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Interregional Seminar on Industrial Location
and Regional Development
Minsk, August 1968

TECHNIQUES OF INDUSTRIAL LOCATION PROGRAMMING
A SELECTIVE SURVEY [1]

by

Ivan Krešić

1/ The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO.

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TECHNIQUES OF INDUSTRIAL LOCATION PROGRAMMING 1/

[A SELECTIVE SURVEY]

SUMMARY

by

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* This is a summary of a paper issued under the same title as ID/WG.9/5

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1. Nearly a century has elapsed since the first industrial location theory appeared. Both its origin and its development were accompanied by an improvement of corresponding location models. These efforts were for a long time directed predominantly to the individual industrial location programming of Weber's type.

2. The system of planning economic and industrial growth, as applied between the wars, demanded further improvements in methodology. The period was also characterized by a different approach to the theory and methods of location in the East and the West.

3. Recent developments in industrial location programming techniques have been directed towards two essential fields: individual location and group location programming; and the allocation of industry programming. The former makes great use of mathematical methods to determine optimal locations and comparative methods to determine the best among several possible location solutions. Classical mathematical methods of the Weber and Palander type are of little use for the practical needs of industrial location planning.

4. Activities in modern research pay most attention to the improvement of techniques for group industrial location programming. Quantitative economic analysis is the starting point for the investigation and programming of industrial locations.

5. Industrial complex analysis and spatial models analysis are at present the most important specific techniques in group industrial location programming. Of all mathematical methods, linear programming is the one that can help most in finding quantitative solutions for optimal spatial allocation.

6. The high degree of development of industrial location programming techniques offers considerable opportunities for both research and practical activities. However, different locational problems and dynamic changes of location conditions, as well as the importance attached to certain factors of location, demand continuous progress in and further improvement of industrial location programming techniques.

Contents

Introduction

Current research and development of scientific endeavours in the field of locational programming, including efforts to widen the fields for application of the relevant methods, have been intensive. All of the results in the field of methodological innovations cannot be summarized in one paper, even if that review is limited to the techniques of programming industrial locations. In this paper emphasis has been put upon locational methods that are important both for research and practical purposes. Priority has been given to methods of location verified by practice.

Considerable attention has been devoted to locational problems and methods of programming individual and group locations that have not been widely written about in the economic literature of the major languages. For articles that have been written, the original sources have been indicated for the convenience of the reader. However, some valuable locational methods may have been overlooked as the author may not have been aware of them at the time of writing this paper.

Due to set limitations, it was possible to mention only the most important techniques of programming individual and group locations. Titles of the original papers are given in the list of references.

I. ECONOMIC THOUGHT ON THE PROBLEM OF LOCATION

Survey of the development of the theory and methods of location

1 The Industrial Revolution of the nineteenth century meant for many countries intensive economic development. It was then that the Ruhr Valley became the world's biggest industrial centre. The Industrial Revolution spread throughout the rest of politically and economically disunited Germany and by the end of the century the industrialization of the country had already become intensive. Accelerated industrialization created many problems brought on by aspirations of increased productivity and profitability, and severe competitiveness. Realization of these aspirations depended, among other things, upon the location of industrial activities

2. For obvious reasons the nucleus of the industrial location theory appeared just at this time. In 1882, Launhardt published in Berlin his tentative method of determining optimal location.(1)[1/] Thirty odd years later Weber constructed

1/ Numbers in parentheses indicate references.

the so-called "locational triangle" method for the same purpose and in almost the same way.(2) He wanted to determine the methodological approach and the optimal location for industries according to their needs. Since that time, the approach to the formulation of the locational problem has been simplified. According to Launhardt locational optimality depends upon only one locational factor - transport costs. As in the case of Weber's locational triangle, the apices of the triangle are composed of location of raw material, fuel, and consumption of product (market). The task is then to find the place of production within such a triangle, that is, where transport costs will be lowest.

3. In these investigations Weber went much further than his predecessor. He was the first to formulate the original industrial location theory. According to him, the determination of an optimal location depends upon three factors: transport costs, labour and agglomerative-deglomerative factors. Weber widened considerably the instruments applied by the methodology of determining optimal location, but all of his methods (locational triangle, isodapane system and Varingnon model) have been reduced to a technique of determining the individual industrial location with the minimal transport costs. Other factors have been only of corrective importance. It is not clear what their locational influence can be upon the methods mentioned above.

4. All attempts to apply these early methods have shown how imperfect, impractical and rather naive they are. Weber's numerous follows had as little success in trying to perfect these methods as he did.

5. Among other theorists Palander of Sweden contributed most valuably towards perfecting Weber's technique.(3) Although he showed a great deal of ambition in trying to find practical solutions to the location problem, his work was of limited practical value. In his methodological approach Palander improved Weber's isodapane method by showing ways to determine industrial location when applying this method. To stray from the teaching examples in applying this method requires a deeper knowledge of the schematic importance of that complicated locational technique.

6. The first locational theory has, within the past fifty years, developed into a number of theories of different approach, subject, or extent. Simultaneously with the development of the theories, contributions have been made towards perfecting relative locational methods. Although it makes little sense

and is very difficult to separate the analysis of development within various methodologies from the creation of the theory, a number of theorists have given most interesting contributions towards perfecting the technique of determining location (A. Lösch, E. Hoover, Chanukov, S. Florence, H. Hotelling, A. Smithies, G. Ackley and others).(4)

7. Lösch has kept himself within the bounds of the importance of stressing the Weber-Palander method of isodapane for locational research, with reference to a number of contributions of his own.(5)

8. Hoover has emphasized demand as one of the problems in location research. His original method of determining the role of the lowest transport costs has not surpassed other similar methods used by his predecessors.(6)

9. The most comprehensive importance of transport costs for the allocation of industry in the Union of Soviet Socialist Republics has been given by Chanukov; it includes a methodological aspect of how to solve these problems.(7)

10. Research performed by P. Sargant Florence led to the formulation of what is known as the "coefficient of location", which denotes the tendencies of an industry towards dispersion or concentration.(8) If we take this for granted, such a method can hardly show how to solve existing locational problems. However, this method represents an attempt to transfer from the individual methods of research to the group industrial locations.

