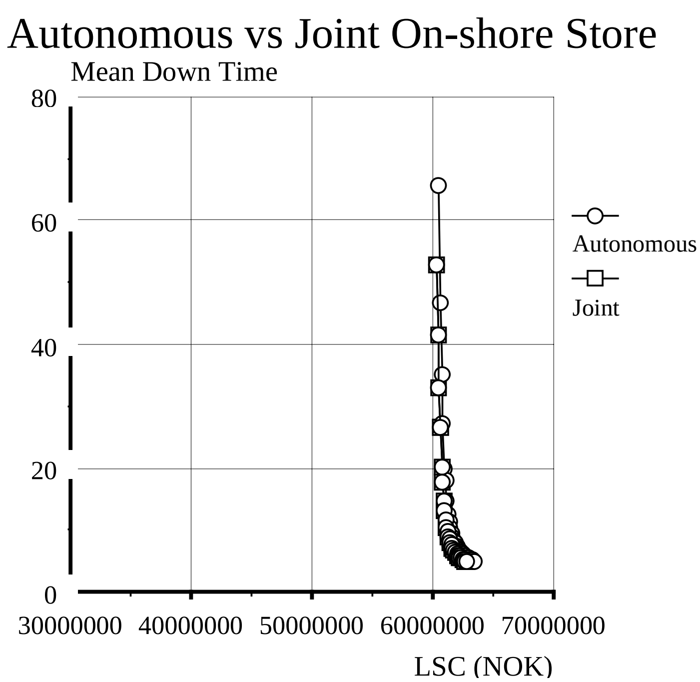

Figure 4.10

The impact of having joint stores is small.

4.4.6 Autonomous throw-away

The oversized existing stores implies benefit by throwing away.
A certain saving can be achieved by a throw away strategy (approx 4 MNOK).

4.4.7 Contractor depot store and repair

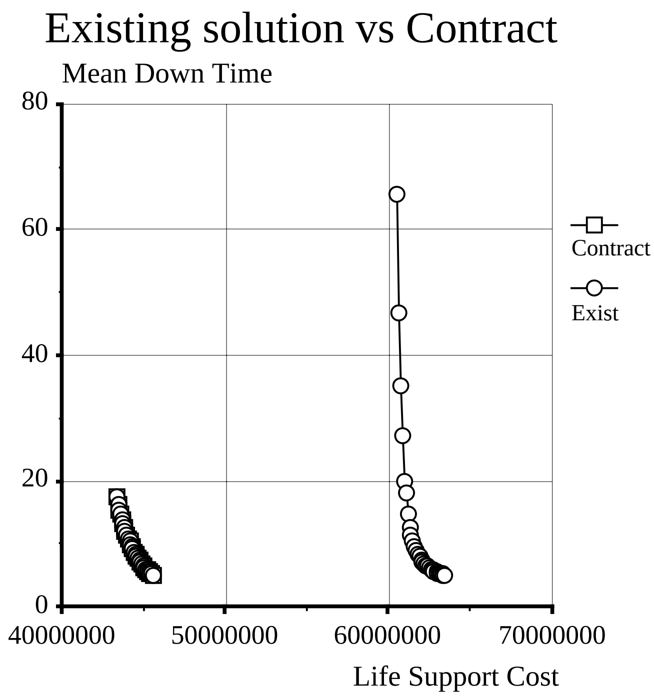

Figure 4.11

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

4.4.8 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 5.6 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

- Contractor central depot and repair
- Possible sell back of certain items
- 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).

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

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

More reading on LSA is given in ref [WåI 92].
More coments on suitable actions when too many spares have been acquired can be found in ref [Isd 99].

4.5 Viggen Aircraft Engine LSA

4.5.1 General

Ref [DaW 75] contains a summary of the analysis work performed from the late 60'ies to early 70'ies in order to optimise the maintenance and logistic support for the RM8 - the Viggen (Aircraft 37) aircraft engine. A description of the overall analysis would be far to comprehensive for this document. We shall however look at some of the details of the investigation.

4.5.2 Aircraft Engines

Aircraft engines are very expensive and require a lot of advanced maintenance. This is shown by the table below (MMH/FH = Maintenance Manhours per Flight Hour).

Maintainability	RM8A	
characteristic	Corrective maintenance	Preventive maintenance
MMH/FH Organisational Level	0.3	0.8
MMH/FH Intermediate Level	0.15	0.65
MMH/FH Depot Level	1.2	5.76
Total	1.65	7.20

Furthermore, to the cost for those manhours should be added the cost for spares of approximately the same magnitude.

Since the cost of engine operation and maintenance tends to increase with every new aircraft generation (J29, A32, J35) much effort has been put into cost/effectiveness analysis of the engine (RM8). Areas of special interest have been:

- repair/discard analysis
- identification of maintenance needs
- allocation of maintenance and support tasks and resources on the maintenance organisation
- determination of "best" engine overhaul turn-around-time
- analysis of required depot work-shop capacity
- computation of the number of spare engines and other rotables to be acquired

4.5.3 Optimum turn-around-time

Engines are sent to the depot (at the time of the study) for major overhaul and for approximately 10% of the failures. In case the turn-around-time at the depot is short, fewer spare engines are needed for replacement. This shorter turn-around-time however will require more resources at the depot. This is illustrated by the following diagram.

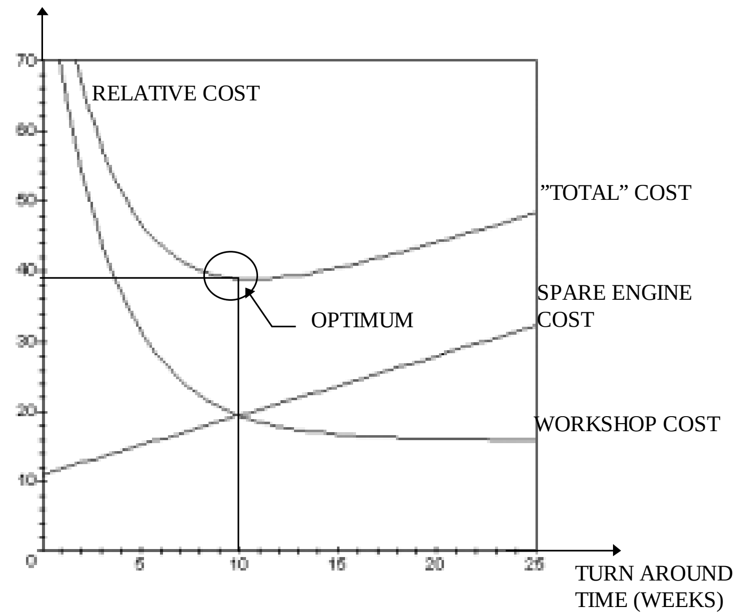

Figure 4.12: Optimum turn-around time

As can be seen from the graph a turn-around-time of approximately 10 weeks seems to give the lowest total cost.

4.5.4 Planning the overhaul-flow

In order to achieve a pipe-line-time close to 10 weeks it is required that the overhaul-flow is relatively even spread over time. Otherwise engines will queue up and the total pipe-line-time will increase rapidly.
The number of engines arriving at the central workshop is mainly a function of the fleet flying time distribution and possibilities for controlling this distribution by management. The number of overhauls per year with ideal planning and without any planning at all is shown in figure 4.13. The graph stresses the importance of careful planning and efforts have been initiated to investigate possible ways of increasing such controls.

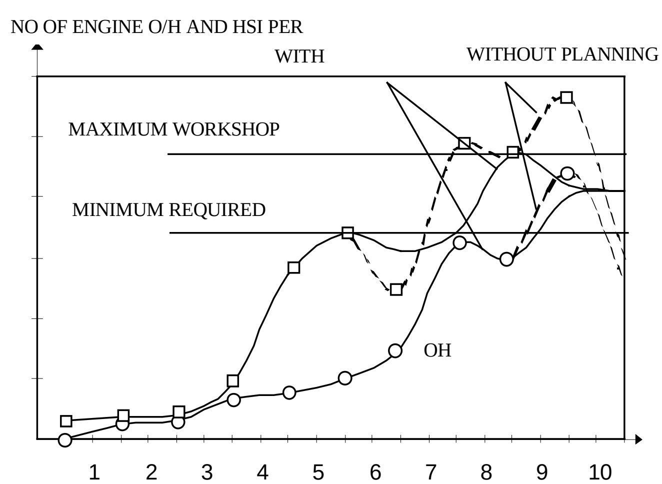

Figure 4.13: No of engine OH and HSI per year (HSI (Hot Section Inspection) is performed at intermediate level)

4.5.5 Optimum combination of engine repair and overhaul

This can be illustrated as follows:

At a certain point in time when X hours have transpired since latest overhaul a failure on the engine occurs. Should it be combined with a complete overhaul or not? The compromise is as follows.
The repair as such would be much less expensive if combined with an overhaul.
The overhaul (measured per cost per flight-hour) would be more expensive since it is distributed on fewer flight hours.

Alternative 1: Repair + Overhaul at X

Cost per X flight-hours $\frac{C(ROH)}{X}$

Alternative 2: Repair at X $\frac{C(R)}{X}$

Overhaul at 600 hrs $\frac{C(OH)}{600}$

Cost per flighthour is $\frac{C(R)}{X} + \frac{C(OH)}{600}$

The break-even point is at

$$\frac{C(ROH)}{X} = \frac{C(R)}{X} + \frac{C(OH)}{600}$$

which gives

$$X = \frac{600xC(ROH) - 600xC(R)}{C(OH)}$$

As an example: C(ROH) = 1.05 x C(OH) and C(R) = 0.3 xC(OH) gives X = 450 hrs.

