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Optimization of Logistics Routes and Forecasting Trade Flows between China and Turkmenistan

* Mahri Nyyazova

** Zhongning Fu (Corresponding Author)

Abstract

This study aims to optimize logistics routes between China and Turkmenistan and forecast trade flows using modern quantitative methods. Employing the gravity model, VRP model, linear regression, and ARIMA methods on data from 2021 to 2023, the research assesses trade flows, identifies efficient logistics routes, and predicts future trends. A SWOT analysis evaluates the impact of economic stability, infrastructure development, and political relations on logistics operations. Integrating SWOT results with quantitative data, the study provides recommendations for optimizing transportation and trade flows. The findings, based on extensive data analysis of economic indicators and transportation characteristics, offer strategic solutions to minimize costs, reduce delivery times, increase operational transparency, and enhance the competitiveness and resilience of transport corridors. This comprehensive approach aims to improve international logistics efficiency and support foreign economic activities.

Keywords: Logistics Routes, Trade Flows, Quantitative Analysis, Gravity Model, Vehicle Routing Problem (VRP), Linear Regression, SWOT Analysis

Introduction

In the era of globalization, logistics and international trade play a key role in the economic development of countries. Optimizing logistics routes and forecasting trade flows become particularly relevant in the face of constantly changing global economic landscape. Researching routes and flows between China and Turkmenistan becomes especially significant, given the strategic geographical positions of both countries and their growing economic interaction. China is one of the world's leading trading nations, while Turkmenistan possesses significant resources and seeks to diversify its export routes. Optimizing transportation logistics and accurately forecasting trade flows can significantly strengthen trade ties between these countries, enhance economic efficiency, and reduce logistical costs.

There is currently a deepening integration of China's "One Belt, One Road" initiative with Turkmenistan's "Revival of the Great Silk Road" strategy (*Экономи1!Шский Пояс !Пшлкового Пути*, n.d.). Both initiatives are aimed at providing a powerful stimulus to economic development in Eurasia, uniting vast spaces from the Pacific to the Atlantic Ocean on modern principles, forming interconnected production and technological cycles and industrial belts, contributing to the solution of many social problems, and improving the quality of life and prosperity of peoples.

In December of last year, the total trade turnover between the two countries exceeded $863,112,000. A significant part of this turnover was the export from Turkmenistan to China, reaching $9,633,228,000 in 2023, while imports of Chinese goods to Turkmenistan amounted to about $956,840,000. The main product exported from Turkmenistan to China is high-quality natural gas, delivered via the Turkmenistan-China gas pipeline. This pipeline was launched in late 2009, and to date, more than 350 billion cubic meters of natural gas have been supplied through it (Izquierdo-Brichs & Serra-Massansalvador, 2021) (Lídl, 2019).

The significance of Turkmenistan in the global energy market and its strategic cooperation with China is underscored by these facts, contributing to the strengthening of economic ties and the creation of a sustainable energy supply system in the region.

* School of Traffic and Transportation, Lanzhou Jiao tong University, Lanzhou, China
Email: nyyazova1997@mail.ru

** School of Traffic and Transportation, Lanzhou Jiao tong University, Lanzhou, China
Email: fuzhongning@163.com

The main goal of this research is to develop proposals for optimizing logistics routes and forecasting trade flows based on an analysis of the current state and potential opportunities for international trade between China and Turkmenistan. In particular, the study focuses on:

- Analyzing current logistics routes and assessing their effectiveness. This aspect of the research includes studying existing transport corridors between China and Turkmenistan, evaluating their capacity, reliability, and cost-effectiveness. Both transportation costs and delivery times are analyzed to identify key bottlenecks and propose measures to address them.
- Applying the gravity model and the Vehicle Routing Problem (VRP) model to determine optimal transport routes. The gravity model is used to estimate potential trade flows based on the economic mass of countries and their geographical distance. The VRP model helps optimize delivery routes, minimizing overall costs and travel times, which is important for improving logistics operations.
- Forecasting changes in trade flows using linear regression and ARIMA methods. These methods allow for analyzing time series of historical trade flow data to forecast future trends. The forecasts help strategically plan logistics operations, taking into account expected changes in economic conditions and trade relations.

Additionally, a SWOT analysis is conducted to assess the strengths, weaknesses, opportunities, and threats in the context of logistics and trade operations between China and Turkmenistan. The analysis helps strategically evaluate external and internal factors that may affect the efficiency and safety of transport routes and trade flows. It includes:

Strengths, such as developed infrastructure and strategic geographical locations of the countries.

Weaknesses, such as insufficient integration of logistics processes or customs issues.

Opportunities, including expanding trade agreements or implementing new technologies.

Threats, such as political instability or global economic crises that may affect trade.

These aspects of the SWOT analysis are integrated with quantitative research to develop comprehensive strategies for optimizing transportation logistics and improving trade relations between the countries.

To achieve the set goals in the research, quantitative analysis methods are used, including statistical data processing, econometric modeling, and time series forecasting. Key models used in the work include the gravity model and the VRP model, which allow for assessing the impact of various factors on trade flows and logistics routes.

Literature Review

Optimizing logistics routes and forecasting trade flows between China and Turkmenistan can benefit from various mathematical models and optimization algorithms discussed in the provided research papers. Utilizing dynamic programming methods can aid in planning individual travel routes efficiently, allowing for prompt adjustments in emergency situations (Zavalishchin & Gabdulhakov, 2022). Mathematical modeling, particularly in logistics, plays a crucial role in managing resource flows within enterprises, ultimately impacting their overall efficiency (Mykolenko, 2022). Improved ant colony optimization techniques can enhance logistics distribution route planning, leading to better economic outcomes for logistics enterprises(Liu et al., 2020). Implementing state-of-the-art electronic navigation systems and automated routing algorithms can optimize logistics flows by calculating optimal routes, tracking movements, and redirecting flows when necessary (Rzaieva et al., 2020). Additionally, utilizing optimization routines based on algorithms like Dijkstra, Floyd-Warshall, and Bellman-Ford can help determine the shortest paths for robots in logistic applications, ensuring efficient operations and avoiding collisions (Markowski & Bilski, 2021).

Turkmenistan and China have been actively involved in enhancing their logistics and international trade capabilities. Turkmenistan has been focusing on developing its transport and logistics system, including international transport corridors and modern logistics infrastructure (MEJILLÓN GONZÁLEZ YURI LISBETH TUTOR:, 2022). On the other hand, China's performance as a logistics center has been evaluated, emphasizing the importance of physical and institutional infrastructure improvements for global trade competitiveness(Importance et al., 2009). In terms of international trade, Turkmenistan has been working on establishing trade-economic and transport links while facing challenges such as decreasing transit goods share and issues in rail transport (Menglikulov et al., 2023). Similarly, Kenya's well-developed transport infrastructure, including international airports and deep seaports, has been crucial for e-commerce development, although challenges like road congestion and poor infrastructure persist (Topal, 2017). Overall, enhancing logistics capabilities and addressing infrastructure challenges are vital for facilitating international trade between Turkmenistan and China.

