

# Improving the Efficiency of Harvesting and Transportation of Grain Crops

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**Abstract:** The article provides a rationale for an improved technological process for transporting grain from combine harvesters (GH) by a semi-trailer-dump truck (STT), combined for field work with a tractor and a saddle trailer. The study of the most common grain transshipment technology showed a number of its shortcomings: - the need for timely access to trailers-loaders of trucks causes their downtime (up to 30% of the shift time); - the use of dump semi-trailers in the standard version is unacceptable due to the strong overconsolidation of the soil by their wheels. As a result of the analysis, it was found that the minimum specific duration of harvesting and transport work in the field is achieved when using a semi-trailer-dump truck with a tractor with minimal time spent on the formation of transport units. using a semi-automatic fifth wheel coupling. We offer a technical solution, which consists in the temporary redistribution of the grain mass in the back of the STT during its transportation in the field. At the same time, the STT rear wheels are partially unloaded and do not compact the soil, and the saddle trailer, equipped with wide-profile low-pressure tires, takes on additional load without significant soil compaction. The use of STT, operating in a semi-shuttle way in two parts: in the field and on the road section, increases the productivity of the harvesting and transport complex by 1.5 times.

**Keywords:** Grain Transportation, Combine Harvesters, Semitrailer Movement, Semi-Trailer Tipper, Trailing Semi-Trailer, Productivity

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## 1. Introduction

The article substantiates the advanced technological process of grain transportation from grain harvesters (GH) by a semi-trailer dump truck (STT) with a tractor and a truck trailer (TT). One of the main reserves for increasing the productivity of the combine is to increase the utilization of its time of change through the use of reloading technology based on interoperable compensators - trailer-reloader (TR) brands PBN-30, PBN-40, PBN-50, Kinze 850 and others, and trucks. The disadvantage of this technology is the significant downtime of vehicles. The use of dump semi-trailers in the standard version is unacceptable due to the strong overconsolidation of the soil by their wheels.

A comparative analysis of different technological schemes

of harvester work and vehicles showed that the minimum specific duration of harvesting and transport operations is achieved when using the STT with a tractor to work in the field with minimal time spent on the formation of transport units using a semi-automatic fifth wheel coupling. STTs are used as reversible, which allows to organize continuous operation of tractors in the areas "GH - field edge" and "field edge - grain receiving point (GRP)", where possible downtime TT is replaced by downtime only STT, which if necessary complement technological units.

We have proposed a technical solution that contains a temporary redistribution of the mass of grain in the body of the STT by loading it into the front of the body. At the same time, the rear wheels of the STT are partially unloaded and do not over-compact the soil, and the trailer mounted trailer, equipped with wide-profile low-pressure tires, absorbs

additional load without significant soil compaction.

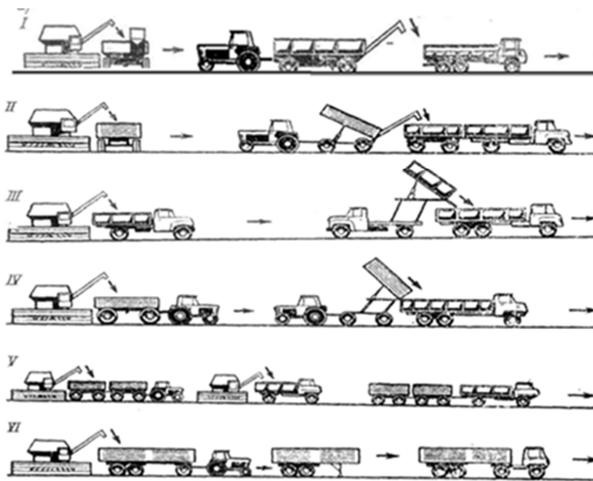
Theoretical analysis of the rhythm of grain movement by individual technological units of the harvesting and transport complex allowed to determine the analytical dependences of the main parameters of these units on the productivity of the GH and the volume of its hopper, nominal capacity of the STT, duration of the use of semi-shuttle STTs in two parts: in the field and on the road, increases productivity (average production) of TT by 1.5 times, as well as eliminates the cost of specialized trailers, reloaders and double grain overload.

## 2. Method

### 2.1. Analysis of Technological Schemes of Grain Transportation from Combines

Introduction into the technological line between combine harvesters and vehicles during the harvesting of the intermediate link - interoperational compensator can significantly, compared to direct road transport of grain, reduce the time of harvesting and transport operations and generally increase the efficiency of the harvesting complex. LC while waiting for grain to be unloaded from the hopper.

