Linear Model of Information System of Industrial Processes in Crop Production

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Abstract. The timeliness of information received during the implementation of any production process, as well as its qualitative composition, significantly affect the efficiency of this process. This is particularly important for agricultural production, as field operations are highly time-sensitive, both in terms of start-up and duration. The real possibility of a significant increase in the efficiency of production processes in crop production appeared at the current level of information technology and the spread of digitalization of various fields of activity. On the basis of existing methodological approaches to the system representation of objects of reality, we have developed an information system of the production process in crop production. The elements of the system are the amount of knowledge of specialists in the cultivation of crops, information about the composition of cultivation technologies, information about the objects processed in the implementation of production processes, recorded in any form replenished special knowledge, knowledge about the goals achieved in the implementation of production processes. Elements of the system are interconnected, developing in a certain way and, at the same time, limiting each other. The formalization of the relationships between elements of the information system allowed us to obtain ten equations with fifteen unknowns. To solve this system of equations, a set of simultaneous linear equations is presented. Five sets of simultaneous equations can be defined, depending on which of the relationships of the elements of the information system of the type will be broken. The obtained solutions will allow to quantify the volume of elements of the information system, which makes it very promising to use information technology management of production processes in crop production.

1. Introduction
The efficiency of any production process depends on the timely receipt of the information and its qualitative composition [1-3]. This is especially true for production processes in crop production, where the time factor is especially important. At the same time, in addition to the operational information which is necessary for the current correction of the field operations, the knowledge accumulated during the implementation of production processes in previous years is needed. This can be facilitated by fixing the personal experience of agricultural production specialists. At the present level of information technology development, the positive effect of the use of previously accumulated knowledge can be very significant.

2. Results
On the basis of the conceptual design of the technical service system, taking into account the methodological recommendations [4], we have developed an information system that adequately describes the production processes [5–6]. For the crop industry, the information system of the production process is shown in Figure 1.
The elements of the system are:
- the amount of knowledge of specialists in the cultivation of crops, hereinafter referred to as «Specialists (S)»,
- the information on the types of crop technologies, hereinafter referred to as «Technologies (T)»,
- the information about the agricultural objects processed during the implementation of production processes - soil, seeds, plants, crops, hereinafter referred to as «Objects (O)»,
- the special knowledge recorded in any (paper, electronic) form, hereinafter referred to as «Knowledge (Z)»,
- the knowledge of the goals achieved in the implementation of production processes, hereinafter referred to as «Goals (C)».

We consider the relationship between elements of the information system, taking into account that the main element of the system are «Specialists (S)».

1. Specialists (S) determine which technology will be selected (T).
2. The implemented technologies (T) affect the objects (O).
3. The information about the objects (O), changing under the influence of the technology (T), adds the knowledge (Z).
4. The knowledge (Z) forms and develops concepts about the goal (C), which is possible to achieve in the future.
5. The developing goals (C) expand the orientation of specialists (S) when choosing the technologies (T).

The formalization of these relations can be expressed as a combination of (1) dependencies:

\[
\begin{align*}
T &= f_1(S) \\
O &= f_2(T) \\
Z &= f_3(O) \\
C &= f_4(Z) \\
S &= f_5(C)
\end{align*}
\]

In turn:
6. Specialists (S) limit which exposure objects (O) will be selected.
7. While changing, the objects (O) limit the goal achievement (C).
8. The goals (C) limit the choice of technology (T).
9. The technologies (T) unilaterally increase the knowledge (Z).
10. The knowledge (Z) orients specialists (S) in a certain direction.

\[
\begin{align*}
O &= \varphi_1(S) \\
C &= \varphi_2(O) \\
T &= \varphi_3(C) \\
Z &= \varphi_4(T) \\
S &= \varphi_5(Z)
\end{align*}
\]

(2)

The dependencies of both sets are a mathematical model of the information system of the production process in the crop production.

Ten dependencies contain 15 unknowns: five elements of the information system, five functionals of the type \(f_i\), five functionals of the type \(\varphi_i\). Determining the impact of the system elements on each other, you can describe the existing relationships by a set of simultaneous equations. Then the dependences of the type \(f_i\), highlighted in Figure 1 by solid lines, are represented as the following system of simultaneous equations:

\[
\begin{align*}
T &= a_1 + b_1 \cdot S \\
O &= a_2 + b_2 \cdot T \\
Z &= a_3 + b_3 \cdot O \\
C &= a_4 + b_4 \cdot Z \\
S &= a_5 + b_5 \cdot C
\end{align*}
\]

(3)

