AN EXAMINATION OF THE USE OF QUANTITATIVE METHODS IN THE ECONOMIC DIRECTION OF INDUSTRIAL RESEARCH

PART III.

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Two cases, which differ from one another from the point of view of the application of quantitative methods, may arise in the preparation of a research program.

One is, when all the necessary data — including, for instance, the significance of a particular problem from some point of view, the expectations of success, the expenditure of intellectual work and other resources necessary to achieve the planned result, the duration of research, the returns of the expected result, etc. — may be *precisely determined* beforehand.

The more frequent case, however, is when the necessary *initial data* for compiling the possible research programs may only be approximately *estimated* within *fairly wide limits*, moreover when, for instance, the evaluation of the expected research result also contains uncertainties. The application of different quantitative methods is advisable in each of the two cases.

The pre-conditions for the application of quantitative methods are generally the following:

a) A large number of proposed research problems.

b) The relative uncertainty of previous evaluation, *i. e.* the presence of many probability variables.

c) A relatively large number of possible research programs.

In order to prepare a research program it is necessary to examine:

1. The possible sources of research problems.
2. The necessary and the possible expenditures.
3. To select the optimal research program.

The establishment of the optimal research program differs in many respects from the optimal programing of production. In the former case many phenomena have to be considered, which it is difficult or impossible to express numerically, moreover in certain cases the uncertain data obtained by forecasting must also be used. It evidently follows from these peculiarities of the programing of research that there are mostly no quantitative methods whose use would prove a substitute for the knowledge and experience of excellent research specialists. The quality of the program is thus undoubtedly dependent on the skill of the experts, but *not only* on them.

Quantitative relations of some kind may be found in the greater part of the estimates used for preparing a program of research, even though their conclusions do not always contain numerical constituents. When, for instance, we say that research worker X is more suited to working on a particular problem than is Y, then we have a relation which is essentially quantitative in character. The consideration of large numbers of such statements in the preparation of the research program is, however, a complex task. It is, therefore, especially in this respect that an opportunity offers, with the help of quantitative methods, consistently to consider the above-mentioned initial premises for a research program, provided that the statements involved contain quantitative relations.

Re 1. The first task is generally to compile the *list of research problems* which can be considered at all.

The problems which are mooted as the program of a research institution, may be taken from three sources:

The *first* is the investigation of the process of production and the *requirements of production*, on the basis of the initiative of the firms concerned.

The *second* is a consideration of the situation of the branch of science concerned and of' the viewpoints of the higher direction of industry, based on the *initiative of the research institutions.*

The *third* are the ideas, opinions and research ambitions of the research workers.

Conclusions on the magnitude, duration, expenditure requirement and quality (fully applied, applied and fundamental research, etc.) of the research projects stemming from these three sources, may be drawn from their distance or propinquity *from the world level.*

Since the various proposed research plans may also contain several problems which are parts of one another, it is necessary, as a following step, to *arrange the problems.*

Re 2. It follows from the planned and organized nature of Socialist research that the *compilation of the list of projected problems* must everywhere take place in accordance with the interests of the people's economy, moreover that in evaluating the expected results of the various problems it is necessary to compare the *necessary* and the *possible* expenditures for each problem, with a view to determining the realistic volume of the research program.

The *necessary* expenditures spring partly from the requirement of intellectual manpower and of financial resources for the research work itself and partly from the requirement of intellectual manpower and of investments for putting the research results into practice.

The *possible* expenditures may similarly be divided into two factors, consisting of the permissible expenditures for research, and those for putting the results of research into practice.

While the expenditure of financial resources necessary for research over a particular problem to be completed, and that required for its results to be put into practice, may in the majority of cases easily be expressed numerically, the estimation of the research work necessary for the various problems, and particularly its numerical expression, is generally, harder. The reason is that the significance of the differences between individual research workers for the progress of research is very great, moreover that it is not always possible to compute accurately how many research workers can complete a particular job of industrial research and how much time they require to do so.

The financial resources available for research and the realization of research results, constituting the possible expenditure of financial resources, may be accurately stated, while the realistic determination of the actually available capacity for intellectual work to be done on the research project is again a difficult task, particularly in the case of highly qualified intellectual workers. Here it is not always possible — though this is a method of numerical evaluation that is fairly widespread in practice — to use hours of research works as a basis for quantitative appraisal. There may here too, be cases where instead of an exact numerical expression only certain relations can be determined, *e. g.* that a particular research worker who is suited for research on problems "*a*", "*b*", "*c*" and "*d*", may in the period of the program engage simultaneously in problems "*a*", "*b*" and "*c*", or in problem "*d*" only.

Re 3. The mathematical programing of industrial research *differs both in content and form* from the method adopted in *programing production*, because the parameters of the program include very many uncertain, anticipated quantities and because several of the parameters of the program can only be described with the help of certain relative values.