This means that if this special failure occurs after 450 hrs the overhaul should be performed as well.

4.5.6 Overall results

- A decentralised maintenance philosophy provides for achievement of operational requirements and the best utilisation of maintenance resources at a reasonable life-cycle cost.
- Non-professional technicians could be used at the organisational level.
- Hot section inspections should be performed at the intermediate level.
- ”Optimum” overhaul turn-around-time is approximately 10 weeks.
- Mean time between corrective maintenance is predicted to be 105 hours.
- Maintenance Manhour per flighthour is predicted to be 8.85 hours including maintenance performed at depot level.
- Spare engines should be provided for repairs that take more than 12 hours.
- The adaptation to existing US Air Force logistic support equipment results in a low support investment and a reduction in total life-cycle cost.
- The direct maintenance cost per flighthour is predicted to be 1012 Swedish crowns (manhours and spare parts only and unfortunately in approximately 1970 price level).

5. SPARES PROVISIONING

5.1 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.

5.1.1 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

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

where

A = Availability
MTBF = Mean Time Between Failure
MDT = Mean Down Time (per failure)

MDT can be divided into to parts

MDT = MTTR + MLDT
where

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.

Let us assume a system with

MTBF = 200 hours
MTTR = 0.5 hours

The availability then will be

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

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:

MLDT = $2/5 \cdot 4 + 1/5 \cdot 48 = 11.2$
MDT = $0.5 + 11.2 = 11.7$

Our availability will then be

$$A = \frac{200}{200 + 11.7} = 0.945$$

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.

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

5.2 Methods for Spares provisioning

Basically there are three provisioning methods

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

5.2.1 Engineering judgements

Although the engineering judgements can give valuable contributions in the spares provisioning process the method has distinct drawback.

The advantages are

- o Contributions to criticality assessments
- o A second opinion on the credibility of data predictions and assessments

Those advantages are to be taken into the process. However, the drawbacks of the engineering judgements are related to the ***handling*** of the data.
The following weaknesses can be noted

- o No formal method (i.e. 2 spares assessors probably will reach different results)
- o There is no control over the effectiveness

An illustration of the consequence of those weaknesses is given below. 5 different spares assessors are requested to suggest the spares content for a very simple case (only 4 different items and 1 store). (Ref: [Bec90]).

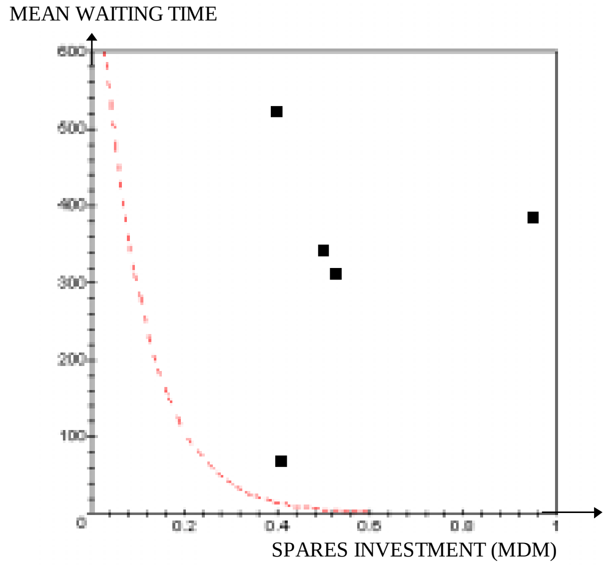

Figure 5.1: 5 different spares assortments compared to optimum

The conclusion is fairly obvious.

5.3 Simple example

5.3.1 Problem Data

The case used in this paper is very simple - one echelon, one indenture level. The data have been taken from a spares investigation performed in co-operation between an airline and Systecon AB. The data have been slightly changed in order not to reveal any confidential information. Furthermore the case has been simplified. The overall investigation is taken from [OPUS10].

System Data

Number of systems	=	QTYPS	=	15 aircraft
System failure rate	=	FRT(System)	=	$4420 \cdot 10^{-6}$ /flying-hour
Utilisation rate	=	UTILF	=	0.29

MTTR + delay times not depending upon spares = TO = 3.5 hours

The operational availability can in this situation be defined as

$$A = \frac{1}{1 + UTILF \cdot FRT \cdot (TO + WT)}$$

WT = Average waiting time for spares.

We can note that the availability with no waiting for spares is

$$A = \frac{1}{1 + 0.29 \cdot 4420 \cdot 10^{-6} \cdot 3.5} = 0.9955$$

This availability certainly looks impressing but remember that it is related to WT = 0. Such a value requires a very large investment in spares - in principle infinitely large.

The system data are given below.

Denomination	*Unit Cost (1000 SEK)*	*Fail rate/ 10^6 hours-op*	*No per system*	*Turn-around time (hours-calendar)*
Engine	10000	110	2	2856
APU	600	450	1	2016
CSD	750	280	2	3024
Pump	40	200	2	2352
FCU	400	190	2	3360
Stab Ctrl	710	360	1	2352
Gyro Vert	85	340	2	840
Door Mlg	135	120	1	1344
Pitch Comp	150	1010	1	840
Flap Act	210	240	1	1344

Table5-1 System Data for the Aircraft case

For the reader who is not involved in aircraft logistics it must be pointed out that we are talking about replacement rates, rather than any "catastrophic" failures. You still do not need to be afraid of flying. This airline has an exceptionally good safety record. It must be admitted however, that flying that special aircraft while spending the time calculating the probability of two engine failures created a certain excitement.

Organizational Data

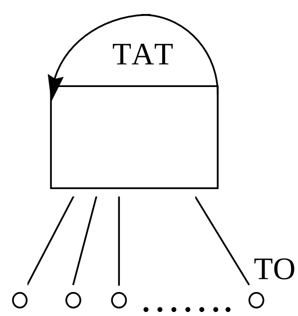

Figure 5.2

TAT = Average turn-around-time

TO = MTTR + Delay times not depending upon spares

5.3.2 Random assortments

A fact that has to be recognised when dealing with spares is the amount of combinations that can be achieved. This is realised in spite of the fact that we look at a very simple maintenance organisation - only 1 stock. If we look at all possible combinations to buy between 0 and 9 of our 10 LRU's it will give us 10^{10} combinations. This is illustrated by the diagram given below - although in a slightly smaller scale - "only" about 100 points.

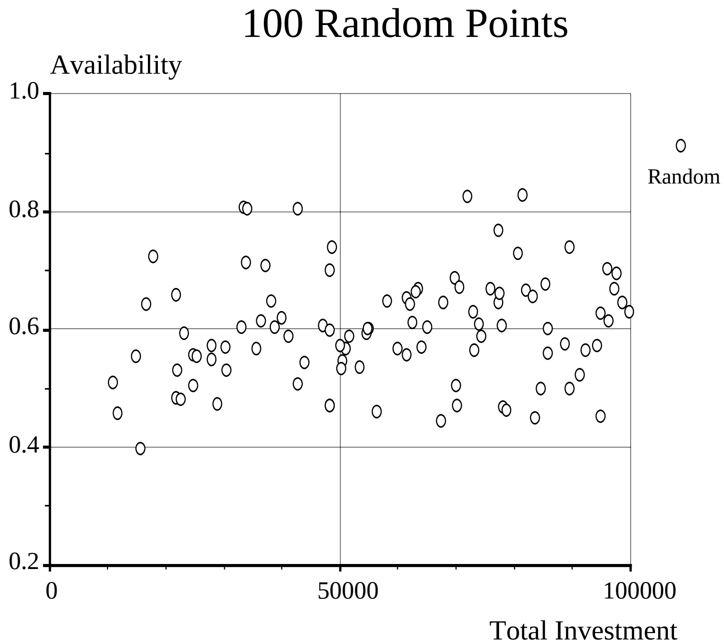

Figure 5.3 Availability as function of Investment. 100 Random combination of spares

The diagram shows 100 random combinations of spares investment and availability. Each assortment is generated by a random, uniform selection of a number between 0 and 10 for each item. The corresponding cost and availability is then calculated by OPUS10 using the ”Analysis” function. (See para 5.4.1 for further clarification.)

The diagram clearly shows the risk of making bad selections in case one does not have a good strategy. Two things can be noted just for the fun of it.

a) We have few points with high or low availability.
b) Some random points might be fairly good with regard to availability and investment.

The first notation depends upon the fact that high availability requires fairly high number of all spares. This has low probability. The reverse goes for the low availability.

The second notation shows that it should be possible to achieve optimal assortments, given time - a lot of time even - with a large efficient computer. There must be better ways.

5.3.3 The “Same of Each”

Admittedly the same number of all spares is a very simple policy but it has two major drawbacks

a) How to determine how many - what is the effectiveness?

b) Does it give good assortments?

