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Mathematical methods of data processing in formation and evaluation of sectoral structure in agricultural enterprises

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ABSTRACT

The sectoral structure of most agricultural enterprises is unbalanced and uncoordinated, which underlies the need in deepened research of its improvement. This paper is dedicated to the formation and evaluation of the sectoral structure with the use of mathematical methods of data processing. Mathematical economic modeling based on optimization and simulation models has been applied for the formation and evaluation of sectoral structure in agricultural enterprises. The approbation of aforementioned models has been carried out in certain agricultural enterprise. The simulation modeling has been used to develop production model by the types of products that enterprise does not produce (milk, fish products and honey). The optimization model has been developed taking into account the rational use of the enterprise's land with the prospect of livestock sector development. Obtaining the maximum net income (proceeds) from products sales has been chosen as the optimality criterion. According to calculations, the maintenance of cows is unprofitable; the production of fish and honey is profitable. Due to the diversification of sectoral structure, the enterprise's profitability level will increase from 16.6 to 45.8 percent. The implementation of optimization and simulation models allows to assess the existing level of sectoral structure in agricultural enterprise and to form its optimal sectoral structure with ensuring the rational use of resources and obtaining profit.

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INTRODUCTION

Material and technical resources and especially natural resources are not used effectively (arable land, perennial crops) or not used at all in production and economic activities in many agricultural enterprises (forage lands, forest cover areas, ponds, etc.). Contradictions and imbalance exist in the internal structures of agricultural enterprises. This leads to a number of economic, social and environmental problems, hampering the development of both enterprises and rural areas. Issues of rationalizing, organizing and improving the sectoral structure of agricultural enterprises are relevant and solved by leading scientists. The fundamentals of specialization and diversification in the agricultural sector are reflected in the works of Andriychuk, 2002, the features of sectoral transformations– in the works of Chaika, 2013. The aspects of the diversification strategies implementation in agricultural enterprises have been explored by Bartolini *et al.*, 2014 and specified in the context of Ukraine's integration into the European Union by Tkachuk, 2016; Barbieri and Mahoney, 2009 have researched the implementation of diversification for the purpose of obtaining additional income and developing livestock sector. The impact of diversification on social and ecological processes with account of the creation of agricultural parks in human settlements is considered by Bacon *et al.*, 2012 and Kremen and Miles, 2012 consider the use of biological diversification in agriculture. Smagina, 2010 suggests the use of an entropy indicator to assess the level of specialization and diversification. Tomilin, 2012 researches the use of diversification in the agricultural sector of Ukraine as crisis response measures. Lysenko and Lysenko, 2009 believe that the formation of a sectoral structure should be made taking into account the reduction of low-profitable industries. Danko, 2016 suggests the formation of a sectoral structure taking into account the situation in the market of agri-food products. The issues of creating and implementing strategies of sector development through simulation modeling are disclosed in the works of Semenova (2011). The economic and mathematical modeling allow to optimize existing production resources of agricultural enterprises, to identify reserves of resource potential, to rationalize their use and to increase the economic efficiency of economic activity (Farafonova, 2012). Gavaza, 2014 substantiated the use of economic and mathematical models to optimize the sectoral structure and maximize profits. Advantages of optimization models usage in economics are substantiated by Neogy *et al.* (2016). Researchers consider the possibility of applying simulation modeling in economic processes and systems (Bratuska, 2009), explore the possibility of using AnyLogic and Arena simulation systems for solving management problems (Malikov, 2012) and for development of models of enterprises economic growth (Krivovozyuk and Tishko, 2009). Asafiyev and Aliyev (2009) consider the use of simulation modeling for the formation of tactical and strategic planning in the enterprise. Geisendorf (2009) suggests applying innovative and simulation models in the study of micro-environment and macro-environment. Luttmer (2012) examines the features of simulation modeling at the enterprise level to obtain data on long-term growth rates. Grégory and Sandholm (2013) studied the effect of changing the range during stochastic approximations. König *et al.* (2016) considered the use of simulation modeling to develop a convenient dynamic model of enterprises productivity growth. However, there is currently no research on the use of optimization and simulation models for the formation and evaluation of the sectoral structure in the transition process from specialized to diversified agricultural enterprise. In this context, mathematical methods of data processing in formation and evaluation of the level of sectoral structure in agricultural enterprises should be substantiated. This study has been carried out in Kharkiv National Agrarian University named after Dokuchayev, Kharkiv, Ukraine in 2018.

