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Optimization of Functioning of Crystallization Compartment in Sugar Production

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***Abstract* — Agriculture is the main resource component of food processing enterprises. It is necessary to find lines of contact between industry and agriculture. Such a connection can be seen in the development of cross-cutting scientific and technological areas, which include diverse modeling, the use of advanced planning methods, artificial intelligence (AI) systems and everything that is understood as digital technologies. Small and large businesses are making an active transition to digital technology. Industrial companies are rapidly advancing in the field of AI, investing in research and development in the field of industrial Internet. In this regard, smart agriculture is also coming to the fore. The docking of food processing industry, agriculture and business is the introduction of information technology in the agro-industrial complex (AIC). The comprehensive digitalization of agricultural production, from cultivation, harvesting and storage of crops to its delivery to a processing plant with subsequent processing, is a modern view of doing business. The article discusses the parametric optimization of a two-product workshop for the production of sugar. A mathematical model of the optimization process is proposed, and its numerical solution. The task of parametric optimization is to choose from a set of possible control actions a certain set of alternative options with a constant structure of the technological process. To solve the optimization problem, we used the method of extrapolation of expert estimates with non-transitive preferences.**

Keywords* — *expert systems, parallel computing, digital technology, MEEE, optimization problem, production of granulated sugar, control actions.

I. Introduction

Food processing enterprises play a leading role in food safety and the quality of life of Russian citizens. Digitalization of food production is of great importance [1]. The basis of the food industry is the development and conduct of agricultural production. The efficiency of production processes is positively influenced by integrated engineering solutions both in that and in other industrial areas. The first steps in digital technology are also being observed. Digitalization is manifested both in the use of automated lines and sections at processing enterprises, and in prescription solutions. At the technical level, digital solutions are built, synchronized and supported – the use of new advanced equipment. The introduction of modern software and wireless standards with the support of the Internet plays a large role in digitalization. This allows remote control of production processes and if necessary, quickly elimination of technical problems.

The development of modern information technologies almost erases the boundaries of traditional ideas about the collection, processing and analysis of information. But today, one of the main problems is that more than 2/3 of the collected production information is not in demand. A distinctive feature of modern production is the use of expert systems [2]. Their basis is intelligent data analysis tools. Artificial intelligence will allow manufacturers to process the huge amounts of data generated by their industries, operations and consumers, and convert this data into management decisions.

Nowadays the maintenance of modern technologies is inextricably linked with scientific developments and the justification of the results of production. The variety of tasks to be solved is very large: operational management, optimization of the production process, minimization of production losses while maximizing the receipt of the final product. Any real production does not have the ability to create real emergency situations. Therefore, to solve scientific and practical computational problems of wide purpose, including the problems of operational optimal control, mathematical modeling is used. The solution to such problems is associated with large amounts of data that need to be processed promptly to minimize the time delays in calculations. The process of dividing data into several processing cores is usually called a computing pipeline, which consists of the same type of execution stages [3]. In this way, we can significantly speed up the data processing process, providing results with the frequency of data arrival. Many processing algorithms use the same type of massive computing, which requires more computing power. Such algorithms can be executed in several independent streams using parallel or distributed systems, which will reduce the total processing time of the source data and accelerate the receipt of control actions. Using modern technologies of parallel computing allows solving complex resource-intensive tasks of modeling physical processes on a personal computer (PC). In the presented work, the team of authors offers a numerical solution to the mathematical model of the parametric optimization of the two-product department in the production of granulated sugar. Previously, to solve such problems it was possible only with the use of specialized hardware systems. The indispensable necessity of modern production is the availability of control centers (CI) of production, equipped with modern computer technology, communications and telecommunications. Personal computers today already include everything we need to do enough computing in parallel or competitive mode. However, it is necessary to take into account the features of the constructed model to develop effective parallelization algorithms for calculations. Multicore and multiprocessor personal computers, or cluster systems today are used as computing systems for parallel computing [3].