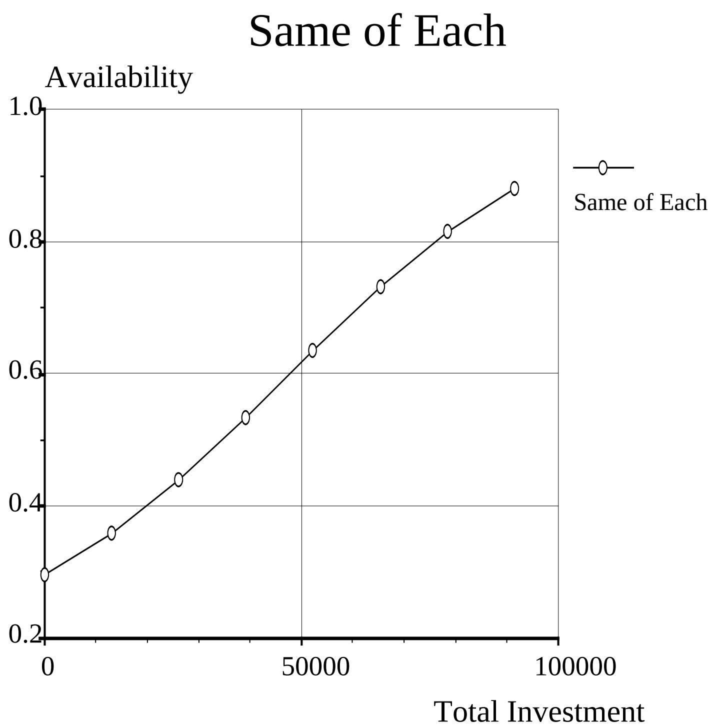

Figure 5.4: Analysis of assortments with Same of Each

The question whether the rule gives good assortments or not can be answered by the diagram below.

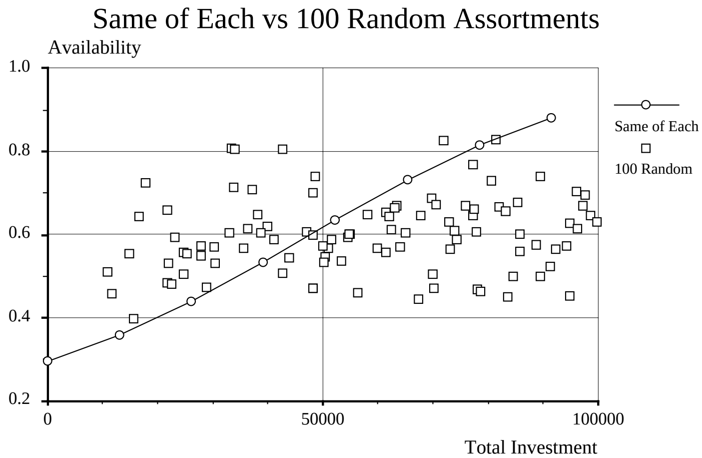

Figure 5.5 100 Random assortments vs. ”Same of Each” assortments

The result is not too impressing and "the same of each" is in general not a good stocking policy although with the possible exception of systems with very high reliability like radio-links etc. In such cases **one of each** is sometimes used with good results.

5.3.4 Constant Confidence Against Stockout, item-by-item

This is a fairly common policy which - unfortunately - is not the same as a good one. All spares are calculated to a number to assure that we will have a confidence against stockout for a certain period of time of a constant value, say 95%. The principle is shown by the calculations below.

The utilisation is shown more clearly by the following example for the engine:

UTILF	= Utilisation factor	= 0.29 flight hour/hour
QTYPS	= Quantity of systems	= 15
QTYPM (Engine)	= No of Engines	= 2
FRT(Engine)	= Failure rate engine	= $110 \cdot 10^{-6}$ f/flight hour
T(Engine)	= Turn around time	= 2856 hours

D = Expected demand = $0.29 \cdot 15 \cdot 2 \cdot 110 \cdot 10^{-6} \cdot 2856 = 2.73$

By using a nomogram (or a calculator) we achieve the following table

Confidence level	*No of spare engines*
70%	3
80%	4
90%	5
95%	6
99%	7
99.9%	9

Table 5-2 Confidence levels

It should be noted that the rule applied is "Approx. equal to X%" rather than "At least X%".

Two questions remain however:

- o What is the effectiveness of the assortments measured in system performance terms (like availability, average waiting time etc.)
- o Are the assortments cost effective?

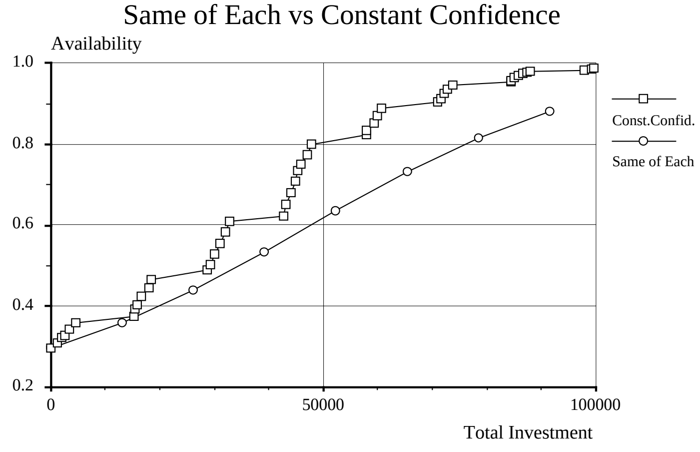

Figure 5.6: ”Same of Each” versus Constant Confidence

Obviously a constant confidence technique is more efficient than "same of each". This is of course not surprising since one considers some information available (failure flow as well as turn around times) in the constant confidence technique compared to the same of each.

One weakness with the constant confidence technique is the fact that it does not take the item price into account. It can be shown that it is optimum in the case all prices are the same and it is reasonably good in case the prices do not deviate too much within the assortment. In a case like this where one of the items is considerably more expensive than the other ones the method is less effective. Another weakness with the method is that the measure is directed towards the effectiveness of the stock - not towards the effectiveness of the systems.

5.3.5 Optimisation

It is clear from pure intuition that for each cost level it is possible to find a combination of spares that is more efficient than all other combinations. If the results for each cost level are connected with each other an optimum curve is achieved. On this curve each point represents an optimal assortment. The curve below shows the result from the optimisation function in the OPUS10 computer program.

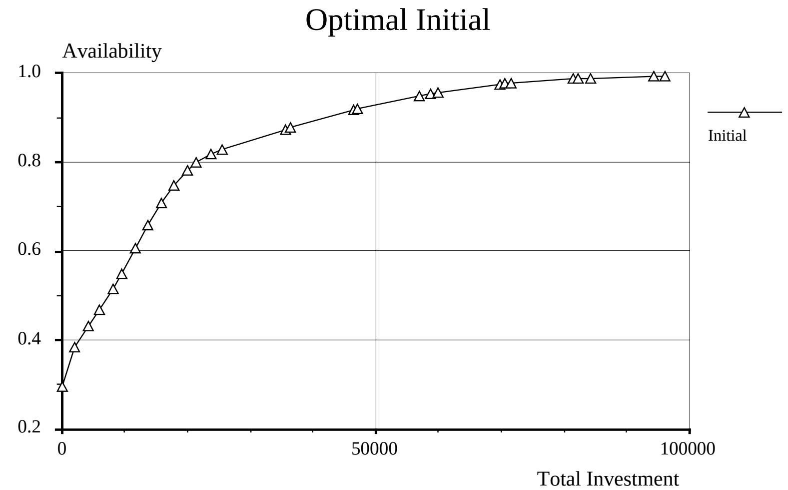

Figure 5.7 Availability as a function of the investment in spares. Optimum curve

A comparison with the constant confidence and one of each methods is given below.

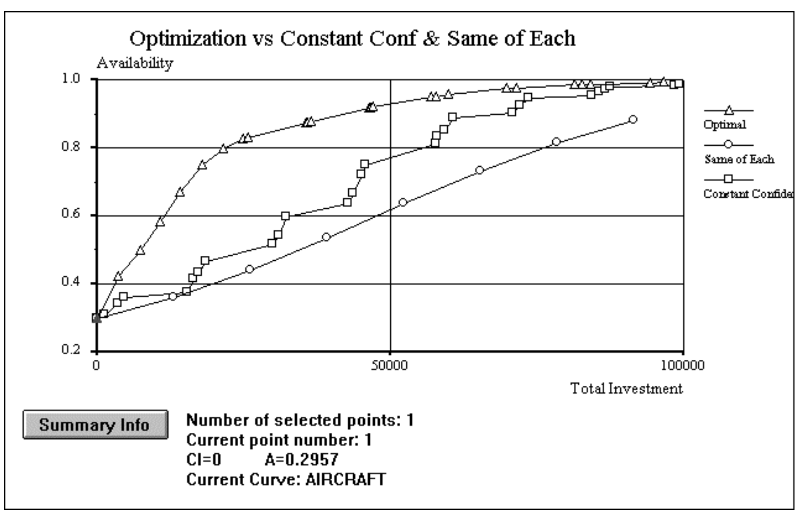

Figure 5.8 Availability as a function of the investment in spares. Optimal points vs. Constant confidence and Same of Each

The curves give an impression of overlapping at high investments. This is partly an illusion which can be seen from the following diagram.

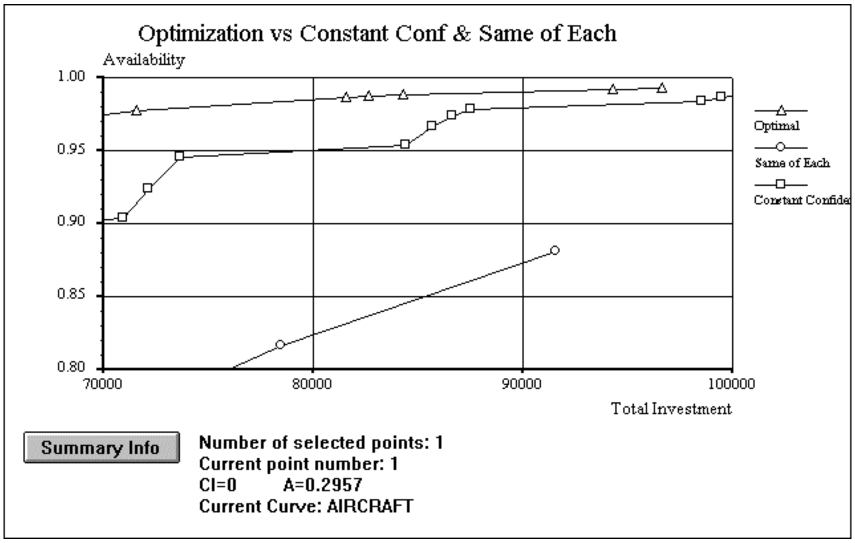

Figure 5.9 Enlarged part of previous diagram

Now we have established some of the requirements that are reasonable to put forward on an optimisation method.

