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# IDENTIFICATION OF TRANSPORT AND TECHNOLOGICAL PROBLEMS IN THE GRAIN PRODUCT SUBCOMPLEX

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***The study focuses on the grain-product subcomplex within the Republic of Kazakhstan, aiming to dissect and address the prevalent issues plaguing this sector. It identifies several challenges, including technological deficiencies, inefficiencies, and increased production risks.***

***There was a notable decrease in fixed capital investment in the agricultural sector in 2023, suggesting a shift in investment strategies or priorities, particularly with a significant reduction in food production investments. Agricultural exports in 2023, while showing a decrease compared to 2022, still represent a substantial economic activity. The capacity and utilization of grain storage facilities indicate a robust infrastructure capable of supporting the nation's grain production, with a considerable portion of storage capacity currently utilized and a significant amount of grain released in 2023.***

***Furthermore, the research delves into cross-border rail transport of crops, with Uzbekistan emerging as a regional leader in exports. This analysis, along with the examination of export activities and grain storage capacities, emphasizes the role of innovation and technological advancements in enhancing the agroindustrial sector's efficiency and competitiveness.***

***Optimization methods for modeling transport processes in agribusiness, such as digital technologies and intermodal transport, are proposed to address existing shortcomings.***

***The study's findings are distinguished by their complex approach to addressing the problems within the grain-product subcomplex. This approach, highlighting the practical application under local conditions, makes the results uniquely tailored to Kazakhstan's context, offering a pathway towards improved agricultural practices and sectoral growth***

***Keywords: grain-product subcomplex, transport and technological processes, productivity, elevators, grain transportation, optimization, capacity***

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## 1. Introduction

The agricultural sector, especially the grain-product subcomplex, is facing serious challenges, including technology obsolescence, equipment shortages and personnel problems, which emphasizes the relevance of research in this area. The need for increased public financial support for the renewal of agricultural machinery and the introduction of innovative solutions is key to overcoming these challenges. Innovative approaches, such as developed control models and process automation, promise to significantly improve the efficiency of grain transport and drying processes [1–3].

Methods of grain cargo logistics and transport flow management are limited, resulting in suboptimal resource utilization and higher costs. The study proposes new strategies to reduce turnover cycles and improve grain flow management, which can contribute to the development of specialized grain zones and increase grain production in the Republic of Kazakhstan [4].

Modern conditions require active implementation of innovations and increasing the level of state support in the agricultural sector, which makes research in this area particularly relevant. The results of such research can offer practical solutions to improve the efficiency and competitiveness of the grain sector, which in turn will contribute to the sustainable development of the agroindustrial complex as a whole [5–7].

The development of a model for optimizing grain transportation in the context of grain processing enterprises has an important role. Such models allow you to take into account factors such as technical capabilities, distance, and annual needs. Simulation models can be used to assess the impact of changes in various constraints on the overall performance of the system. For example, travel time, cost, and bandwidth. The use of such models turns out to be faster and more cost-effective.

Consequently, scientific research aimed at improving technologies and management methods in the grain subcomplex is relevant in modern conditions. They can provide a significant contribution to the optimization of agroindustrial production, strengthening of economic ties between market participants and increasing the level of food safety.

## 2. Literature review and problem statement

The paper [8] describes measures aimed at simplifying, improving and reducing the number of cargo operations related to grain handling. The main focus is on the possibility of using multiple containers for grain transport and the introduction of new technologies for handling grain cargo at stations. These innovations offer simplification and optimization of processes, making them more efficient in terms of practicality and energy consumption. The implication is that the realization of such technologies may face technical and economic challenges. Thus, the authors of the paper emphasize the significant potential of the proposed measures in improving the efficiency of freight operations in grain handling.

The paper [9] deals with the problem of optimizing the number of transport units for efficient harvesting and transportation of grain crops based on the criterion of minimizing energy consumption. The authors emphasize the importance of optimizing the parameters of the transport process and present a comprehensive method that includes the use of road transport to reduce specific energy consumption during harvesting and transportation to storage. It is pointed out that the optimal number of vehicles plays a key role in reducing energy consumption. However, the paper identifies limitations of the study, such as potential difficulties in generalizing the findings to other agricultural production, failure to consider the influence of other factors on transport efficiency, and insufficient attention to environmental sustainability and social aspects. Thus, while the study highlights the importance of optimizing transport processes in the agricultural sector, it also identifies the need for further research for in-depth analysis and improvement of the proposed optimization model.

The significance of vehicles for agricultural maintenance is crucial for the national economy. The paper [10] highlights the necessity of efficient grain transport, introduces a mathematical model for optimization, and underscores the enhancement of transport and logistics through technology within the grain processing sector. Key conclusions underscore the critical need for well-organized grain exportation, the adverse effects of excessive long-haul transport on expenses, and the imperative to refine the use of resources and the composition of the vehicle fleet in the grain industry. Traditional linear programming approaches fall short in addressing this issue. The solution's complexity is amplified by the challenge of precisely defining the Z function and its derivatives. The deterministic model's failure to consider the variable nature of quantities suggests the adoption of stochastic programming models. Overall, the authors provide mixed evidence for adopting stochastic linearization methods.

The study [11] introduces a discrete event simulation model focused on grain transport to assess how limitations in trucks and drivers affect the efficiency of material flow and overall system capacity, proving its precision in forecasting daily shipments and overall system functionality. The developed model is capable of examining the effects of constraints related to trucks and drivers on the efficiency of material movement, the use of resources, and the throughput of the system. Its application across various harvesting scenarios revealed a tight correlation between actual and simulated daily shipments. The authors indicate a critical role in modeling the efficiency of grain transportation gains by adding more vehicles or workforce.

