VOL. 17, NO. 21, NOVEMBER 2022 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

# APPLIED SOFTWARE MANAGEMENT OF TECHNOLOGICAL PROCESS OF GRAIN PRODUCTION ON THE GRANARY

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## ABSTRACT

Detailed analysis of each technological operation at the stage of post-harvest processing of grain in the granary system is characterized by a variety of technological parameters of machinery and equipment, these parameters can be both controlled and uncontrolled, which causes some difficulties in complex mechanization and automation of production processes. This aspect also creates difficulties in the development of application software for the management of the technological process of grain production on the ground, as a holistic controlled system which includes all the basic equipment and additional hardware in the granary system. Therefore, the development of methods for assessing the effectiveness of automated process control systems on site is an urgent problem. Due to the stochastic dynamic nature of the technological system of post-harvest grain processing, mathematical modeling methods cannot fully describe the work of this system as a whole, so scientists are increasingly using computer modeling methods. The article considers the main issues related to the development of the optimal structure of applied software for process control of grain production on ground, as well as developed methods for evaluating the effectiveness of applied software for process control, based on the calculation of comparative efficiency. Design approach to the management of the system of machines for post-harvest processing of grain, the causal links between the technological parts of the system.

**Keywords:** software, mechanized work planning, model, factors, algorithm, simulation model, technological system, productivity.

## INTRODUCTION

This article is devoted to the description of the application software for managing the technological process of grain production in the granary. Software for controlling the technological process of grain production on the current, designed to control the flow of grain mass depending on the intensity of their receipt.

With a significant intensity of grain flow, modern grain cleaning complexes do not always process the required mass of grain in time, resulting in grain stagnation in the interval between adjacent links of the post-harvest technological line and increase the area of grains in the granary, which require immediate processing. During storage of unrefined grain from light and straw impurities, as well as grain with high humidity, in 3-4 days there is a phenomenon of self-heating of grain and increasing the intensity of microbiological processes, which reduces the sowing and nutritional qualities of grain. As a result, up to 5% of the harvest is lost.

Such negative phenomena arise due to the insufficient level of planning of technological systems for servicing multi-item flows of grain crops. Improving the efficiency of production and commodity quality of grain, reducing its losses can be achieved by rational planning of multi-item flows, as well as available technological equipment for post-harvest processing of grain. To date, research on the development of organizational and technological projects of machines for post-harvest processing of grain has been almost not conducted, so a very important task is to increase the efficiency of existing complexes of machines for post-harvest processing of grain in intensive grain harvesting through organizational and project planning.

The idea of this work is to harmonize the parameters of technical support of granaries with production programs for growing crops, which will reduce the cost of growing crops.

The result of the application of this application software is the structure of the reduced operating costs of grain production in the granary and the efficiency of investment.

## LITERATURE REVIEW

The article by the authors [1] presents both a literature review and empirical findings from three case studies that reveal how companies conduct continuous planning. The results indicate that continuous planning is not commonly adopted and applied throughout these organizations and that it currently involves only a certain kind of planning (e.g., release planning). The results of this study bring to light that the main elements of continuous planning (i.e., organizational, strategic and business planning) are tightly related to each other and thus should be considered when companies seek to improve their planning processes and practices. The importance of continuous planning will only increase dramatically in turbulent business environments that include ever shorter planning cycles and the need to improve transparency and knowledge-sharing in organizations.

The paper [2] applies research in dependency modelling to a process-based risk assessment methodology suitable for critical infrastructures. The proposed methodology dynamically assesses the evolution of cascading failures over time between assets involved in a business process of an infrastructure. This approach can be applied by a CI operator/owner to explore how a failure in a single component (asset) affects the other assets and relevant business processes. It could also be applied in an analysis that includes multiple CI operators in the same supply chain to explore the dependencies between their assets and explore how these affect the provision of key societal services. The paper presents a proof-of-concept tool, based on business-process risk assessment and graph modelling, and a realistic case example of a rail scheduling process. The approach allows risk assessors and decision makers to analyse and identify critical dependency chains and it can reveal underestimated risks due to dependencies.

Modern societies are becoming increasingly dependent on critical infrastructure systems (CISs) to provide essential services that support economic prosperity, governance, and quality of life. These systems are not alone but interdependent at multiple levels to enhance their overall performance. To better understand CISs to support planning, maintenance and emergency decision making, modeling and simulation of interdependencies across CISs has recently become a key field of study. This paper [3] reviews the studies in the field and broadly groups the existing modeling and simulation approaches into six types: empirical approaches, agent based approaches, system dynamics based approaches, economic theory based approaches, network based approaches, and others. Different studies for each type of the approaches are categorized and reviewed in terms of fundamental principles, such as research focus, modeling rationale, and the analysis method, while different types of approaches are further compared according to several criteria, such as the notion of resilience. Finally, this paper offers future research directions and identifies critical challenges in the field.

