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MODELLING TERRITORIAL LOGISTICS BASED ON ECONOMIC DISTANCE

This article examines methods for modeling territorial logistics using the concept of economic distance. Logistics plays a key role in the socio-economic development of Kazakhstan by facilitating the efficient movement of goods and integrating the country into international transport corridors. The study explores the principles of modeling transport flows by applying models that assess the impact of transport accessibility and infrastructure capacity on the effectiveness of logistics processes.

A comparative analysis was carried out on the Huff Model, the Rayleigh Distribution, and the Modified Gravity Model across six parameters. Based on a hypothetical example using the Huff and Rayleigh models, a practical study was conducted for three regions of Kazakhstan's transport network. As an example, the transport network of Kazakhstan, including logistics hubs in the cities of Astana, Almaty, and Karaganda, was examined. The calculations demonstrated that the distribution of cargo turnover is determined not only by the volume of freight flows but also by economic distance, which reflects the logistics attractiveness of hubs in regional development.

The practical analysis of Kazakhstan's transport network shows that hubs with high cargo turnover located in close proximity to consumer regions possess enhanced logistical attractiveness. This enhances the significance of economic distance, which combines physical distance and the economic costs of transport.

Optimizing the territorial logistics infrastructure helps reduce transport costs, improve the efficiency of freight transport, and facilitate the integration of regions into national and international transport corridors. The models and methods presented in the article can be employed for strategic planning of logistics processes and the development of effective cargo distribution schemes.

Key words: territorial logistics, economic distance, Huff Model, Rayleigh Model, Modified Gravity Model, transport accessibility, cargo turnover.

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Экономикалық қашықтық негізінде аумақтық логистиканы модельдеу

Бұл мақалада экономикалық қашықтық тұжырымдамасын қолдана отырып, аумақтық логистиканы модельдеудің әдістері талданады. Логистика Қазақстанның әлеуметтік-экономикалық дамуын қолдауда шешуші рөл атқарады, жүктің тиімді тасымалдануына және елдің халықаралық көлік дәліздеріне интеграциясына ықпал етеді. Жұмыста көлік ағындарын модельдеу принциптері қарастырылады, ол арқылы көлік инфрақұрылымының қолжетімділігі мен өткізу қабілетінің логистикалық процестердің тиімділігіне әсері бағаланады.

Зерттеу барысында Хафф моделі, Рейли моделі және модификацияланған гравитациялық модель алты параметр бойынша салыстырмалы талдауға алынған. Гипотетикалық мысал негізінде Хафф және Рейли модельдері үш аймақтың (Астана, Алматы және Қарағанды қалаларының логистикалық жүйесі) көлік желісі үшін практикалық зерттеу жүргізуге пайдаланылды. Есептеулер көрсеткендей, жүк айналымының бөлінуі тек жүк ағындарының көлеміне ғана емес, сонымен қатар экономикалық қашықтыққа байланысты анықталады, ол аумақтардың дамуына әсер ететін логистикалық хабтардың тартымдылығын сипаттайды.

Қазақстан көлік желісіндегі практикалық талдау көрсетуі бойынша, жоғары жүк айналымы бар және тұтынушы аймақтарға тікелей жақын орналасқан логистикалық объектілер жоғары логистикалық тартымдылыққа ие, бұл физикалық арақашықтық пен тасымалдау шығындарын біріктіретін экономикалық қашықтық параметрін күшейтеді.

Аумақтық-логистикалық инфрақұрылымды оңтайландыру көлік шығындарын азайтып, жүк тасымалының тиімділігін арттыруға және аймақтарды ұлттық және халықаралық көлік дәліздеріне интеграциялауға ықпал етеді. Мақалада ұсынылған модельдер мен әдістер логистикалық процестерді стратегиялық жоспарлау және тиімді жүк бөлуді қамтамасыз ететін схемаларды әзірлеуге арналған.

Түйін сөздер: аумақтық логистика, экономикалық қашықтық, Хафф моделі, Рейли моделі, модификацияланған гравитациялық модель, көлік қолжетімділігі, жүк айналымы.

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Моделирование территориальной логистики на основе экономического расстояния

В данной статье рассматриваются анализ методов моделирования территориальной логистики с использованием концепции экономического расстояния. Логистика играет ключевую роль в социально-экономическом развитии Казахстана, способствуя эффективному перемещению грузов и интеграции страны в международные транспортные коридоры. В работе рассматриваются принципы моделирования транспортных потоков с применением моделей, позволяющих оценить влияние транспортной доступности и пропускной способности инфраструктуры на эффективность логистических процессов.

Проведён сравнительный анализ модели Хаффа, Рейли и модифицированная гравитационная модель по шести параметрам. На основе гипотетического примера моделей Хаффа и Рейли проведено практическое исследование для трёх регионов транспортной сети Казахстана. В качестве примера рассмотрена транспортная сеть Казахстана, включая логистические узлы в городах Астана, Алматы и Караганда. Расчеты показали, что распределение грузооборота определяется не только объемами грузопотоков, но и экономическим расстоянием как логистическая привлекательность узлов в развитии территорий.

Практический анализ, проведённый на примере транспортной сети Казахстана, демонстрирует, что узлы, обладающие высоким грузооборотом и находящиеся в непосредственной близости к потребительским регионам, имеют повышенную логистическую привлекательность, что усиливает параметры экономического расстояния, которое объединяет физическую дистанцию и экономические издержки перевозки.

Оптимизация территориально-логистической инфраструктуры способствует снижению транспортных издержек, повышению эффективности грузоперевозок и интеграции регионов в национальные и международные транспортные коридоры. Представленные в статье модели и методы могут быть использованы для стратегического планирования логистических процессов и разработки эффективных схем грузораспределения.

Ключевые слова: территориальная логистика, экономическое расстояние, модель Хаффа, модель Рейли, модифицированная гравитационная модель, транспортная доступность, грузооборот.