Shuttle service offers quicker grain transport and lowers the costs associated with the logistical supply chain compared to traditional services. The paper [12] presents models that compare traditional rail service to shuttle service within the domestic grain supply chain, revealing that shuttle service not only speeds up transportation but also cuts costs and boosts rail system capacity. Transitioning to shuttle service from conventional service enhances speed, cost efficiency, and rail infrastructure capability. However, the study also points to limitations. The research is derived from a singular case study, which may limit its broader applicability. The focus is exclusively on the transportation component, overlooking additional elements of the supply chain.

The study [13] focuses on enhancing the efficiency of food grain transportation within India's supply chain through the development of a bi-level nodal capacity network flow issue, employing both linear and mixed integer non-linear models. It aims at minimizing transportation costs and maximizing rail-road transport flexibility, with particle swarm optimization algorithms employed to analyze and compare solutions. The core contributions include the optimization of food grain logistics in the Indian context by conceptualizing the transport mechanism as a bi-level nodal capacity network flow challenge, emphasizing cost reduction and transport flexibility, and leveraging particle swarm optimization for solution evaluation. The research, however, is limited to the initial phase of the transportation and distribution sequence, does not encompass the entire supply chain comprehensively, and acknowledges the necessity for subsequent studies to broaden the model's scope to include the full supply chain continuum.

The heuristic introduced is highly effective, delivering quality solutions rapidly. The paper [14] focuses on the rail transport of food grains by the Food Corporation of India (FCI) for India's Public Distribution System, proposing a penalty factor-based method for transportation planning and introducing a heuristic called ORAA for generating efficient solutions. This aims to support FCI managers in effectively orchestrating food grain transportation. These findings indicate that AREA heuristic is notable for producing high-quality solutions quickly, and its model and solution approach result in superior rake allocation plans relative to current methods.

A simulation model was created to assess and identify the preferable choice across anticipated future scenarios. The research [15] discusses the multimodal transportation and storage of soybeans and corn, examining a variety of factors and utilizing a simulation model to inform decision-making and future logistic investments. It explores several transportation modes within the logistics framework, devises a simulation model for future scenario assessment, and offers recommendations to steer future investment directions. The research [15] utilizes simulation models, which might not capture all real-world complexities and uncertainties. It bases its findings on anticipated future scenarios, which may not precisely predict actual future states. The selection of warehouse locations suggested by the model might not be the most effective in real-world applications. The research overlooks [15] the practical challenges or limitations of implementing the preferred logistics options in a real-world context.

The paper [16] examines the current trends and future directions in the global grain seed delivery systems, highlighting the significant role of containerization in enhancing transport efficiency and reducing expenses. It introduces a structural framework for the transportation of grain seeds from the USA to Ukraine, taking into account the interplay of subsystems and the risks inherent in international logistics. Key outcomes of the study involve an assessment of the costs associated with delivery and the elements affecting the selection of an efficient methodology for shipping grain seeds in containers from the USA to Ukraine. The proposed models take into account a variety of considerations essential for the system's operation. The study [16] overlooks the potential benefits of employing different modes of transportation. It does not assess how order specifics might influence the delivery mechanism. It lacks an evaluation of risk levels throughout each phase of the operational process.

Selecting the most efficient transportation method for grain crops enables farms to decrease their logistics supply chain expenses. The paper [17] explores how to optimize the grain crops supply chain in Ukraine by modeling the logistics network, facilitating informed decisions regarding grain transportation. This aims at enhancing profit margins through cost reduction and fostering the growth of the agricultural sector. By optimizing transport within the grain crops supply chain, profitability can be improved, contributing to the expansion of agriculture. The introduced model accounts for various aspects affecting harvesting, storage, and transportation to efficiently manage costs. The process of grain delivery encompasses a series of interconnected components, creating a sophisticated system. Additional research is required to cover all possible scenarios within the grain crops supply chain and pinpoint critical determinants for the profitability and growth of farms.

The authors of the mathematical model [18] identify the best strategies for grain transportation logistics and infrastructure investments, including the placement of new processing facilities and the enhancement of road and rail capacities. This model aims to decrease post-harvest losses in the grain supply chain by optimizing logistics and infrastructure to reduce the overall cost of the system while accounting for losses in quality and quantity. It employs numerical analysis to find the most effective system design, with a case study focused on a real-world network in Illinois. Key outcomes involve pinpointing the most efficient logistics and infrastructure upgrades to lower total system costs in light of post-harvest losses, alongside offering insights into the best system layout through numerical evaluations. The model overlooks uncertainties in data like demand, supply, and transport costs. It does not take into account the stochastic (random) nature of these issues. The model does not factor in the time value of money. It does not assess the environmental consequences of infrastructure development.

The analysis of numerous studies [8 18] in the field of challenges in optimizing grain transportation and logistics was carried out, each focusing on specific aspects such as simplification of operations, energy consumption minimization, and the efficiency of transport models. Unexplored areas across these studies often relate to broader applications to different agricultural contexts, environmental sustainability, and comprehensive supply chain analysis. These gaps primarily arise from methodological limitations, such as the narrow focus of some studies, mathematical complexities associated with expanding models to incorporate variability and stochastic elements, and the challenges of applying findings to broader contexts. Overcoming these limitations would necessitate an expansion of research methodologies, the adoption of more sophisticated mathematical approaches.

## 3. The aim and objectives of the study

The aim of the study is to identify transport and technological problems in the grain product subcomplex. This will allow us to find solutions aimed at optimizing transportation and technological processes, focusing on reducing operational costs and enhancing logistical efficiency.

