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INVESTIGATIONS OF PRODUCTION FUNCTION IN COMPLEX BUSINESS MANUFACTURING SYSTEMS

Abstract: *The paper presents the models for expressing the production effects via physical and economic indicators of the product – representative. Mathematical models enable the investigations of production functions for a group of products, timely identification of production-program and economic trends and application of simulation processes in strategic management.*
Keywords: *Product, production, representative, models, simulations, strategic management*

1. INTRODUCTION

Production systems' sustainable development is enabled by organization, technology, marketing and production doctrine, whose impact and effects, in compliance with the situational approach, is optimized by management as a connecting and integrating factor. Since 1990s a volume of books, professional-scientific papers and expertise have been published offering frameworks for each of the domains mentioned. Scientists invented programs and doctrines, while professional associations, following the results of practical achievements, posed concepts for diverse conditions and environments. Practice shows that there has been no global program doctrine so far due to profound differences between nations or civilization entities in the domain of economic, cultural, industrial and mental specificities.

Complex business manufacturing systems (CBMS) belong to a group of material, organizational, complex, dynamic or stochastic systems and as such tend to their own degeneration unless adequate inputs are steadily provided. Complexity is conditioned by the structure, large number of products, inputs, processes and complexity of managerial function. Since 1990 a comparatively small number of such systems have survived, however, in our enterprises there is still a conspicuous discrepancy between technical-technological and organizational levels compared to similar enterprises in developed countries.

Production program scope and heterogeneity require the definition of models for expressing production effects through corresponding indicators of the adopted product-representative. Timely identification and analysis of production trends can prevent production orientation failures, provide insight into economic trends by investigating the turning point of business operations, and enable the application of corresponding software solutions from strategic management domain. The paper presents the methodology, impact factors and results of investigations of production functions in 'Sloboda" Co. Cacak to identify and design program and financial trends.

2. IMPACT FACTORS AND BMS CHARACTERISTICS

The purpose, complexity and characteristics of the "Sloboda" Co. production program demand involvement of various branches of technology and production technologies that ensure the entirety of weaponry production. This type of production was initiated with the aim of developing, producing and overhauling anti-aircraft ammunition as a basis of the special-purpose production program. Over the past 64 years the production program has been extended, so that now it comprises over 140 articles. The basic characteristics of the range of products that are of significance for investigating the production function are: several variants of a product (live, blank, training, school), a large number of various-purpose articles and various types of weaponry, a large number of parts (positions, elements, joints, sub-units, units) ranging from 12 – 117, a large number of installment technological levels: vertical - from 3 – 7, horizontal - from 4 -22, per cent of parts produced by cooperating members is, on average, 15 against total number of parts in the article, a smaller number of key parts is installed in a number of articles limiting their manufacturing and delivery priorities. Production development and mastering ends by zero series product manufacturing and testing, when product function is analyzed in detail with respect to its purpose and level achieved in meeting standards and requirements set in technical documentation. The practice of applying zero series procedure extends to several series of regular production, so as to fully master the 'art of production' and 'economical manufacturing' by undertaking corrective measures to improve work procedure, technology, tools etc. Such approach to development proved to be broad and effective enough because it extends the process of designers and technologists' creative participation in creating a new product. On the other hand, participation of experts is possible in production, control, logistics and marketing development. It should be noted that product character and purpose require the highest possible quality and reliability level, but also the participation of other plants manufacturing specific components (gunpowder, caps) or producing means that use the products (pistols, rifles, guns).

