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Optimization Problems of Current Calendar Planning

Lyudmila N. Rodionova[a], Olga G. Kantor[b] and Amir A. Khakimov[c]

[a]Faculty of computer science and *robotics*, Ufa State Aviation Technical University, Ufa, RUSSIA; [b]Institute of Social and Economic Research, Ufa Scientific Center of the Russian Academy of Sciences, Ufa, RUSSIA; [c]Chernyshev Moscow Machine-Building, Enterprise, Moscow, RUSSIA

ABSTRACT

The paper deals with the statement, formalization and implementation of the problem of choice and grounding of the technological equipment stock with account of organizational conditions of functioning. A criterion of optimal capacity load is chosen as one of the parameters. It is demonstrated how via transition from the problem of integer programming to the problem of linear programming, in which a feasible solution set is built in accordance with the described procedure, one can determine objectively determined valuations according to the results of application of the duality theory provisions and implement qualitative analysis of the produced solution.

KEYWORDS
Technological equipment, linear programming, calendar planning

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Introduction

Settlement of production planning problems is a determining factor that ensures efficient functioning of an enterprise. Methods of mathematical modeling in economics have been used for a long time in this sphere. Tools have been developed within these methods to settle quite a large number of typical problems. Problems on capacity load, assignment, transportation are among the well-studied ones in terms of methodology. It is evident that in real situation a number of existing features and certain conditions taking place at an enterprise should be taken into account. This might not allow putting the settled problem in the frames of a typical one, as “individual approach” will be required for its settlement.

An example of such a problem is the problem of optimal capacity load in the set timeframe at a large enterprise consisting of the set of production modules (Under “module” we shall understand a technological equipment batch (located

CORRESPONDENCE Lyudmila N. Rodionova rodion@ufanet.ru

at a stand-alone production department, workshop, line, etc) with a fixed assortment of parts, the manufacturing of which is performed on this equipment.). The complexity of this kind of problems is determined by several aspects: multivariance, lack of availability of resources, dynamic component.

Literature Review

The optimization problem set in this paper is a special case of the production problem of current calendar planning. A need for rational decision making with choosing one or several optimization criteria is driven by multivariance of production processes. A conventional approach formed during planning economy years and especially during the years of economy of scarcity is secondariness of organizational conditions of functioning as compared to engineering and technologies. The standards of current calendar planning were estimated basing on the existing technology and conventional production chains. The priority of the technology has become a norm for formation of temporal and spatial forms of production (Ghallab et al., 2004; Berry, 2011).

In the 80s of the previous century economists proposed a system of parameters that would rigidly fix the components of the production process: engineering, technology, form of organization, the so-called organizational and technical level of production. It abounded with the parameters which often doubled each other or were in evident correlation dependence. Universal and "low-function" character of the equipment contributed to formation of this tendency in the production organization theory (Sergeev & Veretennikova, 2006; Tolpegina, 2006 Methodology instructions, 1980; Satanovskiy, 1981; Zhuravlev, 2004; Rodionova, 1998).

Let us determine the boundaries of the studied process. In most cases organization of production means a rational combination of material and personal elements of production in space and time to output products in the required volume of high quality with the most effective use of all the resources allocated to an enterprise (Kozlovskiy, 1998; Latenko & Turovets, 1982). Some wordings note that the goal of production organization is implementation of plans (Smith, 2004).

Today one can find several notions similar in content and acting as measures of effectiveness of production organization. The notions are a production system development level, a local level of production development, a technical and economical level of production, a production maturity level, a scientific and engineering level of production, a technical level of production, an organizational and technical level of production, an organization level of production (Lvov & Satanovskiy, 1984).

The production system development level is a relatively new notion for Russia. It is connected with stable tendency for development of lean technologies at successful Russian enterprises. With no clear definition, it assumes the degree of exploitation of lean production principles at a specific enterprise and bears, as a rule, a subjective character. In scientific literature this notion has not gained a wide spread and will hardly gain, as within the theory of lean production there is a parameter that gives a quantitative estimate of the production efficiency – the parameter of the overall equipment effectiveness (OEE). OEE is a system of analysis of the overall effectiveness of equipment intended to control and enhance the production efficiency, and it is based on measurement and processing of specific production parameters («Calculating OEE» Vorne Industries, 2002). The OEE tools are widely used as key parameters of effectiveness (KPI).

