The Modelling Methodology of the New Product Release on the Open Market Based on the Production Systems and Rival Products Interaction Dynamics

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Abstract: The relevance of the problem is related to the necessity of improving production systems economical efficiency in constantly changing market conditions and their rivals' behaviour. In the article, it is suggested to use predictions that include diffusion component and production system models constructed on their basis which allows us to synchronize external and internal in relation to the system under consideration processes. To take into account the possible price and quality changes, the model based on markets equilibrium where there is only non-symmetrical information is suggested. The models' formalization received allows us to set a lot-scheduling planning problem that includes internal and external environmental changes. Eventually, solving this problem, we will get both lot-scheduling production plans and warehouse requirements for the products considered taking into account possible market and production systems constraints. The practical significance of the paper is related to the possibility to verify and clarify business planning data in production management tasks which makes it possible to increase the objectivity of decisions by increasing the production processes formalization rate, incorporation the diffusion factor when releasing new products and the possibility to take into consideration various rival behaviour strategies.

1 INTRODUCTION

The increasing number of market goods released leads to increased competition among production systems and goods. The competition is developing in the management and decision-making systems fields. The evolution of production systems management methods at present is an incorporation of many approaches and methods of such areas as system analysis, cybernetics, mathematical economics.

Nowadays, these practical methods by J. Von Neuman [1] and L. Kantorovich [2] of system analysis and their variations in fuzzy and interval formulations [3], [4]; production systems' efficiency management methods based on the allocation of limited key indicators and multi-criteria assessments [5], [6]; innovation and investment management methods [7], [8]; portfolio management methods [9], [10]; system dynamics methods [11]; theory of active systems [12], hierarchical systems management methods and the approaches based on the hierarchical systems management methods [13], different types of diffusion [14], [15], [16]; features of markets behaviour and equilibrium theory of markets [17], [18], [19] have become widespread.

Thus, we can conclude that the problem of economic efficiency is a complex task affecting many areas of knowledge which were developing parallel over time [20]. Despite the obvious statement, the combination of many approaches into a single theory, model or algorithm has not been done yet due to the complex nature of the problem. Neither existing models nor different methods can solve this problem properly since they make assumptions related to interaction simplification that is associated with the knowledge of decision-makers. Besides, decision-makers do not take into account the dynamic behaviour of the competing production systems due to the generalized market analysis [21], [22].

Agent-based modelling can be used to test the competing production systems' behaviour based on their models [23], [24], [25]. Systems based on agent modelling are frequently used as a process research tool which depends on many dynamically changing parameters.

Several approaches have been developed for building agent-based models (inclusive agent interaction). Such approaches allow to tackle agent communication and synchronization problem [26], [27].

Thus, a mathematical and algorithmic base has been formed which allows us to build interaction models as shown in Figure 1.

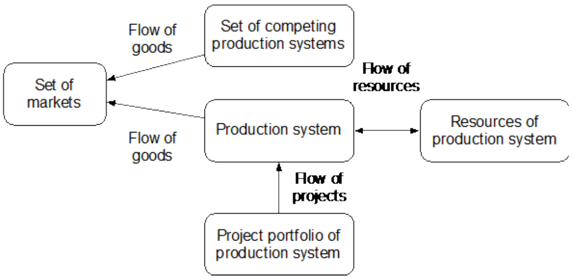


Figure 1: The scheme of production system interaction through their products on the market.

Constructing different models of the production systems this way makes it possible to take into account the behaviour of individual competing systems by building models for them or simulate situations when the other systems will perform similar actions (i.e. situations hindering the development of a managed production system).

2 MODELLING

The model development is associated with the implementation of a group of models that exchange data. The minimum required set of models is:

- The production system model that uses demand predictions for optimal planning.
- A warehouse model for accounting the volume of funds withdrawn from circulation, additional storage costs and a mechanism to meet customers' demand based on the products stockpiling when production capacity and variety of the products is limited.

As a result of the model evaluation, we can determine not only the volume-schedule plan for every product type but also products' price ranges and quality requirements. If we meet these requirements the production system will remain effective.

