Making cost effective decisions in early program phases despite lack of data – an analytical approach

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ABSTRACT

Procurement and ownership of advanced technical systems such as aircraft are associated with large investment costs, high complexity and operations and maintenance costs that often are several times larger than the up-front investment over the life cycle of the system.

It is well known that early decisions regarding concepts, requirements and choice of suppliers will have a decisive impact on the Total Ownership Cost. The challenge is that these critical decisions are made in the early phases when there is little exact knowledge about the future system as well as many other influencing parameters. To make such decisions despite these major uncertainties calls for an efficient and systematic decision making process. One must make best use of available information to analyse, understand and predict the consequences of a decision on capabilities, performance and cost. The use of modelling and simulation for front end analyses is a powerful way to estimate these consequences.

There are different ways to handle uncertainty and lack of data depending on what stage in the life cycle you are and what your decision is about. This paper describes approaches and methods to support project specific decisions in early stages with almost no specific data available for the technical system. The following will be discussed:

- Generating a model of the technical system from high level information
- Grouping engineering estimates in a logarithmic matrix
- Use of a reference system
- Prediction of data based on inherited operations
- Identification and management of uncertainties in input data

These methods have been proven to support decisions such as:

- Which system alternative is most cost-effective?
- Which logistic support concept will be most cost effective?
- Which requirements on availability performance and life cycle cost for the technical system are feasible?
- What key performance parameters should be used in a performance based support agreement?
- What should my budget be from a Total Ownership Cost (TOC) perspective?

In this paper, we will show that the inaccuracy in results caused by imprecise or approximated data is surprisingly small. The value of qualified decision support early on, far outweighs the drawbacks of minor inaccuracies. Hence, ”Garbage in – Garbage out” is a very poor excuse for delaying various forms of logistics oriented analyses.

ABOUT THE AUTHORS

Mr. Robert Hell is the Managing Director of Systecon and board member of the Swedish Security and Defense Industry Association. Systecon is a leading logistic support consulting company and the company behind the OPUS Suite™ – the logistics support optimization software which is used by defense forces and defense industry leaders worldwide. Before joining Systecon in 2003, Mr. Hell has a long history within the Swedish Defense Materiel Administration (FMV), where he last had the position of Chief Engineer Integrated Logistic Support. Earlier titles at FMV include Head of the Aircraft Logistics Division, with responsibility for Integrated Logistic Support for all aircraft programs (both fixed wings and helicopters) in the Swedish Defense. Before that, he was manager for the LSA/LCC-specialists. Mr. Hell has extensive experience from Logistics Engineering and Life Cycle Costing Air Force projects, including the JAS 39 Gripen program. Mr. Robert Hell holds a M.Sc. in Mechanical Engineering from the University of Linköping, Sweden, with a specialization in Quality and Maintenance Engineering.

Mr. Thomas Olinger is consulting in logistic support, with Systecon since 2009 he has worked on projects focusing on availability performance and life cycle cost for defense systems. Currently, he holds the position of ILS manager at Swedish Defense Materiel Administration, FMV, in the joint Swedish Norwegian procurement project for heavy trucks. Previously employed by FMV between 2001 and 2009 where he worked on a range of projects, the most notable projects are the Swedish Combat Vehicle 90 project, the light tactical vehicle RG32 Galten and Fenix, the Swedish Air Force's Maintenance Management System. Mr. Olinger holds a M.Sc. in material science from the Royal School of Technology in Stockholm. He was cowriter on the white paper "Simulation as support for decision making in negotiations" presented at the 14th Annual Systems Engineering Conference organized by NDIA.

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INTRODUCTION

Procurement and ownership of advanced technical systems such as aircraft, trains and energy production plants is associated with huge investment costs, high complexity and substantial costs for operations and maintenance over the whole life cycle of the system.

It is well known that early decisions regarding concepts, requirements and choice of supplier will impact the Total Ownership Cost (TOC) more than anything else. Unfortunately these decisions need to be made without exact knowledge about all influencing parameters. To make these kind of decisions under major uncertainties calls for an efficient and systematic decision making process, using modelling and simulation tools to analyse the consequences of the decisions

This paper discusses opportunities to make project specific decisions in early stages with almost no specific data available for the technical system.

