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Analysis of Studies of the Distribution of Input Disturbances of Potato Harvesting Machines and Evaluation of Moment Functionals in a Competing Risk Model using an Empirical Bayesian Approach

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Abstract. *This article studies the input disturbances of potato harvesting machines, i.e. separation of potato tubers from the mass and estimation of moment functionals in a competing risks model using an empirical Bayesian approach. The process of separation of soil from potatoes at the elevator of a potato harvester, which is exposed to competing risks, is considered as an elementary event. Here, the studied non-negative random variable (r.v.) means the stable operation of the tested technical device under consideration.*

Introductions

The main factors influencing the increase in productivity and quality indicators of potato harvesting machines are high-quality soil preparation, high-tech inter-row cultivation and timely planting. Scientific research is being carried out around the world to create new technologies and technical means for cultivating the soil before planting potato tubers . Issues related to the study of the development of soil-cultivating machines and the parameters of working bodies were considered in the works [1]-[4] and others.

These studies examined the design, energy and agrotechnical performance of technical means of soil preparation before planting potatoes.

A comparison of the working bodies and the degree of stability of the proposed parts are considered in the study [5] and [6]. However, in the listed studies, the influence of the incoming mass over time on the influence of the failure-free operation of the machine has not been sufficiently studied.

In this work we will study the results of the average longitude and performance of a potato digger. From time to time using the method of statistical parameter estimation.

Research materials

Let's consider a series-connected separating mechanism for k layers dug by a potato harvester's ploughshare with failure-free operation times, $Y^{(1)},...,Y^{(k)}$ i.e. performing the separation of soil from tubers during the period of work according to agrotechnical requirements and with the corresponding distribution functions (d.f.) $G^{(i)}(t)=P(Y^{(i)}\le t),\ (t;i)\in R^{+}\times J$. Let us assume that these r.v. independent and $P(Y^{(i)}=Y^{(j)})=0,\ i\neq j\ \ i,j\in J$. Then the failure-free operation time of the entire chain of separating working parts of the machine will be $Z=\min\left\{Y^{(i)},i\in J\right\}$ r.v. and failure at the same time – it is impossible for two layers of separating masses, where is $Z:(\Omega,A)\rightarrow\left(R^{+},B\right)$ a non-negative r.v. meaning the operating time of the technical device being tested. Here $B=\sigma\left(R^{+}\right)$ is the sigma algebra of Borel sets from R^{+}. Let be P a probability measure on a measurable space (Ω, A).

Based on this and taking into account the above, the structural circuit of the soil separation process can be presented in the form of the following model shown in Figure 1. The output factors for a potato harvester are generally uncontrollable. However, a high level of soil preparation and cultivation technology can have a positive effect on them.

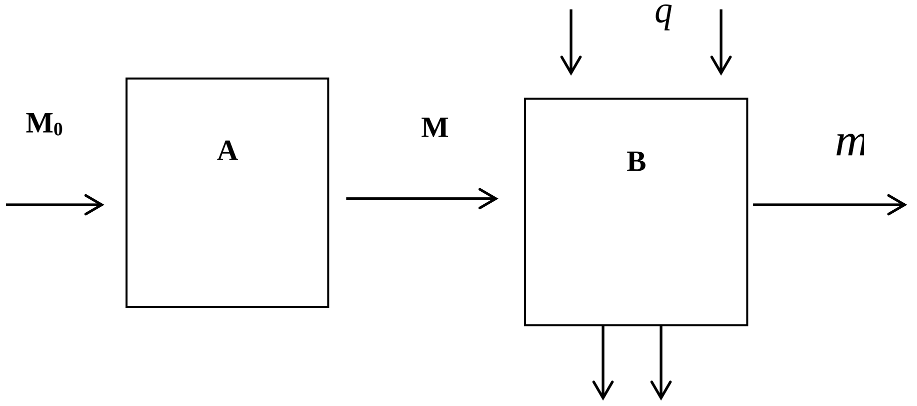

Fig.1 Soil separation model

A- The accumulator , which is loaded with soil , has some property of quantity M_0 and transfers soil with initial mass M ;

B- Separator and working body, which gives speed q to the separating working element of the potato digger .

