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PROCEDURE FOR DETERMINING OPTIMUM EQUIPMENT RANGES. (U)

MAY 80 Y V CHUYEV

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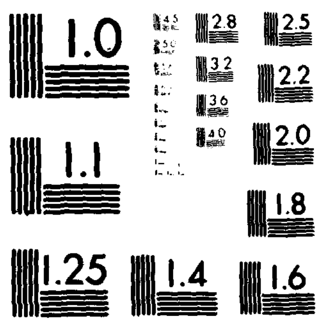

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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

PROCEDURE FOR DETERMINING OPTIMUM EQUIPMENT RANGES

by

Yu. V. Chuyev

FOREIGN TECHNOLOGY DIVISION

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80 8 5 016

FTD-ID(RS)T-0825-80

EDITED TRANSLATION

14 FTD-ID(RS)T-0825-80 11 28 May 1980

MICROFICHE NR: FTD-80-C-000641

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21 ~~English pages: 8~~

Edited trans.

~~Source:~~ Standarty i Kachestvo ~~No. 7, 1969~~ (USSR) n7

pp 52-54 1969. 6

Country of origin: USSR

Translated by: Roger T. Crozier

Requester: FTD/TQF

Approved for public release; distribution unlimited.

12 11

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

PROCEDURE FOR DETERMINING OPTIMUM EQUIPMENT RANGES

Professor Yu.V. Chuyev, Doctor of Technical Sciences

The methods of a now rapidly developing science, operations analysis, should provide the methodological basis for determining optimum ranges of equipment, assemblies and parts [1, 2, 3].

Let us look at some of the simplest examples of the process of selecting optimum equipment ranges utilizing these methods.

Let us assume we know the function of the required nonstop passenger aircraft flight distance (it may be obtained by statistical analysis of available material). We have now to solve the following problem: should we develop a single type of aircraft capable of flying any distance which would be encountered in actual operation; two types, one of which can cover any distance, the other capable of only shorter flights but therefore simpler and less costly; or several types?

The more types of aircraft, the lower the cost of each flight, since the type of aircraft required will be selected on the basis of the flight distance required. At the same time, however, expenditures increase for aircraft development, testing and production (several types have to be developed rather than only one); the production cost of a given type of aircraft goes up because of the reduced volume of production of aircraft of each type; and, finally, relative expenditures for the operation of aircraft of each type may possibly increase.

This problem thus has an optimum solution.

This type of problem may be encountered in the process of calculating a range of load capacities for motor vehicles and riverine and maritime vessels, the capacity of forging and pressing equipment, lathe dimensions and so forth.

An analogous problem might be posed in connection with individual equipment assemblies, or even parts. We will henceforth refer to them as articles.

Let us give the mathematical formula for this problem.

The following are given:

$g(x)$ - function of the cost of producing a single article;

$g_1(x)$ - function of the cost of developing and testing a new model and putting it into production;

$g_2(x)$ - cost of model operation for a unit of time;

$F(x) = \int \varphi(x)\,dx$ - integral function of the demand for articles having argument x (range, load capacity, etc.), where $\varphi(x)$ - - differential function of demand.

We have now to find the optimum number of types of article and the values of their arguments with which total expenditures will be minimized.

Let us assume N - types of articles selected, whose arguments consist of $x_1, x_2, \ldots, x_k, \ldots, x_N$. Each article of the (k+1)th type is used within the range of argument values from x_k to x_{k+1}. Disregarding malfunction of the article according to operation, we may then write the following expression for total expenditures:

$$S_N^* = \sum_{k=0}^{N} [F(x_{k+1}) - F(x_k)]^{\nu} g(x_{k+1}) + \sum_{k=0}^{N} g_1(x_{k+1}) + \int_0^T \sum_{k=0}^{N} [F(x_{k+1}) - F(x_k)] \cdot g_2(x_{k+1})\, dt. \quad (1)$$

Here T - period of time under consideration;

ν - coefficient of the degree of increase in expenditures for production of a batch depending on the number of articles produced.

We have now to calculate that set of x_k, including their N number, in order to minimize S_N^*.

The problem here under consideration is single-dimensional since it has only one argument. Other varieties of series-selection problems are also possible. an example of the classification of which is presented in the diagram below.

We have in actual practice to deal with problems involving two dimensions and more. Flight range and aircraft load capacity may be selected simultaneously, for example. These problems are substantially more complex.

Two-dimensional problems require minimization of a functional of the following type:

$$S_N^* = \sum_{k=0}^{N} [F(x_{k+1}, y_{k+1}) - F(x_k, y_k)]^{\nu} \times g(x_{k+1}, y_{k+1}) + \sum_{k=0}^{N} g_1(x_k, y_k) + \int_0^T \sum_{k=0}^{N} [F(x_{k+1}, y_{k+1}) - F(x_k, y_k)] g_2(x_{k+1}, y_{k+1})\, dt \quad (2)$$

Here we must also select pairs of values x_1; y_1; $\ldots x_k$; y_k; $\ldots x_N$; y_N, and including N as well.

