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OPTIMIZATION OF MARKETING STRATEGIES IN THE AGRO-INDUSTRIAL COMPLEX OF KAZAKHSTAN BASED ON A HYBRID METHOD

Abstract. In the development of the agro-industrial complex (AIC) of the Republic of Kazakhstan, one of the key aspects is the improvement of information and consulting activities of enterprises and companies in the agricultural sector, in particular, aimed at increasing the efficiency of production and marketing of agricultural products. A significant aspect is also the development of agromarketing in the AIC, which will ultimately improve market mechanisms and increase the competitiveness of products of local agricultural producers. The study proposes a hybrid method for solving the problem of multi-criteria optimization of marketing strategies in the AIC. The method combines the use of the NSGA-II algorithm and machine learning based on K-means to analyze the results. The quality of the solution was assessed using the hypervolume parameters and visualization of the found optimal strategies using the Pareto front. The theoretical and practical significance of the study is confirmed by the possibility of adapting the proposed hybrid method for enterprises of the AIC of Kazakhstan, taking into account existing regional restrictions.

Keywords: agro-industrial complex (AIC), digital marketing, agromarketing, strategy, target functions, optimization, hybrid method, machine learning, models, agricultural products.

1. Introduction

As part of the strategic development of the agro-industrial complex (AIC) of the Republic of Kazakhstan (hereinafter RK), one of the priority areas is the improvement of information and consulting work with enterprises and companies in the agricultural sector. This process is aimed at increasing production efficiency, improving the marketing of agricultural products and creating favorable conditions for sustainable growth of the industry. The main areas in this area are: dissemination of information on the latest technologies and developments introduced in the agricultural sector, the creation of regional consulting centers, as well as the involvement of foreign specialists, which will help improve the qualifications of local specialists. An essential element of this process is the analysis of the needs of agricultural market participants in order to

optimize offers and improve interaction between various segments of the industry [1], [2].

An essential factor for the successful development of the agro-industrial complex of the Republic of Kazakhstan is agromarketing, which contributes to the improvement of market mechanisms and increased competitiveness of local producers. Marketing in the agro-industrial complex of Kazakhstan has a number of specific features due to the structural features of the economy of the Republic of Kazakhstan, geographical and demographic conditions, as well as the level of digitalization of the agricultural sector. Unlike marketing in traditional consumer segments, the promotion of agricultural products in the conditions of Kazakhstan requires taking into account many factors, such as significant spatial dispersion of producers and consumers, limited infrastructure and seasonality of demand [16], [20].

The specific features of the agricultural sector of Kazakhstan are largely related to climatic and natural conditions that affect the stability of production cycles and, as a consequence, the variability of supply. This, in turn, requires the implementation of adaptive marketing strategies that are able to flexibly respond to changes in the volume and structure of agricultural production. An essential aspect is the need to develop marketing solutions that would effectively interact with changing market conditions and taking into account the instability in agricultural production [1], [13].

Another characteristic feature is the prevalence of B2B communications over B2C models. A significant share of agricultural products in Kazakhstan is sold through wholesale channels and processing enterprises, which necessitates the development of marketing strategies aimed not only at the end consumer, but also at the corporate segment. This requires a different logic of interaction, as well as the use of more complex methods of analytics and demand forecasting. In this regard, marketing strategies should include flexible mechanisms that would take into account the interests and needs of both business and the end consumer.

The third significant feature is the insufficient level of digitalization of rural areas of the Republic of Kazakhstan, which limits the possibilities of using standard digital communication channels, such as social networks and targeted advertising. This requires the development of hybrid marketing models that would combine online and offline activities, as well as use traditional means of informing consumers. However, with the growing availability of the Internet and mobile devices in rural areas, new opportunities are opening up for the use of machine learning (ML) and data mining (DMP) technologies. These methods can be effectively used in areas such as demand forecasting, market segmentation and personalization of offers for agricultural products, which helps to increase the effectiveness of marketing campaigns.

