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Optimization of Advertising with Consideration for Pricing Policy

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ABSTRACT: *an actual problem in economic activities of any enterprise is the optimum advertising campaign. Thusit is necessary to consider influence of a price policy of the enterprise at formation of demand for its production.The modified method of J. Forrester is developed for construction of mathematical model of an advertising campaign in work. Themodel allows to consider influence on a customer demand of advertising campaign and enterprise price policy. Two alternative projects of the enterprise are considered. Work of logistic system of the enterprise for each project is researched. Calculation of dynamics of all basic indicators of logistic system in both cases is executed. The enterprise net profit for a year is chosenas criterion of efficiency of projects. Advertising expenses anda goods price were consideredas a variationalparametres of a task of optimisation. Economic efficiency of each project is analysed. It is found optimum the decision for both cases. It is proved that it makes sense for enterprise to reconstruct the work according to the project with a greater capacity. The reasons of economic efficiency improvement of the project with capacity growth have been considered.Themethodologyforcalculatingthepaybackperiodofaproductionmodernizationprojectisproposed. The conclusion is drawn that the offered model is quite adequate and can be used at designing of new production systems.*

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I. INTRODUCTION AND LITERATURE REVIEW

Thearticle deals with building a model foroptimizationof an advertising campaign in the case when the demand for goods depends on their price. Thealgorithm of model calculationsproviding for the optimization of the price of goods and advertising costs with consideration for the main parameters of the logistics system (LS) is presented. A thorough analysis of the behavior of the main parameters of the LS is carried out.

The economic success of any enterprise is determined by the balance between its production and sales. One of the tasks of an enterprise is to optimally expand its market niche and bring the production capacity in line with the current demand for its products (Pedchenko, 2011); (Voronov, &Marıýta, 1997). In theoretical studies, an important role is played by the development of models which connect all the basic parameters of a logistics system in a single system of equations.

Since a change in the price of products as well as an advertising campaign can affect the number of potential consumersQ, the dependence of Qon the price and advertising should be considered within the framework of one model.

Many aspects in planning the current activities of enterprises are investigated already. For example, work (Pedchenko, 2011)presents a dynamic model of market pricing and manufacturing, which is intended for determining the nature of influence of production and technological specifics of anenterpriseon the evolution of the economic system. The theoretical basis for constructing the model is the equilibrium relationship, combining the approaches of L. Walras and A. Marshall to describe the behavior of prices and volumes of industrial products on the market for a single product. The synthesized mathematical model is a system of two linear difference equations for determining the price and volume of goods in discrete time. For this dynamic system, conditions for equilibrium position stability are obtained and the corresponding parametric analysis is performed.

Work (Voronov, &Marıýta, 1997) deals with building behavior models of consumers of the same type of products and presents their analysisby means of simulation methods, namely, agent-based modeling. To set the behavior of agents within the simulation model, J. Ferber’sreactive multi-agent system is used. A characteristic feature of models of reactive agents is the application of the concept of state and transition as well as mechanisms of stimulus-response behavior.

In work(Gvozdetsky, &Ostapchuk, 2011), a system of methods of quantitative and qualitative research in the management process (adaptive approach) is used; the simulation of a real economic enterprise with regard to the external environment is carried out.Probabilistic decision-making methods,which are widely used by enterprises operating under unstable market conditions, are considered.Adaptive methods and models that have a single information base and are capable of describing the adaptability of business entities to changing conditions are developed.

However, these works do not sufficiently disclose the quantitative relationship between the parameters of the logistics system of an enterprise and the current characteristics of the consumer market – potential demand for products, rates of consumption of products. This drawback of modern theory complicates studying the influence of an advertising company on economic efficiency of an enterprise. Work (Gorsky, et al., 1998) presents a model that, from a fundamental point of view, meets the formulated requirements. This model allows taking into account the detailed characteristics of the market, but it has a significant drawback.The application of the model results in unstable solutions in a wide range of parameters. Inwork(Sherstennykov, 2013), a method for eliminating this drawback is proposed. The method is based on averaging the rate of sales and transportation of products for a certain time interval. To date, there are no effective methods to plan a real-time advertising campaign of an enterprise, taking into account the logistics of the enterprise and market demand for its products.The methodology applied in this work is similar as in work (Sherstennikov and Yakovenko, 2019)