And the type dependencies highlighted in Figure 1 with dashed lines are described by the following system of simultaneous equations:

\[
\begin{align*}
O_t &= a_1 + b_1 \cdot S_t + \gamma_1 \cdot T_t \\
C_t &= a_2 + b_2 \cdot O_t + \gamma_2 \cdot Z_t + \gamma'_2 \cdot Z_{t+1} \\
T_t &= a_3 + b_3 \cdot C_t + \gamma_3 \cdot S_t \\
Z_t &= a_4 + b_4 \cdot T_t + \gamma_4 \cdot O_t \\
S_t &= a_5 + b_5 \cdot Z_t + \gamma_5 \cdot Z_{t-1} + \gamma_5 \cdot C_t
\end{align*}
\]

(4)

Each system consists only of endogenous (dependent) variables. Specialists in the methodology and theory of science point out to the circularity of the system relationships. In other words, we get a system consisting of identities.

For our case:
-S-T-O-Z-C- etc.,
-S-O-C-T-Z- etc.

3. Discussion

Instead of exogenous variables, some models may use lagged variables, that is, endogenous variables obtained in the previous period. Thus, the goals can depend not only on the knowledge \((Z_t)\) available at a given time, but also on the knowledge of the previous years (old experience) \((Z_{t-1})\), and can also be predetermined by knowledge \((Z_{t+1})\) which will be obtained later. It is rational to choose variables that can be regulated as exogenous variables. Now, following the proposed project of the information system, interpreting each equation of the system from different points of the pentagram, you can get the solution of the whole system \([7 – 8]\).

Choosing the technology as an exogenous (independent) variable, we break the ring of interconnections of the system elements and obtain a system of simultaneous equations in which the first equation specialists limit the objects and affect the technology. In the second equation, the objects limit the goals and affect the knowledge that is available at a given time \((Z_t)\), and the knowledge that will only be obtained \((Z_{t+1})\). In the third equation, the goals limit the technology and influence the specialists; in the fourth equation, the technology limits knowledge and affects the objects. And in the last equation we see that the knowledge of previous years (old experience) \((Z_{t-1})\) as well as the real knowledge limits the specialists and affects the goals. Now we examine our system for identification to
determine the method by which this system can be solved. Identifiability is uniqueness correspondences between the reduced and structural forms of the model [7, 9].

From the standpoint of identifiability, the structural models can be divided into three types: identifiable, unidentifiable, over-identifiable.

Necessary condition for identifiability:

D + 1 = H – the equation is identifiable;
D + 1 < H – the equation is unidentifiable;
D + 1 > H – the equation is over-identifiable,
where H– the number of endogenous variables in the equation, D– the number of exogenous variables that are contained in the system, but are not included in this equation.

Sufficient condition of identifiability:

the equation is identifiable if it is possible to obtain a matrix from the coefficients of the missing variables in other equations of the system, the determinant of which is not zero, and the rank of the matrix is not less than the number of endogenous variables in the system without one.

A model is considered identifiable if each equation of the system is identifiable. If at least one of the equations is unidentifiable, then the whole model is considered unidentifiable.

If the model is accurately identifiable, then we use the indirect least squares method, if over-identifiable, we use the two-step least squares method.

According to the necessary condition of identifiability we obtain:

\text{Endogenous variables} - O_t, C_t, Z_t, S_t;
\text{Exogenous variables} - T_t, Z_{t-1}, Z_{t+1}.

First equation:

\[ O_t = \alpha_1 + \beta_1 \cdot S_t + \gamma_1 \cdot T_t \]

\[ H = 2(O_t, S_t)\] D = 2(Z_{t-1}, Z_{t+1}) obtain 2 + 1 > 2 ; the equation is over-identifiable.

Second equation:

\[ C_t = \alpha_2 + \beta_2 \cdot O_t + \gamma_2 \cdot Z_t + \gamma_2' \cdot Z_{t+1} \]

\[ H = 3(C_t, O_t, Z_t)\] D = 2(T_t, Z_{t-1}) obtain 2 + 1 = 3 ; the equation is identifiable.

Third equation:

\[ T_t = \alpha_3 + \beta_3 \cdot C_t + \gamma_3 \cdot S_t \]

\[ H = 2(C_t, S_t)\] D = 2(Z_{t-1}, Z_{t+1}) obtain 2 + 1 > 2 ; the equation is over-identifiable.

Fourth equation:

\[ Z_t = \alpha_4 + \beta_4 \cdot T_t + \gamma_4 \cdot O_t \]

\[ H = 2(Z_t, O_t)\] D = 2(Z_{t-1}, Z_{t+1}) obtain 2 + 1 > 2 ; the equation is over-identifiable.

Fifth equation:

\[ S_t = \alpha_5 + \beta_5 \cdot Z_t + \beta_5' \cdot Z_{t-1} + \gamma_5 \cdot C_t \]

\[ H = 3(S_t, Z_t, C_t)\] D = 2(T_t, Z_{t+1}) obtain 2 + 1 = 3 ; the equation is identifiable.

