Analysis of functioning of potato-terminal technological system based on probability-statistical approach

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Abstract. The process of harvesting potatoes with transport support is considered as the functioning of the potato-harvesting technological system consisting of the subsystems: person (P), machine (M), environment (E) and transport (T). The evaluation of the functioning of the system was carried out according to the developed methodology, based on a probabilistic-statistical approach, using the theory of Markov random processes and correlation and regression analysis. The applied method of time-keeping observations of the work of the potato harvester (tractor MTZ-80 + KPK-2-01) made it possible to carry out element-by-element analysis of the temporal characteristics of healthy and inoperable system states. According to the obtained statistics of the balance of the shift time, some regularity is established between the parameters of the system under consideration. The results of the research can be used to identify reserves for improving the functioning of potato technological systems, as well as to develop measures to reduce unproductive time spent in performing operational, technical, technological and organizational operations for harvesting potatoes.

1. Introduction

Mechanized potato harvesting is one of the most complex and time-consuming technological processes and includes the pre-harvest removal of haulm, digging up the tubers with a combine loading them into vehicles or a digger followed by manual picking, transporting potatoes from the field and loading them into the storage bin or unloading them into the receiving bin of the sorting station [1].

The quality of harvesting operations depends on the yield of potatoes, the technical condition of the potato harvesting equipment, the qualification of the machine operator, the organization of harvesting, the soil and climatic conditions of the region. In this regard, it is advisable to consider the process of harvesting potatoes as the functioning of a complex technological system, consisting of elements of different physical nature. Modeling of the functioning of such a system should be carried out on a single methodological basis. As the main approach to the analysis of the efficiency of human-machine systems operating in agricultural processes, a systematic approach using probabilistic and statistical methods [2-6]. Recently, this approach is dominant in the studies of many authors and best reflects the problematic situation - the lack of knowledge about the rational use of technology in the current conditions of its functioning. On its basis, it is possible to determine the reliability of the systems under consideration and find reserves for its increase [7,8], increase the productivity of harvesting [9], improve ways to improve the efficiency of technological systems in crop production [10-13].
The purpose of this work is to improve the reliability of potato harvesting technological system by reducing the unproductive time spent on belonging to the elements of the system, in the performance of technical, technological, operational and organizational functions.

2. Materials and methods
On the basis of the theory of transport processes and systems [14], the technological process of potato harvesting with transport service can be formalized as a system of series-connected elements: "person - P" (mechanic, operator), "machine - M" (tractor, potato harvester); "environment - E" (weather conditions of work, soil, yield, etc.), "transport - T" (vehicles for unloading the combine). The system "person - machine - environment - transport" ("P-M-E-T") works (is in working condition) under the condition of reliability of all its elements and will take an inoperable state when there are "failures" of at least one of its components. The downtime of this system is due to technical, technological, operational, organizational, human, climatic reasons and is random in nature. In this regard, the functioning of such a system can be viewed as a stream of events (working stroke, turning, stopping a potato harvester for various reasons, etc.), occurring alternately one after the other at random points in time.

Let us accept, with some assumption, that this stream of events is the simplest Markov process (process without aftereffects) [15], which is characterized by the probabilities of states: $P(t)$ is the probability of trouble-free operation (reliability) of the system, $q_i(t)$ is the probabilities of the inoperable state of the system for reasons of "failures" of its components, in particular, the probability of system failure for reasons of people ($q_R$), machine ($q_M$), environments ($q_E$), transport ($q_T$). Using the probabilistic-statistical approach, the desired probabilities of the states of the system are determined from the system of Kolmogorov differential equations, which is compiled according to the mnemonic rule [15], according to the system state graph, Figure 1:

$$
\frac{dP(t)}{dt} = -P(t) \sum_{i=1}^{n} \lambda_i + \sum_{i=1}^{n} \mu_i q_i(t), \quad \frac{dq_i(t)}{dt} = \lambda_i P(t) - \mu_i q_i(t),
$$

where $\lambda_i$, $\mu_i$ - respectively the intensity of the occurrence of failures and recovery of system elements.

