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SPARE SUPPLY SYSTEM FOR WORLDWIDE TELECOMMUNICATION SYSTEM GLOBALSTAR

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ABSTRACT

This work describes the Optimal Spare Allocator (OSA), a software tool for Globalstar, which is a worldwide satellite telecommunication system designed at QUALCOMM (San Diego, USA). The Globalstar spare supply system is hierarchical and has three levels: Central Spare Stock (CSS), Regional Spare Stocks (RSS) and On-Site Spare Stocks (OSS). The tool allows solving direct and inverse problems of optimal redundancy. The OSA computer model has a user-friendly interface and a convenient reporting utility.

KEYWORDS

Spare allocation, reliability, optimization, cost, software tool, steepest descent algorithm

GENERAL DESCRIPTION OF THE SPARE SUPPORT SYSTEM

We consider a hierarchical spare supply system for satellite telecommunication system, the Globalstar. Globalstar is expected to have a number of base stations (gateways) dispersed all over the world. Successful operation of such a complex system depends on the ability to perform fast restoration of its operational ability after a failure. Fast and effective gateway restoration after a failure depends on a stock of field replaceable units (FRU). For this purpose, a hierarchical spare supply system (HSSS) is being designed (Ushakov 1994). HSSS includes the central spare stock (CSS), regional spare stocks (RSS), and on-site spare stocks (OSS).

Diversity of gateways and addition of new ones lead to the necessity of a computer tool capable of optimal spare allocation. The problems that arise are: (1) determination of optimal allocation of spares at each OSS depending on the size of a gateway, (2) determination of location and size of each RSS, and (3) determination of size of the CSS.

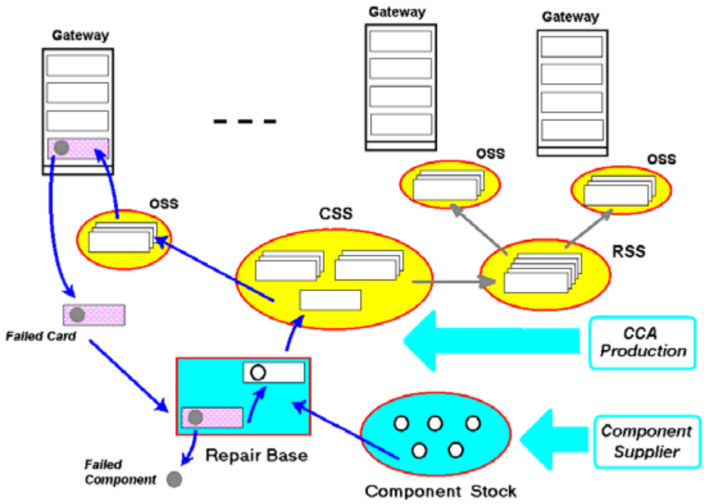


Figure 1. A hierarchical spare supply system

Gateway equipment consists of replaceable units. After each failure, a spare unit from the OSS replaces the failed unit. A failed unit is sent to the repair base. Regional and Central stocks are usually supplied periodically (with priority request for refilling if stock has reached some critical level). On-site stocks are small enough and use the advance delivery; this means that the OSS site sends a request to the RSS after each failure. Structure of Globalstar HSSS is presented in Fig. 1.

FORMULATION OF GENERAL PROBLEM OF OPTIMAL SPARE ALLOCATION

Let the operational system (gateway) consist of N different types of spare units. Request for spare unit of type k, k=1,2...N, arrives to the stock in accordance with a Poisson process with (failure) intensity λ_k. Costs of units, c_k, are assumed to be known. A spare stock contains $x_1, x_2... x_N$ units of different types. The problem is to find the optimal allocation, satisfying requirements on the stock reliability or the total cost.

Let $\mathbf{X}=(x_1, x_2... x_N)$ be a vector of spares at the stock site, x_i is the number of spares of type i; $P(\mathbf{X}, \theta)$ be reliability index characterizing the spare stock with $\mathbf{X}$ spares for period of time θ; and $C(\mathbf{X})$ be the cost of spares. Two optimization tasks (Gnedenko and Ushakov 1995) can be formulated as:

Direct: To minimize the total cost of spares at the stock under condition that the stock reliability index is not less than required level P^*, i.e.,

$$\min_{all\,\mathbf{X}} \{C(\mathbf{X}) | P(\mathbf{X}, \theta) \geq P^*\}. \tag{1}$$

Inverse: To maximize the stock reliability index under condition that the total cost of spares at stock is not larger than a admissible level C^*, i.e.,

$$\max_{all\,\mathbf{X}} \{P(\mathbf{X}, \theta) | C(\mathbf{X}) \leq C^*\}. \tag{2}$$

