INDUSTRY SIMULATION MODEL OF THE PRODUCTION AND SALE OF PETROLEUM PRODUCTS

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ABSTRACT

This paper presents a generalized simulation model of the oil refining industry for analyzing the effect of variability and randomness of demand and supply on the industry's performance. The use of a simulation and analytical model for planning near-term production growth will facilitate the calculation of key parameters and identification of the most appropriate means of using resources and increasing output. We have created a functional diagram of the production and sale of petroleum products as a system that reflects both production and information management functions. In order to describe and analyze the performance of the system, we created an econometric model with the recursive structure of relations. We have also developed an operational algorithm for simulating the production and sale of petroleum products.

Keywords: petroleum products, simulation model, assets, random variable, simulation algorithm.

INTRODUCTION

Choosing the optimal growth strategy in a market economy is essential for effective performance of the country's various industries, including oil refining. Ensuring the optimal ratio between demand and production of petroleum products is one of the key factors of the operation and expansion of this industry. The use of classic mathematical economic models to solve these problems will not produce the intended results due to the high level of variability and stochastic behavior of the key parameters and indicators of this industry. This work proposes a generalized simulation model of the oil refining industry for analyzing the effect of variability and randomness of demand and supply on the industry's performance based on known approaches to creating production simulation models presented in pioneering works [1-3], in other industry-specific studies [4-5], and in previous publications of the authors of this article [6-8].

FUNCTIONAL DIAGRAM OF THE PRODUCTION AND SALE OF PETROLEUM PRODUCTS

Figure-1 presents a functional diagram of the system that reflects both production and information management functions.
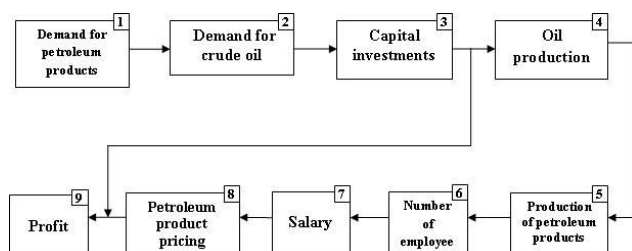

Figure-1. Functional diagram of the system.

There are two approaches to simulating demand for petroleum products: analytical and statistical. The first approach derives econometric relationships of demand on various factors, where demand in the previous period and retail price indexes have an essential role. Blocks 2-5 are related to the level of the industry's fixed production assets, which indirectly determine the functions of the four remaining blocks (6-9). Also we should note that there might be a substantial overlap and correlation of the functions among the elements of the above structure.

Before creating a model of the system, we will consider the generalized performance indicators for the industry. As evident from the functional diagram, the system of interest consists of two business units: oil production and petroleum product production. The first business unit delivers crude oil to the second. Let us state analytical relations that describe the generalized indicators for these business units. Let $\Phi 1(t)$ be the fixed production assets of the first business unit in value terms, and let $\Phi 2(t)$ be the fixed production assets of the second business unit. x_1 is the value of the end product (oil) of the first business unit, and x_2 is the value of the end product (petroleum products) of the second business unit. N_1 and N_2 are the capital inflows into these business units. We write the expressions for the production functions of these business units as follows:

$$x_1 = k_1[\Phi_1(0) + \int_0^t N_1 dt];$$

$$x_2 = k_2[\Phi_2(0) + \int_0^t N_2 dt].$$

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where k_1 and k_2 are the Return on Assets (ROA) ratios.

The control parameter here is λ, which is the share of savings directed to the first business unit. We will take

$$N_1 = \lambda x_1, \ N_2 = (1-\lambda)x_2, \ 0 \le \lambda \le 1.$$

The resulting relationships may be assigned to the following cybernetic diagram (Figure-2) [3].

Using the expressions of the transfer functions of consecutive chains and of the feedback, we obtain the operating forms for x_1 and x_2.

$$x_1(p) = \frac{k_1 \Phi_1(0)}{1 - \frac{k_1 \lambda}{p}},$$

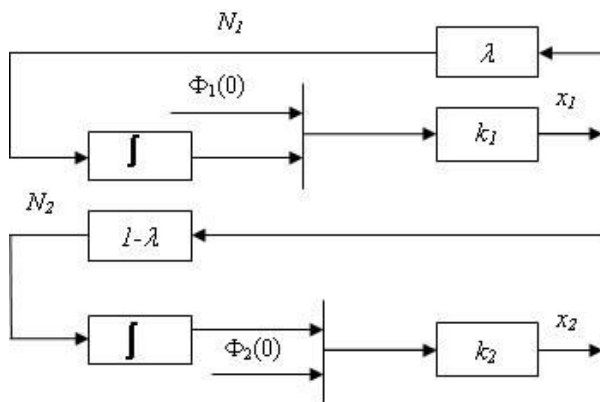$$x_2(p) = k_2 [\Phi_2(0) + \frac{(1-\lambda)x_1(p)}{p}].$$

Figure-2. Cybernetic diagram of the system.