Introduction

Territorial logistics plays a key role in the socio-economic development of the region, country, various inter-country unions including the entire globe (Konkova, 2012, Toluev, 2008). Logistics ensures the efficient movement of goods, services and labour through the development of territorial transport systems.

Kazakhstan, having a strategic geographical location, is actively developing its transport and logistics system, increasing its role in international transit corridors between Europe and Asia. As emphasised by the President of Kazakhstan K. J. Tokayev in his message to the nation, the concept of full utilization of the potential of the transport logistics industry and the development of the country's logistics complex for the long term is one of the key directions of the development strategy until 2030.

The development of the territorial transport system of the Republic is based on the transport infrastructure: an extensive network of roads and railways, air and sea routes, logistics centers, corridors and transit at the international level. Kazakhstan's transport network plays a key role in ensuring logistics flows both domestically and internationally. Over the past 15 years, $35bn has been invested in transport and logistics, which has contributed to a significant development of the industry. It is forecast that by 2025 the share of the transport sector in the country's GDP will grow from 6.2% (in 2022) to 9%.

Kazakhstan has 16,000 km of railways, 94,800 km of roads, 25 airports and major seaports on the Caspian Sea. A significant role in the transport system is played by a 29,000 km pipeline network that transports oil and gas.

Figure 1 illustrates a map of Kazakhstan's transport infrastructure, showcasing key highways, railways, ports, and border crossing points. The country's transit potential is expanding due to the use of Caspian Sea ports, which facilitates Kazakhstan's integration into global trade networks.

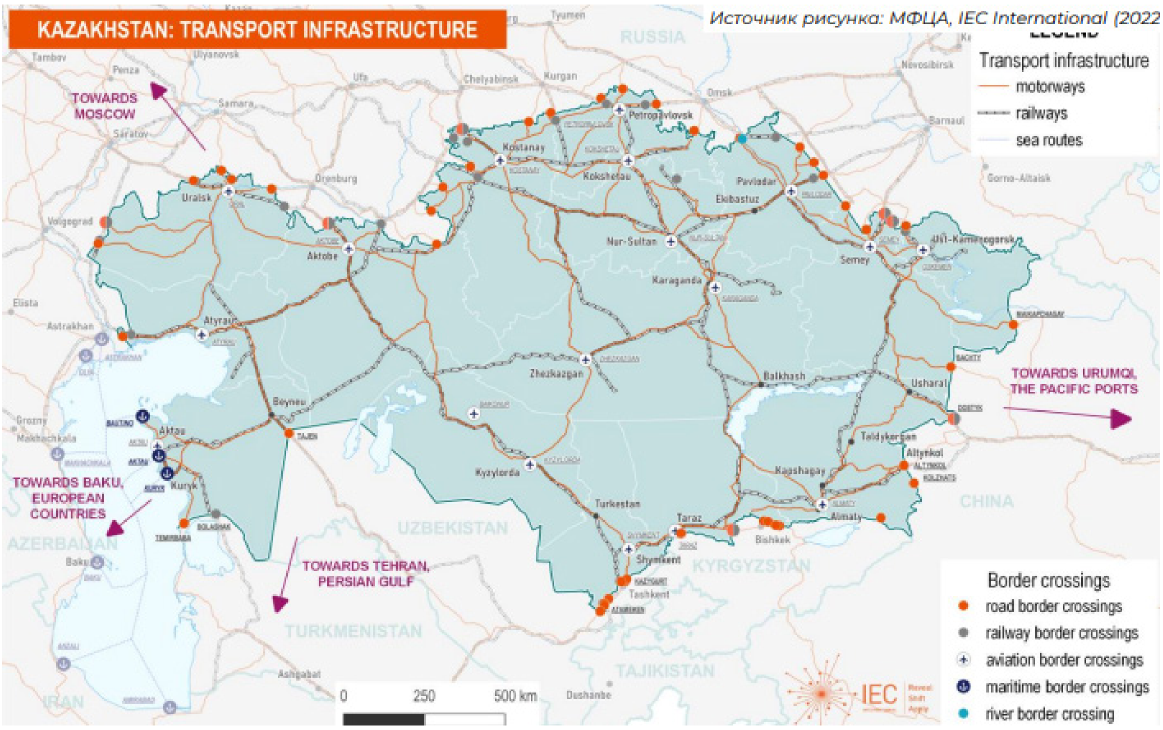

Figure 1 – Transport infrastructure of Kazakhstan
Note – Transport and Logistics Industry of Kazakhstan, 2024

Challenges related to transport accessibility, infrastructure capacity and critical loads on key facilities keep the logistics system in Kazakhstan actively developing. The territorial logistics system is a complex, multi-criteria, multi-level hierarchical structure. The system is affected by external weather conditions, foreign policy, etc. and, as a rule, the output parameters of the system randomly depend on the input parameters, the analysis and study of which is possible using traffic flow modelling methods (Tararychkin, 2016).

This paper considers the key factors and methods of optimal location of elements of territorial logistics infrastructure. It analyses the relationship between the capacity indicators of transport nodes and their location on the basis of Huff models and Rayleigh's law (Kolosov, 2015). The study is based on hypothetical examples demonstrating the improvement of the territorial logistics system taking into account geographical, technological and social parameters. The results that will be acquired will enable the identification of existing problems and propose effective solutions that will help further develop any size territory.

Kazakhstan's President Kasym-Jomart Tokayev has consistently underscored the necessity of modernizing the country's transport and logistics infrastructure. The priority areas include the construction of new railway lines, such as «Moyynty – Kyzylzhar», the expansion of the «Altynkol – Zhetygen» corridor, and the establishment of an international aviation hub with modern cargo and passenger terminals. These measures are aimed at strengthening Kazakhstan's transit potential and increasing its competitiveness in global transport flows (Kazakhstan Government's Extended Meeting, 2024).

