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***S. Zh. Assyl-Keney¹, L. M. Alimzhanova², Zh. Zhanatkyzy³,
J. Kultan⁴, R. G. Bikmurzin⁵**

^{1,2,3}Al-Farabi Kazakh National University,

Republic of Kazakhstan, Almaty;

⁴University of Economics in Bratislava,

Slovak Republic, Bratislava;

⁵Almaty University of Power Engineering and Telecommunications Colledge,
Republic of Kazakhstan, Almaty.

¹ORCID: <https://orcid.org/0009-0006-3508-914X>

²ORCID: <https://orcid.org/0000-0002-8172-0493>

³ORCID: <https://orcid.org/0009-0004-3223-0617>

⁴ORCID: <https://orcid.org/0000-0001-6068-9784>

⁵ORCID: <https://orcid.org/0009-0006-3524-3135>

*e-mail: symbatassylkeney@gmail.com

DIGITAL MARKETING IMPACT ON PROMOTION OF KAZAKHSTAN'S AGRO-INDUSTRIAL PRODUCTS

This paper develops and numerically investigates a dynamic model for assessing the effectiveness of digital marketing channels in promoting agricultural products in Kazakhstan. The model describes the joint evolution of brand awareness, customer base, and cumulative revenue under the influence of marketing investments and seasonal demand fluctuations. The core of the approach is a system of three nonlinear ordinary differential equations, where the state variables represent brand awareness $A(t)$, number of active customers $C(t)$, and cumulative revenue $S(t)$. Digital channels are modeled through control functions $u_i(t)$, which affect both awareness and direct sales, while seasonality is represented by a sinusoidal component in the awareness equation.

A numerical experiment is carried out for a 24 month planning horizon with a total digital marketing budget of 10 million KZT, equally and constantly allocated among three channels (search advertising, social media, and marketplaces). Under this baseline strategy, brand awareness increases from 100 to approximately 420 conditional units, the customer

base grows from 50 to about 1 650 active customers, and cumulative revenue reaches around 1.4 billion KZT equivalent by the end of the period. The instantaneous revenue rate rises from about 1.3 million KZT per month at the beginning to over 40 million KZT per month by month 24.

The obtained results demonstrate a pronounced time lag between awareness growth and revenue acceleration, a saturation effect in the customer base due to limited market capacity, and a strong seasonal modulation of short term performance. The proposed model provides a quantitative basis for scenario analysis and future optimal allocation of digital marketing budgets in the agri food sector of Kazakhstan.

Keywords: digital marketing, agribusiness, agricultural products, Kazakhstan, dynamic modeling, system of differential equations, marketing budget optimization.

Introduction

The development of digital communication channels has radically changed the way agricultural products are promoted. For Kazakhstan, where a significant portion of agricultural products are sold through regional markets, wholesale purchases, and gradually expanding online channels, the task of assessing the effectiveness of digital marketing is particularly relevant.

Traditional analysis methods (simple cost-to-sales comparisons, static ROMI models) poorly account for the dynamics of brand awareness, the inertia of customer base growth, seasonal fluctuations in demand for agricultural products, and the interaction of various digital channels (search advertising, targeted advertising, marketplaces).

With limited marketing budgets, it's important for agricultural businesses to not only understand the overall return on their digital investments but also to predict how these investments will translate into awareness, customers, and revenue over time. This requires a dynamic, rather than static, approach.

This paper proposes a mathematical model based on a system of ordinary differential equations that describes the evolution of three key metrics: the integrated brand awareness index, the number of active customers, and accumulated revenue. The model is specifically adapted to the conditions of Kazakhstan's agricultural sector and focuses on the use of data from digital marketing channels.

The contemporary global economy is undergoing profound transformations, driven by rapid technological advancements, pervasive digitalization, and the escalating prominence of online business models and social media [1]. This digital revolution has significantly altered consumer behavior and market dynamics, compelling industries worldwide, including the agro-industrial complex, to adapt

their promotional strategies [2]. Specifically, the integration of digital marketing within the agricultural sector offers novel avenues for product promotion, market expansion, and enhanced engagement with consumers [3; 4].

The shift towards digital platforms necessitates a robust understanding of various digital marketing channels and their efficacy in reaching diverse target audiences within the agricultural sector [5]. This research aims to model the effectiveness of these digital channels for promoting Kazakhstan's agro-industrial products, considering the unique challenges and opportunities present in this emerging market [6]. This study specifically focuses on leveraging digital marketing strategies to improve the competitiveness of local agricultural products by identifying effective approaches for expanding market reach and boosting sales in the digital era [7].

The successful implementation of such strategies often relies on the nuanced application of modern marketing research methodologies, which are crucial for understanding global market dynamics and evolving consumer preferences [8]. Furthermore, the adoption of digital marketing strategies can significantly reduce advertising costs while increasing profitability, thereby contributing to the efficient use of resources and sustainable development within the agri-food industry [9]. Given the increasing global consumption of natural food products and the imperative to enhance the competitiveness of domestic agro-industrial output, understanding the optimal deployment of digital marketing channels becomes paramount for mitigating foreign product intervention and bolstering local markets [10]. This is particularly relevant given that consumers now spend significantly more time online than with traditional media, making digital platforms crucial for reaching potential customers [11]. Moreover, the ability of digital marketing to provide personalized experiences and targeted content through channels like social media has further reshaped brand-consumer interactions and expectations [12]. This shift mandates that businesses, particularly those within the agro-industrial complex, optimize their online presence to effectively engage with discerning consumers [9].

