Adjustment of the harvesting and transport groups’ composition for grain harvesting in real time

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Abstract. An algorithm and a system for the operational correction of the harvesting and transport complex composition for harvesting grain crops are developed. The system allows to adjust the structure of machine groups for harvesting, transhipment and transportation of grain promptly. The system is based on the machine conditions’ real-time monitoring and the transfer of control actions through a single control centre. The use of such organization of work reduces unproductive downtime of machines. As a result, the cost is reduced and the productivity of harvesting and transport groups is growing.

1. Introduction
There are several basic technologies for harvesting grain and transporting it from combines that are used around the world. The difference in technology is characterized by the rigidity degree of binding different machines to each other. The decrease in the binding rigidity is aimed at reducing the fluctuations’ influence in the cycle time of each complex machine during the operation with other machines. However, these machines interact with each other and the influence is preserved. As a result, there is an imbalance in the harvesting-transport groups’ various components capacities. To eliminate this imbalance or mitigate it, a system of operational adjustment for the harvesting and transport groups structure is proposed.

2. Problem analysis
For the correct analysis of the problem and identifying the reserves for its solution, it is necessary to consider the main technologies for harvesting cereal crops, as well as the features of the selected crops. In addition, information on the modern development of engineering and technology in the field of geolocation and real-time information transfer will be required. These components form the premises for the harvesting and transport groups’ composition operational adjustment system development.

2.1. The first prerequisite to the system development
Cereal crops include winter and spring wheat, winter and spring barley, rye, oats, triticale and rice. These crops are allocated in a separate group since the means and equipment for their harvesting are almost identical, unlike, for example, corn, sunflower or sainfoin that require special reapers. Consequently, these cereals are subject to harvest as they are technically mature. Some of these crops are characterized by possible simultaneous ripening times depending on the region, climatic zone and weather conditions during the growing season. In this case, separate machines may migrate between
harvesting and transport groups, if such a need arises. Such movements may be undesirable only in the case of seed material harvesting, since the necessary varietal purity may be violated here. However, this kind of harvesting makes up a smaller part of the total work volume and is carried out at the specialized agricultural enterprises of the seed-growing direction. Most of the cereal grains are harvested for food purposes, and the admixture of individual residual grains of another variety or culture does not matter.

The potential possibility of such movements for individual machines between the groups during the grain harvesting process is the first message to develop a system of operational adjustment and management of the harvesting and transport groups composition.

2.2. The second message to the system development
The existing technologies for harvesting and transport groups work in harvesting grain crops are considered and their shortcomings, resources to increase productivity by reducing machine downtime are identified. The following technologies are used in the world:
1) direct transportation from combines;
2) with the use of interchangeable semi-trailers and the use of tractors in the field;
3) using storage bunkers equipped with a transshipment mechanism;
4) container technology;
5) with threshing grain in the permanent establishment (after combing the reapers or mowers).

These technologies have different applicability depending on the country. Patterns 1 and 2 are common in Russia, patterns 2 and 3 in the USA and Canada, and pattern 4 in the UK. Pattern 5 is not prevailing and is used as an alternative to others.

Regardless of the scheme used, the composition (quantitative and branded) is determined based on the required performance of the group output link, as well as the adjacent links’ performance equality. Since absolute synchronization of the individual links performance is impossible, the performance level of the next link is provided with a margin of about 5-10% compared to the previous one. This ensures the uninterrupted operation of production chains on the way grain makes from the field to the unloading place.

The presence of such productivity reserves is the second prerequisite to the operational adjustment and management system development for the harvesting and transport groups’ composition.

2.3. The third prerequisite to the system development
The modern development of engineering and technology allows determining the coordinates of any machine with the required accuracy. Also, modern technical means allow capturing and transmitting information about the current state of each machine. In addition, they allow transferring information to a machine containing a control action.

This is the third prerequisite to the operational adjustment and management system development for the harvesting and transport groups’ composition.

2.4. Publications analysis on this issue
The analysis of the existing scientific work in the field of operational adjustment and management of the harvesting and transport groups’ composition has shown that this issue is insufficiently studied in world practice.

The greatest study in the field relating to this topic was discovered in the works of Tikhonovsky [1]. This author examined the structure for harvesting and transporting grain systems from combines in Western Siberia. He investigated the downtime effect of various harvesting and transport system elements on grain harvesting. Also, in his works, the possibility of using the systems for global positioning of machines is mentioned. However, this author reduces the work of a complex system, such as harvesting and transport groups and grain processing points after grain harvesting to classical queueing systems. Moreover, it uses the simplest laws of the requirements’ receipt and servicing in the
system (Markov random processes, Poisson and exponential distribution). The model which is implemented by the author as a computer program is also based on this.

But there is a fairly large number of studies [2, 3, 4, 5], including those carried out by the author of this article, in which the shortcomings of the queuing systems’ theory and the inferiority of this approach with respect to complex systems, which include harvesting transport complex for harvesting grain crops.

In other studies analyzed [6, 7, 8, 9, 10], the positioning of machines, the impact of downtime on productivity, the difference in harvesting technologies are mentioned, but a complete system for operational adjustment and management of the harvesting and transport groups composition in these studies was not built.