MATERIALS AND METHODS

System analysis as a scientific method has been used for the formation and evaluation of the sectoral structure of agricultural enterprises. An agricultural enterprise is considered as a system, an industry (sector) – as its subsystem. The evaluation of the sectoral structure has been carried out on indicators: the structure of net income (proceeds) from sale of products, the structure of production costs, and the structure of harvested acreage. Chosen indicators are contained in official financial statements of agricultural enterprises. This makes them accessible and reliable. These indicators are dynamic, which allows applying economic and mathematical modeling on the basis of optimization and simulation models for the mathematical description of the process of formation and evaluation of the sectoral structure. Unlike other mathematical models, simulation can reproduce not only the statistical correlation between objects of the system, but also simulate the development of the system in time. The methods of modeling economic and other complex systems are called statistical simulation methods, or the Monte Carlo method. This is a universal method that relies on repeated random sampling to solve diverse tasks. Various system simulation models are used in agricultural production management: structural (simulate the internal organization of an object, process and phenomenon), functional (describe the behavior of the original and its function), structural and functional models (the synthesis of structural and functional models) (Asafiyev and Aliyev, 2009; Krivoviazyuk and Tishko, 2009). System structural simulation models have been used to form and evaluate the level of the sectoral structure of agricultural enterprises. Indicators included in the mathematical model can be grouped into 3 groups. The first group includes parameters whose long term data series are subject to the laws of probability distribution. The second group includes uncertainty parameters – the distribution laws are unknown to them, upper and lower values can be set for their evaluation. For the indicators of the third group, there is a slight scattering relative to the mean value and the relationship between the parameters. Insignificant data scattering relative to the mean value and the correlation between the parameters are typical for indicators of the third group. Information for simulation modeling of agricultural production results has a different degree of reliability. Therefore, application of the algorithm for simulation modeling of production in agricultural enterprises in conditions of uncertainty and the existence of correlation between the model parameters has been proposed for the formation and evaluation of the level of sectoral structure (Fig. 1).

The research uses models that can be based on the tasks of conditional and unconditional optimization;

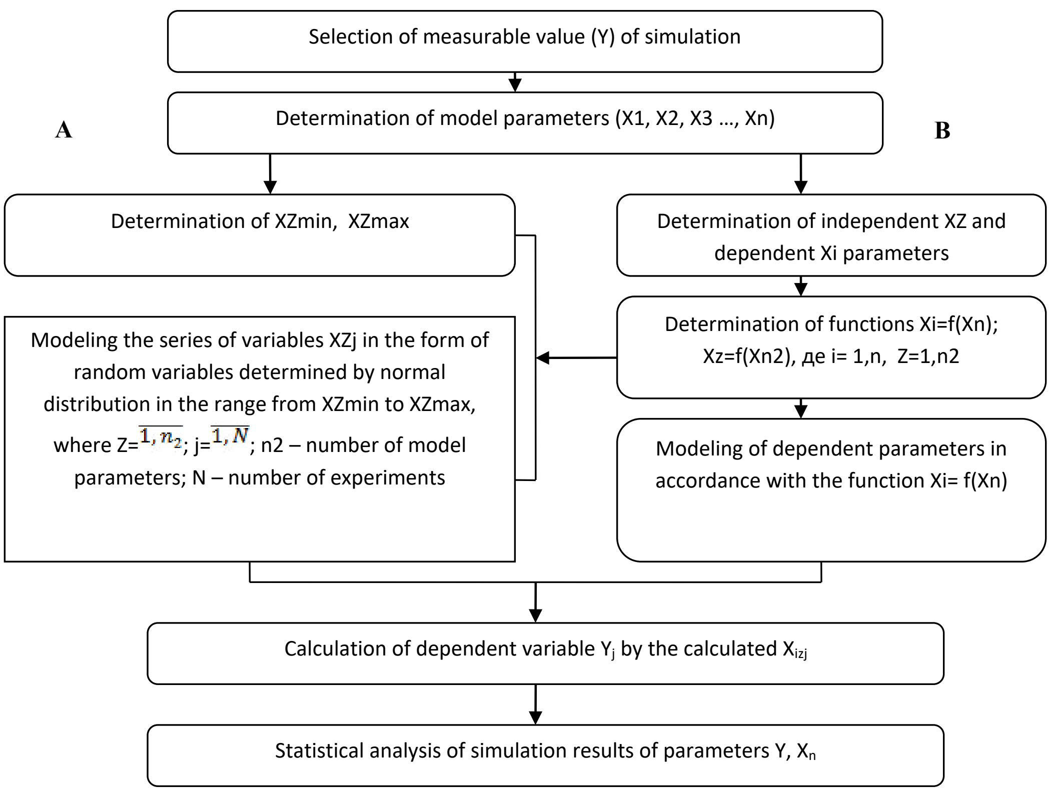

Fig. 1. The algorithm for simulation modeling of production in agricultural enterprises in conditions of uncertainty (A) and the existence of correlation between the model parameters (B)