LIFE CYCLE MANAGEMENT IN EARLY CONCEPTUAL PHASES

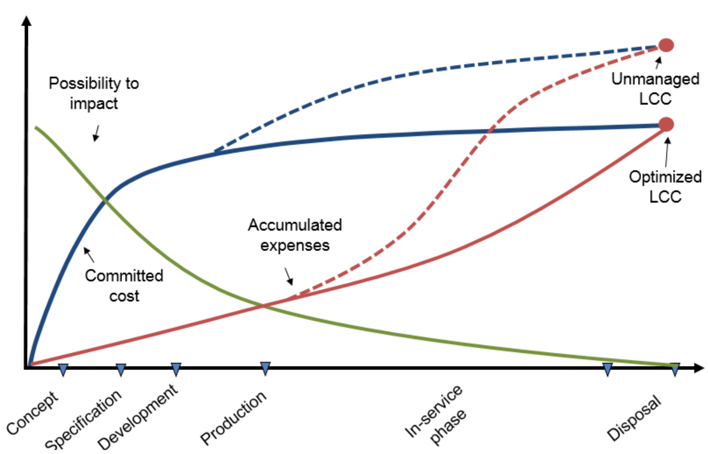

Figure 1 LCM help to control future expenses and minimize Life Cycle Cost. The committed costs are the sum of all future costs that have been committed through the decisions made.

Life Cycle Management (LCM) is a method to manage the system towards fulfilling the operational needs at the lowest Life Cycle Cost (LCC). Finding methods of understanding and controlling cost driving factors while maintaining or increasing system performance is essential.

Any system typically goes through a number of phases starting with concept definition, specification and acquisition, continuing with system design and development, production, entry to service, operations and maintenance and finally disposal. All through the life cycle executive managers need to make a lot of decisions regarding the technical system, its operations and maintenance and the logistic support. The important point here is that consequences of decisions made will not come in daylight until many years after a decision is made. That is the background to the LCC curve below.

The red curve shows the actual expenditures for a system throughout its life cycle. The blue curve however, describes when in time the decisions made lead to a committed future life cycle cost, which usually occur long before the actual expenditures. Thus the possibility to influence the life cycle cost will decrease during the system´s life cycle according to the green curve.

It is also important to point out that decisions made in later phases without analysing the potential consequences on operational performance and life cycle cost, have a great risk of committing to higher life cycle cost.

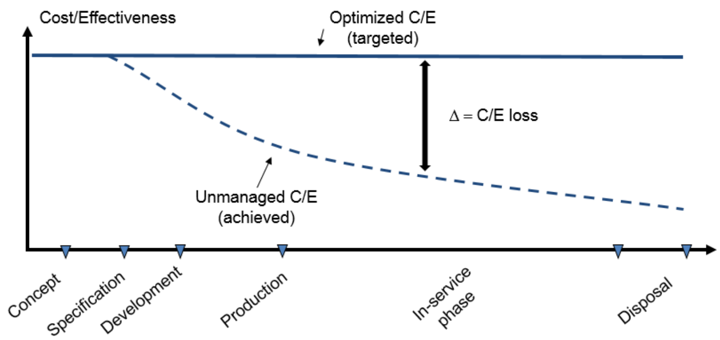

Figure 2 LCM can help to control cost-effectiveness balance of a system over its life cycle.

Not only can unsubstantiated decisions lead to increase in life cycle cost, but also decrease the system's effectiveness, see Figure 2. A well-managed system stays on a targeted (or acceptable) cost-effectiveness level but unmanaged it risks being sub-optimized with costs running out of control while effectiveness [1]is on the decline.

To avoid a sub-optimized system it is important to determine the prerequisites for the logistic support very early, especially requirements on availability performance and life cycle costs. Trade-off analyses must be carried out in order to find the most cost effective balance between the technical system and the logistic support system in order to fulfill the operational performance needs. In other words, how much should be invested in the reliability and maintainability of the technical system and how much should be invested in procurement of logistic support resources to support the system?

By performing early analysis regarding life cycle cost and effectiveness, funding needs can be established for the logistic support resources to maintain the targeted system effectiveness.

Actively working with LCM in early stages

So, what can be done?

To find acceptable levels for life cycle cost and effectiveness, models of the system need to be built and analyzed. To build the model information, three very distinct building blocks are needed, see Figure 3.

Each building block is complex to describe, and changes in one block, for instance a new usage profile, will often create a need for adjustments in the other blocks in order to find acceptable levels for life cycle cost and effectiveness.

