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MATHEMATICAL MODEL FOR ESTIMATION OF THE DIGITALIZATION OF THE PRODUCTION STRUCTURE IN ANIMAL HUSBANDRY

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Abstract

A mathematical model was tested to assess the digitization of stock farms in various sub-sectors of animal husbandry from the region of southwestern Bulgaria. In the assessment of the farm, only the software and hardware devices used by the persons employed in the respective farm were taken into account. The farms consisted of 5 departments located in a hierarchical structure on 4 levels. The results showed a relatively low degree of digitization of the surveyed farms. Comparisons were made for effective transfer and use of incoming information within each department of the surveyed farms. A unified 20-digit code is proposed for use to estimate the degree of digitization.

Key words: *digitalization, animal husbandry, mathematical model*

INTRODUCTION

One of the major challenges in the modern world is how to ensure food security for the growing population while at the same time providing long-term sustainable development. According to the Food and Agriculture Organization [2], agricultural and food production must increase to feed the world's population, which will reach about 10 billion by 2050. Due to the imposition of ever higher standards for the quantity and quality of food products, the issue of food security, sustainability, productivity and profitability is becoming increasingly important. Digitization can help address feeding the growing world population while mitigating the negative environmental and climate impacts of industrial agriculture [6].

Given that the impact of human activity leads to massive environmental pollution, digitization in the food industry is becoming a necessity [3]. The benefits of using the digital technologies are known to farmers and may include higher animal productivity, optimization of production factors, reduction of labour, digitization of the processing a large set of data, improvement of working conditions and reduction of the negative impact of agriculture on the environment [1].

The introduction of computers led to increasingly automated processes, reducing the need for some manual activities. In this case, scholars refer to digitization as the third industrial revolution [4], which affects the business level in using technology. Digitalization has affected agricultural and food production systems and is making possible the application of technology and advanced data processing techniques in agriculture [7]. However, the agricultural sector is complex, dynamic and requires sophisticated management systems. The wider application of digitalization is expected to provide more optimization of production and management processes and as well as additional assistance in making the right decisions [12].

In the last two decades, the marketers of the large corporations have taken up the task of getting feedback from how new technologies enter people's lives and what are the reasons why they enter some spheres of people's lives, while in others they do not find application at

all. This was mainly carried out by consulting companies through individual analysis of firms using a variety of approaches [13].

Currently, there is no single unified method for assessing the degree of digitization in farms [11].

The results from such research were not satisfactory. Hence, in recent years the summarizing of the disparate information from different companies in a common evaluation methodology has been discussed. However, the latter should be based not on methods such as gap or swot analyses but on the assessment of the degree of entering of the IT technologies and software solutions in the respective farm [9, 14, 10]. The latter are the main factor on which every digitization process is based. There are similar examples in assessment the entering of digital solutions in management of the information from the ports [5, 15]. In our opinion, the individual structures of the farm stand out in the foreground in the assessment, as being responsible for different production activities. From our previous studies, we can note that one of the departments where all new solutions, including the digitization of information, are the easiest to enter are the marketing and administrative departments [10]. The need for digitization is evident for every level in all departments of the farm, due to the requirement for continuous transfer of data between them in order to manage more effectively and make quick decisions when critical situations arise.

The objective of our study was to test a version of a uniform rating system for farms in the field of animal husbandry, to be applied to summarize the information from questionnaire surveys. We used a coding that can be processed at a later stage by using a methodology to evaluate the group of farms in some sub-sectors of animal husbandry.

MATERIALS AND METHODS

Mathematical and statistical functions of the Microsoft Office Excel package were used to estimate the digitization of the farm and to present the results. Where necessary, logical operators were also used.

The structure of a stock farm, as in most other enterprises, generally included 5 departments that perform different independent functions (logistics, consulting, production, administration and sales). When preparing the model, a four-level hierarchical pyramid proposed by O'Brein and Marakas [8] was used. It arranged the hierarchical structure in each enterprise in 4 levels, with the 4^{th} level being the lowest in the structure and those working in it have direct contact with the sources of information. They were responsible for its introduction into the system. These were the ordinary workers performing operations in each of the main departments of the enterprise. At the 3^{d} level of the hierarchical structure, employees were responsible for the correct progress of the production processes and/or in any of the other departments of the enterprise. The 2^{nd} level of the pyramid included the so-called subordinate managers responsible for a separate group of activities in the relevant sector of production. The managers managing and handling the information of each of the departments were at the first level It is possible that in smaller enterprises the hierarchical structure is not preserved in its classical form, and the hierarchy of a given department may be reduced from 4 to 3, 2 or 1 level, due to lack of sufficient staff or in order to redirect the existing staff to other departments. The full hierarchical structure is most often seen in large corporations. In small enterprises, a lack of hierarchical structure is very often observed, therefore it is assumed that one person performs all the activities typical for one of the 5 departments of the enterprise.

