

## On Organizing Quick Change-Over Mass Production

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**Abstract.** The terms "type of production" and "coefficient of assigning operations" are analyzed. A new method of calculating the optimum production plan based on profit projections is suggested. We recommend using the cycle time values as initial data for designing and developing technology. On the basis of existing techniques used to convert productions we suggest a new approach to production change-over with the service life of manufacturing facilities equal to the time to product's obsolescence. The factors to maximize profits using this change-over method are indicated, with maximum profits being a condition for the organization of quick change-change mass production.

### Introduction

In accordance with the existing practices as to process designing, the concept of production planning in terms of volume requirements (single-unit, medium series and mass production) is served as a specific criterion for choosing a particular type of technology and equipment configuration to be used. According to the Russian Standards, a type of production is chosen on the basis of the so-called coefficient of assignment of operations representing a ratio of the number of different operations to be made per a month to the number of workplaces involved into performing those operations. This approach, in our opinion, has a significant weak point, namely, at the start of engineering processes an engineer does not know a number of operations in the process to be designed or the number of workplaces. These data should be specified in the course of the subsequent engineering process, so there is considerable uncertainty as to defining a type of production that is essential for making future critical decisions.

### Results and Discussion

Determining an optimum solution to annual production planning

When developing a technology intended for producing machinery, a product design and the so-called annual output program in units appear to be basic initial data. If the design documentation for machinery should be developed in the previous stage of product life cycle (PLC), the issue of determining the optimal size of a series of machinery or run of production items remains open. In the case of planned economy existed in Russia before, production plans were administered with respect to government-controlled needs and interests of the entire population. With the transition to the market – based economy in a competitive environment, this task becomes particularly imperative, since, on one



hand, the number of made and sold products must refund the costs of production and, on the other hand, generate some profits to the owner of an enterprise without overproduction of these products. Therefore, errors in specifying numbers in production plans causing underproduction or overproduction can lead to negative consequences to the extent of bankruptcy of a company.

Analyze a production plan of a machine-engineering company on the basis of the so-called break-even charts [1,4-7], which are specified with respect to the coordinate system "production plan - value" (Figure 1). The total cost to produce a certain type of products  $S_i$  are made up of the initial capital investment  $K_i$  required to organize a new machine production and operating expenses (cost) associated with manufacturing products in accordance with the formula:

$$S_i = K_i + C_i N, \text{ c.c.u.}, \quad (1)$$

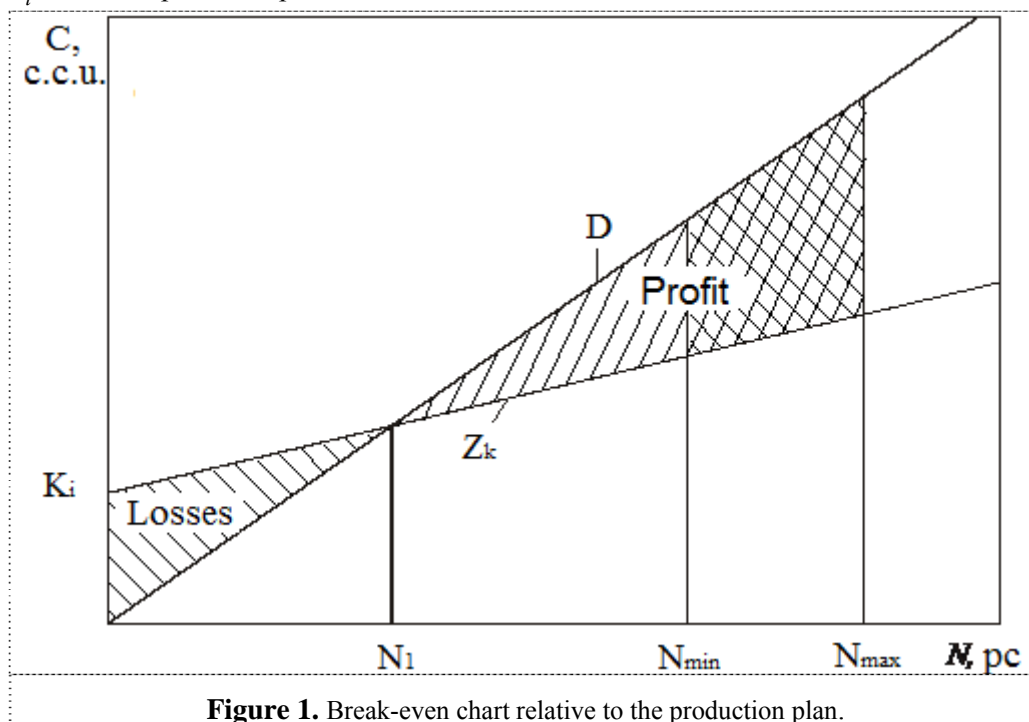
where  $C_i$  is the cost of a product in conditional currency units (c.c.u.);  $N$  is the current production plan in units.