In the early phases this can look very cumbersome to perform, and the common perception is that the information needed is not available. This is actually not true. What is not actually available is detailed information regarding the actual technical system. Generally, alternative solutions for the support organization together with rough estimates on the intended usage is available. That means that two of the building blocks are in place. To be able to complete the model information regarding the technical system is also needed.

[1] Measures of effectiveness (MoE) typically are operational system availability, expected number of systems not operational ready, risk of item shortage and mean waiting time. Many other MoE can be of interest.

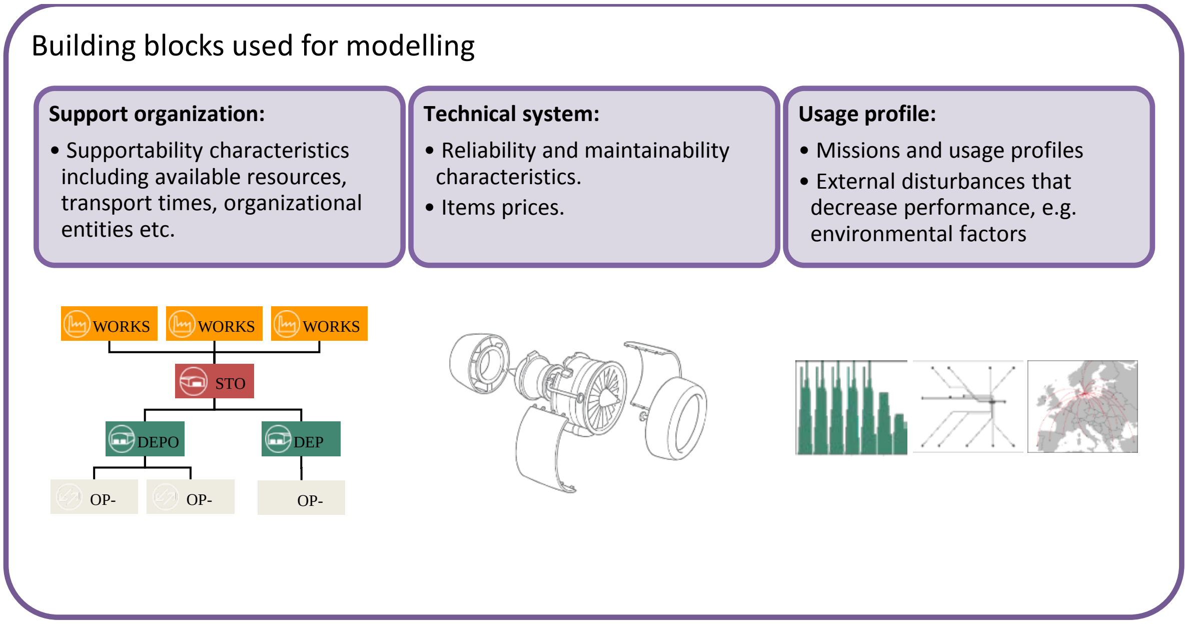

Figure 3 Building blocks for modelling cost-effectivenss and life cycle cost.

Generating data for the technical system

The technical system usually proves to be the most difficult to get reliable data for. Either it has not yet been designed or methods for gathering data are not working properly. Depending on the phase in the system's life cycle there are alternative ways to produce or obtain information about the technical system good enough to make comparative analysis of sorts, find support solutions which are cost driving, and assess requirements on reliability, supportability and maintainability of the technical system, see Figure 4.

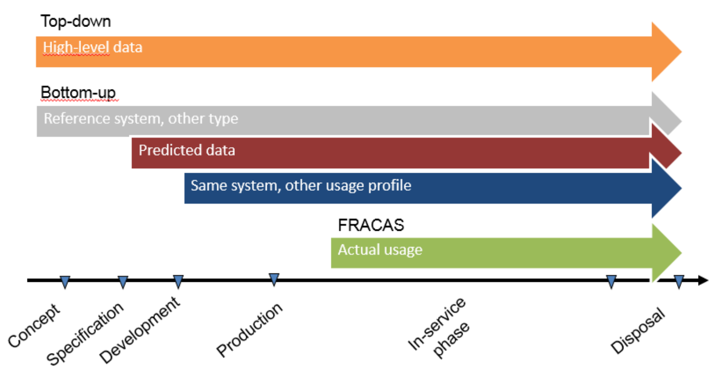

Figure 4 Different sources of information. In principle, the degree of maturity of information grows from left to right. In the early stages of a project the analyses performed must rely on created data or reference system(s), later on actual usage

The first method is a top-down approach to emulate the unknown system by generating a representative set of sub-items. This is based on high level estimates of the number of sub-items, the total price of the system and the total failure rate. From this information a representative data set can be drawn using the lognormal distribution. This method has been implemented in OPUS10, the tool that has been used for analyses in this paper. The greatest advantages of the top-down approach is that the method is extremely fast, effortless, and that it does not require much information. Yet it provides good enough results to answer many of the strategic high level questions one may have early in projects.