This system is solved under the condition that sets the probabilities of states at the initial time $t = 0$, and the normalization condition (2)

$$
P(t) + \sum_{i=1}^{n} q_i(t) = 1
$$

If the streams of events that bring the system from state to state are stationary ($\lambda_i, \mu_i =$ const), then the mode of operation of the system is characterized by limiting (final) probabilities (3)

$$
q_i = \lim_{t \to \infty} q_i(t), (i = 1, n).
$$

For the established mode of operation of the potato-harvesting technological system, the probabilities of its states are determined by the formulas [5]:

$$
P = \frac{1}{1 + \frac{\lambda_p}{\mu_p} + \frac{\lambda_M}{\mu_M} + \frac{\lambda_E}{\mu_E} + \frac{\lambda_T}{\mu_T}},
$$

$$
q_R = \frac{\lambda_p}{\mu_p} \cdot P, \quad q_M = \frac{\lambda_M}{\mu_M} \cdot P, \quad q_E = \frac{\lambda_E}{\mu_E} \cdot P, \quad q_T = \frac{\lambda_T}{\mu_T} \cdot P.
$$
Figure 1. Graph of the state of functioning of the potato technological system "P-M-E-T".

The indicated failure rates ($\lambda_i$) and system restorations ($\mu_i$) for the corresponding reasons were determined according to the timing observations according to the formulas:

$$\lambda_i = \frac{1}{t_{fi}}, \mu_i = \frac{1}{t_{resi}},$$  \hspace{1cm} (5)

where, $t_{fi}$, $t_{resi}$ ($i = "P", "M", "E", "T")$ is the average time of occurrence of “failures” and “restores”, of the system working capacity due to any of its components, this was determined from the balance of the working day time [7]:

$$T_{dn} = t_{m-c} + t_{pa} + t_{kk} + t_{fp} + t_{org} + t_{zpr} + t_{to} + t_{nc} + t_{abc} + t_{np} + t_{xp} + t_{E} + t_{r} + t_{r},$$  \hspace{1cm} (6)

where $t_r$, $t_{m-c}$, $t_{pa}$, $t_{kk}$, $t_{fp}$, $t_{org}$, $t_{zpr}$, $t_{to}$, $t_{nc}$, $t_{abc}$, $t_{np}$, $t_{xp}$, $t_{E}$, $t_{r}$ - time spent accordingly: on the movement of the machine operator from the place of rest to the parking lot of the unit, preparation of the unit, quality control of work, the physiological needs of the operator, organizational measures, filling the unit with fuel and lubricants, system maintenance, troubleshooting, system maintenance, eliminating unforeseen violations of the technological process, idle crossings (including turns), system idle time due to meteorological conditions, waiting for the vehicle, the main work (the main pure working time).

The conditional distribution of time balance components (6) as belonging to the elements of the potato-harvesting system is shown in Figure 2.
Figure 2. Schematic conditional distribution of the balance of time for belonging to the elements of the potato harvesting.

The time spent on idle strokes $t_{xp}$ (turns, moving across the field, etc.), considered as system failures, is distributed between the components of the "machine" and "Person" equally. It should be noted that the more detailed the balance $T_{dn}$, the clearer the distribution of time for the corresponding reasons for the inoperable state of the system.

3. Results and discussion

Observations of technological potato-harvesting processes were carried out in accordance with State Standard 28722-90 [16] in the farms of the Irkutsk region in the fields of Oekskoye and OPH "Irkutskoye" during three harvest seasons. At the same time, the uniformity of chronological time series provided observations of the same aggregates for the entire harvest period. The process parameters required for calculating the performance indicators of the potato harvesting system were determined according to the theoretical assumptions.