To achieve this aim, the following objectives are accomplished:

– to carry out an analytical review of existing capabilities and identification of weak links in transport processes of the grain-product subcomplex;

– to carry out grain transportation modeling in order to optimize and improve the efficiency of transport and technological processes;

– to develop and propose innovative solutions and strategies for the prospective development of transport and technological processes in the above subcomplex, aimed at improving their efficiency and optimizing their work in general.

## 4. Materials and methods

In this study, the object of analysis is transport and technological processes of the grain-product subcomplex of the Republic of Kazakhstan. The hypothesis suggests that the application of modern digital technologies and optimization methods can significantly improve efficiency and safety in transport and technological processes of the grain-product subcomplex. Computer programs for modeling logistic chains and data analysis were used. Special attention was paid to programmes for SWOT analysis, as well as applications for processing statistical information. SWOT methods were also used to assess the external and internal environment of the grain-product subcomplex.

The study was conducted in the period from 2020–2023, covering the main grain-producing regions of the Republic of Kazakhstan. Statistical data processing techniques, including correlation analyses, were used to analyze the data to assess the relationships between technology adoption and changes in key performance indicators. Big data analysis was performed using machine learning techniques to identify trends and predict changes in transport processes. Data for the analysis included statistics on cereal production and export volumes, information on the state of transport infrastructure and the level of adoption of digital technologies in the agroindustrial sector. Information was collected from official reports of the Government of the Republic of Kazakhstan, as well as through surveys and interviews with representatives of agroindustrial enterprises and transport companies.

## 5. Results of the analysis of transport-technological processes of the grain-product subcomplex of the Republic of Kazakhstan

### 5. 1. SWOT analysis of transport processes in the grain-product subcomplex in agricultural regions of the Republic of Kazakhstan

Statistical analysis shows that wheat crops play a significant role in agricultural production. There are 291 grain elevators and grain receiving enterprises registered in the Republic of Kazakhstan. In 2020, the leading regions in wheat production were three regions, as can be seen from Fig. 1: Akmola region, with a yield of 4,127.6 thousand tonnes, Kostanay region, with 3,455.0 thousand tonnes and North the Republic of Kazakhstan region, with 3,299.8 thousand tonnes. Maintaining the quality and safety of raw materials is becoming the most important strategic task for the modern Republic of Kazakhstan. Over the last decade, agricultural practices have been improved, which contributed to the trend of wheat yield growth in the Akmola region and a number of other regions [19]. In the period from January to December 2023, the Akmola region shows a total agricultural output of 1,647.2 million dollars. The index of physical volume (IFO) was 74.6 %, dominated by crop production (824,217 thousand dollars, IFO – 61.9 %) and livestock production (821,816 thousand dollars, IFO – 104.8 %). There are 9,361 agro-formations, including 1,923 legal entities, 695 individual entrepreneurs and 6,743 peasant farms in the region.


Fig. 1. Map of elevators of the Republic of Kazakhstan

*Note: compiled by the authors*

As part of the initiative to develop the Republic of Kazakhstan's agroindustrial sector for 2021–2025, the government allocated 106,843.1 million dollars in 2022 to support the agroindustrial complex. Efforts to develop livestock included improving the quality of livestock products and productivity, along with providing subsidies to animal farms, with 14,438.2 million dollars allocated for this purpose [20].

In addition, the project allocates 38,205.8 million dollars for investment and subsidies in processing, broken down into 36,749.5 million dollars for investment and 1,55 million dollars to cover operating costs of processing plants. In 2023, fixed capital investment in the agricultural sector totaled 186,364.5 million dollars, a decrease of 81.2 percent compared to 2022. This decrease is due to a reduction in capital investments, including in food production, where investments totalled 20,213.5 million dollars (36.2 % of last year's level).

From January to November 2023, agricultural exports reached US$322.8 million, representing 84.8 percent of the level of the same period in 2022.

Table 1 presents data from which it follows that for the whole of Kazakhstan, the total volume of grain storage facilities is 13,219.2 thousand tonnes, the current load is 7,856.2 thousand tonnes (59 % of the total volume), the free volume is 5,362.9 thousand tonnes, and 78,016.5 thousand tonnes of grain was released in 2023.

Thus, in 2023, the agricultural sector of the Akmola region demonstrated significant results despite some challenges. The gross output of agricultural products reached 1,647.2 million dollars, indicating stable development of the sector.

The decline in investment in fixed capital and food production may signal the need for additional measures to stimulate investment in these sectors. At the same time, increased state support through subsidies to the agroindustrial complex contributes to the further development and sustainability of the agricultural sector.

Agricultural exports, although down on last year, remain an important part of the region's economy, emphasizing the need to maintain and expand foreign markets.

Finally, the full harvest and increased acquisition of agricultural machinery underscore the region's commitment to strengthening its agrarian capabilities and improving the efficiency of agroindustrial production.

Table 1

Data on the loading of grain storage facilities in the Republic of Kazakhstan

| Territory | Total volume of grain storage facilities, tonnes | Current load, tonnes | In percentages, % | Free volume, tonnes | Released, tonnes |
|---|---|---|---|---|---|
| East Kazakhstan region | 313,700 | 268,331.9 | 85 | 45,368.1 | 2,320,667.5 |
| Kostanay region | 3,031,900 | 2,217,586.2 | 73 | 814,313.7 | 16,852,037 |
| Karaganda region | 132,500 | 86,564.9 | 65 | 45,935.07 | 373,700.2 |
| Akmola region | 4,529,100.0 | 2,808,358.2 | 62 | 1,720,741.7 | 31,280,678.3 |
| North Kazakhstan region | 3,349,000.0 | 1,966,870.3 | 58 | 1,382,129.6 | 21,329,515.3 |
| Pavlodar region | 277,300.0 | 152,136.3 | 54 | 125,163.6 | 2,018,611.5 |
| Zhetisu region | 14,000.0 | 7,666.6 | 54 | 6,333.3 | 127,216.5 |
| Aktobe region | 391,800.0 | 150,310.3 | 38 | 241,489.6 | 1,277,445.1 |
| Almaty region | 62,600.0 | 13,287.1 | 21 | 49,312.8 | 74,304.1 |
| Astana g.a. | 243,000.0 | 48,480.5 | 19 | 194,519.4 | 1,295,220.3 |
| West Kazakhstan region | 634,800.0 | 110,431.96 | 17 | 524,368.04 | 953,651.02 |
| Abay region | 199,500.0 | 26,241.5 | 13 | 173,258.4 | 113,518.8 |
| Kyzylorda region | 40,000.0 | 0.001 | 0.001 | 40,000.0 | 0.001 |
| By Kazakhstan | 13,219,200.0 | 7,856,266.1 | 59 | 5,362,933.8 | 78,016,566.7 |