can be used in conditions of incomplete information for simulation modeling a separate industry, as well as their combinations on a separate agricultural enterprise or on the group of enterprises. This mathematical economic model provides an extended characterization of such enterprise activities as production, processing, storage of products and service provision; it is based on the determination of profit (loss), production costs and optimal resource allocation. The algorithm includes only blocks with production of products or services. Modules on existing and future types of production activities should be developed in each block. The developed model reflects the multi-level structure of the source data at the local and regional level and provides for the creation of a database for use in simulating the results of other agricultural enterprises activities.

RESULTS AND DISCUSSION

The results of the conducted research indicate imperfection of the sectoral structure of many agricultural enterprises. Commodity producers specialize in the highly profitable crop production and they use resources (primarily land resources) ineffectively and inefficiently. The certain agricultural enterprise has been selected for approbation of methodical toolkit for modeling a balanced sectoral structure. This enterprise authorized to engage in five types of economic activities: to grow fruits, berries and nuts; to grow grain crops and technical crops; to lease real estate; to buy-sell real estate; to provide services in crop production; fish farming. The farm has arable land, hayfields, pastures, perennial plantations, forest land, ponds and household buildings in use. Consequently, the enterprise has resources to diversify production in related industries (livestock, fish farming) and non-related industries (processing and storage of agricultural products, hunting, ecotourism, etc.). In fact, the company receives a net income from the sale of crop production only. To improve the sectoral structure in enterprise, it is necessary to allocate areas for the grain crops (50-70%), technical crops (10-20%) and forage crops (10-30%) in the arable structure. To implement an algorithm for the formation and evaluation of the level of sectoral structure in agricultural enterprise, it is necessary to introduce the production of livestock products, beekeeping and fish farming. The enterprise has the resources necessary for it, but does not use them. Simulation modeling (Monte Carlo method) has been used to develop an appropriate production model. The essence of simulation modeling was to determine the parameters that can affect the final result. For these parameters, the limitations have been checked and the final simulation result has been evaluated. The optimal decision has been chosen based on the results of the study of a large number of variants (experiments). In developing the simulation model of milk production, the income (proceeds) from the milk sale has been chosen as a measurable value, and the variables – the sale price for 1 ton of milk, cow inventory (heads) and milk production per cow and production costs of 1 centner of milk by nature. The minimum and maximum values of the indicators for the last five years average in the corresponding area has been taken as the source data for the simulation modeling in the researched enterprise (Table 1).

Table 1: Source data for simulation modeling of milk production in researched agricultural enterprise by the Monte Carlo method

№	Variables	Variable values	
		Min.	Max.
1	Sale price for 1 ton of milk, UAH	277,11	328,87
2	Cow inventory, heads	1	120
3	Milk production pew cow, centner	4,454	101,35
	Production costs of 1 centner of milk (UAH)		
4	Forage crops	90,12	798,97
5	Petroleum products	20,33	187,62
6	Payment for services and work of third-party organizations	2,82	9,43
7	Rest of the direct material costs	70,11	111,66
8	Labor expenses	92,15	215,46
9	Depreciation	0,44	175,25
10	Social expenditures	34,27	80,41
	Number of experiments	500	

At the next stage, the minimum and the maximum value of each model parameter have been determined. In particular, the restriction of the cow inventory has been determined according to the capacity of the cattle shed. The variation of other variables has been established on the basis of data on milk production in agricultural enterprises of the region over the last year. On the basis of simulation modeling in MS Excel using the random number generator tool (500 simulations have been randomly made for each variable) the net income from the milk sale has been calculated; production costs of 1 centner of milk have been determined, including depending on the productivity and cow inventory. The obtained calculations made it possible to draw conclusions about the efficiency of milk production in the household and to conduct a statistical analysis of the simulation results (Table 2). Simulation modeling allowed to reflect the model sectoral structure of the enterprise with the retention of logical interrelations between its components, to reproduce the probable processes during the transition from specialized to diversified enterprise. The coefficient of variation does not exceed 20% for almost all variables, which indicates the reliability of the calculations. It has been determined that milk production will be optimal in the agricultural enterprise at such costs per unit of production and purchasing prices. However, the inclusion of the milk production cost in the cost of agricultural production will eventually lead to costs equalization and enterprise can profit from the results of products sales in all sectors.