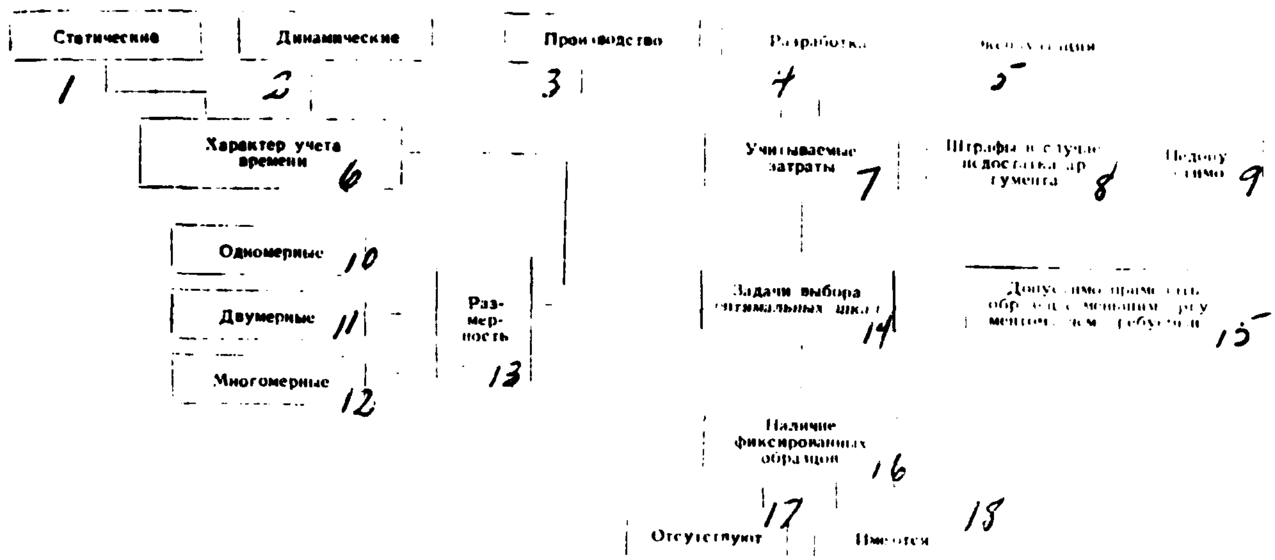
In any of these instances there may also be fixed articles, that is, articles developed and ready for production by a given time. The problem is then reduced to determining the parameters of the additional articles given the range of fixed articles.

Above we have looked at cases in the argument for an article can be no less than a required value. The problem can also be stated somewhat differently: if the argument of a given type of article is less than required, the article may be used; but other expenses are incurred in this instance whose value depends on the ratio of the argument required to the argument of the article. If the maximum flying range of an aircraft is less than that given, for example, it can complete its flights from intermediate airfields, which requires additional expenditures. Insufficient load capacity of an article may result in a need for preliminary disassembly of the load, the use of two articles and then assembly of the load, which also requires additional expenditures. The one-dimensional problem then requires selection of two systems of values: arguments for the articles and the required arguments up to which one article or another should be used.

By selecting the value pairs x_1; z_1; $\ldots$; x_N; z_N, we must in this instance minimize the following sum:

$$S_N^{\circ} = \sum_{k=0}^{N} [F(z_{k+1}) - F(z_k)]\, g(x_{k+1}) + \sum_{k=0}^{N} g_1(x_k) + \int_0^T \sum_{k=0}^{N} g_2\left(\frac{z_{k+1}}{x_{k+1}};\ t_{k+1}\right) [F(z_{k+1}) - F(z_k)]\, dt. \tag{3}$$

Problems of range selection may, finally, be both statistical and dynamic. The latter involve the process of optimum change in a range over time. These problems are a combination of statistical problems in the selection of an optimum range and generalized equipment replacement problems.



KEY: 1 - Statistical; 2 - dynamic; 3 - production; 4 - development; 5 - operation; 6 - nature of time calculation; 7 - expenditures to be considered; 8 - penalty in case of argument deficiency; 9 - impermissible; 10 - one-dimensional; 11 - two-dimensional; 12 - three-dimensional; 13 - dimensionality; 14 - problems in selecting optimum scales; 15 - use of model with argument less than that required permissible; 16 - availability of fixed models; 17 - unavailable; 18 - available.

Problems in selecting optimum range are in character related to distribution problems but differ from the latter in that they involve nonfixed argument values, as well as an unspecified number of arguments, which complicates their solution substantially.

In the general case, these problems may be solved by the dynamic programming method using a computer, but even then their solution requires large expenditures of machine time.