Overall, the data shows a dynamic development of agriculture in the Akmola region, although it does identify certain areas that require additional attention and investment for the sustainable future of the sector.

SWOT analysis involves identifying the strengths, weaknesses, opportunities and threats associated with a particular object, in this case the grain-product subcomplex. Table 2 presents a SWOT analysis of transport processes in the grain-product subcomplex.

Table 2

Results of SWOT analysis of transport processes in the grain-product subcomplex

| Strengths | Weaknesses |
|---|---|
| 1. Innovative solutions: Implementation of innovative solutions such as gate control algorithms and automatic grain drying routing improves process control.<br>2. Effective models: Development of models to ensure stable grain storage facilities and optimize transport units for harvesting conditions.<br>3. Technological achievements: Use of modern technological solutions (trucks with semi-trailers, modern logistics technologies) to improve the efficiency of grain production and transport | 1. Technological and equipment deficiencies: Outdated technology, insufficient equipment and staffing problems.<br>2. Inadequate systems: Existing methods are ineffective in identifying causes of technological shortages, such as wagon shortages.<br>3. Dependence on weather and other risks: The impact of unfavorable weather conditions and other operational risks on efficiency |
| Opportunities | Treats |
| 1. State financial support: The need to increase state financial support for renewal of agricultural machinery.<br>2. Competitiveness in the global market: Improving competitiveness in the global commodity market through state regulation of innovation in the agricultural sector.<br>3. Infrastructure development: Improvement of production and logistics infrastructure, including storage facilities, port facilities and grain cargo handling technologies | 1. Lack of integrated approaches: Potential limitations in international comparisons and limitations in the scope of research.<br>2. Market and Economic Challenges: Deteriorating records of grain availability and movement, poor market infrastructure and low government subsidies.<br>3. Technological deficiencies and reliability problems: Failure to identify the causes of technological shortages of wagons and downtime problems of transport units |

*Note: compiled on the basis of [21]*

Thus, despite the fact that strong innovative approaches and effective models are being developed for the grain-product subcomplex, problems such as outdated technologies, lack of equipment and external factors such as weather conditions remain [21]. Opportunities for improvement lie in increased government financial support and competitiveness in the global market. However, threats such as lack of comprehensive strategies, economic challenges and technological deficiencies need to be addressed to ensure sustainable growth and efficiency of the grain-product subcomplex.

**5. 2. Grain transportation modeling in the grain-product subcomplex**

The Republic of Kazakhstan is a significant exporter of agricultural crops due to its vast land resources and strategic location in the Central Asian region [22].

As part of the study of cross-border rail transport of agricultural crops, it was important to consider not only the volume of exports, but also their relevance to market needs and logistical efficiency. Based on the data, Uzbekistan shows a dominant position in the region with exports of more than 17 million tonnes of agricultural products, indicating large-scale agricultural activities and a well-developed railway network.

From the data in Fig. 2, it is apparent that Tajikistan, rounding out the top three, shows a result of 6 million tonnes, highlighting its role in exporting crops via rail routes. There is a significant decline in traffic between third and fourth place, where Iran holds the position with 4.7 million tonnes, which can be attributed to various factors including economic policies and climatic conditions.

Fig. 2 shows agricultural exports by country in tonnes.

The data shows that Uzbekistan is the leader with exports of over 17 million tonnes, followed by the Republic of Kazakhstan with over 12 million tonnes, and Tajikistan rounds out the top three with 6 million tonnes. Iran ranks fourth with 4.7 million tonnes [23]. From the data in Fig. 2, it is apparent that cargo weights varied significantly among the listed countries. Indonesia handled a substantial 996.78 tons of cargo. Following closely behind was Lithuania with 852.16 tonnes. Senegal managed 674.95 tonnes of cargo.

The noticeable drop in export volumes from Kazakhstan to the Islamic Republic of Iran, which ranks fourth with approximately 4.7 million tonnes, points to a significant variance in agricultural export capabilities among the top-ranking countries. The rest of the countries show significantly lower export volumes. Lower performing countries such as Romania, France and Lithuania, despite their modest export volumes, play an important role in regional trade [23]. This allows us to assess the scale of countries' export activities in agricultural products and can serve as a basis for further study of factors affecting cross-border rail transport volumes.

In Table 3, the analysis of data for the period from 2018 to 2022 for four grain elevators shows a variety in the dynamics of grain intake and shipment.