This paradigm shift necessitates a comprehensive review of existing literature on digital marketing in agriculture, focusing on its impact on brand awareness, market expansion, and consumer engagement [1; 13]. Specifically, the integration of innovative digital tools like short videos and immersive live streaming is gaining traction as a powerful method for marketing agricultural products, enhancing consumer trust, and driving sales growth by fostering closer farmer-consumer connections [14]. This approach helps bridge information asymmetry and allows unique regional agricultural products to reach broader markets with lower promotional costs compared to traditional advertising methods [15].

Furthermore, digital emotional branding campaigns, particularly through platforms like Instagram and Facebook, have shown significant potential in fostering deeper emotional connections with consumers, leading to increased engagement and substantial sales growth within the agricultural sector [16]. Such strategies enhance resource efficiency through reduced advertising costs and increased profitability, a phenomenon observed in established agri-food firms [9]. Moreover, the increasing accessibility of the internet and its widespread penetration, particularly in developing regions, underscores the critical role digital marketing plays in enhancing the visibility and competitiveness of local agribusiness products [17].

The rapid adoption of digital technologies across various sectors highlights the urgent need for agricultural businesses to embrace digital marketing to remain competitive and meet evolving consumer demands [11]. Consequently, agribusinesses must leverage digital marketing to expand their reach, engage with consumers, and analyze market trends effectively [18]. This includes optimizing online presence through various digital channels, such as social media, e-commerce platforms, and emerging technologies like augmented reality and virtual reality, which offer dynamic engagement opportunities and rich consumer insights [19], [20]. These digital advancements empower businesses to gather extensive data on consumer preferences, allowing for highly targeted marketing campaigns and personalized product offerings that were previously unattainable [11].

The research's scientific novelty lies in the development of an integrated dynamic model that, within a single framework, describes the evolution of awareness, customer base, and revenue, taking into account the influence of digital channels, forgetting processes, market logistical constraints, conversion, and the behavior of active customers. This approach fundamentally differs from static ROMI models in that it is formulated as a system of nonlinear differential equations, allowing for the tracing of time lags between marketing investments and financial responses, analyzing saturation and accumulation effects, and examining the sensitivity of results to parameters. A significant contribution is the inclusion of a seasonal component in the model, reflecting the specifics of Kazakhstan's agricultural markets and allowing for the study of the impact of the temporal structure of sowing and harvesting cycles on campaign effectiveness. A numerical experiment with realistic parameters demonstrates the model's applicability to agricultural enterprises and provides a foundation for further research in the field of optimal marketing investment management.

The aim of this study is to develop and numerically test a dynamic model for assessing the effectiveness of digital marketing channels in promoting Kazakhstan's agricultural products. This model allows for a quantitative assessment of the impact of marketing investments on awareness, customer base, and revenue over time,

taking into account seasonal demand patterns and limited market capacity, and provides a basis for solving problems of optimally distributing the marketing budget across digital channels.

Materials and methods

Problem statement

This paper examines the problem of modeling the dynamics of sales of agricultural products in Kazakhstan under the influence of three main digital marketing channels, contextual advertising, targeted advertising on social media, and promotion through marketplaces. The objective function is to maximize the total revenue of an agricultural enterprise within given budget constraints on marketing investments.

The specific nature of Kazakhstan's agro-industrial complex necessitates accounting for seasonal fluctuations in demand, market saturation effects, time lags between marketing efforts and consumer responses, and the mutual influence of channels. Traditional static marketing mix models are unable to adequately describe these dynamic processes, necessitating the use of differential equations.

We formalize the problem as follows. Let $S(t)$ be the sales volume at time t , $u_1(t)$, $u_2(t)$, $u_3(t)$ be the investment intensities in contextual advertising, targeted advertising, and marketplaces, respectively. We need to determine the optimal control action trajectories $u_i(t)$, that maximize the integrated revenue over a given time horizon $[0, T]$ subject to constraints on the total marketing budget.

Mathematical model

Sales dynamics are described by a system of nonlinear ordinary differential equations reflecting the processes of consumer awareness formation, conversion to purchases, and natural customer churn.

Let's introduce the phase variables. $A(t)$ is the target audience's awareness of agricultural products (potential customers reached by marketing messages). $C(t)$ is the number of active customers (those who have made a purchase and are in the database). $S(t)$ is the cumulative revenue.