The second method uses a bottom-up approach using best engineering judgments for the unknown system together with whatever data is available from reference systems or theoretical data. This method will provide a model that answers the same questions as the top-down method, but has the advantage that it can also be indicative on lower levels, such as individual items provisioning requirements. The drawback is that it takes time to generate detailed data due to the labor intensive process of assessing each individual item.

These two methods can also be used in combination.

If actual usage data from a reference system is available it can be used as the starting point in any of the above mentioned methods. However, some caution is required when using real data from other systems. Reliability data is true for the environment in which it has operated and the operational profile. Scaling to fit the system in focus may be necessary.

Method 1: Top-down, generated data

As mentioned above, OPUS10 provides a feature for creating detailed item data for a fictive system based on high-level information about the system. In addition some basic information is also necessary to be able to run OPUS10. To obtain the high-level information experiences from some reference system, or expectations of the new system may be used.

To validate the method described we have compared the cost effectiveness of a real system with four different OPUS10 generated fictive systems. In this example the following high-level information from the real system is used to generate the fictive systems;

- total failure rate
- total price
- number of items and how many of each type there are, discardable units or repairable units

The **real** technical system is consisting of 989 different items, of which 634 are discardable units and 355 are repairable units (Line Replaceble Units, LRU:s). The total unit price is $ 18 million. The total failure rate of about 1 failures per 10 hours of operation. Other maintenance data, the support organization and operation profile is known. Figure 5 shows a scatter diagram of the distribution of failure rates and prices for the 989 items and the corresponding cost effectiveness curve in OPUS10.

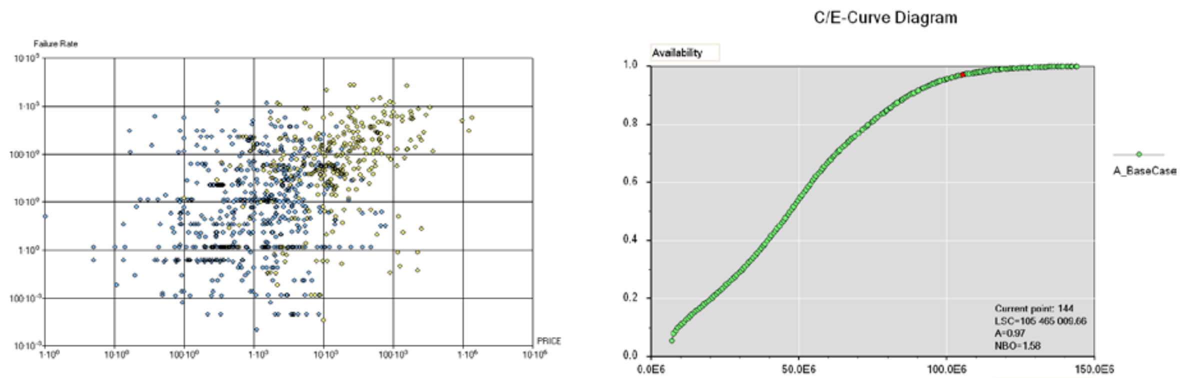

Figure 5 A real technical system. Distribution of prices and failure rates for all items and the corresponding cost-effectiveness curve (C/E-curve) from an optimization in OPUS10.

The high-level information is input into OPUS10 together with some control parameters around the probability distributions, as shown in Figure 6.

Based on different values for the ratio between the standard deviation for price and the mean price, likewise for the failure rates and the logarithmic correlation between price and failure rate, four different fictive systems with the same total failure rate and price are generated.

