SYSTECON
SYSTEMS AND LOGISTICS ENGINEERING

INTRODUCING OPUS10

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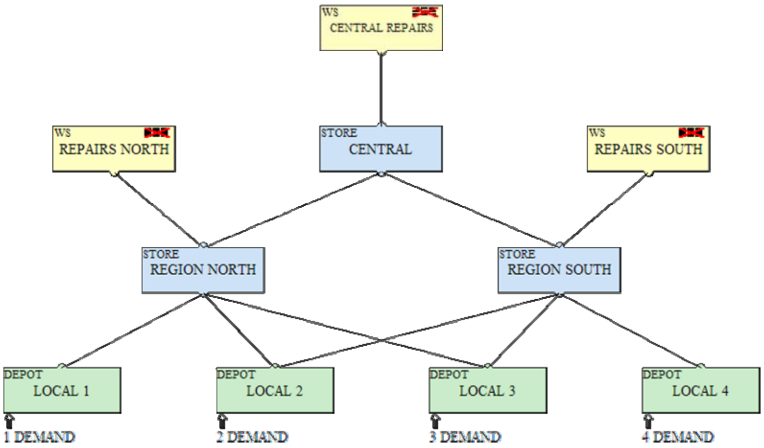
OPUS10 is a software tool for optimizing spare part supply and logistics support solutions. It is an advanced analysis tool providing decision support on a strategic and/or tactical level and is widely used for planning logistics support for technical systems.

This document briefly describes the principles of OPUS10, typical areas of applications, input requirements and results. For a full description, please refer to the OPUS10 User's Reference.

The OPUS10 scenario

Central to the OPUS10 scenario is the logistics support organization. The organization modeled in OPUS10 can include stores, depots, workshops, operational sites, organizational policies and transport links between the sites. Data related to the links between sites are normally in terms of order times, shipping times and ordering policies.



The demand for spares appearing at an operational site generates a flow of materiel in the support structure filling pipelines, modifying stock levels and creating a pattern of backorders and waiting times. The movement of material can include failed or discarded items, replacement spares and corresponding movements resulting from unsuccessful repair at a station or the use of replacement sub items for repair. One single demand therefore may cause a complex mixture of flows and sub flows all controlled by the defined reorder, repair and transport policies.

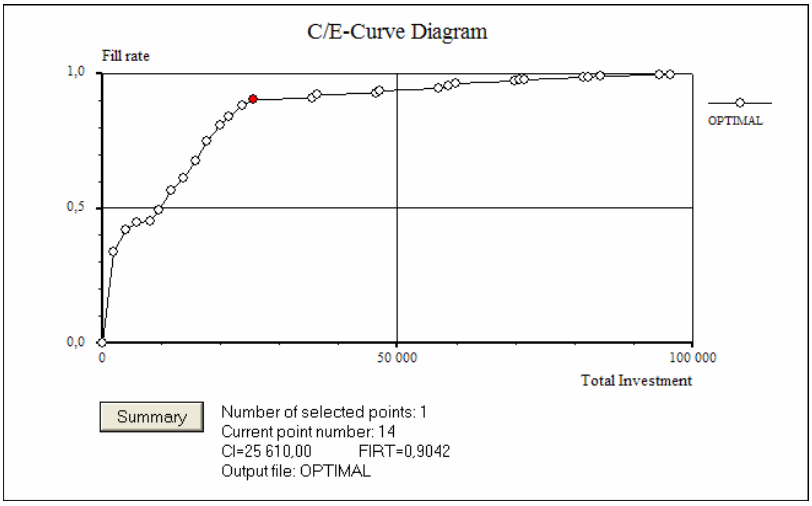
Spares optimization

The optimization of spare part logistics is a core OPUS10 functionality which calculates optimal assortments and allocations of spares from a cost-efficiency perspective.

The output of an OPUS10 spare part analysis contains:

- Stocking policies, reorder points and reorder sizes
- Store locations and capacities
- Transport policies
- Spare part repair/discard strategies

A central element of an OPUS10 optimization is the Cost/Efficiency (C/E) curve. Each point on the curve represent an optimal spares assortment for a given spares investment budget. The overall efficiency resulting from an assortment is shown on the y axis and the associated spares investment cost on the x axis. Each point is thus related to both an efficiency and a cost.



