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IMPROVEMENT OF THE ENTERPRISE'S PRODUCTION PROGRAM AS A WAY TO ADAPT TO MARKET CHANGES

Purpose. Proving the possibility of improving the procedure to adapt the enterprise to market trends based on the self adjustment of its production program using the solutions of direct and dual linear programming problems with the help of the Microsoft Excel package "Search for solutions" add-on.

Methodology. The methodological basis of the study is the provisions of modern economic theory, the fundamental works by foreign and domestic scientists on the formation of management systems and the peculiarities of enterprises' adaptation to changes. The methodological apparatus of economic and mathematical modeling, operations research, in particular, the theory of duality of linear programming problems is widely used.

Findings. The enterprise's adaptation to changes in the external and internal environment with the help of the proposed iterative procedure of unused reserves redistribution between scarce resources made it possible to increase the products' sale by reducing the manufacturing of one type of products and increasing the output of another one under the conditions of a stable range of products manufacturing at the enterprise.

Originality. The article substantiates the procedure of the enterprise adaptation to changes in internal and external environments on the basis of self adjustment of its production program using the solutions of direct and dual problems of linear programming.

Practical value. The article features the applied aspects to self adjust the enterprise production program, aimed to increase the efficiency of economic activity by means of step-by-step improvement of the optimal production plan (works, services).

Keywords: *adaptation, self adjustment, optimal plan, scarce and non-scarce resources*

Introduction. The economic instability of Ukraine, a significant drop in GDP in 2023 caused by the consequences of a full-scale war with the Russian Federation, put forward new requirements to form an effective system of economic entities management, which will be able to respond flexibly and adapt to changes in the external and internal environment. During the crisis events of the global pandemic of COVID-19 investments in the real sector of the economy decreased, the level of enterprises' income and consumers' solvent demand decreased, which, in turn, caused an increase in non-payment, aggravation of competition, increasing threats of bankruptcy. Negative phenomena in the structure of the modern Ukrainian economy require domestic enterprises to introduce and use effective adaptation tools that will create the basis for improving the management efficiency, aimed at developing all spheres of the economy and improving the standard of living of the country's population.

According to R. Hrinchenko [1], adaptation is understood as a continuous process of reaction to changes in the external and internal enterprises' environment by their research, development and implementation of a system of changes in the management of organizational, economic, legal, technological and social components of enterprises performance to achieve activity targets and increase the enterprises competitiveness. Adaptation is based on the following theoretical principles:

- the basis of adaptation is a perfect analysis of the external and internal components of the enterprise's activity;
- adaptation should not be narrowed only to adaptation to the external environment, but also take into account the need to adapt to changes in the internal environment;
- adaptation should be carried out comprehensively on all components of enterprise activity management: organizational, economic, legal, technological and social ones;
- adaptation to only a few management components can lead to an imbalance of the enterprise development and the loss of its competitive positions in the market;
- adaptation of the enterprise should be flexible to market conditions and be based on scientifically sound principles, on the achievements of modern world economic science.

Enterprises that possess the specified adaptation properties are open production systems capable of self adjustment, which means the ability to change their production program depending on changes in the external economic environment. For example, change the structure (range) of manufactured products, its nomenclature in accordance with modern market trends. From these positions of view, the optimization of the enterprise's production program can be considered as one of the ways of self-adjustment and adaptation to modern market trends of such a complex probabilistic system, which any business entity is. After all, the search for the optimal plan of products (works, services) production is essentially the enterprise's self adjustment to use perfectly its production, labor and financial resources.

Literature review. Publications by many well-known foreign and domestic scientists are devoted to the problems of the enterprise's adaptation to market trends. The foundations of adaptation theory were laid by the classics of economic science – R. Akoff, I. Ansoff, G. Kleiner, M. Mescon, R. Pindikle, J. Dolan, D. Lindsay, T. Saati, K. Cairns, P. Doyle, T. Heyman, W. Scott, P. Mott. Various aspects of enterprise adaptation were investigated by leading economists: S. Alekseev, M. Budnik, M. Voynarenko, A. Voronkova, V. Goncharov, V. Grosul, V. Kozak, H. Kozachenko, S. Kravchenko, K. Kryvobok, Zh. Krysko, Ye. Kuzkin, T. Landina, O. Lyashenko, N. Orlova, L. Pankratova, A. Petrenko, Yu. Pogorelov, O. Raevneva, O. Savchenko, L. Sokolova, V. Skubenko, and others. At the same time, despite all the multifaceted scientific works on this issue, there is a polarization of opinions regarding the essence of the "enterprise adaptation" concept in the scientists' research, as well as methods and means of its implementation. This significantly complicates the practical issues of assessing the enterprises adaptability state of various industries as the basis for choosing a rational way to adapt to the conditions of the external and internal environment.

