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Static and Dynamic Aspects of the Problem of Establishing the Production Rates*

The solving of the complex problems of production efficient programming implies the establishment of economically most adequate production rates.

The notion of rate is conceived conventionally, accepting the static hypothesis according to which no problems of succession and spacing out in time appear, all production capacities at a given moment being supposed available.

On the basis of this simplifying hypothesis the following problems can be solved satisfactorily:

— the establishment of the production rates in the hypothesis of a given plan, with secured resources;

— the establishment of the production rates when the resource supplying levels are known.

The taking into account of the dynamic hypotheses has led to the necessity of adopting Forrester's industrial dynamics techniques which are presented in the last part of the work.

The applications were carried out at an enterprise in the electrotechnical machine-building industry.

1. INTRODUCTION

The efficient programming of production represents one of the main preoccupations of specialists in management and organization. Although it was scientifically approached twenty years ago, no agreement was reached so far on the definition of production efficient programming. Moreover, one has not succeeded in the least in clearly delimiting the sphere of problems to be tackled by the efficient programming of production. Nevertheless, there are some ways of formulating the problem of production efficient scheduling accepted by most specialists [2]. One of the ways of putting the problem grasps the *static* aspects of production efficient programming and it can be

* M. Stoica has also contributed to working out the model.

summed up as follows: considering the production capacities of an enterprise (section) for a certain period, the quantities of finished products demanded by various end users, the manufacturing technologies concerning these products and the necessary data on the possibilities for supply with raw and related materials, the optimum plan for the respective period should be established, namely the optimum quantities of products from each assortment. Obviously, this way of putting the problem is based on certain hypotheses almost impossible to turn into practice. Thus, it is considered that all production capacities are free at any moment to be used in the achievement of the new product. However, practically, the *dynamic* aspect appears due to the frequent overlapping of products and semifabs which have to be processed by the same production capacity which results either in the stocking of components which have to be processed after a certain time interval or in the awaiting of the production capacities. Consequently, the "optimum" plan resulting from the static model can almost never be practically achieved. Nevertheless, the static method may be useful in many situations, because it provides general information on the maximum production the enterprise (section) would succeed in obtaining under the ideal conditions of eliminating the expectations.

We may distinguish two situations in practice within the problems with a static character:

1) the carrying out of a given plan considering that each resource can be secured;

2) the carrying out of a plan workable at the level of the effectively available resources.

The substantiation of the plan obtained by static methods may be achieved by considering the dynamic aspects of the problems of production efficient programming (the spacing out in time of the necessary resources, the spacing out of the processing operations within the limit of the before known available resources, stocking problems, inter-operations, etc.).

A method of checking the initial solution obtained by considering the static aspects consists in appyling the industrial dynamics techniques of a Forrester type.

2. ESTABLISHING THE PRODUCTION RATES UNDER THE CONDITIONS OF A GIVEN PLAN, WITH SECURED RESOURCES

It is considered that the enterprise's plan is known and the manufacturing technology is well defined. On the basis of the quantities planned for a given time period and of the specific consumptions the necessary resources for that period are established.

In this case, due to the very big volume of data, the calculation of the necessary resources is likely to be made with the aid of a program system existing within the electronic equipment. Thus, the BOMP program package is used for the IBM system, the ORACLE program package is used for the FELIX 256 system and the PROMPT package for ICL.

The experiment was made on the IBM/370 computer by using the BOMP files [5], namely:

— the main file of articles,
— the file of structures,
— the file of operation routes,
— the file of jobs.

The production plan can be given for a month, decade, week or for a three day interval.

After each calculus of the necessary resources considered for a given period of time the rate equations can be written and calculated in the form:

$$\text{Rate for a certain resource} = \frac{\text{stock subunit}}{\text{the considered time stock}}$$

In the rate equations written in this way, for simplification, a perfect rhythmicity and uniformity are supposed.

3. ESTABLISHING THE PRODUCTION RATES UNDER THE CONDITIONS OF CARRYING OUT A PLAN WORKABLE AT THE LEVEL OF THE EFFECTIVELY AVAILABLE RESOURCES

The situation is frequently met in practice because during the implementatiton of the plan certain deviations may appear between the quantity necessary at a given moment and the effectively available one. The initial production plan will be changed according to these deviations. Finally, the initial plan will be changed an up-dated plan resulting which we shall call a *workable plan.* To work out this workable plan we start from the following input data:

— the production plan initially proposed for a certain period;
— the stocks of materials, the subunits estimated for a certain period of time;
— the estimation of the labour force available on jobs for the period which has been taken into account.