Technic.-technological characteristics result from production program, current production equipment, defined procedures and employees managing and executing the manufacturing process. Special-purpose production comprises technological areas of production such as machining by plastic deformation that includes all types of processing: cold forging, extrusion, extraction with and without wall reduction, pressing, bending, straightening, calibrating, rotary extrusion, piercing, punching and spring manufacturing; machining by cutting involves turning, milling, boring, grinding, broaching, screw manufacturing, or combination of several types of machining on more complex parts; heat treatment (annealing, tempering, hardening etc.) for inter-operational preparation of parts and tool manufacturing; surface protection (galvanic – cadmium plating, nickel plating, tinplating, copper plating, hard and plain anode oxidation, zinc plating; chemical treatment – phosphating, chrome plating, nickel plating; varnishing – base and finishing) and chemical preparation (phosphating and staining) for parts' inter-operational preparation; production of mixtures (ignition, tracer, retarder, smoke, illuminating) and product explosive composition including product laboration; wood processing for package material production (crates); maintenance of own means of production on a separate machine site, which includes responsibility for power and fluid supply; manufacturing and sharpening of special-purpose and non-standard tools on a separate machine location. The equipment consisting of machines for processing by deformation and for the most part for processing by cutting is of universal nature and possesses considerable flexibility in performing the majority of manufacturing operations. Taking into account the realization of production plans, this enables the design of multi-variant technological solutions (alternatives), whereby bottlenecks are eliminated in production. At the same time, possibility is raised for production program changes and optimization processes application.

Having in mind the width of assortment, products' purpose, technical-technological characteristics and technologies applied, the program is divided into eight groups (Tables 1 and 2).

Table 1 - Production program representation per product group – production line

Production program			Number of articles	Internal code $X_{i,j}$	Variants of prod. manufactured
Group code	Name of product groups	Year of prod. start			
1	*2*	*3*	*4*	*5*	*6*
1	AA and A ammunition cal 20 and 23 mm	1952	36	i = 1,36 j = 1	Live, blank, training, specimens, practical
2	AA and A ammunition cal 30, 37 and 40 mm	1952	32	i = 1,32 j = 2	Live-several types, blank, training
3	Rifle mines and spare assets	1960	14	i = 1,14 j = 3	Battle, illuminating, smoke, training, spare, stabilizers
4	Hand rocket-propelled antitank assets cal 64–120 mm	1979	9	i = 1,9 J = 4	Battle cumulative and training
5	Warning highlighting and hail funds	1955	27	i = 1,27 j = 5	Warning ammunition, fireworks, torches for lighting, hail funds
6	Program of cooperation within INVO	1951	10	i = 1,10 j = 6	Explosive charges, retarders, tracers, and parts
7	Program of market cooperation	1949 1982	6	i = 1,6 j = 7	Products and parts for metalworking, electronics and wood processing industries
8	Program of tank and artillery ammunition and AA 57 mm	1955 1991	8	i = 1,8 j = 8	Live (several types and calibres)
TOTAL:			142	X_i , i = 142	-

Table 2 - Dynamics of product development measured by total number of products in production program (total and per group) and per cent of technologies applied

Number of articles in production program (pieces)				Share of technologies (%)				
Group	t_1	t_{18}	Growth	Deformation	Cutting	Protection	Pyrotechnics	Other
1	*2*	*3*	*4=3-2*	*5*	*6*	*7*	*8*	*9*
1.	18	36	18	3 - 16	15 - 38	5 - 12	21 - 34	1 - 7
2.	7	32	25	7 - 18	20 - 37	3 - 13	18 - 33	
3.	12	14	2	0 - 17	19 - 61	1 - 10	12 - 38	
4.	0	9	9	0 - 18	40 - 67	3 - 9	16 - 30	
5.	4	27	23	6 - 22	3 - 12	1 - 5	61 - 75	
6.	2	10	8	0 - 5	0 - 42	0 - 1	68 - 95	
7.	1	6	5	0 - 97	0 - 95	0 - 5	0 - 45	
8.	0	8	8	10 - 22	23 - 41	6 - 14	25 - 31	
Σ	**44**	**142**	**98**	**16**	**42**	**7**	**31**	**4**

The program of military and market cooperation comprises several hundred parts, in various quantities that, irrespective of the type and quantity, depending on purpose, are conditionally treated as a set of products within groups 6 and 7.

For the needs of production function investigations, we carried out the analysis of impact factors in a time interval that embraces 18 years' business cycle (t_7-t_{18}, Fig. 1). Total number of products was increased by 98, i.e. from 44 to 142, which evidences dynamic development in order that the system can respond to demands and challenges from the environment. Fig. 2 shows total number of articles and their distribution in Company's production program in the study period.