Thus, N. Siketina [2] claims that the industrial enterprise adaptation system characterizes the conduct of activities to ensure the competitive position of the enterprise, as well as the formation and development of effective relations within the enterprise or network formation.

McCauley G. [3] indicates that it is important for businesses to constantly be aware of the changes in the marketplace and make necessary changes to stay afloat. Failure to do so could result in extinction. There are many freelancers who specialize in different areas, so businesses can find the perfect freelancer to help them with their specific needs. Globalization is another trend that businesses need to be aware of. With the rise of globalization, businesses are expanding into new markets all over the world. To be successful in these new markets, businesses need to adapt their products and services to meet the needs of these new consumers.

Simpson S. D. [4] cites the example of five of the most adaptive companies (DuPont, Hewlett-Packard, Nokia, Berkshire Hathaway, Apple), which, by diversifying their activities and investing in other industries, achieved financial prosperity thanks to top management teams that saw a different future for business and were not afraid to make large-scale changes in entrepreneurship. "Adapt or die" may seem like a harsh directive for corporate managers, but there does seem to be a certain necessity to constantly move forward and adapt to new market opportunities. Even decades of success are no guarantee that the future will work out – witness the bankruptcies of companies like Woolworth, Bethlehem Steel and Pan-Am.

Anderson A. [5] notes, there are numerous reasons for the ongoing need for market changes. For success, it is necessary to adapt to the constant changes in market trends. He provides some advice on this matter: 1. *Embrace agile project management.* Agile project management is designed to be adaptable. 2. *Hire a consultant.* To help ensure you are not positioned poorly or missing out on market trends, consider hiring a consultant to keep you up to speed. 3. *Stay attuned to your target customers' needs.* Your customers should be the driving force behind changes to your business. Adapting to market changes means keeping the people you serve top of mind. 4. *Hire forward-thinking employees.* If you want to gain a competitive edge in the market, try hiring forward-thinking employees who share the vision and values of your brand. 5. *Elimination outdated products.* A stale brand, product or service can kill a business. Part of adapting and responding to change is knowing when to let go these products.

Kalinichenko Z. [6] emphasizes the expediency of changes in the management of business systems based on the principles of adaptation and ESG guidelines (Environmental, Social and Governance), which have recently become widespread. This is caused by local socio-ecological factors of a certain country which are understood as enterprises' activities for the benefit of the environment and society.

Krivobok K. [7] offers to use bifurcation mechanisms as an approach to the enterprise's adaptation in conditions of unstable external environment. The basis for making informed management decisions should be the results of monitoring with the use of indicators that characterize the trends of changes.

King L. [8] recommends the following. Build strong digital foundations: those who have been able to quickly transition to online, or harnessed the advantage of already thriving digitally, demonstrate that it is no longer feasible to run the majority of businesses purely offline. Online video conferencing tools such as Zoom are a prime example of the way in which technology has been able to support the demand for remote activities. Revaluate your business processes. Business processes that were used under previously 'normal' circumstances may now be outdated. The opportunity brought about by change, however, can be used to see the world in new ways. Start by evaluating the processes and technology you already have, regardless of how successful they are, to see if they are still relevant in the current climate. Listen and adapt. By staying in tune with the needs of your customers, employees and suppliers, you will be prepared to support them when they need it most. Do not ignore contemporary times and culture, either. Assess trends that could potentially have a big impact on your audiences; analyze what they are looking at, which way they perceive it and, ultimately, how it makes them feel.

Unsolved aspects of the problem. The study on publications of recent years on this topic showed that the research by domestic and foreign authors is based mainly on the methodology of qualitative economic analysis. At the same time, quantitative methods for adapting the enterprise to changes in the internal and external environment are practically not discussed. Therefore, we support the opinion of A. Gerasymova [9], who draws attention to the need to adapt the enterprise with the definition of improvement reserves, namely: improving the use of fixed and circulating funds – the possibility of more complete utilization of production capacities, increasing the variability of equipment operation, reducing the size of production stocks, etc.

In our opinion the issue of adapting the enterprise to market trends should be considered with a wider application of economic and mathematical methods and models, in particular, using adaptive planning based on the results of solutions to the linear programming problem (LPP) to determine the optimal production plan. This will allow quantifying the reserves of improving the entity efficiency – the potential growth of the enterprise's profit, the volume of products sold, its cost reduction, etc. As a result, top managers of the enterprise will have the opportunity to outline reasonable ways to self adjust it in the process of adapting to changes in the external and internal environment.