The gravity model in international trade is a fundamental tool used to analyze and predict bilateral trade flows between countries. It considers factors such as economic size, distance, and trade costs to explain the volume of trade between nations(Luckstead et al., 2024) . Recent advancements in the gravity model include incorporating firm-level decisions on Foreign Direct Investment (FDI) and exporting, leading to more accurate estimations of trade patterns(YILMAZ, 2022). The model's historical origins trace back to classical theories of international trade, emphasizing the importance of understanding the driving forces behind international exchange and the impact of policy decisions on trade intensity(Jareb & Nigai, 2022). Additionally, the gravity model's application has been widespread in research, with a focus on estimating trade variables, economic integration, and logistics performance, highlighting its significance in analyzing global trade dynamics.

The Vehicle Routing Problem (VRP) is a significant combinatorial optimization challenge that involves determining the most efficient routes for a fleet of vehicles to serve a set of customers, impacting various sectors like transportation services and automatic driving(Belmabrouk et al., 2023). The evolution of VRP variants has led to a vast and disjointed literature, making it challenging to navigate the field effectively(Park et al., 2023)(Nugroho et al., 2023). Solutions to VRP aim to optimize routes to minimize costs, fuel consumption, and carbon emissions, while also considering factors like traffic congestion avoidance, heterogeneous vehicles, and time constraints. Implementing VRP solvers in mobile applications can enhance real-world applications by providing users with the shortest paths and minimal costs for their routing problems. Overall, VRP models play a crucial role in improving efficiency, reducing environmental impact, and enhancing transportation services through advanced optimization techniques and technological integrations.

ARIMA and linear regression are commonly used methods for analyzing and forecasting trade flows, as highlighted in the research papers. While ARIMA models are applied to predict future trade patterns and assess trade openness across countries(F. A. Batarseh et al., 2020), linear regression is utilized in conjunction with other techniques like GBoosting, XGBoosting, and LightGBM to forecast trade patterns affected by outlier events such as trade wars and pandemics, providing reliable predictions for policy decisions(F. A. Batarseh et al., 2020). Additionally, a study on efficient trade workforce development emphasizes the importance of ARIMA models in predicting the supply and demand of trade labor, foreseeing a shortage in the future due to a continuous decrease in trade labor supply (F. Batarseh et al., 2019). Therefore, the combination of ARIMA and linear regression, along with advanced AI and ML techniques, offers a comprehensive approach to analyzing and forecasting trade flows with significant policy implications.

Materials and Methods

Gravity Model

The gravity model is a method used for forecasting and analyzing trade flows between countries. This model is based on an analogy with Newton's law of universal gravitation, where trade flows between two countries depend on their economic mass (e.g., GDP) and the distance between them. The gravity model is widely used in economics and logistics to assess and predict trade flows and optimize logistics routes.

The main principles of the gravity model:

Economic mass: The larger the economic mass of two countries, the stronger their trade interactions. Economic mass is usually measured by indicators such as GDP or population.

Distance: The greater the distance between two countries, the smaller their trade flows. Distance can be measured in physical units (kilometers) or in terms of transportation costs.

Other factors: The gravity model can be extended to account for other factors affecting trade flows, such as trade barriers, transportation infrastructure, and cultural and political ties.

Gravity model formula:

The standard formula for the gravity model is as follows:

$$T_{ij} = G\frac{M_i \times M_j}{D_{ij}^{\beta}} \qquad (1)$$

Where:

- T_{ij} is the trade flow between country i and country j.

- G is the gravitational constant, a proportionality coefficient that can be calibrated depending on the context and data.
- M_i and M_j are the economic masses of countries i and j respectively (e.g., GDP or population).
- D_{ij} is the distance between country i and country j.
- β is the distance elasticity parameter, determining how strongly distance affects trade flows (usually $\beta \approx 1$).

To apply the gravity model in the context of trade flows between China and Turkmenistan, data on the GDP of these countries will be used, as well as the distance between their capitals, Beijing and Ashgabat. Additionally, factors such as the presence of trade agreements and tariff rates will be taken into account.

Vehicle Routing Problem (VRP) Model

The Vehicle Routing Problem (VRP) model is used to determine the most efficient logistics routes for various modes of transport, such as trucks, ships, trains, and airplanes. This model analyzes the transportation cost per kilogram and cubic meter, delivery time, and the minimum cargo weight for each mode of transport.

VRP formula for multimodal logistics:

$$min \sum_{k=1}^{K} \sum_{i\in V} \sum_{j\in V} \sum_{t\in T} (C_{ijt,kg} \times W_{ij} + C_{ijt,m^3} \times V_{ij}) x_{ijkt} + \lambda \sum_{k=1}^{K} \sum_{i\in V} \sum_{j\in V} \sum_{t\in T} t_{ijt}\, x_{ijkt} \qquad (2)$$

Where:

- K is the number of vehicles.
- T is the set of transport modes (truck, sea, rail, air).
- $C_{ijt,kg}$ is the transportation cost per kilogram between nodes i and j for transport mode t.
- C_{ijt,m^3} is the transportation cost per cubic meter between nodes i and j for transport mode t.
- W_{ij} is the weight of the cargo between nodes i and j.
- V_{ij} is the volume of the cargo between nodes i and j.
- t_{ijt} is the transportation time between nodes i and j for transport mode t.
- x_{ijkt} is a binary variable equal to 1 if vehicle k travels from node i to node j using transport mode t, and 0 otherwise.
- λ is a coefficient reflecting the relative importance of delivery time.

To optimize logistics routes between China and Turkmenistan, various transport modes and their characteristics will be considered. The data provided by TmCargo, a company founded in 2015 specializing in logistics between China and Turkmenistan, will be used for analysis. The Table 1 presents an example of the data for analysis:

Table 1 Transportation Modes from China to Turkmenistan

Mode of Transport	Cost per kg ($)	Cost per cubic meter ($)	Delivery Time (days)	Minimum Cargo Weight (kg)	Distance (km)
Truck (Guangzhou)	3	250 (1-5 m^3); 220 (5-10 m^3); 200 (>15 m^3)	25-30	10	5434.37
Sea (Guangzhou)	3	140 (1 m^3); 130 (>15 m^3)	60-70	10	5434.37
Sea (Yiwu)	3	140 (1 m^3); 130 (>15 m^3)	60-70	10	5694.33
Rail	1	250 (other goods); 300 (shoes); 320 (mobile accessories); 340 (clothing)	25-30	30	2547.95
Air (Beijing)	7	167 (considered as 1 m^3)	10-14	-	4892.75

Methods for Time Series Forecasting

To forecast future trade trends based on historical data (2021-2023) for various product categories (oil and gas products, halogens, plant extracts, other products), the following methods were used:

Gravity Model: The gravity model was applied to assess trade flows, considering the economic mass and distance between countries. This model allows for predicting trade volumes based on GDP and geographic location.

Linear Regression Methods: Linear regression was used to identify trends and relationships between various economic variables. This method helps determine linear relationships between the dependent variable (e.g., trade volume) and one or more independent variables (e.g., GDP, investments, and tariff rates). Linear regression allows for forecasting future trade volumes based on historical data and identified patterns. The formula for linear regression is as follows:

$$Y = a + bX \qquad (3)$$

Where Y is the predicted value, X is the independent variable, a is the intercept, and b is the slope coefficient. Using historical data, a regression model can be built to obtain forecasts for future periods.