In this study, we assumed that the existence of each of the departments of the stock farm was mandatory, since every single company, regardless of the number of employees, performs the activities typical for each of the above-mentioned departments. We accepted that in developing of the coding, the absence of a hierarchical structure was permissible, contrary to the absence of any of the 5 departments. The evaluation model was based on our previous research [10] and represented the positioning of each of the evaluated cells

according to the software and hardware applications that it actively uses in one of the 9 degrees of digitalization that we have proposed. The degrees of digitization were coded as follows (Table 1).

Table 1. Evaluation table for degrees of digitization of information and their code

N	Degree of digitalisation	Numeric code
-	Absence of unit	X
0	Lack of digitalization	0
1	Availability of specialized simplified software for data processing and storage	1
2	Data transfer by using the capacities of the Internet	2
3	Use of passive internet based solutions	3
4	Use of active internet based solutions	4
5	Use of cloud based software solutions	5
6	Full automatization and digitalization at the 4th level	6
7	Absence of control fuctions of the subjective factor on the 3d and 4th level	7
8	Absence of control functions of the subjective factor on 2nd to 4th level	8
9	Absence of control functions of the subjective factor on 1st to 4th level	9

Source: Authors' original model for evaluation of the digitalization in the studied farm.

The higher level in the hierarchy also requires a higher degree of digitization. We set requirements for maximum digitization at the top level in the hierarchical structure, with each subsequent lower level the degree of digitization decreases by one.

The digitization model that we propose can be represented as a matrix with 4 rows and 5 columns, with the coefficient in each cell in the matrix representing the degree of digitization for the corresponding level and department. The maximum score on the 9-point scale is 9 for the first level (all coefficients from a1 to a5 of the first row), respectively 8 for the second level (coefficients from b1 to b5), 7 for the third level (coefficients from c1 to c5) and 6 for the fourth lowest level (coefficients d1 to d5) as shown in Figure 1.

$$\begin{pmatrix} a1 & a2 & a3 & a4 & a5 \\ b1 & b2 & b3 & b4 & b5 \\ c1 & c2 & c3 & c4 & c5 \\ d1 & d2 & d3 & d4 & d5 \end{pmatrix}$$

Fig. 1. Model of digitization of the stock farm
Source: Authors' original model for evaluation of the digitalization in the studied farm.

The assessment of the degree of digitization of the farm that we propose was done in 2 stages. In the first, the degree of digitization of the farm as a whole was assessed and calculated as percent of the maximum possible degree of digitization, which is 100%. In the second stage, we indicated departments whose activity was not efficient enough and required restructure. These were levels of departments whose degree of digitization was lower than those down in the hierarchical structure of the farm.

Stage 1

In the model that we propose, the degree of digitization was presented in %, with each of the departments at each level in the stock farm (respectively, each of the coefficients in (1) participating with an equal share and was % of the maximum possible digitalization estimate for the respective level. We postulated that each farm had 5 departments with 4 levels. Since the farms have different degrees of output volume, it is quite possible, especially for smaller enterprises, that some of the hierarchical levels are missing, as well as some of its departments or functions have been taken over by other departments. We have tried that the lack of departments does not affect the degree of digitization of the farm. For example, if the presented model is missing 6 of the departments out of the possible maximum of 20 departments for all 4 levels, the degree of digitization will be assessed only for the existing 20 – 6 = 14. Mathematically this can be expressed as follows:

$$S = \frac{100}{f} \times \sum_{g=1}^{f} K_g \quad \text{.....(1)}$$

where:
-S is the degree of digitization of the entire model (%),
-K is the level of digitization of each level,
-f is the number of levels that are digitized.
The detailed equation is:

$$S = \frac{100}{f}\left(\sum_{i=1}^{n}\frac{a_1 + \cdots + a_n}{a_{max} \times n} + \sum_{i=1}^{l}\frac{b_1 + \cdots + b_l}{b_{max} \times l} + \sum_{i=1}^{m}\frac{c_1 + \cdots + c_m}{c_{max} \times m} + \sum_{i=1}^{p}\frac{d_1 + \cdots + d_p}{d_{max} \times p}\right) \quad (2)$$