Literature review

Area logistics is becoming an important area of research in modern logistics, which deals with the management of economic and human flows for the optimal location of transport nodes of a region, state and territory of any type in the world, including itself. The works of E.D. Konkova and Y.I. Toluev, E. Sassi, A. Benabdelhafid, highlight the main aspects of the concept of territorial logistics, including a set of methods and services, as well as the need to optimise territories to ensure the effective placement of spatial objects.

Development of territorial transport systems is the logistics infrastructure, which requires the definition of economic, technical and geographical parameters. From the works of authors Singer O. A. and Ilyasova A. V. We can identify 3 parameters: economic, technical, geographical. Including foreign and domestic authors analyse the spatial characteristics of transport infrastructure, the density of transport hubs and methods of optimizing the location of logistics centres.

In this context, several models have been employed to examine spatial interactions and the concept of economic distance in logistics. Foreign authors Bowersox, Donald J., Mentzer, John T. Speh, Thomas W. In an article published in the Journal of Business Strategies, the advantages and disadvantages of logistic shoulders defined by 'economic distance' were noted. It is noted that the term 'logistic leverage' refers to the high market returns that can be obtained with a relatively small investment. The authors Stroeva G.N. and Slobolchikov D.V. in their work revealed in detail the definition of transport accessibility. Kopytova Y.V. in the book 'Young Scientist' investigated transport capacity as the main parameter that determines the place of transport systems in the urban transport structure. In the article by P.V. Popov and I.Yu. Miretsky considered the main methods of solving the problems of logistics infrastructure. Among the models and methods used in practice, the author singled out those that take into account the influence of factors and allow calculating the most favourable location of warehouses in the distribution network. The methods of commercial attractiveness and Arthur Geofrion's centre of gravity method were mentioned in particular.

Modern approaches to developing logistics infrastructure in constrained spaces have been summarized by American economist E. Hoover and Russian researchers V.I. Sergeev and V.V. Dybskaya, emphasizing the integration of economic, technological, and spatial factors. A.O. Kolosov demonstrated the practical application of the Huff Model in this context, quantifying consumer choice based on the ratio of a location's attractiveness to its travel cost using a power-law decay function (Huff, 1963). Additionally, recommendations have been made for using gravity models as tools for retail customer orientation. Kosterin I.G. conducted a sociological analysis of customer movements from small towns to larger cities using Reilly's law, drawing an analogy with Newton's universal gravitation to explain spatial interactions.

This study compares three foundational models for analyzing economic distance—the Huff Model, the Rayleigh Distribution, and the Modified Gravity Model. Together, these models form a robust theoretical framework for understanding and optimizing spatial interactions in territorial logistics.

Territorial logistics includes a set of logistics services that are performed on some specific territory by a logistics operator, which manages logistics nodes in the structure of material flows. However, the services are performed by a logistics operator, which is not a node in the structure of material flows, but it plays a key role in ensuring the effective functioning of the logistics system in a particular territory (Stroeva & Slobodchikova, 2016), (Slobodyanyuk & Gorobchenko, 2020).

A logistics hub is an element of logistics infrastructure as a set of services through which the movement of material and financial flows or the process of distribution of goods is carried out.

The targets of logistics infrastructure are production enterprise warehouses, logistics centers, loading and unloading terminals, distribution centers, sorting and distribution warehouses and retail outlet warehouses. Determining the required number of such facilities, their location and economic functions is the most important element in the formation (design) of the logistics infrastructure of territorial logistics. Integration of infrastructural objects by a logistics operator, provides relevant services regardless of who exactly performs these operations. Thus, the objects of territorial logistics infrastructure (table 1) are divided into three main groups.

Table 1 – Objects of logistics infrastructure of territorial logistics

Level	Description
Local	facilities of local importance, called logistics parks or centres.
Regional	Regional logistic centers in regions where there is well-established transport infrastructure and a stable information system provide the broadest range of logistics services.
International	International logistics centers are large-scale infrastructure facilities located over a significant area and constructed in close proximity to key transport hubs, such as ports, airports, railway junctions, and intermodal terminals.
Note – complied by author	

The facilities of the first group include specialised facilities for the provision of certain types of commodity flow regulation services by individual firms and networks. The facilities of the second group create conditions for effective regulation of input and output flows of various goods in the national and regional markets. The facilities of the third group, using innovative information and communication technologies, ensure the qualitative performance of the entire range of logistics services, respectively, introduce the necessary coordination to ensure a reduction in the time of realisation of goods along the entire chain and pulling commodity flows in transit within the country (Bolodurina, 2019), (Popov, 2019).

Now let us consider the main methods of solving problems of logistics infrastructure facilities location.

Simple models and procedures. These models allow us to establish the coordinates of individual objects of logistics infrastructure and their networks. Among the techniques and models that have gained extensive practical application, we would highlight the Ardalan technique due to which you can determine the optimal location of warehouses in the distribution network by considering the impact of factors, Erlenkotter's 'total optimal market service area' model, commercial attractiveness approaches, and Arthur Geofrion's centre of gravity method. These methods are based on many assumptions and include an operational assessment of the assumed logistics infrastructure.

Complex methods and models. Researchers A. Klose and A. Drexil proposed to divide all complex methods and models into three main groups (figure 2): network modelling, continuous and discrete optimization methods.

Approximate heuristic and metaheuristic methods are used to solve problems with a large number of possible options for the location of logistics infrastructure facilities. They make it possible to approach the optimal location of the network of transport and warehousing facilities in a 'reasonable time'. They include genetic algorithms, local search algorithms and the method of prohibitions.

One of the modern approaches to developing logistics infrastructure in a limited space was systematized by American economist E. Hoover, as well as Russian scholars V. I. Sergeev and V. V. Dybskaia. The location and number of infrastructure facilities are determined based on an analysis of key socio-economic characteristics of the territory, including the location of consumers, demand volume, required level of logistics services, and other factors. The primary criterion for site selection is its proximity to the target market within the designated geographical region (Zinger & Ilyasova, 2015).