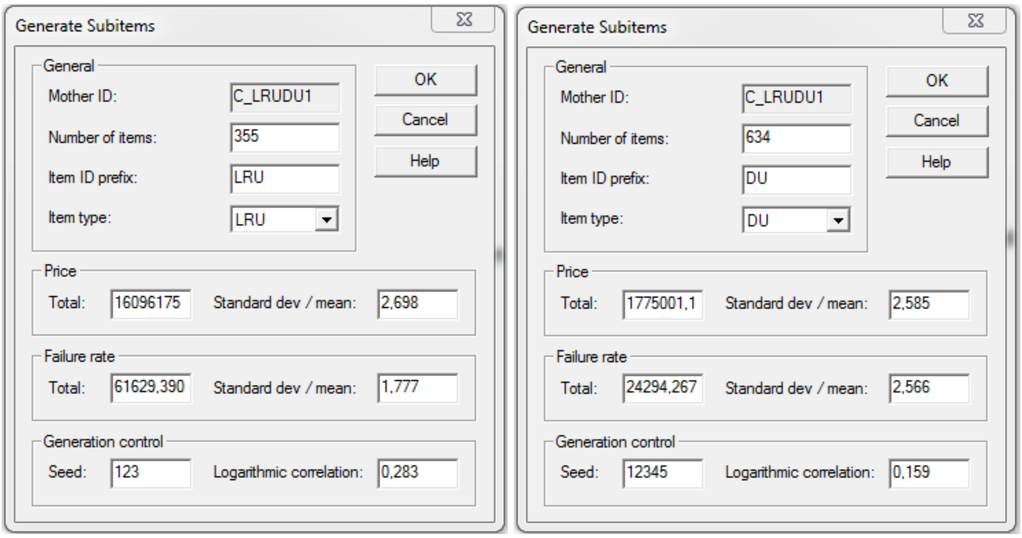

Figure 6 In OPUS10, creating the LRU:s and DU:s of a fictive system generated by high level information.

A comparison between the real system and the four different generated systems give the following C/E-curves, see Figure 7.

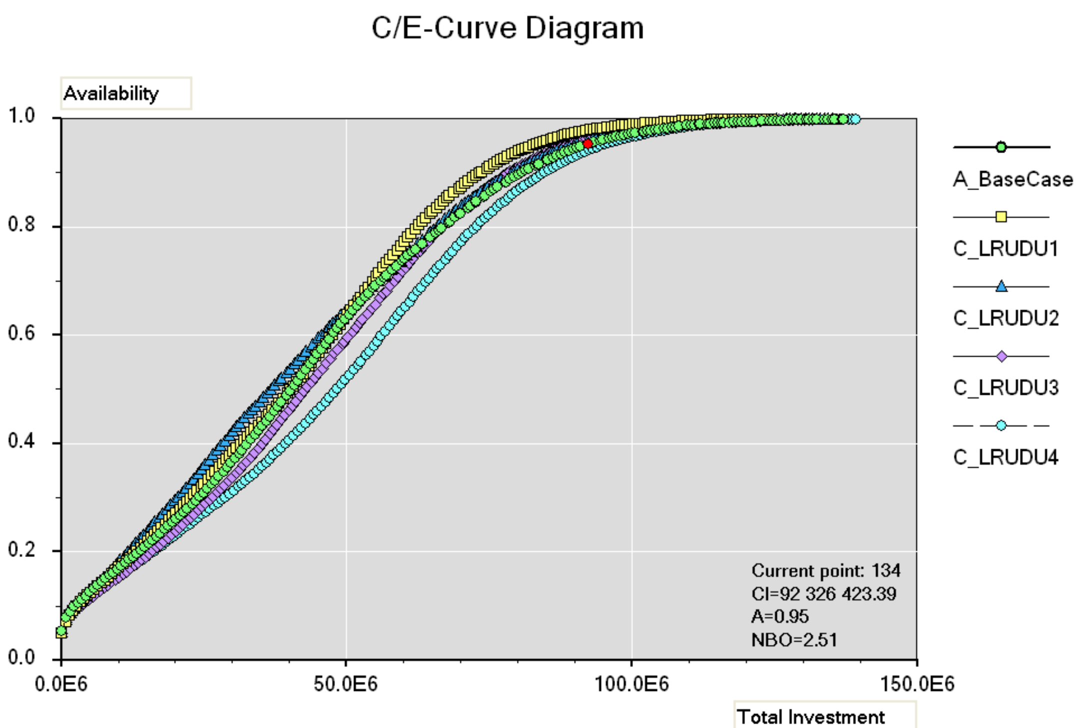

Figure 7 Real system compared to four generated systems.