.....(2)

where:
-S is the degree of digitization of the entire model (5),
-K is the degree of digitization of each level,
-f is the number of levels that are digitized, the coefficients a,b,c, and
-d are the degrees of digitization for the corresponding levels and departments;
-a_{max}, b_{max}, c_{max} and d_{max} are the maximum possible degree of digitization for the corresponding levels,
-n, l, m and p are the existing number of departments in the farm for each of the levels.
An example for the estimation of the degree of digitization for a stock farm/enterprise is shown in Table 2. The numerical value is an estimate of the corresponding degree of digitization. The letter X means that the relevant department does not exist as a structure in the enterprise. The last cell at the bottom right is the final score for the degree of digitization for the entire farm.

Table 2. Example of estimation of the digitalization level in a farm/enterprise

Level	**Department**					**Mean for the level**
	Logistics	Consultancy /R&D	Production	Administration	Sales	
1 Level	9	4	7	X	7	75.00%
2 Level	X	5	3	4	3	46.88%
3 Level	6	6	5	7	4	80.00%
4 Level	5	2	1	2	1	36.67%
Mean for each department	89.68%	56.50%	50.84%	61.11%	47.27%	59.64%

Source: Authors' original model for evaluation of the digitalization in the studied farm.

Stage 2

Table 3 shows the differences in the degrees of digitization of the departments of the farm hierarchical structure.
Comparisons are made of the degrees of digitization between every 2 adjacent levels for each of the departments in the operation (the results from Table 2 are used).
In case the structural unit of the next lower level is missing in the farm, a comparison is made with the next level.
Negative estimation means that the corresponding level for this department is not used effectively and needs to increase the degree of digitalization.
The letter x means that the either the department or the levels in the department that are lower are missing in structure and no comparison is possible.
The digitization evaluation code of the enterprise is a series of the evaluations of the level of digitization of each of the departments, starting from the highest level to the lowest level of the enterprise (the values in Table 2 from the first to the fifth column).
The code for the evaluation of the digitalization of the farm is a series of the evaluations of the level of digitization of each of the departments, starting from the highest to the lowest level of the farm.
This involves the values in Table 2 from the 1st to the 5th column, and hence, the code is "9X65-4562-7351-X472-7341".

Table 3. Example of the efficiency estimation of the respective departments in the stock farm

Differences in levels	Departments				
	Logistics	Consultancy /R&D	Production	Administration	Sales
1- next level	3	-1	4	x	4
2- next level	x	-1	-2	-3	-1
3- next level	1	4	4	5	3

Source: Authors' original model for evaluation of the digitalization in the studied farm.

RESULTS AND DISCUSSIONS

The model we developed was used to assess poultry, sheep, cattle and pig farms in the region of southwestern Bulgaria. This is a private case of a stock farm breeding various species of animals from the region of Sandanski municipality. In the assessment of the farm, only the software and hardware devices used by the employees for the performance of their official duties were taken into account.

Assessment of the degree of digitalization in a poultry farm

The poultry farm has a capacity of 700 laying hens and 12,000 slow-growing broilers. The structure is identical to that of a large farm (including 4 hierarchical levels). Regarding the "Logistics" at the lowest level (d1) e-mail is used to forward information from websites, using and sharing Excel files, therefore it is assumed that this level of the department is located in 3rd level of digitization and is estimated as 2. Information is further transferred as the offers are shared via Google Dropbox. Therefore, the higher hierarchical level (c1) of the same department is assumed to be in a level of digitization 5, numerically evaluated with 4. The next two superior levels (a1 and b1) also use Dropbox in their activities, so we assume that they are at the same level of digitalization and are numerically evaluated with the same evaluation as the previous one. Thus, the part of the code corresponding to this department, which has the sequence “a1|b1|c1|d1”, gives the first four digit sequence, part of the whole 20 digit code “4442”.

Regarding the "Consultancy and R&D", the farm has a contract for consultancy services with a research institute, which actually represents the bottom two levels of the hierarchical pyramid. The technical staff (d2) employed in the lowest level of the pyramid work freely with the application "Spreadsheet" of Gmail, therefore the lowest hierarchical level of this department is considered to be in the 5th level of digitalization and is evaluated numerically with 4. The third level handles a cloud-based platform, which uploads data from a digital hand-held balance equipped with an RFID reader to identify chipped birds with an RFID sensor, therefore assumed to be in 6th level of digitization and is rated 5. The top 2 levels (a2 and b2) of the hierarchy of the department work freely with Google Dropbox as well as with Gmail's "Spreadsheet", hence, it is believed that they are in the 5th level of digitization and receive grades 4.