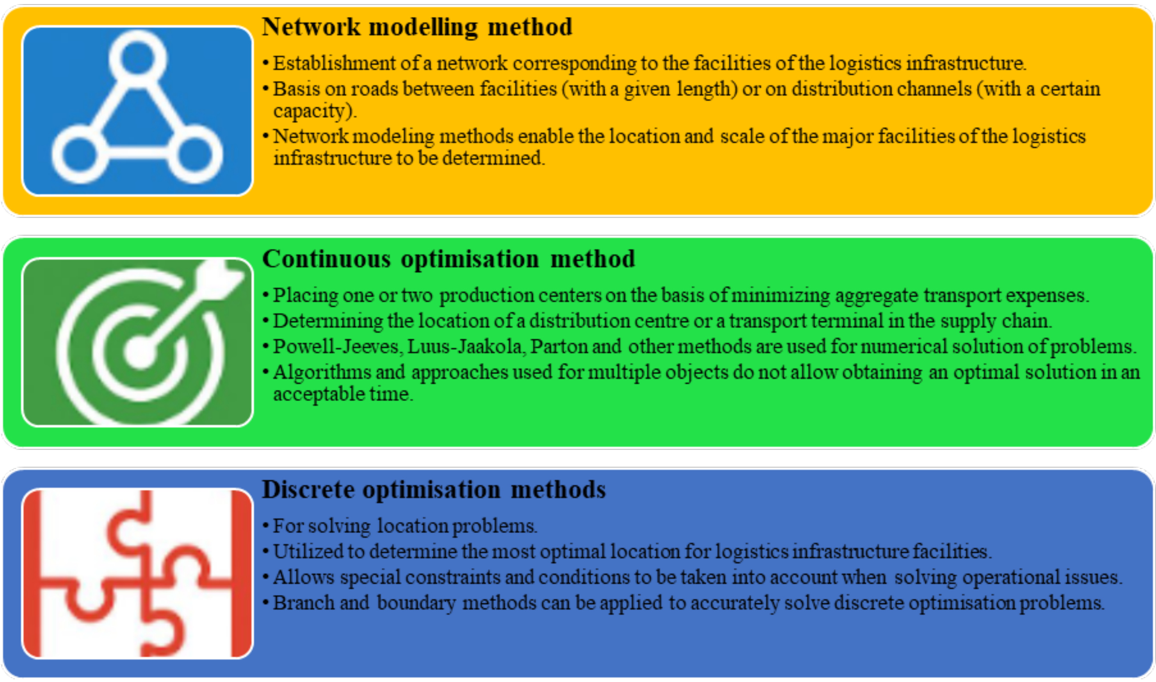

Figure 2 – Complex methods and models for solving problems of logistics infrastructure facilities location
Note – complied by author

Methodology

Let us consider the main parameters of size, distance, transport costs, infrastructure, attractiveness of the objects according to the infrastructure levels of territorial logistics. Infrastructure objects, for example, at the local level of infrastructure are warehouses, at the regional level distribution centres, and at the international level transit corridors. The placement and interaction of these facilities can be investigated using Huff and Reilly models. (Piketty, 2015), (Bowersox, 2008).

Given that one of the main parameters in logistics is economic distance, which is defined not only by the physical distance between points, but also by a set of factors (transport costs, delivery time, risks, etc.). The Huff, Reilly and modified gravity models demonstrate different mathematical representations that take into account the influence of distance on the intensity of interactions. Such approaches have direct relevance to the concept of economic distance in logistics and the concept of 'logistic shoulder'. In a logistics network, logistics shoulder can be understood as the part where interactions (e.g. delivery of goods, movement of goods) remain economically efficient. It is a kind of 'radius of action' of the logistics system around the central node (warehouse, distribution centre), beyond which the costs of transportation start to exceed the potential benefits of the interaction. For example, in logistics, 'shoulder' can be interpreted as the distance from the loading point to the unloading point. There is a distinction between 'short shoulder' and 'long shoulder', between which there is a fundamental difference.

- A 'short shoulder' is the transport of goods between several settlements at a distance not exceeding 500 km or within one working day.

- 'Long shoulder' in the field of road transport means the carriage of goods over long distances, over 500 km, which requires several days on the road. International freight transport can be attributed to such transportations.

Let us consider the advantages of 'short' and 'long' economic distance (Table 2).

Discussions about which option – 'long shoulder' or 'short shoulder' – is more favourable arise quite often, as both have their significant advantages (Kolosov, 2015).

Table 2 – Advantages of economic distances ('short'/'long') in logistics.

Advantages of 'short leverage':	The 'advantages' of the 'long arm':
- Work on regular routes with regular customers; - Work in a relatively close neighbourhood to the place of residence; - Equal fares for each kilometre travelled in both directions; - Close monitoring of driver and vehicle performance; - Reduced vehicle repair and maintenance costs.	- The number of loading and unloading operations decreases, transport operating time increases, total revenue increases; the efficiency of vehicle utilisation increases. - On the 'long shoulder' the carrier's income at first glance seems quite high. - Working with a smaller number of customers.
Note – complied by author's	

If the parameter of economic distance, as an abstract economic indicator, is transferred to the geographical characteristics of the logistics infrastructure, it is possible to distinguish networks according to the following parameters: density of facilities, network topology, definition of service areas, connectivity and accessibility. Indeed, when using the Huff and Reilly models together, it is possible to optimise the placement of facilities in a logistics network: taking into account not only the individual attractiveness of each node, but also its spatial position relative to the centre or other nodes in the network. Therefore, it is possible to form an efficient topology of the service network, where the objects are placed taking into account optimal territory coverage, minimising transport costs and providing a high level of service.