The local level of production development is a system development of workplaces in the specific space and time of production provided with organization-technical and socio-economic conditions of effective functioning of the reproduction process in the set regime with the goal to create products, implement works, render services for the internal and external environments of an enterprise (Ulitskaya, 2000). Though this notion is close to the essence of the considered process, however (as it proceeds from the definition) it is not its quantitative estimate. N.M. Ulitskaya (2000) proposes constant measurement, determination and change of the quality of a workplace, which is realized in determination of its technical and economical level (TEL).

The technical and economical level of production is the technical and economical state of production at a specific period of time. The technical and economical level of production depends on the age structure of the applied productive facilities, its technical state, degree of mechanization and automation, progressiveness of the applied technological processes, quality of produced items and production efficiency, personnel skills level, organization of production and labor (Libman & Filatov, 1987). As it is seen this definition is close to the essence of the studied process, however, it has not gained wide spread in scientific literature (Turovets, Popov & Rodionov, 2000).

Materials and Methods

The level of organizational maturity of the production is a precisely determined evolution plateau on the way to full maturity of the production process (The Five Levels of Software Process Maturity as classified by the Capability Maturity Model, 1987). Depending on the organizational maturity of an enterprise, the degree of use of information and IT in its business processes is different. The degrees of organizational maturity are closely connected with the problem of quality assurance and quality control. A series of international standards ISO 9000, theory of TQM (Total Quality Management) and a CMM model (Capability Maturity Model) are the most well-known. There is tight relationship between them. At the end of 1987 the Software Engineering Institute (SEI, USA) at the Carnegie Mellon University in collaboration with the Mitre corporation within the cooperation with the US Defense Ministry issued a document that would later effect greatly the quality issues of information systems and requirements imposed on software companies. The document is named "Capability Maturity Model. The Five Levels of Software Process Maturity". It reflects the approach of its authors to the targets and criteria of evaluation of possibilities of different companies when producing software. The International Standard Organization (ISO) uses CMM to create international standards. The CMM model is close to the concept and theory of Total Quality Management (TQM) created by W. Deming, J. Juran and P. Crosby. To greater extent the TQM approaches are described in the standard ISO-9004:2000, which is a study guide for application of the quality system. ISO-9001:2000 contains the required minimum of requirements to meet the needs of consumers. There are fundamental differences between the ISO standards of 9000 series and the TQM concept. The main difference is that the TQM theory is one of the best methods in the world for quality management and is oriented to quality improvement in those cases, when some level is achieved, and introduction of the ISO standards of 9000 series is aimed at reduction of the probability of incorrect actions. As for the CMM, it is a well-recognized model of software production maturity, which comprises a set of corresponding criteria. However, due to closeness to the universal standards of ISO 9000 it can be quite reasonably applied to estimate the maturity level of any enterprise. Using the CMM approach one can classify the stages of enterprise development and existence depending on the way it processes and uses information during its functioning (Evgrafov, 2015).

The organizational level of production is a composite parameter that is characterized by the levels of concentration, specialization and cooperation of production, production lead time, continuity, uniformity and smooth flow of production, and the labor organization parameters (labor division factor, justification of norms, personnel stability and skill level at an enterprise, etc.) (Makeeva, 2003).

The organizational level of production is a quantitative estimate of the organization condition at the enterprise, in its production department (shop, area, division). The organizational level of production at the enterprise is characterized by the level of sophistication of production means used in the production process, the level of technological processes, the level of production organization and management, the efficiency level of the used means of management, application of scientific and technical achievements in production, the quality level of produced items (Stepanov, 2003).

To some extent this drawback has been overcome in the methodology proposed by R.M. Petukhov & E.S. Lazutkin (1972) in E.C. The authors guess that the level of organization can be estimated and measured quantitatively through the parameters characterizing the level of usage of main elements of material production - production assets, labour power - and approximation of the production cycle duration to the period required for implementation of all processes and operations envisaged by the technology. The authors build the system of parameters oriented at achievement of rather high economic results, however they do not explain the choice of the optimal organizational level of production (Petukhov & Lazutkin, 1972).

The multivariance of production starts from choice of one or several criteria, which suppose different variants of engineering and therefore technology with priority of the organization criterion. The maximum capacity load can be such a criterion (especially as high cost of equipment assumes functional redundancy), production lead time (economy is evident due to destocking, work in progress and other elements of floating funds) etc. But in any case the criterion suggests optimization on one of the elements of production such as work equipment, production objects and "labor" itself (main, current capital, and labor power) (Kallrath and Maindl, 2006; Shkurba, 2010).

If the production process at the enterprise is organized in such a way that one and the same part can be produced on different equipment (i.e. on different modules), then multivariance evidently takes place. With account of the fact that large enterprises have to make renovation of production capacities without discontinuing the production process, which results in simultaneous work of several types of equipment (old and new ones) at least for some period of time.