Purpose. The purpose of this article is to prove the possibility of improving the procedure to adapt the enterprise to market trends based on adaptive planning using the solutions of direct and dual LPP with the help of the add-on "Search for solutions" of the Microsoft Excel package. We offer an iterative procedure for adapting the enterprise to changes in the internal and external environment, based on the gradual improvement of the obtained optimal production plan through the solutions of direct and dual LPP. In addition, the task is to illustrate the theoretical provisions of linear programming and the proposed procedure on the example of optimizing the release of 4 types of enterprise products that require the use of 3 types of resources.

Methods. The methodological basis of the study is the provisions of the modern economic theory, the fundamental works by foreign and domestic scientists on the formation, improvement of management systems and the peculiarities of enterprises' adaptation to changes. The methodological apparatus of economic and mathematical modeling, operations research, in particular, the theory of duality of the linear programming problem is widely used.

Results. ***Iteration 1.*** The planning department, in cooperation with other departments of the enterprise management, prepares an information base for the development of an optimal production plan for the planned period in value terms. It is based on the data of internal management reporting, analysis of past periods of operation as well as a result of the study on the external economic environment.

Despite the fact that in the practice of using LPP mainly at lower levels of enterprise management (workplace, site) there is a natural approach to measuring resources – material, labor, financial, etc., we propose to apply their monetary equivalent. This will ensure the ability not only to identify unused resource balances but also to redirect them to other production needs of the enterprise. The planning period is determined by the time during which the prices for production resources and the unit calculation of all product types remain unchanged. As the practical activity of most industrial enterprises shows that such a period is most often a calendar month.

These considerations are due to the fact that in the proposed adaptation procedure the resources $b_1, b_2, \ldots, b_m$ in value terms are best distributed among the technical and technological equipment of the enterprise to manufacture certain types of products – $X_1, X_2, \ldots, X_n$ on the basis of the known matrix $\boldsymbol{A} = \{a_{ji}\}$ of value costs of the j^{th} resource for the production of the unit of the i^{th} type of products ($j = 1, 2, \ldots, m$; $i = 1, 2, \ldots, n$). At the same time, the optimization of the production program is that some target function $Z = c_1X_1 + c_2X_2 + \ldots + c_nX_n$ must acquire its maximum (minimum). The function Z can express the total sale of products (c_i – price of a product unit), total gross profit (c_i – specific profit of products), total production costs (c_i – unit cost of production) or another economic indicator-stimulator (de-stimulator) of the entity's activity.

The question may arise here: at what structural level (workplace, production site, workshop, or enterprise as a whole) is it advisable to use the proposed approach in the form of a solution of conjugated LPP? After all, the process matrix $\boldsymbol{A} = \{a_{ji}\}$ of value costs at the enterprise level will express averaged indicators of completely heterogeneous production.

We will answer this question as follows: indeed, such a remark makes sense, so we recommend introducing an iterative procedure for adapting the enterprise to changes in the internal and external environment mainly at the production site or in a workshop with a more or less homogeneous production technology. If there is a need to apply this approach to the adaptation of the entire enterprise, then the range of future production should be presented in as much detail as possible ($n > 100$).

Note that the implementation of the Microsoft Excel package "Search for solutions" is limited to the following limit indicators: 1) the number of decision variables $n = 200$; 2) the number of simple restrictions on unknown $m = 400$.

Further let us move on to the development of a mathematical model of LPP aimed at determining the optimal production plan. In general, the mathematical model of adaptation on the first iteration coincides with the usual model of linear programming problem in the canonical record and includes three components: the objective function (1), the resource restriction (2) and the restriction on unknown variables (3):

$$Z_1 = \sum_{i=1}^{n} c_i X_i \to \max(\min); \tag{1}$$

$$\begin{cases} \sum_{i=1}^{n} a_{1i} X_i = b_1 - e_1 \\ \sum_{i=1}^{n} a_{2i} X_i = b_2 - e_2 \\ \cdots\cdots\cdots\cdots \\ \sum_{i=1}^{n} a_{mi} X_i = b_m - e_m \end{cases}; \tag{2}$$

$$0 \le X_i \le X_{i0}. \tag{3}$$

The model (1–3) c_i indicates the unit price of the i^{th} type of product; X_{i0} indicates the upper limit of production which is determined by the capacity of the technical and technological equipment of the enterprise X_{i1}, as well as the real market demand X_{i2} for the i^{th} type of product: $X_{i0} = \min(X_{i1}; X_{i2})$.

