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Ranking of transport network development projects in the Sverdlovsk railroad area based on fuzzy logic

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ABSTRACT

Relevance. Due to the turbulence of economic processes in the period of sanctions pressure on the economy, decisions should be made, effective, first of all, from a national position. For this purpose, it is necessary to justify them using multi-criteria and all available information, which at the initial stages is fundamentally incomplete, insufficiently reliable and sometimes weakly formalized. In such cases, it is advisable to use special methods to assess the decisions made in conditions of uncertainty, in particular methods of fuzzy logic and mathematics.

Purpose of the study. The study is aimed at assessing the order of priority of transport rail support on the investigated most important in the federal and regional scale main lines by including the most significant technological and economic criteria, reflecting the nationwide priority.

Data and Methods. To compare different methods of priority construction of the main lines of railway lines, we used the procedure of fuzzy multi-criteria analysis of the projects. The assumed priorities of transport rail support are based on four trunk line projects: the Middle Urals Latitudinal Railway on the N-Tagil – Perm section; the Troitsko-Pechorsk – Ivdel section; the Perm – Chernushka section; the Ust – Aha – Uray – Khanty-Mansiysk – Salym section.

Results. The paper proves the possibility of applying the approach based on fuzzy logic to the analysis of economic processes in the period of shocks to the economy, caused, in particular, by the introduction of sanctions from unfriendly countries. The estimated priority of transport rail support on the four projects of the most important trunk lines is assessed.

Conclusions. With the help of fuzzy logic methods, it is possible to find compromise options that satisfy the various interests of those affecting the decisions, regardless of the structural organization of the backbone industries, one of which is undoubtedly the transport industry.

KEYWORDS

infrastructure projects, transport railway network, freight flows, sanctions pressure, multicriteria, fuzzy sets, expert estimates

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Ранжирование проектов развития транспортной сети в зоне свердловской железной дороги на основе нечеткой логики

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АННОТАЦИЯ

Актуальность. В связи с турбулентностью экономических процессов в период санкционного давления на экономику должны приниматься решения, эффективные, в первую очередь, с общегосударственных позиций. Для этого необходимо их обоснование с учетом многокритериальности и всей доступной информации, которая на первоначальных стадиях обладает принципиальной неполнотой, недостаточной достоверностью и подчас слабой степенью ее формализации. В таких случаях целесообразно применение специальных методов, позволяющих оценивать принимаемые решения в условиях неопределенности, в частности методов нечеткой логики и математики.

Цель исследования заключается в оценке очередности транспортного железнодорожного обеспечения на исследуемых наиболее важных в федеральном и региональном масштабе магистральных направлениях за счет

КЛЮЧЕВЫЕ СЛОВА

инфраструктурные проекты, транспортная железнодорожная сеть, грузопотоки, санкционное давление, многокритериальность, нечеткие множества, экспертные оценки

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включения наиболее значимых технологических и экономических критериев, отражающих общегосударственный приоритет.
Данные и методы. Для сравнения различных способов очередности сооружений магистральных направлений железнодорожных линий использовалась процедура нечеткого многокритериального анализа проектов. Предполагаемые очередности транспортного железнодорожного обеспечения основаны на четырех проектах магистральных направлений: среднеуральский широтный ход (СУШХ) на участке Н-Тагил – Пермь; участок Троицко-Печорск – Ивдель; участок Пермь – Чернушка; участок Усть – Аха – Урай – Ханты- Мансийск – Салым.
Результаты исследования. Доказана возможность применения подхода на основе нечеткой логики к анализу экономических процессов в период шоковых воздействий на экономику, обусловленных, в частности, введением санкций со стороны недружественных стран. Оценена предполагаемая очередность транспортного железнодорожного обеспечения на четырех проектах наиболее важных магистральных направлений.
Выводы. С помощью методов нечеткой логики возможно нахождение компромиссных вариантов, удовлетворяющих различным интересам лиц, влияющих на принимаемые решения независимо от структурной организации системообразующих отраслей, одной из которых несомненно является транспортная отрасль.

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模糊逻辑下斯维尔德洛夫斯克地区铁路交通网络的发展项目优先级

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摘要
现实性：由于制裁压力经济进程面临动荡，必须首先从国家层面做出有效决策。这就要求在考虑到多标准和所有可用信息的情况下对其进行论证。而这些信息在初始阶段基本上是不完整、不够可靠、有时还很不正式的。
研究目标：文章通过纳入反映国家优先事项的最重要技术和经济标准，来评估联邦和区域干线上运输铁路供应的优先权。
数据与方法：为了比较确定铁路干线建设优先次序的不同方式，本文采用了模糊多准则决策法。拟议的铁路运输优先项目基于四条干线：中乌拉尔-塔吉尔-彼尔姆段；特罗伊茨克-佩乔尔斯克-伊夫德尔段；彼尔姆-切尔努什卡段；乌斯-阿赫-乌拉伊-汉特-曼西斯克-萨雷姆段。
研究结果：在经济受到冲击期间，特别是不友好国家实行制裁所造成的冲击期内，应用模糊逻辑分析经济进程的可能性已经得到证明。本文对最重要干线四个项目的铁路运输优先级进行了评估。
结论：使用模糊逻辑法，有可能找到满足决策者各种利益的折衷方案。无论骨干产业的结构组织如何，运输部门都是影响决策的最重要部门之一。