On the basis of the initially proposed plan, the necessary materials and labour force corresponding to this plan are established with the aid of the BOMP program package.

Following some comparisons between the estimated necessary and available materials and labour force, differentiated on resources, situations of a deficit or surplus may appear. Knowing these data, the decision-making factors will take additional measures for obtaining the deficit resources or for redistributing the surplus ones. Following such an analysis which is made for a small number of resources, especially the key resources *the definitely estimated available* resources can be calculated for which the *workable plan* will be calculated.

The calculus algorithm for the workable plan is the following:

Step 1: The calculus of the necessary resources for an initially given plan.

Step 2: The comparison of the outfit resulting from the calculus with the definitely estimated availability for the period taken into consideration.

Step 3: The establishment of the balancing coefficient.

We denote: p_{ji} — the weight of stock j for product i
NEC_{ji} — the necessary stock of resource j for product i
Q_i — the quantity of product i planned to be produced in the plan period

Resulting: $$p_{ji} = \frac{\text{NEC}_{ji} \cdot Q_i}{\sum_i \text{NEC}_{ji} \cdot Q_i}$$

Step 4: The distribution of the available stocks (smaller than the necessary ones) in keeping with a weight aggregate coefficient (λ_i) which is assuming real values.

We denote: S_j — the existent stock (given on the list drawn up by the decision-making factors)
S_{ji} — the stock of resource j for product i
$S_j = \sum_i S_{ji}$.

Resulting: $$S_{ji} = \frac{\text{NEC}_{ji} \cdot Q_i \cdot \lambda_i}{\sum_i \text{NEC}_{ji} \cdot Q_i} \cdot S_j$$

Step 5: The establishment of the number (Q_r^i) of jobs (certain finished products) which can be carried out with the existing stocks in the priority order.

$$P_i \rightarrow \min \left[Q_i, \frac{S_{1i}}{\text{NEC}_{1i}}; \frac{S_{2i}}{\text{NEC}_{2i}}; \frac{S_{ji}}{\text{NEC}_{ji}}; \frac{F_A}{C_{iA}}; \frac{F_B}{C_{iB}} \cdots \right] = Q_i'$$

where: F_A, F_B ... represent the available labour force on jobs
C_{iA}, C_{iB} ... the necessary time for a certain job for the manufacturing of the subunits, semifabs included into product i.

Step 6: The calculus of the remaining stock (S_{ji}'')

$$Q_i' \times \text{NEC}_{ji} = S_{ji}'; \; S_{ji} - S_{ji}' = S_{ji}''.$$

Step 7: Stock S_{ji}'' is redistributed after which step 5 is repeated.

According to the quantity of products/week resulting from these calculations, the chief of section will establish the rate of products, semifabs, parts on the desired time unit (day, shift).

4. THE PROGRAMMES SYSTEM USED

For a practical solution of the previously formulated problem, a programme system is necessary which should take into account the input data into the model, the equations of the model, the form of the desired results. The scheme of the system of programs may be followed in figure 1. As input data into the system we have: the list of jobs, subunits which are produced in the respective period, the available list of stocks (components of jobs) for the respective period, the data in the BOMP files, the monthly plan.

The data contained into the BOMP files [5] refer to: descriptive information of all components (for example, code, denomination, measure unit contained into the files of articles), to the structure of each unit and subunit (for example parent code, component code, specific consumption, etc. contain-