Since, in addition to identifiable equations, we also have over-identifiable equations, the whole model will be over-identifiable. Consequently, our system can be solved by the two-step least squares method [7, 9 - 11].

Thus, we have considered only the case when lagged variables affect endogenous variables, and since the ring can be «broken at any place», then any element of the system can be chosen as an exogenous variable, thereby obtaining five independent models which are easily amenable to analytical and empirical solution using application program packages, for example, «STATISTICA», «EViews», MS Excel [12-14].

The functional structure of the entire information system of the production process in crop production consists of a set of interrelated functional blocks that implement a set of management functions for all processes. It is customary to distinguish between informal and formal management systems. The informal management system is based largely on non-formalized procedures and decision-making methods, which, in turn, are divided into determinant and non-determinant. A formal management system, by contrast, is based on formalized procedures and decision-making methods.

The determinant methods are used when all the conditions of the problem situation are known, i.e. worthwhile the goals have no uncertainties. These methods are divided into direct, answering the question:

«What crop can be obtained if highly qualified specialists will use modern technologies of agricultural crop cultivation, with a large amount of knowledge?»
And the reverse answer to the question:
«What kind of knowledge of specialists is needed, what modern technologies need to be applied, what objects do you need to choose (soil, seeds, plants), what specialists to choose in order for the goal to reach its extreme (minimum or maximum) value?»

Using the economic terms and mathematical models, we see that direct methods allow us to determine the performance indicator $W$ when choosing one of the remaining four of the above basic concepts, and the inverse methods allow us to refine or supplement the concepts with information in which the indicator $W$ will take its extreme (minimum or maximum) value [3,4].

Among the inverse methods there are:
– linear methods, when the dependence $W = W(x, k)$ has the form of a linear function, where $k$ is the set of elements of the information system of the production process in crop production; – nonlinear methods when the dependence $W = W(x, k)$ has the form of a nonlinear function;
– brute force used in those cases, the information system contains a small number of concepts, and for each solution $x$ of the whole set is an indicator of the effectiveness of $W$, and then of all the optimal (minimum or maximum), depending on the formulation of the problem.

But, as practice shows, in most cases, the information system, in addition to the known elements $k$ and solutions $x$ may be some uncertainties (unknown, or require additions and clarification of concepts). To solve such problems, non-determinant methods of substantiation of solutions are used, which can be classified into: stochastic, adaptive, expert evaluation methods.

When using non-determinant methods, it is assumed that the efficiency criterion cannot be calculated because it depends on unknown parameters. Thus, it can be concluded that with the help of non-determinant methods the optimal solution cannot be obtained, and it is impossible to determine the element of the system that allows to find a solution close to the optimal one. We conclude that these methods in practice do not give good answers to the questions.

We will not exclude the use of non-determinant methods, because in practice their use is still quite wide – from bad decisions you can always choose the best. The elementary case of application of such methods is the probabilistic nature of unidentified elements $k$, which are random variables whose numerical characteristics are unknown. In this case, the numerical characteristics are understood as the expectation, variance and distribution law. Here we use stochastic decision support methods which are subdivided into stochastic methods without constraints and stochastic methods with constraints. The most simple are stochastic methods without restrictions, which are used in cases where the situation allows to replace random variables with their mathematical expectations [1,3,5].

For example, if it is necessary to determine the minimum number of specialists in the cultivation of crops, the mathematical expectation of technologies for the cultivation of crops – for example, the number of modern equipment for sowing grain and harvesting can be considered as a criterion of efficiency. Let it be 50 units, then, from the point of view of the goal of obtaining a total crop, nothing terrible will happen if one field will work 10 units, and the other 40. And a completely different situation can arise when different fields include different soil and landscape conditions, different varieties of grain, different sowing time, then as a criterion of efficiency to consider the expectation of 10 and 40 units will not be enough, a small number of units of equipment for one field can not compensate for the large downtime of equipment for another. In such cases, a limit is usually introduced, i.e., with a mathematical expectation of 20 pieces of equipment. And the methods solving such problems are called stochastic methods with restrictions. We must not forget that stochastic methods are used only in repetitive situations. The adaptive models can provide some assistance in case of non-random uncertainty [3,5].