- o It shall optimise the assortment to give the best use of the money
  It shall give the relation between system effectiveness measures (like operational availability) and investment

5.4 Solution to different problem types

This example - taken from the real world - illustrates the need to be able to handle different problem types. The problem types description is taken from ref [OPUS10].

5.4.1 Problem Types

When analysing spares you are 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. We call this mode *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 clean 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.

5.4.2 An example

A user of a certain equipment - system A - got indications that the operational availability was far below the requirements and that the reason was long waiting times for spares.

Since the user had followed the contractor spares recommendation both with respect to assortment and allocation he wished to investigate by performing a calculation using the same data. This is an example of problem type b) above (analysis).

The calculation showed an operational availability of 0.694 at an investment cost of
55 MSEK.

Since this was far below the requirement a first attempt was to perform ***reallocation*** (without adding more spares). This gave a certain improvement in operational availability - from 0.694 to 0.740 (by the use of problem type c).

The next step was to perform replenishment to the reallocated assortment - problem type e) above.
The result can be seen in the diagram below.

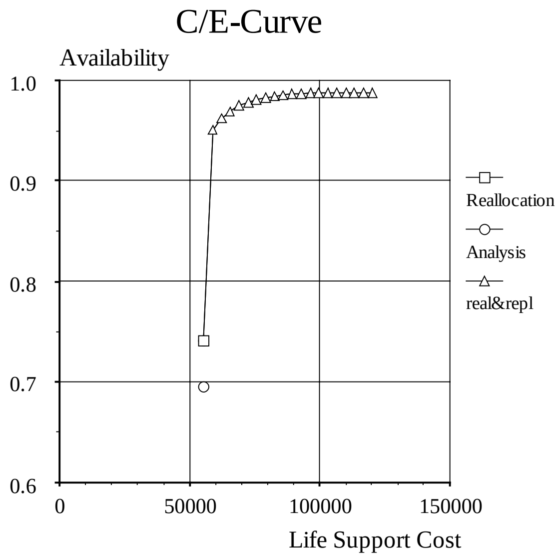

Figure 5.10

As a comparison a computer run acquisition from scratch was performed (problem type a) above).

The result is given below.

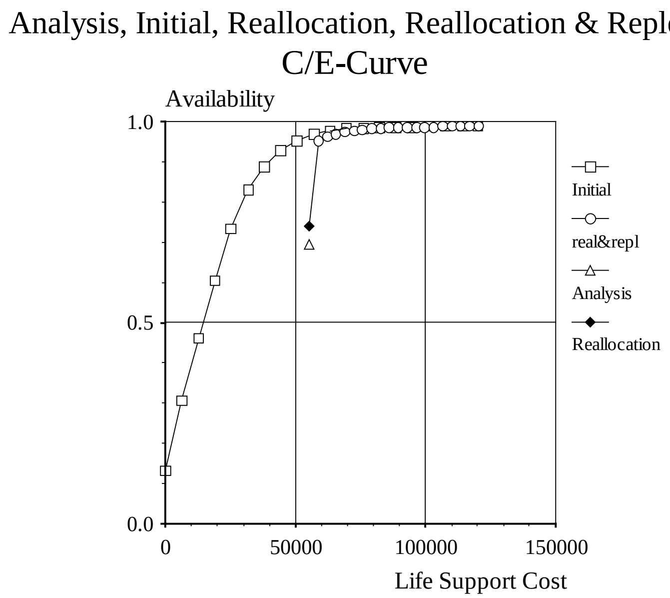

Figure 5.11

5.5 Royal Air Force comparisons

When the Royal Air Force (RAF) changed method from an item-by-item to an optimising they made comprehensive comparisons between the two methods. One of the results is given below. [Cla88]

Serial No	System No	SIM Investment (£)	OPUS10 Investment (£)	Saving	Saving % of Sim
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 5-3

All in all the comparison gave a ***saving potential on 4 projects of 12.6 M£.***

5.6 Offshore Process Control Equipment

A study of the offshore Process Control system as mentioned in para 4.4 gave the following results. [Niv 94]

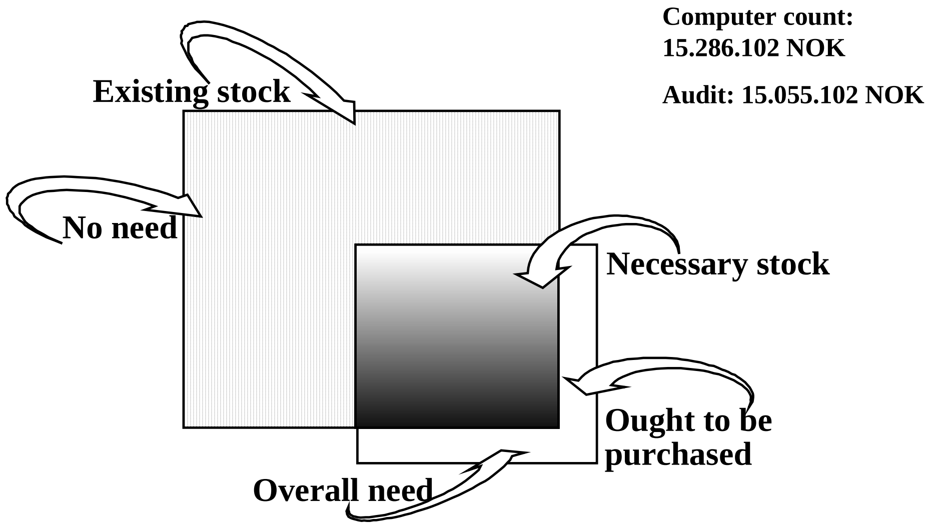

Figure 5.12

The results also can be summarised as:

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

Table 5-4

5.7 Barsebäck subsystem spares

The spares for some subsystems in the Barsebäck have been studied in an award winning Masters Thesis in [AnA 96]. The possibilities to co-ordinate the sparing for identical subsystems in Oskarshamn was a major part of the study.

The results can be summarised in the following way

Present store
- Investment 11.6 MSEK
- Availability 99.58 percent

Suggested
- Investment 2.3 MSEK
- Availability 99.96 percent

Improvements
- Investment: Saving of 9.3 MSEK
- Availability improvement
  0.38% per block (3 blocks)

Some comments can be made concerning the saving.

a) The saving is theoretical i.e. it can not be put into real money unless it is possible to turn surplus spares into real money.
The saving more reflects the situation that would have occurred in case the study had been made at the time of spares acquisition.

b) The major part of the saving is related to the optimisation and **not** to spares co-ordination.

5.8 Other improvements

a) IBM reports [Coh 90] a saving of 250 MUSD in stores investment and 20 MUSD and at the same time an improvement of 10% of the parts availability in the first line stores.

b) A case study with OPUS10 for another major computer manufacturer reports for one of the regional stores:
Case 1: Saving 79.1%
Risk of shortage lowered 40%
Case 2: Saving 82.5%
Risk of shortage lowered 19%

Further studies involving LSA gave even more savings.

c) Sherbrooke [She 92] reports typical savings to be around 25-30%.

5.9 Uncertain data

In order to perform a spares calculation, data are needed on the LRU level. Those data become 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]. 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 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.

5.10 Summary

The spares optimisation has the following advantages:

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

6. OTHER CASES

6.1 Scania trucks

In the previous chapters a concentration has been made on the three methods LCC, LSA and Spares Optimisation basically since it is the author´s opinion that they:

a) Are very efficient and lead to large improvements.

b) Are only used on a fraction of the projects were they ought to be used.

This does not mean that other methods are not efficient. In this chapter a number of successful cases are presented. A problem is that it has been difficult to find out how the improvement work has been done. This does not prevent the successful results.

The diagram below ref [Hör 96]) shows the development of the need for preventive and corrective maintenance for Scania trucks as a function of model year. The need is normalised in such a way that the need for preventive maintenance in the year 1968 is set to 100%.

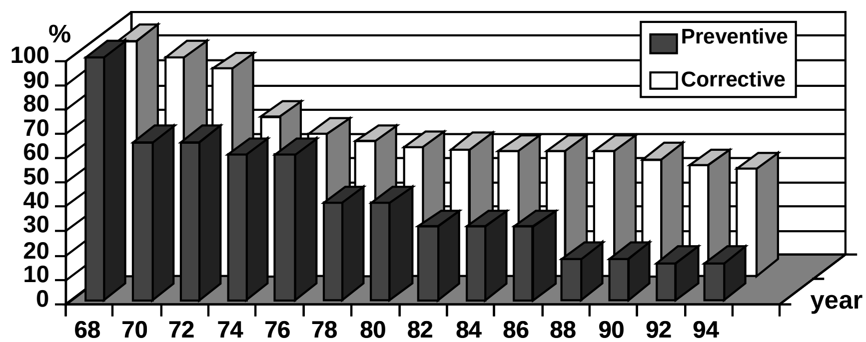

Figure 6.1

A number of observations can be made from the diagram.

a) Both the need for corrective and preventive maintenance have decreased considerably. The decrease is most significant for the preventive maintenance need. The reason for this difference is the ongoing improvements of the trucks. New functions are added and consequently the complexity increases. This will influence mainly upon the need for corrective maintenance since a considerable part of the added complexity is electronics.

b) The ”steps” in the decreased need for preventive maintenance are impressive.

c) The conclusion actually is:
The heading of this document could be misleading. It should not be ”Cut Maintenance and Logistic cost with 50% - A Fantasy or a Feasibility”. In competitive branches like production of trucks it should be ”Cut Maintenance and Logistics Cost with 50% - A Necessity”.