Sugar production plays a significant role in the total volume of the entire agro-industrial complex (AIC). Sugar and a variety of sugar-containing confectionery products are included in the consumer basket and are necessary for the normal functioning of each person. Beet-processing and beet-growing enterprises are links in one chain. The resource for sugar beet processing enterprises is directly the beet itself. The quality of raw materials (beets) is reflected in the quality and quantity of the main product (sugar) produced [4–6]. Therefore, the concept of "lean manufacturing" is applicable to both branches of the agro-industrial complex.

The first stage of Lean Production is the competent and adequate functioning of beet-growing enterprises. They lay the foundation for achieving the main result, starting from sowing, growing, harvesting, and ending with laying the root crops for storage. Mainly the quality of raw materials depends on its safety. Losses during the storage period are the main problem of beet-growing enterprises. The task of forecasting losses, or rather measures to avoid them, is the subject of numerous studies of advanced scientific personnel involved in beet production. The conducted studies allow concluding that the beets storage sites (kagaty) can be considered as a biological system in which some biotic interactions occur. To describe the dynamics of processes occurring in the storage sites of beets, the so-called complex biocenosis, it is necessary to know the degree of influence of dependent organisms. This is a rather complicated task requiring considerable research. The most promising modeling methods are the description of the biosystem by Markov models.

From a mathematical point of view, this approach is related to the use of finite-difference equations, since the Markov model can always be reduced to a system of differential or difference equations [2]. However, in a number of cases the Markov representation is more visual, allows a simpler interpretation of the simulation results and simplifies computational algorithms, which is attractive from a practical point of view. It is also important that in Markov models it becomes possible to introduce in a natural way such a fundamental concept as “probability”, which allows stochasticism to be included in the models of the dynamics of biosystems.

Thus, the beet-growing area needs automation in the field of forecasting possible losses. The cheapening of raw materials occurs for many reasons that were discussed in this chapter. It is these processes that bring the greatest losses to sugar beet-growing enterprises in the field of sugar production. The main reason for these losses can be safely called the activity of microorganisms that absorb sucrose root crops, linking non-sugar and making beet processing impossible. This process cannot be completely excluded from development. Today, there are many activities aimed at reducing the consequences of this process and not one designed to predict its development. Although such methods would help to make decisions about additional investments or changing storage conditions for beet-growing enterprises much easier [4–6].

The need to attract scientists to solve the problems was clearly demonstrated. Here it is necessary to conduct global research in the field of root crop safety, to develop a mathematical apparatus for forecasting losses and software, as the main element of a decision support system (DSS) or an expert system (ES). Accordingly, the involvement of computer technology comes to the fore. This all confirms the need for a transition to the digitalization of the agribusiness sectors.

The second stage of Lean Production is the transportation of beets for processing. There are many problems: field range, road quality, weather conditions, processing plant capacities. The transportation process is also closely related to the safety of root crops. One of the results of the DSS of loss forecasting is the forecast of sugar beet losses depending on external storage conditions and the establishment of timely export of root crops for processing.

The third stage of Lean Production is the processing of root crops at beet-processing enterprises.

The proposed models and algorithms were tested by solving the problem of parametric optimization of a two-product department in the production of granulated sugar.

The product department of sugar factories serves to extract sucrose from boiling supersaturated solutions in vacuum apparatuses (VA) of periodic action at low temperature (under vacuum) and to separate crystalline sugar in centrifuges.

The main indicator of sugar production is the percentage of sugar yield to the mass of processed beets (10–15 %). The increase in the yield of granulated sugar occurs due to the reduction of sucrose losses at all stages of the technological process, and, in particular, with molasses, which is a production waste, in the process of cooking sugar in the food department. This is achieved by improving the technological scheme of the food department (Fig. 1), as well as the optimal conduct of the process.

The food department should operate in such a way that the difference in the benign quality of the syrup from the evaporation station and molasses is as large as possible. Optimization of the crystallization process should be aimed at the maximum extraction of sucrose from beets in the shortest possible time according to the technology with the lowest consumption of steam, and, consequently, fuel, since vacuum apparatuses are one of the main consumers of steam at the sugar factory.

II. Methods and Materials

The task of parametric optimization was to choose from a variety of possible control actions, with a constant structure of the technological process, a certain set of alternative options that are optimal according to the following basic additive efficiency criteria:

- the difference in the quality of the products at the input and output of each process stages $x_1 \to \max$;
- energy consumption $x_2 \to \min$;
- processing time $x_3 \to \min$.