If all the data necessary for programing were available numerically, moreover if *the accuracy of these data is beyond doubt*, the programing can be accomplished without particular difficulty. In this case the method is similar to that used for the programing of production.

In the course of the preparations for programing the resources available for research and for putting eventual research results into practice, must be considered in turn and the *possible* research programs first found. Then, the *optimal* research program must be selected from among them.

Let us, for instance, presume that a small research group consists of five people, the financial resources available for research are 10 million Forint and — for the sake of simplicity — three problems, *a*, *b* and *c* may figure in the research program. Eight different research programs may then be drawn up from these problems. The first possibility is that it is not worth doing research on any of the subjects. The second program is to do research on *a*, the third on *b*, the fourth on *c*, the fifth on *ab*, the sixth on *ac*, the seventh on *bc* and the eight on *abc*. If, moreover, we presume that in the course of programing we must take as our point of departure the expenditure belonging to the various programs, moreover the net returns, the percentage utilization of the research capacity, the percentage utilization of the material capacity, and finally the ratio of returns to expenditure, then the optimal program can be selected according to various points of view. These are, for instance, that the expected net returns should be a maximum, that the labour-power capacity should be utilised to the maximum, that the utilisation of the available material resources should be a maximum, that the expenditure/returns ratio be the most favourable, etc. The four kinds of consideration for an optimum lead to four different optimal programs and in the interest of one optimalization target it is necessary to give up a similarly favourable development of other indices. The inequalities which are the conditions of the program may thus be determined and the objective function established. A premiss for programing is that the variables be discrete.

Required manpower (no. of persons)	2	3	1
Total expenditure on means (millions of Ft)	4	2	6
Gross return (millions of Ft)	7	9	15
Net return (millions of Ft).............	3	7	9

Program	Research requirements	Total expenditure	Net return	Exploitation of capacity research Ft	Ratio expenditure/return
1.					
......					

The available sources: Five persons
10 millions of Ft

The first task is to choose the *possible* programs from the above table and then to pick out the *optimum* program. Program no. 8 obviously exceeds the available capacities in both personal and material requirements and should therefore be disregarded in further programing. This leaves us with the first seven programs to select from.

Having now determined the sphere of the possible programs, we may proceed for the selection of the "best" program in the following way:

1. Let our target be to obtain a research program whose *expected net return is maximum* This requirement leads us to *program No. 7* since the pertaining 16 million Ft net return is the highest of all.

2. Let the requirement now be to make the best use of the available *labour capacity* of the research personnel. This will make us select *program No. 5* since the total capacity is exploited.

3. The maximum exploitation of the *available material means* may also be selected as the primary requirement. This will be fulfilled in *program No. 6.*

4. The variations in the *ratio of expenditure to returns* may be an important factor. The most favourable results are obtained in this case with program No. 6.

A simple example, like this, involves a large variety of possibilities and is in itself conclusive of the sensibility of the choice. The four different angles of optimalisation have lead to four different optimum programs and *in the interest of one optimum we must renounce the favourable constellation of the other indices.*

In compliance with the above, we can write the condition equations of programing. These are:

$$2x_a + 3x_b + 1x_c \leqq 5$$

$$4x_a + 2x_b + 6x_c \leqq 10$$

The possible target functions are:

1. $$3x_a + 7x_b + 9x_c = \text{max.}$$

2. $$5 - (2x_a + 3x_b + 1x_c) = \text{min.}$$

3. $$10 - (4x_a + 2x_b + 6x_c) = \text{min.}$$

4. $$\frac{\text{Gross return}}{\text{Expenditure Ft}} = \text{max.}$$

The condition of programing is that the the variables should be discrete, *i. e.*

$$x_a,\ x_b,\ x_c = 0$$

if a, b, and c are excluded from the program, and

$$x_a,\ x_b,\ x_c = 1$$

if a, b, and c are included in the program.

In the above example the expected net returns for each problem could be unambiguously defined. The more frequent case in the course of industrial research work is where the head of research *can, in place of accurate data, only establish certain relative values.* Thus he may only be able to say of a particular problem that it is, for some reason or other, more important than another.

In this case one task that must be accomplished before programing, is to estimate the expected results of each piece of research.

First an estimate may, for example, be made of the *significance* of the various problems from some particular point of view (*e.g.* the returns obtained).

Second an estimate may, for example, be made of the *hope of success* entertained with regard to the research on each problem.

The *third* step yields the *expected result* of the research, which may be determined as a synthesis of the two previous estimates.

In practice, when estimating the expected results of research problems, it is often only possible to make the following types of statement:

The research result which may be achieved with problem "*a*" is of great significance and according to the evidence of the research done so far and of the literature of the field, the probability of success is great.

The result which may be achieved with problem "*b*" is also of great significance but since — for instance — the research workers available have not sufficient experience in the field, the chances of success are slight.

