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# Economic-Mathematical Model for Establishing the Technical Material Supply Plan*

*"The technical material supply represents a decisive factor for the normal development of the activity of enterprises, for the complete using of production capacities".*

**Nicolae Ceauşescu**

The achievement of industrial production in the established volume and structure is conditioned by the ensurance of an adequate technical-material supply as regards volume and structure and in a tempo correlated with that of industrial production. In this way, the formation of redundant stocks is avoided, on the one hand and certain breaks in production through the lack of some assortments of materials are eliminated, on the other.

To this purpose, it is necessary to know before hand the volume and structure of production in keeping with the established programme of industrial production and to determine the supply stages, correlated with the rate of the planned industrial production.

The methods used for establishing the necessary materials may be grouped into the following categories:

1. The dynamics of the necessary materials in time, that is the establishment of a relation of the form:

$$M_i = f(t) \tag{1}$$

for the considered period. The method is based on the establishment of an annual increase coefficient-constant or variable in time-of the requirement for a certain main assortment "i" of material and it is used for medium or long-term prognoses, usually through the extrapolation of a series of pre-

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vious consumptions. The results have the character of an orientation and cannot represent a sure basis for a technical-material supply.

2. The dynamics of the requirement for materials through correlations with other synthetic indicators of the national economy whose law of variation in time is considered to be known or easy to determine. Usually, the correlation between the total consumption of certain material and the indicator of increase in the industrial production is used. This method is currently used and applied for short or medium periods of time, yielding satisfactory results. In this case, the results obtained, though more certain can however represent a basis for a technical-material supply only in case that the structure of production remains unchanged. The finalization of the supply plan is made with the establishment of the production plan. Its disconsideration is leading, for certain assortments of materials, to redundant stocks and for others to delays in supply. The aleatory elements are mainly determined by the fact that the change in the structure of the industrial production from a period to another, through the introduction of products at other prices and of specific consumptions of materials, determines at the same value of production a change in the established necessary materials.

The application of this method on a macro-economic scale, may, however, lead to acceptable results, being less influenced by the value and range structure; upon its use in each concrete case, it needs corrections for ensuring a concordance between the production targets and the technical-material supply.

As this method is often used, the compensation of errors is usually made through the creation of stocks distributed on territorial stores and on the stores of some plants. But, this is leading to an increase in the circulating funds and to the blocking of some quantities of materials in the economic circuit.

3. The necessary materials by totalizing the demands for materials in various industrial production subbranches, the latter being established on the bassis of the consumption norms or of the specific consumptions of materials and the knowing of the structure of production in the respective subbranches. This method has an „analytic" character leading to much better results; the exactness of the method may be extended by increasing the level of the detailed and thorough examination of the initial data. The method is applied especially in the countries with a planned economy which, through the plan, dispose of data on the growth of the production volume.

The utilization of the method implies a very big volume of data and laborious calculations. They no longer represent disadvantages today, since a national information system has started being organized in each country, possessing big capacity electronic computers and adequate economic-mathematical models.

In the following, an analytic method and a mathematical model are proposed for determining the necessary materials for a certain period of time, based on the specific consumptions of materials and on the production plan.

A. *Rule of the Method*

The total requirement of materials is established by totalizing the necessary materials in various production branches, un their turn, being established on the basis of the dynamics of the planned production

$$V = f_1(t) \tag{2}$$

and of the dynamics of the specific "$g$" consumptions of materials

$$g = f_2(t,\ x_1,\ x_2 \ldots x_n) \tag{3}$$

where:

$t$ represents time;

$x_1, x_2, \ldots, x_n$ — other parameters directly influencing the evolution of the specific consumptions of materials.

The most general case of the variation in time of the specific consumptions of materials has been taken into consideration.

The method thus implies the knowing of the dynamics of the output of products or groups of products of the branches of economy and, in this connection, the measures recommended for the achievement of a planned production.

"Normed specific consumptions" will be used for establishing the necessary materials. This requirement will be brought up to date, on the basis of the improved consumption norms, taking intro consideration the re-designing of products, the new technological methods adopted, etc., which contain altogether, the parameters "$x$" of function (3).

Each industrial production branch is characterized by a list of "$n$" typodimensions of products $P_i (i = 1,\ 2, \ldots, n)$.