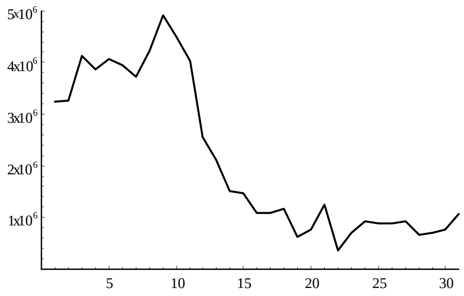

Figure 1 - Annual production program trends during a 31-year period

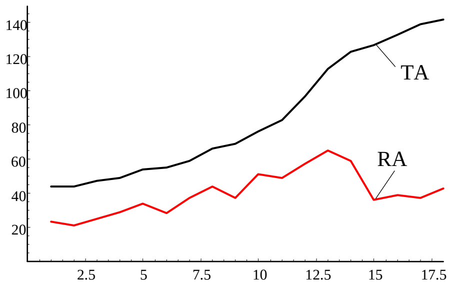

Figure 2 - Number of articles: total (TA) and represented (RA) in the production program (pieces/year)

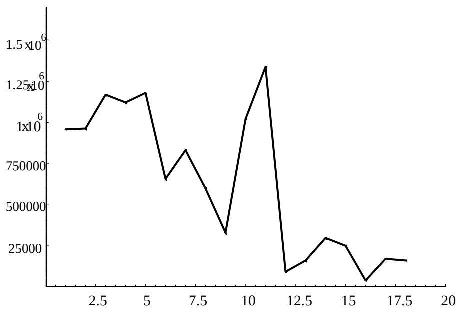

Figure 3 - Unfinished production trends (hourly rates/year) calculated according to current time standards

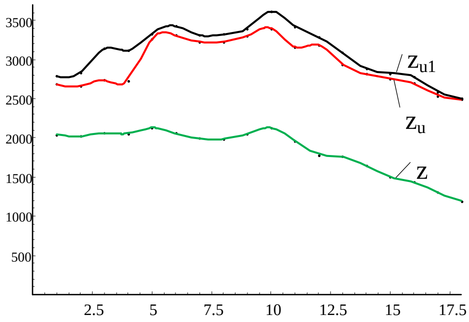

Figure 4 - Total (z_u) and production human resources (z) determined by current state records dated Dec. 31 and total (z_{ut}) calculated based on effective working hours

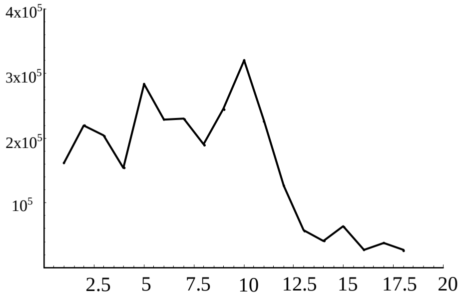

Figure 5 - Lost hourly rates due to extra processing, rejects, testing and revisions

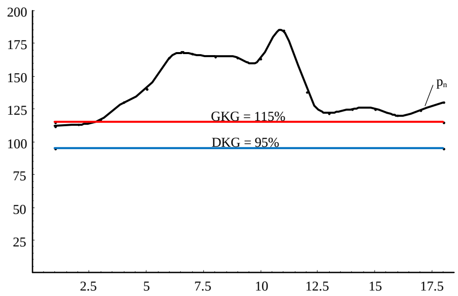

Figure 6 - Per cent of annual norm (standard) realization trends with plotted control limits

Considering the distribution of articles in annual production programs (Fig. 2) two periods of time are evident. In the first 14 years (t_1 – t_{14}) the distribution ranges from 48-67%, and in the last four years (t_{15} - t_{18}) from 27 – 30%. Negative distribution trend is the outcome of political and economic dismemberment, sanctions and blockade, destruction of economy and infrastructure, which all resulted in the loss of customers, cooperating members and suppliers. Steady improvement of performances and innovativeness, being a part of the company's business strategy, directly affects diversification of production program thereby increasing the chances for adaptability, survival and further development of the BPS. In the study period per cent of production equipment written off is very high, 50% of equipment being 30 years old, while 14% is younger than 10 years. The age structure of machines representing the bearers of production capacities (aggregate and CNC tools, automatics, special-purpose machines) is considerably better. The age structure of equipment has adverse effects on production capacities utilization level and justifies the existence of organizational unit for equipment overhauling and maintenance.