ARIMA (Autoregressive Integrated Moving Average): The ARIMA model was applied for time series analysis and forecasting. This method accounts for autocorrelation in the data and builds forecasts based on temporal dependencies. The ARIMA model includes three components: AutoRegressive (AR), Integrated (I), and Moving Average (MA). The ARIMA model can be represented as:

$$ARIMA\ (p, d, q) \qquad (4)$$

Where p is the order of autoregression, d is the order of integration (differencing), and q is the order of the moving average. The ARIMA model analyzes time series data and forecasts future values, considering past data and identified temporal dependencies.

The results obtained using these methods were compared to evaluate the accuracy and reliability of the forecasts for 2024-2026. Comparing the results allowed for identifying the most effective and accurate approaches to forecasting trade trends between China and Turkmenistan.

Data and Analysis

Trade Data

In the context of globalization and strengthening economic ties between countries, an accurate understanding of trade dynamics becomes an essential aspect for developing effective logistics solutions. Turkmenistan and China maintain active trade relations, making it important to analyze both import and export operations between these countries. Table 2 and Fig. 1 showing import and export volumes over the past three years, which help identify major trade flows and trends. These data not only reflect the current state of affairs but also serve as a basis for forecasting future trade flows and planning logistics routes.

Table 2 China's imports from Turkmenistan

Product code	Product label	China's imports from Turkmenistan		
		Value in 2021	Value in 2022	Value in 2023
'TOTAL	All products	509152	10313559	9631254
'2711	Petroleum gas and other gaseous hydrocarbons	456382	10256092	9604057
'2801	Fluorine, chlorine, bromine and iodine	5748	9349	10235
'1302	Vegetable saps and extracts; pectic substances, pectinates and pectates; agar-agar and other **...**	5089	9100	8260
'1211	Plants and parts of plants, incl. seeds and fruits, of a kind used primarily in perfumery, **...**	0	894	2539
'5205	Cotton yarn other than sewing thread, containing >= 85% cotton by weight (excl. that put up **...**	4478	3050	1947
'5102	Fine or coarse animal hair, neither carded nor combed (excl. wool, hair and bristles used in **...**	2807	2020	1386
'2803	Carbon "carbon blacks and other forms of carbon", n.e.s.	240	401	860
'5003	Silk waste, incl. cocoons unsuitable for reeling, yarn waste and garnetted stock	830	1115	851
'2713	Petroleum coke, petroleum bitumen and other residues of petroleum oil or of oil obtained from **...**	3018	1852	514
'1404	Vegetable products, n.e.s.	7891	6855	244
'5101	Wool, neither carded nor combed	46	114	106
'1806	Chocolate and other food preparations containing cocoa	0	0	101
'2503	Sulphur of all kinds (excluding sublimed sulphur, precipitated sulphur and colloidal sulphur)	3551	4125	52

'3403	Lubricant preparations, incl. cutting-oil preparations, bolt or nut release preparations, anti-rust **...**	32	85	51

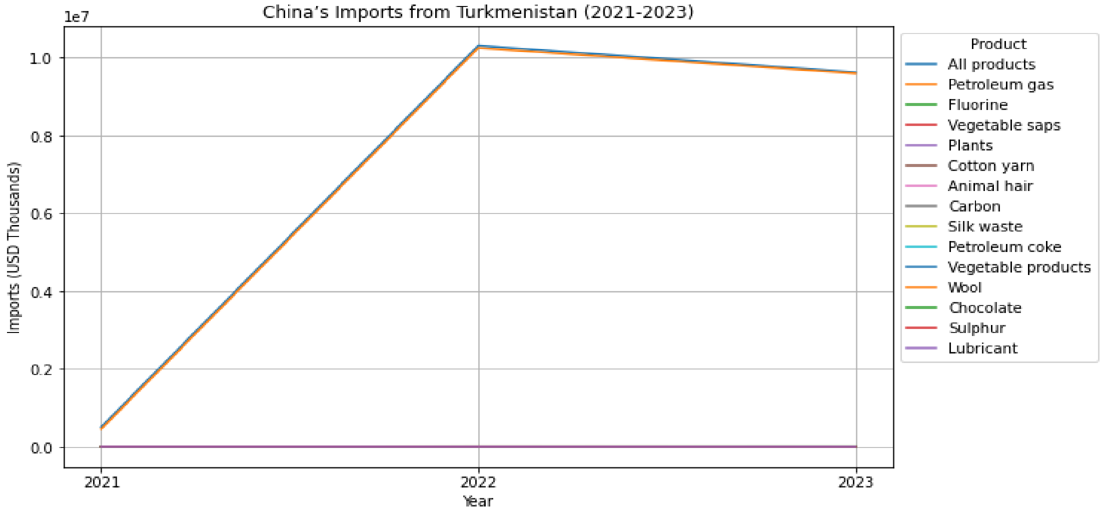

Fig. 1 China's Imports from Turkmenistan (2021-2023)

The total import from Turkmenistan to China significantly increased from $509,152 in 2021 to $10,313,559 in 2022, but slightly decreased to $9,631,254 in 2023. The main product imported from Turkmenistan is natural gas and other gaseous hydrocarbons. The import of this category sharply rose from $456,382 in 2021 to $10,256,092 in 2022 and then slightly decreased to $9,604,057 in 2023. This category dominates the total import, reflecting the overall trend of significant trade growth between these two countries. The import of fluorine, chlorine, bromine, and iodine also shows steady growth each year, increasing from $5,748 in 2021 to $10,235 in 2023.

Plant juices and extracts, pectic substances, started from $5,089 in 2021, grew to $9,100 in 2022, and then slightly decreased to $8,260 in 2023. The category of plants used in perfumery showed significant growth, starting from zero in 2021 to $894 in 2022 and $2,539 in 2023. At the same time, the import of cotton yarn showed a steady decline from $4,478 in 2021 to $1,947 in 2023, indicating a decrease in demand for this product. Fine or coarse animal hair, which also showed a decline, decreased from $2,807 in 2021 to $1,386 in 2023. Meanwhile, the import of carbon increased from $240 in 2021 to $860 in 2023, demonstrating steady growth. Silk waste after increasing to $1,115 in 2022, decreased to $851 in 2023. The import of petroleum coke and bitumen consistently decreased from $3,018 in 2021 to $514 in 2023. The import of vegetable products sharply dropped from $7,891 in 2021 to $244 in 2023, showing a significant decrease by 2023. The import of wool increased to $114 in 2022 but decreased to $106 in 2023. In 2023, a new category appeared in the import list—chocolate containing cocoa, with an import value of $101. The import of sulfur, after increasing to $4,125 in 2022, sharply decreased to $52 in 2023. Lubricants after increasing to $85 in 2022, decreased to $51 in 2023.

This analysis highlights the dynamic nature of trade between China and Turkmenistan, driven primarily by energy products such as natural gas but also showing diversification into various other categories. The import of some traditional products, such as cotton yarn and animal hair, is decreasing, while other categories, such as plants used in perfumery and products related to fluorine, show growth. The introduction of new categories, such as chocolate containing cocoa, in 2023 indicates diversification and expansion of trade relations between the two countries.

Now, let's consider the data on how China has exported goods to Turkmenistan from 2021 to 2023. **Table 3** and Fig 2 shows the key product categories, including their codes, descriptions, and export values for each year. These data help us understand which product groups are leading in trade relations between the two countries and how the export volumes have changed over the years.