After transforming these expressions we obtain

$$x_2(p) = k_2 \Phi_2(0) + \frac{k_1 k_2 (1-\lambda)\Phi_1(0)}{p - k_1 \lambda} =$$
$$= K_{11}(p)\Phi_2(0) + K_{12}(p)\Phi_1(0)$$

where $K_{11}(p) = k_2$, and $K_{12}(p) = \frac{k_1 k_2 (1-\lambda)}{p - k_1 \lambda}$

Then, proceeding from the operating forms to the original leads to the expression

$$x_2(t) = k_2 \Phi_2(0) + \frac{k_2(1-\lambda)}{\lambda}[e^{k_1 \lambda t} - 1]\Phi_1(0).$$

As is clear from this expression, the higher value of production assets at initial time (t=0) will result in

increased output of petroleum products for all t>0. The key role of parameter λ is also apparent; i.e., the larger the portion of savings directed to oil production, the faster the growth rate of the industry. However, the multiplier $(1-\lambda)$ in the exponential function prevents λ from becoming too high, since for λ=1, the second term on the right-hand side of the equation is equal to zero. Therefore, it is important to choose a value of λ which can be analytically optimized for various decision-making criteria; or simulation modeling methods may be used to find the efficient value of λ. The generalized indicators obtained in this section can serve as a benchmark for analyzing the results of simulation modeling for other models, e.g., econometric ones.

CREATING A FUNCTIONAL MODEL OF THE SYSTEM

Let us assume that at the start of a certain period the industry has the value $\Phi(t)$ of available fixed productive assets. The maximum ROA ratio k_m is calculated on the basis of technical and technological characteristics. Then we obtain the following expression for the industry's potential production capacity:

$$M(t) = k_m \Phi(t), \tag{1}$$

where $\Phi(t)=\Phi_1(t)+\Phi_2(t)$, $\Phi_1(t)=\lambda\Phi(t)$, $\Phi_2(t)=(1-\lambda)\Phi(t)$.
The following relationship describes the actual production capacity:

$$G(t) = k_\phi \Phi(t), \tag{2}$$

where k_ϕ is the actual ROA ratio.

These are the baseline indicators for the industry's performance at the start of the period of interest. Industry managers prepare output targets based on studies of market demand. Let $R(t)$ be an expression for demand that determines the output target. We make a preliminary estimate of the intensity value of the target.

Version 1. If

$$R(t) > M(t), \tag{3}$$

the target can be met only if new capacity is added

Version 2. If

$$G(t) < R(t) < M(t), \tag{4}$$

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the target can be met only if innovations that increase the actual ROA ratio are implemented.

Version 3. If

$$R(t) \le G(t) , \qquad (5)$$

measures must be taken to increase demand by improving product quality and the variety of products.

In order to describe and analyze the performance of the system, it is useful [2, 9] to create an econometric model with the recursive structure of relations.

It is clear that the demand in the previous period $R(t-1)$ is the natural departure point for determining the current demand for petroleum products, $R(t)$. The expected difference between these two values depends on a number of factors, the most significant of which are monthly household income MD, the retail price index for consumer goods IS and advertising expenses A. The effect of other unaccounted factors on demand may be taken into account using the random variable W_1 with a predetermined distribution. Then, using the multiple linear regression model, we generate the relation

$$R(t) = R(t-1) + r_1\left[\frac{MD(t-1)}{IS(t-1)}\right] + \\ + r_2\left[A(t-1)\right] + W_1 \qquad (6)$$

The "Production of petroleum products" block is calculated by the recursive relation

$$G(t) = G(t-1) + g_1\left[AR(t)\right] + g_2\left[ZN(t-1)\right], \qquad (7)$$

where G is the production index for petroleum products, AR is the average sales of petroleum products in the previous time interval of a fixed duration (e.g., three months), and ZN are petroleum product inventories at the points of sale in the previous period.