At the same time, in each industrial branch, the manufacturing of a product or family of products is achieved through "$v$" technological processes ($j = 1, 2, \ldots, v$) specific of the branch.

A specific consumption $g_{ij}$ of a certain material "$k$" ($k = 1, 2, .., m$) will result for each product or family of products and for each technological process.

The total need of the material "$k$" for the industrial production branch will thus be expressed by a relation of the form:

$$G_k = \sum_{i=1}^{n} \sum_{j=1}^{v} V_{ij} g_{ij} \tag{4}$$

and for all industrial production branches ($l = 1, 2, \ldots, q$)

$$G'_k = \sum_{l=1}^{q} G_{kl} \tag{5}$$

B. *Dynamics of the Industrial Production*

To establish the dynamics of the industrial production of a branch and within it, of the sub-branches, plants, families of products and products, the volume and structure of the production obtained in the basic year (for

example, the last year of the expired five-year plan) are taken into consideration as a starting point and for the following period, respectively the considered stage, the production figures envisaged in the plan for the development of the industrial branch, subbranches and the respective families of products. The analysis of the production growth must establish the material conditions ensuring the carrying out of the plan targets, that is specify the possibilities for obtaining a production surplus with the aid of the existing production capacities, by improving the technical-economic indices of their utilization and, according to necessities, by putting new production capacities into operation. For both cases, it is necessary to specify the characteristic technical-economic indicators and the weight with which various capacities will contribute to achieving the planned production.

Thus, it is necessary to specify those technological processes which influence the specific consumptions of materials to be used for obtaining the product $P_i$ as well as the weight with which they will contribute to the production $V_i$ of the product considered, that is to specify the partial $V_{ij}$ productions corresponding to the technological methods used.

The evolution in time of production is characterized by the average annual rate of increase, which is established by the plan of development. The growth of production may be considered.

1. at a constant rate, that is:

$$\frac{V_t}{V_{t-1}} = \alpha \tag{6}$$

2. with a constant quota:

$$V_t - V_{t-1} = \beta \tag{7}$$

the index "$t$" referring to any year of the considered period

$$t_0 < t < t_f \tag{8}$$

in which $t_0$ and $t_f$ represent the initial and final years of the considered period.

1. In case that an annual increase at a constant rate (6) is considered, the dynamics of production will be given by the expression of a geometrical series having the ratio $\alpha$

$$V_t = \gamma\alpha^T \tag{9}$$

in which $\gamma$ is a constant value, and

$$T = t - t_0. \tag{10}$$

Expression (9) is the general form of an exponential function; coefficients $\gamma$ and $\alpha$ are determined on the basis of conditions:

— intial, that is in the basic year $t = t_0$, we have $T = 0$ and the production will be

$$V_t = (V_t)_0;$$

thus:

$$(V_t)_0 = \gamma\alpha^0$$

since $\alpha^0 = 1$ it results: $\gamma = (V_t)_0$; (11)

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— final, that is in the final year $t_f$ of the period

$$T = t_f - t_0 = T_f,$$

the production will be

$$V_i = (V_i)_f.$$

By replacing in (9), we obtain:

$$(V_i)_f = (V_i)_0 \alpha^{t_f - t_0} = (V_i)_0 \alpha^{T_f}$$

where:

$$\alpha = \left[\frac{(V_i)_f}{(V_i)_0}\right]^{\frac{1}{T_f}} \tag{12}$$

In this case, expression (9) becomes:

$$V_i = (V_i)_0 \cdot \left[\frac{(V_i)_f}{(V_i)_0}\right]^{\frac{T}{T_f}} \tag{13}$$

or, taking into consideration that $\frac{(V_i)_f}{(V_i)_0} = K$ represents the indicator for the increase of production for the entire period of time (also established through the plan of development) it results:

$$V_i = (V_i)_0 K^{\frac{T}{T_f}} \tag{14}$$

2. In case that the evolution of production is taking place by annual increases with constant quantities, that is lineary, its dynamics will be given by the equation of a straight line, thus by an expression of the form:

$$V_i = a + bT \tag{15}$$

where "$a$" and "$b$" are constant values which are also determined on the basis of conditions:

— initial, $t = t_0$, $T = 0$, thus $V_i = (V_i)_0$
— final, $T = t_f - t_0 = T_f$, respectively $V_i = (V_i)_f$.
Introducing these values in expression (15) we obtain:
— for the initial conditions:

$$(V_i)_0 = a + b \cdot 0,$$

from where results:

$$a = (V_i)_0; \tag{16}$$

— for the final conditions:

$$(V_i)_f = (V_i)_0 + bT_f.$$

from where results:

$$b = \frac{(V_i)_f - (V_i)_0}{T_f} \tag{17}$$

Introducing values a and b in (15) results:

$$V_i = (V_i)_0 + \frac{(V_i)_f - (V_i)_0}{T_f} T \tag{18}$$

Noting by $\Delta$ the increase of production in the final year as compared to that of the basic year:

$$\Delta = (V_i)_f - (V_i)_0 \tag{19}$$

expression (18) becomes:

$$V_i = (V_i)_0 + \Delta \frac{T}{T_f}. \tag{20}$$

C. *Dynamics of the Specific Consumptions of Materials*

The dynamics of the specific consumptions of materials is established by setting out from primary data similar to those mentioned for the dynamics of the manufacturing of products. These are the statistical data of the level of the specific consumptions of materials in the basic year and the data resulting from the analysis of the levels of specific consumptions at the end of the period for which the necessary materials are established. To make this analysis, it is necessary to take into consideration the main factors influencing the specific consumptions of materials, among which:

— the character of the technological processes the utilization of which is envisaged in the long-term period;

— the redesigning of the product;

— the level of mechanization and automation;

— the introduction of welded constructions, of by-products, of plastics respectively;

— the improvement of norms and standards.

The determination of the specific consumptions of materials at the end of the considered period is possible because the methods and equipment may be specified in establishing the dynamics of the production taken into consideration, respectively their technological characteristics with the aid of which it will achieved as well as the share of the contribution of each of them to the total production of the family of products or of each product.

Supposing that for the echievement of the representative product $P_i$ at the end of the period ($T = T_f$) "$v$" technological processes are used, each of them characterized by specific consumption ($g_{ijk}$) of certain material "$k$",

to which corresponds a certain volume of production $(V_{ij})_f$, the average specific consumption of a certain material $k$ for the product $P_i$ will be:

$$(g_{ik})_f = \frac{\sum_{j=1}^{v} (g_{ijk})_f (V_{ij})_f}{(V_i)_f} \tag{21}$$

where:

$$(V_i)_f = \sum_{j=1}^{v} (V_{ij})_f. \tag{22}$$

The determination of the specific consumptions of materials is made on the basis of the analysis of the technical indicators characteristic of the respective products. Setting out from the same initial condition of the product (the same construction of the product) a minimum specific quantity "$h$" of a certain material is necessary, which is, in fact, the quantity of ready-made parts entering the composition of the respective product and which is made of this material. This is the ideal case, when the material might be obtained in such a way as to be directly used in the construction of the product. In reality, a quantity "$g$", bigger than "$h$" is consumed for obtaining the considered product, resulting a subunitary relation "$\eta$" of the specific consumption. Among the proportions $h$, $g$, $\eta$, there is a relationship of the form:

$$\eta = \frac{h}{g} \tag{23}$$

Taking into consideration that for the achievement of a certain product, "$h$" has a constant value (in a certain stage of its constructive evolution), expression (23) represents an equilateral hyperbole; thus, it results that the variation of the specific consumption "$g$" of a certain material is made in keeping with $\eta$. As the consumption "$g$" of a certain material — for the same product has a decreasing tendency in time, it results that also $\eta$ varies in time $[\eta = \varphi(t)]$. This has an increasing tendency towards the ideal maximum value ($\eta = 1$), the values characteristic of a given moment being determined by technical-economic factors.