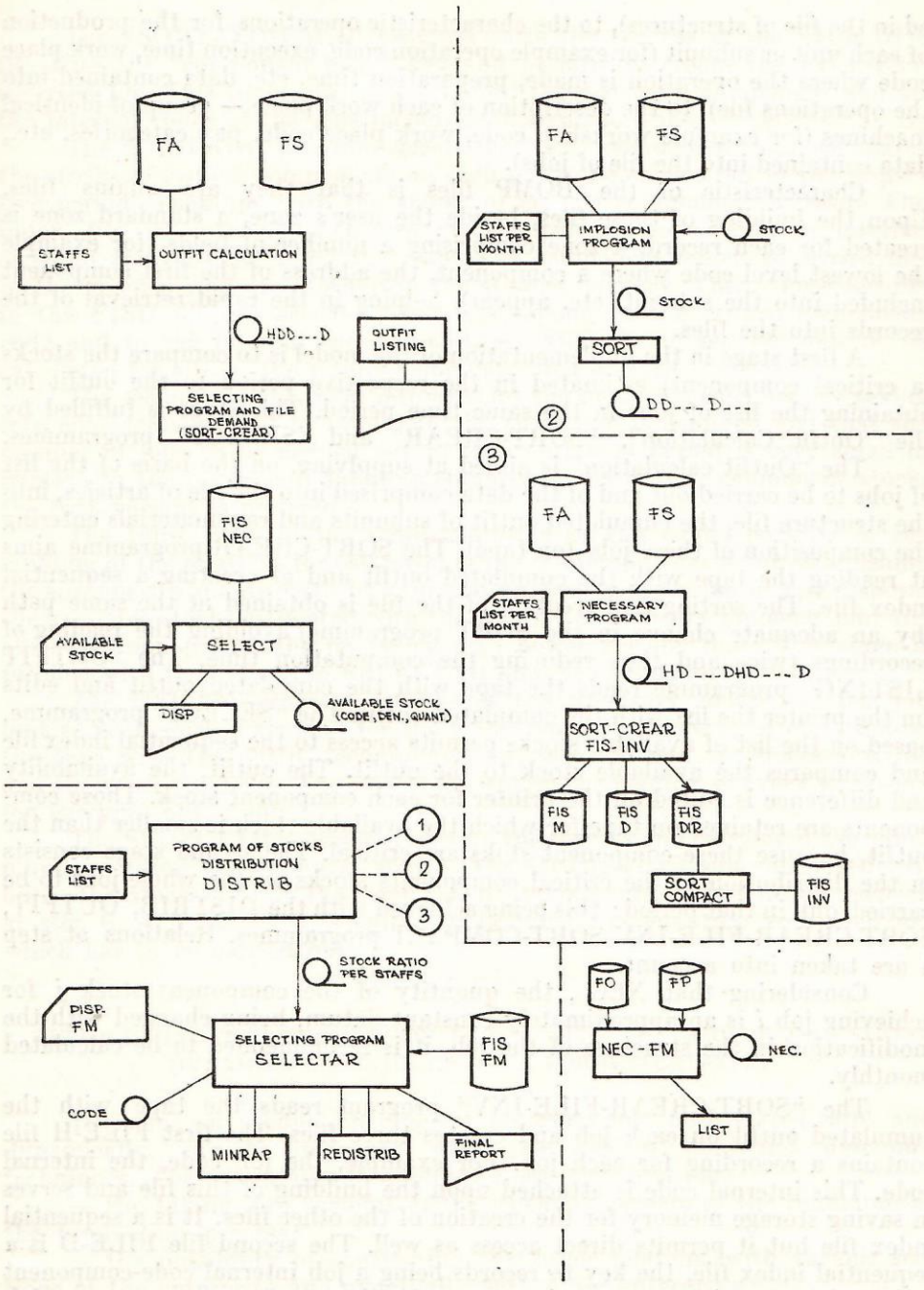

FA
FS
STAFFS LIST
OUTFIT CALCULATION
HDD---D
OUTFIT LISTING
SELECTING PROGRAM AND FILE DEMAND (SORT-CREAR)
FIS NEC
AVAILABLE STOCK
SELECT
DISP
AVAILABLE STOCK (CODE, DEN., QUANT)
FA
FS
STAFFS LIST PER MONTH
IMPLOSION PROGRAM
STOCK
STOCK
SORT
DD---D---
2
3
FA
FS
STAFFS LIST PER MONTH
NECESSARY PROGRAM
HD---DHD---D
SORT-CREAR FIS-INV
FIS M
FIS D
FIS DIR
SORT COMPACT
FIS INV
STAFFS LIST
PROGRAM OF STOCKS DISTRIBUTION DISTRIB
1
2
3
STOCK RATIO PER STAFFS
DISP. FM
SELECTING PROGRAM SELECTAR
FIS FM
FO
FP
NEC - FM
NEC.
CODE
MINRAP
REDISTRIB
FINAL REPORT
LIST

Fig. 1

ed in the file of structures), to the characteristic operations for the production of each unit or subunit (for example operation code, execution time, work place code where the operation is made, preparation time, etc. data contained into the operations file), to the description of each work place — group of identical machines (for example workshop code, work place code, pay categories, etc., data contained into the file of jobs).

Characteristic of the BOMP files is that they are chains files. Upon the building of these files, beside the user's zone, a standard zone is created for each record, a zone comprising a number of fields (for example the lowest level code where a component, the address of the first component included into the subunit, etc. appear), helping in the rapid retrieval of the records into the files.