The "Demand for crude oil" block is calculated by the equation

$$H(t) = H(t-1) + h_1\left[AG(t)\right] + h_2\left[IP(t-1)\right] + W_2 . \qquad (8)$$

Here H is demand, AG is the averaged production index for petroleum products in the previous six months, IP is the production index for durable goods, W_2 is a random variable with a predetermined distribution taking into account the effect of other unaccounted factors of demand. The equation for calculating capital expenditures K has the form

$$K(t) = K(t-1) + k_1\left[AH(t)\right] + k_2 T , \qquad (9)$$

where AH are average monthly oil sales in the previous period (e.g., six months), and T is the trend.

The oil production index Q is a function of the demand for oil; the ratio of oil stocks in storage tanks to the volume of current orders for oil delivery, INV/UO in the previous period; the time of the year $M;$ and the trend $T;$ and is calculated from the expression

$$Q(t) = Q(t-1) + q_1\left[H(t)\right] + \\ + q_2\left[\frac{INV}{UO}(t-1)\right] + q_3 M + q_4 T . \qquad (10)$$

The number of workers N employed in the industry is determined from its output in the given month and in the three previous months $\left[AQ(t-i)\right]$, and from the ratio of monthly household income MD relative to the retail price index for consumer goods IS, describing the real household income in the previous period

$$N(t) = N(t-1) + n_1\left[Q(t)\right] + n_2\left[AQ(t-i)\right] + \\ + n_3\left[\frac{MD}{IS}(t-1)\right] \qquad , \quad (11)$$

In order to calculate the salary E, the trend value must be taken into account along with the number of workers

$$E(t) = E(t-1) + e_1\left[N(t)\right] + e_2 T \qquad (12)$$

The current price index P for petroleum products is calculated from the ratio of petroleum product inventories relative to the volume of delivery orders for these products, INV/UO, in the previous period; the average salary E for the industry; the previous values of the crude oil price indexes B and trend T

$$P(t) = P(t-1) + p_1\left[\frac{INV}{UO}(t-1)\right] + p_2\left[E(t)\right] + \\ + p_3\left[B(t-1)\right] + p_4 T \qquad . \quad (13)$$

The equations of the industry model complete the expression for calculating profit D

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$$D(t) = D(t-1) + d_1[P(t)] + d_2[P(t-1)] +$$
$$+ d_3[H(t)] + d_4\left[\frac{INV}{UO}(t-1)\right] + d_5[E(t)] \qquad (14)$$

Here, oil price and sales volumes are also taken into account along with the price index for petroleum products (P). Salary and material costs of crude oil that are reflected in the value of inventories are accounted for in the ratio of inventories to orders.

All coefficients (r,g,h,k,q,n,e,p,d) in the model (6-14) are calculated using the standard linear regression analysis.

SIMULATION OF RANDOM PARAMETERS OF DEMAND

The values of the parameters W_1 and W_2 are continuous or integer random variables with specified distributions, for example in the form of the density distribution $\varphi(w)$. The simulation of these parameters may be implemented using the inverse function method for simulating random variables based on theorem 1 [10]: "Random variable W, for which realizations are calculated from the expression

$$F(w) = \int \varphi(w)dw = u \text{ or } w = F^{-1}(u), \quad (15)$$

where u is a random number uniformly distributed in the interval [0, 1], has the density function $\varphi(w)$"; or the main method for simulating integer variables based on theorem 2: "Variable w_k, given in the form of the matrix $\begin{pmatrix} w_1 \ w_2 \ldots w_m \\ p_1 \ p_2 \ldots p_m \end{pmatrix}$, occurs with probability p_k when the condition $u \in \Delta_k$ is met, where $\Delta_k = p_k$".

If it is impossible to carry out the transformation (15), or when the distribution laws for parameters W_1 and W_2 are given in a graphic or tabular form, we can use the elimination method of John von Neumann, which follows directly from the theorem 3 "Let u_1 and u_2 be the random variables uniformly distributed in the interval [0, 1] and let $w = a + u_1(b-a)$, $y = Mu_2$, $w \in [a, b]$, then the random variable η, calculated from the condition $W = w$ where $y < \varphi(w)$, has the density function $\varphi(w)$". Proofs of these theorems may be found in [10].

If the density function $\varphi(w)$ is attributed to one of the known standard theoretical distribution laws, we can use the formulas given in Table-1 [11] to simulate the values of w.

Table-1. Generating continuous random variables.