It is of scientific interest to carry out a comparative analysis of Huff, Reilly and modified gravity models according to 6 characteristics (principle, attenuation function, main parameters, application, advantages, disadvantages) (table 3):

Table 3 – Comparative analysis of models for economic distance

Characteristic	Huff Model	Rayleigh Distribution	Modified Gravity Model
Principle	Probabilistic consumer choice based on the ratio of a location's attractiveness to the cost (or distance) required to reach it.	Describes the random distribution of distances with an exponential decay in probability as distance increases from the central point.	Inspired by the analogy with Newton's law of gravitation: the interaction between objects is proportional to the product of their «masses» and inversely proportional to a distance decay function.
Decay Function	Typically a power function: $d_{ij}^{-\beta}$.	The probability density function: $f(d) = \frac{d}{\sigma^2} \exp \frac{d^2}{2\sigma^2}$ where the exponential decay is associated with the square of the distance.	Can adopt various forms (e.g., exponential, logarithmic, or combined decay) to better fit empirical data.
Main Parameters	– Attractiveness of the location Aj. – Distance dij. – Parameter β (rate at which distance influence decays).	– Scale parameter σ\sigma that determines the «width» of the distribution.	– «Masses» of the objects Mi and Mj – Distance function f(dij). – Scaling coefficient k and additional parameters to account for specific factors.
Application	Used for analyzing retail trade, planning commercial zones, and estimating the probability of consumer store choice.	Applied in the analysis of random distributions, spatial modeling of point objects, and in problems involving random process theory and network topology.	Used in modeling migratory, transportation, and trade flows, as well as in demographic and economic modeling where multiple influencing factors are taken into account.
Advantages	– Simple interpretation and calibration. – Convenient for assessing the competitiveness of locations.	– Easy to configure with one or two parameters. – Effective in describing the general behavior of distance distribution.	– Highly adaptable due to the inclusion of additional variables. – Allows for a comprehensive consideration of spatial and economic factors impacting interactions between locations.

Continuation of the table

Characteristic	Huff Model	Rayleigh Distribution	Modified Gravity Model
Disadvantages	– Sensitive to the estimation of the parameter β and the attractiveness measure. – Does not always account for individual consumer characteristics or competitive effects.	– Limited in modeling deterministic preferences since it describes only the overall pattern of distance distribution.	– Complex calibration due to the larger number of parameters. – Potential risk of overfitting if empirical data is insufficient.
Note – The table was compiled by the authors on the basis of sources (Huff, 1963), (Gaul, L. (2011), (Wilson, 2010), (Haggett & Chorley, 1969)			

The analysis demonstrates that each of the presented models has its own strengths and weaknesses, determined not only by the mathematical form and parameters used, but also by the field of application.

- The Huff model is ideal for problems where the main importance is to assess the attractiveness of objects for consumers, but it may not be flexible enough when taking into account a complex set of variables.

- The Rayleigh distribution provides a powerful tool for describing the spatial distribution of objects with a minimum number of parameters, but is not always able to take into account individual consumer preferences.

- The modified gravity model due to its versatility and flexibility can be used in a wide range of problems, but requires more accurate tuning and a significant amount of data.

In general, the choice of model depends on the specific task: if a detailed analysis of consumer choice is required, the Huff model is preferred, for analysing the overall spatial structure – the Rayleigh model, and for complex economic or transport flows – the modified gravity model. It should be noted that the integration of all three models allows for a comprehensive assessment of the logistics system: from the level of interaction with the final consumer, through the distribution of infrastructure nodes in the territory, to the optimisation of transport flows between nodes.

Consider practical examples with the Huff and Reilly models.

The Huff model takes into account the influence of multiple shopping centres and, above all, applies the probability of customer behaviour. Huff's model predicts the flow between two points (in general, between multiple points) based on the number of potential customers or other consumers at each outlet, and is inversely proportional to a certain dimension of the distance or travel time between the points. However, the model also introduces a new 'gravity' concept of the probability of potential customers visiting a site when the external conditions are the same. This gravitational concept can be determined by the internal characteristics of a retail outlet (cleanliness, queues at checkouts, availability of price tags, assortment, etc.) or by economic activity, availability of services or amenities, and the general attractiveness of the location (Ingram, 1982), (Arhipova et al., 2020).

The Huff model also has its limitations. Flow is assumed to be homogeneous, and only distance affects it, while other factors are accounted for through the integral attractiveness factor of the outlet, making the identification of these influences one of the most difficult tasks of model calibration.

Huff's model suggests that the consumer is able to choose a location by analyzing the alternative locations. The market area is thus presented as a line of probability when there are no alternative locations. The point of indifference turns into a point equal to the probability that a customer will visit a particular location, as shown in figure 3.

In the above image, the probability that the client chooses point A (0.71) is much higher than the probability of choosing point B (0.29). The advantage of the Huff model is that it leaves room for the buyer to choose a location.

The Reilly gravitational model (Reilly's law of partial attraction, the Reilly-Converse model) – large cities attract a large number of customers who are willing to cover the distance to large shopping malls, and the force of gravity is proportional to the population or local trade turnover. The model was developed in 1931 by William John Reilly (1899-1970), a professor at the University of Texas, based on empirical research and is similar to Newton's law of attraction, with the addition of work by Paul D. Converse in 1949.

Reilly's law aims to determine the point of indifference between two points, as shown in figure 4, so you can determine the trading area of each of these points.

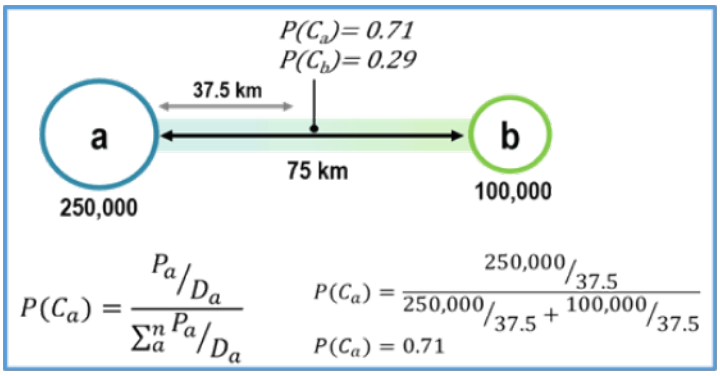

Figure 3 – Huff Model
Note – The Geography of Transport Systems. Huff's Law.

