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Structural Analysis of the Operations and Time for Tank Unloading of Grain Harvesters

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Abstract: ***The reduction of the grain tank unloading time is a key factor for increasing the combine performance when unloading at a standstill. The paper analyzes four variants of grain tank unloading that are applicable in Bulgaria. For each of the four variants, it determines the time algorithms of the operations carried out by the vehicle and the combine operators. These algorithms are used to optimize the unloading time and, respectively, to increase the combine performance when unloading at a standstill.***

Keywords: combines, grain tank unloading time, performance, time algorithm, grain tank full level indicator, coordination between a harvester and a vehicle during unloading.

1. Introduction

The grain harvest is connected with organizing people, combines and vehicles, and should be completed in a short period so as to avoid yield losses as a result of the extended period of harvesting. As a rule, these losses are bigger in adverse weather conditions. Sometimes the difference between the biological and the actual harvested yield reaches up to 30-40% [1]. To meet the short deadlines for harvesting, many farmers buy more expensive combines that have higher theoretical performance. However, this does not automatically lead to a higher actual performance [2]. A successful harvesting campaign depends largely on the effective use of these machines. The key indicator for their efficiency is their actual performance. However, performance depends not only on the technical characteristics of the machine itself, but also on many other factors connected with the overall harvesting process. One such factor is the way the grain tank is unloaded. Grain tank unloading in Bulgaria is widely carried out when the combine is at a standstill.

The determination of the combine performance during unloading at a standstill is calculated in accordance with the following equation [3]:

$$W_c = \frac{1}{\dfrac{10}{B.\beta.v_p.\tau.D} + \dfrac{t_p}{V_t.\rho}}, \quad \frac{t}{h} \tag{1}$$

where *Wc* is the hourly performance during grain tank unloading at a standstill, t/h;
B – working width of the header, m;
β – utilization coefficient of working width;
v_p – working speed, km/h;
τ – coefficient of use of working time which does not include the grain tank unloading time, i.e. this coefficient is absolutely the same as the one used during unloading of the combine in motion;
D – yield, t/ha;
t_p – grain tank unloading time, h;
V_t – grain tank capacity, m³;
ρ – grain bulk density, t/m³.

The above equation shows that the needed unloading time of each grain tank in the vehicle decreases the combine performance. In fact, this is the time when the combine does not harvest and is a sum of the times of the operations related to unloading. The duration of the grain tank discharge operation is between 42.5 and 55 minutes, which is measured for five different high-performance combines that discharge 10,000 bushels of wheat (approximately 280 tons) [4].

The grain tank unloading time at a standstill also depends on the duration of the operations (activities) carried out by the vehicle, for example, from the time at which the combine's signalization for a full tank is present until the vehicle's start, and from the time at which the vehicle starts until its arrival under the combine unloading auger. These times vary considerably since they are largely affected by the overall organization of the harvesting process. It was determined that if well organized, the time during which the combine waits for the vehicle was 9.25 minutes within a day, while it was 54.9 min if bad organized [5].

In order to improve the combine performance, different technical means are used to optimize the operations connected with grain tank unloading and reducing the overall unloading time:

- telematics systems to obtain information about the duration of the unloading idle periods - AgCommand Advanced; CLAAS Telematics; JDLink Ultimate; AFS Connect Executive [6];
- augers with a high unloading speed of up to 160 l/s;
- full grain tank sensor for powering both the indicator light inside the cab and the rotating beacon for warning the vehicle simultaneously;
- two stage grain tank level indication (with two sensors). A rotating beacon switches on at first stage to warn the vehicle. During the second stage, the grain tank is full, and the indicator inside the cab warns the operator to stop the combine. The vehicle should arrive to the combine;

- semi-automatic closing/opening of the unloading auger by momentarily pressing the button. Meanwhile, the operator is able to carry out other functions such as harvesting.

The combine performance during grain tank unloading at a standstill is also affected by the tank capacity, according to equation (1). In a study on this matter, [3] the chart on Figure 1 shows the effect of the tank capacity on the hourly performance *Wc = f(Vt)* of two combines with different threshing capacities (small or high) (lines 2). This performance is compared to the performance during unloading in motion (lines 1), i.e. when not wasting time for stopping and unloading. If the difference between the grain tank unloading performance in motion and at a standstill is shown in percentages, then these percentages will indicate the relative proportion of time when the combine stops for unloading to the total working time. Moreover, the figure shows that the grain tank unloading time reduces the performance significantly, especially in machines with small grain tank capacity.

