Mathematical model for forecasting product losses in crop production projects

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Abstract

The proposed mathematical model for forecasting product losses in crop production projects allows to determine the product losses due to late work, which allows to identify critical works in the project that cause the greatest product losses and accordingly identify resources, the lack of which causes these losses and justify appropriate management decisions. their avoidance. A method for determining product losses in the project of agricultural production, which consists of two stages and technological requirements for the implementation of directive deadlines for operations, and also gives the expected losses of the project product due to late implementation. Based on the established characteristics of the cost of product losses of production projects in different scenarios of their implementation and their visualization in Python 3.8 using the libraries matplotlib, numpy and scipy the construction of distributions of the cost of product losses of production projects was performed in the three scenarios of their implementation.

Keywords

Mathematical model, prognostication, crop production projects, product loss.

1. Introduction

Projects connected with crop production in agriculture have quite a number of specify characteristics and, therefore, traditional network and calendar types of planning frequently cannot be effectively employed there. In particular, such projects foresee performing of a lot of agricultural operations only within optimal agrotechnical terms because of the biological properties of crops, their specify phases of vegetation and agrometeorogical conditions of environment.

The given terms should be considered as directory. Their violation will provoke irreversible losses in crop yields (the output of the project) and, therefore, predictions of losses at the stage of planning the project and developing the corresponding managerial decisions proved to be a serious scientifically – practical objective aimed at minimizing such losses.

2. Analysis of published data and problem setting

Projects connected with crop production in agriculture have quite a number of specify characteristics [9-21] and, therefore, traditional network and calendar types of planning frequently cannot be effectively employed there. In particular, such projects foresee performing of a lot of agricultural operations only within optimal agrotechnical terms because of the biological properties of crops, their specify phases of vegetation and agrometeorogical conditions of environment [4, 7, 8].

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Manager's activity may be sufficiently relieved at each stage if he managed to get a model of calendar planning of performing predetermined operations and their biasing [1-3]. In the projects connected with agrarian production any moving's away of directory terms cause losses of yields (outputs).

Current methods of predicting yields losses caused by ill-timing of technological operations [4-8] are based on the biological specifications of crop vegetation. The analysts possess different views in predicting such losses. The research [5] suggests to employ a linear model of losses under conditions of relatively short periods of time (no more 20 days).

$$U_t = U_{\max}(1 - k_l t), \tag{1}$$

where: U_t –current value of the yielding capacity, c/ha; U_{max} – the yielding capacity of the crop which corresponds to performing operations in optimal terms, c/ha; k_l – coefficient of the yield losses when directory terms of performing an operation are prolonged in one unit of time (a day); t – duration of ill – timed operation carries out with violation of optimal moments, days.

The research [2] suggested the method of deter-mining losses of crop yields caused by ill-timed per-forming of each technological operation. The given method, however, ignores the impact of neighbouring technological operations within a single project on the volumes of crops yields losses.

3. The purpose and objectives of the study

The article is focused on developing the method of predicting losses of the project's output under conditions of violation of directory terms of performing operations.

To achieve this goal should solve the following tasks:

- to substantiate the method of determining the losses of the project product in case of non-compliance with the directive deadlines for operations;
- to develop an information model for forecasting product losses in production projects under given conditions of the project environment.

4. Mathematical model for forecasting product losses in crop production projects

Our project connected with crop growing is implemented on the single field or the group of fields. It faces, therefore, the necessity of performing major operations in one field in succession only. This approach excludes performing of different operations simultaneously there.

In addition, the results of the projects dealing with crop growing frequently face the risks of natural calamities, bad weather, etc which should be taken into con-sideration when making up models.

The project p dealing with crop growing production can be considered as a set of well – organized operations over soils, a plant or a material in accordance with the given agrotechnical requirements.

$$P = \{O_i\}. \tag{2}$$

Each technological operation Oi, is given a finite sequence with the following attributes: type of operation VO_i, (ploughing, cultivation, chemical protection, etc.); a set of agrotechnical requirement to operations $\{AV_i\}$ (depth of procession, rate of application, etc.); directory time of starting $[\tau_i]$ and duration of fulfilment of an operation $[t_i]$.

$$O_i = \langle VO_i, \{AV_i\}, [\tau_i], [t_i] \rangle. \tag{3}$$

When performing major and additional technological operations within a single project one uses a limited number of industrial and technical resources of agrarian enterprises. We may distinguish there a set of farm machines $\{M_i\}$ and energetic instruments $\{T_i\}$ for their drive. The given resources make up the resource pool which may also be used in some other projects of the portfolio of agrarian enterprises. Because of the re-sources scarcity it is reasonable, therefore, to simulate these resources utilization under conditions of variable volumes of jobs Q within the project and limitation of the admissible terms of performing operations.