11. Owing to their diverse character, locational and space problems evoke the need to constantly perfect techniques for solving these problems. The naive methodological location solutions given by Launhardt, Weber, Palander, Florence and others could have been useful only in solving very simple locational problems. Predöhl was the first to use the theory of space balance in explaining the allocation of industry. He gave Lösch a basis by making the problems of location a part of the whole system of economy.(9) Among the numerous contributions of contemporary theorists, outstanding credit belongs to Isard and Leontief for pointing out the relativity of locational factors, possibilities of substituting them and the necessity to give a dynamic basis to the theory of location.(10) The essential investigations of the methodological approach to the problems of location can thus be seen in a different light, this cannot be said of the already mentioned methods of individual locational investigation that are of a more static character.

12. Economic literature of centrally planned economy countries has taken quite a different approach to the theory and methods of location. This can best be seen from the history of the role given to Weber's theory of location.

Differences in East and West theories and methods of industrial location

13. Free enterprise economies, containing elements of liberal economy with private initiative and an aspiration towards the realization of private interests, denote a starting point for the creation and initial development of the first theory of location. Locational methods have been developing in this respect; until very recently their task was to determine the optimal location for a certain industrial activity or factory. Between the two wars efforts were made by Predöhl, Ohlin, Lösch and others to extend the original individual theories into a general theory of location that would also contain elements with a broader social impact. However, only the intensive and manifold progress that has taken place in all fields of space economy after the Second World War has brought about a marked change in that respect.

14. The planning of economic development has often been applied in countries other than those with centrally planned economies. Some economic and social principles, made manifest through emphasizing the need to develop underdeveloped regions (plans of development for southern Italy, Mediterranean regions and Bretagne in France), have gradually become part of development programmes. Industrialization of whole regional units has become the most frequent form of development policy.

15. At the same time, it has become necessary to improve methods of programming industrial locations as well as regional development planning. In this domain of economic literature, investigation of methods applied to individual industrial location gave rise to the problems of programming group locations and to methods of space and regional planning. This tendency in the development of the theory and methods of location can be seen through changes in the professional economic literature of the West. On the other hand, even in a free enterprise economy with private initiative and decentralization of investment decisions, methods of programming individual locations have not lost any of their importance.

16. The importance of the theory and methods of location in centrally planned economy countries developed in a rather different way. Soon after the October Revolution the Union of Soviet Socialist Republics started preparations that were to bring about a planned economy. At the same time, the country was divided into areas. Thus, from the very beginning, economic plans laid down by the Union of Soviet Socialist Republics' Government took on a spatial dimension. In the elaboration and realization of the five-year plans, the distribution of the productive forces and the tendency of industry towards space occupied a special place. Distribution was performed in conformity with the proclaimed economic and political principles. Beside the basic economic principle - the realization of maximal social effects - principles of development of all regions, promotion of the underdeveloped ones, and similar social and political principles played an active role in the distribution of productive forces. For these reasons, research effects and problems of programming individual industrial locations were pushed into second place.

17. Locational theories and methods of the Weber type could not have played an efficient role under such conditions. Weber's theory of location was also used in setting up the first five-year plan of the Union of Soviet Socialist Republics. Soon after his book Über den Standort der Industrien was translated into Russian in 1926, the opinion that Weber's theory could not help to solve problems of industrial locations in a centrally planned economy became evident.(11) Since then, all locational theories of the Weber type have been rigorously criticized in the Union of Soviet Socialist Republics' economic literature.(12) To these theories Feigin, Nemchinov and others contrapose the basic principles of locational distribution of industry in the Union of Soviet Socialist Republics.(13)

The main task of an industrial location does not lie in determining the optimal individual locational effects, but in its broader social role of realizing plans of economic development. Such an attitude towards the role of location did not create in the centrally planned economy countries a basis for a more intensive methodological research towards solving that kind of locational problem.

18. This aspect must be taken into consideration when thinking of the almost non-existent research on the method of individual location. The last couple of years have, in the economic literature of centrally planned economy countries, seen a more intensive investigation of locational methods including mathematical methods that can be applied in these fields of research.

19. When emphasizing the importance of the possible saving in transport costs in the Union of Soviet Socialist Republics and an increased interest for research into locational problems, the French economist Chambre foresaw that locational theories of the Weber type (14) might again be applied.

20. Thus, it can be said that in spite of controversial development, both basic techniques of programming industrial location gradually acquire their proper place, importance and role in the theory and practice of the industrial development of the East and West. Methods and problems of individual location are given more room in the corresponding literature of centrally planned economy countries. On the other hand, programming of group industrial locations has found an important place in the planning of economic development in many countries that clearly have private initiative.

21. In spite of such development of the role and importance of the theories and methods of location, there still remain characteristic differences in tasks attached to the programming of industrial locations, resulting from various systems of political and economic life.

II. METHODS TO DETERMINE INDIVIDUAL INDUSTRIAL LOCATIONS

22. Approaches to determine industrial locations can be best divided into two groups: (a) to determine the optimal location as a function of two or more locational factors; (b) to determine which of two or more locational projects would be optimal for the location of an industrial activity or factory.

23. Defined in this way the determination of industrial locations considerably influences the application of the corresponding technique in solving some of the locational problems. In the first case, some mathematical methods can be applied. In the second approach the comparative method offers some lasting results; taking this into consideration, the techniques to be applied in solving that kind of locational problem are outlined below.

Mathematical methods

Classical mathematical methods

24. Mathematical methods were first used in locational research to determine optimal individual industrial locations. The problems were the subject of research of the previous locational methods, that is, the locational triangle of Launhardt and Weber and the isodapane system of Weber and Palander. The role

of minimal transport costs was one of the most important results of applying these methods. Even when simplified in this way, such methods have proved to be too complicated for a practical solution of the problem.