Dependency (1) corresponds to the line of total costs (see Figure 1), which is a straight line when the value is constant.

On the other hand, the total revenue of the enterprise  $D$  received from the product sales is directly proportional to their numbers according to the production plan:

$$D = Z_i \cdot N \quad (2)$$

where  $Z_i$  is the sale price of a product in c.c.u.



**Figure 1.** Break-even chart relative to the production plan.

With a certain volume of products made and sold, the line of total costs intersects the line of total revenue (see Figure 1). The point of intersection on the x-axis has the following coordinates:

$$N_1 = \frac{K_i}{Z_i - C_i}. \quad (3)$$

Below the value  $N_1$  the company incurs losses due to the necessity of covering the total expenditure made by that time, and when  $N \geq N_1$ , it begins receiving the current profit. It should be noted that

the company can balance absolute total costs and absolute total revenue only when it will manufacture and sell more than the number of products  $N_1$ , which we designate as  $N_{\min}$  (profitable production plan). In the case of linear dependence  $S_i$  and  $D$  upon the production plan, we have the following formula  $N_{\min} = 2N_1$  or taking into account expression (3):

$$N_{\min} = \frac{2K_i}{Z_i - C_i} \quad (4)$$

If the company under examination is able to make a net income (absolute profit) starting from  $N_{\min}$ , then this value is considered as a lower limit in the context of the determination of its production plan.

The analysis of expression (4) shows that the plan profitability is determined by the difference between the price of the product and its cost or what is the same, the income received from the sale of its product. The larger the difference, the less  $N_{\min}$  is, and conversely, when the product's price is close to the cost of its production, the cost-effectiveness of production sharply increases.

The value  $N_{\min}$  defines the quantity of products that makes possible to cover the total costs of their production after selling them on the market. The company starts getting the absolute profit when  $N \geq N_{\min}$ ; and generating the maximum profit is a global goal in the conditions of the capitalist mode of production. On this account, there is a crucial task of determining the maximum output value  $N_{\max}$  within the production plan; after reaching this value by the company the product is discontinued. The so-called "moral depreciation" of a machine should be accepted as a key to this task. Karl Marx was apparently the first to introduce this term. In his work [2], he wrote: "But in addition to the material wear and tear, a machine also undergoes, what we may call a moral depreciation. It loses exchange-value, either by machines of the same sort being produced cheaper than it, or by better machines entering into competition with it. In both cases, be the machine ever so young and full of life, its value is no longer determined by the labour actually materialised in it, but by the labour-time requisite to reproduce either it or the better machine. It has, therefore, lost value more or less. The shorter the period taken to reproduce its total value, the less is the danger of moral depreciation..."

It should be noted that the terms "obsolescence" or "moral depreciation" as well as all the basic concepts in political economy are not clearly defined. Therefore, in future we assume that obsolescence is a calendar period from the moment when the first machine of a new model is manufactured to the moment this model is discontinued.

If we use  $T_m$  to designate this period of product's obsolescence in conditional time units (c.t.u.), then the maximum production plan can be expressed by the following ratio:

$$N_{\max} = \frac{T_m}{t_d} \quad (5)$$

where  $t_d$  is the interval products are made (cycle time), c.t.u.

Figure 1 shows the top line  $N_{\max}$  to limit the area of absolute profit and the bottom line has a zero limit along the line  $N_{\min}$  as it follows from the above. If these values are known, then in the context of linear dependences the size of raised profits  $P$  corresponds to the cross hatched area (see Figure 1). After integration of this area in view of expression (4) we obtain the following formula to calculate the absolute value of profit:

$$P = N_{\max} [0.5N_{\max} (Z_i - C_i) - K_i] \quad (6)$$

The analysis of expression (6) proves that the company's profit will grow by increasing  $N_{\max}$  and the difference between the product price and the product cost, as well as by the decreasing the initial capital invested in organizing the process to make these products. With this, the value  $N_{\max}$  is the most effective means for increasing the absolute profit as it is raised to the second power in formula (6).