ON-SITE SPARE STOCK

We assume that gateways are highly reliable and its units are independent, so we neglect the possibility of overlapping of system down times due to different causes. For highly reliable systems, the approximate formula for the OSS unreliability coefficient, Q_{OSS} is

$$Q_{OSS} \approx \sum_{1\le k\le N} \beta_k q_k(x_k)\,. \tag{3}$$

The weights in Eq. 3 are defined as $\beta_k = \lambda_k n_k \left(\sum_{1\le k\le N} \lambda_k n_k \right)^{-1}$, $q_k(x_k)$ = unreliability coefficient of units of type k (cumulative Poisson function with parameter $a_k = n_k\lambda_k\theta$) , and x_k = number of spares of type k in the OSS. For highly reliable systems, approximate formula for the OSS unavailability coefficient, U_{OSS}, is

$$U_{OSS} \approx \theta \sum_{k=1}^{N} \frac{\lambda_k n_k q_k(x_k)}{x_k + 1}, \tag{4}$$

where θ = time delay corresponding to advance delivery.

PREDICTING APPROXIMATE TRENDS

In many cases of practical interest, we are faced with the problem of sparing a highly reliable system. For a highly reliable system, $\max_k\{a_k\} << 1$ and the cumulative Poisson function may be approximated by its leading term (in practice, $\max_k\{a_k\} < 0.1$ is acceptable). Typically, there is at least one spare for every type of unit in a commercially deployed system. On the other hand, total money allocated for sparing is generally limited. If $1 \le x_i \le 5$, $\ln(x_i!) \approx 0.9(x_i-1)$ is a workable approximation in the Poisson function. These two simplifications linearize the Lagrange equation determining the optimal values of x_i (Ushakov and Chakravarty 1998). For goal function shown in Eq. 3 and for the inverse problem of redundancy we obtain

$$x_k \approx round\left(\frac{K - \ln(c_k / (\beta_k C^*)) - a_k + \ln(0.9 - \ln(a_k))}{\ln(0.9 - \ln(a_k))} \right). \tag{5}$$

Constant K in Eq. 5 can be found from the cost constraint $C(\mathbf{X}) = \sum_k c_k x_k = C^*$.

REGIONAL AND CENTRAL STOCKS

An RSS is periodically refilled from the Central Spare Stock (CSS). The number and location of gateways, which are served by a particular RSS may changing in time with the development of Globalstar. It seems that the best index characterizing the RSS is its unreliability coefficient (3). The same might be said about the CSS, which is replenished by production (probably with different period for different type of units). In principle, the solution for these cases is similar to the previous one with the difference that the advance delivery period starts with the installation of a failed unit.

OPTIMAL SPARE ALLOCATOR (OSA) SOFTWARE TOOL

The “Optimal Spare Allocator” software tool has been developed for use in Globalstar gateways. Globalstar is a worldwide satellite telecommunication system that has gateways dispersed all over the world.

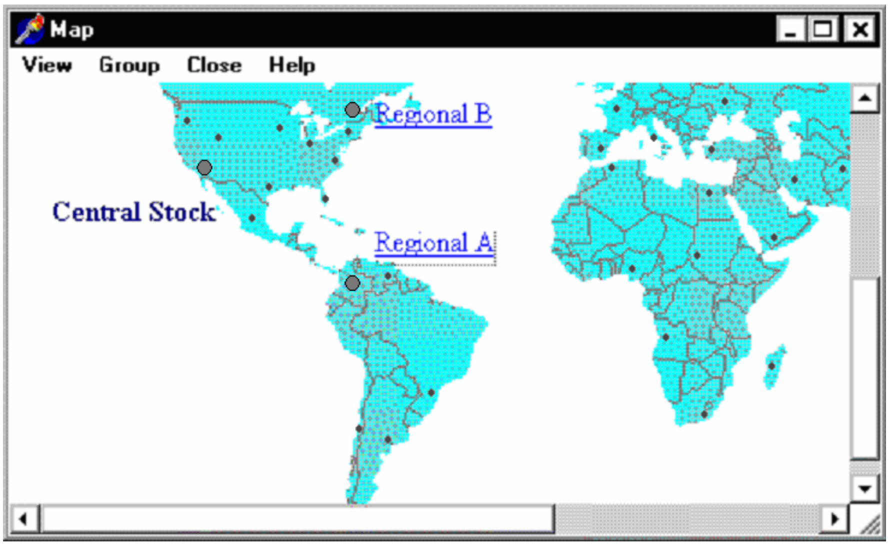


Figure 2. OSA tool: Map of hierarchical stock system.