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An ideal situation would be to achieve the highest possible efficiency with no spares investment, which is represented by the upper left corner of the diagram above. However, there is always a price to pay in the form of a larger stock investment for achieving higher efficiency.

The efficiency requirements on the support solution thus determines the size of the needed stock investment. Conversely, budget constraints will limit the maximum achievable efficiency. The figure above illustrates that to achieve an overall fill rate of 90 %, a stock investment of 25 600 is required. If the budget is limited to 10 000, a fill rate of only 50 % can be reached. The user is free to choose among the range of optimal assortments suggested by OPUS10.

A point on the C/E curve contains stocking policies for each store in the support organisation. These policies considered together, is optimal with respect to the overall efficiency of the support organization in fulfilling the demand for spares.

The spares optimization functionality in OPUS10 can be used for demand created by many different types of processes. From the supply chain point of view, the origin or cause of the spares demand is in many cases not relevant.

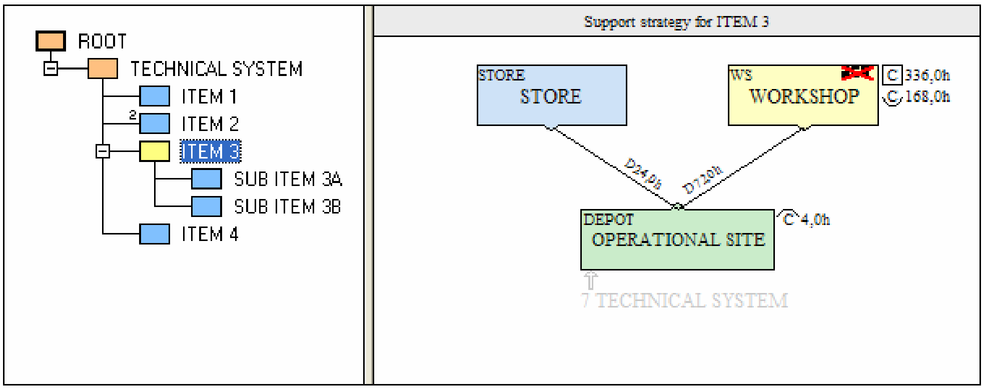
OPUS10 can be used to optimize all types of spare parts. It is particularly suitable for handling expensive slow moving spares and repairable spare parts (rotables). Also spare parts consisting of sub components are handled efficiently.

Logistics support

A key feature in OPUS10 is the option to include operational conditions and maintenance activities in the analysis. Often it is the operation of a technical system and the maintenance performed on it that creates the spares demand.

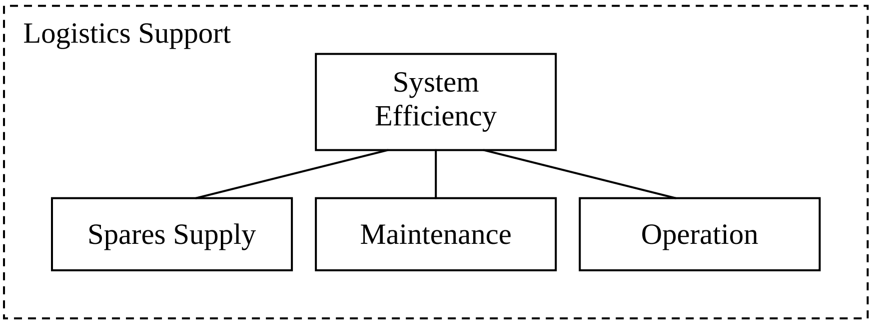
1. Systems and equipment are in operation at a site
2. A system fails or require preventive maintenance
3. The performed maintenance requires spares from the support organization

If data on the operational conditions and the system maintenance is available, OPUS10 is designed to handle the complex interactions between the logistics support organization and the operation and maintenance of the technical system.