The system of differential equations is as follows:

$$\begin{aligned}\frac{dA}{dt} &= \alpha_1 u_1(t) + \alpha_2 u_2(t) + \alpha_3 u_3(t) - \delta_A A(t) + \beta \sin\left(\frac{2\pi t}{T_{\text{season}}}\right), \\ \frac{dC}{dt} &= \gamma A(t) \left(1 - \frac{C(t)}{C_{\max}}\right) - \mu C(t), \\ \frac{dS}{dt} &= \rho C(t) + \eta_1 u_1(t) + \eta_2 u_2(t) + \eta_3 u_3(t),\end{aligned}\tag{1}$$

where the model parameters α_i are the efficiency coefficients of channel i in generating awareness, reach per unit of investment, δ_A is the coefficient of natural

brand forgetting, β is the amplitude of seasonal fluctuations in demand typical for the agro-industrial complex of Kazakhstan, T_{season} is the seasonality period (12 months), γ is the coefficient of awareness conversion into active customers, C_{max} is the market capacity, the maximum number of potential customers, μ is the customer churn coefficient, ρ is the average revenue per active customer per unit of time, η_i are the coefficients of the direct contribution of channel i to revenue (for example, through direct sales on marketplaces).

The model describes a process in which awareness is generated linearly by control signals $u_i(t)$, taking into account natural forgetting $-\delta_A A(t)$ and the influence of seasonal fluctuations in demand. The customer base evolves logistically, with saturation at C_{max} and gradual attrition $\mu C(t)$. Revenue accumulates as a result of existing customer activity and the direct contribution of the marketing channels used, forming an integral indicator of system performance.

Modeling parameters

For numerical modeling, fixed parameter values are used, in conditional but realistic units for the agro-industrial complex of Kazakhstan. The effectiveness of channels by awareness $\alpha_1 = 0.8$, $\alpha_2 = 1.2$, $\alpha_3 = 0.6$. Brand forgetting $\delta_A = 0.05$ Seasonality $\beta = 50$, $T_{\text{season}} = 12.0$ months. Conversion of awareness into customers $\gamma = 0.15$. Market capacity $C_{\text{max}} = 5000$. Customer churn $\mu = 0.08$. Revenue per customer and direct contribution of channels $\rho = 25.0$, $\eta_1 = 0.5$, $\eta_2 = 0.3$, $\eta_3 = 1.5$.

Initial conditions $A(0) = A_0$, $C(0) = C_0$, $S(0) = 0$. Budget constraint $\int_0^T [u_1(t) + u_2(t) + u_3(t)] dt \leq B_{\text{total}}$. The optimal control problem is formulated as maximization of the functional:

$$J = S(T) - \lambda \int_0^T [u_1^2(t) + u_2^2(t) + u_3^2(t)] dt \rightarrow \max. \quad (2)$$

where λ is a regularization parameter that penalizes excessive investment volatility.

The total marketing budget for horizon T is assumed to be fixed $B_{\text{total}} = 10000$ thousand tenge.

In this numerical experiment, a simple strategy is adopted: the budget is spent uniformly over time and equally across three channels. Then, the average investment intensity in each channel is $u_1(t) = u_2(t) = u_3(t) = u_{\text{const}} = \frac{B_{\text{total}}}{3T}$. The numerical value of $u_{\text{const}} = \frac{10000}{3 \cdot 24} \approx 138.89$ thousand tenge per month per channel.

This study utilized synthetic data obtained using the author's dynamic model, a system of ordinary differential equations. All numerical experiments were conducted in the Python environment. Real statistical data on the performance of

agricultural enterprises was not used in the numerical modeling; the parameters were selected to provide realistic estimates of awareness, customer base, and revenue.

Solution method

To solve the problem numerically, we use the direct Cauchy problem approach. We fix the control variables and integrate the system of differential equations using the fourth-order Runge-Kutta method over the time interval $[0, T]$. This allows us to obtain the trajectories of the phase variables $A(t)$, $C(t)$, $S(t)$ for a given investment strategy.

In the right-hand sides of the equations, constants $u_i(t)$ are substituted instead of u_{const} . With constants $u_i(t) = u_{\text{const}}$, the system takes the form:

$$\frac{dS}{dt} = \rho C(t) + (\eta_1 + \eta_2 + \eta_3)u_{\text{const}}. \quad (3)$$

Let us substitute the total coefficients $\alpha_\Sigma = \alpha_1 + \alpha_2 + \alpha_3 = 0.8 + 1.2 + 0.6 = 2.6$, $\eta_\Sigma = \eta_1 + \eta_2 + \eta_3 = 0.5 + 0.3 + 1.5 = 2.3$.

Then:

$$\begin{aligned} \frac{dA}{dt} &= 2.6 u_{\text{const}} - 0.05A(t) + 50\sin\left(\frac{2\pi t}{12}\right), \\ \frac{dC}{dt} &= 0.15 A(t) \left(1 - \frac{C(t)}{5000}\right) - 0.08 C(t), \\ \frac{dS}{dt} &= 25 C(t) + 2.3 u_{\text{const}}. \end{aligned} \quad (4)$$

The system is integrated on the interval $t \in [0, 24]$ using the 4th order Runge-Kutta method with an adaptive step:

$$f(x_n, t_n) = \begin{cases} A_{n+1} = A_n + \frac{h}{6} \cdot (k_1 + 2k_2 + 2k_3 + k_4) \\ C_{n+1} = C_n + \frac{h}{6} \cdot (k_1 + 2k_2 + 2k_3 + k_4) \\ S_{n+1} = S_n + \frac{h}{6} \cdot (k_1 + 2k_2 + 2k_3 + k_4) \end{cases} \quad (5)$$