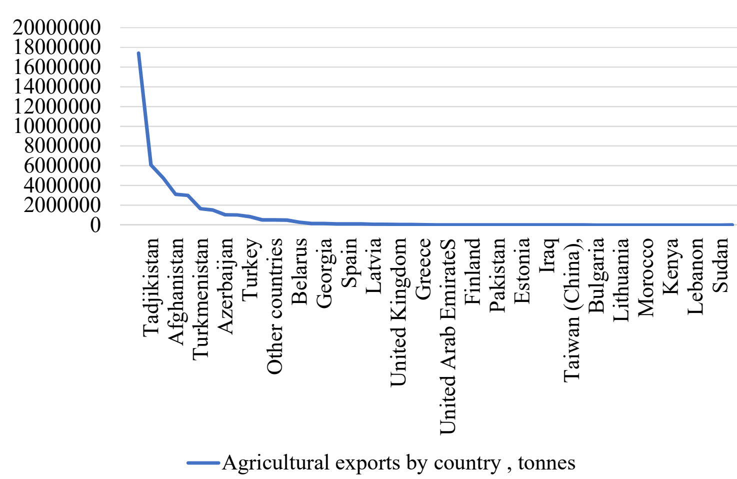


Fig. 2. Agricultural exports by country in tonnes

*Note: compiled on the basis of [23]*

Table 3

Indicators of the total capacity and main operations of grain elevators of Akmola and North Kazakhstan regions for 2018–2022

| Indicator/year | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| Hlebnaya baza No. 1 | | | | | |
| Grain intake, tonnes | 115,000 | 72,000 | 103,000 | 53,000 | 62,000 |
| Grain shipment, tonnes | 95,000 | 127,000 | 92,000 | 48,000 | 42,000 |
| Total elevator capacity, tonnes | 192,800 | 192,800 | 192,800 | 192,800 | 192,800 |
| Grain dryer capacity, t/hour | 150 | 150 | 150 | 150 | 150 |
| Hlebnaya baza No. 2 | | | | | |
| Grain intake, tonnes | 80,000 | 121,000 | 120,000 | 55,000 | 110,000 |
| Grain shipment, tonnes | 85,000 | 86,000 | 102,000 | 83,000 | 68,000 |
| Total elevator capacity, tonnes | 142,800 | 142,800 | 142,800 | 142,800 | 142,800 |
| Grain dryer capacity, t/hour | 268 | 268 | 268 | 268 | 268 |
| Hlebnaya baza No. 5 | | | | | |
| Grain intake, tonnes | 72,000 | 56,000 | 50,000 | 36,000 | 64,000 |
| Grain shipment, tonnes | 90,000 | 82,000 | 34,000 | 33,000 | 43,000 |
| Total elevator capacity, tonnes | 74,900 | 74,900 | 74,900 | 74,900 | 74,900 |
| Grain dryer capacity, t/hour | 130 | 130 | 130 | 130 | 130 |
| Hlebnaya baza No. 7 | | | | | |
| Grain intake, tonnes | 63,000 | 80,000 | 55,000 | 38,000 | 61,000 |
| Grain shipment, tonnes | 42,000 | 83,000 | 54,000 | 35,000 | 49,000 |
| Total elevator capacity, tonnes | 81,200 | 81,200 | 81,200 | 81,200 | 81,200 |
| Grain dryer capacity, t/hour | 100 | 100 | 100 | 100 | 100 |

Hlebnaya baza No. 1 demonstrates high efficiency, with an average shipment-to-reception ratio exceeding 100 %, which indicates successful processing and shipment of almost all received grain. On the contrary, Hlebnaya baza No. 7 has the lowest ratio, about 88 %, which may indicate lower processing efficiency. Hlebnaya baza No. 2 and No. 5 show different stability in the volumes of reception and shipment, while grain elevator No. 2 stands out for its high volatility of reception and relatively stable shipment.

The data in Table 4 presents information on various agricultural firms and their capacities and equipment related to grain storage and processing. The data outlines the capacities and facilities of several LLPs involved in grain storage and processing. "Bread base No. 2" LLP boasts a grain storage capacity of 142.8 thousand tons, with an elevator capacity of 70.4 thousand tons and a warehouse capacity of 72.4 thousand tons. AGRIMER LLP has a slightly higher grain storage capacity of 160 thousand tons, with 100 thousand tons in elevator capacity and 60 thousand tons in warehouse capacity. "Beskaragai" LLP and "Dostyksky elevator" LLP show storage capacities of 145 and 102.5 thousand tons respectively, with varying capacities in elevators and warehouses. The list includes other entities like "Kzyltu FlourMill", "Mamlyutflourmill", and "TALSHIK ASTYK LTD", with "Kzyltu FlourMill" having the highest elevator capacity of 115 thousand tons.

Table 4

Equipment of the most significant large grain enterprises in the North Kazakhstan region

| Indicator | LLP "Bread base No. 2" | AGRIMER LLP | LLP "Beskaragai" | LLP "Dostyksky elevator" | LLP "Kzyltu FlourMill" | LLP "Mamlyutflourmill" | LLP "TALSHIK ASTYK LTD" | "Timiryazevsky elevator" | LLP "HPP "TNS-Export" | LLP "Elevator Smirnovsky" |
|---|---|---|---|---|---|---|---|---|---|---|
| Grain storage capacity (thousand tons) | 142.80 | 160.00 | 145.00 | 102.50 | 202.00 | 145.40 | 209.20 | 158.10 | 120.00 | 100.00 |
| Elevator (thousand tons) | 70.40 | 100.00 | 33.00 | 63.50 | 115.00 | 118.90 | 170.00 | 143.00 | 120.00 | 100.00 |
| Warehouse (thousand tons) | 72.40 | 60.00 | 112.00 | 39.00 | 87.00 | 26.50 | 39.20 | 15.10 | – | – |
| Warehouse, incl. intended for storage of seeds (thousand tons) | – | – | – | – | – | 3.20 | 3.00 | – | – | – |
| Grain drying equipment (pcs/ton/h) | 6/218 | 6/238 | 6/220 | 5/210 | 7/266 | 6/295 | 4/166 | 5/324 | 2/100 | 2/114 |
| Grain cleaning machines (pcs) | 7 | 6 | 8 | 6 | 8 | 17 | 6 | 6 | 9 | 6 |
| Active ventilation equipment (pcs) | – | 20 | 17 | 14 | – | 16 | 1 | – | 48 | 2 |
| Automobile scales* (pcs) | 2 | 2 | 6 | 2 | 4 | 4 | 2 | 2 | 2 | 1 |
| Carriage scales* (pcs) | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 |
| Mobile transport equipment (pcs) | 9 | 24 | 27 | 5 | 9 | 15 | 6 | 3 | 32 | 1 |
| Handling equipment (pcs) | 13 | 11 | 3 | 4 | 16 | 34 | 8 | 2 | 23 | 2 |
| Installations for remote control of temperature and humidity of grain during storage (set) | 1 | – | 17 | 2 | 1 | 2 | 1 | 2 | 24 | 2 |
| Equipment for temperature and moisture control of grain during storage (pcs) | 1 | 144 | 30 | 2 | 20 | 2 | 30 | 11 | 216 | – |
| Loading and unloading devices (pcs) | 5 | 4 | 6 | – | 10 | 20 | 3 | 9 | 7 | 4 |

