Conceptual bases of system technology of designing of logistic schemes of harvesting and transportation of grain crops

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Abstract. The article reveals conceptual principles of creating technology for designing transport and logistics schemes for harvesting, reloading and transportation of grain crops with their flexible adaptation to specific agronomic, technical, natural production, economic and numerous conditions during their harvest. The authors presented the results of system-analytical studies of problem, which formed practical consulting document, which allows the offender in specific conditions to determine choice of optimal transport and logistics schemes for harvesting and transporting crops to granaries. The concept of developing such a document for synthesis of logistics technologies for harvesting and transporting grain involves three stages. The authors described the technology to achieve the result, which does not require without great need to conduct complex, long-term and costly field experiments. In addition, the article made it clear that this approach should be used to solve complex problems, to implement intelligent projects of high complexity. The problem posed in article undoubtedly belongs to this class of problems. The main emphasis is placed on conceptual nature of work and at least the results of first stage of inductive technologies of system information-analytical research are given. The authors, based on complexity and significant lack of initial information base, planned to implement the project on inductive technology.
1. Introduction
The probabilistic nature of the harvesting and transport process causes downtime of combines and vehicles during the harvest of cereals [1] and the use of direct transportation [2]. Thus, with a distance of 8-9 km [3] and optimal combinations of the number of harvesters and vehicles idle harvesters waiting for transport reach 20% [4], and downtime of vehicles –30-36% of the shift time [5]. The use of trucks (N3 wheeled vehicles) on direct grain transportation [6], the loss of time associated with waiting for loading and moving across the field [7], increases to 47% of the shift time [8]. In addition, the use of trucks leads to additional soil compaction [9]. The use of an intermediate compensation link in the technological chain between combines [10] and vehicles allows to significantly reduce the duration of harvesting [11] and transport operations in comparison with direct road transport [12]. The role of interoperable compensators is performed by tractor trailers [13], interchangeable bodies [14] and other devices [15]. The use of compensators, first, allows you to organize the work so that the harvesters can be unloaded immediately after filling the hopper [16], and the vehicle— to be loaded on arrival at the field [17]. Secondly, such compensators as reloading trailers have the ability to solve the problem of eliminating compaction in the ground by heavy trucks that are effective in transporting grain [18]. Theoretical studies of the use of interoperative compensators were initiated in works [19-20], where the main patterns of their use were considered. However, this problem requires further study in relation to the natural production conditions of farms, areas, grain yields, road conditions and distances and, thus, becomes systemic in nature, which, of course, requires appropriate system-analytical tools to solve it [21]. In the process of designing flexible logistics technologies for grain harvesting complexes, we used the scientific and analytical conclusions of previous studies on these issues [22, 23]. Since logistics technology is considered by us as a complex system, the problem of designing such technology and formulating criteria for its effectiveness is expected to be solved using the methodology of systems analysis [24] and in particular using inductive technologies of systems information-analytical research [25]. At the stages of modeling, in particular the classification of technologies, construction of statistical and econometric models, the application of modern methods of inductive modeling of complex systems described in the numerous scientific literature, in particular [26-27].

The aim of research is to build a conceptual position on the creation of technology for the design of transport and logistics schemes for harvesting, transshipment and transportation of grain crops with flexible adaptation to specific agronomic, technical, natural, economic and other numerous conditions during their harvest. The result of system-analytical research of the problem should be a practical consulting document that would allow the decision-maker (decision maker) in specific conditions to determine the choice of optimal transport and logistics schemes in order to most effectively perform the stages of harvesting and transporting crops to granaries.

2. Materials and methods
The problem of creating a flexible logistics technology for harvesting and transporting grain crops during their harvest will be considered as a complex system, a complex object to be studied. The result of solving this problem will be the creation of a comprehensive document of information and recommendation (consulting) nature, which would contain certain mandatory sections and their content in relation to the flexible choice of a set of technical means with optimal economic performance, parameter groups, etc. depending on specific natural, economic, legislative and other numerous conditions during the harvest of cereals.

Since there is no sufficient information base for the content of such a document at the beginning of such a comprehensive study, in our opinion, the solution of this system problem should be performed from the standpoint of inductive approach to modeling complex systems, which has proven itself in solving many complex uncertain problems.