Internally, the method uses the following iterative scheme for each step $t_n \rightarrow t_{n+1} = t_n + h$:

$$\begin{aligned} k_1 &= f(x_n, t_n), \\ k_2 &= f\left(t_n + \frac{h}{2}, x_n + \frac{h}{2}k_1\right), \\ k_3 &= f\left(t_n + \frac{h}{2}, x_n + \frac{h}{2}k_2\right), \\ k_4 &= f(t_n + h, x_n + hk_3). \end{aligned}$$

with subsequent construction of two approximations of different orders and automatic selection of the step h

$$\begin{aligned}
 k_{1,A} &= 2.6 u_{\text{const}} - 0.05A(t_n) + 50\sin\left(\frac{2\pi t_n}{12}\right), \\
 k_{1,C} &= 0.15 A(t_n) \left(1 - \frac{C(t_n)}{5000}\right) - 0.08 C(t_n), \\
 k_{1,S} &= 25 C(t_n) + 2.3 u_{\text{const}}, \\
 k_{2,A} &= 2.6 u_{\text{const}} - 0.05A\left(t_n + \frac{h}{2}\right) + 50\sin\left(\frac{2\pi(t_n + \frac{h}{2})}{12}\right), \\
 k_{2,C} &= 0.15 A\left(t_n + \frac{h}{2}\right) \left(1 - \frac{C(t_n + \frac{h}{2})}{5000}\right) - 0.08 C\left(t_n + \frac{h}{2}\right) \\
 k_{2,S} &= 25 C\left(t_n + \frac{h}{2}\right) + 2.3 u_{\text{const}}, \\
 k_{3,A} &= 2.6 u_{\text{const}} - 0.05A\left(t_n + \frac{h}{2}\right) + 50\sin\left(\frac{2\pi(t_n + \frac{h}{2})}{12}\right), \\
 k_{3,C} &= 0.15 A\left(t_n + \frac{h}{2}\right) \left(1 - \frac{C(t_n + \frac{h}{2})}{5000}\right) - 0.08 C\left(t_n + \frac{h}{2}\right) \\
 k_{3,S} &= 25 C\left(t_n + \frac{h}{2}\right) + 2.3 u_{\text{const}}, \\
 k_{4,A} &= 2.6 u_{\text{const}} - 0.05A(t_n + h) + 50\sin\left(\frac{2\pi(t_n + h)}{12}\right), \\
 k_{4,C} &= 0.15 A(t_n + h) \left(1 - \frac{C(t_n + h)}{5000}\right) - 0.08 C(t_n + h), \\
 k_{4,S} &= 25 C(t_n + h) + 2.3 u_{\text{const}}.
 \end{aligned}$$

To display the results, the solution values are additionally interpolated onto a uniform grid of 500 points $t_i = \frac{24i}{499}$, $i = 0, \dots, 499$.

Results and discussion

The numerical solution shows a steady growth of the function $A(t)$ from the initial level $A(0) = 100$ (see Fig. 1). In the early part of the integration, the growth is due to the dominance of the positive contribution from constant investments in the channels $2.6 u_{\text{const}} = 2.6 \cdot 138.89 = 361.11$, over the decaying term $-0.05A(t)$. The seasonal term $\beta\sin(2\pi t/12)$ generates oscillations around an increasing trend trajectory.

Interpretatively, this means that with a constant intensive budget on all three digital channels, brand awareness of the Kazakh agricultural enterprise increases significantly, while the $A(t)$ trajectory shows annual seasonality, typical for agricultural products.

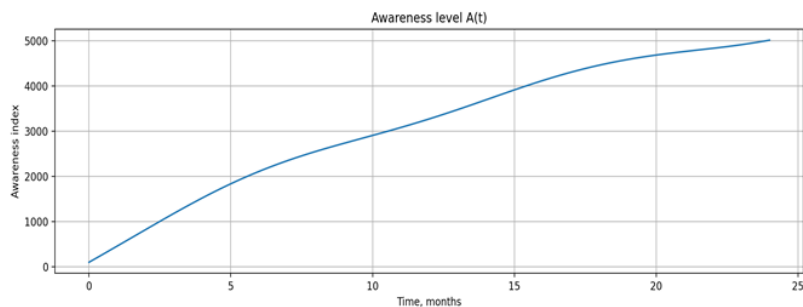


Figure 1 – Dynamics of the awareness function $A(t)$ obtained from the numerical integration of the model under a uniform allocation of the digital marketing budget. The trajectory demonstrates monotonic growth with superimposed seasonal oscillations induced by the sinusoidal term in the awareness equation

In Figure 2, the customer base $C(t)$ also grows monotonically from the initial level $C(0) = 50$. The growth rate at the early stage is low, which is reflected in the close values of $C(t)$ for small t , but as $A(t)$ increases, the influx of new customers increases due to the term $\gamma A(t)(1 - \frac{C(t)}{C_{\max}})$, while $C(t)$ is far from the maximum market capacity $C_{\max} = 5000$. At the same time, the outflow $\mu C(t)$ acts, which stabilizes the growth of the customer base and, in the long term, leads to reaching a quasi-stationary state determined by the balance of inflow and outflow.