The figure above shows a technical system consisting of four primary and two secondary items. Only ITEM 3 can be repaired when failing, all other items are discarded. There are seven systems in operation at one operational site. When ITEM 3 fails, the system is maintained by replacing the ITEM3 at the operational site. If a spare ITEM3 is immediately available at the operational site, the replacement requires four hours. If a spare item is not available, it is requested from the store with a shipping time of 24 hours. The faulty ITEM3 is sent to the workshop where it is repaired in two weeks (336 hours). If the item can be repaired by replacing a sub-item, the repair only requires one week (168 hours). After completed repair, ITEM3 is returned to the operational site for storage.

Considering the whole logistics support picture allows OPUS10 to calculate operational efficiency measures for the technical system. Examples of such measures are system availability performance and system down time. These measures are normally highly dependent on the efficiency of the spares supply solution.



Calculating system efficiency measures of course requires details on the operation of the systems, maintenance breakdown structures, maintenance times, maintenance resources and item criticality.

Areas of applications

OPUS10 is widely used for planning spare part supply and logistics support solutions for technical systems on a strategic and/or tactical level.

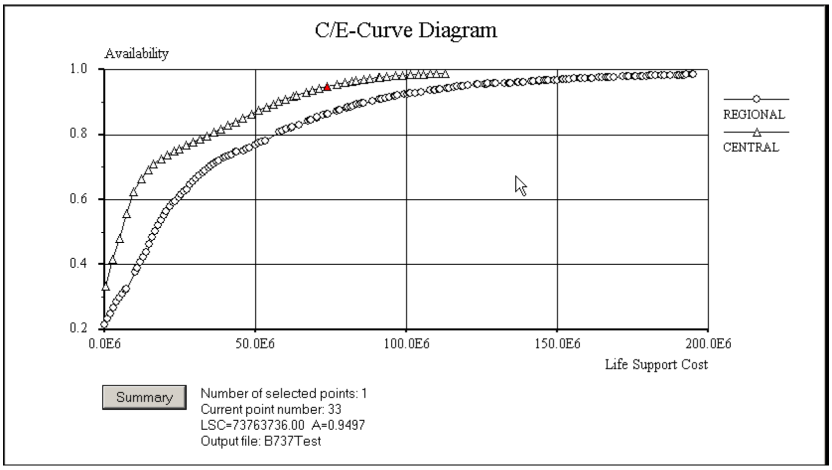
OPUS10 is currently used by 125 customers in 20 countries on five continents. The applications range from airline parts supply to offshore platforms; from military aircraft to high speed trains; from nuclear plants to infantry training equipment. The common denominator within all OPUS10 applications is the tough efficiency and availability requirements, coupled with an extensive and complicated maintenance and support scenario.

Spares optimization

This is a core OPUS10 capability which performs an analytical calculation of the optimal assortment and allocation of spares from a cost-efficiency perspective. Initial sparing as well as optimal re-allocation and/or replenishment of existing spares assortments can be performed. OPUS10 is used to optimize most types of spare parts, but is is particularly suited for handling expensive slow moving spares and repairable spare parts (rotables).

Evaluate alternative support organizations

Comparing different alternatives is easily made in the OPUS10 C/E curve diagram. Each alternative is shown as a separate C/E curve with optimal spares assortments for each alternative. As most significant costs sources are included in the model, a true comparison of the total cost for different alternatives can be done. This makes OPUS10 a very powerful tool for comparing different support organizations. For example, one may compare solutions with central vs. regional warehouse or transportation by truck (longer lead times and therefore more stock) vs. helicopter (more expensive but faster and therefore less stock).



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Evaluate alternative system designs

In the same way as described for “alternative support organizations” above, a comparison is easily made between different system configurations. For example, when choosing between two components performing the same function, is it more economical from a cost perspective to select the expensive component with low failure rate, or a cheap one with a higher failure rate?

LSC analysis – acquisition or design

During acquisition or design of an advanced technical system, a Life Support Cost (LSC) analysis is an important part of the total Life Cycle Cost (LCC) calculation. This may be used during design and development or when comparing different tenderers.