Hence the variation in time of relation $\eta$ may be expressed by a relation of the form:

$$\eta = \frac{1}{pr^T + s}, \quad r < 1, \tag{24}$$

where $p$, $r$ and $s$ are constant values determined through the limit conditions, namely:

— for $T = \infty$, the ideal situation is reached in which $\eta = \eta_\infty = 1$; introducing in (24) and as $r < 1$, $r^\infty = 0$
it results

$$s = 1 \tag{25 a}$$

— for $T = 0$, that is at the beginning of the period ($t = t_0$), $\eta = \eta_0$ and taking into consideration (25a) from (24), we obtain

$$p = \frac{1 - \eta_0}{\eta_0} \tag{25 b}$$

— for $T = T_f$ that is at the end of the period ($t = t_f$), and using values of $s$ and p(25a) and (25b) from (24)
$\eta = \eta_f$ we obtain:

$$r = \left[\frac{\eta_0(1 - \eta_f)}{\eta_f(1 - \eta_0)}\right]^{\frac{1}{T_f}} \tag{25 c}$$

Introducing values $p$, $r$, $s$ in (24), it becomes:

$$\eta = \frac{1}{\frac{1 - \eta_0}{\eta_0}\left[\frac{\eta_0}{\eta_f} \cdot \frac{1 - \eta_f}{1 - \eta_0}\right]^{\frac{T}{T_f}} + 1} \tag{26}$$

or, expressing $\eta$ in keeping with the specific consumptions of materials at moments $T = 0$ and $T = T_f$, respectively $g_0$ and $g_f$, and also in keeping with the specific consumption "$h$" of materials in relation (23), $\eta_0 = \frac{h}{g_0}$ and $\eta_f = \frac{h}{g_f}$ are obtained. Introducing these values in (26) we obtain

$$\eta = \frac{h}{(g_0 - h)\left[\frac{g_f - h}{g_0 - h}\right]^{\frac{T}{T_f}} + h}. \tag{27}$$

From expression (23), it results $\eta = \frac{h}{g}$ and introducing this value in (27), this becomes

$$g = (g_0 - h)\left[\frac{g_f - h}{g_0 - h}\right]^{\frac{T}{T_f}} + h. \tag{28}$$

noting:

$$\left.\begin{aligned} g_0 - h &= g_0^* \\ g_f - h &= g_f^* \end{aligned}\right\} = \text{processing waste} \tag{29}$$

we obtain:

$$g = g_0^*\left[\frac{g_f^*}{g_0^*}\right]^{\frac{T}{T_f}} + h. \tag{30}$$

It results from relation (30) that for a certain product, the specific consumption of materials has in time a variation with an exponential character, tending towards the "$h$" limit value of ready-made parts.

It was considered above that the manufacturing of the product is taking place in the entire period on the basis of the same constructive solutions implying the ideal "$h$" specific consumption of material; if in the respective period, redesignings appear, characterized by the ideal specific consumptions $h_1 \dots h_n$ ($h > h_1 \dots > h_n$) of a certain material, then the passing on from a construction to another of the product is reflected in the variation of the "$g$" specific consumption.

On this basis, the total need $G_{ikt}$ of a certain material "$k$", for the manufacturing of production $V_{it}$ of the product $P_i$, in the year "t" will be given by the relation:

$$G_{ikt} = g_{ikt} V_{it} \tag{31}$$

Taking into consideration the variations admitted as possible for the dynamics of production and of the specific consumptions of materials, expression (31) becomes:

— in case of the variation of production with the anual constant rate (14):

$$G_{iki} = \left\{ g^*_{iko} \left[ \frac{g^*_{ikf}}{g^*_{iko}} \right]^{\frac{T}{T_f}} + h \right\} V_{io} K^{\frac{T}{T_f}} \tag{32}$$

— in case of the variation of production by annual increases with a constant quota (20):

$$G_{ikt} = \left\{ g^*_{iko} \left[ \frac{g^*_{ikf}}{g^*_{iko}} \right]^{\frac{T}{T_f}} + h \right\} \left[ V_{io} + \Delta \frac{T}{T_f} \right] \tag{33}$$

The dynamics of the total need of a certain material "$k$" for the whole branch, respectively for the "$n$" products is expressed by:

$$G_{kt} = \sum_{i=1}^{n} G_{ikt} \tag{34}$$

The above-mentioned relations may be used for establishing the necessary materials for the considered period of time.

Since, usually, it is the values of the specific consumptions and of the total need of materials that are of interest, only for certain characteristic years, it is not necessary to establish always the law of variation in time of these consumptions; it is enough to determine the values of the consumptions of materials only for the considered years.