In essence, this corresponds to the following: digital marketing channels, by raising awareness, generate a steady flow of new customers, at the same time, some customers naturally leave, which hinders unlimited growth.

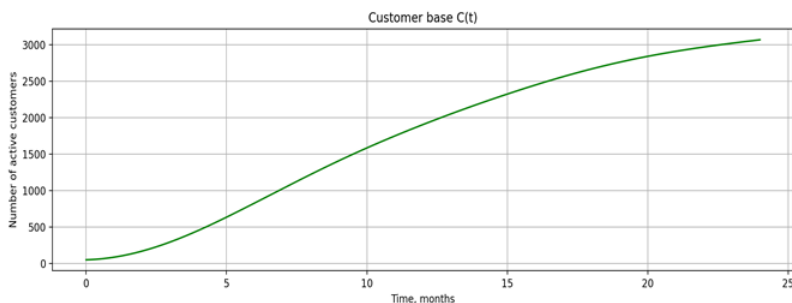


Figure 2 – Evolution of the customer base $C(t)$ over the 24-month horizon

The $S(t)$ function (see Fig. 3) is the integral of the current revenue flow $\frac{dS}{dt} = 25 C(t) + 2.3 u_{\text{const}}$. Even with slow growth of $C(t)$, revenue grows almost linearly with an increasing slope. The first term, $25C(t)$, increases as the customer base expands. The second term, $2.3 u_{\text{const}}$ is fixed and reflects direct sales through channels (e.g., marketplaces).

The figure 3 $S(t)$ shows an upward convex curve: the rate of revenue accumulation increases over time as the customer base strengthens.

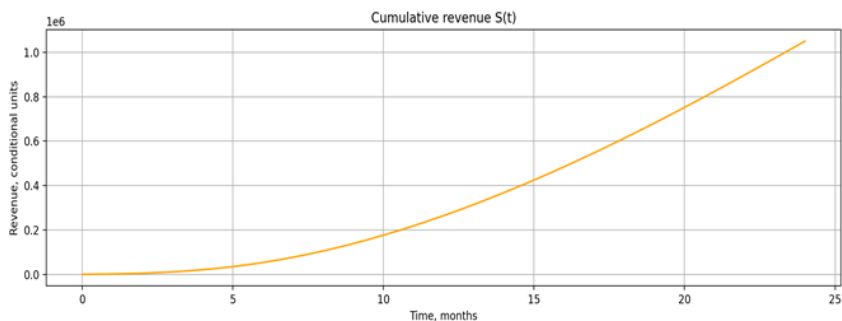


Figure 3 – Accumulated revenue $S(t)$ as the integral of the instantaneous revenue flow. The curve exhibits upward convexity, reflecting the accelerating contribution of the expanding customer base combined with the constant revenue from direct digital-channel effects

Figure 4 illustrates the phase portrait of the system in the $(A(t), C(t))$ -plane, demonstrating a monotonic expansion of the customer base as brand awareness increases, with gradually diminishing marginal gains as the market capacity is approached.

As the integrated awareness indicator $A(t)$ grows, the customer base $C(t)$ expands monotonically. The trajectory has a characteristic convex shape: in the early stages, a small increase in awareness yields a limited increase in customers. Then, upon reaching a certain level of $A(t)$, the sensitivity of $C(t)$ to changes in awareness increases, and as market capacity approaches, growth gradually slows.

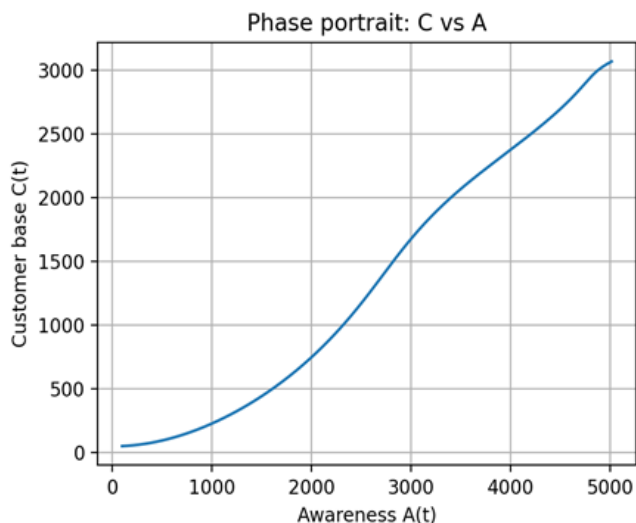


Figure 4 – Phase portrait of the system in the $(A(t), C(t))$ plane. The trajectory illustrates a monotonic increase in the customer base as awareness grows, with diminishing marginal returns as the system approaches the market capacity

Figure 5 presents the evolution of the instantaneous revenue rate $\frac{dS}{dt}$. The trajectory exhibits an increasing trend, driven primarily by the expansion of the active customer base, while the direct contribution of digital channels ensures a non-zero baseline revenue level throughout the planning horizon.