25. The isodapane method has certain advantages. It can be used to determine almost all relevant points within an investigated territory, that is, those with respect to transport that have the same locational conditions. Additional methodological ways make it possible to choose, from a series of locations, the one to which other locational features give a locational advantage. Although a detailed description of its construction has been given and manifold possibilities of its application have been indicated, it has still not been used sufficiently for purposes of practical research. Techniques of programming individual locations are, in fact, of little importance either for research or for practical work.

Polivector method

26. The requirements of both research and practical work mean that the problem of improving the techniques for solving individual locational problems is ever current. Constant development of mathematics brings about an improvement of the vector theory. One of the theorems in this field of mathematical science is the methodological improvement in determining individual location with respect to the older methods already described. Applied in different fields of locational research, this method is called the polivector method.2/

27. Like the other mathematical methods, this one has also been the subject of criticism. The method takes for granted the shortest possible transport connexions and can hardly be applied in regions with poor transportation. By applying this method the optimal solution can be obtained, which mathematically denotes the territorial gravity centre. Also, it denotes an improvement in the application of the locational results.

28. The advantages of this method when determining individual locations are:

(a) It can start simultaneously with a great number of similar factors, such as consumption centres, raw material and fuel supplies, and also with other different factors of location of equal importance.

2/ The method has been applied several times in the last ten years or so in setting up of plans of industrialization in Yugoslavia. It has also been used to determine the location of one of the new cement factories now under construction in central Bosnia.(15)

(b) Application of graphic or analytical forms of the method is relatively simple, it enables locational results to be obtained fairly quickly, and the method can be widely applied in operative research;

(c) The method can help to acquire results for each phase, thus, subregional locational optimum is first investigated and afterwards the definite optimal solution is attained.

The way in which the location for a central transformer station in the far west of Yugoslavia has been determined can be taken as an illustration of the possibilities of applying such a method.3/ Savings in investments for transmission appliances and losses in transmitting the electrical energy depend upon the choice of location; they are in direct relation to the length of transmission ways.

29. The following prior conditions should be defined if this method is to be applied successfully:

(a) Prospective consumption of electrical energy of the region should be centralized to five local consumption centres. Distribution of electrical energy is performed from these centres through transformer stations of 110/35 kV to the final consumers;

(b) Configuration of the soil makes it possible to connect directly consumers' centres to the location of the central transformer station of 220/110 kV;

(c) Sources of electrical energy that feed the central transformer station cannot be defined with respect to location nor with respect to the size of the unit. When elaborating this draft, it was taken for granted that sources of electrical energy have no influence in determining locations for the central transforming stations, although this is not the case.

3/ The necessary parameters in putting this example forward have been formed on the basis of the analysis of the perspective plan of electrification (I. Janić (1961) "Elektrifikacija Istre", *Energija* No. 7/8).

30. Thus, basic parameters that influence determination of the location for a central (regional transformer station of 220/110 kV) are those that show the amount of consumption of the electrical energy being distributed through local transformer stations of 110/35 kV. Annual consumption of each of the local centres will, according to the plan, amount in 1980 to:

<u>Consumption of electrical energy in the local centres in 1980</u>
(Transformer stations of 110/35 kV)

Buje	120 GWh	Rasa	170 GWh
Baderna	130 GWh	Plomin	180 GWh
Pula	250 GWh		

31. The locational task would be to see what was the optimal location for the central transformer station of 220/110 kV with respect to the local transformer stations of 110/35 kV. The optimal location allows the shortest possible transmission of electrical energy thus minimizing investment costs for the transmission appliances, current expenses for maintenance, and the losses in transmitting electrical energy.

32. To use the polivector method means to put a certain region within the system of co-ordinates. All five local centres of consumption (transforming stations of 110/35 kV) are situated within the delineated system of co-ordinates. This also makes it possible to set up the distances by simple measuring of the map, that is to find the length of the abscissa (X) and the ordinate (Y).