6.1.1 How to reach improvements

The improvements are mainly reached when changing models proving the wellknown fact that improvements must be reached during design. Scania follows an internal development procedure: the PDM process (PDM = Product Development Process). The key idea is to make it right from the beginning by verifying all requirements on an early stage in the development process. The requirements on need for corrective and preventive maintenance are set by the support department. The design specialists then ensures that the requirements are met.

As a basis for setting the requirements a number of methods are used.

- o Data collection from the damages during the guarantee period
- o Failure reporting from importers
- o Ten-in-top list (subjective problem list from the importers)
- o Long term follow up. Certain vehicles are followed up in detail - with the customers consent - during a number of years (typically 5-6 years which means 800000-1000000 km)
- o Experience from maintenance contracts (becomes more and more interesting as more and more vehicles are under contract).

6.2 Aitik Enrichment Plant

The following data are taken from [Wal 97]. The situation for the enrichment plant in 1990 was as follows.

Availability: 89%
Lining life: 20 weeks
Segment life: 10 weeks
Feeder life: 10 weeks
Grinder Mill Outlet Life: 4-8 weeks
Bucket for grinding pebbles life: 20 weeks
No planned stops (only when replacing lining)

A vision was set up with regard to the situation 1996.

The following should be met:

Availability: Better than 92%
Lining life: 52-80 weeks
Segment life: 52 weeks
Feeder life: 52 weeks
Grinder Mill Outlet Life: 52 weeks
Buckets for grinding pebbles life: 52 weeks
Planned stops: 4 hrs per serie and month

All of those requirements were met during 1996 or earlier.
A new set of visions have been established. Some of the visions are:

- o Availability: Better than 98%
- o Total stop: 72 hrs every 2:nd year
- o Planned stops: 4 hrs every second month

6.2.1 How were the results achieved?

The following sets of actions/methods were applied:

- o Measurements like vibrations, oil analyses, currents, magnetic fields etc
- o Inspection check lists
- o Risk analysis on new machines
- o Certain use of technique similar to LCC

- o Clear establishments of responsibility
- o Break-down of targets to identifiable level
- o Constant improvement
- o Use of new technology and materiel

6.3 Vacuum Pump improvements

The following example illustrates two factors:

- o Improved measurement technique
- o Improved materials

The example is the SCEMM (See note 1) Annual Maintenance Contractor Award Winner for 1996 - Motala Verkstad.

Note 1: SCEMM = Scandinavian Centre for Maintenance Management

The energy cost for a vacuum pump on 350 KW during 15 years of operation and at the energy price of SEK 250/MWh is more than 95% of the Life Cycle Cost. One of the most efficient methods to save energy is to eliminate the degradation that results from wear and tear. When a pump is worn, the capacity goes down and the energy consumption goes up.

The first step in the improvement process is to measure both capacity and energy consumption. In case the pump is considered to be worn the second step in the process enters since it is possible to perform repair of the pump by reconditioning. Composite material is attached by various methods and the pump is in shape as new - in fact even better than new.

The advantages can be summarised as follows:

a) It is possible - by measurement - to establish the point in time for economic recondition of the pump.
b) It is possible to perform repair of the pump by reconditioning.
c) Since the pumps get better capacity it is possible to reduce the number of pumps - an example from LKAB Svappavara showed a reduction to half the number of pumps.
d) The use of composite material creates a considerably longer life for the recon-ditional pumps compared to a new one. In the LKAB Svappavara case men-tioned above, a factor of 3 in life length has been estimated based on measurements.

6.3.1 How was the improvement achieved?

The improvement is the result of an innovative combination of technology progress within two areas - measurement technique and new material. This made it possible to establish an economic reconditioning point in time as well as repair (instead of discard) of the pumps.

There are many examples like this although most examples use only one of the improvement areas.

6.4 SKF use of TPM

TPM or Total Preventive Maintenance (the term Total Productive Maintenance) also is used is a method that originates in Japan and the Japanese Institute of Plan Maintenance has been the driving force. See for example [Nak 84].

The SKF experience [DI 95] of TPM proved very successful. Arne Wallnander - who was in charge of the TPM activities - points out that it led to

- lower production costs
- less waste
- reduced stocks

As an example it is mentioned that the production losses due to unscheduled repair decreased with 50% between 1988 and 1993 for the whole SKF group.

6.4.1 How was it achieved?

The way TPM is conducted within SKF it can be described as

- Operator’s maintenance: The operators are close to their machines and know best what is needed for a smooth operation. The operator’s maintenance mainly consists of
  - cleaning
  - lubrication
  - minor corrections and repair

  all in accordance with a written instruction.
- Condition monitoring: Aim at finding failures-to-be when they are in an early stage. This may require certain older machines to be stopped for a short break but the goal is to be able to do the inspection/measurement during operation
- Corrective maintenance: This is divided in planned or unplanned corrective maintenance. The aim of course is to have as much as possible as planned corrective maintenance.
- Improvements/modification: Aim at eliminating sources of failures that are revealed during the previous activities.

The TPM method is fairly frequently used in Sweden. There are a number of reasons for this:

- It is effective on existing equipment
- It fits well into Swedish management stile with co-operation between various functions
- It is a fairly straight forward method without the somewhat theoretical aspect that is found in LCC/LSA/Spares Optimisation
- It is successfully implemented in Japan by the Japanese Institute of Plant Maintenance
- The work performed at Chalmers University of Technology (ref[StL96]) has been very successful

7. WHAT CONTRIBUTES TO A SUCCESSFUL IMPROVEMENT ACTIVITY

7.1 General

The basic idea behind this document is to look into a number of successful cases in order to identify some common factors. A large number of cases have been studied (including a large number not included in the report).

It should however be noted that a couple of factors could destroy the findings.

a) There is a natural tendency to write papers, press releases, brochures etc about ***successful*** cases. Very few of us are interested to write about less successful cases or direct failures.
b) There is a dominance for cases where the author has been involved. Also some cases involve close colleagues to the author. The reason is simple - a lot of information from those cases is easily available to the author, information that not necessarily is written in the documentation.

Further as a general comment it could also be noted that projects and cases are not followed up and documented in any larger extent. The reason for this is probably that the people involved are switched to other projects and are not given time for project review.

In the following a number of contributing factors have been collected each of them contributing to successful results. They have not been ranked in any order of importance, nor is the list complete.

7.2 The LCC project sequence

The concentration is made on LCC since much of the LSA and Spares Optimisation relies on the data developed during the LCC work.

First however we have to look how a LCC project is performed.

In a LCC project we basically have the following phases/activities (although under different names is different organisations):

- Study phase
- Preparing Request for a tender
- The tenderers prepare their tenders
- Tender evaluation
- Contract negotiations
- Verification
- Long term follow-up

A very good way of understanding acquisition is the sequence:
- Need
- Requirement
- Commitment
- Verification
- Consequence

The customer has a ***need*** of some kind. Through studies and coordination this need has been transferred into a number of ***requirements*** on the system that is to be acquired. The tenderers in their tenders undertake to fulfil those requirements - they make ***commitments***. At time of delivery the customer (normally together with the contractor (= winning tenderer) in various ways investigates and/or proves that the commitments are fulfilled by ***verification***. The outcome of the verification will lead to on a ***consequence***.

In case of acceptance e.g. the system passes the verification the contractor is paid. In case of rejection e.g. the system does ***not*** pass the verification, the contractor is face with delayed delivery, extra work and eventually penalties. Normally the verification ends up somewhere in the middle and the negotiation starts.

7.2.1 Study phase

Here the overall aim is to establish feasibility and possible profitability of a certain project. The aim further is to plan the execution of the project.

From LCC point of view assistance can be given with respect mainly to certain data necessary for profitability estimates and planning.

Comments on very early data generation and the LSA process is given in ref [Wåå 98] and [Wåå 99:1].

Internally in the LCC work the following tasks should be addressed:
- Understand what is important in the system
- Start asking the right questions regarding the cost drivers
- What people are involved
- Allocate resources in accordance with the plans

Here a note should be made: Plans normally change. In particular this goes for work related to
- Preparing specifications
- Tender evaluation
- Contracting

In those cases the project tend to have high priority as well.

7.2.2 Preparing Request for tender

In this case two major tasks should be completed

- The LCC parts of the Request for tender. (For example see [Wåå 82.2].)
- A preliminary LCC model to allow for supporting the specification work. (For example see [Wåå 82.3].)

The model is necessary at this stage to ensure that all necessary data are requested from the tenderers.

It is further important to write the LCC parts of the request for tender in such a way that it becomes supportive for various unforeseen situations during the tender evaluation and also later phases.