Utilizing the nondecreasing characteristics of the functions $F(x)$, $g(x)$, $g_1(x)$ and $g_2(x)$, V. T. Dement'yev [4] has been able to put forward a substantially simpler algorithm for solving one-dimensional problems without penalties and which may be generalized to the general case of two-dimensional problems without penalties, one-dimensional problems with penalties and to special cases of three-dimensional problems without penalties.

The random search method [5], which makes it possible to obtain an approximate solution with acceptably small expenditures of machine time, might be a third method of solving these problems.

In conclusion, let us present an example with respect to obtaining the analytical formulas.

Let us assume

$$F(x) = bx \text{ when}$$

$$\tag{4}$$

$$F(x) = 0 \text{ when}$$

that is, the differential function of demand is constant within the range $x_n \leq x \leq x_m$ and equal to zero beyond the limits of this range;

$$g(x) = ax, \tag{5}$$

$$g_1(x) = cx, \tag{6}$$

$$g_2(x) = dx, \tag{7}$$

that is, expenditures for production, development and operation are proportional to the argument;

$\nu = 1$, that is, the cost of producing a batch is proportional to its volume.

Total expenditures at optimum argument values as well as the optimum argument values may then be calculated in accordance with the following formulas

[illegible] (8)

where

$$k = \frac{c}{b(a + Td)x_m}.$$

j - number of article type.

The table below shows the dependence of the coefficients on the number of article types.

N	A	B	C	D	E	F	l_1	l_2	l_3	l_4	l_5	l_6
1	1	1	0	0	1	0	0		—	—	—	—
2	1	1	1	1	1	1	1	0	—	—	—	—
	4	2	4	2	2	2	2					
3	2	1	1	1	2	1	1	1	0	—	—	—
	3	3	3									
4	5	1	3	5	5	1	3	2	3	0	—	—
	6	4	8	2	2	2	2		2			
5	3	1	2	5	1	2	2	1	3	2	0	—
	5	5	5									
6	7	1	5	15	7	5	5	1	9	4	5	0
	12	6	12	4	2	2	2		2		2	

Given N, we can use formula (8) to calculate $\bar{S}^*$ and thereby select that number of types N_0 at which $\bar{S}^*$ will be minimal and for this N_0 calculate optimum values for x_j. The figure presents the results of the calculations of S^* and [illegible] when a = 100; b = 2; c = 10,000; x_0/x_N = 0.1 and d = 0. We can see from the figure that by selecting the optimum range (the optimum value of N is 4 in the case under consideration), we can substantially reduce total expenditures (by 35%).

Optimum argument values when N = 4 are as follows: x_1/x_N = = 0.25; x_2/x_N = 0.45; x_3/x_N = 0.70; x_4/x_N = 1.00.

The problem is solved in a manner roughly similar to that described above in standardizing articles of mass production, that is, by selecting the optimum parametric range [6]. In this instance we may impose the following additional condition: the values selected for x_j must be members of a geometric progression with the denominator $\sqrt[n]{10}$. This problem is then simplified substantially. For in fact,

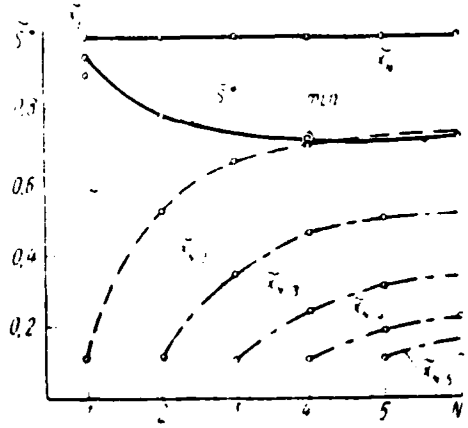
$$x_k = a(\sqrt[n]{10})^k. \quad (9)$$

Taking into consideration the fact that

$$x_N = a(\sqrt[n]{10})^N = a\, 10^{\frac{N}{n}}; \quad (10)$$

$$x_0 = a \quad (11)$$

it is easy with a given N to calculate the value a from (11) and n from the following expression, which is a corollary of (10):



(12)

It is thus necessary to find the extremum of the functional of one variable of N as calculated using equations (1), (9), (11) and (12), which, taking into consideration the discrete character of the value N, does not present difficulties. It is recommended in this connection that total expenditures in the case of compliance with condition (11) be compared with those when this condition is not complied with, which makes it possible to substantiate conclusions concerning the advantage of adhering to this condition.

Finally, we may impose the condition that argument values must be selected from among existing series of preferred numbers (R5, R10, R20, R40, for example). The problem is then reduced to calculating S_N^* when x_k/x_0 corresponding to different series of preferred numbers and selecting that series in which S_N^* will be minimal.

As is true in the preceding case, it is to advantage to compare this value with that which will obtain if we do not impose the condition that the arguments correspond to one of the series of preferred numbers.

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