The second four-digit combination, part of the 20-digit code responsible for "Consultancy and R&D", becomes "4454", following the sequence "a2|b2|c2|d2" shown in Figure 1.

When assessing the "Production" department, it is taken into account that the lowest level (d3) in the hierarchical pyramid does not work with a computer, but only analog (paper media) are used when keeping primary documentation. This level is rated as 0. The second level of the hierarchical pyramid (c3) works freely with Gmail's "Spreadsheet" application, therefore it is considered to be in the 5th level of digitization and is rated numerically as 4. The rest 2 levels (a3 and b3) of the hierarchy of the department work through Google's Dropbox application, therefore they are considered to be in the 5th level of digitization and receive a rating of 4.Thus, the third four-digit combination of the general code corresponding to this department becomes “4440”, following the sequence of Figure 1 - “a3|b3|c3|d3”.

In the evaluation of the "Administration", all four levels (a4, b4, c4 and d4) of the hierarchical pyramid work with Google's Dropbox and Gmail's "Spreadsheet" and hence are located in digitization level 5, which is evaluated with a 4. Therefore, the third four-digit combination of the general code is "4444", following the sequence of Fig.1 - "a4|b4|c4|d4".

The last of the five departments, "Sales", uses the structure and staff of the "Production" and is assessed with the same rating, therefore the third four-digit combination of the general code is "4440" and repeats completely the assessment of the "Production" department. The assessment of the level of digitization of the poultry farm is shown in Table 4.

Table 4. Assessment of the degree of digitalization of the structure of a poultry farm

Level	**Department**					**Mean for the level**
	Logistics	Consultancy /R&D	Production	Administration	Sales	
1 Level	4	4	4	4	4	44.44%
2 Level	4	4	4	4	4	50.00%
3 Level	4	5	4	4	4	60.00%
4 Level	2	4	0	2	0	26.67%
Mean for each department	46.23%	58.13%	37.90%	46.23%	37.90%	45.28%

Source: Authors' original model for evaluation of the digitalization in the studied farm.

The total estimate of the level of digitalisation of the poultry farm according our model is displayed in the right bottom cell in Table 4 and is 45.28%. The code that carries the information of the overall assessment of the poultry farm is given by the cells in the respective columns of Table 4 and is expressed as "4442-4454-4440-4442-4440".

Table 5. Assessment of the efficiency of the departments in the structure of the poultry farm

Differences in levels	**Departments**				
	Logistics	Consultancy /R&D	Production	Administration	Sales
1- next level	0	0	0	0	0
2- next level	0	-1	0	0	0
3- next level	2	1	4	2	4

Source: Authors' original model for evaluation of the digitalization in the studied farm.

The comparisons between the degrees of digitization for adjacent levels in structure of the poultry farm (Table 5) show that the only negative value was obtained for the second level of the "Consultancy/R&D" department. Measures should be taken to increase the degree of digitization at this level in the department for more efficient management of the farm.

Assessment of the degree of digitalisation of a pig farm

In the pig farm, 250 pigs (Mangalitsa and East Balkan Pigs) are raised on pasture. For estimation of the pig farm (Table 6), we used the same method and evaluation table.

Here again, the hierarchical structure of 4 of the departments consists of 4 levels, with the exception of the "Consultancy and R&D", which consists of two levels. In this case, the highest and the lowest levels in the hierarchical pyramid are saved and evaluated as before, while the missing two intermediate levels are marked in the evaluation with the letter code "X".

Table 6. Assessment of the degree of digitalization of the structure of a pig farm

Level	**Department**					**Mean for the level**
	Logistics	Consultancy /R&D	Production	Administration	Sales	
1 Level	4	4	4	4	4	44.44%
2 Level	4	X	4	4	4	50.00%
3 Level	4	X	4	4	4	57.14%
4 Level	4	2	0	4	0	33.33%
Mean for each department	54.56%	38.89%	37.90%	54.56%	37.90%	46.23%

Source: Authors' original model for evaluation of the digitalization in the studied farm.

The overall assessment of the level of digitization of the pig farm according to the model we have chosen is 46.23% (Table 6). The information to evaluate the degree of digitization of the pig farm can be expressed in the following 20-digit code: "4444-4XX2-4440-4444-4440".

Table 7. Assessment of the efficiency of the departments in the structure of the pig farm

Differences in levels	**Departments**				
	Logistics	Consultancy /R&D	Production	Administration	Sales
1- next level	0	2	0	0	0
2- next level	0	X	0	0	0
3- next level	0	X	4	0	4

Source: Authors' original model for evaluation of the digitalization in the studied farm.