7.2.3 The tenderers prepare their tenders

This part of course is crucial both for the future success of the project and for the LCC part of the project. The important matters for the LCC activities are the key tenderers responsiveness to
- Reliability and Logistics Support requirement
- Related data delivery

It should be remembered that the introduction of LCC commitments in an acqusition is not necessarily viewed as a positive factor among the tenderers. It means extra work and extra undertaknings.

7.2.4 Tender evaluation

This is a key activity. It is also a squeezed activity.

An important thing is to try to find time for presentation of the different tenderers result (only of course their own results). That way some important advantages can be achieved

- You get a check that you have understood his data
- The tenderer understands the effects of various design details - improvements could be made. A fruitful dialogue is started.
- The tenderer understands the impact of various commitments and warranties. Again improvements can be made.

Some advice:

Tender evaluation means a lot of work and a lot of calculations to be made. Data will change.

It is important that the right tools are available - not only computer programs but also other resources.

A certain bureaucracy is necessary.
See also [Wåå 94.2], [Wåå 94.3] and [Wåå 99:2].

7.2.5 Contracting

If the proper ground work has been done contracting more or less should be a confirmation of earlier understandings in request for tender and the tender itself backed up by clarification's made during evaluation.

However this never seems to be the case.

Probably there is a natural law forcing negotiations to go until almost too late.

Sample of the LSC (Life Support Cost) part of a contract is given in [Wåå 82.1].

7.2.6 Verification

This is a phase where it is necessary to use experts with experience from inspection, acceptance control etc. That way many problems for both parties can be avoided. Furthermore, it can be noted that it is possible to verify a contractually agree LCC, in particular when concentrating upon system characteristics defining the LCC. See also ref [Wå 94.1]

7.2.7 Long term follow-up

Frequently there is a tendency to forget about equipment and the related agreements once the operations has started. The reason is that the team splits and becomes involved in other activities. The contractual undertakings tend to fall away.

A useful hint is to use the LCC model to understand possible need for modifications.

7.2.8 Summary

The cornerstones for a successful LCC acquisition consequently are:

- o A reasonably good RFT (or RFP/RFQ - whatever the name) is sent out.
  Note: RFT = Request for Tender
  RFP = Request for Proposal
  RFQ = Request for Quotation
- o Reasonably good tenders are received - at least from the most interesting tenderers
- o A good dialogue is initiated between the customer on one hand and each of (at least) the most interesting tenderers on the other hand
- o The achieved improvements are established in contract, design follow-up, verification and long term customer follow-up

7.3 <u>Listing of factors</u>

When starting up an LCC application the following obstacles may occur.

a) The LCC part of the project never gets off the ground.
Reason: Insufficient internal customer determination.

b) Failure to achieve tenderer involvement.
Reason: Poor tenderer responsiveness.

c) Failure to produce results in spite of good internal customer determination and good tenderer responsiveness.
Reason: LCC team shortcomings.
Non-functional specifications

The factors that will have a positive impact to eliminate those obstacles can be listed as follows.

Factors that influence upon: ”Internal customer determination”
- o Long term thinking in the organisation
- o Management support
- o Support from various internal customer functions (e.g. purchase department)
- o Large acquisition
- o Presence of special requirements that make the project unusual
- o Early involvement
- o Presence of a customer internal driving force
- o Presence of experience from LCC acquisitions
- o Functional requirements

Factors that influence upon ”Tenderer responsiveness”
- o Contractor management attitude
- o Contractor customer orientation
- o Contractor opinion of the customer’s determination and capability
- o Degree of competition
- o Trade habits
- o **Can** the contractor be responsive
  - Contractor capability
  - Data availability

Factors that influence upon ”LCC team capability”

- o Welltrained and dedicated team
- o Necessary tools available
- o Data available
- o Presence of a person with experience of LCC acquisition
- o Good preparations
- o Understanding of analytical methods

Finally a very important factor

- o Functional specification

7.4 Comments on factors

7.4.1 General

The factors commented upon below are taken from 7.3. It should be noticed that they tend to overlap each other and that they are by no means independent. So for example the Management support is not independent from the Long term thinking of the organisation and furthermore the Support from other internal departments is of course not independent from the Management support.

7.4.2 Long term thinking

In order to invest today for the benefit of a future saving the future saving must be regarded as a factor to consider. See also [Vin 83], [MaO 96], [MåR 97].

In an organisational environment where individual performance is measured on a short term basis no one can criticise those decisionmakers that tend to favour short term benefits.

This may also be an explanation why LCC, LSA and Spares Optimisation tend to be more common on large, long-term project like Aircraft JAS etc.

In order to get the similar types of improvements on smaller projects a long term thinking has to be introduced into the organisation with methods like

- o Policy statements
- o Mandatory project calculation covering the whole life

7.4.3 Management support

This is one of the most critical factors for 2 reasons:

a) Support for spending of necessary resources
b) Support in case of controversy

It will be necessary to acquire resources of various kinds for the future activities. Examples of such resources could be:

- o Consultant(s)
- o Computer resources
- o Special computer programs

Those resources, of course, will require spending and as a consequence the support for this spending is necessary

Furthermore this types of analyses could be subject to controversy both internally and externally

This is one of the most critical factors.
Normally the types of analyses brought up here could be subject to controversy.

There are a number of reasons why this should occur. Such reasons will be commented upon later. However the fact that such reasons exist mean that every now and then resistance towards the improvement activities will pop up. In such cases management support might be necessary.

7.4.4 Support from other internal functions

When looking at LCC acquisition three different parts of the organisation are critically involved.

- Design/development
- Purchase
- Maintenance/Logistic Support

It is not good if any of those dominate the result. In this balance normally the maintenance/logistic support speaks up for the long term thinking.

The co-operation between the parties has been compared with a stool, a three - legged stool is stable enough, a two-or one-legged stool is not.
The impact of purchase will be commented upon later in this paper.

7.4.5 Large acquisition

It goes without saying that in order to get permission to invest in various resources as well as internal spending there must be a reasonable pay-off and that means in turn that the project must be of a certain size or commit to large future spendings.
It must be pointed out that there is a considerable potential saving also in small projects but initially the project must be of a certain size.

7.4.6 Special requirements

Every now and then organisations are faced with projects that for different reason are special.
Examples of such special requirements could be:

- The necessary availability requirements are of a different magnitude than usual
- Certain failures must not occur (e.g. safety)
- Totally new support requirements etc

These type of special requirements create a special awareness for the project and its development. Experience has shown that the existence of such requirements have been good for the LCC introduction.

7.4.7 Early involvement

This actually refers to two aspects:

a) The involvement must be so early in the project that the design is soft enough to allow for changes (i.e. improvements).

b) The LCC work must be given a fair start to do the necessary work e.g. to prepare the specification

7.4.8 Presence of a driving force

Normally when a LCC acquisition is initiated, someone is appointed to be responsible for this part. It is important that:

- o This person believes in the methods
- o This person is given adequate time for the task
- o Adequate other resources are made available

It could be noted that a safe way for failure is to appoint someone who is not interested in LCC methods and who is overwhelmed with other work. This person will stop at he first obstacle.

The following should be noted:

The improvement work is bound to encounter resistance from various players in the development. Some sources of the resistance are given below.

- o Tenderers that see LCC as a threat since there may be further contractual obligations.
- o Decisionmakers that feel that LCC take away a considerable part of the decision basis (the calculations give little room for subjective weights).
- o Contractors that suspect that their spares recommendations are inefficient.
- o Internal spares managers that expect that their present spares assortments and allocations are unnecessarily expensive

The LCC work on a project could easily stop when facing internal or external (frequently both at the same time) resistance. In such cases it is of outmost importance to have a driving force in the project, a force that can keep the LCC banner high. Probably lack of such force is one of the most common reason for failures to bring LCC projects through.

7.4.9 Presence of a person with experience of LCC work

It has been said: ”LCC work is easy in theory but difficult in practise”.
This is specially true when looking at formulating the Request for Tender. Here a number of possible future problems must be identified and clauses necessary for their successful solutions must be formulated and inserted.

Frequently this person is a consultant. The reasons why it is so is of course that the consultant has experience from other LCC cases (it must be so since there is no need to bring in a consultant that is ***not*** experienced in his field).

The author of this document has worked as a consultant for many years and the suspicion could arise that the author is ”biased”. True as this may be, the author has a very strong belief - based on many cases that the use of a consultant is important to reach results when starting up LCC activities

7.4.10 Functional requirements

In some branches the customer makes the design (within his own organisation or through representatives). The typical example is within the building industry. In such cases there is very little freedom left for possible improvements.

It is important to realise that there are a large number of ways in which a certain requirement shall be fulfilled and that consequently the detailed design not should be frozen too early.This is done by formulating the requirements in a functional way. (What the system should do - not how it should be designed.)

7.4.11 Tenderer management attitude

A tender in response to a LCC oriented will put demands on the tenderers in three aspects:

- Contractual commitments with respect to LCC
- Data delivery
- System characteristics from LCC point of view. (If the tendered system is analysed and even better - optimised - with respect to LCC?)

This will require decisions on a management level and if all tenderers have the same negative view it may be difficult to go ahead. Consequently at least one favourable tenderer management attitude is important. Normally this is the case. There is at least one tenderer set out to win.

7.4.12 Tenderer management customer orientation

An alternative to a favourable tenderer attitude towards LCC may be a customer orientation.
The reasoning may go like ”I do not like this, but my customer likes it and the customer is always right”.