At the same time, as it follows from expression (5), the value  $N_{\max}$  can be increased by either extending the period of product obsolescence or reducing the cycle time for the products. Currently, the market is largely saturated with products having different levels of quality, and increasing the value  $T_m$  is difficult under these conditions. On the contrary, competition leads to a reduction of "moral" service life of a particular product design. This trend has already been noted by professor G.A.Shaumyan [3].

We substitute (5) into formula (6):

$$P = \frac{T_M}{t_d} \left[ 0.5 \frac{T_M}{t_d} (Z_i - C_i) - K_i \right]. \quad (7)$$

From expression (7) it follows that for a specified time of product obsolescence the company's profit will be inversely related to the product time. Thus, the main focus should be laid on the full reduction of cycle time required for manufacturing a product in order to achieve the maximum possible profit within the specified limits. With the focus on the goal of gaining the maximum profit, values of  $N_{\max}$  corresponding to the cycle time is accepted the estimated production plan for product output.

On the other hand, unlimited decreasing a cycle time can lead to the overproduction of a certain model of products causing severe consequences for the manufacturer. From our point of view, the lower limit of cycle time must be associated with a profit target, and relative to its amount the manufacturer maintains an advantage not only over its competitors in the same sector of market but also other manufacturers in various industries with the aim to prevent the drain of capitals there.

Suppose the company's management set a profit target  $\Delta$  as ratio of profit value to sales revenue [6] that is  $\Delta = P / D$ . Then in view of (6) and (2) the maximum acceptable production plan will be equal to

$$N_{\max} = \frac{2(\Delta C_i + K_i)}{Z_i - C_i} \cdot pc.$$

The optimal (also as the minimum) value of cycle time associated with this plan will be determined by the following expression using formula (5):

$$t_{o,opt.} = \frac{T_M (Z_i - C_i)}{2(K_i + Z_i \Delta)}, c.t.u. \quad (8)$$

This value should be the ground for organizing production of a specified machinery product. For the conditions of running a particular machine-engineering enterprise a value of cycle time according to formula (8) should be corrected taking into account the time required for the organizational process, which are not included in the fixed labour costs.

Rationale for the organization of quick change – over mass production

The problem of "painless" changeover to start a new engineering product is a major problem for manufacturers, because costs for production facilities that are idle and a company's associated financial losses are fully dependent on how efficient this conversion process is.

Currently, there are several ways to change productions to run new machine models [4]: a full stop of production for a period of reconstruction, a parallel changeover approach, a "non-stop" approach, reengineering in conditions of a flexible production. These processes used to convert main production

facilities to run a new product have one common disadvantage: the intention to organize a new production where the previous industrial base is located. Karl Marx wrote about changing the means of production [2]: " The instruments of labour are largely modified all the time by the progress of industry. Hence they are not replaced in their original, but in their modified form. On the one hand the mass of the fixed capital invested in a certain bodily form and endowed in that form with a certain average life constitutes one reason for the only gradual pace of the introduction of new machinery, etc., and therefore an obstacle to the rapid general introduction of improved instruments of labour. On the other hand competition compels the replacement of the old instruments of labour by new ones before the expiration of their natural life, especially when decisive changes occur. Such premature renewals of factory equipment on a rather large social scale are mainly enforced by catastrophes or crises. "

This statement has already been discussed in detail by Professor G.A. Shaumyan [3]. "The service life of machinery is not always determined by its physical durability. They are most often defined by the quality of products, the requirements for which are constantly growing, forcing to upgrade or replace all manufactured products ... We can say that the quality of manufacturing equipment is determined by how to use it to produce more, better and cheaper. As we can see, the quality and mass nature are in conflict, since the first requires continuous improvement of products (quick-change production), and the second the stability of product quality... Consequently, the quick changeover of production is a feature inherent to not only small-scale production, as it is commonly supposed, but the particular feature of modern technology development... it is necessary to observe the birth of a new kind of production with the following characteristics: quick change-over mass production ... (emphasis added). This task of huge difficulty must be solved to prevent that the automation from being the instrument of technological progress turns into its brake. "

In our view, it is this situation relating to the world's mechanical engineering industry we have observed in recent years. Refusal to introduce automation of core operations as well as transition to the principles of flexible technology led to the reduction of profit rates in the engineering industry in comparison with other industries and, consequently, to capital outflow to other industries and even to withdrawal of funds from manufacturing. This situation can be improved in terms of attracting investments to mechanical technology only by dramatically increasing profitability of the machine-building industry.

From p.1 it follows that the changeover time required to run a new product must be the same as the time to obsolescence  $T_m$  of the product. Determining a  $T_m$  value is an important task in terms of market research, and this value should be known before the start of production of any given goods, since it is taken as the base for estimating an optimal production plan and expected profit [1,4,7].

