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IMPLEMENTATION OF INDUSTRY 4.0 SOLUTIONS IN THE AGRICULTURAL FIELD OF UKRAINE

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Abstract. This article is devoted to Industry 4.0 technologies implemented in the agricultural industry of Ukraine. For Ukraine, online services ensure a civilized use of land, increase the land value and market intelligence, reduce the risk of corruption to zero. The successful direction for Ukrainian farmers is trade with Europe. The Ukrainian team has been creating agricultural drones for farmers within the frames of the Kray Technologies startup since 2017. The introduction of innovations ensures the accuracy of measurements, the speed of data collection and processing. Drones allow to collect abundant photo data which is applied to estimate the biomass and crops' growth parameters, their storage locations and the percentage of weed contamination. These data make it possible to carry out differentiated enrichment with fertilizers of different brands.

The agriculture was one of the first to feel the consequences of the full-scale Russian aggression in Ukraine, which began on the 24th of February. The war forced farmers to become food security guards. The Cabinet of Ministers of Ukraine with its order approved the action plan aimed to ensure food security in the conditions of martial law. Special attention is paid to the optimization of areas for certain crops. The scientific novelty of the present work consists in the application of the Lagrange multipliers method for solving the problem of optimizing the calendar plan for the sale of agricultural product stocks under price risk conditions. A price risk scenario with non-determined future market prices is considered.

Keywords: Industry 4.0, food security, Lagrange multipliers.

1. Industry 4.0 solutions implementation in the agricultural sector of Ukraine.

The article is devoted to topical issues of Industry 4.0 solutions implementation in the agricultural sector of Ukraine. World recognition of the benefits offered by the concept of "Industry 4.0" makes it necessary to transition the national economy to "Industry 4.0" technologies. Satellite technologies, electronic weather stations, automatic irrigation and soil moisture control systems - as well as mobile applications and special software help Ukrainian farmers.

The basis of Industry 4.0 is composed of the following scientific and technical developments:

1. Large databases and their analysis.

2. Autonomous robots are the robots that are able to perform tasks independently without human intervention.

3. Modeling is currently used to a large extent only while designing the production and business processes, individual new production equipment or new products.

4. Horizontal and vertical system integration.

5. The Industrial Internet of Things will connect all production components into a single network of real-time information exchange.

6. Cyber security involves taking measures related to the protection of data storage and processing facilities, data transmission networks.

7. Cloud technologies.

8. Additive (additional) production based on 3-D printing.

9. Extended (or virtual) reality will be used by employees for training, decision-making, etc.

Table1. Innovative projects in the agricultural sector of Ukraine.

Project name	Description
MHP	The company consistently implements innovative projects in various businesses. In 2017, MHP and Radar Tech technology cluster launched the country's only agriculture startup incubator - MHP accelerator. The largest innovative project is the biogas line using chicken droppings as the raw material.
Kernel	Kernel is a leading investor in innovation. Back in 2016, the company decided to combine all the applied innovative products into a single #DigitalAgriBussiness project. The system integrates Kernel's internal and external IT services for global automation of production processes. Among the production innovations is the expansion of the company's port capacities (the port of Chornomorsk) and the formation of its own wagons fleet.
Nibulon	The company has created a network of 27 modern cargo handling terminals and complexes for receiving, storing and shipping grain and oil crops. In terms of simultaneous grain storage capacity (2.1 million tons), this is currently the largest terminal network in Ukraine. In 2012 Nibulon opened a shipbuilding and ship-repairing plant - the only enterprise in Ukraine that builds full-fledged ships. In 2019, the company put into operation the longest specialized crane vessel of the "river-sea" class built during the independence of Ukraine, the 140-meter Nibulon Max. Now the company's fleet includes 76 vessels. The total amount of investments in the implementation of the company's projects in this marketing year reached 85 million dollars.
Astarta	The company has developed an agribusiness management portal that includes consolidated data on the company's land bank and helps various departments to communicate. The company also develops IT solutions which helps solving a number of production tasks.
IMC	IMC initiated the Ukrainian Farm Management courses. The project was supported by 16 of the country's largest agricultural companies.