117 time observations of the work of the potato harvester (MTZ-80 + KPK-2-01) were conducted. Using the standard and specially developed programs, obtained numerical characteristics of time indicators. Thus, the average working day ($T_{dn}$) was 11.01 hours, and the purely working time $t_r = 3.11$ hours. Every day the system was idle for 1.19 hours due to the lack of vehicles for transportation of potatoes and 1.05 hours due to technical malfunctions of the potato harvester. At idle moves from the parking lot to the field and back spent 0.9 hours. The influence of the human factor on system downtime is insignificant and amounted to 0.75 hours. The greatest number of failures of the potato-harvesting technological system for the entire harvest period was due to failures due to the “machine” ($t_M = 42$ hours), which accounted for 26% of the total duration of potato harvesting or 36% of the total number of failures. Of these, the downtime of the "tractor" was 5%, which consisted mainly of the time spent on the shiftless maintenance and the elimination of minor faults in the process. The system downtime due to combine failure was 31%. The most common malfunctions include breakage of conveyors at the combine, escape of chain transmissions and clogging with tops of its working bodies. The second place in the number of system failures was observed because of its component “person” ($t_P = 35$ hours), which accounted for 29% of all failures or 22% of the duration of the harvest period. The influence of the environment on the work of the technological potato-harvesting system was mainly reflected in the form of precipitation and dew. The presence of dew in the morning restrained the
beginning of the work every week, and the precipitation caused the unit to stop until the end of the working day, sometimes more. The total system downtime due to its component “environment” was determined by $t_E = 23$ hours, which accounted for 20% of all failures or 14.5% of seasonal time. System failures due to “transportation” accounted for 15% of the harvest period (13% of all failures). Figure 3 shows a diagram of the distribution of the time of failure of the elements "person", "machine", "environment", "transport" of the potato harvesting technological system.

![Diagram of element failure time potato processing system](image)

**Figure 3.** Diagram of the distribution of element failure time potato processing system "P-M-E-T".

![Dependence of the probability of the system inoperable due to the "machine"](image)

**Figure 4.** Dependence of the probability of the system inoperable due to the "machine" on the duration of its work.

On the basis of the mathematical apparatus of the correlation-regression analysis, some functional connections between the parameters of the potato-harvesting technological system were revealed. Thus, in figure 3, the approximating logarithmic dependence of the probability of a system failure due to the “machine” on the number of days of the harvesting period is presented. The decrease in the probability of the inoperable state of the potato harvesting system due to the “machine” ($q_M$) is explained by the fact that at the beginning of the harvesting period, the combine has more failures. As work continues, the unit is adjusted, adjusted and eliminated faults. The system adapts to the operating conditions, and after about 3 ... 5 days, its operation is carried out more stably. This is evidenced by the nature of the change
in reliability (probability of failure-free operation) of the P-M-E-T system during the seasonal time of the harvesting process with the complex effect of the failures of its components (Figure 4).

This is evidenced by the nature of the change in reliability (probability of failure-free operation) of the P-M-E-T system during the seasonal time of the harvesting process with the complex effect of the failures of its components (Figure 5).

![Graph showing the dependence of the reliability of the functioning of the potato processing system on the duration of its work.]

**Figure 5.** Dependence of the reliability of the functioning of the potato processing system on the duration of its work.

4. Conclusion

The potato harvesting process, presented as the functioning of the human-machine-environment-transport technological potato harvesting system, reveals the potential for its improvement. On the basis of the decomposition distribution of the shift time and the probability-statistical approach, the temporal characteristics and interrelations between the parameters of a complex system are determined. Improve the reliability and performance of the system, as well as the degree of implementation of its efficiency, perhaps by carrying out well-known events:

- the choice of the optimal timing of cleaning and modern technologies;
- organization of the delivery of the machine operator to the place of work;
- thorough preparation of fields and potato harvesting units;
- equipping workplaces with the necessary tools and equipment;
- ensuring uninterrupted transport and consumer services;
- improving the design of domestic potato harvesters;
- timely training of machine operators and many others.

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