What prevents production facilities of the company from upgrading to the full extent and the simultaneous discontinuation of the product? The answer is obvious meaning different economically justified service lives of equipment that usually exceed the time to obsolescence of a product. This implies a very important conclusion for the stage of a product manufacture: that optimum service life of production facilities, including equipment, tooling and other means of technological equipment should be equal to the time to obsolescence of products. If we accept this statement as a basis, then the suggested in [1] approach relating to the usage of the machine and the optimization of its production process is fully applicable. There is only one difference indicating that in this work the machine is understood as a complete range of casting, forging, pressing, metal-cutting, assembly, material handling and other auxiliary facilities and tooling used for making products of a certain design.

Based on the above, the specified costs at the production stage must be calculated according to formula [1]:

$$S_p = C_p \tau + \frac{K_i}{\tau + 1}; \frac{\text{c.c.u.}}{\text{c.t.u.}}, \quad (9)$$

where  $K_i$  is the capital investments in the organization and development of production of a new machine (c.c.u.);  $C_p$  is the rate of operating expenses associated with the support of running the production.  $\text{c.c.u.}/(\text{c.t.u.})^2$

The minimum expenses according to expression (9) must correspond to the time to obsolescence relating to a product design. Then using formula (9) we obtain the following expressions for:

- Value to estimate obsolescence

$$T_m = \sqrt{\frac{K_i}{C_p}}; \quad (10)$$

- Optimal amount of capital investments in production

$$K_{i,\text{opt}} = C_p T_m^2. \quad (11)$$

If we put (11) into formula (7), we obtain an expression for calculating profit of a machine engineering company that operates in accordance with the stated above principle of optimal changeover to run a new machine (complete replacement of manufacturing facilities at the moment of product shift)

$$P = \frac{T_m}{t_d} \left[ 0.5 \frac{T_m}{t_d} (z_i - C_i) - C_p \cdot T_m^2 \right]. \quad (12)$$

Figure 2 shows the results of calculating profit (12) depending on the value of a product obsolescence and its cycle time based on the following conditions: the product price is 1000 c.c.u.; the product cost is 800 c.c.u.; the ratio of operating expenses  $C_p$  is 10  $\text{c.c.u.}/(\text{c.t.u.})^2$ . On Figure 2 it is seen that there is a maximum profit and an optimal time relating to product's obsolescence for each value of cycle time. If we differentiate  $T_m$  from expression (12) and equate it to zero, we get

$$T_{m,\text{opt}} = \frac{z_i - C_i}{S \cdot C_p \cdot t_d}, \text{c.t.u.} \quad (13)$$

In other words, the optimal value of obsolescence with respect to a particular design of products is inversely proportional to their cycle time, with other conditions being equal. When the value of  $T_m$  is assumed as an initial data, it is possible to calculate the optimal value of cycle time that ensures maximum profit:

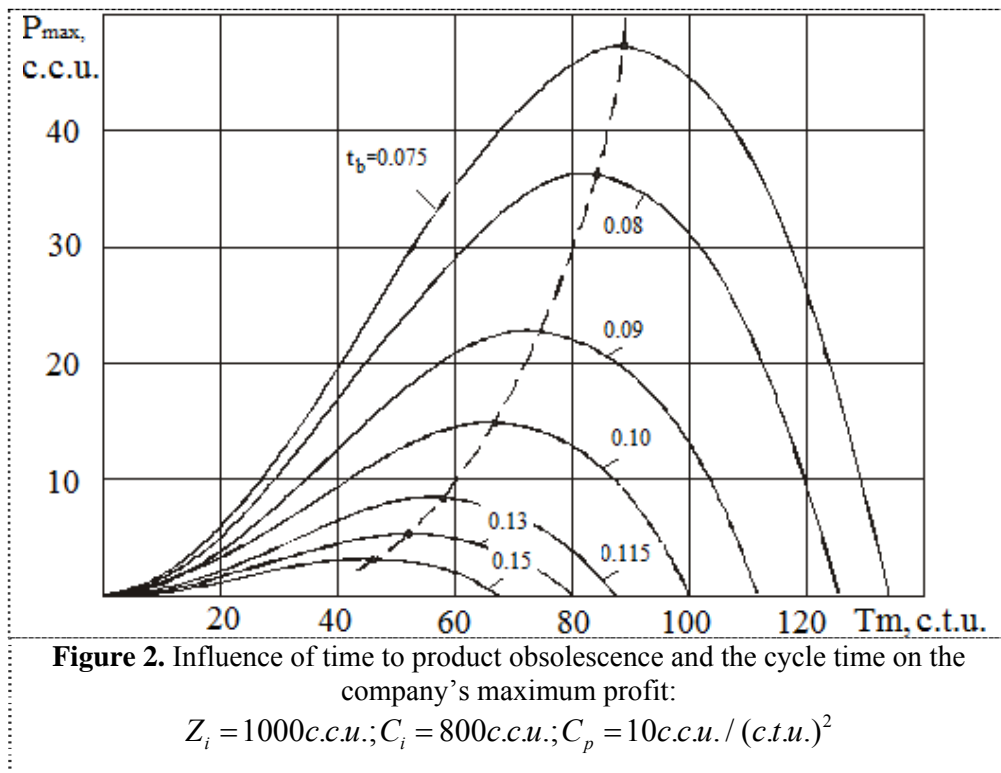
$$t_{d,\text{opt}} = \frac{Z_i - C_i}{3 \cdot C_p \cdot T_{m,\text{opt}}}, \text{c.t.u.} \quad (14)$$