The lack of negative values (Table 7) shows that no problematic departments in the pig farm have been found.

Assessment of the degree of digitalization in cattle farm

The farm has two herds of cattle (dairy of approximately 50 dairy cows and beef of 80 castrated bulls for slaughter), which are reared on pasture during the year. As with the pig farm, 4 of the departments are made up of 4 hierarchical levels, with the "Consultancy and R&D" again being limited to only 2 levels (the highest and the lowest). The results for the assessment of the degree of digitization of the beef farm are shown in Table 8.

Table 8. Assessment of the degree of digitalization of the structure of a cattle farm

Level	**Department**					**Mean for the level**
	Logistics	Consultancy /R&D	Production	Administration	Sales	
1 Level	4	4	4	4	4	44.44%
2 Level	4	X	4	4	4	50.00%
3 Level	4	X	2	4	2	42.86%
4 Level	2	2	0	2	0	20.00%
Mean for each department	**46.23%**	**38.89%**	**30.75%**	**46.23%**	**30.75 %**	**39.33%**

Source: Authors' original model for evaluation of the digitalization in the studied farm.

The overall assessment of the level of digitization of the cattle farm is 39.33% (Table 8). Information to assess the degree of digitalization of the cattle farm can be expressed in the following 20-digit code: "4442-4XX2-4420-4442-4420".

Table 9. Assessment of the efficiency of the departments in the structure of the cattle farm

Differences in levels	**Departments**				
	Logistics	Consultancy /R&D	Production	Administration	Sales
1- next level	0	2	0	0	0
2- next level	0	X	2	0	2
3- next level	2	X	2	2	2

Source: Authors' original model for evaluation of the digitalization in the studied farm.

When evaluating the efficiency of the departments, no negative differences were found in the degree of digitalization of the structure of the farm, which, according to our model, shows that the incoming information is effectively used by all the departments.

Assessment of the digitalization of the sheep farm

The sheep farm consists of 160 sheep. The farm raises sheep for milk and offspring, mainly for meat. The structure of this farm is composed of 3 hierarchical levels, with level 2 missing, except for "Consulting services and R&D" and "Administration" departments. The "Consulting services and R&D" lacks any hierarchical structure, as the highest level in the pyramid performs similar functions. In the "Administrative" department, the hierarchical pyramid is composed of only 2 levels (the highest and the lowest). The results of the application of the model for the evaluation of the digitization of the sheep farm are shown in Table 10.

Table 10. Assessment of the degree of digitalization of the structure of the sheep farm

Level	**Department**					**Mean for the level**
	Logistics	Consultancy /R&D	Production	Administration	Sales	
1 Level	4	4	4	4	4	44.44%
2 Level	X	X	X	X	X	0.00%
3 Level	4	X	2	X	2	38.10%
4 Level	2	X	0	2	0	16.67%
Mean for each department	44.97%	44.44%	24.34%	38.89%	24.34%	24.80%

Source: Authors' original model for evaluation of the digitalization in the studied farm.

The assessment of the level of digitization of the sheep farm according to the model we have chosen is 24.80% (Table 10). Information from the evaluation of the degree of digitization of the sheep farm is given by the following 20-digit code: "4X42-4XX-4X20-4XX2-4X20".

Table 11. of the efficiency of the departments in the structure of the sheep farm

Differences in levels	**Departments**				
	Logistics	Consultancy /R&D	Production	Administration	Sales
1- next level	0	X	2	2	2
2- next level	X	X	X	X	X
3- next level	2	X	2	X	2

Source: Authors' original model for evaluation of the digitalization in the studied farm.

When evaluating the efficiency of the departments in the hierarchical structure of the sheep farm (Table 11), no negative differences in the degree of digitalization between the different levels were found.

CONCLUSIONS

A model was tested for the assessment of digitization of a stock farm located in southwestern Bulgaria. The estimates of the degree of digitization of the studied farms were relatively low and varied between 46.23% (the highest) for the pig farm and 24.80% (the lowest) for the sheep farm. We consider that these low ratings were largely due to the high demands of the model we propose. With few exceptions, the evaluations of the efficiency of data transfer between the different levels of the departments in the surveyed farms were high. The evaluated farms are small-scale farms for the country. For a comprehensive assessment of the degree of digitization of the livestock sectors in the country, survey information on as many farms as possible is needed, which can be done in future research.

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