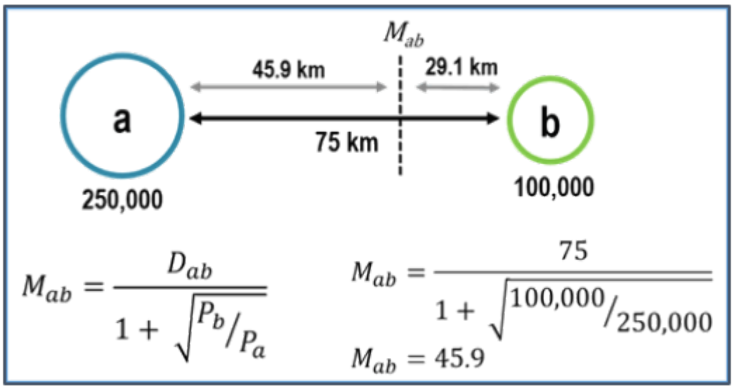

Figure 4 – The Reilly model
Note – The Geography of Transport Systems. Reilly's Law.

This point is a function of the distance between two points, and their respective sizes are taken into account (population is often used for this purpose). Thus, one place may be more attractive than another.

In the image above, two points are located at a distance of 75 km from each other. According to the principle of store placement, the point of indifference should be in the center between them (at a distance of 37.5 km). However, since point A has a larger population (with more weight), it is expected to attract more customers. In such cases, the point of indifference is located at a distance of 45.9 km from point A.

Similarly, 250,000 and 100,000 can serve as indicators of the intensity of freight flows between logistics nodes or regions. Such an indicator is important for developing routing strategies, assessing the cost-effectiveness of transport routes and determining the need for additional infrastructure investments. These parameters help to understand how efficiently infrastructure is distributed, what its capacity to handle freight is, and how adequately it meets demand.

Having considered how economic distance determines the basic costs of transport and how geographical parameters shape the spatial location of logistics hubs, it is important to move on to the aspect that enables the real performance and dynamism of the entire system – the technical parameters of the infrastructure. Modern technology and the level of equipment of logistics centres become the link that connects theoretical optimisation with practical implementation. It is the technical parameters such as freight turnover, transport accessibility and throughput that determine how efficiently an optimal network topology can be realised in practice.

Technical parameters include transport accessibility and indicators of traffic and transport capacity of communications.

Transport accessibility is a complex phenomenon with the time of travel from the point of departure to the destination. As an important indicator of the level of exploration, development, location convenience of a specific region, as well as its investment attractiveness, it should be taken into account in various spheres of human activity:

- production goals (development of new territories, design of various facilities, construction of any infrastructure, etc.);
- personal goals of a person (choosing a place of residence, recreation, drawing up a route, travelling, etc.).

Transport accessibility analysis. Analyses of transport accessibility of territories are necessary for strategic decision-making, including management and investment decisions, such as:

- designing various transport infrastructure solutions;
- assessment of promising territories for the development of various industries, including the oil and gas sector;
- studying the peculiarities of remote territories;
- monitoring the state of the transport network in seasonal conditions;
- complex research of territories with difficult climate or relief;
- logistics of various cargoes and calculation of their cost;
- organisation of passenger transport.

Transport accessibility is an indicator that helps to determine how long it takes to get from home to work, shop, bar, gym or other important places. It takes into account all modes of transport: walking, cycling, private car or public transport (Kosterin, 2007).

One of the indicators of provision of territories with logistics infrastructure is the throughput and transport capacity of communications.

Throughput capacity is an attribute that defines the ability of a specific mode of transport to carry a specific number of passengers (cargo) for a unit time on a single lane.

Transport capacity is the main parameter determining the location of transport systems in the urban transport structure. Low-capacity transport systems, i.e., monorail systems, are used at airports as tourist and transport facilities, and bus and trolleybus systems as vehicles of high-capacity mainline transport, e.g., light rail, subways and electric trains.

Freight turnover is the volume of transport work on the transport of goods, expressed in tonne-kilometres. It is defined as the sum of the product of the weight of each batch (shipment) of transported cargo by the distance of its transport (Agency of Statistics of the Republic of Kazakhstan, 2024).

Thus, technical parameters not only complete the picture of logistics infrastructure, but also serve as a key tool for improving its efficiency. They turn a strategically planned allocation of logistics facilities, based on economic and geographical analyses, into a functioning system.

Results and discussion

In the last ten years socio-economic development of Kazakhstani regions is realized under the influence of the following main trends:

- unevenness and significant differentiation of socio-economic development of regions;
- growth of trade volume surpasses economic development;
- growth of volume, geography and types of transportation, in particular, the Kazakhstani market of container transportation has been significantly expanded.
- growth of mutual trade between CIS and non-CIS nations;
- increase in capacity issues in transportation corridors;
- low competitiveness of the regions in development (Raimbekov & Syzdykbaeva, 2019).

In the context of these trends, territorial logistics aimed at effective management of transport flows and resources is of particular importance. This brings to the forefront the need to create regional transport and logistics systems (RTLS) and logistics clusters with their subsequent integration into a single national transport and logistics system (TLS).

World experience shows that in recent years integration processes in logistics are mainly realized through the formation of interstate and transnational macro-logistic systems (MLS). This approach to the development of territorial logistics is the most effective strategy of integration into the world economy. The creation of a national MLS will allow not only to modernize infrastructure, but also to strengthen internal interregional ties, which will become a stimulus for further economic growth.

The competitiveness of Kazakhstan’s regions is largely determined by effective territorial logistics, rational distribution of production capacities, optimal use of transport potential and improvement of transport and economic links between regions. It is where the creation of the backbone transport network and construction of transport and logistics infrastructure, its modernization, become crucial and are a prerequisite that enhances the economic potential of the country.

Taking into account technological and organizational parameters, the analysis of cargo turnover of all types of transport in Kazakhstan for the period from January to December 2024 was carried out. The total volume of cargo turnover amounted to 514,455.47 million t-km, which is 2.6% higher than in the same period of 2023 (501,414.34 million t-km). In the reporting month (December), cargo turnover reached 47,187.43 million t-km, up 5.7% from the previous month (44,651.86 million t-km).