Calendar schedule of technological operations dealing with crop growing production is planned at three stages. The first stage foresees constructing the model of technology demonstrates orderable by time and con-tent set of operations and vectors of directory calendar terms of their performing. The coordinate of the vector origin of the calendar terms of operation in the model of technology is given the directoty time of the operation starting $[\tau_s]$. The coordinate of completion $[\tau_{e_i}]$ is determinated by the formula:

$$[\tau_{e_i}] = [\tau_{s_i}] + [t_i]. \tag{4}$$

The model of the products output technology sets the ideal calendar schedule of the project. Performing of all technological operations within the directory calendar terms guarantees maximum output.

The second stage foresees selecting for each a-operation farm machines of the set $\{M_i\}$ of machinery available at the enterprise. The selected machines should secure the successful performing of the predetermined types of operations VO_i, and observing a set of agrotechnical requirements $\{AV_i\}$. In case with non-automotive machines, one should select specific energetic tool from the set $\{T_i\}$ of energetic means for these machines drive to secure the most efficient fulfilment of the predetermined technological operation. In this way we, thus, get the technical resource (machine and tractor aggregate) needed for performing the predetermined operation.

Coming from technical characteristics of the given technological resource and environmental factors (specific resistance of the field gon and state of the object of conversion – a plant or material) we determine the variable productivity w_v of the technical resource and its specific fuel costs g_p.

Coming from the determined variable productivity of technical resources we can determine the real duration of each technological operation O_i, taking into consideration the quality of all available technical resources.

$$t_i = \frac{q}{w_v \cdot k_v \cdot n}, \tag{5}$$

where: q – the volume of jobs, ha, t, m^3; w_v – productivity of the aggregate for a shift (standard of the aggregate output) ha/shift; k_v – coefficient of variability; n – number of aggregates involved onto the given operation from the available set $\{M_i\}$ and $\{T_i\}$.

As only a single operation may be carried out in one single field at the given time, one must determine coordinates of the vector of both origin τ_{s_i} and completion τ_{e_i} for each single technological operation. In the case with the first operation of the project coordinates of the vectors origin will be equal to its directory calendar time $[\tau_{s_1}]$, i.e. $\tau_{s1} = [\tau_{s_1}]$.

For all further 1-x operations coordinates of their vectors of starting are determined with consideration of directory time of their starting $[\tau_{s_i}]$ after finishing the previous field operation $\tau_{e_{i-1}}$, i.e.

$$\tau_{s_i} = \begin{cases} [\tau_{si}], \text{ if } [\tau_{si}] > \tau_{e_{i-1}}, \\ \tau_{e_{i-1}}, \text{ if } [\tau_{si}] \le \tau_{e_{i-1}}. \end{cases} \tag{6}$$

Coordinate of completion of the vector of technological operation is determined by addition of the value of duration τ_{s_i} of the operation the coordinate of its starting t_i

$$\tau_{e_i} = \tau_{s_i} + t_i. \tag{7}$$

When performing technological operations in the predetermined volumes one may face the searcity of farm machines $\{M_i\}$ and energetic means $\{T_i\}$, and, hence, the problems of violation of directory terms of operations may arise. The value of duration of performing operations prevailing the directory terms t_u (Figure 1) is determined under the following condition:

$$t_u = \begin{cases} \tau_{e_i} - [\tau_{e_i}], \text{ if } \tau_{\mathrm{e_i}} > [\tau_{e_i}], \\ 0, \text{ if } \tau_{\mathrm{e_i}} \le [\tau_{e_i}]. \end{cases} \quad (8)$$

In case the time of completion of technological operation prevails its directory calendar time of completion $\tau_{\mathrm{e_i}} > [\tau_{e_i}]$ (Figure 1*b*), the problem of the losses of the output may arise.

To avoid such situations, one must modify the duration of one day working time (the coefficient of variability) or the number of machine and tractor aggregates involved into jobs.

If both measures are not able to prevent the duration of operations beyond the directory terms, one must determine the value of losses caused by ill-timed performing of such operations.