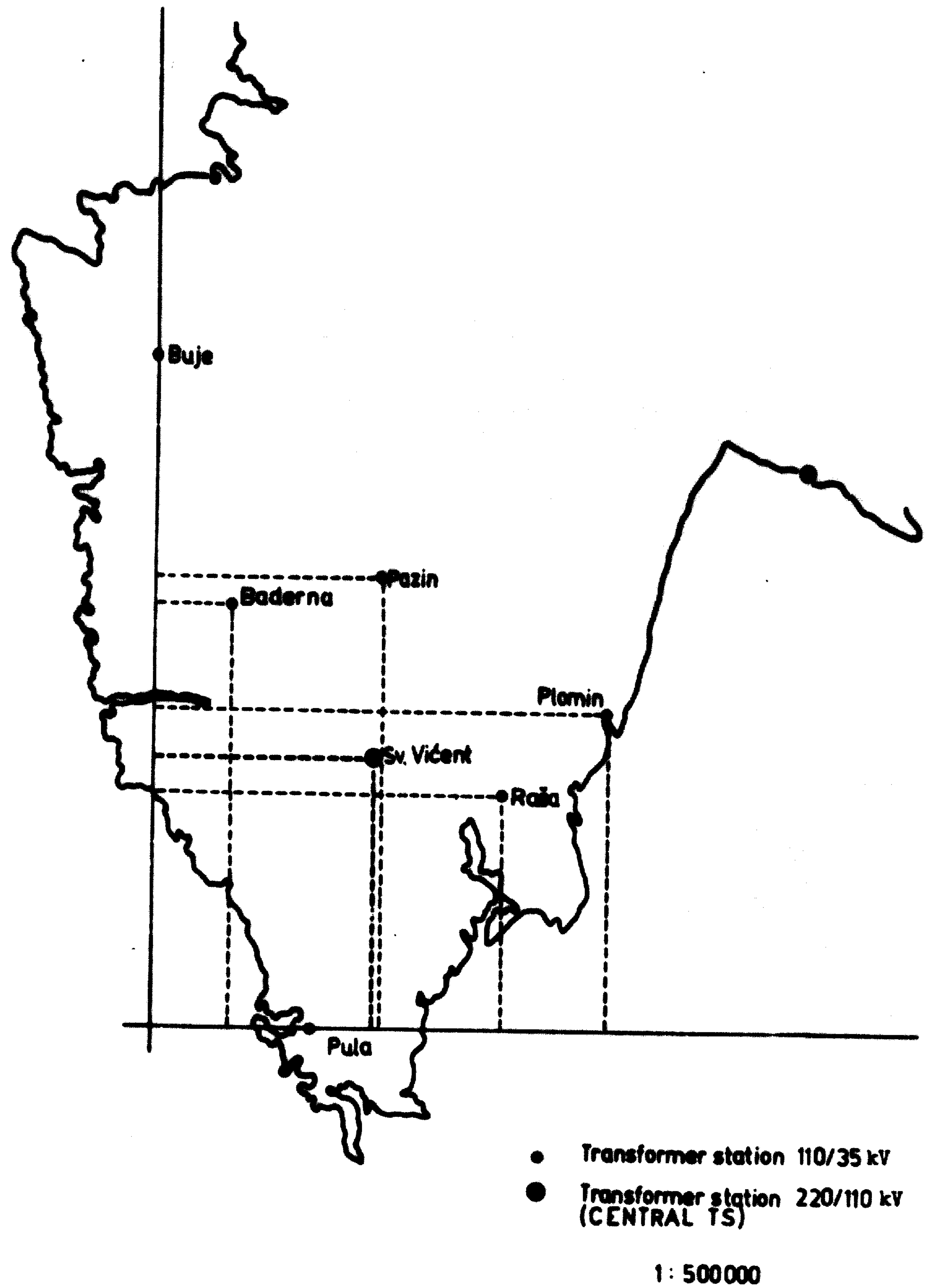
33. In order to measure the resulting abscissa (X) and ordinate (Y), the following table is made:

Centres of energy consumption	K	X	Y	Kx	Ky
Buje	120	-	119	-	14,280
Baderna	130	15	75	1,850	9,750
Pula	250	29	-	7,250	-
Rasa	170	74	42	12,580	7,140
Plomin	180	83	57	14,940	10,260
Total	850			36,720	41,430

K = annual consumption of electrical energy; X = abscissa; Y = ordinate.

Figure

The location choice for central transformer station in the district of Istria



34. After inserting the values given above (Kx and Ky) into the corresponding formula, one gets the required results (X and Y) in the following way:

$$X = \frac{K_a x_1 + K_b x_2 + K_c x_3 + K_d x_4 + K_e x_5}{K_a + K_b + K_c + K_d + K_e} =$$

$$= \frac{\Sigma /Kx/}{\Sigma K} = \frac{36,720}{850} = 40.8$$

$$Y = \frac{K_a y_1 + K_b y_2 + K_c y_3 + K_d y_4 + K_e y_5}{K_a + K_b + K_c + K_d + K_e} =$$

$$= \frac{\Sigma /Ky/}{\Sigma K} = \frac{41,430}{850} = 48.5$$

35. When the given values of the resulting abscissa (X) and the resulting ordinate (Y) are inserted into the prepared co-ordinate system, the required locational solution will be in the intersection, (see figure following). The influence of certain practical requirements can mean minor corrections with respect to determining microlocation for central transformer stations. These are the problems that should be solved within the limits of investment decision-making and technical characteristics of the location of a certain plant.

36. Individual locations in different cases can be determined by this method for industrial and other locations.4/ It is supposed that the locational optimality depends upon one or more locational factors, whose locational activity can be expressed in the same way. In case determination of the optimal locational solution depends upon different factors of location whose locational activity cannot be expressed in the same way, this method can be of no use or only of partial use. In such a case the only possible solution would be to use the polivector method while determining the partial solution based on factors of the same kind and to include, if possible, a factor of the most decisive locational activity. The final locational solution will be found either

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4/ A study of the Academy of Sciences of Czechoslovakia, published in 1965 in Prague, treats problems in connexion with determining the location of a regional shopping centre. The mathematical solution of the problem has been given in a similar way.(16)

analytically or through the comparative method after the given result has been corrected.

Comparative methods

37. Application of the comparative method in locational research is based on gradual adaptation of the general form of comparative analysis. The comparative method has in various forms been applied to many fields of economic and non-economic research. Its high flexibility in adapting to different needs made possible its efficient application in locational research.[5/] This is why this method has a special place among the techniques of programming industrial locations.

38. Under these circumstances this method can be used directly and independently for less complicated cases; for more complicated locational research it is used as an instrument of quantitative economic analysis of the widest range. Its efficiency depends upon the form, tasks and field of application chosen. Here, the aim remains basically the same - to find an optimal locational solution among many possible ones. It thus becomes one of the most important elements in investment decision-making.

39. The comparative method is given a dynamic note as it can be widely applied in different phases and on different levels of investigation of a certain locational problem. Such characteristics are favourable for the efficiency of its application even within the widest range of dynamic economic analyses of very complicated locational problems.

5/ Examples of applying different variants of the comparative method are numerous; of special interest is the role attached to it by Isard in programming industrial locations as part of regional planning. Supply of steel products for three regions is a simplified example of the application of the comparative costs method. The example has been described in Planification économique régionale, by W. Isard and J.H. Cumberland (1961), Paris, p.27. This review has been based on application of the comparative costs method in the interregional research. The method has been further elaborated by W. Isard and E. Smolensky.(22)

40. The influence of temporal changes in conditions of locating upon the optimality of the same locational case, caused mostly by technological changes and technical improvements, can also be quantified through manifold application of the comparative analysis. In locational research, the comparative method can be used in the following methods.