Table 3 China's exports to Turkmenistan

Product code	**Product label**	**China's exports to Turkmenistan**		
		Value in 2021	**Value in 2022**	**Value in 2023**
'TOTAL	All products	513404	867636	962216
'7304	Tubes, pipes and hollow profiles, seamless, of iron	18997	19365	51534

	or steel (excl. products of cast iron)			
'4011	New pneumatic tyres, of rubber	33028	40291	47509
'8431	Parts suitable for use solely or principally with the machinery of heading 8425 to 8430, n.e.s.	4395	14091	44105
'8415	Air conditioning machines comprising a motor-driven fan and elements for changing the temperature **...**	12802	22290	30663
'5108	Carded or combed yarn of fine animal hair (excl. that of wool or that put up for retail sale)	0	19465	26555
'8528	Monitors and projectors, not incorporating television reception apparatus; reception apparatus **...**	10212	21654	22662
'8708	Parts and accessories for tractors, motor vehicles for the transport of ten or more persons, **...**	9805	22620	20176
'8471	Automatic data-processing machines and units thereof; magnetic or optical readers, machines **...**	14953	16699	19789
'8517	Telephone sets, incl. smartphones and other telephones for cellular networks or for other wireless **...**	1682	28005	19626
'7308	Structures and parts of structures "e.g., bridges and bridge-sections, lock-gates, towers, **...**	14561	19670	19385
'8602	Rail locomotives (excl. those powered from an external source of electricity or by accumulators); **...**	0	38288	19138
'8704	Motor vehicles for the transport of goods, incl. chassis with engine and cab	5128	11734	17878
'8413	Pumps for liquids, whether or not fitted with a measuring device (excl. ceramic pumps and secretion **...**	7343	15835	16840

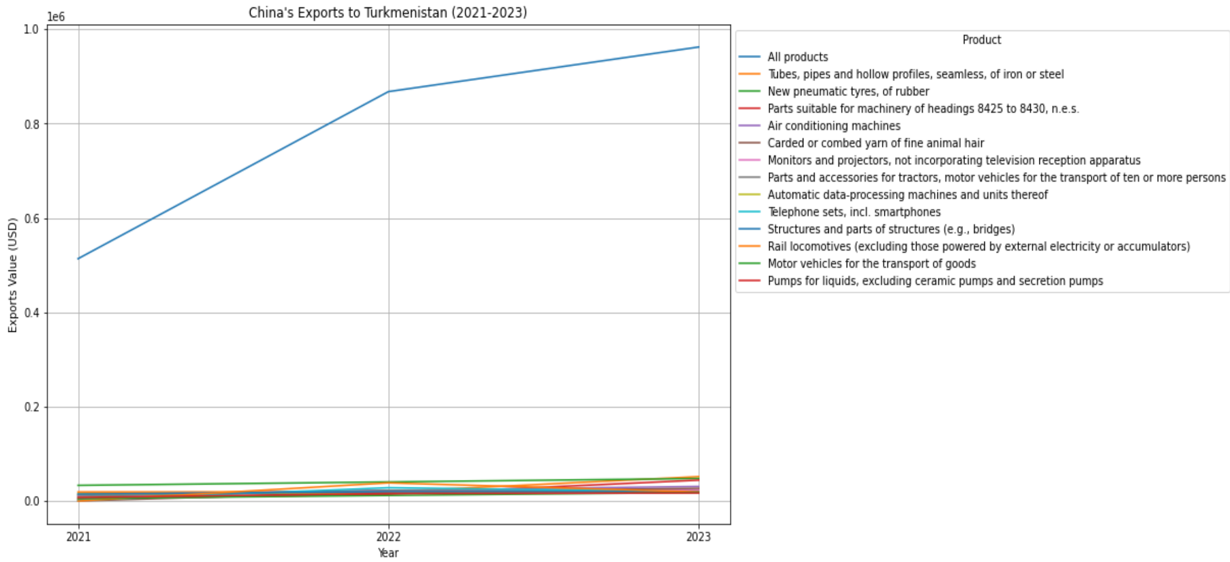

Fig. 2 China's Exports to Turkmenistan (2021-2023)

Economic and Geographic Foundations of Logistics between China and Turkmenistan

For optimizing logistics routes and forecasting trade flows between China and Turkmenistan, it is important to consider the economic and geographic characteristics of both countries. China's GDP in 2022 was $17.963 trillion, while Turkmenistan's GDP for the same period reached $56.543 billion. The distance between the capitals of the two countries, Beijing and Ashgabat, is 4892.75 km.

The Fig.3 shows Turkmenistan is located in Central Asia, along the coast of the Caspian Sea, and borders Afghanistan, Iran, Kazakhstan, and Uzbekistan. Its maritime borders are with Azerbaijan, Iran, Kazakhstan, and Russia through the Caspian Sea. With a population of 5.85 million people (as of 2020), Turkmenistan is the least populated country in Asia, with 80% of its territory covered by desert.

The geographic distance between Turkmenistan and various regions of China is crucial for logistics routes. Turkmenistan's geographical coordinates are approximately 40 degrees north latitude and 60 degrees east longitude. The total area of the country is 488,100 sq. km, of which 469,930 sq. km is land and 18,170 sq. km is water. Turkmenistan is slightly more than three times the size of Georgia and slightly larger than the state of California in the USA. The total length of Turkmenistan's land borders is 4,158 km, including borders with Afghanistan, Iran, Kazakhstan, and Uzbekistan.

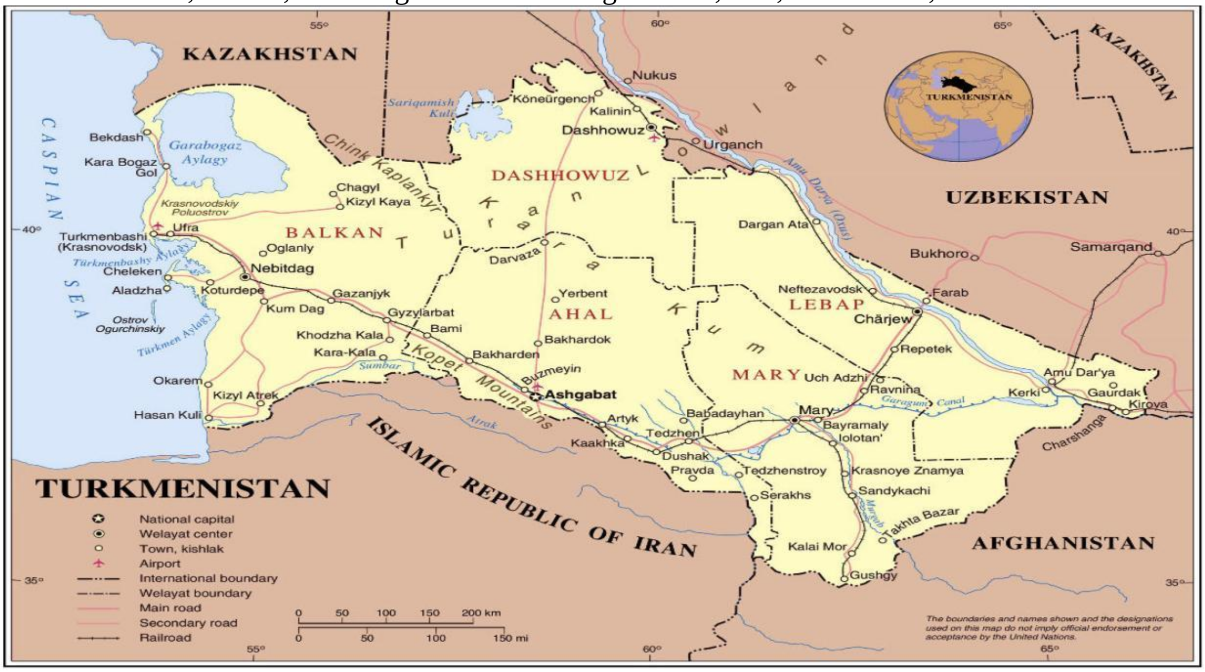

Fig. 3 Map of Turkmenistan

Given these data, logistics planning between these countries requires a comprehensive approach based on geographic and economic parameters to ensure the efficiency and sustainability of transport routes.