The authors [4] considerable attention has been paid to analysing and assessing the criticality of railway infrastructure elements. Publications on the subject mostly assess elements only from a certain point of view, such as purpose, reliability or risk. This leads to only a partial assessment of criticality without continuous correlation, which may result some critical elements of the system being omitted. The article introduces the railway infrastructure criticality assessment tool (RICA tool), which was created to evaluate the criticality of railway infrastructure elements in all aspects. The integral approach of the tool lies in comprehensively assessing the technical and process factors of rail transport. The criticality of railway infrastructure elements is therefore assessed not only in terms of the relevance and resilience of elements but also their interdependence, substitutability, risk and impact.

The railway infrastructure has very specific constraints that lead to the need of maximizing of the availability of infrastructure, with high levels of safety and quality, associated with an optimized cost. Having said this, it is essential to understand the methods behind the inspection and monitoring of existing railway infrastructures, the way of processing their data, as well as existing rehabilitation solutions. The present work [5] begins with a brief description of the components of the ballast track and its operation, the different types of actions to which it is subjected to and the degradation mechanisms at the level of the ballast layer, substructure and transition zones, with particular attention being given to the latter since it is a section of the road with singularities that lead to a more pronounced degradation. The rehabilitation solutions addressed in this work start from a slight attack of the road (which can be considered as a small intervention) until a complete renovation of the road with reinforcement of the foundation. Based on the previously mentioned concepts, it is possible to define which variables, criteria and respective weights are more important and influence the investment decision (on the rehabilitation of the railway infrastructure), thus enabling the methodologies of multi-criteria analysis applied to these variables. Currently, the economic factor is one of the variables that influence the most in decision making due to the lack of investment capacity. Mainly because of this factor and sometimes even without performing an analysis, one of the common practices is the restriction of circulation velocity rather than maintenance or rehabilitation measures. The case study used is an excerpt from a railroad in Portugal, where the entire described process will be applied and consequently analysed. Therefore, this work intends to contribute to a more efficient planning of the railway maintenance and rehabilitation measures, based on a better use of the data resulting from the track inspection, through a multi-criteria analysis.

The paper [6] describes the long process of developing the transport system of risk assessment models. Researchers in Central European countries many years solved the risk assessment models which are based on the accident scenarios. Purpose and objectives realized research directed at finding the dependencies between the state of transport infrastructure and its potential threat. Various hazardous events, which have the potential to lead to casualties probably, were defined by gathering various accident reports and having conferences and workshops with transport safety and security experts. The developed models will be used to assess the accident risk of the road and railway systems. The frequency of each hazardous event was evaluated from the historical accident data and structured expert Judgments by using the technique FTA, ETA technique and other suitable methods were applied. Research results have shown the need to return more new measures in the response to new sources of risk.

The identification of Critical Nodes in technological, biological and social networks is a fundamental task in order to comprehend the behavior of such networks and to implement protection or intervention strategies aimed at reducing the network vulnerability. In this paper [7] we focus on the perspective of an attacker that aims at disconnecting the network in several connected components, and we provide a formulation of the attacker behavior in terms of an optimization problem with two concurrent objectives: maximizing the damage dealt while minimizing the cost or effort of the attack. Such objectives are mediated according to the subjective preferences of the attacker. Specifically, the attacker identifies a set of nodes to be removed in order to disconnect the network in at least m connected components; the final objective is from one side to minimize the number of attacked nodes, and from another side to minimize the size of the largest connected component. The paper by providing a heuristic approach to calculate an admissible solution to the problem at hand, based on the line graph of the original network topology and on the spectral clustering methodology.

The article by the authors [8] Adaptation of the operations research models and methods to planning of the critical infrastructure protection is considered. Adaptation of these models includes taking into account stochastic, informational, and behavioral uncertainty of terrorists. In particular, relevant generalizations of the antagonistic attack–defense game and optimal allocation of protective resources are considered, and methods are proposed to solve the occurring optimization problems.

The paper [9] introduces the CIERA methodology designed for Critical Infrastructure Elements Resilience Assessment. The principle of this method is the statistical assessment of the level of resilience of critical infrastructure elements, involving a complex evaluation of their robustness, their ability to recover functionality after the occurrence of a disruptive event and their capacity to adapt to previous disruptive events. The complex approach thus includes both the assessment of technical and organizational resilience, as well as the identification of weak points in order to strengthen resilience. An example of the application of the CIERA method is presented in the form of a case study focused on assessing the resilience of a selected element of electrical energy infrastructure.