At the beginning of the horizon, the value of instantaneous revenue is small because the customer base is small. As $C(t)$ increases, the contribution of the $\rho C(t)$ term leads to a nearly monotonic increase in $\frac{dS}{dt}$. The constant component associated with the direct contribution of channels (the term $(\eta_1 + \eta_2 + \eta_3)u_{\text{const}}$), sets a non-zero baseline level of cash flow, even with a low customer base.



Figure 5 – Instantaneous revenue rate $\frac{dS}{dt}$ showing a steady increase throughout the planning horizon. The growth is primarily driven by the expansion of the active customer base, while digital channel contributions maintain a non-zero baseline revenue level

Figure 6 depicts the purely seasonal term in the awareness dynamics equation. The sinusoidal pattern with a 12-month period captures the seasonality typical for the agricultural sector, superimposed on the long-term growth trend induced by digital marketing investments.

This figure visualizes the purely seasonal element in the awareness equation, that is, the function $\beta \sin(2\pi t / T_{\text{season}})$. The seasonal component is strictly periodic with an annual cycle (12 months) and determines regular fluctuations in the rate of change in awareness. Combined with constant marketing influence, this leads to sinusoidal fluctuations superimposed on the overall upward trend $A(t)$, reflecting the seasonal specificity of demand for agricultural products.

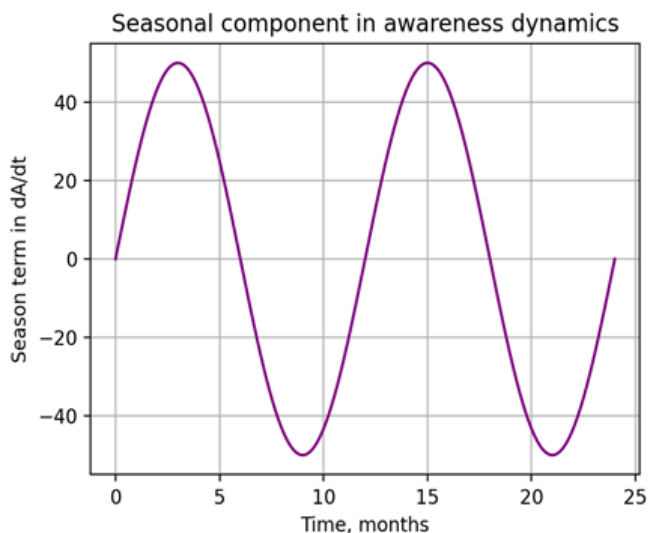


Figure 6 – Seasonal component of the awareness dynamics, represented by the function $\beta \sin(2\pi t/T_{\text{season}})$. The annual sinusoidal pattern captures the seasonality characteristic of agricultural markets and modulates the overall growth trend

Numerical modeling shows that the awareness metric $A(t)$ exhibits a steady upward trend over the entire 24-month horizon. This is driven by two factors: first, ongoing investments in digital channels (constant u_1, u_2, u_3), and second, the relatively low forgetting coefficient δ_A .

This trend is superimposed by pronounced fluctuations generated by the seasonal term $\beta \sin\left(\frac{2\pi t}{T_{\text{season}}}\right)$. The amplitude of these fluctuations is significant relative to the current level of $A(t)$, so that in certain periods, even with constant marketing expenditures, the rate of change in awareness may decrease or transition to a short-term decline.

The customer base $C(t)$ grows monotonically, starting from a small initial level. In the early stages (the first few months), growth is slow: awareness is still low, and the term $\gamma A(t) \left(1 - \frac{C(t)}{C_{\text{max}}}\right)$ yields a relatively small influx of new customers.

As $A(t)$ increases, the impact of marketing intensifies, and the rate of customer influx increases. However, a saturation mechanism is simultaneously at work: the coefficient $1 - \frac{C(t)}{C_{\text{max}}}$ gradually decreases, reflecting the approach to

the market's maximum capacity. Churn $\mu C(t)$ creates an additional stabilizing effect: at a sufficiently high level of $C(t)$, net customer growth declines, and the system tends toward a quasi-stationary regime in which influx and churn are, on average, balanced.

The $S(t)$ (accumulated revenue) graph grows convexly upward: the slope of the curve increases over time. This reflects the fact that the instantaneous cash flow $\frac{dS}{dt}$ depends on $C(t)$ and, accordingly, increases as the customer base expands.

The phase portrait of $C(t)$ versus $A(t)$ demonstrates a characteristic S -like dependence on the trajectory: at low values of $A(t)$, even a significant increase in awareness yields a limited increase in $C(t)$, at medium values of $A(t)$, the increase in customers is maximum; at high $A(t)$, the curve straightens out, reflecting market saturation.

This is important from a decision-making perspective for two reasons. First, the model quantitatively demonstrates that the impact of additional investments in awareness on customer base growth depends significantly on the current position on the curve in the middle zone, customer retention is highest. Second, once awareness levels reach high levels, further budget increases on the same channels will be less effective in terms of customer growth; at this stage, strategies focused on retention and increasing lifetime value (LTV) become more rational than broad reach.