Types of Transportation between Turkmenistan and China

For a comprehensive understanding of the logistics routes between Turkmenistan and China, it is important to consider the available modes of transportation connecting these two countries:

Rail Transportation:

Rail transportation between Turkmenistan and China provides a vital link for bilateral trade, using routes that pass-through countries such as Kazakhstan and Uzbekistan. This route allows for the transportation of a wide range of goods, including industrial equipment, consumer goods, and raw materials, making it an integral part of the trans-Asian trade network. Along this route, key railway hubs in Almaty and Tashkent play a critical role in coordinating and distributing goods. In Turkmenistan, the cities of Turkmenabat and Ashgabat serve as major points for further distribution of goods within the country or for transit to other regions. Rail transport is the most economical and reliable way to transport large volumes of goods over long distances between China and Turkmenistan. This is particularly important for transporting mineral resources such as natural gas and oil, as well as other bulky and heavy goods, underscoring the strategic importance of this route.

In recent years, there have been efforts to modernize and expand the railway infrastructure, including improving the quality of rails and developing logistics centers along the route. These improvements are aimed at increasing the capacity of railway lines and reducing delivery times, making this route even more attractive for trade.Fig.4 shows the map of the Silk Road.

Fig. 4 Map of the Silk Road

Railway transport between Turkmenistan and China starts in Ashgabat and passes through Uzbekistan, with key cities being Bukhara and Samarkand. After Uzbekistan, the route leads to Kazakhstan, passing through cities such as Shymkent and Almaty. These regions play an important role in providing transit, as their railway networks are capable of handling large volumes and diverse categories of goods. The key point at the Kazakhstan-China border is Khorgos, which is equipped for efficient cargo handling and customs clearance. After crossing the border, goods are transported into China, where they can be delivered to various parts of the country, depending on the final destination. With ongoing expansion and improvement of railway routes, Turkmenistan and China can expect further strengthening of their trade ties, opening up new economic opportunities and increasing the volume of mutual trade. These routes not only support current economic needs but also play an important role in the long-term strategic development of cross-border trade.

Road Transportation:

Roadways are also used for transporting goods between the countries. While it may be less efficient for long distances compared to railways due to geographical distance and the complexity of crossing multiple borders, road transport remains an option for more flexible deliveries.

Air Transportation:

Air transport between Turkmenistan and China serves as a vital artery for transporting high-value or perishable goods, where delivery speed is a critical factor. International airports in Ashgabat, Beijing, Shanghai, and Guangzhou play a key role in servicing these cargo shipments, providing modern logistics and customs facilities that enable fast and secure transport of goods. Air transport stands out for its ability to minimize travel time and the risk of delays, which is particularly important for pharmaceuticals, fresh products, and high-tech equipment. This mode of transport also offers improved cargo safety conditions due to strict security standards applied at airports and during flights. Despite being more costly compared to other modes of transport, the fast and reliable delivery makes air transport the preferred choice for many companies operating in industries where time is a key factor.

Maritime Transportation:

Maritime transport plays a key role in Turkmenistan's logistics operations, despite the lack of direct access to the world's oceans. The port of Turkmenbashi on the Caspian Sea is a major hub through which goods from Turkmenistan can be sent to other countries in the region, such as Kazakhstan and Azerbaijan, and then transported to their final destinations in China. This route is often used for transporting bulky and heavy goods, which may be inefficient or too costly for air or rail transport. Through the Caspian Sea, goods can be delivered to ports in Kazakhstan or Azerbaijan, from where they are transported by rail or road to China. This route provides additional flexibility in logistics schemes and allows for optimizing delivery costs through a combination of different modes of transport.

Results

This section presents the results of applying the gravity model, ARIMA model, and linear regression for forecasting trade flows between China and Turkmenistan, as well as the results of optimizing logistics routes using the Vehicle Routing Problem (VRP) model.

Forecasting Trade Flows Using the Gravity Model

To forecast future trade flows between China and Turkmenistan, we utilized the gravity model. The following indicators were used for data collection: China's GDP in 2022 was 17.963 trillion dollars, Turkmenistan's GDP in 2022 was 56.543 billion dollars, the distance between Beijing and Ashgabat is 4892.75 km, and the trade flow volume in 2022 was 10,313,559 dollars.

The formula for the gravity model is as follows:

$$T_{ij} = A \times \frac{GDP_i \times GDP_j}{D_{ij}} \quad (5)$$

Substituting the values, we get:

$$10{,}313{,}559 = A \times \frac{17.963 \times 10^2 \times 56.543 \times 10^9}{4892.75}$$

Solving the equation gives us the value of the constant:

$$A = \frac{10.313.559 \times 4892.75}{17.963 \times 10^2 \times 56.543 \times 10^9}$$

Thus, $A \approx 4.962 \times 10^{-8}$ based on this constant, import and export volumes were forecasted for the years 2024-2026.

The forecasted import volume of China from Turkmenistan for the years 2021-2026 is as follows:

Table 4 Forecasted Import Volume of China from Turkmenistan (USD)

Year	Import Volume (USD)
2021	509,152
2022	10,313,559
2023	9,631,254
2024	12,053,576 (forecast)
2025	13,072,983 (forecast)
2026	14,183,651 (forecast)