Determine optimal location of repair (LORA XT)
The choice of repair/discard strategies and optimal repair locations is a common problem area within maintenance planning and logistics support. The location of the repair affects the investment in repair resources, lead times and the required stock levels. OPUS10 is the first and only tool to offer *system based <u>location</u> of repair analysis* that is done simultaneously with the spares optimization. This means true optimization of repair locations and that different solutions can be justly compared. Furthermore, OPUS10 can be used to evaluate whether to repair or scrap a certain item on failure

“What-if” and sensitivity analysis of maintenance and supply concepts
OPUS10 makes it very easy to evaluate effects of changes in a scenario. For example, it is possible to evaluate how…

…a new customer or support contract…
…a customer’s minimum stock requirement…
…increasing fleet size with 25%…
…increasing operation with 25%…
…increasing failure rates with 25%…
…reduced lead times…
…reduced repair turn around times…
…lateral support…

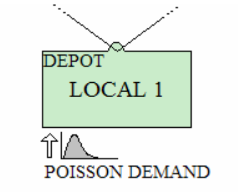
…will affect costs and efficiency of a solution.

How OPUS10 works

OPUS10 contains a mathematical model of the logistics support scenario that has been continously developed for thirty-five years.

Although OPUS10 contains a model of a real world logistics scenario, it is not a *simulation* tool. The mathematical model and all calculations are purely *analytical*. The most important advantage with an analytical model over a simulation model is the speed of calculation. Running a simulation model of a complicated logistics scenario can last for hours while an OPUS10 analysis of the same scenario is completed in only a few seconds.

A key feature in the OPUS10 model is that the spares demand is represented by a probability distribution – the so called *Poisson process*. Another important point is that the model is *stationary* – the demand processes and other conditions do not change over time.



Using a stationary Poisson based model has several important consequences:

- Only the average demand rate is required to describe the distribution.
- The propagation of the demand through the support organization and the complicated dependencies between different stock positions can be determined analytically.
- Supply efficiency and system efficiency measures are easily calculated.

The stationary model implies that OPUS10 does not require any detailed history of the demand processes – only the predicted average demand rate for the period in question is required. The expected demand is typically forecast based on historical demands or from enginering experience.

The most important feature of the analytical OPUS10 model is that the whole support organization with all complex interactions can be treated in one analysis calculation. This fact enables a *true* optimization of the whole support scenario in only one step.

To summarize, the main advantages with the analytical stationary Poisson model used in OPUS10 are:

- Calculation speed
- Analysis/optimization of the complete support organization

The spares demand model

The Poisson demand model used in OPUS10 is described only by the predicted average demand rates for the period in question.

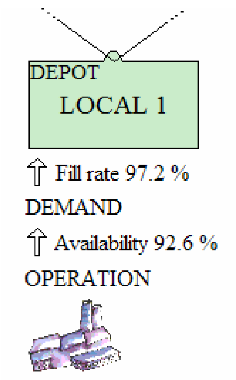
Although only one input value is required for defining the demand for a spare, the demand is not deterministic. The demand processes modeled in OPUS10 is highly stochastic, with the variations incorporated in the variance of the Poisson distribution.

Spares demand generated from preventive maintenance is typically more cyclic in nature. In OPUS10, preventive maintance demand can be treated as a separate demand flow using a Bernoulli distribution with less variance than the Poisson distribution.

In the simplest case, only the total demand rate for a spare at a stock position is required for an OPUS10 calculation. However, if more details of the system operation and reliability is available, OPUS10 can calculate the demand from the whole fleet based on:

- Number of systems deployed (“7 trucks at site A”)
- System utilisation (“12 operational hours per day”)
- Number of components in a system (“4 wheels per truck”)
- Component failure or removal rate (“0,0035 failures per operational hour”)

Supply efficiency and System efficiency



The efficiency of the support solution can be measured in terms related to the spares and the stock positions. Examples of these *supply efficiency* measures are:

- Fill rate; the proportion of the demands that can be satisfied
- Risk of shortage; the proportion of the demands that can not be satisfied
- Waiting time; the time until a demand can be satisfied.