2.1 Production System and WareHouse Models

Let us formulate the production system management model as a model of volumetric scheduling [28]:

$$\sum_n (C_n(t) - (Q_m(t) + I_n(t))) \times X_n(t) \to max$$
$$X_n^H(t) \le X_n(t) \le X_n^B(t)$$
$$(C_n(t) - (Q_m(t) + I_n(t))) \ge 0$$
$$D_{nm}(t) \ge Z_{nm}$$
$$S_{pc} \ge S_n(t) \ge 0$$

where X_n - the product output volume n, $C_n(t)$ – the revenue of the n product, Q_m – the product net cost, I_n – packaging costs, X_n^H – the breakeven point, X_n^B – the market's volume constrains (for every product), n – the product type, m - the variety of its components, t – the time, S_n – the warehouse's empty places, S_{pc} – the warehouse's maximum capacity, D_{nm} - the matrix of available products, which has the form:

Variety of products	1	…	m
Quantity of products	D_{n1}	…	D_{nm}..

Z_{nm} - the matrix of the demanded products, which has the form:

Variety of products	1	…	m
Quantity of products	Z_{n1}	…	Z_{nm}.

In this problem, the values X_n^B will be determined based on the demand forecasting data with a coefficient corresponding to the market share claimed by the production system. The value $C_n(t)$ will be corrected on the base of market model.

In order to predict the X_n^B values, a wide variety of forecasting methods based on statistical data can be used [29]. However, if there is no statistic data available, sales volume data can be used instead.

In the modelling of the real market conditions, the maximum market capacity cannot be reached by any product immediately. The data on sales growth is in good accordance with the data obtained when the phenomenon of physical diffusion is used as an analogy. The diffusion affects the velocity of all the products diffusions on the market during the first stages of any project. In order to solve the management planning problem and estimate the products diffusion degree, the physical parallel (cloud particles' spreading from the point) was used to define the necessary volume forecast shrinking rate will be used:

$$G(x,i) = \frac{1}{\sqrt{4\cdot\pi\cdot D\cdot i}} \cdot e^{-\frac{x^2}{4\cdot D\cdot i}},$$

where D – the diffusion coefficient, empirically determined, either based on the products statistical data or expertly, based on the rival's reputation (its value during the modelling process can vary due to new releases, price changes, the manufacturers' authority growth and so on according to the Walras equilibrium model [30]), i – the calculation step (to take into account the similar products' output time shift, it is crucial to reduce this value by the value of the products delay in the calculation steps), x – the market capacity.

To determine the effect on the magnitude of the forecasted value, it is important to define the value that will be subtracted from the forecast data excluding diffusion (the value of competitors' diffusion) according to the formula:

$$n(x,t) = \sum_k n_0(x_k) \cdot \Delta x_k \cdot G(x - x_k, t),$$

where $\Delta x_i = x_{i+1} - x_i$, $n_0(x_i)$ – the initial diffusion value (for equivalent products), released by the i production system, k – the number of the production system producing equivalents. The use of this component is justified since the release of competitors' products requires recalculation at each step, as the volume of the planned output and demand for the manufactured products will be changing.

As a result of the discussion above, we obtain the task that using modelling tools allows us to research the processes of new products release. The variables that affect this process are i – the product release point, n_0 – the similar products' diffusion rate by our release moment, and the values D – the product diffusion rate on the market (this value will vary depending on the market situation).

The warehouse model in this problem has the simplest form and takes into account only the cost of storing items and their availability. In this form, it can be integrated into the optimal production planning task as described above (adjusted criterial function and restrictions). Thus, the costs associated with overproduction, excess inventory and so on will be considered as well.

Describing every production system with this model and using only different sets of products, methods and data for demand forecasting, we can evaluate the effect of different production systems on each other in dynamics.

2.2 Market Model

The market model in our task is crucial for determining the fluctuation in the product prices (P) and demand. Для этого необходимо установление взаимосвязи между ними. To do so, we need to set connections between them. To get a dynamic behaviour for this dependence, we will use the parameters of quality (Q) and brand (B) (which can be measured in relative units from 0 to 1, where 1 is the maximum confidence, 0 is the minimum).

Then we can write the following models to describe the dependence of the parameters:

$$Q(t) = C_1 \cdot Q(t-1) + C_2 \cdot P(t).$$

By the price of the products in this formula we mean the competitors' products prices which will be predicted by one of the regression methods.