A separate graph of the seasonal component reveals a clear annual cycle. Combined with the dynamics of $A(t)$ and $C(t)$, this allows us to draw an important conclusion: with a constant level of investment in digital channels, the actual system response (in terms of increased awareness, customer acquisition, and revenue) varies significantly depending on the point in time.

Conclusion

Numerical modeling conducted for a 24-month horizon and a total marketing budget of 10 million tenge, evenly distributed between three digital channels, yielded the following key results.

The model shows a significant increase in integrated awareness. From an initial level of $A(0) = 100$, by the end of the period, awareness reaches approximately $A(24) = 420$ conventional units. This is a more than fourfold increase in two years with a constant level of investment. This trend exhibits annual fluctuations due to a seasonal term with an amplitude of $\beta = 50$, which corresponds to the pronounced seasonality of demand for agricultural products.

The number of active clients increases from $C(0) = 50$ to approximately $C(24) = 1\,650$ clients. Thus, by the end of two years, the client base has grown more than 30-fold, while remaining significantly below the market's maximum capacity of $C_{\max} = 5\,000$. This means that, even with the chosen basic strategy,

significant potential for further growth remains, and saturation effects are only just beginning to appear.

Cumulative revenue demonstrates significant accelerating growth. With an initial value of $S(0) = 0$, by the end of the horizon, total revenue reaches approximately $S(24) = 1.4 \times 10^6$ thousand tenge, or approximately 1.4 billion tenge. Instantaneous cash flow dS/dt increases from approximately 1.3–1.5 million tenge per month at the beginning of the period to more than 40 million tenge per month by the end of the second year, reflecting the cumulative effect of the expanding customer base.

The phase portrait in the (A, C) plane demonstrates a monotonic, convex trajectory, indicating that: in the early stages, additional growth in awareness yields a limited increase in the customer base, in the middle zone, the greatest sensitivity of $C(t)$ to changes in $A(t)$ is observed; as market capacity approaches, the return on customers decreases, and the task of retention and increasing profitability per customer comes to the fore.

Explicitly accounting for seasonality in the equations demonstrates that the effectiveness of identical investments in digital marketing varies significantly depending on the time period. Investments made during the positive phase of the seasonal sine wave lead to faster growth in awareness and, consequently, higher customer base and revenue growth than the same investments made during the unfavorable phase.

With a simple strategy of evenly distributing the budget, consistent investments in digital marketing provide significant growth in awareness, customer base, and revenue in Kazakhstan's agricultural sector. However, fully realizing the market potential requires more flexible management.

The time lag between increased awareness and accelerated revenue growth should be taken into account when assessing the ROI of campaigns: short-term indicators may underestimate the long-term impact of investments.

Limited market capacity and customer churn lead to diminishing returns in customer numbers, which justifies a shift from broad coverage strategies to retention and LTV-increasing strategies as the market becomes saturated.

Seasonality significantly impacts the effectiveness of digital campaigns; planning marketing activities without taking seasonal phases into account leads to a distorted assessment of channel effectiveness.

The proposed model and the numerical results obtained provide a foundation for further research, including defining and solving optimal marketing budget management problems, calibrating parameters using real data from Kazakhstani agricultural enterprises, and comparing alternative digital investment allocation strategies.

The proposed dynamic model can be adapted to analyze the digital marketing effectiveness of a specific agricultural enterprise. To do this, simply estimate the model parameters based on the company's internal data (channel costs, customer acquisition funnel, sales dynamics) and set actual budget constraints and target market capacity. As a result, the model can be used to predict the impact of alternative marketing budget allocation strategies and select the most effective digital channel configuration.

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*С. Ж. Асыл-Кеней¹, Л. М. Алимжанова², Ж. Жанатқызы³,
Я. Култан⁴, Р. Г. Бикмурзин⁵

^{1,2,3}Әл-Фараби атындағы Қазақ ұлттық университеті,

Қазақстан Республикасы, Алматы қ.

⁴Братислава Экономика университеті,

Словакия Республикасы, Братислава;

⁵Алматы энергетика және байланыс университеті колледжі,

Қазақстан Республикасы, Алматы қ.

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ҚАЗАҚСТАНДА АГРОӨНЕРКӘСІПТІК ӨНІМДЕРДІҢ ІЛГЕРІЛЕТУГЕ ЦИФРЛЫҚ МАРКЕТИНГТІҢ ӘСЕРІ

Бұл жұмыс Қазақстанда ауылшаруашылық өнімдерін ілгерілетудегі цифрлық маркетинг арналарының тиімділігін бағалаудың динамикалық моделін әзірлейді және сандық түрде зерттейді. Модель маркетингтік инвестициялар мен маусымдық сұраныс ауытқуларының әсерінен бренд туралы хабардарлықтың, тұтынушылар базасының және жиынтық кірістің бірлескен эволюциясын сипаттайды. Әдістің өзегі үш сызықты емес кәдімгі дифференциалдық теңдеулер жүйесі болып табылады, мұнда күй айнымалылары бренд туралы хабардар болу $A(t)$, белсенді тұтынушылар саны $C(t)$ және жиынтық кіріс $S(t)$ көрсетеді.