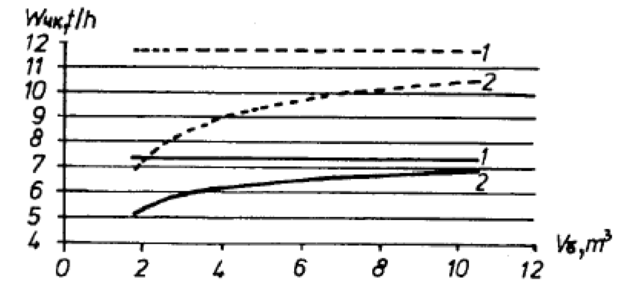

Figure 1: Combine hourly performance according to the grain tank capacity during unloading in motion (1) and at a standstill (2).

Reducing the unloading time is a key factor for increasing the combine performance during unloading at a standstill. To optimize this time it is essential to be aware of the structure and algorithm of operations carried out by the operators of the combines and vehicles.

The objective of this article is to provide a time algorithm of the operations carried out by the operators of the combines and vehicles with different variants for grain tank unloading at a standstill, as well as providing a structural analysis and optimization of the unloading time.

2. Methodology

The study analyzes four variants of grain tank unloading at a standstill that are currently used in Bulgaria:
A – the combines do not have an automatic grain tank level indicator for a full grain tank. This is typical for old machines. The operator observes directly the grain tank fulfillment through a window. After the opening of the auger, the vehicle operator is aware that the combine has stopped for unloading.
B – one stage indicator for a full grain tank. The activation of the combine's rotating beacon is a warning that the vehicle will start to move.
C – two stage indicator. The activation of the rotating beacon (first stage) is a warning that the vehicle will start to move – the grain tank is more than 75% full. During the second stage, the grain tank is full, and the operator stops the combine.
D – with an indicator, however, the combine will move towards the vehicle for unloading outside the field, which is normal during rice harvest.

The vehicles will start to move from the same position upon receiving a full grain tank warning signal, which is valid for all variants. According to the fire safety regulations and the tradition in Bulgaria, this position is at the end of the field, and the logistic support is gathered there – a tractor with a plough, a water tank, etc.

The exact sequence of the operations carried out by the operators of the combines and vehicles has been recorded in each of the variants in two different farms.

The grain tank unloading time, t_p, has been assumed as the time when the combine is at standstill, i.e. the performance is zero.

For the correct interpretation of the results in a graphical presentation of the algorithms, the times of the operations dependent on subjective factors only (the operators) have been assumed to be identical in each of the four variants for combine grain tank unloading. In addition, the time from engaging the unloading auger until its disengagement has been assumed as identical, i.e. the combines have equal unloading speed of the auger and equal grain tank capacity.

3. Results and Discussion

Repetitive operations with the same algorithm have been established for each variant of grain tank unloading. The time algorithms of each variant are shown in Figure 2. The operations are presented with their notional times.

T1 – the time from turning on the combine signalization until stopping the combine. If a combine has a one stage indicator (variant B), the signal will appear before filling up the grain tank, and the combine will continue to work for a while until filling it up completely. After that, it will stop and open the auger. During this operation, the utilization of the entire grain tank capacity cannot be guaranteed, or vice versa – it cannot be guaranteed that the grain tank will not be overfilled, because most of the grain tanks cannot be observed through the window in their upper sections. The operator instinctively determines the duration of the operation. Practically, this is the time to move the vehicle towards the combine, and there are two scenarios – to arrive or not before filling up the grain tank. In the first scenario, the grain tank capacity is not entirely used. However, in the second case, the combine waits for the vehicle in the field. In both scenarios, the performance decreases.

The exact time to top up the grain tank after switching on the signalization can be described with the following equation:

$$t_l = \frac{10.V_l.\rho}{B.\beta.v_p.D}, \quad h \qquad (2)$$

where t_l is the grain tank topping up time after turning on the signalization, h;
V_l – topping up volume, i.e. the grain tank capacity over the signalization level, m³;

The entire grain tank capacity utilization can be guaranteed for two stage indicator combines (variant C) since the second stage signalization (full grain tank) indicates the exact stop. This gives the opportunity to adjust the first stage signalization long before reaching the grain tank full level and to provide time for the vehicle, despite the distance to reach the combine before stopping work.

T2 – the time between stopping the combine and opening the unloading auger. The duration of the operation is minimal and depends both on the driver's "reaction" and the system's technical specifications for opening the unloading auger. If a combine does not have signalization (variant A), the opening of the unloading auger is an indication that the vehicle is moving.