Through e_j the excess is marked of the existing stock of the j^{th} resource compared to its actual use. The restrictions (2) according to which the excesses are equal to zero ($e_j = 0$) define scarce resources in contrast to non-scarce resources observed with a non-zero excess ($e_j > 0$).

From the theory of linear programming, it is known that the solution of the LPP, which satisfies the conditions (2), (3), is called *permissible*. The number of permissible solutions is an infinite set. And the permissible solution that maximizes the objective function (1) is considered *optimal*.

To illustrate the theoretical provisions of linear programming and the proposed iterative procedure let us consider a conditional example of optimizing the release of 4 types of enterprise products that require the use of 3 types of resources (Table 1).

According to Table 1, let us build a mathematical model to optimize the production program of the enterprise

$$Z_1 = 60X_1 + 70X_2 + 80X_3 + 35X_4 \to \max;$$

$$\begin{cases} 4X_1 + 3X_2 + 2X_3 + X_4 \le 3000 \\ 10X_1 + 13X_2 + 14X_3 + 7X_4 \le 6000; \\ 16X_1 + 19X_2 + 15X_3 + 5X_4 \le 7000 \end{cases} \tag{4}$$

$$\begin{cases} 0 \le X_1 \le 2500 \\ 0 \le X_2 \le 1300 \\ 0 \le X_3 \le 2200 \\ 0 \le X_4 \le 2700 \end{cases}.$$

Table 1

Output data to optimize the enterprise's production program

Indexes	Types of products				Limits of resources, monetary units
	A	B	C	D	
1. The price of a product unit, monetary units (c_i)	60	70	80	35	
2. The upper limit of production, natural units (X_{i0})	2500	1300	2200	2700	
3. The rate of material costs per unit of production, monetary units (a_{1i})	4	3	2	1	3000
4. The rate of labor costs per unit of production, monetary units (a_{2i})	10	13	14	7	6000
5. The rate of electricity consumption per unit of production, monetary units (a_{3i})	16	19	15	5	7000

On the basis of the Microsoft Excel package "Search for solutions" add-on, the following optimal solution of the mathematical model (4) was found: $X_1 = 306.452$; $X_2 = 0$; $X_3 = 0$; $X_4 = 419.355$; $Z_1 = 35,161.29$ (Table 2).

So, the enterprise will receive the maximum sale of products in the amount of 35,161.29 monetary units if the products B and C are not being produced since they are unprofitable. Products A should be manufactured in the amount of 306.452, products D – 419.355 natural units. As can be seen from the results, the optimal plan is not integer. Although a significant part of the economic problems related to LPP requires an integer solution. Among them are problems in which variables $X_1, X_2, ..., X_n$ express the number of units of products that cannot be divided: furniture, cars, ships, airplanes, etc. LPPs, which have an additional integer restriction, refer to integer programming problems and their solution is based on special approximate methods, one of which is the Gomori method. However, there is a view that the losses from rounding to an integer can be smaller than the losses when reaching an integer result.

The optimal solution obtained according to model (4) can be considered as the first step towards the self-adjustment of the enterprise in the process of its adaptation to the changing conditions of the internal and external environment.

The question arises: is it possible to improve this optimal plan, that is, with unchanged values $b_1, b_2, ..., b_m$ and $A = \{a_{ji}\}$ to ensure an increase the target function of the Z_1? A positive answer to the question will mean an improvement in the use of enterprise resources and therefore its further adaptation to the conditions and trends of the market economy.

The optimal LPP plan described by the model (1–3), which meets the requirements of $Z_1 < Z_k$, $e_j \approx 0$, will be called an adaptive production plan based on the enterprise self-adjustment.

Table 2

Report on the results of the optimal LPP solution according to model (4) obtained at the I^{st} iteration*

Target function cell (Maximum)					
Cell	**Name**	**Initial value**	**Final value**		
\$F\$5	Z	0.000	35161.290		
Cell	**Name**	**Initial value**	**Final value**		
\$B\$5	$X1$	0.000	306.452		
\$C\$5	$X2$	0.000	0.000		
\$D\$5	$X3$	0.000	0.000		
\$E\$5	$X4$	0.000	419.355		
Restrictions					
Cell	**Name**	**Cell value**	**Formula**	**Condition**	**Excess**
\$F\$10	<= Z	0.000	\$F\$10<=\$H\$10	Without binding	2200.000
\$F\$11	<= Z	419.355	\$F\$11<=\$H\$11	Without binding	2280.645
\$F\$12	Z	1645.161	\$F\$12<=\$H\$12	Without binding	1354.839
\$F\$13	Z	6000.000	\$F\$13<=\$H\$13	Binding	0.000
\$F\$14	Z	7000.000	\$F\$14<=\$H\$14	Binding	0.000
\$F\$8	<= Z	306.452	\$F\$8<=\$H\$8	Without binding	2193.548
\$F\$9	<= Z	0.000	\$F\$9<=\$H\$9	Without binding	1300.000

Iteration 2, 3,..., k. To achieve this adaptive production plan, we propose to apply the redistribution of non-zero excesses of non-scarce resources between scarce resources for which $e_j = 0$ according to the optimal plan obtained above.