The role of such mobile compensators is performed by specialized tractor trailers-reloaders (TR), another name - reloading storage bunkers - PBN, PNB with screw devices for unloading, as well as automobile and tractor universal trailers and semi-trailers [1, 2] (Figure 1).



**Figure 1.** Schemes of grain transportation from combines with the use of mobile interoperative compensators: I-II - specialized tractor trailers-reloaders; III - IV - dump trucks and tractor trailers with pre-lifting of the body; V-VI - tractor trailers and semi-trailers with rolling trailers.

The increase in the productivity of GHs is due to the reduction of their downtime to wait for the unloading of bunkers. The use of TR with wide-profile low-pressure tires reduces soil compaction and prevents heavy trucks from entering the field. The analysis of the technological scheme of grain transportation from combines with the use of PP [3, 6-9, 12] permits also reveals a number of shortcomings that prevent the achievement of the maximum effect, which

include the following:

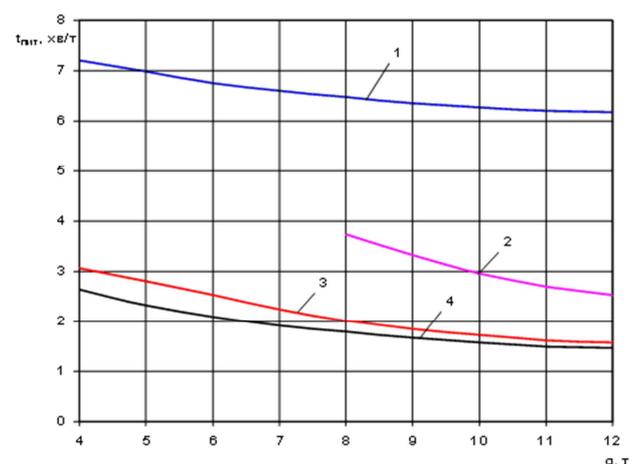
- 1) the need for timely access of the TT to the TR causes downtime TT (up to 30% of the time of change [3]);
- 2) the need for additional operations (compared to the technology of direct transport) - reloading of grain from one vehicle (trailer-reloader) to another (heavy-duty TT). Such overloading of grain with the use of screw working bodies requires additional energy, time and does not exclude mechanical damage to the grain.

### 2.2. Analysis of Recent Research

In order to find rational schemes for transporting crop products from combines, we used data from the analysis of compensators [2, 7]. Since it is possible to use vehicles (vehicles) of different loads for grain transportation, it is expedient to determine the specific duration of harvesting and transport operations (SDO) for comparative evaluation, which is attributed to 1 ton of transported grain. Figure 2 presents the obtained dependences of SDO on the load capacity of the vehicle. The introduction of an intermediate link in the technological line between combines and road vehicles allows to significantly (2-3 times) reduce the duration of the SDO compared to direct road transport.

Production implementation of scheme VI with a minimum specific duration of SDO can be achieved by eliminating soil compaction by the wheels of the STT and due to the rational time spent on uncoupling-coupling of the STT. The semi-trailer in combination with a tractor can perform the function of a mobile compensator - instead of trailers PBN-30, PBN-40, Kinze 850 and others, which will eliminate the cost of purchasing specialized equipment.

At the same time, the vehicles are used as circulating STT, which allows to organize the continuous operation of tractors on the site "Field edge - GRP", where possible downtime TT are replaced by downtime only STT, which, if necessary, complement the technological units.



**Figure 2.** Dependence of the specific duration of collection and transport operations on the load of vehicles for different technological schemes: 1 - direct road transport; 2 - transportation according to scheme V; 3 - transportation under schemes I, II, III, IV; 4 - transportation according to scheme VI.

**2.3. The Purpose of Research**

The aim of the research is to increase the efficiency of the transport and production process during grain harvesting by using a dump semi-trailer as an interoperative compensator in combination with a tractor for field work and with a car or tractor for road transport. To achieve this goal it is necessary to solve the following tasks: 1) to conduct a theoretical analysis of the transport and production process during grain harvesting with some improvement, 2) to calculate the parameters of harvester-transport machine complex (HTC) according to the analysis data.

The object of research is the technological process and methods of transporting grain from combines.. The subject of the study is the regularities of the harvesting and transport process.

**3. Research Results**

Taking into account the positive evaluation indicators and the availability of certain technical support, which allows to reduce the duration of uncoupling-coupling of the semi-trailer from tractors, we adopted for further research scheme VI with some improvement.