In addition, it is necessary to take into account the regional specifics of demand in Kazakhstan, which depends on ethno cultural preferences, income levels of the population and logistics capabilities both within the country and in neighboring states. Regional differences can significantly affect the demand for agricultural

products, which requires the creation of more differentiated and adapted marketing strategies.

Based on the analysis of the current state of agricultural production infrastructure in Kazakhstan, conducted in works [1], [3], [4], it can be concluded that the existing mechanisms aimed at supporting marketing and agricultural production are insufficient to achieve effective results. Despite this, a number of studies, such as works [1], [14], propose specific steps to create and optimize marketing systems that are aimed at improving technological links and logistics in the process of movement of agricultural goods. These proposals are an important step towards improving the state of the agricultural market in Kazakhstan, increasing the competitiveness of local producers and ensuring sustainable development of the agro-industrial complex. Digitalization of the agro-industrial complex of Kazakhstan has given rise to the problem of optimal distribution of marketing budgets between various channels for promoting agricultural products. And traditional methods based on heuristics or single-criterion optimization [5], [6], [7] do not take into account the multiplicity of target indicators, such as advertising effectiveness [8], audience reach [9], and the cost of an advertising campaign [9], leading, as a rule, to suboptimal solutions. In this paper, the multi-criteria evolutionary algorithm NSGA-II (Non-dominated Sorting Genetic Algorithm II) [10], [11] is proposed to solve the problem of Pareto-optimal distribution of marketing resources in the agro-industrial complex. The relevance of the study is due to the need to develop adaptive strategies that can take into account non-linear dependencies between budgetary distributions of items and key metrics of digital marketing efficiency in the agro-industrial complex. Unlike classical methods, where scalar optimization dominates [12], the hybrid method proposed in the article will simultaneously maximize efficiency and coverage while minimizing costs, meeting the real requirements of agro-industrial enterprises of the agro-industrial complex of Kazakhstan, which usually operate under limited budgets [17], [18], [19].

2. Materials and methods

The aim of the study is to develop and implement digital marketing solutions based on machine learning, focused on the specifics of the agro-industrial complex of Kazakhstan.

2.1. The main material of the article

The reform of the agro-industrial complex of the Republic of Kazakhstan in recent decades, despite the complex challenges, has also prompted the sector to adapt to market conditions. In particular, the optimization of digital marketing and advertising processes has become an important tool for agricultural producers. In the market conditions, not only efficient production is becoming increasingly important, but also attention to the needs of end consumers of agricultural products, which is relevant for the agriculture of Kazakhstan, where the production of food, raw materials and food directly affects the socio-economic well-being of rural areas and the security of the state as a whole. Modern agricultural organizations in Kazakhstan have a great influence on the development of rural settlements, often becoming the main employers and economic centers for the local population [15]. It is important to note that the success of agricultural production today largely depends on how well the marketing processes are organized, on the focus on the consumer and on the construction of an effective system of commodity circulation. Otherwise, even successful production may face economic difficulties and a deterioration in the social situation in rural areas. The task of not only state policy, but also agricultural entrepreneurs is to create conditions for the effective operation and development of agricultural enterprises focused on modern market tools and requirements. It is important to invest in the education of agricultural leaders, farmers and managers of agricultural enterprises who will be able to effectively manage marketing and production processes. In this regard, the introduction of digital solutions in marketing for effective communication with end consumers is becoming especially important. Given the dynamically changing food market, agricultural enterprises in Kazakhstan should develop flexible and low-cost marketing mechanisms focused on consumer needs and innovative approaches to product promotion. It is essential that marketing strategies be developed taking into account the specifics of local markets, using modern technologies and tools, including digital platforms, to maximize the availability and attractiveness of products to consumers. Thus, marketers and agricultural producers should focus on studying market needs, reducing costs, improving product availability and an effective advertising strategy. At the same time, it is necessary to study how

government protectionist measures can be used to support domestic producers. An important aspect is the creation of an effective marketing system based on a project approach and process management, which will help strengthen the competitiveness of the agricultural sector of Kazakhstan in the domestic and international markets.