Thus, sooner or later the problem of production multivariance at a large enterprise becomes urgent (Evgrafov, 2015).

Objectively, there is always a problem of destocking (money, materials, labor, etc.) for any enterprise. Several production modules make the problem more complicated.

The account of influence of the dynamic component is conditioned by the necessity to meet the production targets during the whole set period of time with account of available resources.

Results and Discussion

Let us state the problem of optimal capacity load for the set period of time at a large enterprise consisting of a set of production modules from the point of minimization of aggregate costs.

Full range of equipment available at the enterprise will be considered in the breakdown according to its belonging to a certain model range (type). The quantity of equipment models will be noted as n.

The whole range of equipment should be divided into R sets, each of which will be used during the whole time in one regime. The number of possible work variants of each equipment set depends on its type.

The enterprise needs to produce m sets of parts during the period of time $[0, T]$. We shall assume that each set of parts is produced only by one set of equipment. Such approach is justified if the set of parts is known and deviations are not acceptable.

It should be noted that such situation is typical of enterprises specialized in implementation of large and expensive orders. In such cases it is inefficient from the economical point of view to state a problem of maximization of the output volume. The efforts should be concentrated on settlement of the main problem faced by the enterprise. The main problem is organization of production so that to ensure manufacturing of a required quantity of products due to optimal organization of the production process with the available resources.

The optimality criterion will be the aggregate costs borne by the enterprise during the production process. Knowledge of the way the equipment breakdown into sets should be performed will help the enterprise to increase the level of production fitting out and efficiency of corresponding logistic activities, which in its turn will contribute to improvement of the existing production and planning of technical re-equipment and reconstruction of its separate parts.

Let us introduce the following notations.

j – the number of the equipment model , $j = \overline{1, n}$;

r – the equipment set number, $r = \overline{1, R}$;

l – the number of the work variant of the r-th set of equipment, $l = \overline{1, L_r}$;

i – the number of the set of parts set, $i = \overline{1, m}$;

t – the period of time within which the capacity load should be optimized, $t = \overline{1, T}$;

x_{ir}^{l} – the Boolean variable that demonstrates if the l -th variant of work of the r th set of equipment is accepted to produce the i -th set of parts;

a_{ijrt}^{l} – the number of equipment items of the j th model comprised in the r th equipment set at the l th variant of its work to produce the i th set of parts in the t -th period of time;

c_{ir}^{l} – the costs connected with use of the r -th set of equipment at the l -th variant of its work to produce the i -the set of parts;

K_{irt}^{l}, C_{irt}^{l} – the capital and current costs at the t th period of time connected with implementation of the l -th variant of work of the r -th set of equipment to produce the i -th set of parts;

E_H – the norm coefficient of capital investment efficiency (Here a conventional criterion of costs estimation is used. But in real optimization problems, it is possible to use a net present value);

Π_{irt}^{l} – the costs at the t -th period of time for reconstruction of the stock connected with implementation of the l -th variant of work of the r -th set of equipment to produce the i -th set of parts;

b_{jt} – the quantity of available equipment of the j -th model at the t -th period of time;

$P_{irt}^{l}\left(x_{ir}^{l}\right)$ – the quantity of workers required at the t -th period of time to produce the i-th set of parts by the r-th set of equipment operated according to the l-th variant of work;

P_t – the limited number of workers engaged to produce the required set of parts in the t -th period of time;

$S_{irt}^{l}\left(x_{ir}^{l}\right)$ – the production area for manufacturing the i-th set of parts by the r-th set of equipment operated according to the l-th variant of work at the t th period of time;

S_t – the size of actual production area at the t -th period of time;

In terms of the introduced notations the problem of optimal capacity loading from the position of minimization of aggregate costs can be written as follows:

$$f = \sum_{i=1}^{m}\sum_{r=1}^{R}\sum_{l=1}^{L_r} c_{ir}^{l} x_{ir}^{l} \to min, \tag{1}$$

where $c_{ir}^{l} = \sum_{t=1}^{T} c_{irt}^{l} + E_H \sum_{t=1}^{T} K_{irt}^{l} + \sum_{t=1}^{T} \Pi_{irt}^{l}$,

$$\sum_{r=1}^{R}\sum_{l=1}^{L_r} x_{ir}^{l} = 1,\ x_{ir}^{l} = \{0, 1\},\ i = \overline{1,m},\ r = \overline{1,R},\ l = \overline{1,L_r}, \tag{2}$$