Its spare supply system is hierarchical in nature. OSA is a GUI driven user-friendly tool designed to solve the direct and inverse problems of optimal redundancy for a multi level hierarchical spare supply system.

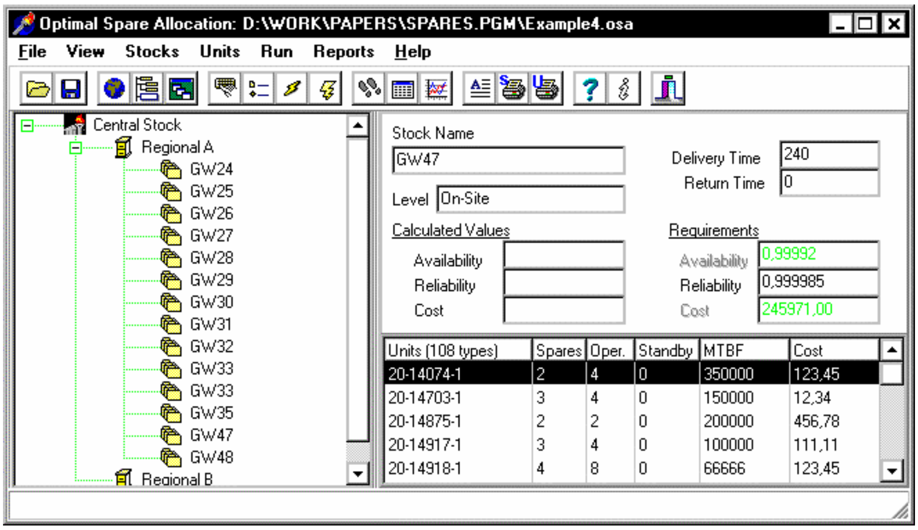


Figure 3. OSA tool: a hierarchical spare supply system structure

It uses the relative increments of the goal function in respect to a unit of cost (steepest descent method) to solve the optimization problem.

A PC with Windows 95 or NT operating system is needed for installing and running the OSA tool. The program's main window includes a menu of all available commands and a toolbar with the most frequently used operations. It has other windows that depict the "hierarchical tree" of the stock supply system (Fig. 3), a table of parameters characterizing a particular stock, including a list of units and quantities used, embedded spares if any, their cost, their mean time between failures etc.

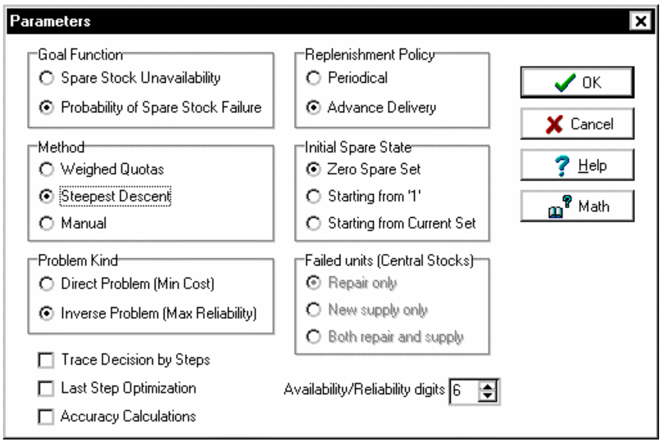


Figure 4. OSA tool: calculation options.

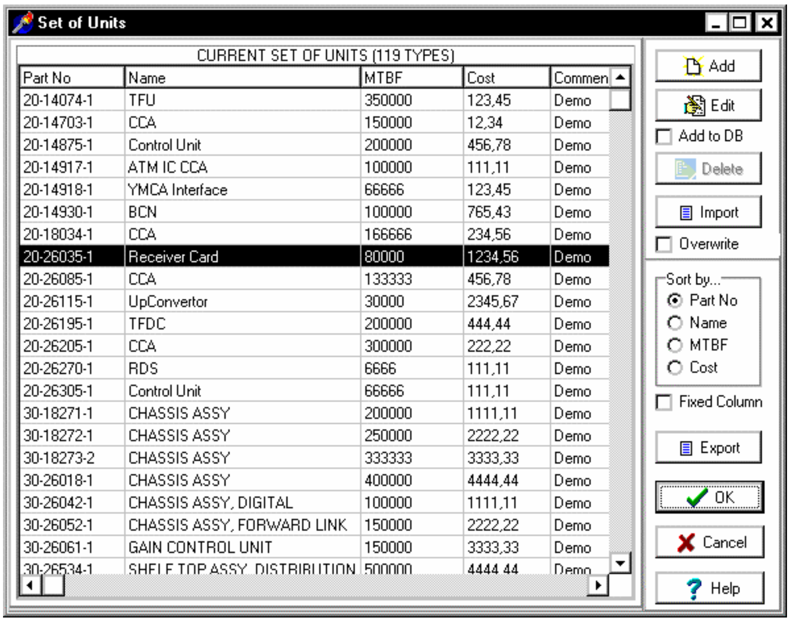


Figure 5. OSA tool: Unit database.