Unfinished production trends, as an indicator of planning and quality managing and reflection of production problems, are presented in Fig. 3. Losses with respect to quality include: rejects (from processing and materials), extra processing, repairs and revision, positions, units and final products destroyed by testing. Fig. 5 shows the diagram of the lost hourly rates for quality. In the 18-year study period they range from 2 – 5.8% against annual production volume (physical indicator) and from 3 – 4.9%, respectively, against total revenue (economic indicator). The domain of factors related to human resources comprises total number and occupational structure of employees, analysis of causes and volume of absence from work, work standardization and pay system. Fig. 4 displays data on human resources total and production trends, and Fig. 6 average norm realization of production units.

3. PRODUCT–REPRESENTATIVE

Extremely wide assortment has adverse effects on utilizing available production capacities and production function optimization. A significant organizational problem related to the problem of planning and production management is time standard. Average realizations of the standard (Fig. 6) indicate that standards are not realistic, are established empirically and overestimated. Production managers and those of other Company's sections are linked, by their pays, to over-fulfillment of the production norm but not to the per cent of production plans realization instead. With respect to production organization and capacities utilization, the presence of oscillations is especially unfavorable in both the amount of some articles and their distribution in annual production programs. 'Sloboda' Co. must be ready to produce all products (142) although in the study period annual plans account for 27 – 67% of articles.

Assortment width and oscillations lead to the choice of the product – representative - within each group of products that would be used as a basis for macroeconomic analyses and establishment of business operations breakeven point (profitability point), analysis and prediction of future production and program orientation trends, analysis of available capacities and their utilization level. The criteria for the representative choice can be numerous but the most prominent are certainly the following: significance in total production volume, significance in total revenues, product complexity and purpose, applied technologies and capacities engagement level in the production process, number of bottlenecks in production, significance in production program structure with respect to life and production cycle, stability in production program and stability of time standard in the period analyzed. Taking into account the above criteria, eight products – representatives – were chosen. To establish the corresponding regularities, the production realized within a group should be expressed through the quantity of a chosen product.

In general, the production program (PP) is constituted of a finite number (n) of products (X_i), where the volume of realized production is determined by the quantity (Q_i) and time standard (t_{ni}), relations (1) and (2). Starting from the formulas for calculating the production realized (T_{os}), relations (4) and (5), adopting for the product – representative X_j (6) that belongs to the production program (3) and introducing the coefficients k_i (7) and p_i (8) we obtain the formula (9) that is used to calculate quantity (Q_i) of all products (X_i) into equivalent quantity (Q_r) of the adopted product – representative – (X_r).

$$PP = \left\{ X_i, Q_i \,\middle|\, i = \overline{1,n} \right\} \tag{1}$$

$$X_i = \left\{ \left(Q_i, t_{n_i} \right) \,\middle|\, i = \overline{1,n} \right\} \tag{2}$$

$$X_r \in \left\{ X_i \,\middle|\, i = \overline{1,n} \right\} \Rightarrow t_{n_r} \in \left\{ t_{n_i} \,\middle|\, i = \overline{1,n} \right\} \tag{3}$$

$$T_{os} = \sum_{i=1}^{n} Q_i \cdot t_{n_i} = Q_1 \cdot t_{n_1} + Q_2 \cdot t_{n_2} + \ldots + Q_j \cdot t_{n_j} + \ldots + Q_n \cdot t_{n_n} \tag{4}$$

$$T_{os} = Q_r \cdot t_{n_r} \tag{5}$$

$$\left\{ X_r \right\} = \left\{ X_j \right\} \Rightarrow \left\{ t_{n_r} \right\} = \left\{ t_{n_j} \right\} \tag{6}$$