More and more companies offering farmers technological innovations at affordable prices began to appear on the Ukrainian market. Design bureaus in Kyiv, Zhytomyr, and Lviv are currently working on this, developing and assembling unmanned aerial vehicles for the army and farmers.

Thanks to cartographic solutions by Ukrainian developers, the following become possible:

- visualization of soil analysis dynamics;
- analysis of satellite images;
- creation of crop yield maps;
- determination of the most productive land lots;
- tracking the dynamics of culture development;
- control of the fields state;
- yield forecast, etc.

The Soil Lines startup demonstrated the technology of laser soil analysis created in Ukraine and based on micro lasers. Developed by a US company, the Climate Corporation 17, it analyzes weather and soil data and provides farmers with recommendations for increasing yields under the given conditions. Digitization ensures the minimization of the human error factor, obtaining real data and making management decisions based on them. A promising direction is the use of artificial intelligence. Software development is ongoing. Agricultural companies implement CRM (Customer Relationship Management) and BPM (Business Process Management) systems. The leading agricultural holding of Eastern Europe "Myronivskyi Hliboprodukt" cultivates one of the largest land banks in Ukraine - about 370,000 hectares in 14 regions of Ukraine. Over 20 years of activity, the company has constantly improved its production, opened up to innovations and actively implemented the latest scientific and technical achievements and methods. We can consider the process of Ukrainian industry automation using the example of one of the largest agricultural holdings in the country - Ukrlandfarming. The company uses a technological system borrowed from foreign collegues, which allows them to easily receive data from all devices updating them on fuel consumption, process speed, engine load level and other factors with the help of the latest GPS trackers.

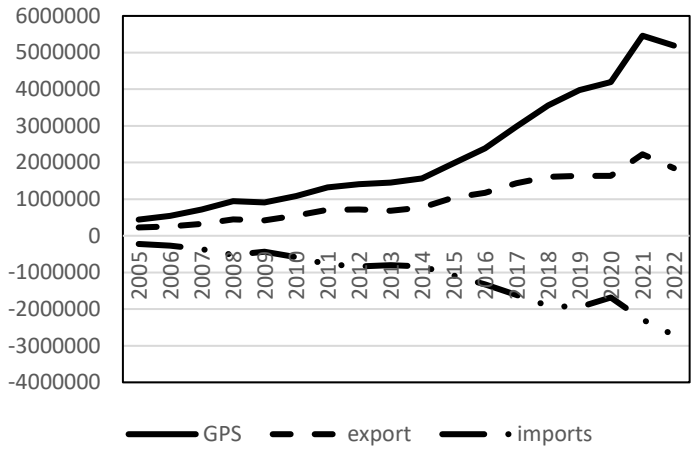

Fig. 1. Foreign trade balance of Ukraine from 2005 to 2021 (million hryvnias).

We will analyze the volume of export-import operations in the pre-war period. In recent years, imports into Ukraine have stably exceeded exports, and their difference sometimes reached 8% of GDP (see **Ошибка! Источник ссылки не найден.**).

According to the results of 2022, the GDP drop in Ukraine is estimated to be 30.4% [1] due to the hostilities. This is the worst indicator in the entire history of the country's independence. Since some territories are temporarily occupied, it became necessary to optimize agricultural areas in order to support the state food security program.

2. Presenting main material.

Optimization of agricultural areas in order to support the state food security program. According to the data of the State Statistics Service [1] for 2021, the most profitable were agriculture, forest and fish industries, with the profitability comprising 18.4%.

The largest profit was obtained by agricultural enterprises that grew: sunflower - about 21.1 billion hryvnias, wheat - 19.0 billion hryvnias, corn for grains - 11.9 billion hryvnias, rapeseed - 6.6 billion hryvnias, as well as milk - 3. 8 billion hryvnias.

At the same time, according to the data of the State Statistics Service, sunflower oil of Ukrainian production on the domestic market rose in price by 64%, sugar - by 68%, eggs - by 34%, bread - by 17%, meat - by 10.5%. At the same time, according to the statistics for 2020, the income of Ukrainian families increased by only 2.6% [3]. Among the agricultural crops of Ukraine, wheat occupies more than half of the cultivated areas. In recent years, Ukraine has entered the top ten major producers and has become one of the world's leading wheat exporters.