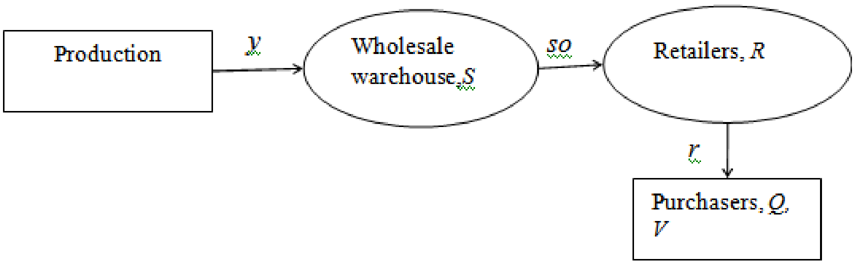
1.2. Research Objectives

The aim of the article **is to** develop an economic and mathematical model of production activities of an enterprise with regard to its retail sales and dependence of product demand on the price for a product; applying the developed model for the co-optimization of the company's advertising and the prices for everyday goods produced by it.

1.3 Research Methodology and Data

We will consider an enterprise which logistics corresponds to the scheme shown in Figure 1.

Figure1: Scheme of the enterprise's logistics



Time will be treated as a discrete variable $i\,(i = 0, 1, 2, \dots, T)$. We will analyze the project of the Tlength(the planning horizon). Let us assume that the influence of advertising on the potential current demandQ_{i+1}in the $(i+1)^{th}$period is described by the formula:

$$Q_{i+1} = Qr(Z) * \left(1 - \exp\left\{-\frac{i}{t}\right\}\right) + Qn(p), \qquad (1)$$

where$Qn(p)$represents the value of potential demand that depends onthe price for the product (p)in the absence of advertising;$Qr(Z) = Qm * (1 - \exp\{-Z/tz\})$is the maximum value of additional potential demand due to advertising;$t$and$tz$are the parameters of lagging.

Formula (1) means that the impact of the advertising campaign$Q_i$on the potential demand is described by the first-order lag model (Forrester, (1958); (Forrester, 1971). (see(Sherstennikov, 2018)). In the absence of advertising, the potential demand for the product is determined only by its price $Qn(p)$.

We suggest the linear dependence of the impact of advertising $Qn(p)$on the price:

$$Qn(p) = Qn + kp * (p0 - p),$$

where$Qn$is the value of the potential demand at the price$p0$.

Let us formulate the system of equations that describe the logistics system of the enterprise depicted in Figure1. We will assume that the company is fully provided with working capital.

1. The change in the demand $Q_i$for products on the market is an input impact for the enterprise whose task is to bring its output in line with the demand.

$$r_{i+1} = n \cdot R_i \cdot (Q_i - V_i) \qquad (2)$$

wherer_{i+1} is the rate of sales in the (i+1)th period; $n$is the parameter which is determined by the average sales level for the previous quarter (or year);$R_i$is the inventory level (quantity od goods) at the retail in the ith period; $V_i$is the inventory level in the hands of the consumer (not consumed yet).

2. Quantity of goods (inventory level – using the terminology of J. Forrester) at the retail R_i is determined by the recurrence formula:

$$R_{i+1} = R_i + Td \cdot (so_i - r_i) \qquad (3)$$

where$so_i$is the rate of delivery (units per week) from the warehouse to retailers; Tdis the period of discretization of the model (the time interval between decisions).
3. The level $R_i$should be within the limits $0 \le R_i \le Rm0$, where$Rm0$ is the maximum possible inventory level at the retail. The requirement is described by the following formula for the rate of delivery from the wholesale warehouse to retailers:

$$so_{i+1} = \min\left[r_i \cdot \left(1 + \frac{Rm\,0 - R_i}{Rm\,0}\right), \frac{Rm\,0 - R_i}{Td}, \frac{S_i}{Td}\right], \qquad (4)$$

where$S_i$represents the inventory level at the wholesale warehouse.
Publication [5] substantiates the need for averaging in performing the calculations with the proposed model:

$$\overline{so}_i = \langle so \rangle_{i-ps}^{i},$$

wherepsis the averaging time interval.
4. The production rate $y_i$is determined by the following formulas:

$$y_{i+1} = \left(y_i + \frac{ym - y_i}{ty}\right) \cdot A(S_i), \qquad (5)$$

$$A(S_i) = \begin{cases} 1, \text{if} S_i < 0.88 \cdot S_m, \\ \frac{0.88 \cdot S_m}{S_i}, \text{otherwise} \end{cases} \qquad (6)$$

where$y_i$is the production capacity in the i^{th} period; ym is the planned value of production capacity; Sm is the maximum inventory level at the wholesale warehouse. These formulas allow avoiding the overflow of the wholesale warehouse.
5. The inventory level at the wholesale warehouse $S_i$is calculated using the following formula:

$$S_{i+1} = S_i + Td * (y_i - so_i), \qquad (7)$$

where$y_i$is the rate of goods flow which goes into the wholesale warehouse from the production.
6. To determine the net profit of the enterprise, the following formula is applied:

$$M_i = (1 - kp) * [(1 - kad) * p * r_i - p * c * y_i - \\ - k2 * S_i - z * Rm - z1 * (Rm)^2 - qz \cdot Z] - B(y_i), \qquad (8)$$

where

$$B(y_i) = \begin{cases} 0, \text{if} i < 1 \\ qy|y_i - y_{i-1}|, \text{otherwise}' \end{cases}$$

wherecis the share of the prime cost in the price for products; pis the price for a production unit; k2 ispayment per one period of the storage of a product unit at the wholesale warehouse; kpis the income tax rate; kadis the value-added tax rate; qy is the cost of ‘including’, ‘excluding’ a unit of production capacity.

The formula for calculating the net income takes into account the quadratic dependence on the maximum volume of the retail sales, which is assigned to products of a certain manufacturer under the contract. The dependence can occur for a number of reasons. For example, with an increase in the number of retail outlets, the transportation distance increases, etc.
We will perform calculations for model (1) – (8) with the following values of its parameters:

$$Q = 1200,\ n = 0{,}0001,\quad k1 = 0{,}33,\ \ z = 0{,}01,\ z1 = 0{,}00017,$$
$$k2 = 0{,}01,\ So = 100,\quad Sm = 200,\quad Ro = 40,\quad n = 0{,}00005 \qquad (9)$$
$$kp = 0{,}25,\ \ kad = 0{,}06,\ \ c = 0{,}6,\ \ p = 10,\ qy = 20,\ Td = 1.$$

II. KEY RESEARCH FINDINGS

Working in a competitive market requires the director of an enterprise to pay attention to increasing the sales of the enterprise’s products or at least maintaining the sales at some acceptable level. One of the main ways to achieve this goal is to align the enterprise’s retail sales with its production capacity. For example, the chief executives of the enterprise, having evaluated the possibilities of the product market, decided to double its production capacity from 5.1 (product units per day) to 10.2 (product units per day). In this regard, they set the task for managers: to co-optimize the price of goods and advertising in order to maximize profits from the modernization project.

Expressed mathematically, the task that managers face is formulated as follows. We will choose the income received over the planned period of life of the project T (planning horizon) as the target function of the optimization task:

$$F_T(p, Z) = \sum_{i=1}^{T} M_i \to \max. \qquad (10)$$

Variable parameters of optimization task (10)are the price for the product pand advertising costs Z. The system of limitations for optimization tasks (9)is the system of equations (1) – (8). As it follows from (1) and (2),both factors pandZinfluence the potential demand Q. Therefore, they should be considered within the same model.
Let us compare the results of solving the optimization task with two values of the planned production capacity: 1) ym = 5,1; 2) ym = 10,2.

In the first case

$\begin{pmatrix} \text{p\_opt} \\ \text{Z\_opt} \end{pmatrix} = \begin{pmatrix} 48{,}14 \\ 5.71 \end{pmatrix}$, $F_T(p\_opt, Z\_opt) = 25024.$ (11)

Figure 2 illustrates the optimal solution for $ym = 5{,}1$.