Mathematically, the problem includes a vector of target functions reflecting the effectiveness, coverage and cost of marketing campaigns, as well as a system of constraints taking into account budget and industry specifications. Formally, the problem is reduced to finding a set of Pareto-optimal budget allocations, for which a modified NSGA-II with adapted crossover and mutation operators is used. The approach is validated on synthetic data simulating real conditions of agro-industrial marketing, with subsequent assessment of the quality of solutions through hypervolume (Hypervolume indicator) and visualization of the 3D Pareto front; real data on enterprises of the Republic of Kazakhstan in the agro-industrial complex were also used.

Let's consider the problem of distributing the marketing budget between channels – digital, TV, Radio, Print, Events (exhibitions, presentations, etc.). We assume that for each channel and segment the following parameters are set: efficiency, audience reach, price. The problem of distributing the marketing budget between $n = 5$ channels – digital (x_1), TV (x_2), Radio (x_3), Seal (x_4), Events (exhibitions, presentations, etc.) (x_5). We assume that for each channel (i) and segment ($s \in [0, 1]$) the following parameters are set: efficiency $e_{s,i} \in [0, 1]$, audience reach $c_{s,i} \in [0, 1]$, price $p_i > 0$. We will also define the efficiency and coverage matrices: $E_s = [e_{s,1} \ e_{s,2} \ e_{s,3} \ e_{s,4} \ e_{s,5}]$, $S_s = [s_{s,1} \ s_{s,2} \ s_{s,3} \ s_{s,4} \ s_{s,5}]$. And the cost vector $P = [p_1 \ p_2 \ p_3 \ p_4 \ p_5]^T$.

Let's describe the objective functions. It is required to maximize the overall efficiency $f_1(X, s) = \sum_{i=1}^5 x_i \cdot e_{s,i}$ and overall audience reach $f_2(X, s) = \sum_{i=1}^5 x_i \cdot c_{s,i}$. And accordingly, minimize the cost of implementing a certain

marketing strategy and advertising

$$f_3(X) = \sum_{i=1}^5 x_i \cdot p_i \rightarrow \max.$$

In the problem of multicriterial optimization we are looking for Pareto-optimal solutions:

$$\max_{X \in F} (f_1(X), f_2(X)), \min_{X \in F} f_3(X), \text{ Where } F - \text{set of feasible solutions.}$$

And we will formulate the corresponding restrictions. On the general budget $\sum_{i=1}^5 x_i < 2,0$.

$$HV = Volume \left(\bigcup_{X \in P} |f_1(X), r_1| \times |f_2(X), r_2| \times |f_3(X), r_3| \right),$$

where P – Pareto front, r – reference point. To test the proposed hybrid method, a computational experiment was conducted. The initial data for the two segments was taken as follows based on data from several enterprises in the agro-industrial complex of Kazakhstan:

$$E_0 = [0.95, 0.75, 0.85, 0.60, 0.90],$$

$$C_0 = [0.85, 0.65, 0.80, 0.50, 0.75],$$

$$E_1 = [0.85, 0.85, 0.75, 0.65, 0.80],$$

$$C_0 = [0.75, 0.75, 0.70, 0.55, 0.70].$$

$$\text{And the cost } P = [1.1, 0.8, 1.0, 0.6, 0.9].$$

The solutions found must satisfy the Pareto-optimal solution, i.e.

$$X^* = \arg \max_{X \in F} (f_1, f_2), \arg \min_{X \in F} f_3.$$

2.2. Methodology details.

In this study, the NSGA-II algorithm was applied with the following parameters: population size = 100, number of generations = 200, crossover probability = 0.9, mutation probability = 0.1. Initial solutions were seeded using uniform distribution of the budget across channels. Constraints were handled by penalizing infeasible solutions exceeding budget or violating channel share bounds.

Min/Max Channel Shares $0, 1 \leq x_1 \leq 0,9$,
 $0, 1 \leq x_2 \leq 0,9$, $0, 1 \leq x_3 \leq 0,9$, $0, 1 \leq x_4 \leq 0,5$,
 $0, 1 \leq x_5 \leq 0,2$. And combined restrictions
 $x_1 + x_2 \geq 0,2$, $x_1 \geq 0,2$.