7.4.13 Tenderer management opinion regarding the customer’s determination

An important incentive for the tenderer of course is the possibility to win the contract. If - in his opinion LCC - is an important factor in this respect he is willing to take on some of the extra burden related to the LCC (e.g. extra commitments, extra data preparation). If - again in the tenderers opinion - the customers declaration regarding LCC is only lip service his willingness might erode correspondingly. Hence, if a customer is serious about introducing LCC it must be whole-hearted as well as visible to the tenderers. The specification must reflect both capability and determination.

7.4.14 Degree of competition

The extra burden for a tenderer/contractor when LCC is introduced has been commented upon. Hence it is natural that the tenderer considers his possibility to win the contract without responding to the LCC requirements. In such a consideration the degree of competition of course has a heavy weight. If the tenderer has the opinion that he will win the contract anyhow his willingness to make extra commitments is lower. (This observation of course is not limited to the LCC area).

7.4.15 Trade habits

The relation between customer and contractor varies considerably between various branches partly due to the different environments for the projects, partly for historical reasons. Whatever the background - those differences are real and has a considerable impact on the possibility to introduce LCC. One example is the building industry where the request for tenderer is very detailed and fix - the space for alternative design solutions is very limited. One area where the difference between branches is significant relates to data - and in particular - to failure rate data. In defence and electronics branches it is more or less standard to be prepared to submit failure rate data. This is not the case in many other branches.

7.4.16 Well trained team

The team - may be a 1-person team - working with the LCC questions must be welltrained, not only in the mechanical handling of data and computer models, but also with respect to other areas such as:

- o The ability to understand tender texts that sometimes can be (deliberately) cryptically with respect to their true meaning
- o The ability to understand the results of the exercise
- o The ability to see alternative solutions or to explain results in order to generate those alternative solutions
- o The ability to respond quickly to changes in data or other changes

7.4.17 Tools

It goes without saying that the team must be properly equipped with necessary hardware and software tools. The methods developed in relation to the low coverage radar covered the following functions

- o Data handling
- o Spares optimisation
- o Effectiveness calculation
- o LCC calculation

See also ref [PaW 82] for more info. It should be noted however that the rapid turn-around of software has lead to replacement of the actual program packages used.

7.4.18 Data availability

This is a key point and one of the most common causes for failed LCC efforts. The most frequent missing data relates to failure rates. A common mistake is to stop the LCC effort and start a long-term data collection. It is however much better to accept shortcomings in the data quality and try to push ahead. This will be commented upon later.

7.4.19 Experience from previous LCC acquisitions

We have earlier (para 7.4.9) touched upon the need for experience in relation to formulation of specifications and how to foresee future problems. In the context here we have to look at experience in terms of

- o How to convince reluctant tenderers to deliver data and accept commitments?
- o How to find improvements
  etc

As has been said before: ”LCC is simple in theory, but difficult in practice” - this type of questions requires experience.

7.4.20 Good preparations

The need for good preparations of course is nothing unique for LCC work. There are however some reasons why it is extra important.

a) In initial attempts it works in a controversial environment which means that even small mistakes can be fatal to the whole effort e.g. used as an excuse to stop the exercise.
b) The times allocated frequently are very tight and do not allow for any ”fumbling”

7.4.21 Understanding analytical methods

Parts of the LCC work are related to theoretical models that sometimes can be very complex and that require great theoretical skill. The important thing here is to understand the modelling enough well to be able to explain their behaviour. This of course is extra important in case the results are controversial.

7.4.22 Functional specifications

It is necessary not only to have a functional view on the system but also to have functional formulations in the specifications and to allow the functional view to continue into the contractual agreements. The reason is obvious - one of the key reasons or LCC work is to support Systems Analysis and Systems Analysis will by necessity lead to changes in the design. Hence it is necessary to allow for flexibility and possibilities for changes.

7.5 Factors present in cases

7.5.1 General

In this document we have looked at a number of successful cases. Also we have listed a number of factors considered to be of importance. A question now is, if it is possible by some form of cross-reference to see if some of those factors tend to be more important than others. However a couple of drawbacks with the method used can be noted:

a) Many factors have been listed and some tend to be
   - Overlapping
   - Trivial in its nature (like welltrained team etc)

b) Many of the cases have been using the same methods and tools
c) The author has been involved in several of the cases thus adding a common factor
d) A lot of information is missing in the cases where the author has ***not*** been involved
e) It would have been extremely helpful to have a number of ***not successful*** cases documented as well. It should however be noted that very few people are interested in writing about failed cases

7.5.2 Factors: Low Coverage Radar

Practically all factors were present.

Some comments:

a) Although the requirements within the availability performance area were not special, quite some effort went into studies of their possible feasibility and cost impact. This was beneficial to the project in several ways not least on the team capability and good preparation area
b) Since this was a pilot project some of the tools were developed directly within the project work hence contributing again to a capable team and good preparations with good understanding of the methods and tools
c) The tenderer attitude was mixed which can be expected since the method was fairly new although some contractors had faced similar principles in earlier acquisitions with the same customer. Some of the new tenderers however were sceptical although the hard competition ensured that data were delivered. Also the comprehensive and detailed presentation of each

tenderers result to him made certain that the tenderers were not in doubt of the teams capability

7.5.3 Factors: Oslo Air Traffic Control Centre

All factors were present.

Some comments:

a) Special requirements

Probably the presence of two special requirements were crucial for the success of the LCC acquisition

- o Very difficult and critical Availability Performance requirements
- o Interesting Logistics Support challenges

The presence of the first point of course is no surprise due to the nature of the project. The requirements however were strengthened since the air coverage for all of Southern Norway was concentrated into one site (instead of three which was the less critical alternative). The logistics challenge to ensure the availability for a very complex site also contributed to make the project special.

b) Trade habits

It became apparent that the trade habit of having contractor workshop repair of all electronic items was not really cost effective. Hence considerable improvements could be made by challenging the standard Logistics Support habits.

7.5.4 Rapid Trains

All factors were present although with some question mark related to

- o Management support
- o Tenderer management attitude
- o Trade habits

The customers upper management was not entirely clear in their support to the LCC approach which to some degree sent ambiguous signals to the tenderers. This was amplified by the trade habits - at the time of the acquisition the LCC approach was fairly new within the rolling stock area. The winning tenderer however identified the LCC tool in the ever ongoing competition and decided to change attitude and put effort into the work.

7.5.5 Aircraft 39 Gripen

Again basically all factors were present although with the following comments:

a) It can be argued how hard the competition was since this type of super-large projects may diminish the real competition. In terms of LCC work however this possible situation effectively was eliminated by the winning contractors identification of a low LCC figure as a very important sales argument in other future tenderers. Consequently he was very positive to the LCC activities and requirements.

b) Tenderer management attitude was mixed. The winning tenderer had a positive view but some tenderers were fairly negative to data deliveries. A reason for a tenderer to resist LCC activities can be seen here. It may be of interest not to reveal the cost for various resources until the major contract is signed. This way it is possible for a tenderer to quote a low equipment price and then later on charge heavily for various resources e.g. test equipment.

This could have been a reason for some tenderers to be negative. The important thing however is that at least one good tenderer has a positive attitude

7.5.6 Offshore Equipment

Most of the factors were present. Some comments can be made:

a) Special requirements.
The decision had been taken to co-ordinate the acquisition for 5 fields thus creating a large acquisition that really made the competition fierce.
Furthermore the requirements were functional which turned out to be important

b) Trade habits
The LCC approach was totally new on this type of equipment and as a consequence there were difficulties in achieving data. The existing data and estimates however were sufficient for achieving very large improvements.
As a summarising comment however this acquisition would not have been successful if the competition had not been so fierce and the team factors so favourable. See also [Wåå 94.3].

7.5.7 Offshore Process Control Equipment

Since this study was a Master's Thesis and not a real world acquisition a comparison with other projects is difficult. It is however interesting to note that the teams effort led to interesting results and that those results clearly illustrated possibilities for improvements.

Some comments:

- Master's Thesis frequently produce good results (more commented upon below)
- Data were available
- An advanced computer tool for Logistics Support and Spares Optimisation was available (OPUS10)
- The assistance from an experienced consultant was available

These factors for a basis for production of good results but they do not warrant the implementation of the results. In order to get the results implemented internal support and/or management support is necessary.

7.5.7.1 Master's Thesis

Master's Thesis frequently produce good results that pinpoint considerable improvements for the following reasons:

a) The students allocate considerable and concentrated time to the effort - they do not have to split so much between various tasks.
b) The students are not biased on how certain problems should be solved.
c) The students can easily apply computers and computerised tools.

On the negative side it can be noted difficulties to implement the findings since

a) The findings and their presentation can be regarded as theoretical
b) The students have a tendency to believe what they are told.

7.5.8 Viggen Aircraft Engine

Although this was not an acquisition most relevant factors were fulfilled. The lack of competition was more than well compensated for by other motifs for the contractor to be co-operative. In fact he took a very active role in the study not only as a source for data.

7.5.9 RAF comparison/other spares cases

When using an optimising computer program to compare with other results the huge improvement is more or less unavoidable. It is like digging gold in the National Banks gold reserve vault. The following conditions have to be met.

- Data have to be available
- A trained team (could of course be 1-person team) must be available
- Access to an optimising computer program must be ensured
- Implementation support

7.5.10 Scania trucks

Although the author has not been involved more closely in this case it seems as if most of the positive factors are fulfilled although in a modified interpretation.