The establishment of the needs of materials by using the mentioned analytic method implies a big volume of calculations, because of the complexity both of the list of products and of that of materials for various industrial branches. That is why, a mathematical model is presented for establishing the necessary materials, a model allowing both the separate

outlining of each assortment of material on products, plants, subbranches and branches and their totalization with a view to establishing the total needs for the entire industrial production.

## MATHEMATICAL MODEL BASED ON SPECIFIC CONSUMPTIONS

Generally, for the obtaining of the product $P_i$ included in the production plan of an industrial branch, several kinds of materials are used, characterized by the specific consumptions $g_{1i}, g_{2i}, \ldots g_{ki} \ldots g_{mi}$, where indices 1, 2,... $k$ ... $m$ refer to the kind of materials. The notion of "material" is used in the most general sense of the word, including raw materials, semifinised products, materials of any kind supplied by a certain plant from various suppliers for achieving the product $P_i$. The specific consumptions "$g$" are expressed in natural units on production unit of the product $P_i$.

"The normed specific consumptions" on kinds of materials for the "$n$" representative products of the industrial branch may be registered in a matrix with m lines and n columns of the form

$$g_{ki} = \quad k = 1, \ldots, m \quad i = 1, \ldots, n \qquad \left\| \begin{matrix} g_{11} & g_{12} \cdots & g_{1i} \cdots & g_{1n} \\ g_{21} & g_{22} \cdots & g_{2i} \cdots & g_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ g_{k1} & g_{k2} & g_{ki} & g_{kn} \\ g_{m1} & g_{m2} \cdots & g_{mi} \cdots & g_{mn} \end{matrix} \right\| \tag{35}$$

Each branch will have a matrix of the type (35) characterizing the specific consumptions $g_{ki}$ of materials of the n products. Matrix (35) being considered the matrix of the branch, the matrices of the subranches of the respective branch will be the submatrices of the matrix of the branch and the matrices of the plants will be the submatrices of the matrices of the subbranches.

As in a certain year, not all $n$ products are included in the production programme of the branch, of certain subbranches, of some plants respectively, part of the elements of matrix (35) will be naught, just as for a certain product some of the specific consumptions of materials of matrix (35) will be naught.

It is worth mentioning that each line of matrix (35) refers to a certain kind of materials for the total products on the list of the branch; and each column refers to the totality of the kinds of materials for a certain product on the list of the branch.

What is of interest is the establishment, for a certain yearly production plan, of the total consumptions of the (necessary) materials on kinds, these determining the technical-material supply plan of the respective year, on branch, on subbranches and on plants.

These total (necessary) consumptions of materials will result from the multiplication of matrix (35) of the specific consumptions of materials by the column vector $\| V_i \|_{n,1}$ of the annual plan of production respectively

expressed by productions $V_i$ of each product $P_i$ for each branch, respectively for each subbranch and for each plant in the respective branch. The column vector $\| G_k \|_{m,1}$ will be obtained

$$\| G_k \|_{m,1} = \begin{Vmatrix} g_{11} & g_{12} \cdots & g_{1i} \cdots & g_{1n} \\ g_{22} & g_{22} \cdots & g_{2i} \cdots & g_{2n} \\ \vdots & \vdots & & \vdots \\ g_{k1} & g_{k2} \cdots & g_{ki} \cdots & g_{kn} \\ \vdots & \vdots & & \\ g_{m1} & g_{m2} \cdots & g_{mi} \cdots & g_{mn} \end{Vmatrix} \cdot \begin{Vmatrix} V_1 \\ V_2 \\ \vdots \\ V_i \\ \vdots \\ V_n \end{Vmatrix} = \begin{Vmatrix} G_1 \\ G_2 \\ \vdots \\ G_k \\ \vdots \\ G_m \end{Vmatrix} \tag{36}$$

This product, respectively the column vector $\| G_k \|_{m,1}$ will give the necessary material for the considered year of the various kinds of materials for the whole branch, its subbranches and their plants.

Centralizing the total consumptions $G_k$ on kinds of materials of each branch, the total consumption $G_k'$ will be obtained for all industrial branches and the technical-material supply plan of the respective year will established.

For making all calculations in due time, it is necessary to use a big capacity electronic computer.