The brand significance assessment can be performed based on the prices, quality, advertisement rate of the product of the previous step (R):

$$B(t) = C_1 Y(t-1) + C_2 Q(t-1) + C_3 R(t-1).$$

Using these relationships, you can evaluate the redistribution of market shares. Analyzing two production systems, the competitor's market share will be calculated using this formula (the parameter will be in the range $0 \leq M \leq 1$):

$$M = \frac{B_r * P_r * Q_r}{B_o * P_o * Q_o} \cdot 0.5,$$

Where index r means that these are the values of the rivals' products, and index o – variables that describe the products of the production system.

The proposed interrelation allows performing calculations for researching possible changes in the strategy of the considered production system and the impact on the competitor's behavior strategy changes.

3 MODELLING AND PRODUCTION SYSTEM MARKET EFFICIENCY TASK SOLUTION

For testing and verifying purposes, we consider three situations that may occur in a market environment:

- manufacturers rivalry (the situation where two production systems produce the same product and the results of their labor compete for a place on the market);
- the rivalry of two products (the situation when two production systems offer similar goods fighting for the same audience on the same market);
- production system portfolio rivalry.

To give a dynamic character to the experiments, we will be changing the values of prices, volumes, quality, advertisement rate within the confidence interval.

For the first experiment, we used the Amazon online store sales data of the group of products. To set up the model, Feltcraft Doll Emily and Feltcraft Doll Molly sales' and prices' data were used.

As a result of the first experiment, we obtain the values given in Figure 2. The graphs show that the sales and production volumes of every system grow and each of them gets its market share.

Doing the second experiment, for the initial setup of the model, we used sales data for Feltcraft Doll Emily and Toy Tidy Dolly Girl Design and obtained the results shown in Figure 3. This experiment also shows that as a result of competition observed in the first stages, production systems come to the equilibrium state. However, it is important to note that even in the search of steady state, production activity is effective. Thus, the model used allows the system to operate under the influence of factors that were not taken into account in the formulation of the task.

The research of the third situation is more curious since in this case, the values of the parameters characterizing the size of the brand are not stable (see Figure 4). For simulation, we selected the following products for the first and second production systems.: Mr Robot Soft Toy, Toy Tidy Spaceboy, Toy Tidy Dolly Girl Design.

As in the previous experiments, we can observe the diffusion of products in the market with a stabilization process after taking a certain market share.

Unlike the two previous experiments, the graphs show the influence of quality and brand factors on sales and profits. The production volume diagrams show that both on the market and inside the production system there is a competition for production capacity. Based on the graphs of production volumes in warehouses, we can be assumed that the model performs well in the rivalry market environment, and, therefore, sets market shares. Moreover, according to the price changes, we can observe patterns of the Walras spiral model [31], which is a factor that confirms the adequacy of the description.

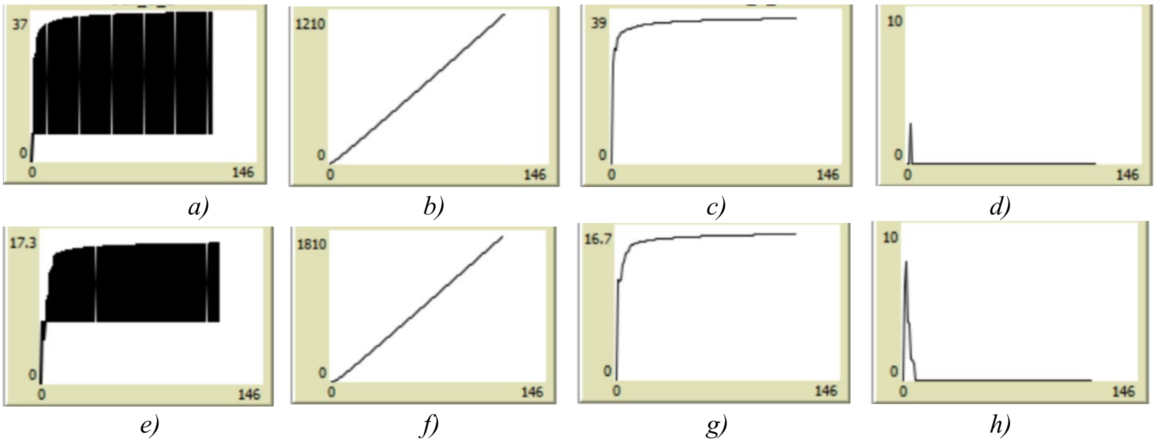


Figure 2: The first experiment modelling results (the first row describes the first production system, the second one – the second production system): a) and e) – the sales volume, b) and f) – the net profit, c) and g) – the production volume, d) and h) – the warehouse stock.