*Note: compiled by the authors based on the source [23]*

Facilities also differ in terms of equipment. For instance, grain drying equipment ranges from 2 to 7 units across these LLPs, with the capacity per hour varying significantly. The number of grain cleaning machines also varies, with "Mamlyut flour mill" having the highest number at 17. Additionally, some firms have asphalt sites for grain storage, with "Beskaragai" LLP having the largest at 30 thousand square meters [24].

Additionally, the significant number of small-scale, non-commercial farms should be acknowledged as a contributing factor. In Kazakhstan's agricultural sector, there are approximately 200,000 agro-enterprises, with 94 % being individual entrepreneurs and peasant or farm enterprises. These smaller farms primarily yield limited quantities of agricultural produce. They contribute to 31 % of the gross agricultural output, with the average peasant farm generating around 15468.28 dollars. Moreover, an examination of the cost formation for grain logistics within one of these medium-sized agro-enterprises could provide further insights [24].

The average transportation radius is calculated by the formula:

$$\pi R^2 = \frac{S_0}{0.8} \cdot 1.5, \qquad (1)$$

where $R$ – the average radius of cargo transportation;

$S_0$ – the area of agricultural land, m$^2$;

0.8 – the average share of agricultural land in the area of land use;

1.5 – increase in the average distance of on-farm transportation due to the inadequacy of the territory, the curvature of roads, and the location of crop rotation fields [24].

The average distance for transporting goods from the fields is found to be 7.3 km. To harvest an area of 9,000 hectares within a fortnight, factoring in variations in yield, the ideal number of combine harvesters is determined to be 30.

The farm's transportation cost calculations are based on a per-ton tariff for each kilometer traveled, incorporating fuel and lubricant costs, driver wages, and the expenses associated with vehicle maintenance and repairs.

Transport work could be carried out throughout the year, while from August to November and April-May, 60 % of the total volume of transported wheat is produced. The average distance from the farm to the elevator is 100 km. Grain is transported in bulk from the farm using Kamaz brand dump trucks, which have an average operational lifespan of 8 years. The data in Table 5 presents; that the availability of trucks with only a 14 and 14.5-ton carrying capacity necessitates additional trips to transport the same volume of grain [24].

Table 5

Characteristics of cargo vehicles

| Car brand | Bodywork volume, m$^3$ | Load capacity, kg | Total car weight, kg | Engine power, hp (kW) |
|---|---|---|---|---|
| Availability of trucks | | | | |
| Kamaz 45142 | 15 | 14,000 | 24,400 | 300 (220) |
| Kamaz 65115-6059-50 | 10 | 14,500 | 25,200 | 300 (220) |
| Suggested option | | | | |
| Kamaz 45142 with dump truck trailer TZA-8551M4 | 35 | 25,000 | 27,795 | 300 (220) |

As can be seen in Table 5, the farm employs three pieces of equipment for grain transportation: two dump trucks, each able to carry 14 and 14.5 tons. An alternative is proposed – one dump truck with a trailer Kamaz 45142 with a capacity of 25 tons.

When transporting grain on a vehicle of the $h$-th model from the $i$-th field to the $k$-th temporary storage point, the economic costs are found by the formula:

$$P_{ikh} = T_{ikh} \cdot L \cdot Q_h, \text{ dollar}, \qquad (2)$$

$$i=1,...;\ k=1,...;\ h=1,...,$$

where $T_{ikh}$ is the tariff for grain transportation in the unit of the $h$-th vehicle model from the $i$-th field to the $k$-th temporary storage point, t/t·km;

$L$ is the distance from the field to the storage point, km;

$Q_h$ is the carrying capacity of a vehicle of the $h$-th model, tonnes.

The data in Table 6 presents total transportation costs, taking into account grain losses.

By applying these figures to a given formula, it is calculated that the transport costs from the farm to the grain-receiving facility using a Kamaz 45142 amount to 196.2 dollars. In contrast, utilizing a Kamaz dump truck with a 14.5-ton capacity results in economic costs of 93.71 dollars. Consequently, the average cost savings of ride, dollars (from each thousand tons) for grain transportation using the suggested option on the farm is estimated at 62.77 dollars [24].