As a solution method, we use NSGA-II at the first stage to search for the Pareto front. The quality assessment (Hypervolume Indicator) is performed as follows

For the hypervolume indicator, normalization of all objectives was performed, and the reference point was set to (0,0, max cost). K-means clustering was applied after normalization of solutions, with the optimal number of clusters determined by the elbow method (k=3). Standard scaling was used to balance efficiency, coverage, and cost in clustering.

K-means clustering was applied on normalized solutions using k-means++ initialization. The number of clusters (k=3) was chosen based on the elbow method and validated with silhouette score (0.67) and Davies–Bouldin index (0.54), indicating robust separation. Experiments used both synthetic and real aggregated data. The synthetic dataset simulates budget allocations across 5 channels (Digital, TV, Radio, Print, Events) with varying effectiveness, coverage, and costs. Real aggregated data were collected from 10 enterprises of Kazakhstan’s agro-industrial complex for 2018–2022, including budget allocations, efficiency (ROI, %), coverage (thousand people), and costs (K USD). Only anonymized aggregated statistics are reported for confidentiality.

3. Results

The results of the computational experiments are presented in Table 1 (synthetic data) and in Figures 1, 2.

Table 1 – Results of modeling the analysis of the effectiveness of various media channels for promoting agricultural products on the RK market.

Cluster	Avg Efficiency	Avg Coverage	Avg Cost	Avg Score	Key Channels
0	1.260	1.110	1.290	0.690	TV, Print, Radio
1	0.680	0.600	0.750	0.610	Radio, Print
2	1.560	1.390	1.730	0.660	Digital, TV

The conducted research was aimed at analyzing the effectiveness of various media channels (Digital, TV, Radio, Print, Events) to study their impact on the indicators of effectiveness (Efficiency), coverage (Coverage) and cost (Cost) for various segments (Segment) and clusters (Cluster). As a

result of data processing, the following key patterns were identified. Cluster 0 demonstrates high values of the Efficiency and Coverage indicators, which indicates the high effectiveness of media strategies focused on this segment. The greatest contribution is made by TV and Print channels.