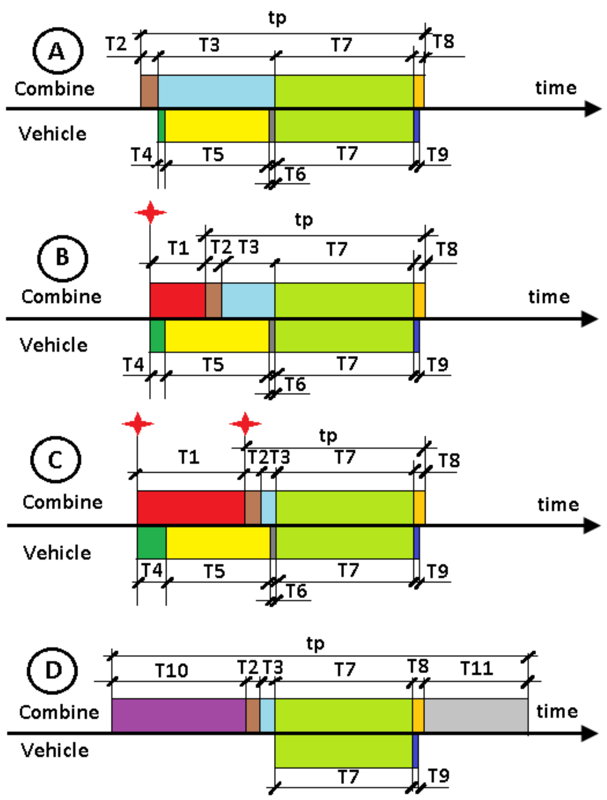

Figure 2: Variants of grain tank unloading at a standstill.

T3 – the time from opening the unloading auger to the moment of its engagement. The duration of this operation in variants A, B and C depends on the position of the vehicle in the field. This is the waiting period (time) during which the vehicle should reach the combine and stand under the unloading auger.

T4 – the time from switching on the combine signalization to the vehicle start. The duration of the operation can be minimal provided that the operator's actions are correct. During observations, we have found that some of the operators leave the vehicle while waiting for the combine signalization, which increases this time. In the two stage indicator variant (variant C), the vehicle operator has more time for reaction, but he or she should coordinate the departure time with the time that is needed to reach the combine.

T5 – the vehicle departure time until its arrival under the unloading auger. The duration is defined by the following equation:

$$T5 = \frac{L}{V_v}, \quad h \qquad (3)$$

where L is the distance traveled by the vehicle from the place of the logistic support to the stopped combine, km;
V_v – the speed of the vehicle, km/h.

T6 – the time from the moment the vehicle stands under the unloading auger to the moment when the grain tank starts unloading. The duration of the operation is minimal and depends on the operator's qualifications.

T7 – the time from engaging the unloading auger to its disengagement. The duration of this operation depends on the combine's technical specifications and is defined by the following equation:

$$T7 = \frac{V_t.\rho}{Q} = \frac{V_t.\rho}{\frac{60.\pi.(d_o^2 - d_i^2).S.n.\rho}{4}} = \frac{4.V_t}{60.\pi.(d_o^2 - d_i^2).S.n}, \quad h \qquad (4)$$

Where Q is the unloading auger performance, kg/h;
d_o – unloading auger diameter, m;
d_i – unloading auger shaft diameter, m;
S – pitch of the auger, m;
n – auger speed, min^{-1}.

T8 – the time from the completion of the unloading to the departure of the combine. This is the time for retraction of the unloading auger.

T9 – the time from completing the unloading to the departure of the vehicle.

T10 - the time it takes the combine to move to the vehicle. The duration of the operation is defined by the following equation:

$$T8 = \frac{L_k}{V_k}, \quad h \qquad (5)$$

where L_k is the distance traveled by the combine to the stopped vehicle located outside the field, km;
V_k – the speed of the combine, km/h.

T11 - the time it takes the combine to move from the vehicle to the point where the harvest should continue. The duration of the operation can also be defined by the equation (5).