Consider that the mechanism under test exposed to competing risks, characterized by pairwise incompatible events $\left\{A^{i},i\in J\right\}$, where $J=\{1,...,k\}$ (or at least $P\left(\cup_{i\in J}A^{(i)}\right)=1$ $P\left(A^{(i)}\cap A^{(j)}\right)=0,$ $i\neq j$). Let's introduce subdistributions to $\left(R^{+},B\right)$:

$$\left\{Q^{(i)}(B)=P\left(\omega\cap A^{(i)}:Z(\omega)\in B\right),B\in B\right\},i\in J.$$

Note that $Q^{(1)}(B)+...+Q^{(k)}(B)=P\left(\omega:Z(\omega)\in B\right)$ for everyone $B\in B$.

In order to calculate the numerical characteristics of the random process of soil crumbling and separation in a rod elevator, it is necessary to construct a probabilistic model of this process that reflects the action of the main random factors.

A soil lump that has entered a rod elevator may be in different states depending on its size and location relative to the elevator surface. Figure 1 shows a geometric diagram or otherwise a graph of the states of a soil lump when the rod elevator is fully loaded.

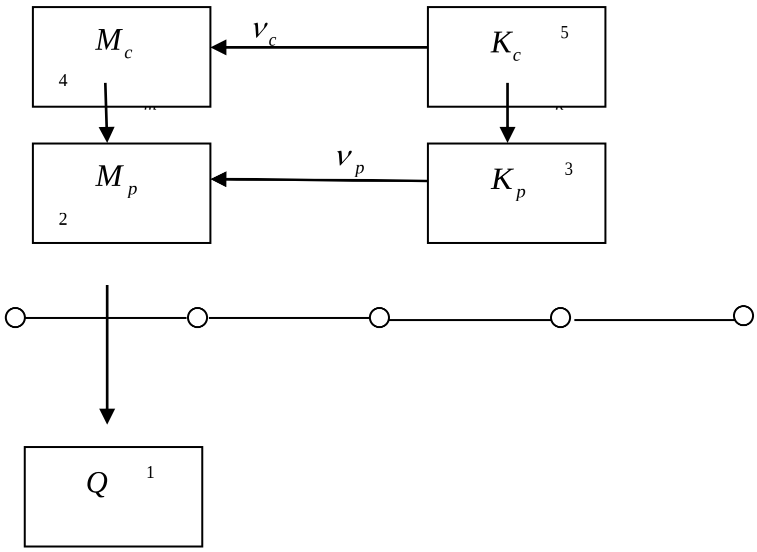

Fig . 2 Graph of possible soil states lump when the elevator is fully loaded.

Arrows on the graph show possible transitions of a soil lump from one state to another. The state M_p corresponds to the location of a soil lump of fine or passable fraction (less than 25 mm in size), and K_p - a lump of coarse soil fraction directly on the surface of the rod elevator. Similarly, the states M_c and K_c correspond to the location of soil lumps of passable and non-passable fractions in the upper soil layer of the elevator. A soil lump of fine fraction that has squeezed between the elevator rods is in the state Q.

a Markov random process with discrete states and continuous time can be used [8].

We further assume that the measures $Q^{(i)}$ are continuous. On a measurable space, (R^+, B) we also consider non-negative and continuous and finitely additive measures, $\{\alpha^{(i)}(\cdot), i \in J\}$ as well as their sum $\alpha(B) = \alpha^{(1)}(B) + + \ldots + \alpha^{(k)}(B),\ \ B \in B$. Let be $D\left(\alpha^{(1)}, \ldots, \alpha^{(k)}\right)$ a Dirichlet distribution with vector parameter $\left(\alpha^{(1)}, \ldots, \alpha^{(k)}\right)$. In the Bayesian approach, we assume that $\left(Q^{(1)}, \ldots, Q^{(k)}\right)$ is a random vector process on (R^+, B) with a Dirichlet prior distribution $D\left(\alpha^{(1)}, \ldots, \alpha^{(k)}\right)$. It is known that under these conditions, at $B = [0;t]$, subdistributions $Q^{(i)}([0;t]) = P\left(Z \le t, A^{(i)}\right) = H(t;i),\ \ (t;i) \in R^+ \times J$ is r.v. with corresponding prior beta distributions $Be\left(\alpha^{(i)}(t); \alpha(R) - \alpha^{(i)}(t)\right), (t;i) \in R^+ \times J,$ where $\alpha^{(i)}(t) = \alpha^{(i)}([0;t])$. Let be $\left\{\left(Z_j, A_j^{(1)}, \ldots, A_j^{(k)}\right),\ \ j = 1, 2, ..\ \right\}$ a sequence of independent copies of the population $\left\{Z; A^{(1)}, \ldots, A^{(k)}\right\}$ and an observed sample of size n is $S^{(n)} = \left\{Z_j, \delta_j^{(1)}, ..., \delta_j^k\ j = 1, \ldots, n\right\}$, where $\delta_j^{(i)} = I\left(A_j^{(i)}\right)$ are indicators of the specified events. In the considered model of competing risks, the properties of pairs are of interest $\left\{\left(Z, A^{(i)}\right), i \in J\right\}$ and the task is to estimate the reliability functionals of subdistributions $\{H(\cdot;i), i \in J\}$. Some of these important functionals are the exponential functionals