When redistributing funds, it is advisable to use the results of solving not only the direct but also the dual to it LPP. Moreover, this information is contained in three reports of the solution to a direct problem, obtained using the Microsoft Excel package "Search for solutions" add-on. Among the specified reports, the report on results (Answer) and the report on stability (Sensitivity) are the most interesting from the point of view of the goal set in this article, so we recommend paying special attention to them.

1. The results report includes the initial and final values of the target function and the cells (cells) of the spreadsheets as well as additional information about restrictions, in particular, excesses (Table 2, Target function cell, Variable cells, Restrictions).

2. The sustainability report contains information about the sensitivity of the solution to small changes in the cells containing the values $X_1, X_2, ..., X_n$ or in the restriction formulas. The optimal solution of the mathematical model (4) is presented by the following stability report (Table 3).

3. The report on limits (Limits) includes the value of the objective function at the optimal solution as well as within what limits it varies when the corresponding cells of the solution $X_1, X_2, ..., X_n$ take a zero or the optimal value.

The following basic concepts and terms are used in these reports:

1. "Binding" (Table 2) when the corresponding excess $e_j = 0$, that is, this resource has been used completely, it is scarce for the enterprise. In the report on the results (Table 2), the highlighted lines of Table "Restrictions" characterize the state of the resources of the enterprise under investigation: material costs "Without binding" ($e_1 = 1354.839$ monetary units), that is this resource is non scarce and labor and electricity costs with "Binding" ($e_2 = e_3 = 0$), that is, are scarce.

2. In the sustainability report (Table 3), "Present value" – the value of the normalized gradient (Lagrange multiplier) shows how much the target function will change in the case of forced inclusion of a unit of this product in the optimal solution. There are two values in this example (according to the number of types of products unprofitable for the enterprise): the target function of Z_1 will decrease by 7.419 and by 1.613 monetary units respectively when the unit of production B and C is forced.

3. "Shadow price" (Table 3) or the dual estimate of the resource y_j obtained as a result of solving the dual in relation to the direct problem (4). The values y_j, which L. Kantorovych, one of the founders of the theory of optimization in economics, called objectively determined estimates, reflect the value for the enterprise of an additional unit of the j^{th} resource and are calculated only for scarce positions, for non scarce positions $y_j = 0$. There are two positive values y_j – according to the number of scarce types of resources in the report on the sustainability: labor is a much more valuable resource for the enterprise ($y_2 = 5.484$) compared to electricity ($y_3 = 0.323$).

4. Columns "Permissible increase", "Permissible decrease" of table "Variable cells" (Table 3) provide an opportunity to analyze the received plan for sensitivity. Namely they specify the intervals for a possible change in the sale of a unit of production (or the price of each product type), in which the structure of the optimal plan (assortment) will not change, although the value of the target function will change. The same columns in Table "Restrictions" determine the intervals for possible changes in b_j resource reserves while their shadow price y_j remains constant, but the new target function value will change. For non-scarce resources the value of the "Permissible Decrease" is equal to the corresponding e_j excess.

Using the third theorem of duality theory, it is easy to determine the effect on the change in the objective function Z of increasing (decreasing) the volumes of individual resources:

Table 3

Report on the sustainability of the LPP optimal solution according to model (4) obtained at the *1st* iteration