Table 6

Total transportation costs, taking into account grain losses

| Car brand | Grain transportation tariff, dollar | Grain volume, tonnes | Transportation costs, dollar | Number of rides |
|---|---|---|---|---|
| Kamaz 45142 | 0.08 | 1,000 | 109.85 | 72 |
| Kamaz 65115-6059-50 | 0.08 | 1,000 | 113.77 | 69 |
| Kamaz 45142 with dump truck trailer TZA-8551M4 | 0.08 | 1,000 | 196.16 | 40 |

**5. 3. Prospects for the development of transport and technological processes in the grain-product subcomplex**

Table 5 presents a list of solutions and methods, as well as their advantages and disadvantages for modeling transport processes in the grain-product subcomplex of the agroindustrial complex.

Implementing advanced logistics technology offers benefits like streamlined operations and improved efficiency through digital modeling, AI, and intermodal transport. However, challenges include high costs, technical issues, and regulatory compliance, highlighting the importance of strategic planning and integration to maximize benefits while mitigating risks.

Table 5

Proposed solutions and approaches for the development of transport and technological processes in the grain-product subcomplex

| Category | Item | Description |
|---|---|---|
| Solutions and methods | 1. Digital modeling and optimization of logistics | Application of supply chain modeling software, automation of route planning |
| | 2. GPS and telematics | Real-time vehicle tracking for route optimization |
| | 3. Artificial intelligence and machine learning | Big data analytics for stock forecasting and optimization |
| | 4. Intermodal transport | Combining different modes of transport to speed up delivery |
| | 5. Predictive models | Identification of risks in transport processes through data analysis |
| | 6. Automation of warehouse operations | Implementation of automated systems in warehouses |
| | 7. Blockchain | Ensuring transparency in supply chains |
| | 8. Traffic management | Developing systems for efficient transport distribution |
| | 9. Drones and UAVs | Monitoring and transport of grain over short distances |
| | 10. Environmental vehicles | Utilization of alternative energy sources |
| | 11. Data management | Centralized management of transport process information |
| | 12. Planning and forecasting | Development of methods based on data analysis |
| Advantages | 1. Improving efficiency | Automation and optimization improve efficiency |
| | 2. Cost reduction | Digitalization reduces transport costs |
| | 3. Forecasting accuracy | AI and machine learning for accurate planning |
| | 4. Eco-friendliness | Reducing environmental impact |
| | 5. Security and transparency | Blockchain and GPS increase security |
| | 6. Reducing downtime | Warehouse automation increases efficiency |
| Disadvantages | 1. High initial costs | Significant investment in technology deployment |
| | 2. Technical problems | Ongoing maintenance of complex systems |
| | 3. Complexity of integration | Compatibility issues between new and legacy systems |
| | 4. Staff training | Need for training to work with new technologies |
| | 5. Dependence on technology | Risks in the event of disruptions or cyber-attacks |
| | 6. Restrictions on application | Inefficiency in certain conditions |
| | 7. Privacy issues | Data privacy risks |
| | 8. Environmental challenges | Potential negative environmental impacts |
| | 9. Regulatory restrictions | Compliance with the law can be complicated |

*Note: compiled on the basis of [8–18]*

## 6. Discussion of the results of the analysis and prospects for the development of transport and technological processes in the grain-product subcomplex

As can be seen from Tables 1, 2 and Fig. 2, the results demonstrate the significant role of wheat crops in Kazakhstan's agroindustrial production, with particularly high yields in Akmola, Kostanai and North the Republic of Kazakhstan regions. The statistics show how improvements in farming practices have contributed to increased production. Furthermore, the diversity in the list of countries, ranging from large economies like China to smaller nations like Belgium and even countries with less global market presence in agriculture like the United Arab Emirates, highlights the global nature of agricultural trade. The presence of European countries like Italy, Belgium, and even Finland and Estonia in the list, though with much lower volumes compared to the leaders, indicates a wide geographical spread in agricultural exports. The significant tapering off in export volumes as we move down the list, transitioning from millions to thousands and even hundreds of tonnes, reflects the vast differences in agricultural export capabilities across countries. This could be attributed to various factors such as the size of the country, the focus of the economy, agricultural production capabilities, and the strategic importance placed on agricultural exports. The data illustrates the central role of Central Asian countries in the agricultural export market of the Republic of Kazakhstan. Economic policies, climatic conditions, and infrastructural factors play crucial roles in shaping these outcomes. However, the wide range of countries involved in agricultural exports underscores the global interconnectedness of food production and supply chains [10].

Promoting sustainable and balanced growth in the agricultural sector is a key component of food security strategies in the Republic of Kazakhstan. The role of transportation expenses in enhancing the agricultural sector's competitiveness and its sustainable advancement is undeniable. Agricultural logistics display unique characteristics: the seasonality of harvests, frequent need for transport, variability in yields, spatial disparities in production volumes across regions, sometimes challenging road conditions, limited harvesting periods, and the necessity for timely field clearance, all contribute to the intensive demand on transportation services. Moreover, the cost of transporting grain is influenced by several variable factors, including the amount of grain transported, the distance (or average transportation radius), the efficiency of transport operations, the state, quantity, and capacity of the vehicles used, the rates charged for grain transport, the cost of fuel and lubricants, and the methods and timing of loading and unloading activities [10].

As can be seen from Table 5, the implementation of advanced technological solutions in logistics offers a spectrum of benefits alongside challenges. Leveraging digital modeling and optimization tools streamlines supply chain operations, while GPS enable real-time tracking for efficient route planning. Artificial intelligence and machine learning enhanced stock forecasting accuracy, and intermodal transport combines different modes for faster delivery. Predictive models identify risks, automation in warehouses reduces downtime, and blockchain ensures transparency. However, challenges such as high initial costs, technical complexity, and staff training requirements loom, alongside concerns over dependence on technology, privacy issues, and environmental challenges. Regulatory restrictions add another layer of complexity, underscoring the need for strategic planning and integration to fully capitalize on the potential advantages while mitigating risks. These results further support the idea [24] that strategic framework guides enterprises towards greater cooperation and coalition, emphasizing the critical roles of direct engagement, supportive services, and conducive government policies in fostering a collaborative ecosystem.