Wheat imports to Africa, Southeast Asia and the Western Hemisphere were expected to increase in 2022/23. Wheat is one of the most important crops for food security globally, as well as a source of income for part of the Ukrainian population.

Export of flour in 2022 decreased to 79 thous. tons (25% less compared to 2021 y.). The main reason for the decrease in export volumes was the blockade of sea ports, which created the necessity to the search for new alternative sales channels. Since the beginning of 2022/23 year 80 thousand tons were exported, where 36.6 thous. tons - to EU countries, which is 437 times more than in the same period of the previous year.

Buckwheat is an important crop for Ukrainians. In 2021, 86.4 thous. tons of buckwheat were harvested from an area of 65.3 thous. hectares. The average yield is 1.32 t/hectare. In 2020, Ukrainian farmers harvested 99,000 tons of buckwheat. In 2019, buckwheat production reached 85.1 thous. tons, compared to 137 thous. tons in 2018 y. The average yield of buckwheat in 2019 was 1.23 tons/hectare, compared to 1.21 tons/hectare in 2018 (in 2017 y. — 0.97 t/hectare, in 2016 y. — 1.15 t/hectare).

This year, farmers harvested an area of 69.3 thous. hectares (113.3 thous. hectares in 2018). In 2018, buckwheat production amounted to 137,000 tons compared to 180,400 tons in 2017.

Buckwheat prices in Ukraine have already dropped by 15%, however, some experts believe that the price for the popular crop will not decrease any more. In addition, as early as in 2023, a shortage of buckwheat in Ukraine is expected and the price for the product will increase.

The domestic market was always assumed to be 40 million people, but now it is actually 30 million people. The domestic buckwheat market is 120,000 tons. 3 kg of

buckwheat are consumed per capita in a year, which means that only 90,000 tons are necessary for 30 million population.

It was noted that in peacetime the surplus of the buckwheat could be exported, but only some countries of the former USSR and China consume buckwheat. It is very far to take buckwheat to China, and Europe's consumption is rather small.

Therefore, producers will have to sell the entire harvest in Ukraine, in this case they will earn almost nothing or just get the amount of the cultivation costs.

The area of buckwheat cultivation in Ukraine has decreased 20 times over the past twenty years - from 570,000 hectares in 2000 to 60,000 hectares this year.

The Cabinet of Ministers of Ukraine by its order approved the action plan to ensure food security in the conditions of martial law.

First of all, it envisages the monitoring of the conditions of food security and agricultural infrastructure as a whole. Secondly, a state support will be provided to national food producers. Thirdly, the most socially vulnerable population will receive targeted food benefits. In addition, monitoring and appropriate regulation of prices for food will be under special control of the state.

Special attention is paid to the optimization of areas for certain crops.

This year, the area for buckwheat cultivation will increase both due to the need to implement the state food security program and due to the expected demand for the product.

In recent years, the demand for buckwheat comprised 3.5 kg per capita in a year. For comparison, the highest level of this crop consumption is in Latvia and comprises more than 7 kg per capita in a year.

Ukraine's need for buckwheat as a strategic product comprises 250,000 tons. Due to hostilities in the south-east, the area of peas cultivation has decreased from the usual 240,000-250,000 hectares to 118,000 hectares.

Drought in Canada has had a devastating effect on the pea crops, causing prices' increase for the product globally. Meanwhile, steady international demand and dwindling stocks could push up pea prices (see Fig.2).

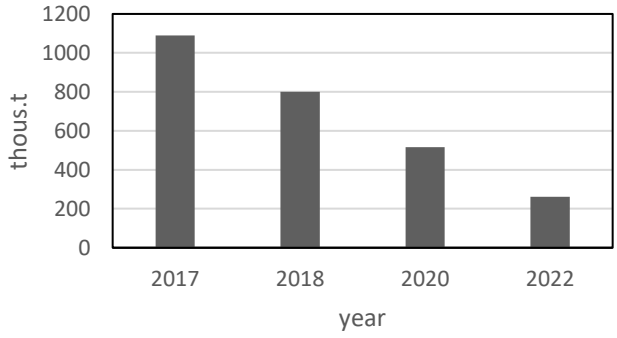

Fig. 2. Peas production 2017-2022 y.