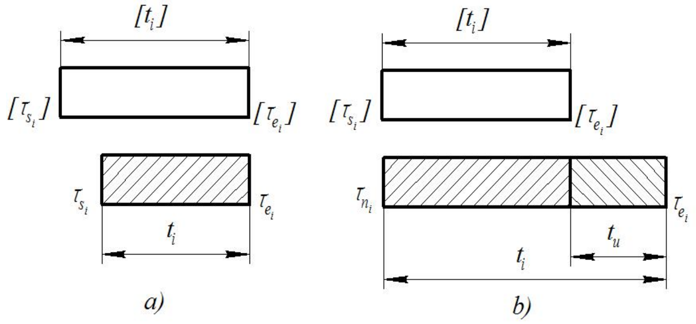

Figure 1: The technological operation which does not prevail (a) and prevails (b) the directory terms of its carrying out.

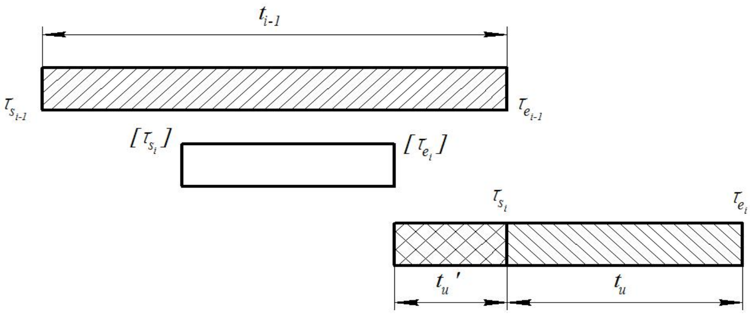

Figure 2: The technological operation with the starting lagged behind the directory term of carrying out jobs.

$$Z_i = 0{,}5 \cdot U_{\max_i} \cdot q_{u_i} \cdot t_{u_i} \cdot \kappa_l \,, \quad (9)$$

$$q_{u_i} = q - W_{d_i} \cdot ([\tau_{ei}] - \tau_{si}) \,, \quad (10)$$

where: U_{max} – maximum yielding capacity of a crop (the project output), c/ha; q_{ui} – the area of the field where the operation is performed with violations of directory terms, ha; t_u – duration of performing the operation beyond the directory terms, days; k_l – coefficient of the crop losses caused by 1 day delay of the technological operation; W_{di} – the delay standard of the aggregate output when performing the given operation, ha/day.

When field or technical resources are employed in the previous operation may, the time of starting of the next technological operation, the time of the next technological operation may be lagged behind the directory terms predetermined for it (Figure 2). The output losses caused by ill – timed starting of the operation t_n, then, are calculated by means of the formula:

$$Z_i^{'} = q_u \cdot t_u^{'} \cdot U_{\max_i} \cdot \kappa_{l_i} \,, \quad (11)$$

$$t_{u^{'}} = \begin{cases} \tau_{s_i} - [\tau_{e_i}], \text{ if } \tau_{\mathrm{s_i}} \ge [\tau_{e_i}], \\ 0, \text{ if } \tau_{\mathrm{s_i}} < [\tau_{e_i}]. \end{cases} \quad . \quad (12)$$

The next step is determining the total output losses for each operation of the project caused by its ill – timed performing:

$$\sum Z_{S_i} = Z_i^{'} + Z_i \,. \tag{13}$$

Coming from the construction of the calendar schedule we determine the expected losses of the output for all operations of the project *P*, and their gross expected losses of the output by means Z_{P_i} of the formula:

$$Z_{P_i} = \sum_{i=1}^{n} Z_{S_i} \,. \tag{14}$$

The received results give grounds for motivating organizationally technical decisions on realization of the project.

Analysis of the technical operations give the opportunity to determine the critical operations of the project causing the most dramatical output losses as well as to determine such technical resources whose scarcity provokes these losses. Managers supervising the project should constantly take into consideration the said above and feel their personal responsibilities for satisfactory supply of technical resources through cooperation, rent and additional purchase of the given type of resources.

If it is impossible or unreasonable to employ the additional resources one should think about the opportunities of diminishing the range of the project which, in its turn, will lead to diminishing demands in technical resources and, hence, minimal losses of the output.