$$\sum_{i=1}^{m}\sum_{r=1}^{k}\sum_{l=1}^{L_r} a_{ijrt}^{l} x_{ir}^{l} \le b_{jt},\ j=\overline{1,n},\ t=\overline{1,T}, \quad (3)$$

$$a_{ijrt}^{l} \ge 0,\ i=\overline{1,m},\ r=\overline{1,R},\ l=\overline{1,L_r},\ j=\overline{1,n},\ t=\overline{1,T}, \quad (4)$$

$$\sum_{i=1}^{m}\sum_{r=1}^{k}\sum_{l=1}^{L_r} P_{irt}^{l}\left(x_{ir}^{l}\right) x_{ir}^{l} \le P_t,\ t=\overline{1,T}, \quad (5)$$

$$P_{irt}^{l}\left(x_{ir}^{t}\right) \ge 0,\ i=\overline{1,m},\ r=\overline{1,R},\ l=\overline{1,L_r},\ t=\overline{1,T}, \quad (6)$$

$$\sum_{i=1}^{m}\sum_{r=1}^{k}\sum_{l=1}^{L_r} S_{irt}^{l}\left(x_{ir}^{l}\right) x_{ir}^{l} \le S_t,\ t=\overline{1,T}, \quad (7)$$

$$S_{irt}^{l}\left(x_{ir}^{t}\right) \ge 0,\ i=\overline{1,m},\ r=\overline{1,R},\ l=\overline{1,L_r},\ t=\overline{1,T}. \quad (8)$$

The target function (1) determines the aggregate costs for the period of time $[0,T]$, which depend on the choice of equipment batching technique. In this case the costs include not only the capital and currents expenses but also the expenses connected with possible activities directed at relocation of equipment and logistics.

All the parameters K_{irt}^{l}, C_{irt}^{l} and Π_{irt}^{l} will be considered as reduced to the initial moment of time, which is achieved with the help of application of discounting procedure.

The constraint (2) notes that the i –th set of parts can be produced by a single equipment set for which only one operation mode is chosen. The condition of integrality of variables of the model x_{ir}^{l} notes that each of the considered variants of the equipment batching can be accepted as a whole or rejected completely.

The constraint (3) notes that the equipment planned to be used at the t-th period should not exceed the resources available at the enterprise.

The constraint (5) notes that at the t-th period the quantity of workers not exceeding the existing limit can be engaged.

The constraint (7) notes that at the t-th period the production areas can not exceed the existing limit.

(4), (6) and (8) – the conditions of assignment of the corresponding coefficients of the model. All the coefficients of the model should be known a priori, their values depend on the chosen equipment batching, variants of its work and purpose.

The problem (1)-(8) relates to the class of problems of *integer programming*. There is a large number of special program products to settle them, which allow effectively achieving numerical answers. The following values are its solution $\{x_{ir}^{l*}\}$, $i=\overline{1,m}$, $r=\overline{1,R}$, $l=\overline{1,L_r}$. They characterize the optimal way to batch the available equipment and optimal values of the aggregate costs f^{*}, which the enterprise will have to bear to produce all the required sets of parts. The main complication of the problem settling (1)-(8) is its size, which requires special carefulness when preparing the initial data.

One of the key parameters of efficient production organization is the employment of the available equipment. Application of main provisions of the duality theory of linear programming is the most reasonable in order to answer the question, in the process of production planning, how efficiently the available equipment is used and how it effects on the aggregate costs of the enterprise.

It is known that any problem of liner programming is closely connected with another problem of linear programming, the view and solution of which definitely proceed from the initial one. The optimal values of target functions of the initial and dual problems coincide. The components of the optimal solution of the double problem named objectively determined valuations of resources have a special sense. On the basis of double variables values one can obtain the characteristics of the resources scarcity degree: *non-zero double variables correlate with fully usable (i.e. scarce) resources, zero ones correlate with non-scarce resources* (Kremer et al., 2002). The values of double variables in the optimal solution show the elasticity of the target function according to the respective resource limits. In other words objectively determined valuations of resources demonstrate for how many currency units the optimal value of the target function of the initial problem will change, when the corresponding resource changes by one unit.

Thus, use of main provisions of the duality theory (Kantorovich, 1960) as applied to the problems of linear programming helps answering important practical questions, which influence the efficiency of production organization. Indeed, if the double problem solution reveals that some resources are excessive, measures can be initiated to reduce these resources and/or their modernization to enhance the efficiency of subsequent use without prejudice to the existing production plans.