One of the effective tools of this approach to the creation of this type of document is the inductive technology of system information-analytical research, which applies the main principles of the theory of inductive modeling of complex systems. It will be recalled that the result $R^\ast(I_0)$ of complex
inductive technologies of system information-analytical research is a specific document $D\{R^*(I^*_b)\}$, which reflects the results of system subject analysis of a complex object (process, phenomenon or problem in general), which is based on the optimal information base $I^*_b$ constructed in the research process. Requirement has an information-recommendatory (consulting) nature, endowed with a certain official status and level of access. $D\{R^*(I^*_b)\}$ means a document prepared and executed in accordance with the requirements, based on a set of optimal research results $\{R^*(I^*_b)\}$, which may still have a certain sketch character. This is the only difference between the results $R^*(I^*_b)$ and the resulting document $D\{R^*(I^*_b)\}$.

3. Results
Here are the main stages that must be passed in accordance with the inductive technology of system information and analytical research to create a meaningful document.

Stage I. Formation of the top-level expert commission and construction of the primary information base, selection of analytical groups $A$ and $B$ to perform system-analytical research and synthesis of the optimal information base $I^*_b$, which should generate results $R^*(I^*_b) \in \{R^*(I^*_b)\}$.

Stage II. Creating a matrix of reference (target) result:

$$E = E\{R^0(I^*_b)\} = (e_{ij}) = \begin{pmatrix} e_{11} & \ldots & e_{1n} \\ \vdots & \ddots & \vdots \\ e_{m1} & \ldots & e_{mn} \end{pmatrix},$$

in which the $i$-th line, $i = 1, 2, ..., m$, reflects one of the indisputable types of requirements for the target result of the study from the standpoint of the expert commission, and the $j$-th column, $j = 1, 2, ..., n$, possible gradations of estimates of the $i$-th element. The line in our case is one of the necessary sections of the future document, and the elements of the line are the formalized values of expert assessments (requirements) to its subdivisions. The elements $(e_{ij})$ of the matrix $E\{R^0(I^*_b)\}$ are formalized according to a certain algorithm based on the assessments of top-level experts. For example, this may be the median on the set of expert tolerances (conclusions) regarding such an element $(e_{ij})$.

It is important to note that the matrix $E\{R^0(I^*_b)\}$ concerns only the form of the future result and the importance of reflecting in it the most important positions and their parts. In addition, in contrast to the known analytical technologies such as the Delphi method, the key point is that members of the top-level expert commission who agreed with the generalized estimates of matrix $E\{R^0(I^*_b)\}$ tolerances $(e_{ij})$ cannot change their conclusions about the shape of future results throughout the project. That $(e_{ij})$ is, there are constant estimates. The semantic content of all these positions is performed by analytical groups and tested by experts from the top-level expert commission at each step of the next stage III.

Stage III. Execution of information-analytical project by iterative procedure.

Step 1 of stage III. Groups $A$ and $B$ synthesize analytical results $R_k(I^*_b)\{(A,B)\}$, $k = 1, 2, ..., K$, which include only the initial information base $I^*_b$, and for each such result, experts make estimates, i.e., build matrices that are formalized on the same principle as for the matrix $E\{R^0(I^*_b)\}$.

$$W_k^{(A,B)} = (w_{ij}) = \begin{pmatrix} w_{11} & \ldots & w_{1n} \\ \vdots & \ddots & \vdots \\ w_{m1} & \ldots & w_{mn} \end{pmatrix}. \quad (2)$$

That is, the matrix $W^A$ – reflects the formalized $k$-th result $R_k(I^*_b)$, achieved by the analytical group $A$ in the $s$-th step of the study ($s = 1, 2, ..., S$) and, accordingly $W^B$ – reflects the formalized $k$-th result $R_k(I^*_b)$ achieved by the analytical group $B$ in the same $s$-th step of the study.