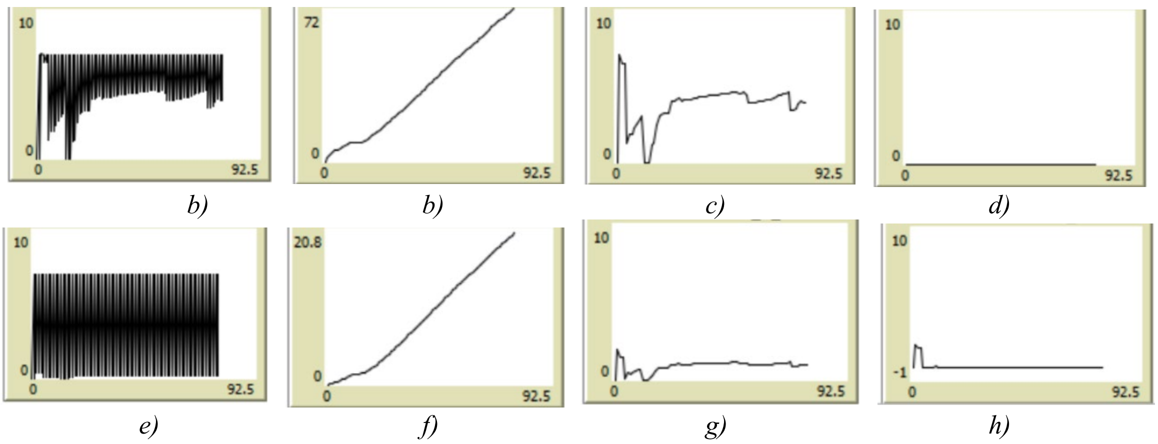
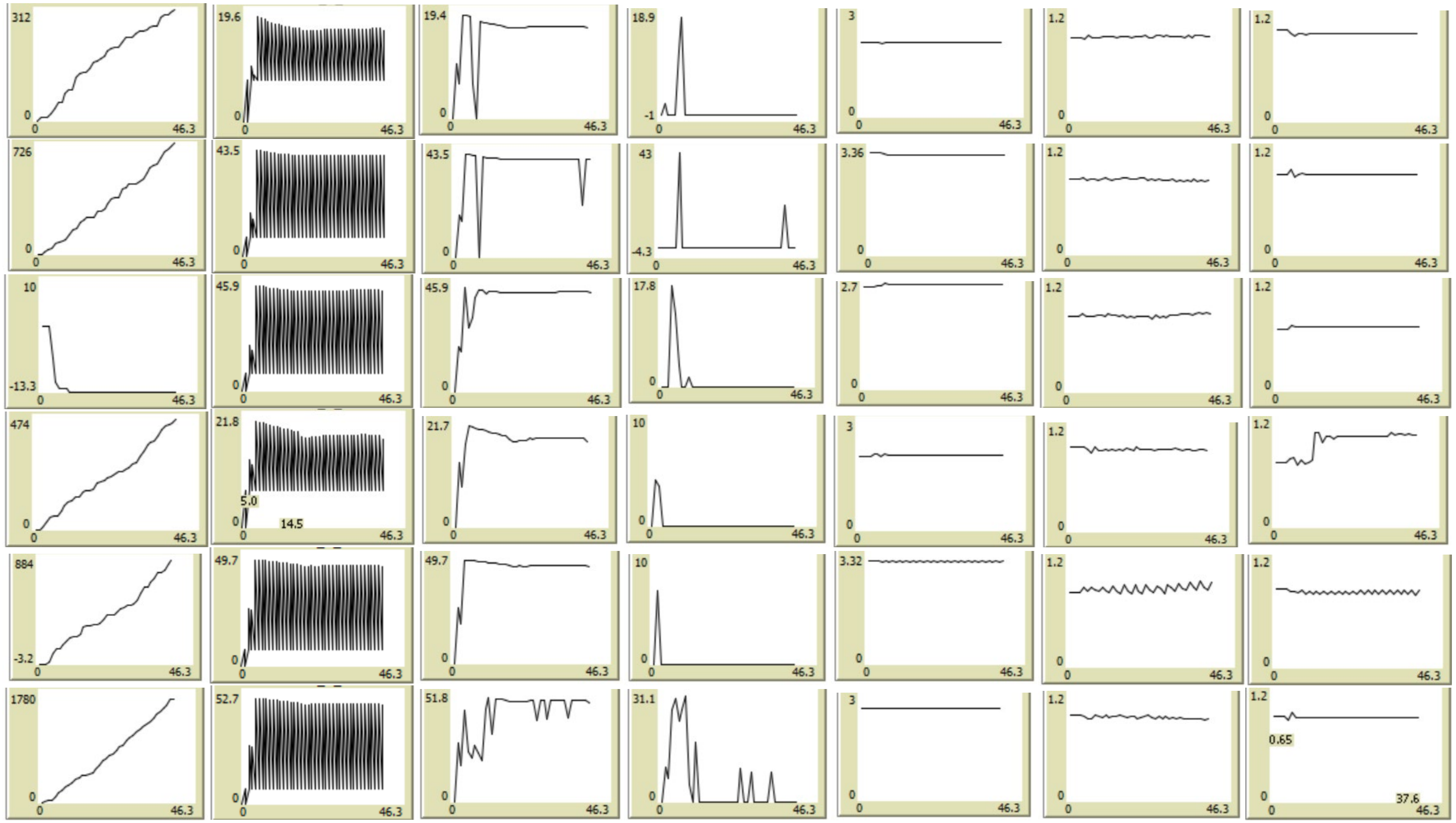