As the demand for pea protein has increased dramatically mainly due to the growing interest in plant protein alternatives as a substitute for meat. The protein market continues to grow every day, and that's what creates the demand.

In the current situation, it is much more profitable for Ukrainian farmers to sell more expensive goods or products with added value, therefore, the legumes production in Ukraine can still have new developments.

Theoretical issues of land management have been developed in the works of such foreign scientists: Sitikantha, P.,[9], Bhattacharya R,[12]. The works of Takha Kh. [14].

Let's consider the method of the land distribution optimizing in wartime. Let's consider the following agricultural crops: wheat, buckwheat, peas. Since the future prices on the market are not fixed, the decision must be taken based on the following two criteria: maximizing expected total net income and minimizing the variance of total net income. The Lagrange method is used to solve the problem. The methodology is developed for the case of probabilistic nature of the future market prices for products. The methodology makes it possible to take inflation into account.

Since future market prices are not fixed, the decision must be taken based on two criteria: maximizing expected total net income and minimizing the variance of total net income. The Lagrange method is used to solve the problem. The developed method is for cases when the price for agricultural products is of a probabilistic nature. We find the maximum income according to formula (1):

$$\bar{z}_{max} = \sum_{i=1}^{N}(p_i - c_i)x_i \tag{1}$$

$\bar{z}_{max}$- maximum profit, p_i- the selling price of a product unit at a moment in time, c_i- expenses, x_i - volume of agricultural crops production; $\sigma(z)_{min}$- minimum variance, a - product scopes, N- the number of agricultural crops. Then maximum variance makes (2):

Next, the worst values of the criterion indicators are calculated for a set of effective variants of the calendar plan:

$$\sigma(z)_{min} = \frac{a}{\sqrt{\sum_{i=1}^{N}\frac{1}{\sigma_i^2}}} \tag{2}$$

$$\bar{z}_{min} = \frac{a}{\sqrt{\sum_{t=1}^{T}\frac{1}{\sigma_t^2}}}\sum_{t=1}^{T}\frac{\bar{p}_t - c_t}{\sigma_t^2},$$

We calculate the range of variation for criterion indicators (2):

$$(\bar{z}_{min} \le \bar{z}_0 \le \bar{z}_{max},\quad \sigma(z)_{min} \le \sigma_0 \le \sigma(z)_{max}) \tag{3}$$

The optimal calendar plan for the sale of agricultural products stocks is determined. This plan $x^* = (x_1^*, ..., x_T^*)$ is computed by solving a convex programming problem (3):

$$\begin{gathered} s \to max, \\ \sum_{t=1}^{T} (\bar{p}_i - c_i) x_i \geq \bar{z}_0 + s(\bar{z}_{max} - \bar{z}_0) \\ \sum_{i=1}^{N} \sigma_i^2 x_i^2 \leq \sigma_0^2 - s(\sigma_0^2 - \sigma_i^2(z)_{min}), \\ \sum_{t=1}^{T} x_i = a, \\ x_2 \leq 250; \\ x_i \geq 0, i = \overline{1, N} \end{gathered} \quad (4)$$

It shall be mentioned that the optimum value of s^* will indicate whether the product owner chose realistic admissible levels for criterial indices (at $s^* \geq 0$), or not (at $s^* < 0$).

With the help of the Lagrange multipliers method, the necessary conditions are established that allow the identification of optimal points in optimization tasks with constraints-equalities. At the same time, a problem with constraints turns into an equivalent problem of unconditional optimization with some unknown parameters, called Lagrange multipliers.

Table 2. Harvesting of agricultural crops on the 1st of December, 2021.