If information about the operating systems is available, OPUS10 can also calculate *system efficiency* measures. Examples of such measures are:

- Operational availability
- Down time
- Number of systems operationally ready

The system efficiency is often highly dependent on the supply efficiency, but also depends on the operational conditions, the reliability of the system and the efficiency of the maintenance solution.

Input requirements

The spare part data required for an OPUS10 analysis are:

- Item identifier or part number
- Item price
- Item demand rate or failure rate

The demand intensity can be given either directly as a demand rate (“3.2 demands per year”) or as as a failure rate (“0.0035 failures per operating hour”). OPUS10 converts failure rates to total demand rates using deployment and operational data.

No data on the demand history is required – only the predicted average demand rate for the period in question. The demand rates input to OPUS10 are often based on historic data, but the prediction or forecasting should be performed with some other tool. Failure rates used in OPUS10 are normally based either on historical data or on engineering estimates.

In addition to the spare part data, OPUS10 requires a definition of the support organization:

- Site definitions; stores, depots, workshops, etc
- Transport times and delay times between the involved sites

The organization data can be given generally or specifically for each item. One item can be supplied from one set of supporting stores, another from a completely different set of stores. Also transportation and lead times can be different between different items.

Finally, for a basic OPUS10 analys, the distribution of the spares demand onto the different sites must be specified. This is done by defining “systems” containing groups or sets of spares. A system can for example be:

- A technical system (i.e. an aircraft) including it’s component spares
- A specific customer and the spares relevant for this customer
- A support contract for a defined set of spares
- Any other grouping of spares relevant for the analysis

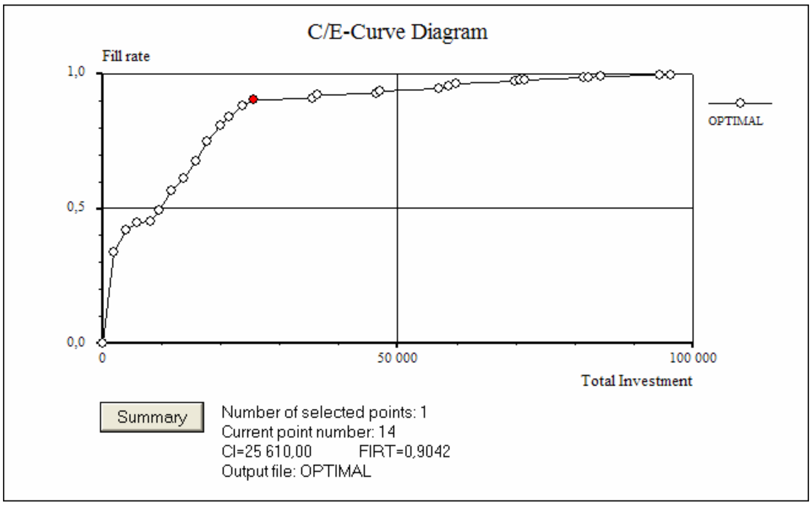
By “deploying” a system to a site in the support organization, the demand from the spares in the system are assigned to the site.

When performing more advanced modelling in OPUS10, typical input data are:

- Maintenance breakdown of the technical system
- Repair locations and repair times
- Preventive maintenance avtivities
- Required maintenance resources
- Storage constraints and restrictions
- Existing stock
- Lateral support

OPUS10 output

A central result of an OPUS10 optimization is the Cost/Efficiency (C/E) curve. This graph summarizes the spares assortments suggested by OPUS10. On the x axis, the cost associated with a particular assortment is shown, typically the spares investment cost, but also storage, transport and repair costs. The y axis shows the overall efficiency of the support organization and/or the technical system resulting from a given spares assortment.



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Current point number: 14
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Output file: OPTIMAL

Each point on the curve represent an optimal spares assortment for a given spares investment budget. The overall efficiency resulting from an assortment is shown on the y axis and the associated spares investment cost on the x axis. The figure above illustrates that to achieve an overall fill rate of 90 %, a stock investment of 25 610 is required. The user is free to choose among the range of optimal assortments suggested by OPUS10, subject to the relevant cost or efficiency constraints.