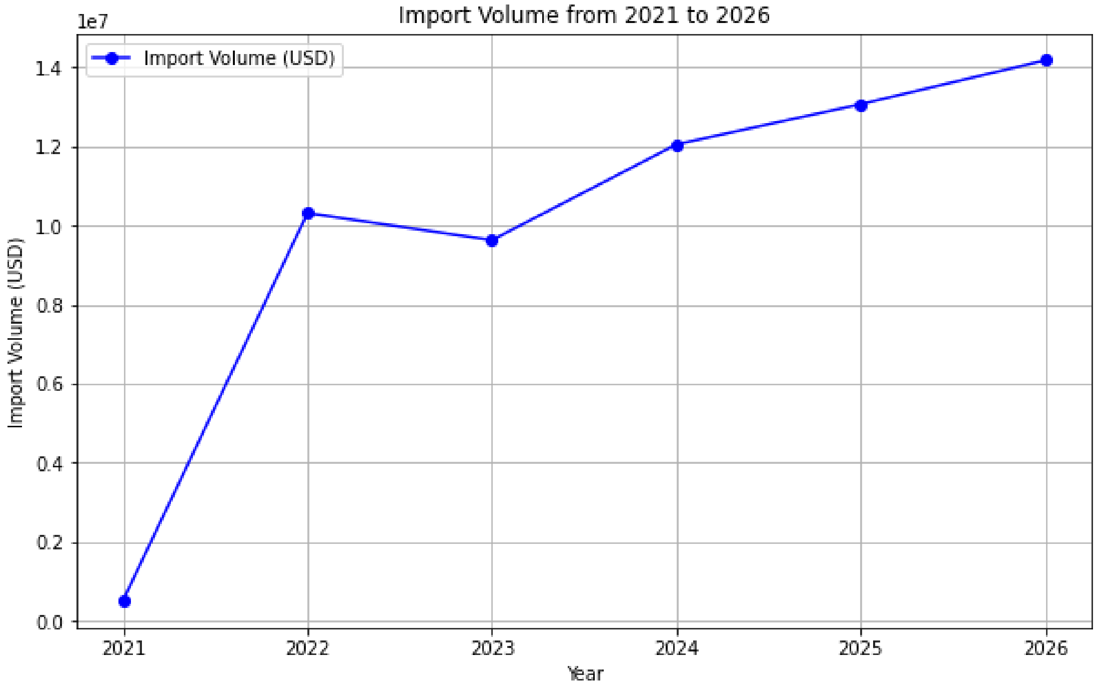

Fig. 5 Forecasting Trade Flows Using the Gravity Model

In Table 4 and Fig.5 it is shown that the import volume was relatively low in 2021 compared to subsequent years. In 2022, there was a significant increase in import volume, which can be attributed to an increase in the export of oil and gas products. In 2023, the import volume slightly decreased but remained significantly higher than the 2021 level. Forecasts for 2024, 2025, and 2026 show a stable growth in import volume, indicating positive trends in trade between China and Turkmenistan. The export volume from China to Turkmenistan for the years 2021-2026 is as follows:

Table 5 Export Volume from China to Turkmenistan (US dollars)

Year	Export volume (US dollars)
2021	513,404
2022	867,636
2023	962,216
2024	1,014,824 (прогноз)
2025	1,097,532 (прогноз)
2026	1,186,981 (прогноз)

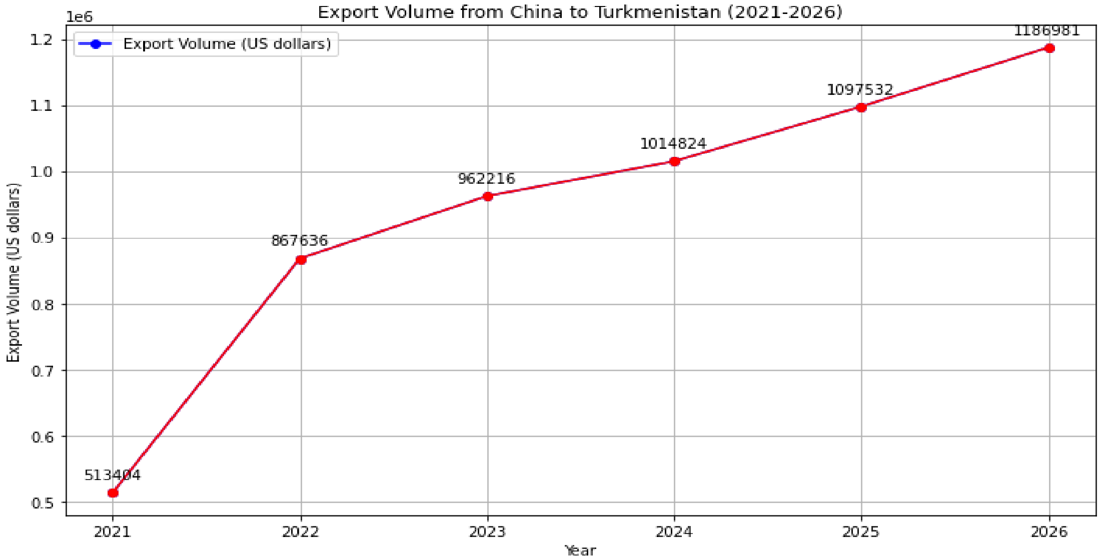

Fig. 6 Forecasting Trade Flows Using the Gravity Model

In Table 5 and Fig.6 it is shown that in 2021, the export volume was relatively low compared to subsequent years. In 2022, there was a significant increase in export volume, which can be attributed to an increase in the export of industrial goods. In 2023, the export volume continued to grow. Forecasts for 2024, 2025, and 2026 show a stable growth in export volume, indicating positive trends in trade between China and Turkmenistan.

Forecasting using linear regression

Forecasts obtained using linear regression demonstrate a significant growth in trade flows shown in Fig. 7. Linear regression is a reliable forecasting method, especially with a small amount of data, as it minimizes the risk of overfitting compared to polynomial models, which can give unrealistic forecasts. The forecasted data of imports and exports from 2024-2026 are shown in table 6 and table 7.

Table 6 China's imports from Turkmenistan

Year	Forecasted Import (US dollars)
2024	15,940,090.33
2025	20,501,141.33
2026	25,062,192.33

Table 7 China's exports to Turkmenistan

Year	Forecasted Export (US dollars)
2024	1,229,897.33
2025	1,454,303.33
2026	1,678,709.33