Analysis of the data showed that the leader in cargo turnover was Atyrau region with 4,290.00 mln t-km for December and 46,409.55 mln t-km for the whole year. The lowest volume was recorded in Ulytau region – 611.91 mln t-km for December, which is due to geographical and infrastructural peculiarities of the region.

In large cities of Kazakhstan cargo turnover was distributed as follows:

- Astana – 3,787.00 mln t-km for December;
- Almaty – 2,245.04 mln t-km for December;
- Shymkent – 1,221.88 mln t-km for December.

Some regions showed significant growth of cargo turnover in the reporting month:

- North-Kazakhstan region – 18.7% increase compared to November;
- Mangistau region – growth by 11.9%;
- Shymkent city – increase by 41.7%, which is the highest indicator in comparison with other regions.

At the same time in Zhetysu there was a decrease in cargo turnover by 2.5% in comparison with the previous month.

The positive flow of cargo turnover in Kazakhstan affirms to the effective utilize of transport foundation and its potential for encourage advancement. Regional differences highlight the need for a targeted approach to modernizing the transport network in less developed areas such as Ulytau and Zhetysu.

Table 4 – Cargo turnover of all modes of transport for January-December 2024

	Actual volume in 2024.			Actual volume in 2023.		As a percentage of the corresponding period of 2023.		Percentage of previous month
	reporting month	previous month	period since beginning of the year	period since beginning of the year	reporting month	period since beginning of the year	reporting month	
Republic of Kazakhstan	47 187,43	44 651,86	514 455,47	501 414,34	42 941,69	102,6	109,9	105,7
Abay	1 262,83	1 209,89	13 956,24	15 230,73	1 282,01	91,6	98,5	104,4
Akmola	2 416,69	2 335,55	26 183,29	26 757,88	2 257,65	97,9	107,0	103,5
Aktobe	3 821,45	3 775,75	42 679,88	45 571,90	3 845,99	93,7	99,4	101,2
Almaty	1 685,25	1 637,75	19 640,90	20 443,47	1 740,66	96,1	96,8	102,9
Atyrau	4 290,00	3 832,54	46 409,55	44 459,85	3 915,83	104,4	109,6	111,9
West Kazakhstan	1 040,67	1 123,81	11 501,58	11 210,18	890,50	102,6	116,9	92,6
Zhambyl	3 801,22	3 799,05	44 134,68	41 471,64	3 491,71	106,4	108,9	100,1
Jetisu	933,88	911,33	11 116,95	14 201,44	1 235,40	78,3	75,6	102,5
Karaganda	3 627,82	3 445,45	39 659,03	40 687,84	3 408,73	97,5	106,4	105,3
Kostanay	2 501,65	2 354,71	27 322,76	27 137,95	2 291,47	100,7	109,2	106,2
Kyzylorda	3 103,01	2 955,21	34 034,61	33 728,85	3 070,81	100,9	101,0	105,0
Mangystau	2 608,51	2 496,74	29 000,82	28 584,78	2 583,30	101,5	101,0	104,5
Pavlodar	3 446,45	2 899,76	32 784,37	27 931,20	2 351,02	117,4	146,6	118,9
North Kazakhstan	915,23	890,99	10 171,58	11 487,87	988,16	88,5	92,6	102,7
Turkestanskaya	1 871,18	1 914,13	23 400,94	24 828,64	2 155,23	94,2	86,8	97,8
Ulytau	1 269,74	1 202,47	14 020,39	15 592,57	1 328,40	89,9	95,6	105,6
East Kazakhstan	624,14	611,91	6 892,76	7 609,76	633,44	90,6	98,5	102,0

Continuation of the table

	Actual volume in 2024.			Actual volume in 2023.		As a percentage of the corresponding period of 2023.		Percentage of previous month
	reporting month	previous month	period since beginning of the year	period since beginning of the year	reporting month	period since beginning of the year	reporting month	
Astana city	3 934,82	3 787,00	43 218,15	34 377,02	2 880,16	125,7	136,6	103,9
Almaty city	2 301,87	2 245,94	23 656,93	19 045,74	1 641,77	124,2	140,2	102,5
Shymkent city	1 731,03	1 221,88	14 670,06	11 055,03	949,45	132,7	182,3	141,7
* Taking into account the volume of work done by individual entrepreneurs engaged in commercial transport.								
Note – Bureau of National Statistics, 2024 (https://stat.gov.kz)								

Kazakhstan's transport infrastructure plays a key role in ensuring logistics flows both domestically and internationally. The development of road, railway and pipeline routes, as well as the creation of modern logistics hubs, helps to improve transport accessibility of regions and increase the efficiency of cargo turnover. Optimisation of logistics infrastructure facilitates Kazakhstan's integration into global transport chains and stimulates economic growth by increasing the capacity of transport corridors and developing regional hubs.

Geographical location and territorial characteristics play a key role in the distribution of freight turnover between regions. This paper considers three cities in Kazakhstan: Karaganda, Astana and Almaty, between which cargo flows are redistributed.

To demonstrate the applicability of the models under consideration, we will perform calculations based on data on freight turnover and distances between the regions. This will allow us to assess the degree of influence of various factors on the choice of a logistics hub based on the Huff and Reilly model.

$$P_{ij} = \frac{S_j/T_{ij}^{\gamma}}{\sum_k (S_j/T_{ij}^{\gamma}} \quad (2)$$

P_j – logistic node selection probability j
S_j – logistics hub cargo turnover
T_{ij} – distance to a logistics hub
γ – distance sensitivity parameter {1}
$\sum_k$ – sum of all logistics node alternatives.