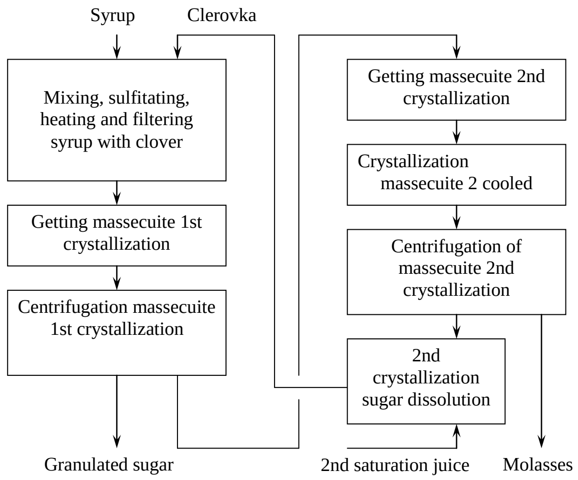

Fig. 1. The basic technological two-crystallization scheme of the grocery compartment

The additivity of each criterion is explained by the possibility of their use both for characterizing individual stages and for the entire TP variant.

The following were selected as the main control actions at the stages:

- the amount of syrup with clever;
- the amount of pumped juice in the vacuum apparatus of the 1st product;
- the amount of water for washing sugar 1 in centrifuges;
- the amount of pumped solution in VA of the 2nd product;
- the amount of water supplied to the crystallizer;
- the temperature of the massecuite 2 supplied to a centrifuge;
- the amount of juice of the 2nd saturation supplied to the dissolution of yellow sugar.

As a result, a lot of Pareto alternatives for control actions were obtained, consisting of 38 options (Table 1), from which several resulting effective solutions should be selected.

TABLE I. MANY EFFECTIVE SOLUTIONS

Option number	Difference in the quality x1, unit.	energy consumption x2 · 10^{-6}, kJ	processing time x3, minutes
1	32.5	2539	3024
2	27.7	2393	2706
3	32.0	2565	2975
4	28.1	2422	2743
5	33.0	2565	3073
6	31.3	2603	2937
7	28.6	2458	2803
8	32.9	2553	3057
9	28.9	2478	2827
10	33.4	2586	3113
11	29.2	2508	2834
12	33.8	2635	3168
13	29.5	2540	2806
14	30.5	2613	2872
15	29.8	2563	2807
16	31.7	2580	2953
17	30.1	2579	2844
18	30.7	2623	2896
19	29.6	2552	2791
20	30.3	2595	2859
21	30.9	2619	2912
22	31.1	2611	2926
23	28.4	2449	2781
24	31.5	2594	2946
25	29.9	2567	2829
26	31.9	2572	2959
27	27.9	2412	2722
28	33.5	2593	3129
29	32.4	2551	3011
30	27.6	2384	2684
31	32.7	2544	3043
32	28.8	2464	2816
33	28.3	2433	2767
1	2	3	4
34	33.2	2573	3096
35	29.0	2496	2841
36	32.2	2558	2992
37	33.6	2611	3147
38	29.4	2521	2821

Further, from this set, the best solutions were selected using the method of extrapolation of expert estimates. In order to conduct an expert survey, a training sample consisting of seven options was randomly generated from the set of effective solutions that were received: x^{13}, x^{15}, x^{22}, x^{26}, x^{28}, x^{35}, x^{38}, which was transferred for ranking to experts. This sample was ordered by them as follows: $x^{26} \succ x^{28} \succ x^{15} \succ x^{22} \succ x^{38} \succ x^{13} \succ x^{35}$. However, this ordering gave an empty set of acceptable values for the coefficients of generalized criterion (GC). An analysis of this streamlining was carried out, with expert opinions divided on the location of alternative x^{13}. To resolve the conflict, the 13th alternative was replaced by the 4th, and experts came to a consensus.