***Figure*2**: **Illustration of the optimal solution for $ym = 5, 1$**

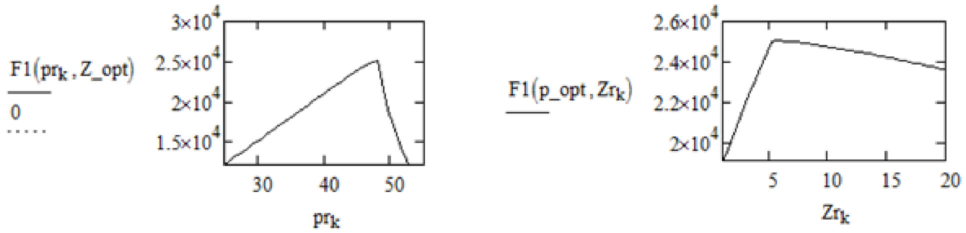


Figure 2 demonstrates changes in the total income for one of the parameters with a fixed value of the other at $ym = 5{,}1$.

The solution of the optimization task for the planned capacity $ym = 10.2$is as follows:

$\begin{pmatrix} p\_opt \\ Z\_opt \end{pmatrix} = \begin{pmatrix} 45 \\ 47.04 \end{pmatrix}$, $F_T(p\_opt, Z\_opt) = 32248{,}7.$ (12)

Figure3 illustrates the optimal solution for $ym = 10{,}2$.

***Figure*3**: **Illustration of the optimal solution for $ym = 10, 2$**

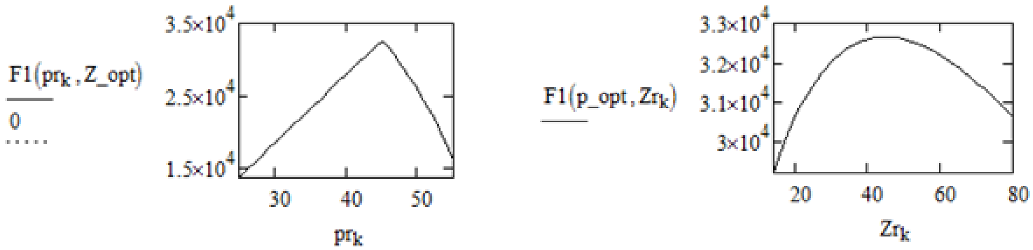


Figure 3 demonstrates changes in the total income for one of the parameters with a fixed value of theother at $ym = 10{,}2$.In the second case, the value of the optimal price for the product is lower while the optimal advertising costs are higher, with the value of the total income being1.3times as large as that in the first case. Such excess of the complete income in the second case to become clear at studying of time dependence of the current income.

Figure 4: Time dependence of the current income: for $ym = 5, 1$ (on the left); for $ym = 10, 2$ (on the right)

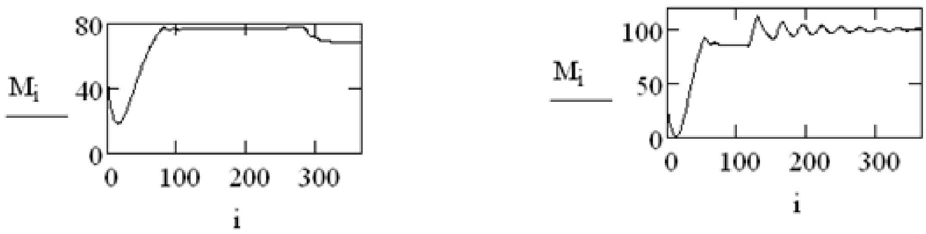


Figure 4 illustrates the behavior of the current income.As it follows from formula (8), the value of the current income of the enterprise is determined by the sales rate r_i, the production rate y_i, the goods level in the wholesale warehouse and goods maximum level in rhe retail trade.

To perform a more thorough analysis of the results presented in figure 4, let us calculate the time dependence of all basic characteristics of the LS.