Crops	Harvested area, thous. ha	Volume of production, thous. tons	Yield, centners from 1 hect. of harvested area /	Prices for crops UAH/t	Standard price variance, UAH
wheat	7, 055.5	327, 196.7	46.4	8,030.00	491.00
buckwheat	87.8	1, 133.5	13.0	42,000.00	1,339.00
peas	239.2	5, 819.3	24.3	13,000.00	520,00

The general problem of conditional optimization with constraints-equalities is reduced to the problem of unconditional minimization using the Lagrange function, which is written down in the form of:

$$F(x1, x2, x3; \lambda_1, \lambda_2) = f(x1, x2, x3) + \sum_{i=1}^{K} \lambda_k h_k \quad (5)$$

An obligatory condition for using an expression (4) is that the number of constraints must be less than the number of variables. If this condition is not met, then there

is no optimization problem, because the number of variables' connections exceeds their number. Thus, the task is reduced to finding the minimum of the function:

$$\frac{\partial F(x_j;\lambda_k)}{\partial x_j} = 0$$

So, at this stage, we will first find the best values of the criterial indicators for:
expected total net income:
$\bar{z}_{max} = 32719{,}67 * 8030 + 113{,}33 * 42000 + 581{,}9 * 13000 =$275064,740(mln. UAH)
standard variance of total net income:

$$\sigma(z)_{min} = 18346{,}9(\text{млн. грн})$$

and then their worst values on the set of effective calendar plan options

$$\bar{z}_{min} = 114033{,}8021(\text{mln. UAH})$$

Let the acceptable levels of our problem be as follows:

$\bar{z}_0 = 114033{,}8021$(mln. UAH); $\sigma_0 = 18346{,}9(\text{mln. UAH})$

We solve our problem using the method of Lagrange multipliers.

To calculate it in MathCAD, write down the maximum income using the formula:

$F(x1, x2, x3, \lambda_1, \lambda_2)$=8030x1^2+42000x2^2+13000x3^2

where dispersion

u(x1,x2,x3)= 491x1+1339x2+520x3

System of partial differential equations:

$$\frac{dF(x1, x2, x3, \lambda_1, \lambda_2)}{dx1} \to 491 - 16060\lambda_1 x1 - \lambda_2$$

$$\frac{dF(x1, x2, x3, \lambda_1, \lambda_2)}{dx2} \to 1339 - 84000\lambda_1 x2 - \lambda_2$$

$$\frac{dF(x1, x2, x3, \lambda_1, \lambda_2)}{dx3} \to 520 - 26000\lambda_1 x3 - \lambda_2$$

$$\frac{dF(x1, x2, x3, \lambda_1, \lambda_2)}{d\lambda 1} \to 7436x1^2 - 1132x2^2 - 13000x3^2$$

$$\frac{dF(x1, x2, x3, \lambda_1, \lambda_2)}{d\lambda 2} \to 275064 - x1 - x2 - x3$$

The results of the calculations were as follows.

Optimal areas for: wheat - 7,000 thous. hectares; buckwheat - 250 thous. hectares, peas - 240 thous. hectares; expected total net profit: 2.820 billion UAH.

We also observe that there has been an improvement in the acceptable levels of criterial indicators originally chosen by the owner: the amount of expected total net income has increased by 6,813,507 thous. UAH.

Such results can be obtained by using the Industry 4.0 innovative technologies, which will bring undeniable progress in all areas. As a result, we will increase production and effectively manage resources; make quality decisions. An integrated production process formed on the basis of real data saves production time. Speaking about

Ukraine, it should be noted that although there are some lags behind other countries in the process of the latest technologies introduction and creation, the national economy still has the potential for development. Not only large agricultural holdings, but also small agricultural companies in Ukraine are massively implementing robotic processes, quadcopters, motion sensors and sensor technologies. This indicates an increase in the level of advanced technologies availability for all agricultural companies.

The scientific novelty of this study consists in the application of the Lagrange multipliers method for solving the problem of optimizing the agricultural crops areas under conditions of uncertainty. The case of price risks, when future market prices are not fixed, is also considered. Therefore, when making a decision it is necessary to take into account the two following criteria: to maximize the expected total net income and to minimize the variance of the total net income.

Implementing the order of the Cabinet of Ministers of Ukraine with regard to the action plan ensuring food security in the conditions of martial law, the optimization of areas for different crops was analyzed.

The work was carried out in support of the state food security program, as well as due to the forecasted demand for the crops.

Implementation of this program is not possible without application of Industry 4.0 innovative technologies in the agricultural sector.

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