Harvester and transport complex (HTC) contains a group of GHs and tractor trains (Figure 3), which includes a tractor, semi-trailer and trailer PSP-20 (Figures 4 and 5).



Figure 3. Scheme of a tractor road train with PSP-20.

Saddle trailer PSP-20 (Table 1), which connects the tractor (tractor) and the state of the train, equipped with a special hitch (SH), also contains a drawbar for connection to the tractor and running gear, provides the ability to rotate the semi-trailer relative to the tractor around the axis of the coupling pin in the horizontal plane.



Figure 4. PSP-20 saddle trailer.

Table 1. Technical characteristics PSP-20.

Length, mm	4 900
Width, mm	2 400
Height, mm	1 150
Saddle height (regulated hydraulic cylinders), mm	1 250 - 1 400
Maximum load on the saddle, kg	20 000

Semi-trailers with tractors are used consistently in two technological links: for work in the field "GH - STT - tractor" and for transportation on the road from the field to GRP - "STT - road tractor (TT - car or tractor)" (Figures 5 and 6). In the first link, the STT functions as an interoperable compensator, which is loaded with grain from the hoppers of at least two combines.

After filling with grain, the STT is transported to the edge of the field, uncoupled and replaced with an empty one for further work in the field, and loaded STTs are transported by road tractors to GRP, where they are unloaded and returned empty to the field edge. The use of a trailer with special semi-automatic hitch (SH) allows to reduce the duration of time for hitching (uncoupling - coupling) STT.

In order to reduce soil compaction, we analyzed the results of soil compaction studies by the wheels of cars [10, 11, 13-15] and proposed a technical solution that contains a temporary redistribution of grain mass in the body of a semi-trailer during its transportation in the field [4]. Taking into account the fact (to see Figure 3) that the STT body has two generalized wheel bearings on the soil: a rear three (two) axle bogie and the front two-axle in the form of a rolling semi-trailer PSP-20, which is equipped with wide-profile low-pressure tires, it is advisable to load grain from the combine bunker into the front part of the semi-trailer body.



Figure 5. NPS 3250 grain truck semi-trailer with PSP-20 saddle trailer for work with a tractor in the field.

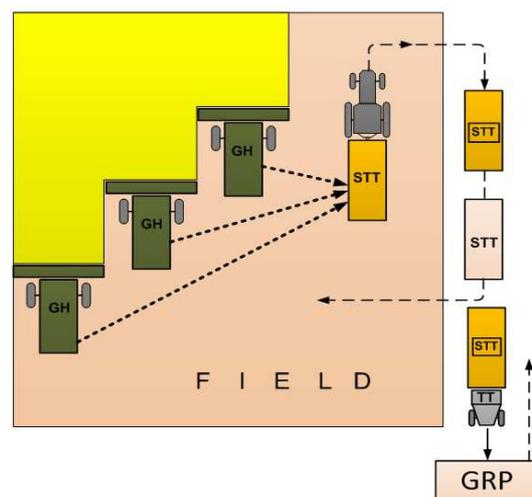


Figure 6. Technological scheme of grain loading from combines and transportation with the use of state of emergency: GH - combine harvester; STT - semi-trailer (empty and loaded); TT - truck or tractor; GRP is a grain receiving point.

This creates such a distribution of pressure on the ground when the tractor road train with PSP-20 moves across the field, in which the rear wheels of the STT will be partially unloaded and do not compact the soil, and the rolling saddle trailer takes on additional load and, thanks to wide-profile low-pressure tires, does not significantly compact the soil. According to preliminary calculations when using a semi-trailer NPS 3250 grain truck with a capacity of 25 tons (board height 2.1 m, body length 6.3 m) loading grain into the front of the body can reduce the load on the rear wheels to 5 tons with loading SPS-20 up to 20 tons.

After transportation to the edge of the field and hitching for transportation on the road, the body of the STT with the help of a hydraulic cylinder is tilted to the horizon for uniform distribution of grain under the action of gravity on the bottom of the body. The technical result provided by the above set of features is to reduce the pressure on the ground of the rear wheels to the allowable agricultural requirements.

To calculate the operating parameters of HTC in [1] considered the rhythm of the first technological link: "GH - semi-trailer dump truck with tractor" and determined the number STT  $n_{II1}$ , which serve a group of combines  $m_K$  according to the formula:

$$n_{II1} = \text{CEILING} \frac{m_K}{m_{KH}}, \text{ units} \quad (1)$$

where CEILING is a function that returns the nearest larger integer value;

$m_K$  - total number of combines in the group;

$m_{KH}$  - the number of combines serviced by one of STT.