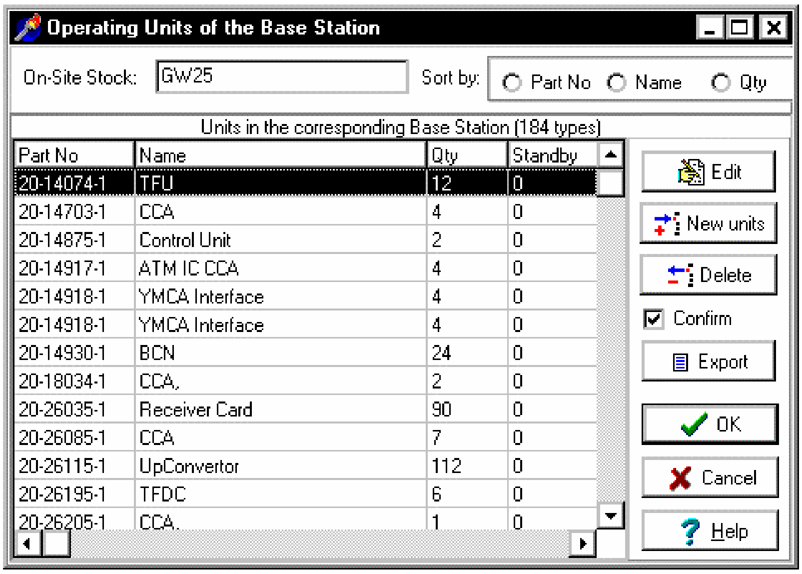
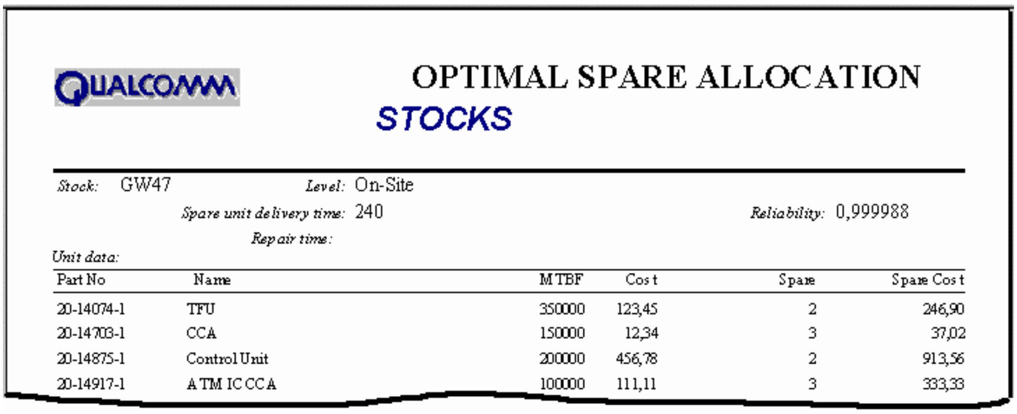


Figure 6. OSA tool: Gateway specification


OPTIMAL SPARE ALLOCATION
STOCKS

Stock: GW47 Level: On-Site
Spare unit delivery time: 240 Reliability: 0,999988
Repair time:
Unit data:

Part No	Name	MTBF	Cost	Spare	Spare Cost
20-14074-1	TFU	350000	123,45	2	246,90
20-14703-1	CCA	150000	12,34	3	37,02
20-14875-1	Control Unit	200000	456,78	2	913,56
20-14917-1	ATM IC CCA	100000	111,11	3	333,33

Figure 7. OSA tool: sample of reporting

The OSA tool is flexible and offers various calculation options to the user. It is able to solve the direct and inverse problems of optimal redundancy with two different goal functions. It also offers two separate replenishment policies, and lets the user choose minimum number of spares consistent with the total cost. Results of calculations are presented in a report whose layout can be specified by the user. Reports generated by the OSA tool may be saved in ASCII format for further processing or documentation.

REFERENCES

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2. Ushakov, I. (1994). *Handbook of Reliability Engineering*. John Wiley, New York.