$$Q_1 \cdot t_{n_1} + Q_2 \cdot t_{n_2} + \ldots + Q_j \cdot t_{n_j} + \ldots + \ldots + Q_n \cdot t_{n_n} = Q_r \cdot t_{n_j} / t_{n_j} ,$$

$$k_i = \frac{t_{n_i}}{t_{n_j}}, \; i = \overline{1,n} \tag{7}$$

$$Q_r = Q_1 \cdot k_1 + Q_2 \cdot k_2 + \ldots + Q_j \cdot k_j + \ldots + \ldots + Q_n \cdot k_n = \sum_{i=1}^{n} Q_i \cdot k_i ,$$

$$p_i = \frac{Q_i}{Q_j}, \; i = \overline{1,n} \tag{8}$$

$$Q_r = Q_j \cdot \sum_{i=1}^{n} k_i \cdot p_i, \left(X_r = X_j\right)\left(\frac{piece}{year}\right) \quad (9)$$

$$T_{os} = Q_r \cdot t_{n_j} \quad \left(\frac{hourly\ rates}{year}\right) \quad (10)$$

$$\forall Q_j = 0 \Rightarrow \left(Q \neq 0 \wedge Q = 1\right) \quad (11)$$

$$Q_r = Q \cdot \sum_{i=1}^{n} k_i \cdot p_i - Q = Q\left(\sum_{i=1}^{n} k_i \cdot p_i - 1\right) = = \sum_{i=1}^{n} k_i \cdot p_i - 1\left(\frac{piece}{year}\right) \quad (12)$$

$$T_{os} = \left(\sum_{i=1}^{n} k_i \cdot p_i - 1\right) \cdot t_{n_j} \left(\frac{hou.\ rates}{year}\right) \quad (13)$$

Coefficients k_i and p_i are used to relativize effects of time standard (internal factor) and quantity of products (external factor), with cumulative effects being expressed by the sum of products (9). This is of importance when production cumulative effects are monitored over a longer period of time to avoid the influence of unrealistic time standards, which is present in this concrete case. If in some period of time or year the product – representative – is not manufactured (Q_j = 0), and it is necessary then to express total production via its equivalent quantity, taking into account the relation (8) we adopt quantity Q = 1 and use the relations 11 – 13.

4. PRODUCTION FUNCTIONS

Using formulas (9) and (10) and (12) and (13), respectively, annual effects of realized production were calculated into corresponding equivalent effects of chosen products – representatives. Current trends, with means shown in corresponding time intervals (t_1-t_5, t_6-t_{10}, t_{11}-t_{15} and t_{16}-t_{18}) are presented in Figs 7 – 14.

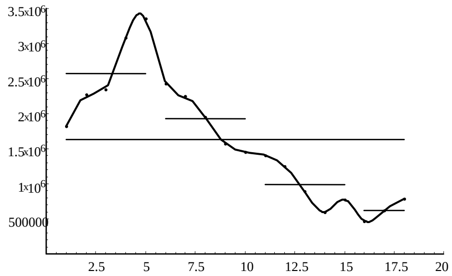

Figure 7 - Realized production of articles from group 1 expressed in (piece/year) of prod. – represent. $X_{1,1}$

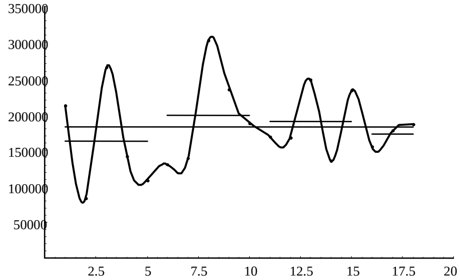

Figure 8 - Realized production of articles from group 2 expressed in (piece/year) of prod. – represent. $X_{3,2}$

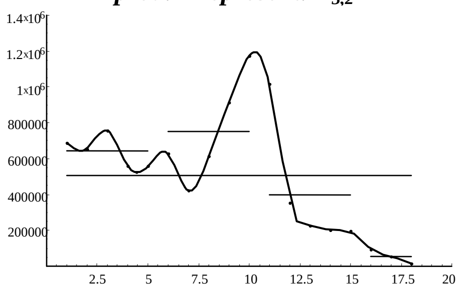

Figure 9 - Realized production of articles from group 3 expressed in (piece/year) of prod. – represent. $X_{1,3}$