Complex comparative method

41. When applying this form of comparative method, all locational factors of technical or economical importance are taken into consideration, whether directly or indirectly connected with the investigated locational problem. Qualitative and quantitative locational factors are both relevant in such a comparative analysis. Such a complex comparative method accords the widest analytical approach in investigating locational problems. The following are the negative features of applying the complex comparative method.

(a) As a rule, it requires a relatively large amount of research work and time, and in some cases it involves high costs before any final results are reached. It thus becomes less efficient, especially in the field of operative locational research.

(b) Locational results as functions of a great number of locational factors of different intensity, meaning and direction of activity, are often not clear or are somewhat difficult to understand. Such locational results cannot always be relied upon in cases where all parties are not equally interested in the final results.

Abridged comparative method

42. This variant of the comparative method introduces into the locational estimate only those relevant locational factors and elements of locational investigation that are of direct influence upon the final result. The basic way of selecting and choosing the relevant factors implies the elimination of all locational factors that are of equal importance for all competing locations; and all factors and parameters of locational estimate that are not of essential importance for the final result and thus also for the determination and sequence of competing locations.

43. This variant of the comparative method is especially suitable when determining optimal industrial and other locations where locational factors are equal or where there are only a few decisive factors of location. It thus shows its applicability for operative and practical cases of determining the location.

In such a way it is not only easier to obtain the final result, but it also becomes comprehensible and logical, creating the impression of an objective approach.

44. It might prove dangerous to oversimplify or encourage inadvisable vigour in selecting the relevant factors. "Unimportant" locational factors must not be forgotten as this might result in either incomplete or incorrect data creating a basis for inaccurate locational decision-making.

45. On the other hand, if the choice of the relevant location factors and parameters is made competently, the abridged comparative method will prove to be of great practical advantage in all cases where individual location is being chosen; there are several phases in the process of application of the abridged comparative method.

Defining the locational task

46. A prior condition for a successful application of the abridged comparative method means to define the task clearly and in advance. Although it can be also applied in some specific cases, it is basically to determine the optimal among numerous possible locations for a certain industrial activity or project. To select the location that enables minimizing of the costs of losses or maximizing of the economic effects is one of the most frequent tasks in applying this and other locational methods.

The preliminary selection

47. When determining the best of the possible locations through the abridged comparative method, it is often possible to simplify the task beforehand. One must first eliminate those competing locations that do not meet the basic locational conditions. For example, when building an integrated steelworks, the minimal necessary ground would be 300 hectars, its carrying capacity at least 2 kilograms per square centimetre, minimal water supply of 2 cubic metres per second and so on. Other technical conditions can be determined in advance for whole series of factories or units. Elimination of the locations that cannot meet economically such needs, or other locational needs, can, in some cases, lead not only to a simplification of the task but also to the definite solution.

Determination of the relevant locational factors

48. A correct choice of the relevant locational factors, that is decisive parameters, is of the greatest importance for the efficiency and quality of the given results through the abridged comparative method. Besides a proper selection and elimination of the less important factors, one must also divide the selected locational factors into quantitative and qualitative factors.

49. Quantitative factors are those from which locational activity can be measured or quantified. They can be introduced into an exact or mathematical operation and directly related; that is, they can be compared. Preliminary operations of putting locational activities of more relevant quantitative factors under a common denominator are often necessary. Most often it is a type of scale of values, but it can also be some natural common scale such as kilometres or tons per kilometres, for example. When production costs, investment costs, transport costs and other costs are taken as relevant quantitative factors, these would be suitable parameters for a subsidiary mathematical technique.

50. In order to measure the locational optimality on the basis of the scale of values of parameters, one must differentiate between recurrent costs and non-recurrent costs.

51. Recurrent costs are those that are repeated in the whole period while the unit is in existence. Their size depends on the characteristics of each location, regardless of their relation to the business conditions (productional parameters, transport costs) or conditions of exploitation (exploitation costs, transport, energy supply exploitation costs and others). They are usually measured in equal temporal intervals, mostly annual. Although transport costs can be taken to represent these costs, all other costs that are repeated throughout the duration of the working capacity of the selected location are also to be taken into consideration (production costs, maintenance costs and permanent losses, for example).

52. Expressed mathematically the general form for the value of these costs would be:

$$C_r = C_{r_1} + C_{r_2} + \dots + C_{r_n}$$

C_r = recurrent costs; n = number of years

53. Non-recurrent costs are closely connected with those relevant locational factors of location whose activity is manifested in one moment, such as investment costs.

54. Some locational factors manifest their locational force in both ways, that is their activity happens only once (value of investment costs) or is a permanent activity of recurrent costs. The supply of water or electrical energy means different costs on different locations. Maintenance costs, losses and other costs for the supply of water and electrical energy are recurrent costs, being repeated at intervals. That is why the activity of one and the same quantitative factor can be manifested in both ways.

55. Locational factors that cannot be measured by objective means such as working skills and industrial atmosphere of a certain location are qualitative. It is difficult to find their common element, but any comparison lacking this element is impossible to make.

Comparison based on quantitative factors

56. The aim of each exact method of determining location is to obtain an equal result in relation to all quantitative factors. In order to reach that aim one must first place various locational activities under a common denominator. Synthesizing recurrent and non-recurrent costs can in our example be done in two ways.

57. Non-recurrent costs, as for example investment costs, can be reduced to temporal costs, this being achieved through the process of determining the annuities.(17)

58. In this way non-recurrent costs are given their temporal value; consequently, they are characterized by the same feature as are the recurrent (annual) costs. Only after both types of costs have been reduced to their term of common value can they be summed up. The given results for any number of competing locations can be compared in order to determine their locational optimality.

59. Recurrent costs can be accumulated into one sum by reducing all temporal costs to the present value. Recurrent costs, (production costs, transport costs, exploitation costs) are repeated throughout the whole period when the unit subject to location is being used. These costs are discounted on the present value which enables their direct summing up and comparison with non-recurrent costs, such as investment costs.