Variable cells						
Cell	**Name**	**Final value**	**Present value**	**Target function Coefficient**	**Permissible increase**	**Permissible decrease**
B5	*X*1	306.452	0.000	60.000	68.000	2.857
C5	*X*2	0.000	–7.419	70.000	7.419	1E+30
D5	*X*3	0.000	–1.613	80.000	1.613	1E+30
E5	*X*4	419.355	0.000	40.000	2.000	1.351
Restrictions						
Cell	**Name**	**Final value**	**Shadow price**	**Restriction Right side**	**Permissible increase**	**Permissible decrease**
F10	<= *Z*	0.000	0.000	2200.000	1E+30	2200.000
F11	<= *Z*	419.355	0.000	2700.000	1E+30	2280.645
F12	*Z*	1645.161	0.000	3000.000	1E+30	1354.839
F13	*Z*	6000.000	5.484	6000.000	3800.000	1625.000
F14	*Z*	7000.000	0.323	7000.000	2600.000	2714.286
F8	<= *Z*	306.452	0.000	2500.000	1E+30	2193.548
F9	<= *Z*	0.000	0.000	1300.000	1E+30	1300.000

the numerical values of dual estimates y_j show by what amount the objective function changes when the volume of the j^{th} resource changes by one

$$y_j = \frac{\Delta Z}{\Delta b_j}. \tag{5}$$

Thus, with a small change in b_j instead of the problem described by the model (1–3) we have a new problem where b_j is replaced by $b'_j = b_j + \Delta b_j$. This article proposed the adaptation of the enterprise to market trends due to the redistribution of excesses between scarce resources so $\Delta b_j = e_j$.

Let X' denote the optimal plan of the new problem. To determine the change in the target function of ΔZ it is not needed to solve the new LPP, just use the formula

$$\Delta Z = Z(X') - Z(X) = y_j e_j, \tag{6}$$

where X is the optimal plan of the initial problem (1–3).

It is obvious that the exclusion of the excesses from the optimal plan does not change the objective function and the optimal plan, since in this case $y_j = 0 = \Delta Z$ in formula (6). That is, there is always an opportunity to withdraw funds from production in the amount of $\sum_{j=1}^{m} e_j$. Therefore, the planning department can reduce the advanced limit of funds for the products manufacturing in the amount of 16,000 monetary units (Table 1) by 1354.839 monetary units (resource excesses "material costs" from Table 2) in the example under discussion.

If the identified excesses e_j are not removed from production but redistributed between scarce resources, then the formula for the total increment of the target function ΔZ for k scarce resources ($k \le m$) has the form

$$\Delta Z = y_1 e_1 + y_2 e_2 + \ldots + y_k e_k. \tag{7}$$

Formula (7) provides evaluation of the ΔZ and preservation of the structure of the enterprise production optimal plan (assortment), provided that, in general, the amount of addition of the quantity of each type of resources b_k does not exceed the total 100 % of the maximum permissible values of changes in the number of resources, specified in the column "Permissible increase" Table "Restrictions" of the sustainability report. This is the meaning of the term "at a small change in b_j" in formula (5), i. e., at $\sum_{j=1}^{m} \frac{\Delta b_j}{\Delta b_j^+} \cdot 100 \le 100\,\%$. Here Δb^+_j is the maximum "Permissible increase" in the j^{th} resource.

However, it is necessary to recalculate the LPP solution after each redistribution of the excesses since with a constant assortment of the optimal production plan some bindings and excesses change. At the same time, the conditions for improving the previous plan are checked at each step: $Z_{k-1} < Z_k$ at $e_j \to 0$.

If the direct LPP, which is described by the model (1–3), has an optimal solution, then the following five resource states are theoretically possible. They are given in the results reports:

1. One binding – one excess.
2. One binding – multiple excesses.
3. Multiple bindings – one excess.
4. Multiple bindings – Multiple excesses.
5. All bindings – zero excesses.

Let us consider the managers' potentially useful actions of the enterprise planning department when reallocating excesses funds between bindings in each of the five specified resource states [10, 11]. Note that the redistribution of funds within individual states of resources can be carried out in several steps, as long as the target function of the LPP increases and the amount of excesses decreases.

1st state of resources. This case is simpler (the number of resources $m = 2$) and has rather theoretical interest since in practice the enterprise always uses many more resources in production. Nevertheless, its understanding will help master even more complex situations ($m > 2$).

It is necessary to add the excess e_1 of the non-scarce resource for which $y_1 = 0$ to the scarce resource b_2. At the same time according to formula (7), the increase in the objective function ΔZ_2 at the second iteration will be equal to

$$\Delta Z_2 = y_1(-e_1) + y_2 e_1 = y_2 e_1. \tag{8}$$

Since all the variables are positive on the right side (8) so $Z_2 > Z_1$. Therefore, the target function Z_2 increases as a result of such addition, i. e. $Z_2 > Z_1$.

2nd state of resources. This case does not fundamentally differ from the previous one, except that initially all excesses are ranked by the value of e_j and successively added to the scarce resource starting with the largest e_j, which provides the maximum increase in ΔZ at each step.

3rd state of resources. All scarce resources are ranked by the value of y_j and the excess is distributed among all bindings successively starting with the resource with a maximum shadow price. This provides the largest increase in the target function ΔZ.