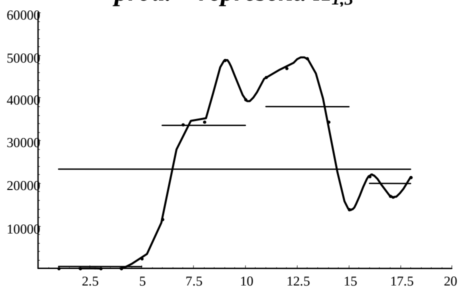

Figure 10 - Realized production of articles from group 4 expressed in (piece/year) of prod. – represent. $X_{1,4}$

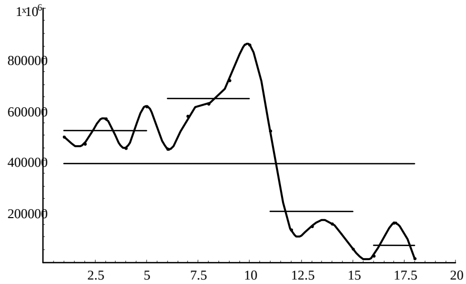

Figure 11 - Realized production of articles from group 5 expressed in (piece/year) of prod. – represent. $X_{1,5}$

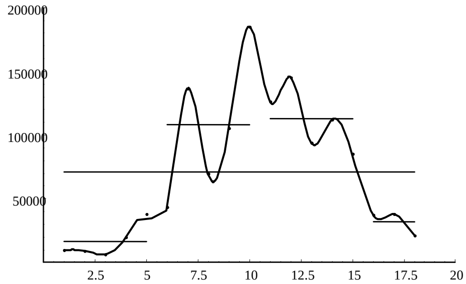

Figure 12 - Realized production of articles from group 6 expressed in (piece/year) of prod. – represent. $X_{3,6}$

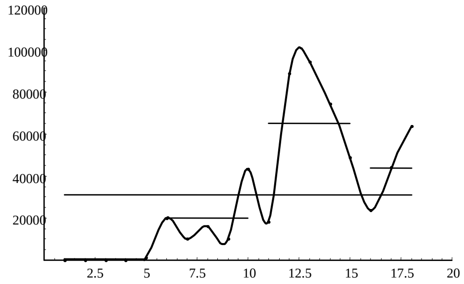

Figure 13 - Realized production of articles from group 7 expressed in (piece/year) of prod. – represent. $X_{1,7}$

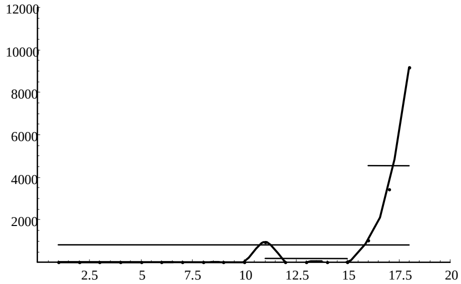

Figure 14 - Realized production of articles from group 8 expressed in (piece/year) of prod. – represent. $X_{8,8}$

5. CONCLUSION

Diagrammatic representations in Figs. 7-14 indicate possible stages of product lifecycles within corresponding product groups. In general, products from groups 1, 3, 5 and 6 are in the declining stage of demand, those from groups 2, 4 and 7 are in the saturation stage of demand, while products from group 8 are in the stage of being placed on market. It should be noted that oscillations emerge in a physical volume of production mainly due to dynamics and structure of orders within groups 1-4 that are the framework of production program. Wide assortment, small production distribution, oscillations in the volume and structure of orders, export orientation, production cycle duration, a large number of constraints and uncertain trends of changes in the environment all imposes prediction and risk-taking as unavoidable dimensions of strategy. Since there are no reliable indicators of market needs and possibilities of product sales to reduce risk in program orientation failure, the present paper investigated and presented production functions trends as a starting point for applying the prediction and decision making model.

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