关键词
基础设施项目、运输铁路网、货运流量、制裁压力、多标准、模糊理论、专家评估

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Introduction

The sanctions war declared by Russia in response to its decisive actions to protect Donbass has significantly changed the structure of transport flows throughout the EAEU. The dominance of east-west cargo flows has been replaced by an increasing transport load on the network in the direction of China and the Asia-Pacific region. The largest cargo flows are formed by natural gas exports from Russia via pipelines and coal exports via the eastern railroads. The most important new direction of foreign economic flows in the medium term will be the southern one, where Russia's largest partner will be India, as well as transit states of Central Asia and the Middle East.

Infrastructure projects in the coming period, on the one hand, are an opportunity to ensure economic ties both within the country and inter-

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nationally. And on the other hand, intensifying the construction of new infrastructures is a way to maintain domestic demand for investment products and, thus, a way to ensure the sustainability of the Russian economy, income, which is also very important in a special period.

The development of Russia's rail network is outlined until 2035 in the Transport Strategy of the Russian Federation[1] and the Strategy for the Development of Rail Transport in Russia[2]. The dominant feature of the first of these documents is a set of strategic initiatives for the long-term planning of modes of transport and the main-line transport infrastructure as a whole. The second one specifies strategic provisions for railway transport, highlighting the strategic vision of all elements of the railway transport system of its network, rolling stock, management system. Simultaneously with its development of railway lines in the territories not yet covered by the network of railway transport, and the second – the concentration of investment resources, especially its own, on income-generating directions and elimination of "bottlenecks" that limit the passage of existing flows. At the same time in recent years there has been a very slow increase in the operational length of Russian railroads. But the additional financial and production resources released due to the sanction's regime allow us to bring closer the start of the construction of new additional rail lines. They will improve transport accessibility and the conditions for locating new production facilities.

Over the past 20-30 years, there are numerous project initiatives to develop the network in the Greater Urals area. These initiatives are associated with the need to prepare new resource bases, diversify the production profile of many territories, with a sharp increase in the volume of transit traffic, the development of the Russian Arctic, the global reorientation of major international economic flows and other key factors of economic development. Meanwhile, in view of the fundamental limitations of development resources, it is necessary to select priorities and appropriate ranking of investment projects for the development of the transport network with cyclic monitoring and updating.

Work on the development of strategic plans, programs and projects has intensified since 2014, when the Law "On Strategic Planning in the Russian Federation"[3] replaced the Law on State Forecasting and Programs of Socio-Economic Development of the Country.

After that, most of the current policies and programs adopted. In connection with them, the list of project initiatives began to expand rapidly. Not all of them quickly pass into the category of ongoing projects. For example, one of the largest projects started in 2009, the Industrial Urals – Polar Urals project to build a new 814-kilometer-long railroad from Polunochnoye station to Obskaya station along the eastern slope of the Ural Mountains, was subsequently frozen for an indefinite period of time. Other major railroad construction projects around the Urals North have gained real priority: the Northern Latitudinal Railway, as well as projects for a large railroad diagonal in the direction of new ports on the Arctic coast of European Russia, which are currently under study. The list of prospective transport network projects in the JSC "Russian Railways" portfolio is now extensive. Unfortunately, there are no project initiatives for the Urals, including the Sredneuralsky Latitudinal Railway, on the head section of which (the section from Bolsheselsky near Tobolsk to Tavda) design work has been completed. This section plays an important transport-economic and geopolitical significance, as it would become the second railroad crossing between the Urals and Siberia after the Trans-Siberia Railway, running exclusively through Russian territory.

Until the issue of the unity of state planning in the development of the railroad network is resolved, local conflicts on the actualization of project portfolios will be entrenched, which means that project initiatives of uncertain status will coexist for a long time. Some initiatives, not yet supported by the industry, may be very valuable for the regions.

There are project proposals for the construction of local sites that cannot be implemented at the same time, but also cannot be considered as alternatives. These are not variants of a major project, but rather different independent projects, so it is not valid to compare them directly. But all the same, the urgency and priority of such projects must be assessed, including for the pos-

[1] Transport strategy of the Russian Federation until 2030 with the forecast for the period until 2035. Approved November 27, 2021, No. 3363-r.