4th state of resources. First, the sum of all excesses is found, provided that each excess is included in the amount that does not exceed the maximum decrease in a non-scarce resource. The sum of all excesses is distributed among all bindings starting with a resource with a maximum shadow price. This provides the largest increase in the target function ΔZ.

The 5th state of resources is ideal since all excesses are zero and the problem of their redistribution among scarce resources is solved. The obtained optimal plan according to definition 1 is an adaptive production plan built on the basis of the enterprise's self adjustment. All other resource states should be brought closer to this ideal state.

An example of the production plan adaptation based on the self adjustment of the enterprise, which is under consideration (Tables 1–3), refers to the *3rd* state of resources: Two bindings – one access (Table 2).

In the sustainability report (Table Limits) the resource excess "Material costs" is equal to 1354.839 monetary units and the resource with a maximum shadow price of 5.484 – "Labor costs". Therefore, it was decided to direct the entire excess of "Material costs" to the scarce resource "Labor costs", "Permissible increase" limit of which is 3800 monetary units. According to formula (8), the increase in the objective function will be

$$\Delta Z_2 = y_2 e_1 = 5.484 \cdot 1354.839 = 7429.76.$$

This result completely coincides with the calculation of the target function increase in the new optimal production plan obtained at the *2nd* iteration (Table 4).

Indeed, if calculations are made with 7 signs after a coma, then

$$\Delta Z_2 = Z_2 - Z_1 = 42{,}591.05 - 35{,}161.29 = 7429.76.$$

We also note that the range of optimal output at the *2nd* iteration remained unchanged ($X_1 = 197.19$; $X_2 = 0$; $X_3 = 0$; $X_4 = 768.99$), since the share of growth of the resource "labor costs" in relation to the maximum permissible increase was $(1354.839 : 3800) \cdot 100 = 35.65\ \% < 100\ \%$. Noteworthy is the fact that with the growth of the target function, the resource excess "Material costs" has significantly decreased: from 1354.839 monetary units at the *1st* iteration to 87.41 monetary units at the *2nd* iteration.

Table 4

Report on the results of the optimal LPP solution according to model (4) obtained at the *2nd* iteration

Target function cell (Maximum)					
Cell	**Name**	**Initial value**	**Final value**		
\$F\$5	*Z*	0.000	42591.047		
Variable cells					
Cell	**Name**	**Initial value**	**Final value**		
\$B\$5	*X*1	0.000	197.190		
\$C\$5	*X*2	0.000	0.000		
\$D\$5	*X*3	0.000	0.000		
\$E\$5	*X*4	0.000	768.990		
Restrictions					
Cell	**Name**	**Cell value**	**Formula**	**Condition**	**Excess**
\$F\$10	<= *Z*	0.000	\$F\$10<=\$H\$10	Without binding	2200.000
\$F\$11	<= *Z*	768.990	\$F\$11<=\$H\$11	Without binding	1931.010
\$F\$12	*Z*	1557.752	\$F\$12<=\$H\$12	Without binding	87.410
\$F\$13	*Z*	7354.838	\$F\$13<=\$H\$13	Binding	0.000
\$F\$14	*Z*	7000.000	\$F\$14<=\$H\$14	Binding	0.000
\$F\$8	<= *Z*	197.190	\$F\$8<=\$H\$8	Without binding	2302.810
\$F\$9	<= *Z*	0.000	\$F\$9<=\$H\$9	Without binding	1300.000

Continuing the process of transferring the value excess of the first resource to the second resource at the *5th* iteration the final optimal solution was obtained. Table 5 shows the results of the iterative procedure for improving the enterprise optimal production plan according to the model (4).

The data analysis of Table 5 shows that at each iteration there was an improvement in the original optimal production plan: the value of the target function for four additional iterations steadily increased from 35,161.29 to 43,103.31, that is, by 7942.02 monetary units, and the resource excess "Material costs", on the contrary decreased from 1354.839 to 0.024, that is, by 1354.815 monetary units. At the same time, the product range remained unchanged due to the fact that the percentage of increase in the "Labor costs" resource in relation to the maximum permissible increase during the investigated procedure rapidly decreased, remaining within 100 %. As a result, the "Shadow price" of scarce resources "Labor costs" and "Electricity" remained unchanged throughout the iteration procedure of improving the optimal production plan: $y_2 = 5.484$; $y_3 = 0.323$ respectively.