3. Research, modelling, production verification
To build a model for the harvesting and transport groups functioning and control their composition, it was decided to apply the simulation modeling approach, which allows reproducing various situations with high accuracy. But this approach application is based on information about the random components’ distribution laws for the machines and processes operation.

3.1. Research
In order to form a model based on simulation modeling, it is necessary to conduct the studies that establish the distribution laws of random components for technological machines’ functioning processes of harvesting and transport groups.

These studies were carried out at the agricultural enterprises of the Zernograd and Remontensky districts in Rostov region, as well as in Oryol region. The studies were carried out on various harvesting technologies, while the agricultural enterprises were in various soil and climatic conditions, which made it possible to obtain the most reliable data with high reproducibility.

As a result of the obtained timing data statistical processing, it was possible to determine the distribution laws of random components for the harvesting and transport groups processes (an example is presented in Figure 1)

![Figure 1](image_url)

Figure 1. The unloading time approximation for the combine by the Weibull distribution law

3.2. Modelling
Based on the statistical processing results of timing studies’ results, a mathematical model that allows statistical experiments using various grain harvesting technologies, is obtained.

This model allows testing hypotheses before conducting the field tests. To assess its adequacy to real systems, a comparison was made of simulation data and timing observations. It was found that the
Data convergence is high enough, which allows concluding that this model is adequate and possible for the statistical research (Figure 2).

![Graph showing real data and model data comparison](image)

**Figure 2.** Comparison of the real and simulated harvesting and transport group performance

Further, the model was supplemented by the operational management functioning and adjustment of the harvesting and transport groups’ composition. This model made it possible to study the proposed system’s operation before purchasing and installing real equipment, which made it possible to determine the best system parameters without unproductive costs. This makes it possible to avoid errors in the real harvesting process. The block diagram of this model (Figure 3) shows the logic of its operation and data processing. On its basis, a computer program that gives recommendations on the required control actions, was created. With its help, the system dispatcher makes a decision on adjusting the structure of the harvesting and transport groups and gives commands to machine operators about their movement between groups.

The type of control effect depends on the harvesting technology used, the harvesting and transport groups composition. The program allows making a choice of the technology used. Depending on the machines’ composition, the adjustment can be made by moving an excessively idle vehicle between the harvesting and transport groups, or by adding a vehicle from the reserve, for example, from the grain technologically involved in post-harvest processing. It is similar to the combine and storage hopper (in the case of using the technology with such units).
Figure 3. The block diagram of the operational adjustment program for the harvesting and transport groups structure during grain harvesting.
3.3. Production check

After system research and development on a simulation model, its production testing was carried out at the real agricultural enterprises in Rostov region and Oryol region, where timekeeping studies had previously been conducted.

In the process of testing, one drawback was revealed in the initial assumptions for the system development. Since for the operation of information transfer systems between machine operators and the dispatcher a smartphone is used, it is necessary to provide stable cellular coverage of the territories where this work is carried out, the use of these systems is limited. In a number of areas, such as the Remontnensky district of Rostov Region, such a connection is not well established, and in some places, it is completely absent. For such agricultural enterprises, a solution to this problem was found in the use of VHF radio stations.

As a result, the system is as follows.

In the simultaneous operation process of the harvesting and transport groups on several fields of the farm, the dispatcher receives data on the location and condition of the machines through the GPS-GLONNAS satellite navigation system and in the form of messages from smartphones or radio stations of machine operators (for example, about long downtimes or machine breakdowns). The data are entered into the computer program, and it gives recommendations on the required movement of machines between groups, or on the need to attract additional machines from the reserve (if it is provided).

The dispatcher transmits movement instructions to the machine operators. Then the machine operators follow the corrective instructions and inform the dispatcher about the implementation. The dispatcher enters the data about the new system configuration into the program and checks the compliance of the parameters issued by the model and those in real conditions.

As a result of the production audit, the data on the effectiveness of the operational adjustment system at various transportation distances from the field to the current using various technologies are obtained. Here is the effect of the operational adjustment system on productivity when using the direct transportation scheme (Figure 4) and the scheme using storage bins (Figure 5).

![Figure 4. Comparison of the direct shipping scheme with and without a system performance](image-url)
Figure 5. Comparison of the real and simulated harvesting and transport group performance

Production testing has shown the effectiveness of the proposed system for the operational adjustment of the harvesting and transport groups’ composition. As it can be seen from Figures 4 and 5, the system gave an increase in productivity to a greater extent when using the direct transportation scheme and when using the scheme with a storage hopper the increase is also noticeable, but it is much smaller. This can be explained by the presence of more rigid connections between the vehicles during direct transportation, and consequently, a larger supply of vehicles in terms of productivity. The proposed system allows these reserves to operate. The storage hopper scheme itself already optimizes these performance margins by mitigating the connection rigidity between the machines.

A detailed analysis of the results and findings is given in summary.

4. Summary
The production audit of the operational adjustment system for the harvesting and transport complex composition showed that the best results are achieved when the distance between the adjacent harvesting and transport groups is within 6 kilometers.

The average productivity gained due to the machine downtime reduction when using this system is 10-12%, which reduces the harvesting time by 1-2 days.

The best efficiency of the system is achieved when the distance between the field and the grain current is not more than 20 kilometers. For large distances, the efficiency system is reduced to 3-5%.

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