In the same way, a simulation modeling of the implementation results of fish and honey production at the enterprise has been carried out. It has been established that the production of honey at this enterprise is profitable. The optimum is the retention of 105 bee families at an average productivity of 0.27 centner per family. In order to maximize profits from fish production, it is best to use 25.42 hectare of water mirror at 2.39 centner per hectare. Consequently, simulation modeling allows making calculations of the probable state of a system when variables are varied in the given range. In this case, some variables, such as the sale price or the animal inventory, may have one value for a given number of experiments.

The mathematical economic optimization model has been created to substantiate the development of sectors in an agricultural enterprise, their size and the most appropriate combination in order to increase the efficiency of the production system functioning. Optimization of the structure of harvested acreage has been carried out taking into account the prospect of livestock sector development. The following data has been used in the model development: the area of agricultural land in use of the enterprise; a list of the main agricultural crops that can be grown in the region and the standards for the establishment of crop rotation; the size of land which must be limited given crop rotation or erosion processes. The simulation modeling results have been applied to develop an optimization model. The optimality

Table 2: Statistical characteristic of the simulation modeling variables of milk production in the researched agricultural enterprise by the Monte Carlo method

Variables	Mean value	Standard deviation	Min	Max	Coefficient of variation
Production costs of 1 centner of milk, UAH:					
- forage crops	356,12	79,08	90,79	798,58	0,22
- petroleum products	95,17	17,28	20,74	186,72	0,18
- payment for services and work of third-party organizations	5,29	0,89	2,85	9,42	0,17
- rest of the direct material costs	91,38	11,81	70,18	111,65	0,13
- labor expenses	122,51	25,98	92,18	215,46	0,21
- depreciation	56,18	9,03	1,23	175,09	0,16
- social expenditures	56,89	13,27	34,28	80,28	0,23
Milk production pew cow, centner	52,21	7,07	4,62	101,30	0,14
Sale price for 1 centner of milk, UAH	377,81	58,47	277,11	485,14	0,15
Cow inventory, heads	90	14,36	1,09	119,59	0,16
Net income (proceeds), thousand UAH	1785,51	201,24	4,91	5363,62	0,11
Production costs of 1 centner of milk, UAH	783,52	227,85	456,82	1463,61	0,29
Total costs, thousand UAH	3702,85	683,27	11,53	13494,84	0,18
Profit (loss), thousand UAH	-1917,34	931,67	-8673,87	-6,62	-0,49

criterion in this model is aimed at maximizing profits from agricultural production using Eq. 1.

$$Z_{max}=X_k-X_i\ (k\hat{I}K,\ i\hat{I}I), \quad (1)$$

Where, k – Cost index;
X_k - Cost index value;
K – The number of cost indexes;
i- Resource type index;
X_i – The volume of the i-th type resource, which is determined in the process of problem solving;
I – The number of resource types that are determined in problem solving.

The list and nature of constraints imposed on the variables were determined at the next stage of the extended mathematical economic model development. In this mathematical economic model 28 constraints have been imposed on 10 variables. The first group of linear constraints is a system of inequalities that express the production cost. Data on crops not grown in the researched enterprise, but whose cultivation is necessary for the implementation of crop rotation and the effective use of land resources, has been equated to the average in the district. Data on milk production has been based on the results of simulation modeling and calculated per 1 head taking into account the productivity of cows. The variables express the sown area of agricultural crops in the second subsystem. In obedience to the existing enterprise specialization and taking into account the need for livestock sector development, the area under grains and leguminous crops should

Table 3: The results of optimization modeling of sectoral structure in researched agricultural enterprise

No	Variables	Value: Existing	Value: By project	Difference
	Production costs, thousand UAH			
1	Seeds and planting material	0,0	224,7	224,7
2	Mineral fertilizers	1,2	207,0	205,8
3	Petroleum products	108,9	392,0	283,1
4	Payment for services and work of third-party organizations	0,0	187,7	187,7
5	Rest of the material costs	53,0	310,2	257,2
6	Direct labor costs	63,3	181,2	117,9
7	Depreciation of fixed assets	79,0	229,1	150,1
8	Social expenditures	23,5	66,6	43,1
9	The rest of other direct and general production costs	15,7	320,5	304,8
Total		344,6	2118,9	1774,3
	Sown areas (ha)			
10	Grain and leguminous crops	0,0	239,0	239,0
	Inc. - wheat	0,0	76,7	76,7
	- barley	0,0	64,1	64,1
	- soybean	0,0	24,4	24,4
	- grain corn	0,0	75,7	75,7
11	Technical crops (sunflower)	0,0	103,2	103,2
	Arable land area	0,0	342,2	342,2
14	Fruits	439,0	640,4	201,4
15	Berries	0,0	37,0	37,0
Total agricultural land		439,0	1019,6	580,6
	Gross collection (centners)			
16	Wheat	0,0	2912,8	4949,7
17	Barley	0,0	1282,5	1804,6
18	Sunflower	0,0	2683,8	2656,2
19	Soybean	0,0	803,9	522,1
20	Grain corn	0,0	4200,2	4905,0
21	Fruits	6075,0	8856,5	2781,5
22	Berries	0,0	48,1	48,1
	The objective function			
	Net income (proceedings)(X_k), thousand UAH		3090,0	
	Production costs (Xi), thousand UAH		1936,9	
	Profit (Z_{max}), thousand UAH		1153,1	