This completes the process of adaptation to changes in the internal and external environment based on the enterprise's self adjustment. The mathematical model of adaptation at step k^{th} takes the form

$$Z_k = \sum_{i=1}^{n} c_i X_i \to \max(\min);$$

$$\begin{cases} \sum_{i=1}^{n} a_{1i} X_i^* \approx b_1 \\ \sum_{i=1}^{n} a_{2i} X_i^* \approx b_2 \\ \dots\dots\dots\dots \\ \sum_{i=1}^{n} a_{mi} X_i^* \approx b_m \end{cases};$$

$$0 \le X_i^* \le X_{i0}.$$

If necessary, the optimal production plan, obtained at the last iteration of the enterprise, can be brought to the natural expression $b_1, b_2, \dots, b_m$ based on the known prices of production resources.

Conclusions. Thus, the use of the proposed iterative procedure for redistributing the value of excesses of non-scarce resources between scarce resources makes it possible to improve significantly the obtained initial optimal plan.

So, the enterprise top managers had the opportunity to reduce the advanced funds limit, after the 1st iteration in the example considered, for the products manufacturing by 1354.84 monetary units, and use the remaining money to the production of products A in the amount of 306.5 natural units and products D in the amount of 419.4 natural units. This would provide the enterprise with sales revenue of 35161.3 monetary units.

However, the enterprise has adapted to changes in the external and internal environment with the help of the proposed iterative procedure for redistribution of unused reserves between scarce resources. This made it possible to increase the sales of the enterprise products by 7942 monetary units due to a decrease in the manufacturing products A to 189.7 natural units and an increase in the production of products D to 793.1 natural units. At the same time, the manufacturing product range at the enterprise remained stable.

As directions of further development of this problem, we think it expedient to consider the possibility of additional ways to adapt the enterprise to market trends by introducing the

Table 5

The results of the iterative procedure for improving the enterprise optimal production plan according to the model (4) based on the redistribution of excesses of non-scarce resources between scarce resources

Characteristics of the optimal plan	Iterations				
	1	2	3	4	5
1. Function *Z*, monetary units	35,161.29	42,591.047	43,070.387	43,101.31	43,103.31
2. Excess of resource e_1 “material costs”, monetary units	1354.839	87.41	5.64	0.365	0.024
3. Plan for the production of products, natural units:					
A	306.452	197.19	190.141	189.687	189.657
B	0	0	0	0	0
C	0	0	0	0	0
D	419.355	768.99	791.548	793.003	793.097
4. Percentage of increase in the “labor costs” resource in relation to the maximum permissible increase, %	35.65	3.57	0.24	0.02	0.001

most effective means of adaptation. They are based on economic and mathematical methods and models and will contribute to the development of all the domestic economy spheres. It is implied that the enterprise not only adjusts its production program, but also acts as a system capable to self-organizing, that is, to change its internal structure. For example, it is capable to increase (reduce) the capacity of certain technical and technological equipment due to an increase (decrease) in the demand for specific products in conditions of rising or declining economy.

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Удосконалення виробничої програми підприємства як спосіб адаптації до змін ринку

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Мета. Доведення можливості удосконалення процедури адаптації підприємства до ринкових трендів на базі самоналаштування його виробничої програми з використанням розв’язків прямої та двоїстої задач лінійного програмування, отриманих за допомогою надбудови «Пошук рішення» пакету Microsoft Excel.

Методика. Методологічну основу дослідження становлять положення сучасної економічної теорії, фундаментальні праці зарубіжних і вітчизняних учених з питань формування систем управління та особливостей адаптації діяльності підприємств до змін. Широко використовується методологічний апарат економіко-математичного моделювання, дослідження операцій, зокрема, теорії двоїстості задач лінійного програмування.

Результати. Проведена адаптація підприємства до змін зовнішнього та внутрішнього середовища за допомогою запропонованої ітеративної процедури перерозподілу невикористаних резервів між дефіцитними ресурсами дозволила підвищити реалізацію продукції за рахунок зменшення виробництва одних видів продукції та зростання випуску продукції інших видів в умовах сталого асортименту.

Наукова новизна. Полягає в обґрунтуванні процедури адаптації підприємства до змін внутрішнього й зовнішнього середовищ на базі самоналаштування його виробничої програми з використанням розв’язків прямої та двоїстої задач лінійного програмування.

Практична значимість. Визначається прикладними аспектами самоналаштування виробничої програми підприємства, спрямованими на підвищення ефективності господарської діяльності за допомогою покрокового удосконалення оптимального плану випуску продукції (робіт, послуг).

Ключові слова: *адаптація, самоналаштування, оптимальний план, дефіцитні й недефіцитні ресурси*

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