Figure 5: Calculation of the main levels of the LS for $ym = 5,1$

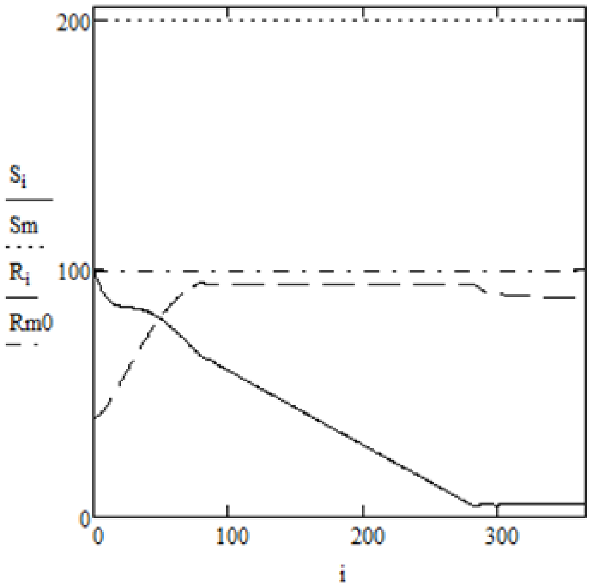


Figure5showsthatthe goods stock in a wholesale warehouse decreases, and goods level in a retail trade network by the 90th period reaches the maximum value which remains till the 280thperiod and further goods level in retail trade decreases a little. To understand such behaviour of levels of the goods in a wholesale warehouse and in retail trade, we will consider figure6.

Figure 6: Calculation of the basic rates of the LS for $ym = 5,1$

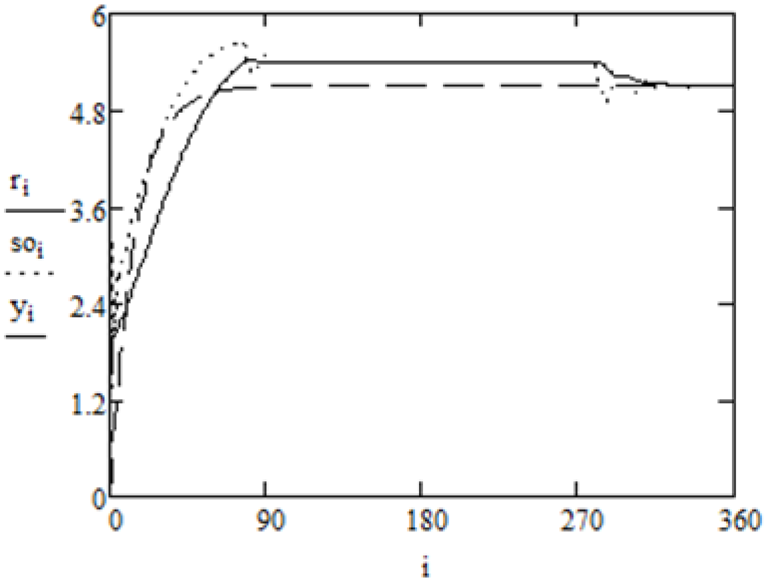
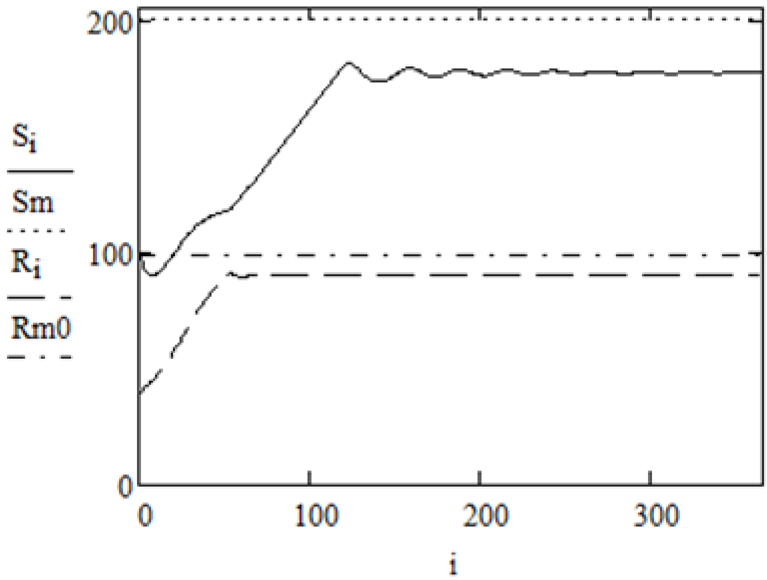