5. Results of development and use of intellectual information system for optimization of hybrid project portfolio

We tested the developed mathematical model for forecasting product losses in crop production projects. Three scenarios for planning production projects were considered, which provide for the formation of the composition of production and technical resources for:

1. The planned scale of production projects and the volume of work in them.
2. The planned scale of production projects, the volume of work and their streamlining by identifying the types of technical resources that are simultaneously used in different blocks of work and, accordingly, shifting the timing of these works, taking into account the priorities of blocks of work.
3. The planned scale of production projects, the volume of work, their ordering, changing the scale of these projects and attracting additional resources.

Based on the established characteristics of the cost of product losses of production projects in different scenarios of their implementation and their visualization in Python 3.8 using the libraries matplotlib, numpy and scipy the construction of distributions of the cost of product losses of production projects was performed in the three above-mentioned scenarios of their implementation, as shown in Figure 3.

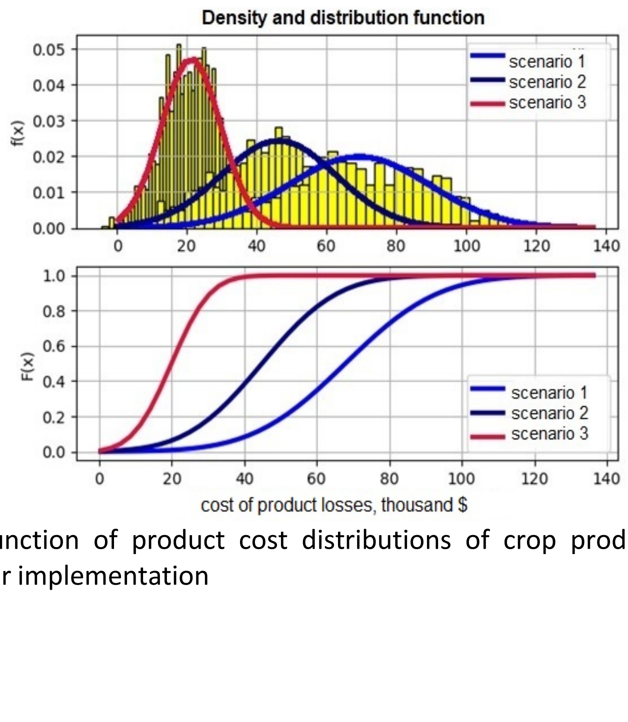

Figure 3: Density and function of product cost distributions of crop production projects under different scenarios of their implementation

The obtained densities and functions of product cost losses of production projects indicate that the formation of production and technical resources on the planned scale of projects, the volume of work, their ordering, changing the scale of these projects and attracting additional resources can improve the quality of resource management in these projects.

6. Conclusions

Projects connected with agrarian production have their specific characteristics caused by limitation of calendar terms of performing operations. This phenomenon needs further developments or improvements of the current methods of constructing calendar schedules and supervision of the projects.

The suggested method of constructing calendar schedule considers optimal versions of interdependence of technological operations conserving both the timely realization of the project and violation of directory terms of performing operations within the project.

The developed mathematical model for forecasting product losses in crop production projects proved to be a reason for grounding the needs in additional resources and the change of the range of the project for preventing irreversive losses of the output.

7. References

[1] A. Tryhuba, I. Tryhuba, O. Bashynsky, I. Kondysiuk, N. Koval, L. Bondarchuk, Conceptual Model of Management of Technologically Integrated Industry Development Projects, in: IEEE 15th International Conference on Computer Sciences and Information Technologies, CSIT-2020, IEEE, Lviv, 2020, pp. 155–158. doi: 10.1109/CSIT49958.2020.9321903.

[2] P. Lub, A. Sharybura, L. Sydorchuk, A. Tatomyr, V. Pukas, M. Cupial, Information-analytical system of plants harvesting project management, in: 1st International Workshop IT Project Management, ITPM 2020, CEUR vol. 2565, Slavsko, Lviv region, 2020, pp. 244–253.

[3] A. Tryhuba, V. Boyarchuk, I. Tryhuba, O. Boiarchuk, N. Pavlikha, N. Kovalchuk, Study of the impact of the volume of investments in agrarian projects on the risk of their value, in: 2nd International Workshop IT Project Management, ITPM 2021, CEUR vol. 2851, Slavsko, Lviv region, 2021, pp. 303–313.

[4] P. Lub, V. Pukas, A. Sharybura, O. Lysiuk, Modelling of the technological systems projects of harvesting agricultural crops, in: 14th International Conference on Computer Sciences and Information Technologies, CSIT-2019, IEEE, Lviv, 2019, pp. 19–22, doi: 10.1109/STC-CSIT.2019.8929815.