- A welltrained and dedicated team (Agrees, but probably there is a lot to gain by using LCC/LSA/Spares Optimisation methods)
- Fairly large acquisition. (Although it is not an acquisition it is a development of enormous impact for the company. It must not fail)
- Presence of a consultant with previous experience from LCC. No consultants were involved in this function. However capability and continuity were provided for in other ways
- Support from management (agrees)
- Support from and good co-operation with other functions (like program management, purchase etc) (agrees)
- Heavy competition which made the tenderers co-operative. The external competition is such that competition always is present
- Good preparations making the mandatory time squeeze acceptable (agrees)
- Date were made available. Although data are available they are not utilised to full extent.

7.5.11 The Aitik Enrichment Plant

This case is difficult to compare with the others. Also the author has little information about the work. Some comments can be made:

- Presence of a dedicated person that never lost sight of the target - to make improvements
- The competition is heavy and since the Aitik has a low grade or, the production cost is extremely important

7.5.12 Vacuum Pump

No background information is available to the author at this stage.
It seems however as most of the factors were available although it is the authors estimate that limited analytical effort was used.

7.5.13 SKF use of TPM

Although the author has very little background information it seems like that:

- There is a welltrained and dedicated team
- The team has been assisted by the group from CTH University of Technology (can be regarded as consultants in this function)
- Support from management

8. WHY ARE THE SYSTEMS ORIENTED METHODS NOT USED MORE?

8.1 Background

A relevant question is ”If those system oriented methods (LCC, LSA, Spares Optimisation) are so efficient, why are they not used more”.

In Sweden the use of those system oriented methods (pre-dominantly LCC) are as follows:

- Within the Swedish Defence (in particular Air Materiel Department and Army Materiel Department -less within the Navy Materiel Department) all those methods are used regularly and in principle on all projects of a reasonable size.
  Also the Defence Authorities run training courses within this area for its personal (and for ”outsiders” as well - e.g. contractors to the Authorities). As a consequence of the Defence Authority’s use of system oriented methods the defence industries are also knowledgeable about those methods and use them extensively. As an example can be mentioned how the JAS aircraft is marketed. The low life-cycle cost for the JAS aircraft is given a prominent role in the marketing - and rightly so.
- Also, the methods (although more LCC and less LSA and spares optimisation) are used within the Swedish State Railways and the Swedish State Power Board.
- The methods also have been used within the Stockholm Local Traffic (SL) in the recent acquisition of new subway trains.
- However, the methods have found little use within the bulk of the Swedish industry.

Below some reasons for this have been collected and commented upon.

8.2 Lack of Knowledge

In spite of considerable effort in training a deep lack of knowledge exists within the industrial maintenance and logistic support society with regard to LCC, LSA and Spares Optimisation. This is both true with regard to the effectiveness of the methods and how they should be applied within the business at hand.

8.3 The Logistics Managers

The maintenance and logistics managers within Swedish industry tend to be practical oriented men (very few women). We are talking about men of action rather than analysis oriented men. The typical logistics manager has risen through the ranks partly due to his ability as a manager partly due to his ability to handle maintenance and support as a sort of fire fighting activity. In short he is a man you like to see on your side when the ”going gets tough”.

The analogy with fire fighting is interesting. The early analysis (on a drawing level) of buildings and other infrastructure projects performed by representatives of the fire fighting authority is far less glamorous than the actual fire fighting. However, it is far more effective. The attitude to ***prevent*** fires rather than fight fires should apply to maintenance and logistics as well. The consequence for logistics managers is that they have to add more theoretical skill to their teams. They have to add personnel that can perform advanced analysis and optimisation - and to transfer the results into clear recommendations. In the long run it may lead to a new type of logistics managers. In short terms one might expect that a number of managers just will strengthen their teams to be stronger on the theoretical side.

8.4 Lack of Trust in the Methods

The theoretical nature of some of the problems involved in the execution of the system methods may cause some problems. As an example the mathematics behind the computer programs for spares optimisation is very advanced. It is difficult to understand even for a person with a masters degree in Engineering. It is difficult to rely 100% on a method that you do not fully understand.

8.5 Lack of Long Term Thinking

We have previously touched up the problem that arise due to lack of long term thinking. It is difficult for a person to put effort into an activity that costs money today in case future savings are not valued. The constant push for shorter and shorter time horizon works in a different direction.

8.6 The need for future improvements has not been identified

It is very easy for the organisation to concentrate on today's problem and not look ahead. The improvements made on the Scania trucks (para 6.1) however are very clear. In case those improvements had not been made Scania would be in trouble - the annual maintenance and support simply would have been too expensive and they would have lost a lot of their customers.

8.7 Need of Data

The methods like LCC, LSA and spares optimisation require input data and those data are not necessarily available. In such cases the normal mistake to stop the investigation either permanently or while waiting for data to be developed. The reason why this is a mistake has been commented upon (see para 2.5 and 4.1.3).

The best way forward is to use the data available and in the meantime start the long term work to build up a database for future needs. See also [Wåå 98].

8.8 Mistakes might be discovered

Spares optimisation is a very sensitive method to display earlier mistakes. It is only human to try to avoid those mistakes to be found out. It is however important both to be able to decrease an effect of those mistakes and to prevent new ones.

8.9 Lack of design improvement opportunities

In many cases the use of LCC oriented methods is limited since standard equipment is being used. Thus it is not possible for a customer to change the design of a tenderers item

9. ACTIONS TO IMPROVE THE SITUATION

9.1 General

It has been shown in the previous chapters that

a) Very efficient methods exist for large improvements within the area of Logistics Support and Maintenance. The improvement are surprisingly large both in terms of Availability increase and cost decrease.
b) The use of those methods tend to be - although with notable exceptions - limited to defence projects.

The actions to be taken are simple in theory - and perhaps a little more difficult in practise. Anyhow:
o Try to create a situation where as many as possible of the positive factors exist
o Try to avoid as many as possible of the negative factors

9.2 Better information

Different organisations can be regarded as being on various stair steps in terms of the methods they apply. (Slightly modified from ref [Fra 93].

Step 1: Break-down oriented work (Fix it when it has broken).
Step 2: Going from corrective maintenance to preventive maintenance. (This also includes improvements in the ***administration*** of the maintenance and logistics support - Maintenance Management Systems.)
Step 3: Integrated approach. TPM
Step 4: Analysis and improvement oriented methods
Step 5: Availability oriented methods. Optimisation

The LCC/LSA/Spare Optimisation methods will be found on steps 4 and 5.

A drawback with this way of viewing the use of various methods is that it

a) Creates a view where some methods are regarded as being inferiors to others
b) Creates a view that only one method at the time is applicable

Those aspects will be commented upon in the next chapter and in particular the relation between TPM and LCC/LSA/Spares Optimisation.

An ***advantage*** with this way of viewing various methods however is the understanding of need for information and training in the application of the various methods as well as understanding the need for assistance and computer tools.

With this later way of viewing it is possible to understand that

a) There is a competition on funding for computer tools between the administrative programs needed for more effective maintenance and logistics support work - e.g. for preventive maintenance and analysis tools.
In such cases it is easier to get approval for the administrative programs since it is a more direct task to explain the benefit with those.

b) There is a fierce competition for the scarce times available within the maintenance and support organisations. Here the need for training in the use of the administrative programs compete with methods for introducing TPM on one hand and LCC/LSA/Spares Optimisation on the other.
When introducing the LCC/LSA/Spares Optimisation methods the existence of those competing methods has to be recognised.

9.3 TPM versus LCC/LSA/Spares Optimisation

TPM has shown itself to be a very efficient method for improvements. It has been developed and carefully improved and implemented over the years by JIPE (Japanese Institute for Plant Maintenance). It can shortly be described as getting the operators into the maintenance and logistics support work. See ref [Nak 84].

The nature of the method is such that the improvements are made on operation and maintenance of ***existing*** equipment.

The nature of the LCC/LSA/Spares Optimisation is such that the improvements are made ***before ending the design*** of the equipment.

- o The TPM work is not prevented by the fact that the equipment has been analysed to be well suited for operation maintenance and support, that the maintenance and logistics support has been well adapted to its purpose and that the spares assortment and allocation has been optimised
- o The LCC/LSA Spares Optimisation work can only benefit from a situation where the equipment and its maintenance (logistics support organisation is handled by motivated people turned to co-operation and improvement).

9.4 New trends

A trend that will have a significant impact on the wider use of LCC/LSA/Spares Optimisation methods is the increasing use of leasing equipment rather than buying them. The customers concentrate on his own core business and leaving the maintenance and logistics support to the equipment manufacturer ”Pay by operating hour”, ”Pay by drilling meter” etc.

This means that there is a much more visible bonus for equipment manufacturers to supply reliable equipment giving high operational availability and low operating cost as well as maintenance and logistics support cost. Those costs now becomes real.

List of References

In order to make this list easy to use, the following technique is being used.
This List of References is split into 2 parts. Part 1 contains direct references to quotes etc. Part 2 contains a listing of a couple of text books for the reader that like to dig a little deeper.

Part 1

a) The author(s) name(s) is/are used in the abbreviation.
Example: A paper written by Akselsson and Burström published in 1994 is abbreviated as [AkB94].

b) The references are listed alphabetically in accordance with this abbreviation independent upon from where in the report the reference was made.

A number of Swedish references have been included. The author apologised to the non-Swedish readers but it would in this case not be of benefit to exclude a number of very useful references. After all, a number of readers will be Swedish.

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(an award winning paper - and rightly so)

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Part 2. Some textbooks

A vast amount of books are available particularily within the Reliability area. Only a very small selection has been made.

a) ”The Blanchard library”

Professor Benjamin S Blanchard has a long experience both as a practitioner from industry and from the academic life.

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O'Connor Patrick D.T. Practical Reliability Engineering. 3rd edition 1991. John Wiley and Sons.

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