This paper [10] deals with cargo security and its optimization as a result of transport experiments. It also statistically evaluates these transport experiments with its emphasis on local extremes (accelerations) and compares the result of each day's measurements. The article includes a model of cargo security on a medium size off-road T-810 6 × 6 truck, where the measured data was applied for logistics purposes. The completed transport experiment points to larger inertial forces during transport than predicted based on the set of normative acceleration coefficient values. Although the results of the experiment show that the highest measured value of the coefficient of acceleration is 3 times greater than the normatively determined, we found the value to actually be 3.4 times higher than predicted, using the standard values. Due to the not inconsiderable percentage values which exceed the specified values of normatively set coefficients of acceleration (10.83%, respectively 13.31%) exceeding the set values of inertia forces can be expected in these cases as well.

The article by the authors [11] identifies and classifies subject-agro meteorological events in the technological processes of cultivating grain crops. The analysis of these events made it possible to classify them according to the periodicity of their appearance, as well as to indicate the content of the influence of each of them on the course of these processes, which made it possible to develop appropriate algorithms for modeling the time of occurrence of these events.

The distribution of the time of occurrence of subject-agro meteorological events in technological processes of growing of grain crops, in particular: the time of restoration of spring vegetation, the completion of the autumn vegetation period of winter grain crops, the time of reaching their characteristic predecessors, and the patterns of change in the duration of soil warming have been established. The obtained regularities allow to predict (generate) the onset of phases of development of plants and time constraints for the implementation of mechanized operations in the technological processes of cultivating grain crops for different natural and production conditions. The developed scientific and methodical principles of modeling of subject-agrometeorological events in the technological processes of cultivating grain crops underlie the creation of their computer models. The practical use of these models will allow you to predict the time constraints for performing mechanized operations and the characteristics of the flow of orders for their execution.

The methods of analysis and synthesis, system-factor and system-event approaches to the study of technological processes of cultivating grain crops were used in the work. To develop algorithms for modeling these technological processes, a discrete-event approach was used.

The article by the authors [12] developed method rationale parameters equipping items postharvest processing of grain under the coordination of programs with the characteristics of industrial harvesting of early grain crops and grain systems parameters given the variability of agrometeorological conditions of the region.
The article by the authors [13] suggest methodology of rational seasonal scenario of inter-farm combine harvester threshers use that is based on the design and management of technological processes of harvesting of early -grain crops is revealed. The proposed methodology involves a step-by-step study of the combined influence of natural-production and agrometeorological factors on the efficiency of the technological processes of harvesting early grains and the monetary evaluation of these indicators. This gives reason to justify on cost criteria (profit earned by reducing the yield loss of the crop), rational seasonal scenario of inter-farm combine harvester threshers use by business entities, united geographically or administratively. The automated system for designing and controlling the processes of harvesting early grain crops, which was created to implement this technique, also described. Using this automated system allows: for each business entity to predict fields for which there is a risk of loss of cultivated yield due to the untimely harvest of it by the available fleet of combines; to define combine harvesters which must additionally involve to the harvesting on such fields; to predict the duration of the involvement of these harvesters and select business entities from which it is expedient to involve combine harvesters. The developed automated system makes it possible to increase the efficiency of the use of combine harvesters of economic entities and to reduce the losses of the cultivated harvest of early grain crops.

Researches of technological systems of postharvest processing of grain were performed mainly in the form of the description of work of separate links of technological system by mathematical dependences with elements of the theory of probabilities and mathematical statistics, and also in the form of tables with statistical characteristics [14, 15, 16]. At the same time, these studies do not take into account the dynamics of the technological system as a whole and do not give a complete description of the impact of the stochastic nature of the process on the performance of the technological system. Computer simulation is an alternative to studying the behavior of post-harvest grain processing systems and their characteristics.

Changes in humidity, purity of grain, the intensity of its receipt within the season is random (stochastic), which was proved by subsequent scientists using probability theory [17, 18].

The developed method [19] foresaw the need for equipment for post-harvest processing of grain and seeds, which assumed the constancy of the characteristics of grain flows. Analysis of known studies and publications does not provide complete information to the designer on the development of technological equipment for cleaning and sorting grain in the granary in conditions of intensive multi-item flow of grain to the cleaning-drying-storage point. Therefore, the urgent task is to develop a mathematical apparatus, as well as a simulation model of the technological process of postharvest processing of grain and storage in the current system, description of the structure and development of basic principles for building the developed model.

The studies presented in [20, 21] reveal the possibility of using fuzzy systems of automatic control of technical means in the storage of plant products, the use of thermodynamic equations somewhat complicates the calculations, but gives more accurate calculations.

## METHODOLOGY

System-design approach to the study of technological systems for servicing multi-nomenclature flows involves identifying, comparing and justifying alternative solutions that increase the efficiency and productivity of technological systems.