To determine the number of GHs served by the semi-trailer, the technological chain of interaction of GHs and STTs is considered. After loading the first grain hopper from the GH, the STT moves in turn to the next combines serviced by it, loads with grain, goes to the edge of the field, uncouples the STT and attaches an empty STT and returns to the first unloaded GH for the next loading. The number of units of

$m_{KH}$  combines serviced by one STT is defined as [1, 5]:

$$m_{KH} = \text{INT}(\omega_K d_B (\frac{9,25}{W_{KP}} + \frac{8,33}{W_{IIIK}}) - 8,33 t_{BII} - 0,667) \text{ units}, \quad (2)$$

where INT is the function that returns the nearest least integer value;

$W_{KP}$  - productivity of GH for 1 hour of the main time of its work, t/h;

$W_{IIIK}$  - productivity of the unloading auger GH for 1 hour of the basic time, t/h;

$t_{B-II}$  - average duration of hopping (uncoupling - coupling) STT;

$\omega_K$  — volume of the combine hopper,  $m^3$ ;

$d_b$  — volume mass of grain, t/ $m^3$ .

On the basis of this equation, the graphical dependence of  $m_{KH}$  on  $W_{KP}$  and  $\omega_K$  is constructed (Figure 7).

The analysis of the given dependences shows that the capacity of the bunker of GH is the essential factor influencing quantity of grain loaded for one working cycle in STT. The number of  $m_{KH}$  combines serviced by one STT increases due to the increase in the volume of GH bunkers. Thus, the amount of GH with  $W_{KP} = 9.5$  t/h, which can be serviced by one STT, increases from 1 to 6 units with increasing bunker capacity from 3 to 11  $m^3$ . For GHs with a constant hopper volume, an increase in  $m_{KH}$  is achieved while decreasing the  $W_{KP}$  performance.

The choice of loading capacity of STT is carried out, proceeding from a condition of multiplicity of loading capacity of a body of STT and the bunker of GH:

$$q_H \geq q_B \rho \tau, \quad (3)$$

where  $q_H$  - the rated capacity of the selected state of STT;

$\rho$  - the number of bunkers GH, which will fit in the body of the STT;

$q_B$  - the mass of grain contained in the hopper GH.

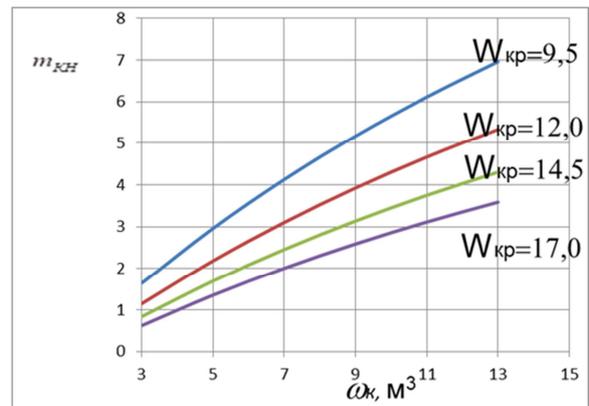


Figure 7. Dependence of the number of  $m_{KH}$  combines, which are serviced by one STT, on the capacity of the bunker GH for a certain productivity  $W_{KP} = 9.5; 12.0; 14.5$  and  $17$  t/h.

The second condition for choosing the brand of STT: the capacity of the body of the selected STT must be a multiple of the capacity of the combine

$$\omega_H \geq \omega_K \rho. \quad (4)$$

Based on expressions (2-4), choose the appropriate load capacity brand of STT.

The total rational amount of GH that works in a particular HTC is defined as

$$m_K = m_{KH} \cdot n_{II1} \text{ units.}, \quad (5)$$

where  $n_{II1}$  - the number of STT with a tractor in HTC.

The current condition of the second link "STT - TT" is considered by us and it has the following form:

$$R_2 = I_2, \quad (6)$$

where  $R_2$  - the working rhythm of the STTs with tractors, hours;  $I_2$  - interval of coming, hours.