Figure 6 shows thatall the rates stabilize after 290th period at the level of 5.1 in the first case and at the level of 9.22 in the second case.First of all, we are interested in the production ratey_i. Figure 6 shows the production rate reaches the planned value of 5.1 by the 90th period and remains at this level. All the rates stabilize after the 290th period at the level of 5.1. It means that after the290th period levels in the LS remain invariable as it is visible from figure5.Considerable excess of rate of deliveriesso_i over rate of salesr_i takes place till the 80th period (see figure 6). It leads to fast growth of a stock of the goods at theretail.Thentheseratesbecomeequaltillthe 290thperiodand the goods stockR_i atthe retail network is stabilisedwithin this interval(see figure 5). The enterprise should first of all care of filling with the goods of a retail network, as according to the formula (2), current values of rate of salesr_i are defined by value R_i(as one of the factors).The formula (4) is designed to provide the maximum filling of retail trade. Figure6showstherate of

export of the goods from a wholesale warehouse so_iexceeds rate of receipt of the goodsy_i within the interval [0; 290] and as a result goods stocks at the warehouse $S_i$decrease to a minimum level.
Figure 5 also shows that the inventory level at the wholesale warehouse critically decreases by the 270th periodat $ym = 5.1$. This results in a decline in the inventory level at the retail (R_i), which in turn leads to a decrease in the sales rater_i (see figure 6).
The similar analysis can be executed for planned capacity$ym = 10{,}2$.

Figure 7: Calculation of the main levels of the LS for $ym = 10,2$



From a figure 7 we can observe that overflow of a wholesale warehouse does not occur. The kind of formulas (5) and (6) is chosen from these reasons.

Figure 8: Calculation of the basic rates of the LS for $ym = 10,2$

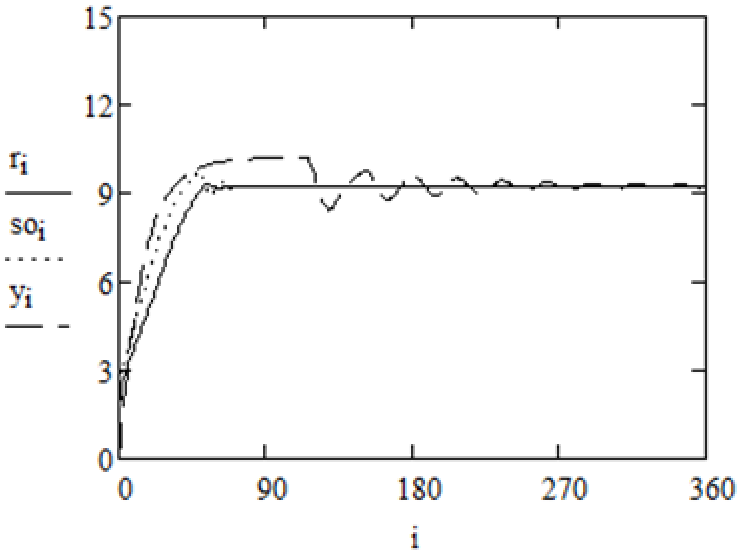


Figure 8 demonstrates that all rates do not reach the planned level of 10,2 in this case. After the 100th period, the production rate demonstratesdamped oscillations around the value of 9,22. Such behaviour of capacity is a payment that the wholesale warehouse is not overflowed.The quantity of the products manufactured per year amounts to 1795at $ym = 5{,}1$and 3346 at $ym = 10{,}2$.

From figure 4 we can observe that In both cases, there is a certain time range within which the value ofcurrent income is decreasing. Such behavior of the current income is typical for the initial period of any project. As it follows from formula (8), the value of the operating income of the enterprise is mainly determined by the sales rate r_i and the production rate y_i. The comparison of these rates for the first 150 periods (days) of the operation of the enterprise is presented in Figure 9.