Input factors are indicators that determine the quality of grain entering the granary: $W_{gin}$ - the moisture content of grain entering the granary; $\Psi_{gin}$– the clogging of grain entering the cleaning-drying-storage point; $Q_{gin}$- the intensity of grain supply. Also important are the characteristics that determine the structure of the multi-item flow: the duration–$\Delta t_{gin}$, the nomenclature–$\eta(t)_{gin}$, the volume of individual batches–$Q_{ngin}$.

In addition, an important initial condition is also a change in the quality of the harvest over time, both during the day and during the harvest period. After processing of grain grain by a technological complex of machines of granary, grain weight receives properties which can be characterized by the following parameters: $W_{out}(j)$–the final grain moisture; $\Psi_{out}(j)$–the final grain clogging. An important final parameter is the speed of grain processing by a system of granary machines–$Q_{out}(j)$.

The instantaneous daily supply of grain from combines to grain cleaning and drying and storage points of agricultural enterprises differs significantly from the average daily and depends mainly on simultaneously operating combines and their vehicles, crop yields, combine productivity, distance between fields and cleaning and storage. Sown area of the harvested crop. The average daily grain yield for the entire harvest period and the average daily grain supply during the busiest harvest period fluctuates significantly even in farms with the same size of sown area, this is due to different levels of organization of harvesting. The unevenness of the daily grain supply characterized by the coefficient of daily unevenness:

$$\delta = \frac{\overline{\Delta Q_{3d}}}{\overline{\Delta Q_d}}, \qquad (1)$$

Where $\Delta Q_{3d}$–the arithmetic mean of the three maximum daily incomes of grain for the period of harvest;$\Delta Q_d$–the average daily grain supply for the entire harvest period.

This coefficient is usually in the range from 1.5 to 2.2. It depends on the technical equipment of farms, agricultural techniques for growing cereals (yield), and the use of harvesting equipment and soil and climatic conditions of farms. The coefficient of daily unevenness significantly affects the optimal load line of the cleaning-drying-storage point. The quality of processing and technological efficiency directly depend on the rhythmicity and constancy of the lines.

As can be seen from Figure-1, that with increasing coefficient of non-uniformity δ technological efficiency of the system of machines for post-harvest processing of grain decreases. Therefore, when the value of the coefficient of daily unevenness over 2.0 transitional hoppers are used, or use additional technological equipment for grain cleaning.

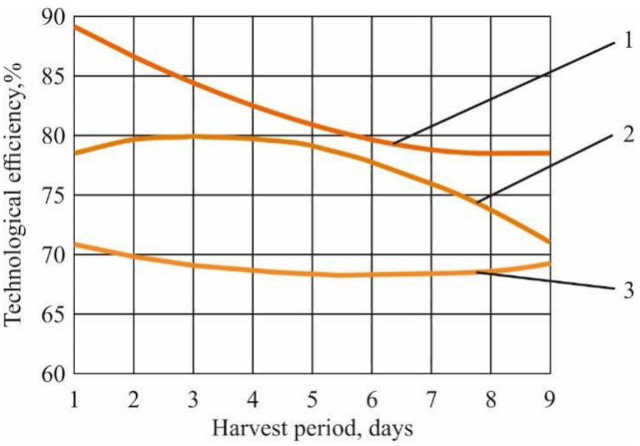
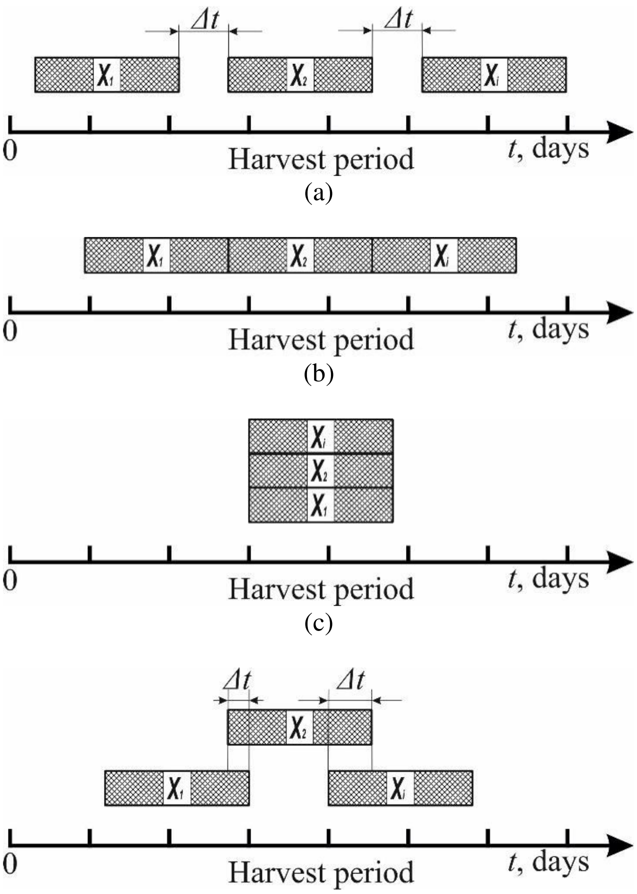


**Figure-1.** Dependences of technological efficiency on the period of harvest at different values of the coefficient of non-uniformity: 1 - when δ = 1.58; 2 – when δ = 1.8; 3 - when δ = 2.3.