The figure shows that in variants A, B and C in which the vehicle is moving towards the combine during unloading, the unloading time tp is defined by the following equation:

$$t_p = T2 + T3 + T7 + T8 \qquad (6)$$

The difference between these variants is in the time duration T3. During T3, the combine does not harvest but waits for the vehicle. This time depends on the duration of operation T5 (from the time the vehicle departs to its arrival under the unloading auger) and operation T4 (the reaction time of the vehicle's operator). Equation (3) indicates that time T5 is defined by the speed of the vehicle, which can be assumed to be constant (movement on stubble), and by the distance L, which is a very variable value. To compare the different variants, we have assumed that the distance *L* is constant. Also, the graphics on Figure 2 indicate that time T3 decreases when time T4 increases. Therefore, the reduction of the unloading time t_p and, respectively, the increase in the combine's performance, can be achieved by providing enough time for the movement of the vehicle to each stop of the combine for unloading. Practically, this can be achieved through an automatic two stage indicator (variant C). If a combine has a one stage indicator (variant B), especially when the distance between the vehicle and the combine is considerable, on the one hand, the time T1 cannot be predicted and the time T3 will be extended. On the other hand, the use of the full grain tank capacity cannot be guaranteed. This leads to a decrease in the performance according to equations (1) and (2).

In variant D (the combine moves towards the vehicle for unloading) the unloading time t_p is the highest because a greater number of operations are being performed:

$$t_p = T10 + T2 + T3 + T7 + T8 + T11 \qquad (7)$$

The unloading time *tp* is not connected with the operation performed by the vehicle.

The time algorithms (Figure 2) give a full idea of the entire process of grain tank unloading. If analyzed, it can be seen that the unloading time t_p might be shortened for all grain tank unloading variants, and, respectively, the performance might be increased.

Figure 3 shows optimized variants of the grain tank unloading process:

Variant A. In this variant the combine operator opens the unloading auger shortly before filling up the grain tank in order to warn in advance the vehicle operator. Here T2 is the time from opening the unloading auger to the point at which the combine stops. The vehicle leaves before the combine stops, which leads to a decrease in the waiting period (time) T3. Moreover, the operator retracts the unloading auger (operation T8) as soon as the combine starts work. The figure shows that in this case the unloading time is $t_p = T3 + T7$. In addition, the time T3 is shorter than the variants on Figure 2.

Variant B and C. The unloading time t_p is also defined by the duration of operations T3 and T7. The opening of the unloading auger is carried out while the combine is working but while the light signalization is working (within operation T1). The significant reduction in the unloading time t_p is due to the duration of operation T3. In variant C, the unloading time t_p is minimal because of the presence of a two stage indicator, which provides enough time for the vehicle to move so that the combine does not wait for it.

Variant D. A decrease in the unloading time t_p ($t_p = T10 + T3 + T7 + T11$) can be achieved by opening (T2) and closing (T8) the unloading auger in motion, respectively, while performing operations T10 and T11.

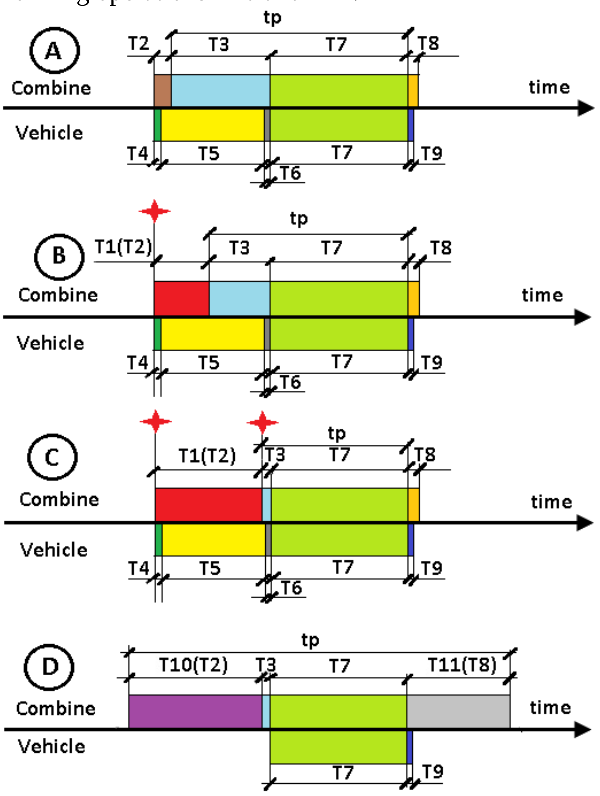

Figure 3: Optimized variants of grain tank unloading.

4. Conclusions

A time algorithm has been established for the operations carried out by the operators of the combines and vehicles with different variants for grain tank unloading at a standstill. The time algorithm analysis can be used for optimizing the unloading time and at the same time for increasing the combine performance during unloading at a standstill.
The structural analysis shows that the unloading time is minimal for a two level signalized combine for a full grain tank. The correct adjustment of the levels for signalization is important for the performance.

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