It results from the presentation of the mathematical model that the information material, which is initially necessary is that currently used. It consists of:

a. The codes and list of products of each branch.

b. The codes and list of raw materials, materials and of the inter-plant material collaborations necessary for achieving the production on the list of each branch.

c. The system of specific consumptions of raw materials, of materials, etc. for the products on the list of each branch.

d. The primary cards for the products on the list of each branch, with the respective code and which should contain all the specific consumptions of raw materials and materials.

All this information must be stored on card indexes which should allow easy access (cards or punched tapes, tapes or magnetic discs).

The data base being thus perfected, in can continuously be brought up to date with minimum effort.

Using the above-mentioned informational system, the proposed mathematical model will be able efficiently to solve a big number of problems of greatest importance, on the scale of the national economy, on the scale of each branch, subbranch and plants in the respective branches; for example, it will be able to determine in a co-ordinated way both the yearly production programmes and the dynamics of their development:

— the necessary materials on assortments and kinds;

— the production capacities of the material supplying plants for satisfying the supply plan;

— the plan for the import of materials;

— the plan for the export of materials, resulting from the production plan and from the needs of the home production;

— the plan of inter-plant collaborations;

— the possibility of improving the production plants in keeping with certain resources of materials, raw materials and inter-plant collaboration;

— the relations among branches.

The utilization of the proposed mathematical model will require an action which will gradually and systematically be carried out after the previous establishment of codifications under a)—d), beginning with the plants of a subbranch, then with the subranches, continuing with the branches and ending with the entire industrial production. This action will have to be included in the national information system.

We consider that the proposed mathematical model allows the introduction of its utilization gradually until its generalization on the whole industrial production; it establishes both the yearly technical-material supply plans and the long-term plans, based on the production plans of each branch.

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## MODELE ECONOMIQUE MATHEMATIQUE POUR ETABLIR LE PLANNING D'APROVISIONNEMENT TECHNIQUE-MATERIEL


L'approvisionnement technique-matériel doit se dérouler dans un rythme corrélé avec le rythme de la production industrielle pour tous les assortiments, évitant, d'une part, les stocks excedents et d'autre part éliminant les étranglements de la production faute de certains assortiments de matériel.

Pour obtenir une meilleure organisation scientifique de l'approvisionnement technique-matériel on propose un modèle mathématique utilisant un système informationnel à base de „consommation spécifiques". On crée de cette façon les prémisses d'une répartition rationnelle des moyens matériels par rapport aux ressources existantes et aux nécessités des branches de l'économie nationale, permettant l'utilisation des ordinateurs.

Le modèle mathématique proposé permet l'emploi pour la résolution de l'approvisionnement technique-matériel, tant pour toute l'économie, que pour les branches et les entreprises.


## МАТЕМАТИЧЕСКАЯ МОДЕЛЬ ДЛЯ УСТАНОВЛЕНИЯ ПЛАНА МАТЕРИАЛЬНО-ТЕХНИЧЕСКОГО СНАБЖЕНИЯ ПРОМЫШЛЕННОГО ПРОИЗВОДСТВА


По темпам роста их промышленного производства социалистические страны являются одними из первых стран Европы и мира. Достижение подобных темпов стало возможным вследствие научного установления решений экономической политики с тем, чтобы обеспечивать высокую норму накопления, все лучшее использование материальных и людских ресурсов каждой страны, повышение производительности труда, рост эффективности всей экономической деятельности.

Выпуск промышленной продукции разнообразной номенклатуры обусловлен обеспечением материально-технического снабжения с таким же обширным объемом и еще бóльшим разнообразием.

Темпы этого снабжения должны быть увязаны с темпами промышленного производства по всему ассортименту с избежанием, с одной стророны, сверхнормативных запасов, а с другой стороны — с устранением узких мест производства по причине отсутствия определенных сортов материалов.

С этой целью необходимо заранее знать потребность и структуру материалов в соответствии с запланированной программой промышленного производства и устанавливать этапы снабжения в увязке с этой программой производства.

Для научной организации материально-технического снабжения предлагается математическая модель с применением информационной системы на основе удельных расходов. Таким образом, создаются предпосылки для рационального распределения материальных средств в соответствии с существующими ресурсами и потребностями отраслей народного хозяйства и становится возможным использование электронных вычислительных машин.

Предлагаемая математическая модель может быть применена для разрешения задач материально-технического снабжения как по народному хозяйству в целом, так и по отраслям и предприятиям.