[2] Strategy of railway transport development in the Russian Federation until 2030. Approved June 17, 2008, No. 877-r.

[3] Federal Law "On Strategic Planning in the Russian Federation" of 28.06.2014 No. 172-FZ (last edition). Consultant.ru. date of reference 19.06.2022.

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sibility of their inclusion in newly developed programs. It is extremely difficult to reliably measure their importance relative to each other, because they are not interchangeable. There is extremely insufficient and poorly reliable information on their evaluation.

This kind of assessment needs a special model-methodological toolkit for the full generalization of not always structured expert knowledge. To solve the problem of its effective application we propose the simulation of aggregate expert assessment with elements of fuzzy logic.

A set of several of these kinds of project initiatives is selected as the object of evaluation. We included four new rail lines that are potentially necessary to strengthen the transport network. Their selection for further analysis by the proposed method is carried out in the logic of a gradual transformation of the network structure from predominantly tree-like on a framework of main lines to a complex closed large transport grid (Petrov, 2019; Petrov, 2021). There are powerful highways of latitudinal orientation, but very weak rail connections even between neighboring regional centers in the meridional direction.

Project P1: continuation of the Middle Ural Latitudinal Railway with passage through the Urals along the route Nizhny Tagil (Smychka station) – Perm. The purpose is to strengthen the connection between the Urals and the European part of Russia and to increase the carrying capacity for unloading the main route Tyumen – Yekaterinburg – Perm.

Project P2: Troitsko-Pechorsk section (now a dead end railroad in the southeast of the Komi Republic) – Ivdel (a dead end station Polunochnoye in the far north of the Sverdlovsk Region) with a crossing over the Urals Ridge. Destination – the Urals element of the future main line port Indiga on the Northern Sea Route – Komi – Urals (BarentsKomUr).

Project P3: Perm – Chernushka section (south of Perm Krai on the main line of the Moscow – Kazan – Yekaterinburg railroad). Purpose: creation of the currently missing railway connection between the city of Perm and the southern part of Perm Krai and organization of a through meridional railway route from the north of the region (Solikamsk) to its south (Chernushka).

Project P4: the Ust'-Akha section (now a dead-end station in the Tyumen Region from the Sverdlovsk Region on the Tavda – Ust'-Akha line) – Uray – Khanty-Mansiysk – Salym (station on the meridional course Tyumen – Surgut). The purpose is to create an element of the large transport grid by connecting the dead-end entrance from the Sverdlovsk region to the Tyumen region with the main railway line of the Tyumen region and to provide the city of Khanty-Mansiysk with railway transport (Fig. 1).

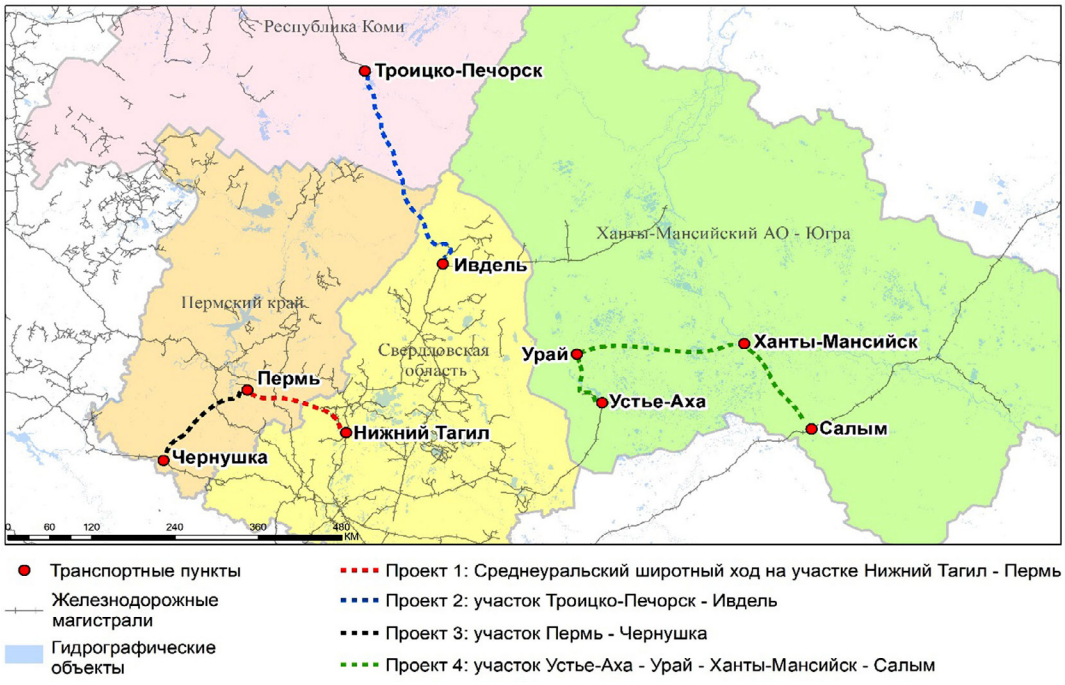

Figure. 1. *Map of compared projects*
Source: the authors' calculations.