The composition and characteristics of technological systems for servicing multi-item flows depend not only on the volume of grain supply to the cleaning-drying-storage point, but also on the number of crops harvested at the same time. It is also possible to simultaneously harvest different varieties of the same grain crop, which differ in their characteristics. In these cases, the nomenclature of the incoming grain flow $\eta(t)_{gin}$> 1 [17].

Consider several options for the receipt of a multi-item flow of cereals (Figure-2).



(a)

(b)

(c)

(d)

**Figure-2.** a) The consistent with the intervals between periods of harvesting different crops *Δt*; b)the consistent without intervals between periods of harvesting different crops; c)the parallel harvesting of different crops; d) the sequential with intervals *Δt* parallel harvesting of different crops

Figure-2a shows the most optimal of the considered methods is the method, namely when the multi-nomenclature flow is decomposed into single-nomenclature in certain time intervals, and between the periods of collection there is a gap *Δt*. During this period, it is possible to reconfigure the system of machines of the cleaning-drying-storage point to another culture. In practice, this case is observed at the beginning and end of the multi-item flow. This is due to the fact that both at the beginning and at the end of the harvesting period, grain crops ripen in single fields, so in most cases there is a situation where it is necessary to harvest several crops in parallel. In many cases, the phenomenon is shown, which is shown in Figure-2b and is characterized by the fact that over a period of time *Δt* there is a parallel harvesting of different cultures. For effective functioning in this period it is necessary two and more current lines, or to involve a complex of self-mobile grain cleaning machines which are on a granary. The most unfavorable regime is the case shown in Figure-2c, in which case there is a parallel harvesting of several crops or different varieties of one crop. To do this, you need to have several current lines for cleaning different varieties, or a group of grain cleaning machines, depending on the crops that are collected at the same time or use transitional hoppers for temporary storage.

To prevent losses of grown products and facilitate the management of current flows, developed software for managing the technological process of grain production in the granary.

The process of developing application software for managing the technological process of grain production in the granary (PPZ) can be divided into several steps:

a) Substantiation of the structure of PPZ;

b) Development of the structure of PPZ;

c) Calculation of automation tools;

d) The choice of basic means of automation of PPZ.

Consider the block diagram of the PPZ (Figure-3).

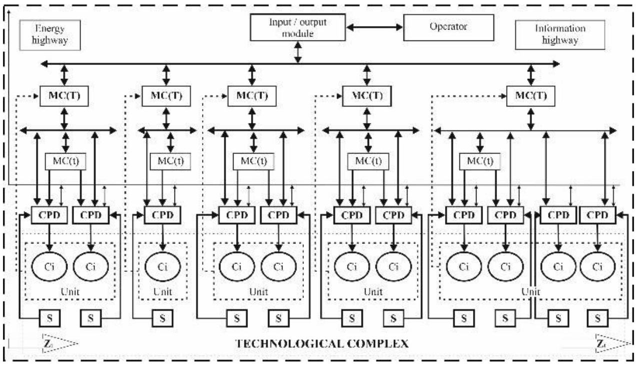


**Figure-3.** S - sensor; CPD - control and protection device; MC(T)-technological microcontroller; MC(t)-microcontroller drive technical means; Ci-appropriate equipment (unit, machine); $Z_1$ - flow initial state of the grain; $Z_2$ - grain flow in the final state

The problem of the algorithm for the synthesis of the effective structure of PPZ includes:

- Synthesis of the structure of the controlled system, ie the optimal division of the set of controlled objects into separate subsets with specified characteristics. At this stage: 1) selection of the number of levels and subsystems; 2) the choice of principles of management, ie the establishment of the correct levels between the levels; 3) the optimal distribution of functions performed between people and computer equipment; 4) the choice of organizational hierarchical structure.

- Synthesis of the structure of information transmission and processing systems (including information-control multifunctional complex): 1) synthesis of the structure of information transmission and processing systems; 2) synthesis of the structure of the information and management complex (including the problem of placement of service points of this complex).