The C/E-curves show the same characteristics with small deviations in result. Since the deviations are so small it shows that the method is good enough to study big picture issues regarding support solutions, requirements assessments, LCC budgets etc. Studies have also shown that this method will provide better accuracy when the number of items in the system is increased.

Method 2: Bottom-up, best engineering judgment

The rationale behind the method is to gather information from all available sources with known information pertaining to the system in focus. That is, using reference systems, reliability prediction and best engineering judgments to assess each individual item (or assembly) of a technical system.

For items with known characteristics regarding failure rate and price (and repair times) this data should be used in the model. For items where this is not the case, the engineers have to estimate this data. It may prove too difficult to have the engineers make estimates on exact figures, and the uncertainties in such estimates would also be big. It is much easier to have them to place their estimates in an interval, e.g. a failure rate between 30 and 100 failures per million hours. The same applies to item prices.

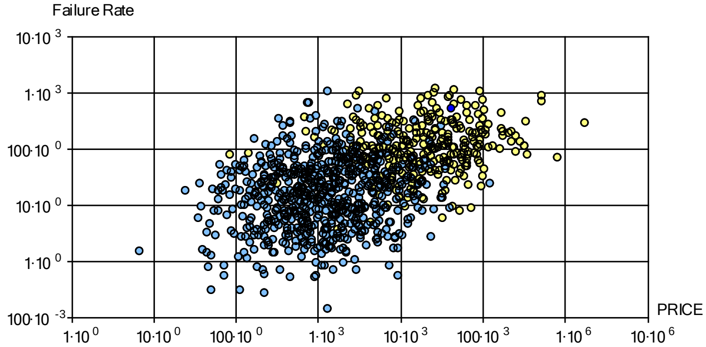

Figure 8 Real system: Scatter diagram with real prices and failure rates.

For many systems a lognormal distribution of failure rates and prices is true, or at least, gives a good approximation. The use of logarithmic scales then makes sense to use for defining intervals for your engineering estimates. Our studies have also shown that using the geometrical mean gives more true results than using a rectangular mean or average of min and max in the intervals when grouping the items placed in intervals.

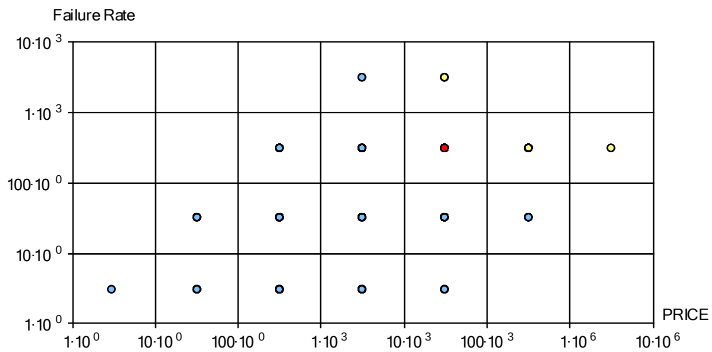

Figure 9 Scatter diagram, intervals 1-10-100 etc. used on real system data and then calculated as the geometrical logarithmic mean value for both price and failure rate.

Using the grouping method is appropriate when a little bit more is known about the technical system and the product breakdown structure starts to take shape, but detailed data such as prices, failure rates and repair times are not readily available.

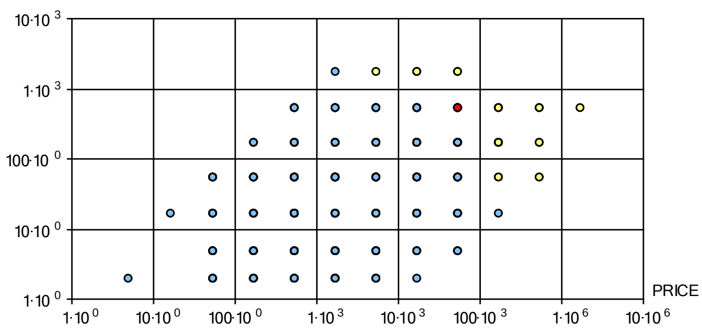

Figure 10 Scatter diagram, intervals 1-3-10-30-100 etc. used on real system data and then calculated as the geometrical logarithmic mean value for both price and failure rate.