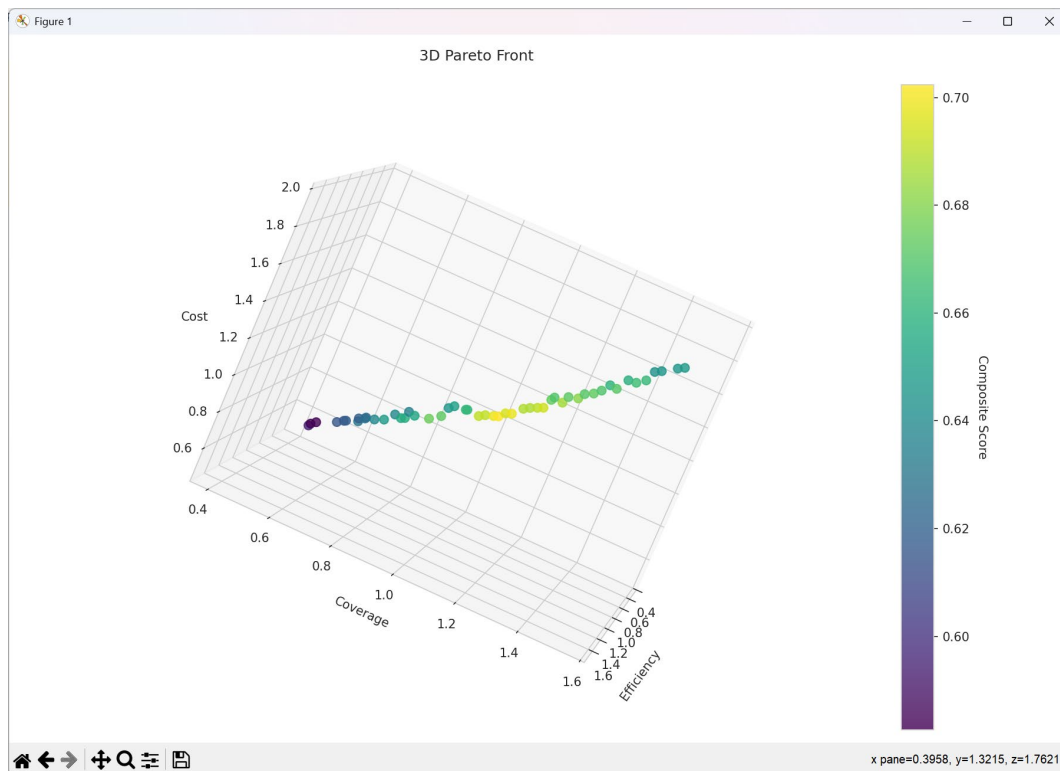


Figure 1 – 3D Pareto front in 3D format, formed as a result of applying the hybrid method.
 Axes: Efficiency (ROI, %), Coverage (audience $\times 10^3$), Cost (K USD).

The results of the study allowed us to conclude that the effectiveness of media strategies significantly depends on the choice of channels and their adaptation to specific segments and clusters. The greatest effectiveness is achieved with the combined use of Digital and TV, especially in cluster 2. The data obtained can be used to optimize

media planning and increase the ROI of marketing campaigns of agricultural enterprises in Kazakhstan.

Figure 2 – 2D Pareto frontier reflecting the trade-off between the effectiveness of marketing strategies and the reach of the target audience. Axes: Efficiency (ROI, %), Coverage (audience $\times 10^3$). Marker size represents cost (K USD).

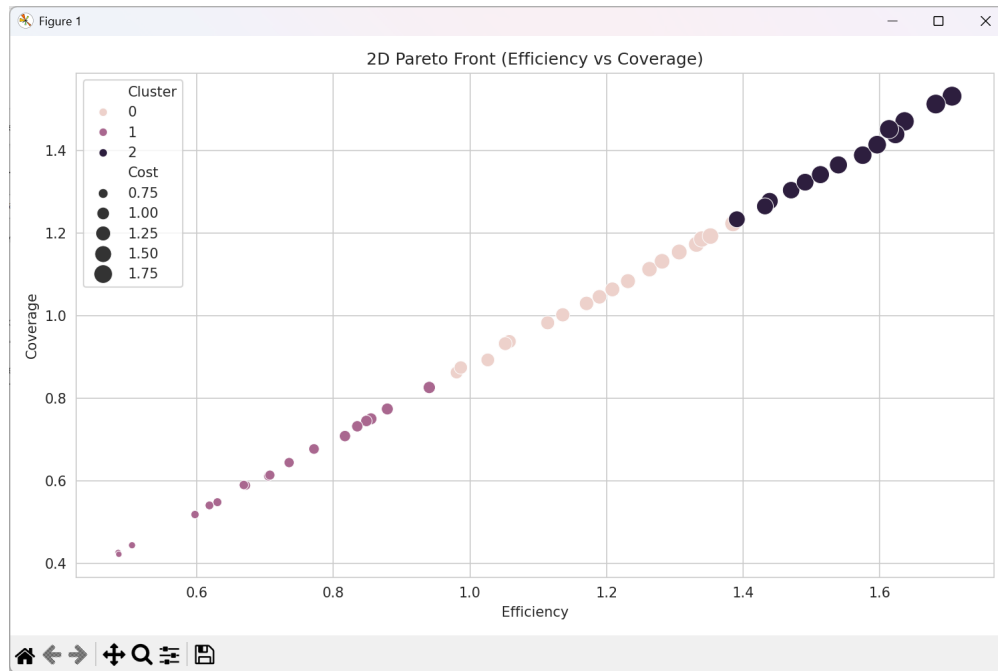


Figure 2 – 2D Pareto frontier reflecting the trade-off between the effectiveness of marketing strategies and the reach of the target audience.
 Axes: Efficiency (ROI, %), Coverage (audience $\times 10^3$). Marker size represents cost (K USD).