The spares assortment selected in the C/E curve can be presented as a report table. The table below presents the required stock size of each spare to reach the desired efficiency overall efficiency, but also the optimal *allocation* of spares onto the different storage sites.

`Stock_ItemStation (POINT:  20)`

`STSIZ / Station: Stock allocation`

IID Item identifier	DESCR Description	STSIZ Total per item	STID: Station identifier QTY: Total number of each station						
//////////	//////////	//////////	CENTRAL	REGION N	REGION S	LOCAL 1	LOCAL 2	LOCAL 3	LOCAL 4
			1	1	1	1	1	1	1
ITEM 1	Item 1	0	-						
ITEM 2	Item 2	7	4	1	1			1	
ITEM 3	Item 3	3	2					1	
ITEM 4	Item 4	10	-	3	2	1	1	2	1
SUB ITEM 3A	Sub-Item 3A	3	3	-	-	-	-	-	-
SUB ITEM 3B	Sub-item 3B	3	3	-	-	-	-	-	-

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In addition to the nominal stock size, also other stock policy parameters such as reorder point and reorder size are available, as in the table below.

`Reorder_ItemStation (POINT:  20)`

IID Item identifier	STID Station identifier	STSIZ Stock size	ROPNT Reorder point	ROSIZ Reorder size	TBREO Time between reorders [Days]
ITEM 2	CENTRAL	4	3	1	9,6
ITEM 4	REGION N	3	2	1	23,1
ITEM 4	REGION S	2	1	1	28,9
SUB ITEM 3A	CENTRAL	3	2	1	27,2
SUB ITEM 3B	CENTRAL	3	2	1	21,0

Other reports available in OPUS10 are:

- Cost/Efficiency curve
- Repair volumes
- Reorder volumes
- Cost summary
- Demand rates and resupply times
- Cost and efficiency measures

What OPUS10 is not

OPUS10 is not a simulation tool, it performs calculations according to an analytical mathematical model.

OPUS10 is not used for predicting demand rates from historical data.

OPUS10 is normally not used for ”command and control” type decisions on an operational day-to-day basis.

OPUS10 does not include functionality to administer transactions and material flow during operation.

The mathematics of OPUS10

The OPUS10 tool contains a sophisticated mathematical model of the logistics support scenario. The first version of the OPUS model appeared in 1970, and the model has now been continously extended and improved for thirty-five years into the current model, OPUS10 version 6.

Central in the OPUS model is the *number of units in resupply*, X_k, for the spare k at a given stock position. This quantity is an integer stochastic variable describing the number of outstanding demands at the stock position at any given time.

The probability distribution for X_k is essential for calculating the efficiency measures in OPUS. For example, the *expected number of backorders* for spare k, is defined as

$$\mathrm{NBO}_k(s_k) = \sum_{n=s_k}^{\infty} (n - s_k)\mathrm{P}[X_k = n] = \sum_{n=s_k}^{\infty} (n - s_k) p_{n,k}$$

where s_k is the nominal stock size for spare part k and $p_{n,k}$ is the probability distribution for X_k. If the the number of units in resupply is larger than the nominal stock size at a given time, there are X_k - s_k backorders at this particular time. The expected number of backorders is the object function normally used in an OPUS optimization.

The expected value and the variance of the number of units in resupply can be calculated from the demand rate and the resupply times for the spare at the stock position. An appropriate probability distribution is then fit to these calculated parameters. In OPUS10, the probability distribution for X_k can be one of the following:

- Poisson
- Geometric compound Poisson
- Negative binomial

The idea to use the Poission distribution was first proposed by Craig Sherbrooke in 1968 and is known as the METRIC approximation. The Poisson assumption is very attractive in its capability to decompose even complex support organizations, and the METRIC approach was used in all versions of OPUS from 1970 to 1988.

The METRIC approximation is known to underestimate the number of backorders. In 1985, Stephen Graves at MIT, USA, presented a paper explaining how the benefits of the METRIC approximation could be kept while significantly improving the estimate of the number of backorders. Graves idea was to use a Negative binomial distribution to describe the number of units in resupply. This approximation is often refered to as the VARI-METRIC model and was incorporated in the OPUS model in 1990.