Each synthesized result is evaluated according to the criteria of systemic correlation:
\[ CR_{corel} = \sqrt{\sum_{i=1}^{m} \sum_{j=1}^{n} (\delta_{ij}^2)_{WB}^A} \]  
\[ CR_{rel} = \sqrt{\sum_{i=1}^{m} \sum_{j=1}^{n} (\delta_{ij}^2)_{WB}^{(A\cup B)}} \]  
and systemic relevance:

\[ \Delta^2_{(s)} = \begin{pmatrix} \delta_{11}^2 & \cdots & \delta_{1n}^2 \\ \vdots & \ddots & \vdots \\ \delta_{m1}^2 & \cdots & \delta_{mn}^2 \end{pmatrix} \]  

and are equal to the squares of the differences of the corresponding elements of the pairs of matrices \( W[R_k(I_b^s)]^{(A\cup B)} \) and \( E[R_k(I_b^s)]^A \), \( W[R_k(I_b^s)]^B \), respectively, and all these matrices have dimensions \( n \times m \). The sign * means to which pairs of matrices, and therefore to which criterion, the object belongs \( \delta_{ij}^2 \) (relevance or correlation).

Therefore, these system criteria require minimal differences both between the achieved two groups of results (2) and between such results and the reference. Then the information monitoring system is activated, an additional target portion \( I_b^+ \) of monitoring information is formed, which should complement the already existing ensemble \( I_b^s \), \( s = 1, 2, ..., S \), in order to improve the results \( R_k(I_b^s) \), bringing them closer to the reference \( R_k(I_b^0) \).

Step 2 of stage III, ..., S. Analytical results \( R_k(I_b^s) \), \( k = 1, 2, ..., K \), \( s = 1, 2, ..., S \) are synthesized, which are based on the results of previous steps and information \( I_b^+ \) of purposeful information monitoring. Again, each synthesized result is evaluated by criteria of systemic correlation (3) and systemic relevance (4).

Criteria (3) and (4) should theoretically have minima, which indicate the cessation of the inductive procedure for the synthesis of the optimal result \( R^*(I_b^s) \) (or a certain limited set of such results \( R^*(I_b^0) \)). The last step of the procedure of inductive technologies of system information-analytical research is one in which:

- The result is obtained, which is objectively the best according to the system criteria (3) and (4) and satisfies the customer;
- The result is obtained, which can still be improved, but it already satisfies the customer;
- Exhausted research resources (time and money, for example).

Stage IV. Formation of the optimal result \( R^*(I_b^0) \) and the corresponding consulting document \( D[R^*(I_b^0)] \). Both analytical groups should already work here under the control of the project manager.

Stage V. Protection of the document \( D[R^*(I_b^0)] \) and its transfer to the customer. Obviously, the described technology does not require complex, long-term and costly field experiments to achieve the result (although in the general case it is not denied). In addition, it is also obvious that such an approach should be used to solve complex problems, to implement intelligent projects of high complexity. The problem undoubtedly belongs to this class of problems. Thus, comparing the above, a consulting document that would contain simple and at the same time sufficient for decision-making procedures (schemes) for the synthesis of flexible logistics technologies for harvesting and transporting grain to granaries and optimally adapted to specific natural production, economic, technical and other conditions during the collection period, it is advisable to create, based on the described inductive technology of system information and analytical research. The concept of
developing such a document for the synthesis of logistics technologies for harvesting and transporting grain involves the following stages.

Step 1 of stage V. Creation of a matrix of the target (reference) result \( E\{R^0(I^0_b)\} \) and the primary information base \( I^0_b \) by the previously formed expert commission of the top level. As a result of the substantive analysis of the problem and, based on previous studies, the experts proposed conclusions that allowed to obtain the following formalized matrix of the target result \( E\{R^0(I^0_b)\} \):

\[
E\{R^0(I^0_b)\} = \begin{pmatrix}
997878540 \\
787877504 \\
688865600 \\
975698678 \\
989999978 \\
878888780 \\
989999880 \\
332231110
\end{pmatrix}.
\]

The first column of the matrix (6) shows agreed estimates of the importance of a section of the final document. The following columns reflect the experts’ assessments of certain group parameters from the optimal information base \( I^0_b \). The first four rows of the matrix (6) to some extent coincide with the groups of the primary information base. From the 5th line to the 8th – the requirements of experts from the expert commission of the top level concerning indisputably necessary processing of the following sections of the final document (on lines) are reflected:

- 5th – schemes of synthesis of harvesting and transport technological processes;
- 6th – technical and economic analysis of optimal harvesting and transport technological processes;
- 7th – forecasting the economic efficiency of the selected by the accident harvesting and transport processes;
- 8th – appendices (instructions, nomograms, numerical information, etc.).