The size of the markers on the graph is proportional to the cost of implementing the strategy, providing a clear representation of the relationship between the key parameters – efficiency and coverage. Analysis of the distribution of solutions shows that the strategies of cluster 0 are characterized by relatively high efficiency with moderate coverage, while cluster 1 combines solutions with increased coverage, but lower efficiency. Cluster 2 includes strategies with intermediate values of both indicators. The upper right part of the graph shows the solutions demonstrating the best values of both efficiency and coverage, but their implementation is associated with higher costs, which is evident from the increased size of the corresponding markers.

4. Discussion

Such strategies can be recommended for use in conditions of sufficient budget for enterprises in the agro-industrial complex. On the contrary, solutions with smaller marker sizes, corresponding to lower costs, can be preferable for agro-industrial enterprises with limited resources.

It should be noted that the novelty of the model lies in the development of a comprehensive method

combining evolutionary algorithms and machine learning for marketing optimization tasks in the agro-industrial complex. And the practical significance is confirmed by the application of the obtained solutions for planning advertising campaigns taking into account the regional characteristics of agro-industrial enterprises in Kazakhstan and resource constraints. The proposed approach expands the arsenal of decision-making methods in the conditions of multi-criteria and uncertainty characteristic of agro-industrial marketing. Further research can be aimed at integrating predictive models of channel efficiency and taking into account dynamic changes in market conditions.

4.1. Reproducibility.

To ensure reproducibility, the random seed for NSGA-II and K-means was fixed (seed=42). The code used for optimization and clustering is available from the authors upon request. The synthetic dataset can be regenerated following the described procedure, while aggregated real data statistics are provided in the Data description section.

4.2. Correlation analysis.

A correlation matrix was constructed to support the observed relationships between channels.

Pearson's correlation coefficients are shown in Table 2. Results indicate a strong positive correlation between Digital and Radio (0.88), a

moderate positive correlation between Digital and TV (0.65), and a negative correlation between Print and other channels (around -0.40).

Table 2 – Correlation matrix of media channels

	Digital	TV	Radio	Print	Events
Digital	1.00	0.65	0.88	-0.42	0.21
TV	0.65	1.00	0.55	-0.36	0.30
Radio	0.88	0.55	1.00	-0.41	0.25
Print	-0.42	-0.36	-0.41	1.00	-0.28
Events	0.21	0.30	0.25	-0.28	1.00

5. Conclusions

It is shown that the developed hybrid method combining the NSGA-II algorithm and K-means clustering provides an effective solution to the problem of multi-criteria optimization of marketing budgets under conditions of limited resources typical for a number of enterprises in the agro-industrial complex of Kazakhstan. The obtained Pareto-optimal solutions demonstrate a compromise between the criteria of efficiency, coverage and cost, which is confirmed by the analysis of the hypervolume and cluster structure of the decision front. The greatest efficiency is demonstrated by strategies with a combination of digital and television channels (cluster 2), while radio and print media are appropriate for segments with a moderate budget (cluster 1). Correlation analysis revealed a strong relationship between digital channels and radio (0.88), as well as a negative correlation of print media with other channels. The approach proposed in the article

allows adapting marketing strategies to the dynamic conditions of the agro-industrial complex market in Kazakhstan, minimizing costs while maximizing key metrics.

Note: Avg Score is a normalized composite indicator combining efficiency, coverage, and cost with equal weights (0.33 each).

Author Contributions

Conceptualization, – Zh.A. and R.K.; Methodology – Zh.A. ; Software, N.K.; Formal Analysis, G.B.; Investigation, X.X.; Resources, V.L, A.D.; Data Curation, X.X.; Writing – Original Draft Preparation, .L, A.D.; Writing – Review & Editing, Zh.A.; Visualization, Zh.A. and R.K.; Supervision, Zh.A. and R.K.; Project Administration, Zh.A.; Funding Acquisition, Zh.A.

Conflicts of Interest

The authors declare no conflict of interest.

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