$$1-F(\cdot;i)=\exp\{-\Lambda(\cdot;i)\},\ i\in J,\ (1)$$

Where $\Lambda(t;i)=\int_0^t \frac{dH(u;i)}{1-H(u)},(t;i)\in R^+\times Z,$ - and integral functions of intensity (i.f.i.) of risks and $H(t)=H(t;1)+\ldots+H(t;k)=P(Z\le t),t\in R^+,-$distribution function (d.f.) of r.v. Z.Bayesian estimates of distributions $H(t;i)$and $H(t)$samples were constructed $S^{(n)}$with respect to the quadratic loss function in the form:

$$H_n^\alpha(t;i)=q_nH_0(t;i)+(1-q_n)H_n(t;i),\ (2)$$

$$H_n^\alpha(t)=\sum_{i=1}^k H_n^\alpha(t;i)=q_nH_0(t)+(1-q_n)H_n(t),$$

Where

$$q_n=\frac{\alpha(R^+)}{\alpha(R^+)+n},\quad H_0(t;i)=\frac{\alpha^{(i)}(t)}{\alpha(R^+)},$$

$$H_0(t)=\sum_{i=1}^k H_0(t;i)=\frac{\alpha(t)}{\alpha(R^+)},\quad \alpha(t)=\alpha([0,t]),$$

$$H_n(t;i)=\frac{1}{n}\sum_{j=1}^n I\left(Z_jt,\delta_j^{(i)}=1\right),$$

$$H_n(t)=\sum_{i=1}^k H_n(t;i)=\frac{1}{n}\sum_{j=1}^n I\left(Z_jt\right).$$

Using the substitution method [7] using Bayesian estimates (2), the following three types of estimates for the functionals were constructed and studied: $F(t;i)$:

$$F_{1n}^\alpha(t;i)=1-\exp\{-\Lambda_n^\alpha(t;i)\},$$

$$F_{2n}^\alpha(t;i)=1-\prod_{ut}\{1-\Delta\Lambda_n^\alpha(u;i)\},\ (3)$$

$$F_{3n}^\alpha(t;i)=1-\{1-H_n^\alpha(t;i)\}^{R_n^\alpha(t;i)}$$

where for $(t;i)\in R^+\times J$:

$$R_n^\alpha(t;i)=\Lambda_n^\alpha(t;i)\{\Lambda_n^\alpha(t)\}^{-1},\Lambda_n^\alpha(t)=\sum_{i=1}^k\Lambda_n^\alpha(t;i),$$

$$\Delta\Lambda_n(t;i)=\Lambda_n^\alpha(t;i)-\lim_{u\uparrow t}\Lambda_n^\alpha(u;i),$$

And

$\Lambda_n^\alpha(t;i)=\int_0^t\frac{dH_n^\alpha(u;i)}{1-H_n^\alpha(u)}-$appropriate assessment for i.f.i. (1).

Let us consider each selected part in the process of mass transfer as some element. D.f. r.v. Z will $H(t)=1-\prod_{i=1}^{k}\left(1-G^{(i)}(t)\right)$ and event $A^{(i)}=\left\{Z=Y^{(i)}\right\}$, $i\in J$, mean that a circuit break will occur due to the processing $i-$ of the element. These events form a complete group and the subdistributions are defined as

$$H(t;i)=P(Z\le t,Z=Y^{(i)})=\int_0^t 1-\prod_{\substack{l=1\\ l\ne i}}^{k}\left(1-G^{(l)}(u)\right)dG^{(i)}(u).$$

Then there is the representation

$$G^{(i)}(t)=1-\exp\left\{-\int_0^t\frac{dH(u;i)}{1-H(u)}\right\}$$

for everyone $(t;i)\in R^{+}\times J$. Thus, the characteristic

$$\mu\left(m;i\right)=\int_0^\infty C\,t^m\,dF\left(t;i\right),\quad i\in J,\ (4)$$

is the moment $m-$ of the order $i-$ of risk $Y^{(i)}$ and C is the coefficient of centralization.