Distribution	Density function	Simulation formula
Normal	$\varphi(\tau) = \dfrac{1}{\sigma_\tau \sqrt{2\pi}} \exp^{-\frac{(\tau - m_\tau)^2}{2\sigma_\tau^2}}$, $-\infty < \tau < \infty$	$\tau = m_\tau + \sigma_\tau *$ $*(\sum\limits_{i=1}^{12} u_i - 6)$
Uniform	$\varphi(\tau) = \dfrac{1}{b-a}$, $\tau \in [a,b]$	$\tau = a + u(b-a)$
Exponential	$\varphi(\tau) = \lambda e^{-\lambda\tau}, \tau \geq 0$	$\tau = -\dfrac{1}{\lambda}\ln u$
Linear	$\varphi(\tau) = \lambda(1 - \dfrac{\lambda}{2}\tau)$, $\tau \in (0, \dfrac{2}{\lambda}]$	$\tau = \dfrac{2}{\lambda}(1 - \sqrt{u})$
Gamma	$\varphi(\tau) = \dfrac{\alpha^k}{(k-1)!}\tau^{(k-1)} e^{-\alpha\tau}$, $\alpha > 0, k > 0, \tau \geq 0$	$\tau = \dfrac{1}{\lambda}\ln(u_1 *$ $* u_2 * . * u_k)$

A more complete list of standard continuous theoretical distributions and their formulas is provided in [10].

OPERATIONAL ALGORITHM FOR SIMULATING THE PRODUCTION AND SALE OF PETROLEUM PRODUCTS

The operational algorithm for simulating the production and sale of petroleum products includes the following steps:

Step 1. Determining the industry's potential production capacity from (1) for a given value of λ.

Step 2. Determining the industry's actual production capacity from (2).

Step 3. Determining demand for petroleum products in the current period from (6).

Step 4. Calculating demand for crude oil from (8).

Step 5. Calculating capital expenditures from (9).

Step 6. Calculating the oil production index from (10).

Step 7. Calculating the production index for petroleum products from (7).

Step 8. Calculating the number of workers employed in the industry from (11).

Step 9. Calculating salary from (12).

Step 10. Calculating the current price index from (13).

Step 11. Calculating profit from (14).

Step 12. Analyzing the correspondence of the values of production capacity obtained from formulas (2) and (7).

Step 13. Analyzing the preliminary estimate of the

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intensity values of the targets following three different versions (equations 3-5).

Step 14. Determining the effective value of parameter λ describing the distribution of total capital expenditures between oil production and petroleum product production.

Long-term studies of business planning activities in various industries allow us to create a dynamic operational framework, in which factors such as the rate of growth of the value of fixed production assets, the pace of improvement in utilization of fixed and current assets, and the rate of productivity growth, have an essential role.

CONCLUSIONS

We have developed a simulation model for the analysis of the oil refining industry system. The proposed operational algorithm for the production and sale of petroleum products allows us to identify various industry development options, depending on a functional relation with ROA ratios, uncertain demand and other indicators. Thus, the model proposed in the study allows us to identify the optimal ratio between demand and production of petroleum products and facilitates more efficient business planning.

The use of the simulation results will also help determine the priority areas for the oil-refining industry that should be developed with consideration of available resources.

REFERENCES

[1] Buslenko N.P. 1968. Modelling of complex systems. Nauka, Moscow, Russia.

[2] Naylor T.N. 1971. Computer simulation with models of economic systems. John Wiley and Sons, NY, USA.

[3] Bagrinovsky K.A., T.I. Konnik, M.R. Levinson. 1989. Simulation of economic decision-making. Nauka, Moscow, Russia.

[4] Abdel-Aal H.K., M. Aggour, M.A. Fahim. 2003. Petroleum and gas field processing. CRC Press, USA.

[5] Considine T.J., E. Heo. 2000. Price and inventory dynamics in petroleum product markets. Energy Economics. 22(5): 527-547.

[6] D.N. Shukayev, V.Z. Abdullina, N.O. Yergaliyeva and Zh.B. Lamasheva. 2014. Modeling the processes of distribution of resource flows. Proceedings of the Romanian academy, Series A. 15(1): 85-94.

[7] D.N. Shukayev, V.Z. Abdullina and Zh.B. Lamasheva. 2015. Simulation and analytical modeling of production-marketing system. International Journal of applied and fundamental research. 3: 82-87.

[8] D.N. Shukayev, Zhumagaliyev B.I., Yergaliyeva N.O. and Lamasheva Zh.B. 2014. The extension method in flow allocation problems. International Conference on Electronics Technology, Computer Science and Information processing (ETCSIP 2014), April, 19-20, Beijing, China. Applied Mechanics and Materials. 556-562: 3692-3702.

[9] Forrester J.W. 1966. Industrial Dynamics. New York-London.

[10] Shukayev D.N. 2004. Computer Simulation. KazNTU, Almaty, Kazakhstan.

[11] Pugachev V.S. 1960. Theory of random functions and its application to problems of automatic control. Fizmatgiz, Moscow, Russia.