An example of the calculation of the Huff model:

Data:

Almaty cargo turnover (S_1) = 2301.87 million tonne-km

Astana cargo turnover (S_2) = 3934.82 million tonnes-km

Distance Karaganda – Almaty: d_{K-} = 1000 км
Distance Karaganda – Astana: d_{K-c} = 1000 км
Computations:

$$P_{ij} = \frac{2301{,}87/1000^2}{\left(\frac{2301{,}87}{1000^2}\right) + (\frac{3934{,}82}{200^2})}$$

$$P_{ij} = \frac{0{,}00230187}{0{,}00230187 + 0{,}0983705} =$$

$$= \frac{0{,}00230187}{0{,}10067237} = 0{,}0228649628$$

$$P_{стана} = 1 - \mathrm{P} = 0{,}977$$

Conclusion: Based on the Huff model, the probabilities of redistribution of cargo flows from Karaganda to Almaty and Astana were calculated. As can be seen on the map, most of the freight flows (≈97.7%) are directed to Astana, which is explained by its shorter distance from Karaganda (200 km) and higher freight turnover (3934.82 million tonnes-km). At the same time, Almaty receives only 2.3% of freight traffic, despite its significant freight turnover (2,301.87 million tonnes-km), which is due to the city's remoteness (1,000 km).

Thus, the results of the analysis confirm that territorial proximity and economic capacity (freight turnover) play a decisive role in the redistribution of freight flows.

According to the Rayleigh model, we make calculations.

This model is used to estimate the probability of choosing a logistics node depending on its cargo turnover and distance to it.

$$\text{M}_{ij} = \frac{S_j}{d_{ij}^2} \qquad (3)$$

Where:

M_{ij} – attraction of the logistics node $_j$ for the region $_i$,

S_j – volume of cargo turnover of the logistics hub,

d_{ij} – distance between the region $_i$ and the node $_j$,

$d_{ij}^{\ 2}$ – the square of the distance (to account for the decrease in influence with increasing distance).

Let us calculate the attractiveness of Almaty and Astana as logistics hubs for the Karaganda region.

Data:

Almaty cargo turnover (S_1) = 2301.87 million tonnes-km

Cargo turnover of Astana (S_2) = 3934.82 million tonnes-km

Distance Karaganda – Almaty: d_{K-} = 1000 км км

Distance Karaganda – Astana: d_{K-c} = 1000 км

Computations:

$$\text{M}_{K-} = \frac{2301{,}87}{1000^2} = 0{,}00230187$$

$$\text{M}_{K-c} = \frac{3934{,}82}{200^2} = 0{,}0983705$$

The results of the calculations show that the logistic attractiveness of a node is inversely proportional to the square of the distance to the region, which confirms the validity of the gravity model of transport flows. Despite Almaty's high freight turnover, its remoteness (1000 km) results in low attractiveness (0.002302), while Astana (200 km) shows a much higher indicator (0.098370). This is consistent with the gravity model of traffic flows and shows that distance plays a key role in the distribution of freight flows.

Huff's and Reilly's laws were used to analyse the distribution of freight flows in the logistics system of Kazakhstan. As an example, let us consider Karaganda region and two possible logistics hubs – the cities of Astana and Almaty. Data on cargo turnover of these hubs, as well as distances between them and the region are presented in table 4. The Huff model calculations show that Astana has a 97% probability of being selected, while Almaty has a 3% probability of being selected. This is due to the shorter distance to Astana, as well as the greater volume of cargo turnover, which indicates its higher role in the territorial and logistics infrastructure of the region.

Similar conclusions were obtained from the Rayleigh model. Raleigh's law revealed that the attractiveness of a logistics node decreases with increasing distance, which is consistent with the theoretical provisions of the model. According to the calculations, the logistics hub in Astana has a higher attractiveness for freight traffic from Karaganda than Almaty due to its shorter distance and significant cargo turnover. Thus, the results confirm that the choice of logistics hub is determined not only by its freight turnover, but also by the distance to the consumer of transport services. This confirms that, all other things being equal, a logistics hub with higher freight turnover located closer to the region is more attractive.

Thus the use of these models in Kazakhstan confirms their effectiveness in optimising transport flows and strategic planning of logistics processes. The results obtained can be used in further research in the field of territorial logistics, including the development of recommendations on the location of new logistics centres and expansion of the existing transport infrastructure.

Conclusion

This paper provides a comprehensive analysis of territorial logistics modelling based on the concept of economic distance, which allows us to combine economic, geographical and technical parameters of transport and logistics infrastructure. The study demonstrates that economic distance, defined not only by physical distance, but also by the totality of transport costs, time and risks, is a key indicator affecting the distribution of logistics flows and the optimal placement of nodes in the network.

Analyses of the Huff, Rayleigh distribution and modified gravity models showed that:

The Huff model, which takes into account the attractiveness of facilities and the costs of reaching them, is suitable for detailed analyses of consumers' choice of logistics nodes and the definition of service areas.

The Rayleigh distribution effectively describes the spatial distribution patterns of logistics facilities, allowing the identification of activity 'cores' and peripheral zones.

The modified gravity model, capable of taking into account multiple factors, demonstrates high adaptability in modelling migration, transport and trade flows.

The application of these models allows not only to assess the basic characteristics of freight flow distribution (including such indicators as freight turnover, transport accessibility and capacity), but also to identify the 'weaknesses' of the existing logistics infrastructure in Kazakhstan's regions. Calculations carried out on the example of the country's transport network confirmed that territorial proximity and economic capacity of logistics hubs play a decisive role in redistributing freight flows. Moreover, the results of the research underline the need for strategic infrastructure development, taking into account the optimal location of logistics centres, which will reduce transport costs and increase the efficiency of freight traffic.

Thus, a comprehensive approach based on the integration of economic, geographical and technical parameters allows the formation of an efficient logistics network capable of adapting to the dynamics of the external environment and meeting the growing demand for transport and logistics services. The presented models and methods can serve as a basis for further research and practical recommendations for optimising transport and logistics infrastructure, which, in turn, will contribute to the socio-economic development of regions and strengthening the integration position of Kazakhstan in the international arena.

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