In particular when $m=1$ and $C=1$ get the average failure-free operation time $i-$ of the element.

The most important asymptotic properties of estimates (3) were previously established. In particular, on the final segment $[0,T]$, where the number of achievements T of subdistributions is reliable , i.e. $T<T_H=\inf\left\{t\ge 0:H(t)=1\right\}$, estimates (3) differ from each other by an amount of order $O(1/n)$. We will take this circumstance into account to evaluate the functionality $F(\cdot;i)$.

When estimating characteristic (4), consider the following condition:

Let it be for everyone $i\in J$ at $i\to\infty$:

$1-F(t;i)=o(t^{-m})$;

are usually satisfied for many d.f.s in reliability theory. According to the introduced condition, characteristic (4) can be written in the form

$$\mu(m;i)=C\square m\int_0^\infty t^{m-1}(1-F(t;i))dt,\ i\in J \qquad (5)$$

In view of formula (5), the estimate for $\mu(m;i)$ let's build it like

$$\mu_n^\alpha(m;i)=C^\alpha m\int_0^{T_n} t^{m-1}(1-F_n^\alpha(t;i))dt,\ i\in J \qquad (6)$$

where $T_n<T_H$ is the sequence of numbers and at $n\to\infty$, $T_n\to\infty$ with sequence

$$\lambda(n)=\left(\frac{\log\log n}{n}\right)^{1/2},\ b_n=(1-H(T_n))^{-1},$$

$$\overline{\mu_n(m;i)}=Cm\int_0^{T_n} t^{m-1}(1-F(t;i))dt,\ i\in J$$

$$\varepsilon_n(i)=cm\int_{T_n}^{\infty} t^{m-1}(1-F(t;i))dt,\ i\in J$$

and $R_n = T_n^m \cdot \lambda(n) \cdot b_n^2$. Note that from the existence of integrals (4) it follows that for $n \to \infty, \overline{\mu_n(m;i)} \to \mu(m;i)$ and $\varepsilon_n(i) = o(1),\ i \in J$.

Next, we will show that the result on the strict consistency of estimates (6) for characteristics (5) holds.

Let it be for everyone $i \in J,\ \mu(m;i) < \infty$. Then

$$\left|\mu_n^\alpha(m;i) - \mu(m;i)\right| = O(R_n^{(i)}),\ \ i \in J,$$

Where

$$R_n^{(i)} = \max(R_n, \varepsilon_n(i)).$$

Using an elementary inequality $|a-b| \le |\log a - \log b|,\ 0 < a,\ b \le 1$ we get

$$\left|\mu_n^\alpha(m;i) - \mu(m;i)\right| \le \left|\mu_n^\alpha(m;i) - \overline{\mu(m;i)}\right| + \varepsilon_n(i) \le$$

$$\le cm \int_0^{T_n} t^{m-1} \left|\Lambda_n^\alpha(t;i) - \Lambda(t;i)\right| dt + \varepsilon_n(i) \qquad (7)$$

Replacing T with T_n we get an estimate

$$\max_{i \in J} \sup_{0 \le t \le T_n} \left|\Lambda_n^\alpha(t;i) - \Lambda(t;i)\right| = O\left(\lambda(n) b_n^2\right) \ (8)$$

Conclusions

This means that the reliability functional $1 - F(\cdot;i) = \exp\{-\Lambda(\cdot;i)\}, i \in J,$ describes the existing process of trouble-free operation of separating working bodies. After the proposed working bodies, the evaluation function is considered with functionals $F_{in}^\alpha(t;i)$ i.e. the change over time of this function decomposes from the existing one insignificantly and this proximity is defined as $O\left(\lambda(n) b_n^2\right)$. This means that the given convergence statement follows from (7) and (8). It is clear that the sequence T_n must be chosen so that when $n \to \infty,\ R_n = o(1)$.

Thus, the possibility of failure-free operation of the proposed working body has been proven using the mathematical method of competing risks with an empirical Bayesian approach.

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