Figure 3: The second experiment modelling results (the first row describes the first production system, the second one – the second production system): a) and e) – the sales volume, b) and f) – the net profit, c) and g) – the production volume, d) and h) – the warehouse stock.



a) b) c) d) e) f) g)

Figure 4: The third experiment modelling results (1st – 3rd rows – three products of the first production system, 4th – 6th rows – three products of the second production system): a) sales volume group, b) instant sales group, c) production volume group, d) products in stock, e) price fluctuations, f) quality fluctuations, g) brand fluctuations.

Since the indicators of quality and pricing were considered as interrelated, we observe their interconnection on the graphs. The brand value in our model is used, apart from other things, as a compensation factor, aggregating non-economic indicators such as product advertisement rate, its recognition, fluctuation in its quality and price over time.

4 DISCUSSION

The article suggests a way how to simulate market competition based on a market model. The results of the simulation obtained correspond to well-known models like Walras model, a cobweb-like model, a market model with asymmetric information which indicates that the market situation will come to a steady-state after the disturbing effects.

However, unlike the others, our model can use different formalization methods and parameters describing production systems.

Another distinguishing feature of our model is the principle of using and adjusting forecast data based on the forecasting of our competitor's data and adjusting, if necessary, our input data for the following periods. As a result, the obtained data can be explained not only by theoretical knowledge of market behaviour but also by the statistical data of the retrospective periods (see. Figure 5).

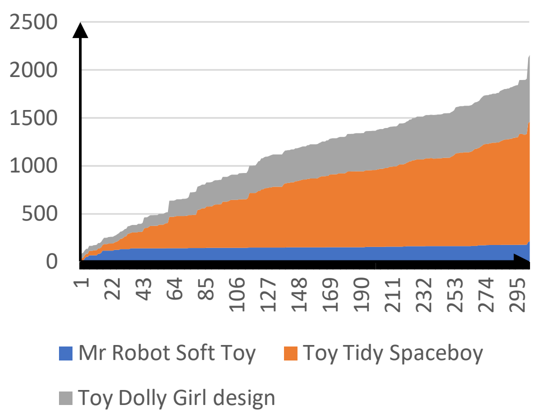


Figure 5: Real sales volume.

5 CONCLUSIONS

As a result of the discussions and calculations presented in the article, we can conclude that it is not enough to use only one approach to evaluate the situation in order to form a cost-effective project portfolio, it is also necessary to build a combination of methods and approaches which will be able to interact with each other through parameter values.

At the same time, system management does not come down to finding the optimal solution but to searching for the system state which will make it stable and effective in a constantly changing environment.

Moreover, it should be noted that the release of any new product is gradual. To describe this phenomenon, we use forecast correction based on the physical resemblance with the cloud of particles diffusion, which allows avoiding the accumulation of unclaimed products at the warehouses and heavy circulating assets freeze.

The results obtained correspond to the statistical data and theoretical knowledge in the innovation project management field. Thus, the structuring of models, the predictive approach, and the diffusion phenomenon, which we used to research the products release behaviour, should be considered as an essential part in modelling and analyzing the processes associated with the implementation of projects [16].

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