60. For such an analysis one must, for the unit subject to location, determine what is the economic expectation of life that is at the same time the capitalization term. For the same purpose, one must determine the profitability rate for the branch of activity (it will also be the rate of interest for discounting the recurrent costs). Thus, discount term and rate of interest enable recurrent costs to be reduced to the present value by applying the classical formula for discounting:

$$T_n = A \frac{r^n - 1}{r^n(r-1)}$$

T = total costs; A = amount of annual expenses; n = number of years; $r = (1 + \frac{P}{100})$

61. The mathematica expression would be as follows:

$$C = C_i + C_r$$

$$C_n = C_i + C_r \cdot IV_p^n$$

C = costs; C_i = investment costs; C_r = annual recurrent costs; n = number of years; IV_p^n = discount coefficient in Spitzer tables.

62. The amounts obtained in such a way on the basis of the equal relevant parameters make a direct comparison possible. Comparing the quantitative results gives an insight into the level of optimality of a certain location. Quantification of the activity of all of the relevant factors as it exists is no doubt the best way to determine the most optimal of all locations.

63. An example of the application of the abridged comparative method on the basis of chosen quantitative factors has been set forth in a study. The study considers the sequence of seven competing locations for a planned steelworks on the Yugoslav coast.(18) Table 2 gives the sequence of the competing locations in accordance with the optimality, based on quantitative parameters.

A review of the global locational optimality

64. When consideration is given only to quantitative locational factors, some important locational factors with qualitative characteristics may fail to be taken into consideration, such as the industrial atmosphere, applicability for further expansion, the birthrate in the region and supply of local manpower.

Taking these factors into consideration is methodologically difficult and can lead to subjective judgement in determining locational importance. However, these should not be disregarded; review and consideration will be given to the comparative method as a means of their locational activity.

65. The qualitative locational factors cannot be quantified; consequently, the very possibility of the simple synthesizing with other relevant locational factors does not exist In cases where these factors have a predominant influence upon the optimal results to determine a location, this might prove to be a real difficulty in seeking the objective result.

66. The abridged comparative method can be met most often when such methodological difficulties are involved. It is helpful to decide first what would be their real impact upon the quality of a location. In such cases the system of points is used to determine the locational importance of these locational factors.6/

67. It is much easier when the pointing of qualitative factors means only a correction of the sequence of locations and the results achieved on the basis of quantitative, measurable parameters. A direct pointing of all of the relevant locational factors (quantitative and qualitative) is incompatible with the research ideas that demand greater reliance on quantitative methodological ways. Determination of the objective locational result shows us that only as little as possible of the subjective element is to be considered in such research work; this means that locational activity of each of the factors should be objective.

68. Naturally, there would not always be need to apply, or be able to apply, such strict criteria. Neither can the locational importance of qualitative factors be neglected.

69. In order to get a better insight into the technique of synthesizing the results achieved on the basis of determining the locational activity of both

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6/ In the postwar period there were several reviews published of the point system in locational research. They appeared first in American economic literature. An outstanding example is given in Industrial Management, by A.S. Knowles and R.D. Thomson, New York, 1944, pp.52-73.

kinds of locational factors, examples of such a method follow. This would in fact, be a correction or complement to the results from tables 1 and 2, both achieved on the basis of quantitative factors.

70. It is necessary first to distribute the total amount of points among the qualitative and quantitative factors. By the analysis of such a locational example it has been determined that from 1,000 possible points, the quantitative factors share 800 points (for the most suitable location D, table 2). The most suitable location can gain a further 200 points on the basis of qualitative factors. This is the case with the C location of the given example in table 3). In order to get the most objective results, the pointing should be performed by commission, later, points of each of the locations may be compared.

71. Table 3 shows that the limited influence of the locational factors with qualitative characteristics has caused a correction of the achieved results and sequence of locations based on quantitative factors. Locations under D and C have rotated in the scale of the locational optimality (table 2 and table 3).

III. PROGRAMMING METHODS FOR GROUP INDUSTRIAL LOCATIONS AND ALLOCATION OF INDUSTRY

72. Much less time has been devoted to the development of theories and methods of programming group industrial locations than to investigation of industrial locations. Weber was aware of that area of locational problems,(19) yet during the two following decades no significant activity took place. The problems of group industrial locations and the allocation of industry were tackled only after Lösch, Ohlin and others, and after planned industrialization had been initiated by the Union of Soviet Socialist Republics. These are still the most dominant problems of contemporary locational economy.

73. The problems of programming group industrial locations are numerous and complicated. They multiply rapidly due to the intensity of modern industrial development. Advanced methodology faces increasingly complicated tasks. These are the main obstacles that prevent a simple and quick development of new techniques in programming group industrial locations and the allocation of industry.

Table 1

Locationally relevant recurrent costs of seven competing locations

Location	Exploitation costs				Transport costs				
	Electrical energy	Supply of water	Supply of lime-stone	Total	Sea fares	Road fares	Railway fares	Total	Total
A	3.23	2.40	2.90	8.53	4.43	-	80.55	84.98	93.51
B	1.97	2.03	2.78	6.78	0.83	0.64	74.95	76.42	83.20
C	2.90	3.44	3.44	9.78	0.83	-	84.30	85.13	94.91
D	2.22	1.03	3.10	6.35	1.58	-	81.50	83.08	89.43
E	2.22	5.18	2.87	10.27	2.43	1.20	82.26	85.89	96.16
F	2.01	1.90	3.93	7.84	1.58	0.24	80.84	82.66	90.50
G	2.22	1.31	2.75	6.28	-	-	84.69	84.69	90.97

Table 2

Sequence of seven competing locations

(based on quantitative parameters)