As applied to the problem (1)-(8) the above-written notes that the double variable values determined by the group of constraints (3), can characterize the way the change in the equipment quantity of the j -th model at the t -th period of time impacts the aggregate costs of the enterprise.

Thus, consideration of a double problem to the model (1)-(8) is reasonable. Statement of the double problem to the model (1)-(8) is not a trivial procedure as problems of integer programming are not the problems of linear programming in the pure state, for which the duality theory was developed. Nevertheless, considering the peculiarity of the integer problem (1)-(8), especially the fact that all its *feasible solutions are at the unit cube corners i*n the space of the corresponding dimension, in order to obtain objectively determined valuations of constraints of the given problem, one can use the approach the sense of which is in consecutive implementation of the following steps.

Step 1. To settle the initial problem of integer programming on the unit cube. To obtain the optimal vector X^*. (implementation of the subsequent steps has sense only in case if the initial problem has a solution.)

Step 2. To state the double problem to the initial one without accounting the integrality conditions.

Step 3. To settle the double problem and give interpretation of the obtained objectively determined valuations.

The sense of the described approach is demonstrated by the following example. Let us consider the problem of integer programming, in which its feasible solutions are inside the unit cube E^2:

$$f = x_1 + 2x_2 \to max$$
$$-9x_1 - 4x_2 \le -3$$
$$3x_1 - 4x_2 \le 1$$
$$0 \le x_1 \le 1 \qquad (9)$$
$$0 \le x_2 \le 1$$
$$x_1 \in Z,\ x_2 \in Z.$$

Its optimal solution: $X^* = \{1, 1\}$, $f^* = 3$. In fig. 1 dots stand for the set of feasible solutions of problem (9).

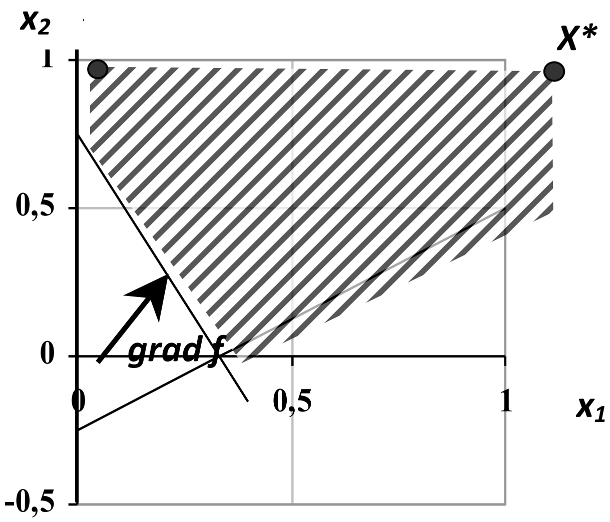

Figure 1. Geometric interpretation of problem solution (9)

A variety of feasible solutions of the problem (9) without integrality condition is highlighted by hatch in Fig. 1.

The double problem to the problem (9) without integrality of variables has the following view:

$$\tilde{f} = -3y_1 + y_2 + y_3 + y_4 \to min$$
$$-9y_1 + 3y_2 + y_3 \ge 1 \qquad (10)$$
$$-4y_1 - 4y_2 + y_4 \ge 2$$

$y_i \geq 0,\ i = \overline{1,4}.$

Its optimal solution: $Y^* = \{0, 0, 1, 2\},\ \tilde{f}^* = 3$.

In the problem (9) the constraints on the maximum values of the variables x_1 are x_2 are determining, they formed the optimal solution X^* (X^* lies on the intersection of boundaries of the corresponding half-planes). The doubles estimates corresponding to these constraints (i.e. the components y_3 and y_4 of the optimal solution Y^*) are different from zero. Each of these components shows how the target function value will change, if the free members of the corresponding constraint in the problem (9) change by 1. It should be noted that the constraint $x_2 \leq 1$ is the most "scarce", as a forth component of the vector Y^* has the highest value.

Conclusion

Thus, switching from the problem of integer programming to the problem of linear programming, in which the set of feasible solutions is built in accordance with the procedure described at step 1, one can determine objectively determined valuations and implement qualitative analysis of the produced solution basing on the results of the duality theory provisions application.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

Lyudmila N. Rodionova - Faculty of computer science and *robotics,* Ufa State Aviation Technical University, Ufa, Russia.

Olga G. Kantor - Institute of Social and Economic Research, Ufa Scientific Center of the Russian Academy of Sciences, Ufa, Russia.

Amir A. Khakimov - Chernyshev Moscow Machine-Building, Enterprise, Moscow, Russia.

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