Figure 9: Behavior of the sales rate r_i and the production rate y_i: for $ym = 5,1$ (on the left); for $ym = 10,2$ (on the right)

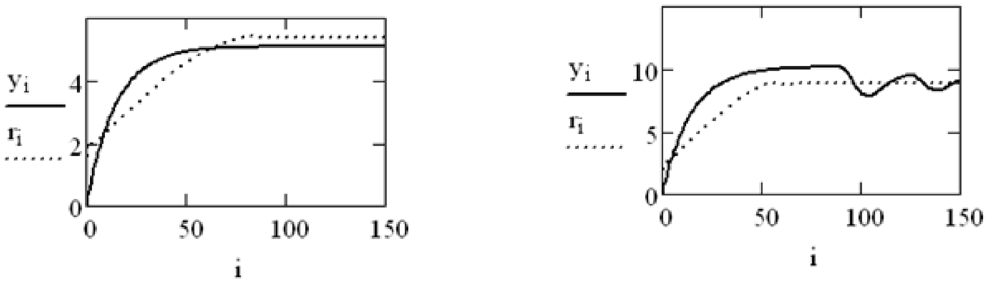
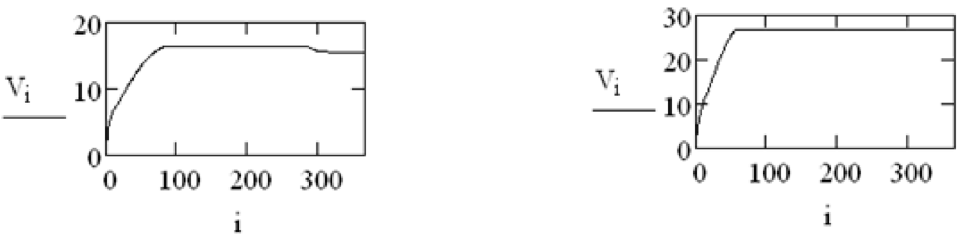


Figure 9, with consideration for formula (8), explains the behavior of the current profit of the enterprise presented in Figure 4.

Figure 10: Behavior of the inventory level in the hands of consumer V_i: for $ym = 5,1$ (on the left); for $ym = 10,2$ (on the right)



To complete the picture, figure 10 illustrates the behavior of the inventory level in the hands of consumer.
Thus from the formula (8) and figures 5 – 8 it is possible to see the reason of that the complete profit at$ym =$ 10,2 exceeds complete profit at $ym = 5{,}1$.

1.4 Findings and Interpretation

Let us consider the business sense of the results. The values related to the first (second) case will be denoted by the superscript “1” (“2”). Thus, as a result of solving the two optimization problems, we obtain:
Project 1: $y_{plan}^{(1)} = 5.1, \quad \sum_{year} y^{(1)} = 1735, \; {F_T}^{(1)} = 2920.4.$
Project 2: $y_{plan}^{(2)} = 10.2\,, \quad \sum_{year} y^{(2)} = 3346, \; {F_T}^{(2)} = 3810.$
In order to justify the transition from Project 1 to Project 2, it is necessary to assess whether additional investments,whichneed to be made in the transition from Project 1 to Project 2,will pay off. The ratio between the cost of manufactured products and fixed production assets can be estimated in a first approximation as a linear relationship
$p \sum_{year} y = f \cdot K,$
where$f$ isthe return on assets.
Thus, in the transition from Project 1 to Project 2, it will be necessary to purchase additional production assets in the amount of:
$\Delta K = \frac{p \cdot \Delta(\sum_{year} y)}{f}.$ (13)
Taking into account that with the usual values of the return on assets (at which the project will be profitable)itcan be assumed that its values are within the intervalf $= [2; 4]$, using formula (13) we will obtain:
$\Delta \mathrm{K} = \frac{\mathrm{p} \cdot \Delta \sum_{\mathrm{year}} \mathrm{y}}{\mathrm{f}} = \frac{45 \cdot (3346 - 1795)}{4 \div 2} = 17448 \div 34897$(monetary units). (14)

Expression (14) is the estimation of the amount of investment that must be made if the management of the enterprise wants to move from Project 1 to Project 2. It is clear that the investment cannot pay off within one year. Since, with the transition, the additional profit received for the year will amount to

$32248.7 - 25024 = 7224.7$ (monetary units) (see optimal solutions), the payback period of the transition will be: $\frac{17448 \div 34897}{7224,7} = 2,4 \div 4,8$ (years).

A model of the logistics system of the enterprise has been developed. This model allows performing the co-optimization of the advertising campaign and the pricing policy of the enterprise. These are the factors that directly influence the demand for the enterprise's products, which ultimately conditions the pace of manufacturing and sales of the products, and determine the work of all other links of the logistics system through a closed system of equations. The proposed methodology for calculating the payback period of a production modernization project requires further refinement.

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