We are based on the data table 1, a search was made for the best solutions using the selection model with non-transitive preferences. Mentioned contradiction in the opinions of experts when ordering alternatives x^{22}, x^{38} and x^{13} they say that they have close utility values. The comparison of alternatives close in values gives a more informative result (more accurate values). In this regard, we will consider the same sample, and to overcome the contradiction, we will use the model we developed.

For convenience, we normalize all the criteria (Table 1) and bring to the $x_i \to \max$ (Table 2).

TABLE II. LOTS OF NORMALIZED EFFECTIVE SOLUTIONS

Option number	Difference in the quality x1, unit	energy consumption x2 · 10^{-6}, kJ	processing time x3, minutes
1	0.790323	0.38247	0.297521
2	0.016129	0.964143	0.954545
3	0.709677	0.278884	0.39876
4	0.080645	0.848606	0.878099
5	0.870968	0.278884	0.196281
6	0.596774	0.12749	0.477273
7	0.16129	0.705179	0.754132
8	0.854839	0.326693	0.229339
9	0.209677	0.625498	0.704545
10	0.935484	0.195219	0.113636
11	0.258065	0.505976	0.690083
20	0.435484	0.159363	0.63843
21	0.532258	0.063745	0.528926
1	2	3	4
22	0.564516	0.095618	0.5
23	0.129032	0.741036	0.799587
24	0.629032	0.163347	0.458678
25	0.370968	0.270916	0.700413
26	0.693548	0.250996	0.431818
27	0.048387	0.888446	0.921488
28	0.951613	0.167331	0.080579
29	0.774194	0.334661	0.32438
30	0	1	1
31	0.822581	0.36255	0.258264
32	0.193548	0.681275	0.727273
33	0.112903	0.804781	0.828512
34	0.903226	0.247012	0.14876
35	0.225806	0.553785	0.67562
36	0.741935	0.306773	0.363636
37	0.967742	0.095618	0.043388
38	0.290323	0.454183	0.716942

First we need to determine where the alternative x^{13} should be in the original sample. Combining the conflicting opinions of experts, we got the following ranking: $x^{13} \succ x^{22}$, $x^{22} \succ x^{38}$, $x^{38} \succ x^{13}$ i.e., there was non-transitivity in the preferences of experts. With such ranking of alternatives, a system of inequalities of the form (1) has a unique solution, which does not satisfy the stability principle

$$\sum_{u=1}^{k} b_u [f_u(x) - f_u(y)] = b^T [f(x) - f(y)] \geq 0, \quad (1)$$

where b_u are unknown parameters (weights), $f_u(x)$ are known functions.

To eliminate the resulting non-transitivity, we do the following. According to experts, the first criterion is the main one. Let us write the matrix for the values of ξ taken with the opposite sign, based on the assumption that all alternatives belong to the relation (2)

$$F(x^p) - F(x^s) \geq \varepsilon, \quad (2)$$

where $\varepsilon > 0$ is a small number.

Compare pair	Threshold value		
	ξ_1	ξ_2	ξ_3
$x^{38} \succ x^{13}$	0.016	-0.075	0.031
$x^{22} \succ x^{38}$	-0.27	0.36	0.22
$x^{13} \succ x^{22}$	0.25	-0.28	-0.23

Since the first criterion is the main one, we look for ξ_{minmax} by the first column: $\xi_{minmax}\{0.016, 0.25\} = 0.016$. The resulting value can be interpreted as small. Since the obtained threshold value corresponds to a comparison of $x^{38} \succ x^{13}$, from the point of view of the utility function, this ranking is incorrect, and a small threshold value explains this error. Therefore, we come to the ranking: $x^{13} \succ x^{22} \succ x^{38}$.

Based on the results, the training sample was eventually streamlined: $x^{26} \succ x^{28} \succ x^{15} \succ x^{13} \succ x^{22} \succ x^{38} \succ x^{35}$. The system of inequalities based on the new ranking has four basic solutions: (0.5017; 0.1702; 0.3281), (0.4951; 0.1852; 0.3197), (0.4759; 0.1185; 0, 4056), (0.4951; 0.0741; 0.4308), which satisfies the principle of stability. Let's move on to the new criterion functions:

$r1(x) = 0.5017\, f1(x) + 0.1702\, f2(x) + 0.3281\, f3(x)$;
$r2(x) = 0.4951\, f1(x) + 0.1852\, f2(x) + 0.3197\, f3(x)$;
$r3(x) = 0.4759\, f1(x) + 0.11856\, f2(x) + 0.4056\, f3(x)$;
$r4(x) = 0.4951\, f1(x) + 0.0741\, f2(x) + 0.4308\, f3(x)$.