Millions of new dinars

Location	Exploitation and business costs: Annual cost	Exploitation and business costs: Present value	Locationally relevant investments	Total relevant costs	Difference in accordance with minimal location	Order of locations with regard to optimality
A	93.51	848.79	362.13	1,210.92	+ 180.89	VII
B	83.20	755.21	442.60	1,197.81	+ 167.78	VI
C	94.91	861.50	201.81	1,063.31	+ 33.28	II
D	89.43	811.76	218.27	1,030.03	-	I
E	96.16	872.85	295.60	1,168.45	+ 138.42	V
F	90.50	821.42	247.56	1,069.03	+ 39.00	III
G	90.97	825.74	336.39	1,162.13	+ 132.10	IV

Table 3

Final order of the seven competing locations

(based on quantitative and qualitative factors)

Location	Quantitative result: Value in millions of new dinars	Quantitative result: Points (80%)	Qualitative result (20% of points)	Total of points	Corrected priority order
A	1,210.92	680	79	759	VII
B	1,197.81	688	87	775	VI
C	1,063.31	775	200	975	I
D	1,030.03	800	166	966	II
E	1,168.45	705	110	815	V
F	1,069.03	771	105	876	IV
G	1,162.13	709	172	881	III

74. In the methodology of space planning the following problems must be differentiated: programming group industrial locations on the basis of their technological and economic connexions; and efficiency of space allocation of industry.

75. Differentiated in such a way, problems of group industrial locations were solved in various ways by applying corresponding methods of programming. The results obtained in creating specific techniques for programming that kind of industrial location, are not sufficient. For this reason, the use of quantitative economic analysis is still important.

76. Bearing in mind the two groups of problems already mentioned, two specific methods for solving locational problems can be pointed out. These are industrial complex analysis of the Isard type, and spatial models in allocating the industry. Economic analysis can serve as a basis for both, although each approaches modern mathematical methods in a different way, especially in investigating the final results and effects. Other methods, especially modern mathematical ones, can be of considerable help.

Quantitative analytical methods

77. Intensive industrial development and the process of industrialization bring about new locational problems and features. Different approaches and new methods in programming industrial locations are being created. These locational techniques are concerned with programming group industrial locations regardless of whether they are called industrial complexes, combinates, industrial centres, focuses of development or anything else.

Industrial complexes analysis

78. The industrial complexes are a group of industrial activities and individual locations which, from the technological and economic point of view, form a unit. French economist Jean Chardonet was the first to give a detailed analysis of these complexes.(20) He also paid more attention to the complex agglomerative industrial problems - to which Weber and some other theoreticians of the older school paid only sporadic attention - than to individual problems. However, Chardonet's analysis is still within the limits of classical economic analysis, as it does not even touch on the problems of quantitative measurement in industrial complexes. The industrial complex analysis, as elaborated and applied by Isard and his co-operators, represents this type of methodological

system for investigating group industrial locations and their problems.(21) This methodological approach is still kept within the limits of quantitative economic analysis. Industrial complex analysis comprises many methods including quantitative ones, such as the comparative costs analysis, and the input-output technique. These methods are also applied in analysing final results.

79. Owing to its complex approach and flexibility, this technique of programming can be applied in different cases of research done for group industrial locations. The possibility of quantifying the expected results through this method is of vital importance for both locational programming and investment decision-making. For example, the comparative advantage of the so-called "Dacron A" in Puerto Rico, when compared with the second best variant, was estimated to have a yearly net profitability of $US 311,000.(22)

80. The technique of programming industrial aggregates as shown above can help a great deal to solve these locational problems, but it cannot provide the solution for all group locations. Exact locational results depended on exact subsidiary methods rather than on the industrial complex analysis as a whole.

Other quantitative and analytical techniques

81. Professional literature of the Union of Soviet Socialist Republics analyses the method of programming group industrial locations in the same way. These analyses remain mostly within the limits of classical economic analysis. They comprise the analysis of technical parameters of location rather than quantitative analytical elements.(23) The analysis of focuses of development, established as a part of the regional theory in France, shows similar characteristics.

Spatial models

82. Industrial agglomerations and complexes still represent, as a rule, just one of the forms of group industrial locations. There still remains the problem of discovering methods that would serve to solve the problems of programming group industrial locations for a whole territorial or regional unit and answer the question, "How can all industrial enterprises or industrial capacities of a region be economically or even optimally allocated?" Besides general analytical methods, spatial models can also be used in programming the locations.

83. In spite of a difference in the aim and scope of construction and application, the method using spatial models can be considered as a specific instrument in programming group industrial locations. In countries with a planned economy, the method of spatial models helps to determine the most economic locational realization of the industrial development plans.

84. When trying to determine the most economic distribution of coal in the United States, Henderson adopted this method, although he omitted some of its specific features.(24) A similar path was followed by Marschak to determine the best productional effects in the oil industry.(25) In both of these cases suitable mathematical methods were used to find those spatial solutions that would produce maximum economic effects. Both Böventer and Lefeber wished to determine the general spatial balance in a similar way, yet their work differed; emphasis, however, was laid on the theoretical solution of the problem.(26) Spatial models can be arranged in three essential groups:1/ homogenous, heterogeneous and complex.

<u>Homogenous spatial models</u>

85. The subjects of research in this group are units and activities of the same kind, although territories may vary. Homogenous spatial models require the most economic allocation of similar factories in a country or region, such as steelworks, refineries, or cement factories, for example. These are the so-called spatial models of industrial groups. At the moment, this sort of spatial model provides the greatest achievements and the most exact results and effects of spatial allocation in a region or country.

86. This method can also be applied to solve problems of distribution of various tertiary economic and non-economic activities, such as laundries or medical centres within an urban area, or the allocation of hospitals in a region or country.

1/ Böventer, in his "Theorie des räumlichen Gleichgewichts" (page 2) divided them into "Totalmodelle" and "Partialmodelle".

87. Due to its relative simplicity, the homogenous spatial models method is at the moment the only one to be applied in programming that type of industrial locations.8/

88. The application of the spatial models method demands corresponding analytical preparations. It comprises the definition and volume of the subject investigated (for example, allocation of sugar mills or cement factories in a country). The scope of the method must also be determined: minimizing transport or locationally relevant production costs, and maximizing productional output and so on. The cuality of the results obtained depends not only on the analysis of the given situation but must also take into account the variations in quantity and size of objects and factories in a given region.