A first stage in the implementation of the model is to compare the stocks (a critical component) estimated in the respective period to the outfit for obtaining the list of jobs in the same time period. This stage is fulfilled by the "Outfit Calculation", "SORT-CREAR" and "SELECT" programmes.

The "Outfit calculation" is aimed at supplying, on the basis of the list of jobs to be carried out and of the data comprised into the file of articles, into the structure file, the cumulated outfit of subunits and raw materials entering the composition of these jobs (on tape). The SORT-CREAR programme aims at reading the tape with the cumulated outfit and at creating a sequential index file. The sorting and creation of the file is obtained at the same path (by an adequate change in the SORT programme) avoiding the reading of recordings twice and thus reducing the computation time. The "OUTFIT LISTING" programme reads the tape with the cumulated outfit and edits on the printer the list with the cumulated outfit. The "SELECT" programme, based on the list of available stocks permits access to the sequential index file and compares the available stock to the outfit. The outfit, the availability and difference is edited on the printer for each component stock. Those components are retained on tape for which the available stock is smaller than the outfit, because these component stoks are critical. The second stage consists in the distribution of the critical components stocks on the whole jobs to be carried out in that period; this being achieved with the DISTRIB, OUTFIT, SORT-CREAR-FILE-INV SORT-COMPACT programmes. Relations at step 4 are taken into account.

Considering that NEC_{ji}, the quantity of the component stock j for achieving job i is an approximately constant datum, being changed with the modification in the structure of the job, it is recommended to be calculated monthly.

The "SORT-CREAR-FILE-INV" program reads the tape with the cumulated outfit on each job and creates three files. The first FILE-H file contains a recording for each job. For example, the job code, the internal code. This internal code is attached upon the building of this file and serves in saving storage memory for the creation of the other files. It is a sequential index file but it permits direct access as well. The second file FILE-D is a sequential index file, the key to records being a job internal code-component code and it contains the quantity accumulated of each component on a job unit. The third FILE-DIR file contains as records the pairs of codes: internal code-recording code.

The "SORT-COMPACT" program sorts the records in the FILE-DIR file after the "component code" key and permits to create the FILE-INV inverted file. This file contains as a record the code of a component and all the internal codes of the jobs including this component.

The "DISTRIB" program selects the NEC_{ji} components and calculates the stocks of critical components on each job to be carried out in the respective period. Thektape with the stocks of critical components is read. The index file is acceded with critical component code and the internal codes of the jobs including the respective component which is carried out in the given period are selected in the storage memory. Then, those records in the FISD file are acceded which correspond to the critical component code and to the internal codes, quantities NEC_{ji} being selected and S_{ji} is calculated for all i-s; the results being deposited on tape.

The second variant takes into account the implosion calculus. By taking into consideration that at implosion the entire file is explored and that the number of jobs to be carried out in the considered period is very small in relation to the number of subunits comprising the critical component stock, the first variant is prefered.

The third stage in the implementation of the model consists in the building of the relations for establishing the minimum, that is for establishing the appropriate quantities to be achieved on each job, having at our disposal the available stocks estimated with the priority coefficients for each job, the available man power, the necessary man power per job unit. This stage is fulfilled with the aid of the SELECTAR and NEC-FM programmes.

The NEC-FM program establishes the necessary manpower per job unit at each work place and for the whole workshop, having at our disposal the tape with the outfit accumulated on each job and the operations file and the work place file. The FIS-M file enters the loading at every workshop for carrying out a job.

The SELECTAR program draws up the reports and calculated the minimum according to relation at step 5. The REDISTRIB subroutine redistributes the stocks left at the next job by taking into consideration relation at step 6. A final report is edited underlining the quantity from each job which has to be carried out.

5. ESTABLISHING THE PRODUCTION RATES WITH THE AID OF INDUSTRIAL DYNAMICS TECHNIQUES (OF A FORRESTER TYPE)

Decisions on production efficient programming, both statistically and dynamically, can be improved with the aid of industrial dynamics techniques. The advantages in appliyng these techniques are:

— the taking into account of the dynamic aspects of the unfolding of the production process;

— the possibility of considering any other relations with various sections of the enterprise and eventually with other enterprises;

— the possibility of keeping a record of the various perturbative factors in a certain time period (the lack of labour force, lack of materials, lack of semifabs, etc.);

— the checking of the proposed strategies and the selection of suboptimal strategies (on production efficient programming);

— the analysis of the stability of the production system in time, etc.