[5] A. Usov, S. Maksimov, Calendar planning model application for the project management in civil engineering, Eastern-European Journal of Enterprise Technologies 67 (2014) 39–42. doi: 10.15587/1729-4061.2014.20344

[6] A. Tryhuba, V. Boyarchuk, I. Tryhuba, O. Ftoma, R. Padyuka, M. Rudynets, Forecasting the risk of the resource demand for dairy farms basing on machine learning, in: 2nd International Workshop on Modern Machine Learning Technologies and Data Science, MoMLeT+DS 2020, CEUR vol. 2631, Lviv-Shatsk, 2020, pp. 327–340.

[7] V. Tymochko, R. Padiuka, Possibilities of the use of automated management of projects for the conditions of agricultural production, Eastern-European Journal of Enterprise Technologies 63 (2013) 26–28. doi:10.15587/1729-4061.2013.14677.

[8] V. Tymochko, Yu Kovalchuk, R. Padiuka, Organization and technological measures of energy saving during oil and grain crops harvesting, Motoruzacia i energetuka rilnictwa Motrol 13D (2011) 22–30.

[9] A. Choudhury, J. Jones, Crop yield prediction using time series models, Journal of Economics and Economic Education Research 15(3) (2014) 53–58.

[10] T. Klemm, R. A. McPherson, The development of seasonal climate forecasting for agricultural producers, Agricultural and forest meteorology 232 (2017) 384–399. doi: 10.1016/j.agrformet.2016.09.005.

[11] G. Hoogenboom, Contribution of agrometeorology to the simulation of crop production and its applications, Agricultural and forest meteorology 103 (2000) 137–157. doi: 10.1016/S0168-1923(00)00108-8.
[12] D. Buklagin, V. Goltyapin, Digitalization of crop production: development trends, IOP Conference: Earth and Environmental Science 723(3) (2021).
[13] A. Saxena, M. Dhadwal, M. Kowsigan, Indian Crop Production: Prediction And Model Deployment Using Ml And Streamlit, Turkish Journal of Physiotherapy and Rehabilitation 32 (2021).
[14] R. Lecerf, A. Ceglar, R. López-Lozano, M. Van Der Velde, B. Baruth, Assessing the information in crop model and meteorological indicators to forecast crop yield over Europe, Agricultural systems 168 (2019) 191–202.
[15] M. A. Martins, J. Tomasella, D. A. Rodriguez, R. C. Alvalá, A. Giarolla, L. L. Garofolo, G. L. Pinto, Improving drought management in the Brazilian semiarid through crop forecasting, Agricultural Systems 160 (2018) 21–30.
[16] P. Panagos, G. Standardi, P. Borrelli, E. Lugato, L. Montanarella, F. Bosello, Cost of agricultural productivity loss due to soil erosion in the European Union: From direct cost evaluation approaches to the use of macroeconomic models, Land Degradation & Development 29(3) (2018) 471–484.
[17] M. Weiss, J. Frédéric, G. Duveiller, Remote sensing for agricultural applications: a meta-review, Remote Sensing of Environment 236 (2020).
[18] L. Parker, C. Bourgoin, A. Martinez-Valle, P. Läderach, Vulnerability of the agricultural sector to climate change: The development of a pan-tropical Climate Risk Vulnerability Assessment to inform sub-national decision making, PloS one 14(3) (2019).
[19] R. L. F. Cunha, B. Silva, M. A. S. Netto, A scalable machine learning system for pre-season agriculture yield forecast, in: 14th International Conference on e-Science, IEEE, 2018, pp. 423–430. doi:10.1109/eScience.2018.00131.
[20] A. Tryhuba, M. Rudynets, N. Pavlikha, I. Tryhuba, I. Kytsyuk, O. Komeliuk, V. Fedorchuk-Moroz, I. Androshchuk, I. Skorokhod, D.Seleznov, Establishing patterns of change in the indicators of using milk processing shops at a community territory, Eastern-European Journal of Enterprise Technologies, Control processes 102 (2019) 57–65. doi: 10.15587/1729-4061.2019.184508
[21] A. Tryhuba, V. Boyarchuk, I. Tryhuba, O. Boiarchuk, N. Pavlikha, N. Kovalchuk, Study of the impact of the volume of investments in agrarian projects on the risk of their value, in: 2nd International Workshop IT Project Management, ITPM 2021, CEUR vol. 2851, Slavsko, Lviv region, 2021, pp. 303–313.