Having considered determinant and non-determinant decision-making methods, we focus on the linear function of inverse determinant methods. To obtain the maximum yield in the presence of specialists, technologies, objects and knowledge, we will make a mathematical model:
Table 1  Result maximization model

|                | Product 1 | Product 2 | Product 3 | Product 4 | Product 5 |
|----------------|-----------|-----------|-----------|-----------|-----------|
| Specialists    | \( a_{11} \) | \( a_{12} \) | \( a_{13} \) | \( a_{14} \) | \( a_{15} \) | \( b_1 \) |
| Technologies   | \( a_{21} \) | \( a_{22} \) | \( a_{23} \) | \( a_{24} \) | \( a_{25} \) | \( b_2 \) |
| Objects        | \( a_{31} \) | \( a_{32} \) | \( a_{33} \) | \( a_{34} \) | \( a_{35} \) | \( b_3 \) |
| Knowledge      | \( a_{41} \) | \( a_{42} \) | \( a_{43} \) | \( a_{44} \) | \( a_{45} \) | \( b_4 \) |
| Harvesting     | \( c_1 \)   | \( c_2 \)   | \( c_3 \)   | \( c_4 \)   | \( c_5 \)   | \( \text{max} \) |

\[
\begin{align*}
(a_{11} \cdot x_1 + a_{12} \cdot x_2 + a_{13} \cdot x_3 + a_{14} \cdot x_4 + a_{15} \cdot x_5) & \leq b_1 \\
(a_{21} \cdot x_1 + a_{22} \cdot x_2 + a_{23} \cdot x_3 + a_{24} \cdot x_4 + a_{25} \cdot x_5) & \leq b_2 \\
(a_{31} \cdot x_1 + a_{32} \cdot x_2 + a_{33} \cdot x_3 + a_{34} \cdot x_4 + a_{35} \cdot x_5) & \leq b_3 \\
(a_{41} \cdot x_1 + a_{42} \cdot x_2 + a_{43} \cdot x_3 + a_{44} \cdot x_4 + a_{45} \cdot x_5) & \leq b_4 \\
\end{align*}
\]

\[f(x) = c_1 \cdot x_1 + c_2 \cdot x_2 + c_3 \cdot x_3 + c_4 \cdot x_4 + c_5 \cdot x_5 \rightarrow \text{max}
\]

We can consider an example of minimizing the use of objects with the growth of knowledge, goals, specialists and technologies.

Table 2 – Resource minimization model

|                | Product 1 | Product 2 | Product 3 | Product 4 | Product 5 |
|----------------|-----------|-----------|-----------|-----------|-----------|
| Knowledge      | \( a_{11} \) | \( a_{12} \) | \( a_{13} \) | \( a_{14} \) | \( a_{15} \) | \( b_1 \) |
| Goals          | \( a_{21} \) | \( a_{22} \) | \( a_{23} \) | \( a_{24} \) | \( a_{25} \) | \( b_2 \) |
| Specialists    | \( a_{31} \) | \( a_{32} \) | \( a_{33} \) | \( a_{34} \) | \( a_{35} \) | \( b_3 \) |
| Technologies   | \( a_{41} \) | \( a_{42} \) | \( a_{43} \) | \( a_{44} \) | \( a_{45} \) | \( b_4 \) |
| Object using   | \( c_1 \)   | \( c_2 \)   | \( c_3 \)   | \( c_4 \)   | \( c_5 \)   | \( \text{min} \) |

\[
\begin{align*}
(a_{11} \cdot x_1 + a_{12} \cdot x_2 + a_{13} \cdot x_3 + a_{14} \cdot x_4 + a_{15} \cdot x_5) & \geq b_1 \\
(a_{21} \cdot x_1 + a_{22} \cdot x_2 + a_{23} \cdot x_3 + a_{24} \cdot x_4 + a_{25} \cdot x_5) & \geq b_2 \\
(a_{31} \cdot x_1 + a_{32} \cdot x_2 + a_{33} \cdot x_3 + a_{34} \cdot x_4 + a_{35} \cdot x_5) & \geq b_3 \\
(a_{41} \cdot x_1 + a_{42} \cdot x_2 + a_{43} \cdot x_3 + a_{44} \cdot x_4 + a_{45} \cdot x_5) & \geq b_4 \\
\end{align*}
\]

\[f(x) = c_1 \cdot x_1 + c_2 \cdot x_2 + c_3 \cdot x_3 + c_4 \cdot x_4 + c_5 \cdot x_5 \rightarrow \text{min}
\]

These tasks can be easily solved with the help of the built-in function «Search for solutions» of the MS Excel spreadsheet processor [14].

4. Conclusion

The use of information technologies in management is not always effective because of the underdevelopment of theoretical ideas about the information processes taking place in production systems. The information system developed by us, as well as one of the possible options for formalizing the relationships of the elements of the information system, make it possible to use information technologies in the management of production processes in the agricultural production. Although the main element of the information system is «Specialists(S)», significant potential opportunities for
improving the efficiency of production processes are contained in the development of the element of «Knowledge (Z)» system. With a constant increase in the volume of knowledge, the problem of structuring this volume and developing methods for converting them and providing them to «Specialists (S)».

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