The model for resupply of non-repairable spares (discardables) in OPUS was introduced in 1991. The reorder model is based on a result by Hadley and Whitin in 1963 that approximates the distribution for the number of units in resupply given the lead time, the reorder point and the reorder size at a stock position. This approximation allows fast calculation of the required effieciency measures and enables true optimization of reorder points and reorder sizes.

From the ideas of Sherbrooke, Graves and Hadley-Whitin, the OPUS model has been extended and improved for thirty-five years. The model used today contains the mathemathics to handle:

- Multi-echelon support organizations
- Multi-indenture maintenance breakdowns
- Autonomous operation
- Partially repairable spares
- Lateral support
- Complete location of repair analysis (LORA XT)

Some work on the current OPUS model was published by Patrik Alfredsson in 1997 and 1998.

Calculating measures of efficiency

The key to calculating the efficency measures in OPUS10 is the probability distribution for the number of units in resupply, X_k, for spare k at a stock position.

The most important efficiency measure in OPUS10 is the *expected number of backorders*, which is calculated as

$$\mathrm{NBO}_k(s_k) = \sum_{n=s_k}^{\infty} (n - s_k) p_{n,k}$$

where s_k is the nominal stock size for spare part k and $p_{n,k}$ is the probability distribution for the number of units in resupply, X_k, at the stock position.

Using Little´s formula, the *mean waiting time* for spare k can be calculated from the expected number of backorders as

$$\mathrm{MWT}_k(s_k) = \frac{1}{\lambda_k} \mathrm{NBO}_k(s_k)$$

where λ_k is the demand rate of spare k at the stock position.

Other stock related efficiency measures such as *risk of shortage*, *fill rate* and *service level* are calculated in a similar way.

Calculating system related efficiency measures requires information about the configuration, operation and maintenance of the system. Consider a technical system consisting of K components. Let s be a vector $(s_1, s_2, \ldots, s_K)$ with the number of each component spare in store. The failure rate of the system, λ, is given by the sum of the component failure rates so that the *mean time between failure* for the system can be calculated as:

$$\mathrm{MTBF} = \frac{1}{\lambda} = \frac{1}{\sum_{k=1}^{K} \lambda_k}.$$

The *mean down time* for the system is calculated from a weighted average of the mean waiting time for each component spare as

$$\mathrm{MDT}(s) = \mathrm{MTTR} + \frac{1}{\lambda} \sum_{k=1}^{K} \lambda_k \mathrm{MWT}_k(s_k)$$

where MTTR is the mean time to repair the system. The mean down time thus becomes a function of the stock allocation s.

The *availability performance* for the system as a function of the stock allocation s is easily calculated as

$$A(s) = \frac{\mathrm{MTBF}}{\mathrm{MTBF} + \mathrm{MDT}(s)} = \frac{{}^{1}\!/_{\lambda}}{{}^{1}\!/_{\lambda} + \mathrm{MDT}(s)} = \frac{1}{1 + \lambda \cdot \mathrm{MDT}(s)}$$

where λ is the system failure rate calculated as sum of the component failure rates.

Location of repair analysis (LORA XT)

Finding optimal repair/discard policies and repair locations is a common problem within maintenance planning and logistics support. The location of the repair affects the investment in repair resources, lead times and the required stock levels.

Traditional tools performs Level Of Repair Analyses (LORA) for one item at a time with an approach that assumes symmetrical support structures. The item-by-item approach does not account for the fact that different items normally use the same repair resources. Furthermore, the traditional approach means performing LORA as a separate calculation, not involving the effects of different spares supply solutions. All these factors are closely interdependent and should not be regarded in isolation.

OPUS10 offers system based *Location Of Repair Analysis* that is performed simultaneously with the spares optimization. The LORA XT functionality in OPUS10 does not require a symmetrical support structure. A LORA XT analysis states wether to repair or scrap a certain item on failure and where the repair resources should be located.

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