be between 50 and 70% of the arable land area from 162.5 to 227.5 hectares (ha). The cultivation of industrial crops can fill from 10% to 30% of arable land area (from 32.5 to 97.5 ha), forage crops up to 10% of arable land area (up to 32.5 ha). The harvest of fruits and berries should take place from the total area of gardens (640.4 ha) and berry plantations (37 ha). The next group of constraints expresses the link between forage production and the cows' needs in them. The dairy herd will be formed from different ages and different feed needs of animals. Therefore, the constraint has been imposed taking into account the production and use of juicy, green and coarse feeds and takes into account feeds that can be obtained from 65 ha of permanent pasture and 110.1 ha of hayfields. The results of simulation modeling revealed that the average productivity of cows will be 52.21 centners per head, therefore, one head per year needs 46.8 centners of fodder units. The need for concentrated feeds will be 11.7 fodder units (10.6 centners per head); for hay – 9.4 fodder units (18.8 centners per head), green mass – 23 fodder units (26.1 centners per head). Constraints mean that an agricultural enterprise must produce feed at least in amount that needed by the dairy industry. The next group of constraints provides for the provision of a guaranteed production volume of agricultural commodity products. The coefficients for variables express crop yield and productivity of cows in the appropriate constraints lines. At the same time, yields of wheat, barley, sunflower, soybean, fruit and berry have been selected for the lowest values of the enterprise's productivity over the research years. The productivity of cows has been calculated in the process of simulation modeling. Obtaining the maximum net income (proceeds) from products sales has been chosen as the optimality criterion. Therefore, the estimates of products from 1 sown ha of commodity crops and from one cow calculated at actual sales prices have been introduced into the functional. The calculations of the optimization model have been carried out in MS Excel. The simulation modeling results show that the total amount of production costs increases by 1774.3 thousand UAH (Table 3). Almost all of the arable land is involved in agricultural production due to the introduction of grain and leguminous crops (wheat, barley, soybean, grain corn) and technical crops (sunflower). The project will fully utilize the area of perennial plantings of the enterprise. At the same time, keeping cows for milk production under the project is inappropriate. Having considered each component of the sectoral structure of the enterprise, it can be concluded that the enterprise remains highly specialized in terms of the structure of commodity products by industry, while the structure itself becomes more ordered and coordinated. Normality and adequacy of the models are confirmed by the results of simulation that are within the ranges of the given constraints.

CONCLUSION

This study concentrated for the development of simulation algorithm in the presence of correlation between model parameters (livestock, animal productivity and production cost) at the local and regional levels. The correlation formulas have been calculated for dependent model parameters and became the basis for simulation modeling. The approbation of optimization and simulation models in conditions of incomplete information has showed: as a result of the recommendations implementation the agricultural enterprise can receive 1153.1 thousand UAH profit, the profitability level of production will increase from 16.6% to 45.8%. The total production cost will increase to 2118.9 thousand UAH or by 1774.3 thousand UAH. Almost all of the area of arable land (342 ha) and perennial plantations (677 ha) will be involved in agricultural production with the introduction of technical crops. From the highly specialized (the coefficient of specialization is equal to 1) the enterprise will acquire the characteristics of diversified – the coefficient of specialization is equal to 0.13 according to the structure of commodity products; is equal to 0.17 according to the structure of gross output. The results of the carried simulation modeling are the basis for the experimental implementation on the researched agricultural enterprise for the purpose of improving indicators of economic, social and ecological activity. The simulation and optimization simulation is appropriate to use in an economic imbalance at the local and regional levels. These models help to identify imbalances and with a high degree of reliability, to simulate the results of production in any industry. The simulation and optimization modeling is appropriate to use in the conditions of an economic imbalance at the local and regional levels. The identification of the disproportion and modeling the production results in any industry with a high degree of reliability are possible with the help of these models.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

%	Percentage
Eq.	Equation
ha	*Hectare*
Max.	Maximum
Min.	Minimum
UAH	National currency of Ukraine

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