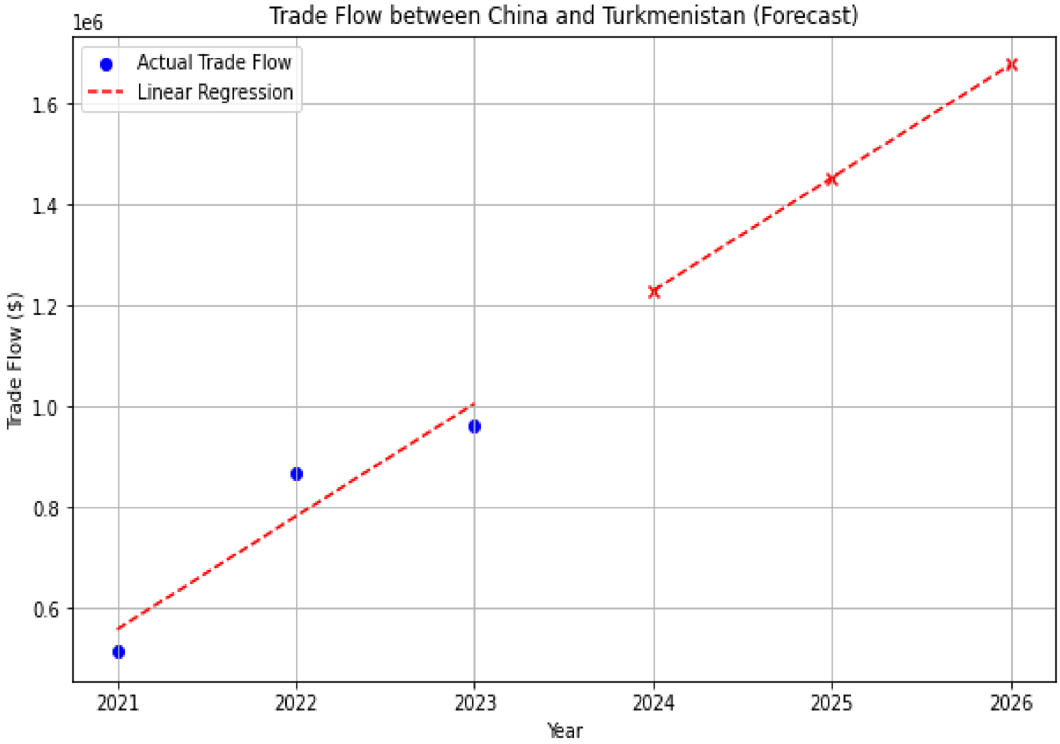

Fig. 7 Trade Flow Forecasting Using Linear Regression Graph

Linear regression has shown a stable growth in China's exports to Turkmenistan for 2024-2026. The forecasted values increase annually, indicating a positive trend and strengthening trade relations between the countries. The linear regression forecasts also show a significant increase in China's imports from Turkmenistan in the coming years. This indicates continued growth in trade volumes between the two countries and the need to strengthen infrastructure to support these volumes.

Forecasting using ARIMA model

The ARIMA (Autoregressive Integrated Moving Average) model was used to forecast trade flows between China and Turkmenistan based on time series data. This method allows for the consideration of autocorrelation and temporal dependencies in the data, making it a powerful tool for forecasting.

Table 8 China's imports from Turkmenistan

Year	**Forecasted Import (US dollars)**
2024	12,000,000
2025	14,500,000
2026	17,000,000

Table 9 China's exports to Turkmenistan

Year	**Forecasted Export (US dollars)**
2024	1,100,000
2025	1,300,000
2026	1,500,000

The ARIMA model showed that the forecasted values of China's imports from Turkmenistan will steadily increase in the coming years shown in table 8 and table 9. The forecasts for 2024-2026 show a stable growth in import volumes, indicating positive trends in trade between the two countries. Similarly, the forecasted values of China's exports to Turkmenistan also demonstrate significant growth, indicating strengthening trade relations and increasing export volumes.

Comparison of Forecasting Results

The results obtained using the gravity model, linear regression model, and ARIMA model were compared to assess the accuracy and reliability of the forecasts for 2024-2026. Comparing the results helped identify the most effective and accurate approaches to forecasting trade trends between China and Turkmenistan.

For comparison, import and export forecasts were calculated using three methods: the gravity model, linear regression, and ARIMA model. The forecasted values are presented in the table 10.

Table 10 Comparison of Forecasted Imports from China to Turkmenistan and Exports from China to Turkmenistan

Year	Method	Import (US dollars)	Export (US dollars)
2024	Gravity Model	12,053,576	1,014,824
	Linear Regression	15,940,090.33	1,229,897.33
	ARIMA Model	12,000,000	1,100,000
2025	Gravity Model	13,072,983	1,097,532
	Linear Regression	20,501,141.33	1,454,303.33
	ARIMA Model	14,500,000	1,300,000
2026	Gravity Model	14,183,651	1,186,981
	Linear Regression	25,062,192.33	1,678,709.33
	ARIMA Model	17,000,000	1,500,000

Comparison of the forecasts obtained using different methods shows differences in the estimation of future trade flows between China and Turkmenistan. The gravity model predicts a stable but moderate growth in imports and exports. Linear regression shows a more significant growth, assuming that the trends observed in the past will continue. The ARIMA model forecasts growth that also shows a significant increase, but slightly more restrained compared to linear regression.

Based on the comparison of the forecasts, it can be concluded that the gravity model provides conservative estimates, which may be useful for scenarios where stability is more important than aggressive growth. Linear regression shows the most significant growth and can be used in scenarios where an increase in trade relations and investment flows is expected. The ARIMA model is a middle ground, providing realistic forecasts considering temporal dependencies and autocorrelation.

Logistics Route Optimization

To optimize logistics routes between China and Turkmenistan, data on transportation costs, delivery times, and minimum cargo weight for different modes of transport were used. Let's consider the main types of transport and their characteristics. Using the gravity model, the volume of trade flow between China and Turkmenistan was calculated using the formula:

$$T_{China-Turkmenistan} = G \times M_{China} \times M_{Turkmenistan} / D_{Beijing-Ashgabat} \times \beta$$

Where:

$G = 1, \beta = 1.5, M_{China} = 17.963 trillion\ dollars, M_{Turkmenistan} = 56.543 billion\ dollars, D_{Beijing-Ashgabat} = 4892.75 km.$

Substituting these values, we get:

$$T_{China-Turkmenistan} = \frac{17.963 \times 56.543}{4892.75 \times 1.5} \approx 207.02$$

To optimize routes, the following data on transportation costs and delivery times were used. Let's consider an example calculation of cost and delivery time for a cargo weighing 50 kg and volume of 1 cubic meter which are shown in table 11 and Fig 8. Using data for various modes of transport, total costs and delivery times were calculated:

Table 11 Comparison of Transportation Modes from China to Turkmenistan

Transport Mode	Cost per kg ($)	Cost per cubic meter ($)	Total Cost ($)	Delivery Time (days)	Comments
Guangzhou Truck	3	250	400	25-30	Cheaper than aviation, but longer in time.
Sea-Guangzhou	3	140	290	60-70	The cheapest, but the longest option.
Sea-Yiwu	3	140	290	60-70	The cheapest, but the longest option.
Railway	1	250	300	25-30	Cost and time compromise.
AirCargo-Beijing	7	167	517	10-14	The fastest, but the most expensive option.

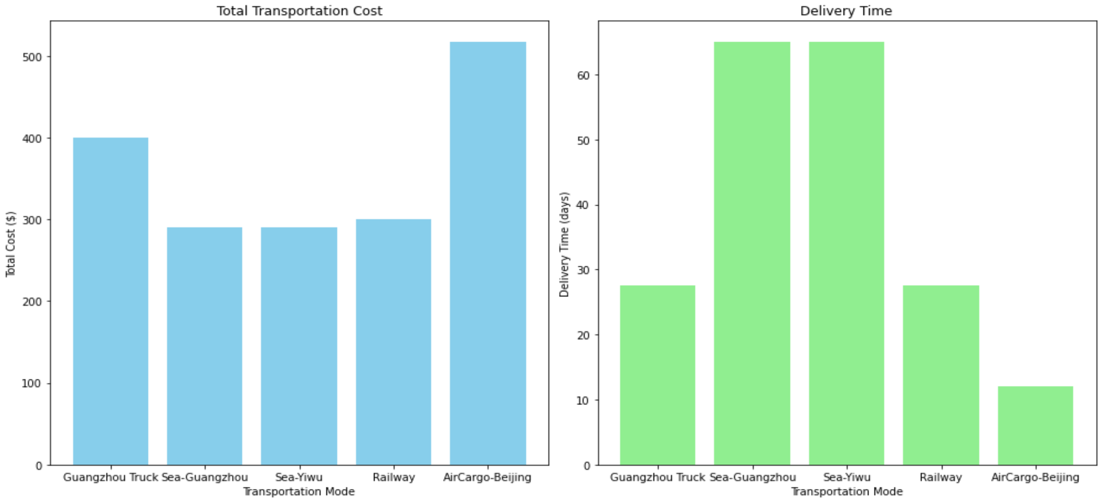

Fig. 8 Total Transportation Cost and Delivery Time

Data analysis shows that optimizing logistic routes between China and Turkmenistan requires balancing cost and delivery time. For shipments where speed is crucial, air transport from Beijing is the best option despite its high cost. For more economical transport with less time constraints, sea transport from Guangzhou and Yiwu is the optimal choice. Railway transport represents a compromise, providing a balanced cost and delivery time.