To determine the optimal structure of the PPZ, the initial data are:

a) Performed by the system functions that can be formalized in the form of many problems $A = \{A_i\}$. Each of the problems $A_i, i = \overline{1,a}$ (where $a$ - the total number of problems solved by the system) may consist of stages $g_i, g_i = \overline{1,G_i}$ (where $G_i$ - the number of stages of solving the problem $A_i$) and have solutions in the PPZ $\omega_i, \omega_i = \overline{1,\Omega_i}$ (where $\Omega_i$ - the number of options for solving the problem $A_i$).

b) Relationships between problems and their stages, which can be specified in the form of a graph $Q_A = \{A_{g_i}, A'_{g_i}\}$, where $\{A_{g_i}, A'_{g_i}\} \in A$. Graph arcs characterize the relationship of the path that exists between the problems to be solved and their stages, and correspond to the directions of information flows.

After analyzing the description of the system, we can conclude that the technological process of post-harvest processing of grain in the granary system is a rather complex, continuous stochastic process. Applying a systematic approach to the technological line of grain production in the granary system at the level of structural elements can be represented as a number of relationships of technical and technological subsystems of postharvest processing of grain in the granary system (Figure-4).

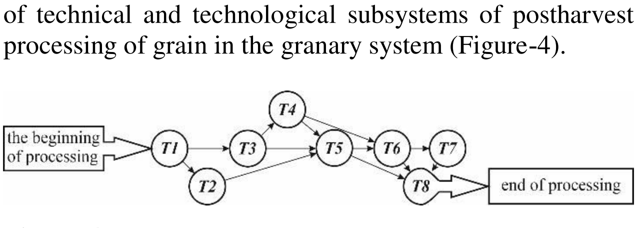


**Figure-4.** *T1* - Formation of grain in the granary; *T2* - Pre-cleaning in the sides; *T3* - Pre-cleaning of grain in the complex; *T4* - Grain aspiration; *T5* - Drying of grain; *T6* - Primary grain cleaning; *T7* - Secondary grain cleaning; *T8* - Storage of cleaned grain (storage subsystem).

c) Many possible nodes of PPZ $V = \{V_j\}$ and connections between them, which are given in the form of a graph $Q_V = \{V_j, V'_j\}$, where $j, j = \overline{1,J}$. Vertices of the graph $Q_V$ represent nodes and arcs are the connections between them.

In some cases, a finite set of possible node variants can be specified PPZand the connections between them, ie $Q^{\xi}{}_V, \xi = \overline{1,B}$, де $Q_V^{\xi}$ - $\xi$-th possible option, $B$ - number of possible options.

d) Types and characteristics of technical means, the use of which is possible in the PPZ, let $T = \{t_C\}$ –many possible technical means and $C = \overline{1,L}$, where $C$ – type of technical means, $L$ –number of technical means.

e) External to the system sources and consumers of information at all stages of the problems.

Therefore, the problem of the optimal structure of PPZ is to find:

- system nodes $V$;
- connections between them $Q_V$;
- problems assigned to technical means $A$and options for their solution $\omega_i, \omega_i = \overline{1,\Omega_i}$ in their distribution by levels and nodes of the system and in the choice of a set of technical means $T$, which maximizes the effect of solving problems in the PPZ, ie

$$\max \sum_{g_i \in A,\ \omega_i \in \Omega} E_{g_i}^{\omega_i} \sum X_{g_i, j, t_C}^{\omega_i} \tag{2}$$

where $E_{g_i}^{\omega_i}$ –the effect of implementation $g_i$-th stage on the $i$-th problem when using $\omega_i$-th variant of its decision; variable $X_{g_i, j, t_C}^{\omega_i}$ takes the value 1, if $g_i$-th phase $i$-th problems when using $\omega_i$-th variant of its implementation is solved in the $j$-th node $t_C$-th technical means of type $C$, and the value of 0 - otherwise.

Therefore, it is assumed that each stage of the problem is solved in one node.

The optimal structure of PPZ is determined by resource constraints, loading of technical means and timeliness of solving problems, i.e.

$$\sum_{g_i \in A, \omega_i \in \Omega, t_C \in T} W_{g_i, j, t_C, r}^{\omega_i} \cdot X_{g_i, j, t_C}^{\omega_i} \le W_r, \tag{3}$$

where $r = \overline{1,R}$ – the resource type; $W_r$ – the magnitude of the resource used.

The total number of options for the analysis of the construction of PPZ can be calculated by the formula:

$$\sum_{g_i \in A, \omega_i \in \Omega, t_C \in T} I_{g_i, j}^{\omega_i} \cdot F_{g_i, j, t_C}^{\omega_i} \cdot X_{g_i, j, t_C}^{\omega_i} \le \Psi_{j, t_C}, \tag{4}$$

where $I_{g_i, j}^{\omega_i}$ –the intensity (frequency) of the decision $g_i$-th phase $i$-th problems when $\omega_i$-th variant of the decision; $\Psi_{j, t_C}$ –loading $_C$-th technical means of type $C$ in $j$-

thnodes; $F^{\omega_i}_{g_i,j,t_C}$ - execution time $g_i$-thstage of the $i$-th problem in the $j$-th node $t_C$-th technical means when $\omega_i$-th solution option.