However, it should be mentioned that the application of the Forrester techniques has some disadvantages too, the most important of which are:

— great difficulties in establishing a common measure unit of the production obtained at various work places or sections;

— the increased probability of making inadmissible errors in selecting some conventional measure units;

— the relatively big duration for preparing the data and for calculation in case an analysis is pursued in natural units or closer to the natural units;

— the necessity for the managerial staff of the enterprise to acquire the industrial dynamics techniques.

But, all these disadvantages can be gradually overcome with the application of the method. The essential advantage of the application of the Forrester techniques consists in the possibility of establishing the evolution of the state of the production system, all the variables of the elaborated model representing time functions.

At the initial moment $T = 1$ (the first day of the plan period) all variables are considered to be known. The time period for which simulation may be applied with the aid of the Forrester techniques is the plan month. It has been agreed that the time interval be a day ($T = 1$ day). Thus, it has resulted that 25—26 simulation cycles should be carried out, the equivalent of the effectively worked days.

To exemplify the application of the industrial dynamics techniques, a technological process with a restricted number of work places has been considered, according to figure 2.

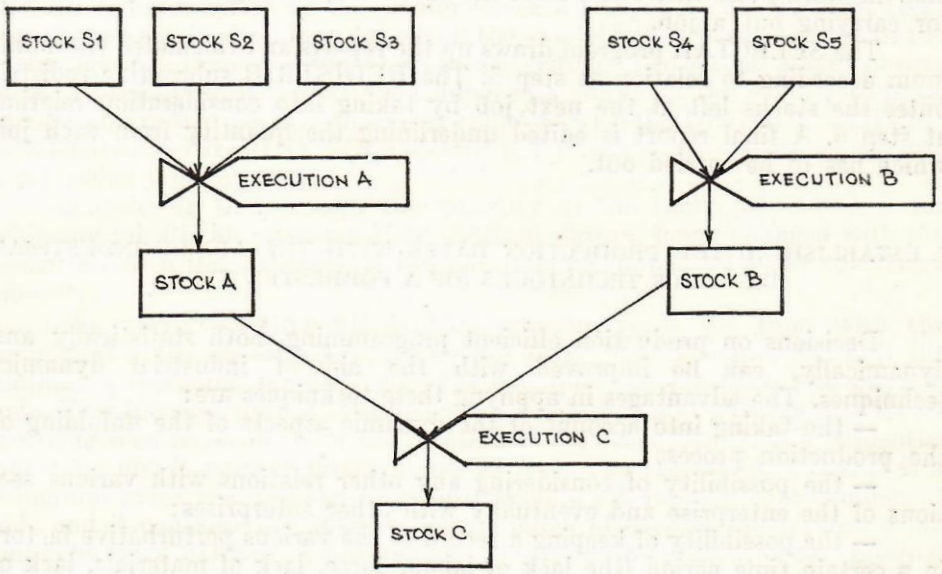


Fig. 2

The dynamic conduct of the modelled technological process may be described with the aid of a set of equations (state equations of the model) made up of level, rate and auxiliary equations.

A. **Level equations** permit the establishment of stocks every day. The general form of a level equation is [3], [7]:

$$S^j(t) = S^j(t-1) + \sum[R^I(t-1) - R^E(t-1)]\Delta T$$

where

ΔT	represents	the time interval in which simulation is carried out with the aid of the Forrester techniques (1 day);
$S^j(t-1)$, $S^j(t)$	—	the existent stock at moment $t-i$, respectively moment t, for resource j;
$R^I(t-1)$	—	the rate of inputs at moment $t-1$;
$R^E(t-1)$	—	the rate of outputs at moment $t-1$.

B. **The rate equations** are used in establishing the quantities obtained every day in keeping with the available resources. Generally, the rate equations are of the from [3], [7]:

$$S^j(t) = \text{Min}\left[\text{Min}_i\left(\frac{S^{ij}(t)}{C_s^{ij} n_s^j F T_j}\right);\ \frac{FMD_j(t)}{CFM_j(t)};\ \alpha_j(t)\frac{Q_{rj}^t}{TD_{rj}^{(t)}}\right]$$

where:

$S^{ij}(t)$	represents	the stock from resource i, distributed at work place j;
C_s^{ij}	—	the specific consumption at work place j for resource i;
FT_j	—	the time stock per shift at work place j;
n_s^j	—	the number of shifts at work place j;
$FMD_j(t)$	—	the available time stock at work place j;
$CFM_j(t)$	—	the consumption of labour force at place j for producing a unit of semifab j;
$Q_{rj}(t)$	—	the quantity left to be produced at moment t, calculated with the aid of relation;

$$Q_{rj}(t) = Q_{pj}(T) - Q_{ej}(t)$$

where:

$Q_{ej}(t)$	represents	the quantity effectively produced from job j until moment t;
$Q_{pj}(T)$	—	the planned quantity of job j until moment t (where T is the planned period, for example 26 working days);
$TD_{rj}(t)$	—	the available time left for j at moment t;
$\alpha_j(t)$	—	the dynamic coefficient.

C. **The auxiliary equations** permit the generation of random variables (such as is the case of the available labour force), the generation of random trajectories (such as is the case of the dynamic coefficient) $\alpha_j(T)$ in time, the generation of conditioned strategies, the establishment of the values of the economic efficiency function, etc.

Thus, a uniform random variable (or normal if it is the case) between two statistically established limits is generated for the available labour force.

In case of the dynamic coefficient $\alpha_j(t)$ (linear, exponential, etc) functions can be established and then, for each case $t = t_i$ $(i = 1, 2, ..., T)$ a random residue (comprised between two given limits, for example 0.01—0.3) be added or deducted.

An example of the generation of a conditioned strategy can be given for labour force. If the minimum of the rate equation is achieved for the random variable $FMD_j(t)$ and if the plan is not fulfilled, in this case the available time stock on shift (FT_j) is increased by 2 hours.

* * *

Production efficient programming represents a complex of preoccupations concerning the theoretical and particularly the practical solution of problems for the establishment, launching, control and up-dating of the optimum production plan on very short time periods, at an enterprise, section and team level by taking into account the technological aspects, the aspects concerning the necessary and available resources, the ergonomic and psycho-sociological aspects.

This is the consideration for which the introduction of modern modelling methods and the electronic data processing in the efficient programming of production should be done gradually, by tackling for the beginning the statical and then the dynamic aspects, by accepting for the beginning the solving of the practical problems on aggregate modules and by accepting an analytical tackling only in a subsequent stage.

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ASPECTS STATIQUES ET DYNAMIQUES DU PROBLEME DE LA DETERMINATION DES RYTHMES DE FABRICATION

Trouver la solution des problèmes complexes de la programmation opérationnelle de la production implique la détermination de certains rythmes de fabrication, les plus avantageux du point de vue économique.

La notion de rythme est conçue de façon conventionnelle, en acceptant l'hypothèse statique, selon laquelle il n'y a pas de problèmes de succession et de décalage dans le temps, toutes les capacités de production étant supposées disponibles à un moment donné.

Ayant pour base cette hypothèse simplificatrice on peut résoudre d'une manière satisfaisante les problèmes suivants:

— détermination des rythmes de fabrication ayant les ressouces assurées dans l'hypothèse d'un plan arrêté;

— détermination des rythmes de fabrication lorsque les niveaux d'approvisionnement en ressources sont connus.

La prise en considération des hypothèses dynamiques a conduit à la nécessité d'adopter les techniques dynamiques industrielles de Forrester présentées dans la partie finale de l'ouvrage.

Les applications ont été effectuées dans une entreprise de l'industrie des constructions mécaniques à spécifique électrotechnique.

СТАТИЧЕСКИЕ И ДИНАМИЧЕСКИЕ АСПЕКТЫ ВОПРОСА УСТАНОВЛЕНИЯ ТЕМПОВ ФАБРИКАЦИИ

Разрешение сложных вопросов оперативного программирования производства предполагает установление наиболее соответвующих с экономической точки зрения темпов фабрикации.

Понятие темпа дается условно, принимая во внимание статическую гипотезу, согласно которой не возникают проблемы последовательности и расхождения во времени, все производственные мощности в определенный момент предполагаются использованными.

На основе этой упращающей гипотезы можно на удовлетворительной уровне разрешить следующие вопросы:

— установление темпов фабрикации при условии заданного плана и обеспеченных ресурсов;

— определение темпов фабрикации в том случае, когда известны уровни снабжения ресурсами;

Принятие во внимание динамических гипотез привело к необходимости использования динамической промышленной техники форрестера, которая дается в последней части работы.

Применение этого метода было проведено на предприятии машиностроительной промышленности электротехнического профиля.