The experts included and classified the following parameters into groups in the primary information base \( I^0_b \) (table 1).

Step 2 of stage V. Formation of analytical groups \( A \) and \( B \), which should perform system-analytical research in the direction of content filling of matrices \( W\{R_k(\delta^2_{ij})\}^A, W\{R_k(I^0_b)\}^B \) and in order to achieve the optimal result \( R^*(I^0_b) \) (or a certain limited set of such results \( R^*(I^0_b) \)) and minimize criteria (3) and (4). Execution of the project in parts of rows (lines) 5-th to 7-th of the matrix \( E\{R^0(I^0_b)\} \) to obtain numerous analytical models and dependencies involves the use of inductive methods for modeling complex systems.

Step 3 of stage V. Formation of the source document \( D\{R^*(I^0_b)\} \) and its transfer to the customer.

4. Discussion
The article presents the conceptual principles of creating a system technology for designing logistics schemes of harvesting and transport technological processes of schemes in a very short period of harvesting and transportation of grain crops [28]. Such schemes are obviously technology in turn. Despite the conceptual nature of the work, it already contains at least the results of the first stage of inductive technologies of system information and analytical research, because, based on the complexity and significant lack of initial information base, the project is expected to perform such inductive technology [29]. This was done due to the already conducted theoretical studies of the processes of application of interoperative compensators, which obtained the basic patterns of their use [30].
Based on the agreed conclusions of top-level experts, a matrix of the target result (document) is synthesized, which should become a clear guide in the form of further system-analytical research in the direction of semantic content of the final document. Such a document, according to experts, should allow a person who makes decisions that are optimal according to the criteria constructed in the research scheme of harvesting and transport processes in a short time of harvesting and transport work at harvest [31]. The concept stipulates, and this is reflected in the matrix of the target result, that the effectiveness of information base schemes in the project of flexible synthesis should be evaluated both by technical parameters and by economic factors [32].

5. Conclusion
The matrix $E[R^0(I_{0b}^f)]$ concerns only the form of the future result and the importance of reflecting in it the most important positions and their parts. In addition, in contrast to the known analytical technologies such as the Delphi method, the key point is that members of the top-level expert commission who agreed with the generalized estimates of matrix $E[R^0(I_{0b}^f)]$ tolerances $(e_{ij})$ cannot change their conclusions about the shape of future results throughout the project.

Creation of a matrix of the target (reference) result $E[R^0(I_{0b}^f)]$ and the primary information base $I_{0b}^f$ by the previously formed expert commission of the top level. As a result of the substantive analysis of the problem and, based on previous studies, the experts proposed conclusions that allowed to obtain the following formalized matrix of the target result $E[R^0(I_{0b}^f)]$.

Formation of analytical groups $A$ and $B$, which should perform system-analytical research in the direction of content filling of matrices $W[R_k(\delta I_{0b}^f)^{A}], W[R_k(I_{0b}^f)]^{B}$ and in order to achieve the optimal result $R^*_b(I_{0b}^f)$ (or a certain limited set of such results $\{R^*(I_{0b}^f)\}$ and minimize criteria (3) and (4).

| Table 1. The primary information base in the project of synthesis of flexible. |
|---------------------------------------------------------------|
| **Number and name of group**          | **Parameter in group** |
|--------------------------------------|------------------------|
| **name of group**                    | **number** | **symbol** | **name and its unit of measurement** |
| I. Combine harvester                 | I.1   | $W_k$ | Nominal productivity, t/h |
| II. Reloader trailer                | II.1  | $V$  | Capacity of the loader trailer, m$^3$ |
| III. Wheeled vehicle of category N3 | III.1 | $g_\alpha$ | Load capacity of the vehicle, t |
| IV. Natural and production conditions | IV.1  | $K_p$ | Coefficient of complexity of natural production conditions |
|                                      | IV.2  | $K_w$ | Weather coefficient |
|                                      | IV.3  | $T_{\alpha}$ | Agroterms (harvesting period), days |
|                                      | IV.4  | $U$ | Yield, t/ha |
|                                      | IV.5  | $S$ | Field area, ha |
|                                      | IV.6  | $L$ | Length of the run, m |
|                                      | IV.7  | $l$ | Distance of transportation, km |
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