89. Final results of the model are given through the application of the mathematical programming method, most often through the so-called transport model of linear programming. The elaboration of the corresponding algorithms depends on the type of subject and task; the final result depends mostly on the correct choice of locational factors or parameters.

8/ Simultaneously with the elaboration of the current five-year plan of the economic development in Yugoslavia (1966-1970), homogenous spatial models are being elaborated for some locationally relevant groups. This is being done in order to check whether this method could be applied in the locational realization of the planned programme of industrial development. The author of this paper has also prepared a basic methodological study for the needs of Federal Planning Bureau, Beograd.(27)

90. To obtain the locational distribution of a homogenous industrial group, for example the cement industry of a region, in which a harmonious relation exists between production and consumption, a mathematical solution can be found within the limits of the one-stage closed transport model. The general form would be as follows:

1. $\text{Min } T = \sum_i \sum_j c_{ij} \; x_{ij}$ provided that

2. $\sum_i x_{ij} = b_j$ $\quad j = 1,2,\ldots\ldots n$

3. $\sum_j x_{ij} = a_i$ $\quad i = 1,2\ldots\ldots m$

4. $\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j$ $\quad x_{ij} \geq 0$

T = total costs, c_{ij} = matrix elements, x_{ij} = transported quantities of cement from the producer "i" to the consumer "j", a_i = capacity of producer "i", b_j = needs of the consumer "j"

91. In this way we obtain the commuting areas of specific consumers; by introducing a fictitious consumer j = n+1, we get the most economic distribution of productional centres.

92. The mathematical solution will take a different form provided that optimality of the location does not depend entirely on marketing the goods, but also on providing raw materials. In such a case, the so-called double-stage transport model will be used. The mathematical formula would be as follows:

$$\text{Min } T = \sum_{i=1}^{r} \sum_{j=1}^{\ell} c_{ij} \; x_{ij} + \sum_{i=r+1}^{m} \sum_{j=\ell+1}^{s} c_{ij} \; x_{ij}$$

$i=1,\ldots\ldots, r$ = delivery of raw material; $j = 1,\ldots\ldots \ell$ = processing of raw material; $i = r+1,\ldots\ldots m$ = processing of raw material by the producers of final goods; $j = \ell + 1, \ldots\ldots s$ = consumers of the final product.

93. Naturally, different problems that appear in programming group locations will require different procedures which is of no essential importance here as all of them remain within the limits of mathematical programming of the linear and non-linear type. This is, at present, the only way of gauging the optimum variant of distribution.

Heterogeneous spatial models

94. This method involves investigation of economic activities or industrial groups. The method is often concerned with seeking the maximum effects of distribution of several or all groups of industry in any region. In such a case, several industrial institutions or factories belonging to different branches of industry can be subject to investigation; these would comprise the contents of two or more homogenous spatial models. At the moment, there is no specific methodology in programming such group industrial locations other than classical economic analysis.

Complex spatial models

95. This method includes the whole territory or region; it could be roughly identified with methods of regional planning. A detailed discussion of such models is unnecessary as they do not strictly belong to the techniques of industrial locations programming.

Modern mathematical methods

96. The aspiration towards exact locational results directed the theory of location from the very beginning towards a full use of mathematical methodical means. Thünen developed a whole bookkeeping system that would quantify his locational results. The mathematical section is one of the composite parts of Weber's main work "Über den Standorts der Industrien". A number of other theorists directed their research mainly towards improving those methods.

97. Modern development of space economy was also accompanied by an adequate development of quantitative methods; mathematical theorems became a part of the industrial locations programming technique.

98. A dynamic and complex approach to locational problems prevents static and schematic solutions. Thus, the dynamic economic analysis, with the final results greatly quantified, remains the basis of research and programming for

almost all types of locations. Mathematical methods, applied in quantifying the results, are becoming an indispensable tool in almost all fields of locational research.

99. Mathematical programming must be emphasized among the modern mathematical methods relevant to economic research. The transport model in linear programming gained vital importance in programming some locations, especially in quantitative and analytical locational methods. Other mathematical methods and theorems can be given only a sporadic role in locational research.

100. In general, the application of mathematical methods, including mathematical programming, is still used in scientific work rather than in practical solutions of locational problems. This applies particularly to the programming of group industrial locations, in finding the optimal solutions in the allocation of industry. One must bear in mind that the process of applying modern mathematical methods in programming locations is still at the research stage, and further results can be expected.

Conclusion

101. Although considerable achievement has been made in improving a number of methods for industrial locations programming, still no universal methodological means or "ready-made" schemes exist that could be applied to solve all locational problems. This lack has not been caused by imperfect techniques in programming and determining location, but rather by various locational problems, constant changes of locational conditions and varying degrees of importance attached to locational factors.

102. However, there do exist locational problems that can be solved in a simple way. In some cases, such as operative programming of industrial locations, text-books and indicators compiled specifically for spatial research can be used.(28) One thing is certain, schematic and hasty locational solutions and hasty location programming do more harm than good.

103. Quantitative economic analysis still represents the best methodology to be applied to the needs of industrial locations programming. Many exact methods can be efficiently applied within the limits of this method.

104. The type of locational problem determines the methodology chosen. Although a number of possible techniques in programming industrial locations are given in this paper, the author does not wish to imply that there are no other locational methods that can be used for the same or a similar purpose.

Chart

Major techniques in industrial location programming

Basic methodological approach	Locations programming methods: Individual locations	Locations programming methods: Group locations
	Quantitative economic analysis	
I. Quantitative-and-analytical approach	Comparative method	-
	-	Industrial complex analysis
	-	Planning models analysis
II. Mathematical approach	Classical mathematical methods	-
	Polivector method	-
	-	Linear programming
	Subsidiary mathematical methods	

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29. 6. 72