Temporary constraints for different PPZ problems can be complex and require analysis of the operation of different nodes. For example, to solve operational problems it is necessary that the probability of exceeding the time of solving the problem of the allowable value $F^{\text{admission}}_{g_i}$ was not more than the specified value $\Delta_{gi}$:

$$P\left\{F^{\omega_i}_{g_i,j,t_C} + H^{\omega_i}_{g_i,j,t_C} > F^{\text{admission}}_{g_i}\right\} \le \Delta_{g_i}, \tag{4}$$

where $H^{\omega_i}_{g_i,j,t_C}$ - waiting time in the $j$-th node.

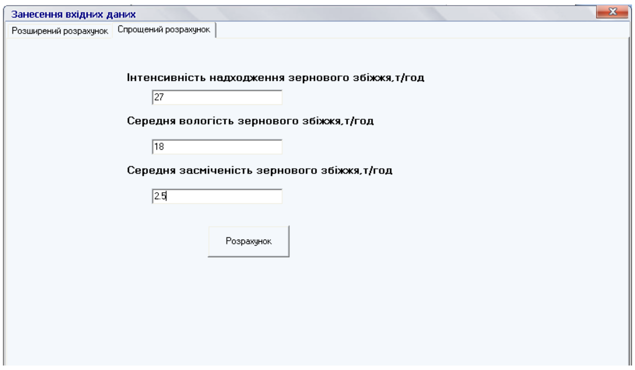
The effectiveness of application software is based on a reasonable ratio of profits and timing of their receipt.

## RESULT AND DISCISSIONS

To start working with the program, you need to create a new farm file, where you specify the name of the farm, production conditions.

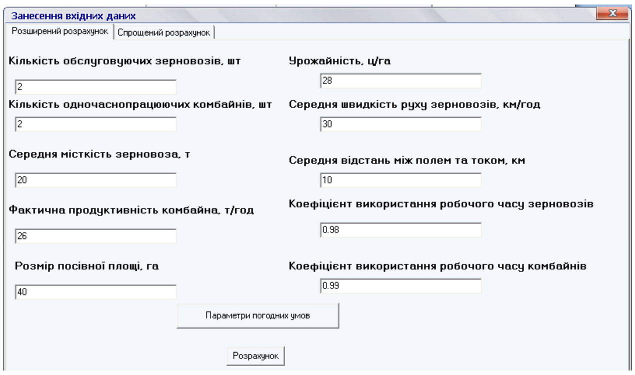
A general view of the input interface of a computer program for calculating the composition of the system of post-harvest grain processing machines is shown in Figure-5. The program provides for two calculation options: simplified calculation (Figure-5a) and extended calculation (Figure-5b).

So, for example, having passed to the tab "simplified calculation" the user, enters in fields the following parameters: intensity of receipt of grain grain, t/h; the average moisture content of grain for the harvest period, %; average contamination of grain grain during the harvest period, %.



Інтенсивність надходження зернового збіжжя,т/год
27
Середня вологість зернового збіжжя,т/год
18
Середня засміченість зернового збіжжя,т/год
2.5

(a)



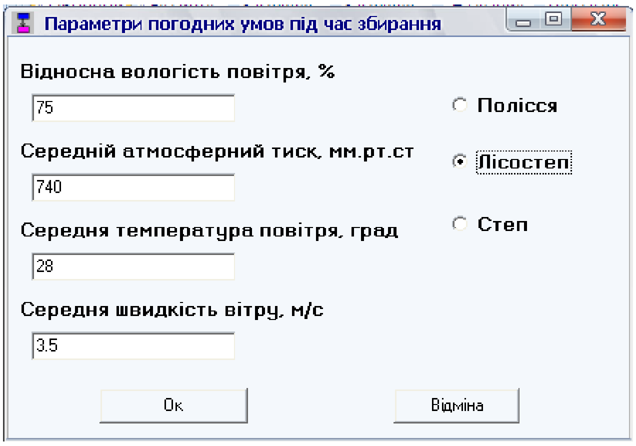
Кількість обслуговуючих зерновозів, шт
2
Кількість одночаснопрацюючих комбайнів, шт
2
Середня місткість зерновоза, т
20
Фактична продуктивність комбайна, т/год
26
Розмір посівної площі, га
40
Урожайність, ц/га
28
Середня швидкість руху зерновозів, км/год
30
Середня відстань між полем та током, км
10
Коефіцієнт використання робочого часу зерновозів
0.98
Коефіцієнт використання робочого часу комбайнів
0.99

(b)

**Figure-5.** a) - tab "simplified calculation"; b) - tab "advanced calculation".

On the tab "extended calculation" it is possible to enter the following parameters in the fields: the number of serving grain trucks, pcs.; number of simultaneously operating combines, pcs.; average capacity of the grain truck, t; actual productivity of the combine, t/h; size of sown area, ha; yield, c/ha; average speed of the grain truck, km/h; average distance between the field and the granary, km; working time utilization rate of grain trucks and combines.