Сандық арналар $u_i(t)$ басқару функциялары арқылы модельденеді, олар хабардарлыққа да, тікелей сатуға да әсер етеді, ал маусымдық хабардарлық теңдеуінде синусоидалы компонент көрсетіледі.

Цифрлық маркетингтің жалпы бюджеті 10 миллион теңгені құрайтын 24 айлық жоспарлау көкжиегі үшін сандық эксперимент үш арнаға (іздеу жарнамасы, әлеуметтік медиа және базарлар) бірдей және тұрақты бөлінген. Осы базалық стратегия аясында бренд туралы хабардарлық 100-ден шамамен 420 шартты бірлікке дейін артады, тұтынушы базасы 50-ден шамамен 1650 белсенді тұтынушыға дейін өседі және жиынтық табыс кезеңнің соңына қарай шамамен 1,4 млрд теңге баламасына жетеді. Лездік кіріс деңгейі басында айына шамамен 1,3 миллион теңгеден 24 айға қарай 40 миллион теңгеден асады.

Алынған нәтижелер хабардарлықтың өсуі мен кірістің жылдамдауы, шектеулі нарық сыйымдылығына байланысты тұтынушылар базасындағы қанықтыру әсері және қысқа мерзімді өнімділіктің күшті маусымдық модуляциясы арасындағы айқын уақыттық кідірісті көрсетеді. Ұсынылып отырған модель сценарийді талдау және Қазақстанның агрозық-түлік секторындағы цифрлық маркетингтік бюджеттерді болашақта оңтайлы бөлу үшін сандық негізді қамтамасыз етеді.

Кілтті сөздер: цифрлық маркетинг, агробизнес, ауылшаруашылық өнімдері, Қазақстан, динамикалық модельдеу, дифференциалдық теңдеулер жүйесі, маркетингтік бюджетті оңтайландыру.

*С. Ж. Асыл-Кеней¹, Л. М. Алимжанова², Ж. Жанатқызы³,
Я. Култан⁴, Р. Г. Бикмурзин⁵

^{1,2,3}Казахский национальный университет имени аль-Фараби,
Республика Казахстан, г. Алматы;

⁴Братиславский экономический университет,
Словацкая Республика, г. Братислава;

⁵Колледж Алматинского университета энергетики и связи,
Республика Казахстан, г. Алматы.

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ВЛИЯНИЕ ЦИФРОВОГО МАРКЕТИНГА НА ПРОДВИЖЕНИЕ АГРОПРОМЫШЛЕННОЙ ПРОДУКЦИИ КАЗАХСТАНА

В данной работе разработана и численно исследована динамическая модель оценки эффективности цифровых маркетинговых каналов в продвижении сельскохозяйственной продукции в Казахстане. Модель описывает совместную динамику узнаваемости бренда, клиентской базы и совокупного дохода под влиянием маркетинговых инвестиций и сезонных колебаний спроса. В основе подхода лежит система трёх нелинейных обыкновенных дифференциальных уравнений, где переменные состояния представляют узнаваемость бренда $A(t)$, количество активных клиентов $C(t)$ и совокупный доход $S(t)$. Цифровые каналы моделируются с помощью управляющих функций $u_i(t)$, которые влияют как на узнаваемость, так и на прямые продажи, а сезонность представлена синусоидальный компонент в уравнении узнаваемости.

Численный эксперимент проводится для горизонта планирования 24 месяца с общим бюджетом на цифровой маркетинг в размере 10 миллионов тенге, равномерно и постоянно распределяемым между тремя каналами (поисковая реклама, социальные сети и маркетплейсы). В рамках данной базовой стратегии узнаваемость бренда увеличивается со 100 до примерно 420 условных единиц, клиентская база увеличивается с 50 до примерно 1650 активных клиентов, а совокупный доход к концу периода достигает около 1,4 миллиарда тенге в эквиваленте. Мгновенный доход увеличивается с примерно 1,3 миллиона тенге в месяц в начале до более чем 40 миллионов тенге в месяц к 24-му месяцу.

Полученные результаты демонстрируют выраженный временной лаг между ростом узнаваемости и ускорением роста выручки, эффект насыщения клиентской базы ввиду ограниченной емкости рынка и сильную сезонную модуляцию краткосрочных показателей. Предложенная модель обеспечивает количественную основу для анализа сценариев и оптимального распределения бюджетов на цифровой маркетинг в агропродовольственном секторе Казахстана в будущем.

Ключевые слова: цифровой маркетинг, агробизнес, сельскохозяйственная продукция, Казахстан, динамическое моделирование, система дифференциальных уравнений, оптимизация маркетингового бюджета.

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Торайғыров университеті

140008, Павлодар қ., Ломов к., 64, 137 каб.

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Торайғыров университеті

140008, Павлодар қ., Ломов к., 64, 137 каб.

8 (7182) 67-36-69

e-mail: kereku@tou.edu.kz

www.vestnik.tou.edu.kz

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