The rhythm of work of the group of STT with tractors in the field is

$$R_2 = \frac{0,08 + 0,12\rho + 2t_{B-\Pi}}{n_{\Pi 1}} \text{ h.} \tag{7}$$

TT coming interval:

$$I_2 = \frac{t_{OE}}{n_{AT}} = \frac{2t_{B-\Pi} + \frac{2l_{ij}}{v_T} + t_{BIB}}{n_{AT}} \text{ h,} \tag{8}$$

where  $t_{OE} = 2t_{B-\Pi} + \frac{2l_{ij}}{v_T} + t_{BIB}$  - the duration of the turnover

of TT, hours;  $n_{AT}$  - number of truck tractors, units;  $t_{BIB}$  — the duration of the STT at the unloading point, depending on the level of mechanization and organization of work, hours;  $l_{ij}$  - the distance of grain transportation from the field (point i) to the point of unloading GRP (point j), km;

$v_T$  — average technical speed of TT.

After substituting the values from (7 and 8) to (6) and the corresponding transformation, we obtain the number of tractors for transporting grain in GRP from the equation:

$$n_{AT} = \text{CEILING} \frac{n_{\Pi 1} (2t_{B-\Pi} + \frac{2l_{ij}}{v_T} + t_{BIB})}{0,08 + 0,12\rho + t_{B-\Pi}} \text{ units.} \tag{9}$$

The total number of STTs required for the operation of HTC (moving, waiting to be hitched and under load) is equal to the number of STTs operating in both links and is determined by the formula [2]:

$$\Pi = n_{\Pi 1} + n_{AT} + n_3 \text{ units,} \tag{10}$$

where  $n_3$  - the additional number of STT, which takes into account the stochasticity of their movement on the road and is necessary for use during accidental delay of TT. This amount is determined experimentally during the operation of HTC and is placed on the edge of the field.

To quantify the transportation of grain from the field, we use the indicator of productivity of vehicles for the working day

$$W_{W\Delta} = \frac{Q_{W\Delta} \cdot l_{ij}}{n_{TT}} \text{ t} \cdot \text{ km/working day,} \tag{11}$$

where -  $Q_{W\Delta}$  the amount of grain that is collected and transported by the harvesting and transport complex for 1 working day.

Thus, on the basis of the theoretical analysis of the work of the harvesting and transport complex of machines with circulating semi-trailers dump trucks, the method of determining the composition of HTC is substantiated.

Let's compare this variant of grain harvesting and transportation technology with the most advanced in terms of the pace of implementation in Ukraine reloading technology with the use of reloading trailers in the following example. Consider the application of technological schemes for harvesting grain from an area of 2100 ha by John Deere 9780 combine harvesters and grain transportation to the receiving point ( $W_{KP} = 15.3 \text{ t/h}$ ,  $d_B = 0.75 \text{ t/m}^3$ , yield  $U = 6 \text{ t/ha}$ , number of working days for harvesting grain according to agricultural requirements  $D_w = 10$  days, shift duration is 8 hours, coefficient of variability of shift  $K_s = 1.5$ , distance of grain transportation  $l_{ij} = 8 \text{ km}$ ,  $v_T = 40 \text{ km/h}$ ), transport composition is shown in Table 2.

### 4. Discussion of the Results

Calculations of parameters for the technology with the use of STT were carried out in accordance with the methodology presented in this paper. For reloading technology, the calculations were performed according to the methodology contained in [1]. The results of the calculations are presented in Table 2.

From the presented data it is seen that the use of STT, which work on semi-shuttle traffic in two parts: in the field and on the road, provides an increase in productivity (average output) TT 1.5 times from 210 to 315 t/working day by reducing their downtime. This allows to reduce their quantitative composition in HTC accordingly.

**Table 2.** Comparative technical-operational and quantitative indicators of HTC work.

Technological options	Machines of the harvesting and transport complex						Average production of one TT, t/working.day.
	GH John Deere 9780	III Kinze 850	STT NP grain truck 3250	John Deere 8440 tractor	Iveco Trakker AT260T44 tractor	Kamaz 6520 AGRO	
Reloading technological scheme	9	3	-	3	-	6	210
Transportation by semi-trailers	9	-	7	3	4	3	315

### 5. Conclusions

- 1) Temporary redistribution of grain mass in body NP

during its transportation in the field by a tractor and application of the PSP-20 saddle trailer with wide-profile low-pressure tires allows to reduce soil compaction.

2) Improvement of technological process of grain transportation from combines by semi-trailers by dump trucks is substantiated and the corresponding technique of definition of rational parameters of a complex at application in the field of saddle trailers PSP-20 is specified. The use of semi-shuttle vehicles in two links: in the field and on the road, provides an increase in productivity (average production) of blood pressure by 1.5 times from 210 to 315 t/wd. by reducing their downtime, which allows to reduce their number in the HTC.

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