Clicking the "Weather Parameters" button opens a window for the user to enter weather conditions parameters during compilation (Figure-6).



Відносна вологість повітря, %
75
Середній атмосферний тиск, мм.рт.ст
740
Середня температура повітря, град
28
Середня швидкість вітру, м/с
3.5

○ Полісся
● Лісостеп
○ Степ

**Figure-6.** General view of the window for entering the parameters of weather conditions of the computer program for calculating the composition of the system of machines for post-harvest processing of grain.

The user enters the values of relative humidity, average atmospheric pressure, average air temperature and average wind speed in the appropriate fields, and you need to select one of the natural and climatic zones of Ukraine. If the user clicks the "Cancel" button, all values entered by the user in the fields are erased. When you click "OK", all field values are fixed and passed to further calculation.

After entering the required parameters both on the tab "Simplified calculation" and on the tab "Advanced calculation" to calculate the user must click "Calculation".

After that, the program to calculate the composition of the system of machines for post-harvest processing of grain checks the entered values for correctness. If the entered data do not meet the required criteria, the application software displays a message to the user and the calculation stops. Until the user meets the requirements specified in the message, the calculation is not performed.

Якщо дані були введенні коректно, то ППЗдля розрахунку складу системи машин післязбиральної обробки зерна виконує розрахунок.Далі, розраховані параметри вхідного зернового потоку обробляються таким же чином, як і при спрощеному розрахунку передаються до основного модуля програми.

Розраховані площа зерноскладу та об’єм бункера-компенсатора відображається у вихідному інтерфейсі у відповідних полях. Далі з автоматично з відповідних баз вибираються продуктивності машин попереднього очищення, сушарок та машин первинного очищення, після чого визначається необхідна кількість відповідних машин.

Relevant pre-cleaning machines, dryers and primary cleaning machines found on request are displayed in the initial interface in the relevant tables, where you can find the machine brand, manufacturer, passport performance, technological efficiency, machine weight, electric power consumption, specific energy and material consumption. A general view of the interface is shown in Figure-7.

Машина попереднього очищення: Кількість: 1

| Питома матеріалоємність, кг?год/т | Питома енергоємність, кВт?год/т |
|---|---|
| 0 | 0 |

Сушарка: Кількість: 1

| id | Підприємство виробник, держава | Марка машини |
|---|---|---|
| 2 | ВАТ "Карлівський машзавод", Україна | А1-ДСП-10 |

Машина первинного очищення: Кількість: 1

| id | Підприємство виробник, держава | Марка машини |
|---|---|---|
| 18 | Фірма "RIELA", Німеччина | Prof Seed 1006 2A |

Площа зерноскладу, м$^2$: 4559.22

Місткість бункера-компенсатора, т: 338.4909

**Figure-7.** General view of the output interface of a computer program for calculating the composition of the system of post-harvest grain processing machines.

If necessary, the user can print the results of the calculation by clicking on the "Print calculation results" button. The tabular data of pre-cleaning machines and their number, tabular data of dryers and their number, tabular data of primary cleaning machines and their number, calculated area of grain storage and capacity of the compensator hopper are displayed in the column.

Thus, the developed program for the effective functioning of technological systems for servicing multi-item flows of grain crops allows the designer of grain cleaning points, knowing the parameters of harvesting systems and parameters of incoming grain flow, quickly decide on the composition and parameters of postharvest machines.

## CONCLUSIONS

During the substantiation of the rational structure with the help of the developed software it is possible to obtain information about the structure of the reduced operating costs of grain production on electricity and capital efficiency.

Developed mathematical models of technological efficiency and total cost ratio include parameters of service systems and machines in the form of a mathematical set of parameters that allows them to be applied to any technological system of postharvest processing and determine the direction of project improvement in developing technological systems of postharvest processing.

Experimental verification of statistical models for determining the quality of grain flow from weather conditions showed that statistical models describe the process with satisfactory reliability and can be used to predict the characteristics of grain flow.

The application software developed during the research allows the user to quickly select the necessary equipment for post-harvest processing of grain and calculate its parameters using a database and has great prospects for use.

Structural and functional mathematical models have been developed that allow to reproduce all the main technological options, the interaction of elements and subsystems, to take into account the stochastic nature of the external environment.

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