However, the limited carrying capacity of the current fleet, at just 14 and 14.5 tons, necessitates multiple trips to transport the same volume of grain, as highlighted in Tables 5, 6. The introduction of a Kamaz 45142 dump truck with a trailer, boasting a 25-ton capacity, significantly reduced the number of trips required for the same volume of grain. The comparative cost analysis reveals that while the use of a Kamaz 45142 incurs a transportation cost of 196.2 dollars, the smaller capacity Kamaz dump trucks lead to higher economic costs of 93.71 dollars. This strategic enhancement in transportation logistics not only optimizes operational efficiency but also significantly contributes to cost savings.

Unlike other studies [25] that may focus on general analyses of the agroindustrial sector, this study offers specific data on the contribution of different areas and investments to improving yields and quality of agricultural products. Alternative solutions, such as the use of other crops or technologies, may be effective in certain conditions, but it is important to take into account the specifics of regional agroindustrial production. Comparison with other regions shows that it is adaptation to local conditions and state support that allows the Republic of Kazakhstan to effectively develop its agroindustrial sector.

According to the study [26], it underscores the intricate connection between the economic security of agriculture and food security, highlighting the importance of addressing both for ensuring the sustainability and resilience of the agricultural sector.

These results reflect those of [27] who also highlights the crucial role of grain production not only as a standalone industry but also as a foundational element for numerous other sectors due to its system effect, acting as a vital raw material. In [28, 29], the authors have proved that a qualitative assessment of the transport and logistics system, for its adaptation to the world requirements, needs to be carried out according to internationally recognized methods, in particular, the Logistics Performance Index (LPI) developed and implemented by the World Bank.

Overall, there seems to be some evidence that the study covers key aspects including quality management, raw material safety and export activities. However, there are certain limitations, such as dependence on climatic conditions and the need to further improve the efficiency of transport processes. Suggestions for improvement include integrating digital technologies for better resource management and optimizing supply chains.

The study has the advantage of analyzing in detail the impact of agroindustrial innovation and government support on the development of the sector. The present study extends our knowledge of the current situation of transport and technological problems in the grain product subcomplex of the Republic of Kazakhstan and will serve as a base for future studies.

The paper's limitations include unclear farm zoning in several instances, necessitating re-evaluation of depreciation calculation methods. This need arises from the ambiguity in establishing equipment service life and the absence of uniform production standards across various machine types. Additionally, there's a requirement to distinguish between depreciation charges for older and newer equipment. The coefficients utilized for recalculating the cost of various mechanized tasks under specific conditions also require refinement. Planning for the future is challenged by insufficient information regarding new equipment models anticipated to be launched shortly. However, the scope of this study was limited in terms of transportation and technological challenges within the grain product subcomplex, without considering the potential influence of specific local government policies.

The disadvantages of this research are the theoretical approach and weak instrumentation for a discussion of the implication of the findings to future research into transport and technological problems in the grain product subcomplex of the Republic of Kazakhstan. It is necessary to use specific methods by which analyses bring together various theoretical and empirical strands to find factors influencing the development of transport and technological problems in the grain product subcomplex.

## 7. Conclusions

1. The current state and dynamics of the Republic of Kazakhstan's agricultural sector indicate a focus on wheat production and its impact on the country's economy, especially in the Akmola region. In 2023, the region showed significant results in agriculture with a total output of 1,647.2 million dollars, despite the reduction in investment in the agricultural sector. The importance of maintaining the quality and safety of agricultural raw materials and state measures taken to support the agroindustrial complex, including through financing and subsidies, is highlighted. The analysis of export indicators and the level of loading of grain storage facilities emphasizes the role of innovation and technological development in improving the efficiency and competitiveness of the Republic of Kazakhstan's agroindustrial sector. SWOT analysis of transport processes in the grain-product subcomplex identified key challenges and opportunities for further growth and sustainable development of the industry, indicating the need to eliminate technological shortcomings, strengthen government support and adapt to changing external factors.

2. A study of cross-border rail transport of crops revealed Uzbekistan as the dominant leader in the region with exports of over 17 million tonnes, reflecting its large-scale agricultural activities and developed rail network. The next most important exporter, Tajikistan with 6 million tonnes, underlines the importance of its role in exports via rail routes, while Iran with 4.7 million tonnes ranks fourth, highlighted by its different economic and climatic condi-

tions. Low export volumes in countries such as Romania, France and Lithuania nevertheless emphasize their importance in regional trade. Thus, cross-border rail transport data provide valuable information for analyzing export activity and can serve as a basis for studying the factors affecting it. As a result, the proposed method for grain transport on the farm is projected to yield an average cost reduction of 62.77 dollars per thousand tons.

3. A number of innovative solutions and methods for modeling transport processes in agribusiness, including the use of digital technologies, artificial intelligence, intermodal transport and clean transport will help to remedy the situation. These approaches offer significant benefits such as increased efficiency, cost reduction, improved predictive accuracy, environmental friendliness, safety and transparency of operations. However, they also come with a number of drawbacks, including high upfront investment, technical and integration challenges, the need for staff training, dependence on technology, privacy concerns, environmental challenges, and regulatory constraints. This points to the need to carefully weigh all aspects when implementing these technologies to optimize transport processes in the agricultural industry.

**Conflict of interest**

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

**Financing**

The study was conducted without financial support.

**Data availability**

All data are available in the main text of the manuscript.

**Use of artificial intelligence**

The authors have used artificial intelligence technologies within acceptable limits to provide their own verified data, which is described in the research methodology section.

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