In Figure 8 the real system data is used. Figure 9 and Figure 10 simulates engineering judgments by placing the items in Figure 8 into intervals according to 1-10-100 and 1-3-10-30-100 etc. Figure 11 shows the corresponding C/E- curves. Examining the curves it becomes evident that the method of using intervals does come close to the real data, close enough for carrying out logistic support analyses and cost estimates in very early stages.

However, the drawback compared to the first method is that it takes much more time and effort to accomplish.

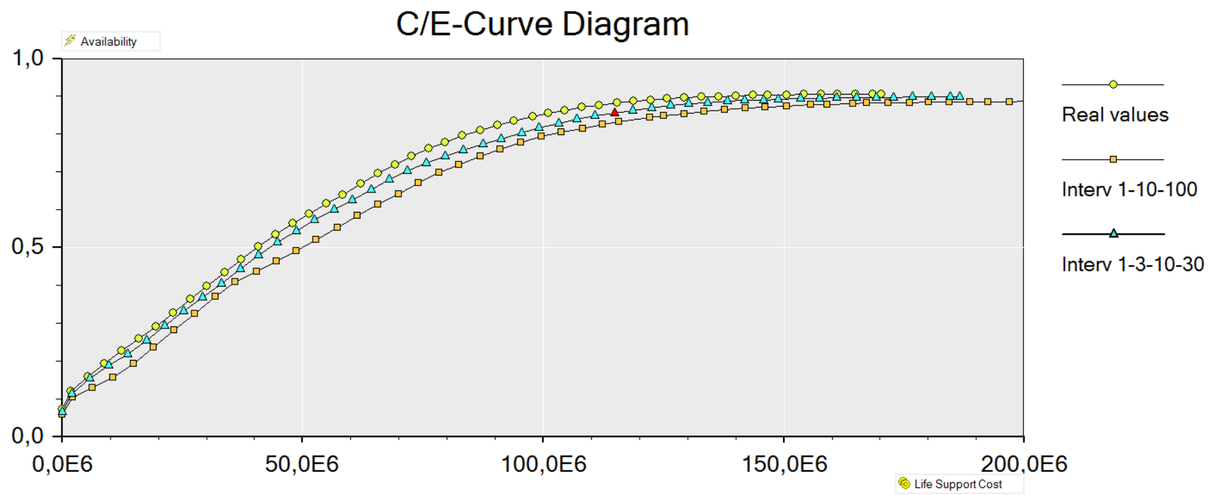

Figure 11 C/E-curve diagram for all three models as described in the scatter diagrams. The narrower interval provides better accuracy, but both are sufficiently accurate.

Managing uncertainties

There are always sources of error and uncertainty in data and since we in this paper focus on the early phases and rough data estimates we can assume that these uncertainties are big. This can be handled by performing sensitivity analyses. The idea is to study the impact of changes to the input data on the analyses results to identify both how big the uncertainties are and what parameters that affect the model most. In this way a decision maker will be able to assess the risk for the project associated with decisions to be made, and also be able to manage the risks early.

One approach to assess whether the model works as intended is to go to the extremes and see how the results will vary, so-called extreme value analysis.

There will also be uncertainties in the overall scenario. Military operations are controlled largely by external events and political decisions. To deal with that kind of uncertainty we need to test different scenarios. One such case could be to study the effects of whether supplies could be transported to the designated operational sites within the desired times or not. Another case could be to test what happens if two workshops be merged, etc.

Operation profiles are also an area of uncertainty. Of course, the analyses should be based on a planned (or required) operational profile, but what happens if the plan is changed in the future? How robust are the results from the analyses?

Understanding uncertainties, what effect they might have, and mitigate these risks are an essential part of the front end analyses.

CONCLUSION

This paper discusses opportunities to make project specific decisions in early stages of a project with almost no specific data available for the technical system. The conclusion is that the inaccuracy generated by inaccurate or approximated data is surprisingly small, in particular when viewed in relation to other uncertainties. Making decisions based on analysis with rough data is far better than guessing. The value of achieving the results early, far outweighs the drawbacks of minor inaccuracies and hence - ”Garbage in – Garbage out” is indeed a very poor excuse for delaying various forms of Logistics oriented analyses.

The methods have proven good enough to support decisions such as:

- Which system alternative is most cost-effective?

- Which logistic support concept will be most cost effective?
- Which requirements on availability performance and life cycle cost for the technical system are feasible?
- What key performance parameters should be used in a performance based support agreement?
- What should my budget be from a Total Ownership Cost perspective?

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