Note, however, that the smaller  $T_{m,\text{opt}}$  is, the less maximum profit a given company can raise (see the dashed line on Figure 2).

When substituting (13) into (12), we have a formula for calculating the maximum profit:

$$P_{\text{max}} = \frac{(Z_i - C_i)^3}{54 \cdot C_p^2 \cdot t_d^4}, \text{c.c.u.} \quad (15)$$

In expression (15) when we compare with (12), the maximum profit  $P_{\text{max}}$  is inversely proportional to the cycle time as well, and not to the second power but the fourth power. From (15) it follows that to maximize profits it is necessary to increase the difference between the product price and its cost, to cut operating expenses of production, to reduce the cycle time for production. If the first two approaches are traditional and also practically assured among businessmen, the third approach in the context of increasing profit requires careful analysis due to a number of reasons.



First, the relationship between the cycle time and the maximum profit is the most strong (to the fourth power), and this proves that cutting cycle time to the possible extent is the most effective way to improving company's profitability. According to Figure 2, when  $t_d$  decreases two times (from 0.15 c.t.u. to 0.075 c.t.u.), the maximum profit increases almost 16 times (from 2.9 mln c.c.u. to 46.8 mn. c.c.u.).

Secondly, according to expression (13), decreasing  $t_d$  automatically leads to increasing the optimal value of time as to machine's obsolescence, which is primarily determined by performance and competitiveness of the product design.

Thus, to maximize profits (see Figure 2), both conditions (13) and (14) must be observed at the same time, i.e. it is required to optimize the design engineering phase using  $T_{m.opt}$  and the production phase using  $t_d$ . The conclusion is: The design of a machine and technology for its manufacture are closely connected with each other by means of the maximum possible profit.

It should be noted that the above stated is true only for a production created on the principle of optimal product shifting. How can this changeover be implemented in practice to enable a new machine production running without significant loss? In our view, production capacities of a machine engineering company should be divided into two equal parts, with one part being in operation at a particular moment and producing conventional products. At the same time the second part is used for setting up and gearing the production for making a new product with a predetermined manufacturing cycle time. At the moment when the product made using the first part capacities becomes obsolete, the second production facilities are quickly changed over to start run a new product, and the first production facilities are subject to a full dismantling for further production organization of more promising goods. To put in other words, an enterprise is supposed to have two parallel production lines at the same time. This approach allows solving successfully a problem relative to quick-change mass production detected by Professor A.G. Shaumyan.

For sustainable operation of main production facilities it is required to set up a sufficient material base for auxiliary production. The auxiliary production is mainly focused on designing and manufacturing equipment and tooling to support main processes engaged in making a new machine. And this work must be carried out systematically on an ongoing basis to ensure optimal changeover to production of more sophisticated goods. Since this type of production is characterized as a single-made and small-scale industry, the extensive application of principles aiming at using flexible technology is appropriate. Strong tool and prototype productions should serve as the third cornerstone of a modern machine engineering company, thereby ensuring sustainability and high profitability of the mechanical engineering industry.

### Conclusions

The quantity of products to be manufactured is calculated on the basis of profit projections and competitive level of profitability of a manufacturer.

The optimum amount of cycle time instead of the production type approach is regarded as basis for designing and developing technological processes.

For a quick and loss-free changeover to production of a new machine, the service life of manufacturing facilities must be equal to the time to product obsolescence.

A product design and its technology are closely connected. To have the maximum possible profit for a company it is required to ensure the cycle time needed for producing a machine corresponds to the time to its obsolescence.

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