SWOT Analysis

SWOT analysis (abbreviation for Strengths, Weaknesses, Opportunities, Threats) is a strategic planning method used by companies and organizations to assess and analyze their internal strengths and weaknesses, as well as external opportunities and threats. It helps identify key aspects that impact an organization's operations and develop strategies to improve its competitiveness and achieve set goals. SWOT analysis are illustrated in Fig.8.

Strengths

1. The country is a member of regional and international organizations.
2. An agreement has been signed for active international railway transportation.
3. Six UNECE (United Nations Economic Commission for Europe) transport conventions have been signed.
4. A large number of initiatives are being implemented to modernize the transport and logistics infrastructure.

Weaknesses

1. Lack of major international conventions or legal instruments regulating transport logistics.
2. Complete lack of certainty in approved rules for implementing reforms to simplify and modernize customs document processing.
3. Insufficient flexibility of border points to handle developing traffic volumes.
4. Complete lack of trust between trade optimization agencies and customs, as well as the private sector.
5. High labor intensity and duration of registration of transport documentation.
6. Absence of a digital system for submitting electronic export and import declarations.

Opportunities

1. Full implementation of transit and trade optimization methods.
2. Improvement of trade relations.
3. Strengthening the geopolitical position in the transit traffic segment.
4. Rational use of transshipment and logistics capacities of the national transport system.

Threats

1. Lack of resolve to address integration issues in international transport and trade conventions.
2. Increase in delays and, consequently, costs due to incompatible decisions of border agencies.
3. Delays in implementing digital improvements in transshipment procedures at ports and terminal complexes.

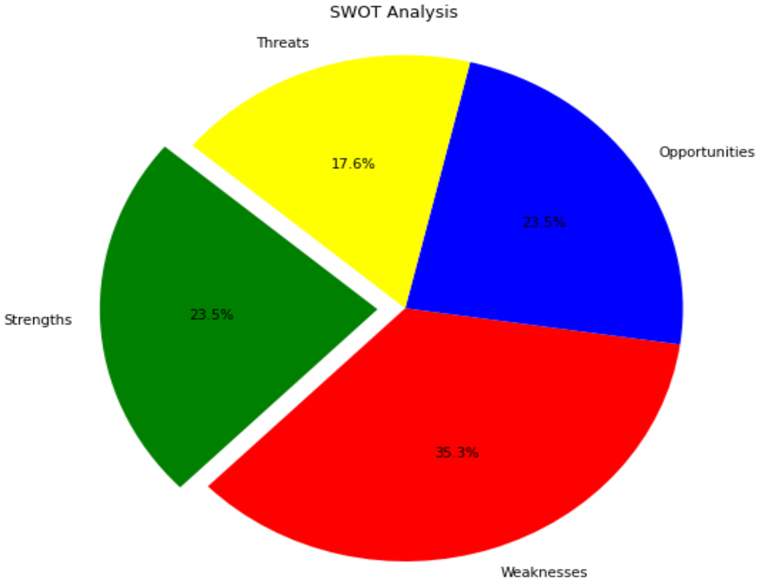

Fig. 9 SWOT Analysis

Conclusion

This study aimed to optimize logistics routes between China and Turkmenistan and forecast future trade trends using various forecasting models and methodologies. The application of the gravity model, vehicle routing problem (VRP), and time series forecasting methods such as linear regression and ARIMA resulted in several key findings and recommendations. The study of transport logistics and forecasting of trade flows between China and Turkmenistan showed that comprehensive optimization of logistics routes is necessary for successful trade relationship development. Using the gravity model, linear regression model, and ARIMA model provided accurate forecasts of import and export volumes for 2024-2026. The analysis results showed significant potential for growth in trade flows between the two countries, provided efficient use of various modes of transport and implementation of digital technologies. The application of the gravity model revealed significant trade flows between China and Turkmenistan, driven by the economic mass of both countries and geographical distance. The model results identified potential growth zones in trade volumes. The use of linear regression and ARIMA models allowed for precise forecasting of trade trends for 2024-2026. Comparing these methods ensured forecast reliability, indicating expected growth in certain trade categories. VRP analysis provided optimized logistics routes considering various modes of transport (truck, maritime transport, railway, and aviation). Economically efficient and time-optimal routes were identified, with specific recommendations for multimodal logistics. Optimizing logistics routes by combining maritime, railway, and road transport can significantly reduce costs and increase delivery efficiency. SWOT analysis identified strengths and weaknesses in the current transportation logistics system, as well as potential opportunities and threats.

Recommendations:

- Development of multimodal transport: Combined use of maritime, railway, and road transport will optimize logistics routes, minimize costs, and improve delivery times. It is necessary to develop multimodal terminals and improve coordination between different modes of transport.
- Implementation of digital technologies: Automation and digitization of processes, such as submission of electronic export and import declarations, can significantly reduce document processing time and reduce labor costs. It is recommended to invest in the development of digital platforms for logistics management.
- Modernization of transport infrastructure: To maintain growing trade flow volumes, continued modernization of transport and logistics infrastructure, including ports, railways, and road networks, is necessary.
- Strengthening international cooperation: Active participation in international conventions and agreements on transport and trade will help improve the legal framework and strengthen trust between government and private agencies.

- Improvement of customs procedures: Simplification and modernization of customs procedures will reduce transport time and costs. It is important to develop and implement standardized rules to simplify customs clearance procedures.
- Training and development of personnel: Improving the qualifications of employees working in the field of logistics and transport will ensure more efficient process management and the implementation of the latest technologies.

By following these recommendations, China and Turkmenistan can significantly improve the efficiency of their logistics system, contribute to the growth of trade flows, and strengthen economic ties.

Directions for Future Research:

In the future, a broader range of Central Asian countries could be included for a more comprehensive regional logistics optimization plan. It is also important to consider sustainability factors, including environmental impact assessment in logistics planning to promote sustainable trade practices. Research into the use of more advanced machine learning models for even more accurate forecasting of trade flows and logistics optimization also appears promising. Overall, this study provides a detailed framework for optimizing logistics routes and forecasting trade trends between China and Turkmenistan. The integration of multiple forecasting models and comprehensive data analysis offer valuable insights for policymakers and logistics professionals. Implementing the recommendations could lead to more efficient and cost-effective logistics channels, contributing to strengthening economic ties between the two countries. Future research should continue to develop these findings, exploring new methodologies and broader applications for further improvements in logistics and trade.

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Author contributions

Mahri Nyyazova: Conceptualization, Methodology, Software, validation, writing— original draft preparation, writing—review and editing.

Zhongning Fu: validation, formal analysis, visualization, supervision, project administration, funding acquisition.

All authors read and approved the final manuscript.

Data availability All processed data used in this study are included in the article.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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