After the Pareto dropout, the following narrowing was obtained according to the obtained criterion functions (Table 3).

TABLE III. THE RESULT OF NARROWING ALTERNATIVES

Option number	x1	x2	x3	ФП
1	0.790323	0.38247	0.297521	0.54706
8	0.854839	0.326693	0.229339	0.54489
29	0.774194	0.334661	0.32438	0.54453
26	0.693548	0.250996	0.431818	0.53874

III. CONCLUSION

Thus, the alternatives x^1, x^8, x^{29} and x^{26} are among the best options. This differs from the result obtained in; however, there is every reason to believe that our result is better than in. The fact is that the presence of nontransitivity in the opinion of an expert means the proximity of the usefulness of the compared alternatives. In turn, a comparison of close options generates a narrower range of acceptable values for the coefficients of OK. The presence of a narrow region entails obtaining more accurate estimates of the coefficients. In [79], the sample was generated in such a way that it did not meet alternatives of similar utility, which provided more comfortable conditions for the examination. This means that the range of acceptable coefficients was very wide, and the estimates obtained were not accurate enough. Therefore, our results are more accurate than in. A group of experts also agreed with this conclusion. The need for modernization of processing industrial enterprises creates the prerequisite for close cooperation between science and production. An analysis of the state of affairs makes us search in this area for the most effective ways of development. The implementation, use and implementation of promising scientific developments in the field of automation, robotization and digitalization will allow solving the problems of increasing labor productivity at domestic enterprises in the food and processing industry. The use of international best practices is important here. Current trends in the digitalization of technology and production are becoming more popular. This applies to both the food industry and the agricultural industry.

References

[1] Y.A. Salikov, I.V. Logunova, I.V. Kablashova, “Trends in human resource management in the digital economy”, Proc. of the Voronezh State Univer. of Engineer. Technol., vol. 81, no. 2, pp. 393–399, 2019. Retrieved from: https://doi.org/10.20914/2310-1202-2019-2-393-399

[2] S.V. Bukharin, A.V. Melnikov, S.N. Chernyaeva, L. A. Korobova, “The method of immersion the problem of comparing technical objects in an expert shell in the class of artificial intelligence algorithms”, [International Conference on Materials, Alloys and Experimental Mechanics (ICMAEM-2017)], IOP Conf. Ser. Mater. Sci. and Engineer. Int. Conf. on Mater., 2017, vol. 225, p. 012208. Retrieved from: https://doi.org/10.1088/1757-899X/225/1/012208

[3] G.V. Abramov, A.N. Gavrilov, A.L. Ivashin, I.S. Tolstova, “The use of parallel computing in resource-intensive tasks of modeling the processes of motion and interaction of particles in a plasma during the synthesis of carbon nanostructures”, Bull. of Moscow State Techn. Univer. n.a. N.E. Bauman. Natural Sci. Ser., no. 5, pp. 4–14, 2018. Retrieved from: https://doi.org/10.18698/1812-3368-2018-5-4-14

[4] N.G. Kul'neva, I.G. Selezneva, I.Yu. Sveshnikov, S.Yu. Kazakevich, “Control of Sugar Beet Indicators of Different Quality During Storage”, Storage and proc. of agricult., no. 4, pp. 32–34, 2017.

[5] G.V. Agafonov, N.G. Kul'neva, L.N. Putilina, “On Technological Qualities of Sugar Beet Affected by Vascular Bacteriosis”, Storage and proc. of agricult., no. 1, pp. 46–50, 2018.

[6] N.G. Kul'neva, L.N. Putilina, “The Choice of Parameters for Bactericide Treatment of Low Quality Beet Before Storage”, Storage and proc. of agricult., no 4, pp. 38–47, 2018.