Information of this type does not, usually, permit the research problems to be arranged unequivocally in order of precedence. They may at best be *classified into a few groups* by significance, *e. g.* as problems of slight, medium and great importance. Experience has also shown that even after the opinions of experienced experts have been heard, the problems can, in respect to the hope of success, also generally only be classified into a few groups, instead of being arranged in an unequivocal order of precedence. There may thus be, for instance, problems where the chances of success are slight, medium and large.

Statements of this type, if they are adequately based, can, however, serve as fundaments for certain decisions to be taken.

If optimalization takes place according to the net return, then each problem has attached to it a number, which is no other than the net return. If, however, the net return cannot be determined accurately but we may only establish certain relative values, then the idea arises of attaching to the various problems a number, by the use of which a program is obtained yielding *approximately* the result that would be obtained if the net return had been known.

Let us assume, for instance, that our head of research knows the following about problems "*a*", "*b*" and "*c*":

In problems "*a*" and "*b*" the chances of success in the results of research are middling, in problem "*c*" they are great.

Moreover, the expected returns for problem "*a*" are small, those for problems "*b*" and "*c*" are medium. These statements may be represented by the following pattern:

Returns

		Returns small	medium	great
The chances of success	small	1.1	1.2	1.3
	medium	2.1a	2.2b	2.3
	great	3.1	3.2c	3.3

In the case of the problems arranged in the above pattern, numbers characteristic of the results which can be expected in connection with them, must be attached to them.

If, for instance, we attach to these problems the sum of the line and column indices for the interval where the problem concerned is located, then the numbers appended to problems "a", "c" and "b" are 3, 4 and 5 in turn. This method of evaluation complies with the main considerations for evaluation, discussed on p. 183.

The programing may now be carried out by maximalizing the sums of the numbers thus appended to each problem. Thus

for program	(a, b)	$3 + 4 = 7$,
,, ,,	(a, c)	$3 + 5 = 8$,
,, ,,	(b, c)	$4 + 5 = 9$

are the appended numbers.

The numbers taken from the pattern and appended to the various problems may be regarded as though these numbers signified the returns, so that we program to obtain an optimal sum.

The above method is obviously not the only possible one, but it is one of those which can be used for calculation when the accurate data are missing, and it is suited, if to do nothing else, at least to prompt the head of research to engage in a more thorough investigation, moreover provides him with a means for recording his opinion of the various problems in an easily surveyable manner.

Each of the methods outlined above contained, in the last resort, a measure of numerical evaluation for the various research problems. When, however, the numerical evaluation of either the expenditures or the efficacy of research is considered everyone is, to some extent rightly, dubious, whether such numerical evaluations can be realistically based. It is, in fact, one of the main faults of most of the investigations of a similar character known to us from the literature, that the numerical figures obtained by some sort of estimate are in the course of further calculations regarded as precisely given, unalterable parameters (*e. g.* Newton's reviewed matrix method). The determination of research programs on the basis of such facts — however elegant the mathematical methods applied — is bound, through the very uncertainty of the initial figures, to arouse the suspicion that the errors of the initial data, if perpetuated in the course of computing, may vitiate the whole result of the calculation. The object of the programing of research is, however, not to determine an unequivocally defined, ultimate research program. The mathematical programing here necessitated is generally one where the only certain thing that can be said of the initial data is within what (often quite wide) interval they may belong, and what relations subsist between the various initial data. Since the initial data for programing may in most cases only be given through relations (inequalities), the result of mathematical programing — precisely in consequence of the previously undertaken analyses — willl be to narrow down the circle of possible programs in such a way, that the remaining program variant can be more easily surveyed, and the varied considerations to which attention must be paid in the preparation of a research program, may be more easily put into effect.

The above theses on the preparation of research subject plans have been concerned only with so-called discrete programing, *i. e.* decisions relating to whether certain problems should figure in the research program, or not. In principle, it is possible also to consider programing with continuous variables, for other types of question may also arise in respect to the various problems. The measure of the intellectual work and financial expenditure which can be devoted to each problem may also vary continuously, and the expected result may vary as its function. A type of programing, however, as a result of which we would also come to know how much the rational material expenditure on each problem should be, would only be successful if we were able previously to determine the expected results for each problem, in terms of the expenditure. This is, however, at present — at last in the overwhelming majority of cases — hardly a realistic requirement.

The methods discussed above have, despite all the difficulties, to be studied because in other spheres differing from industrial research — where at the outset information which is — if possible — still more vague, is obtained, the application of similar methods has already led to considerable economic results.

A further argument to substantiate the applicability of these methods is that the aims of applied industrial research, and particularly of research connected with the development of new products, are fairly well defined and — in contrast to fundamental scientific research — this phase of research will in most cases already make it possible to rely on a whole series of initial data which may be said to be sufficiently accurate.

Finally it is necessary at least to experiment with the application of such methods also because the empirical methods so far used on the determination of programs do not always make it possible with sufficient consistency to consider all the attendant requirements.

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