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Such a set of possible projects requires ranking them according to their complex significance. But for a number of criteria, it is not possible to give a reliable specification of the target functions of these criteria under turbulent conditions. Nevertheless, the meaning of the most important criteria for evaluating transport projects lies a priori in the selection of projects. Among the most important criteria for evaluating transport network development projects, we include 6 criteria: the promotion of diversification of the territory of the line; the presence of a freight base in this territory; the impact of the line on the expansion of the "bottlenecks" of the network; the contribution of the line to transport accessibility; the total capital investment of the project; the operating costs of the new line.

Thus, the aim of the proposed study is to assess the priority of transport rail provision on the most important federal and regional trunk lines under investigation.

The objectives of this study are a process of pairwise comparison of elements of sets (projects and criteria) based on the most significant technological and economic requirements reflecting the national priority and a formalised procedure of fuzzy multi-criteria analysis in relation to comparison of different methods of priority construction of trunk railway lines.

Based on expert comparisons of projects by criteria and on paired comparisons of the relative importance of the criteria, using the maximum method, the degrees of affiliation of a fuzzy solution are determined, the maximum value of which corresponds to the best trunk line project. The best project out of all those considered, satisfying the criteria considered, is the continuation of the Middle Ural Latitudinal Railway on the N.-Tagil – Perm section.

The logic of the study is based on scientific sources on the methodology of transport network development, transport forecasting, logistics, regional economics and geoeconomics.

Theoretical basis

Articles (Vakulenko, 2021) show that it is necessary to develop railroads, which contributes to the retention of positions in the transportation market and increase the competitiveness of rail transport. It is possible to specialize the existing railways into lines with freight and passenger traffic, but the implementation of such projects in places with low road density leads to overrun trains and an increase in the cost of freight and passenger delivery. The departure of freight trains from these lines leads to the loss of the freight base and increases the losses of Russian Railways. It is proposed that new specialized high-speed lines be built in places with high passenger traffic in order to solve this problem (Kolin, 2015)

Articles (Pyanikh, 2020) state that Russia's inclusion in modern multimodal corridors will reduce economic dependence on other countries and strengthen its position in world markets. Russia's geographical position is a natural transport corridor and its use allows it to increase transit potential, taking into account the development of railroads in the direction of China and other Asian countries along the Trans-Siberian Railway, as noted in the article (Stroganov, 2016). Well-established freight shipping along the Northern Sea Route and the construction of the Transpolar Mainline will strengthen Russia's position in the struggle for the most important transoceanic communications connecting the Atlantic and Pacific Oceans.

The ever-increasing sanctions pressure from the West leads to the need for import substitution in the country. The Russian import substitution policy is designed to reanimate and modernize missing elements of production or create new ones. Having analyzed the level of technology by industry, about two thousand areas of import substitution have been identified (Medovshchikov, 2020). For JSC "Russian Railways" the main issue in import substitution is the transition to domestic software, as for him the priority is to ensure security "to anticipate, if possible, to avoid, if necessary to act". Functional security aims to avoid dangerous situations. Information security to preserve the integrity and confidentiality of information. When there is great uncertainty in incoming information, cybersecurity makes it possible to prevent the loss of train controllability under conditions of artificial distortion of information (Sviridova, 2019).

As noted in the works (Kochneva, 2021) regional container transportation systems operate under conditions of significant incomplete information and lack of integration of economic entities. The companies involved in this system pursue only their own economic interests (Ghadimi, 2019). An approach to the integrated management of this system in the region is proposed, using the mutual exchange of information between railroads (Kayikci, 2018), freight owners, terminals

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and resource owners (Cleophas, 2016), which can be implemented on the basis of a digital logistics platform that will ensure the formation of effective logistics chains, as noted in the work (Reser, 2016), which is important in the period of sanctions pressure.

As shown in (Greenberg, 2021) economic sanctions against Russia were imposed by the West in 2014 and in order to effectively counteract them, it was necessary to determine the conditions under which they have the greatest negative impact on our country. It was found that the costs of sanctions pressure are higher for the target country than for the instigator country and the preferred type of sanctions – targeted sanctions, as it turns out, are less effective than traditional comprehensive sanctions, as shown in the article (Cortright, 2018).

The creation of an interconnected system for determining the prospective demand for freight rail transportation between regions, allowing the development of transport infrastructure and regional connectivity to be determined, is important (Shirov, 2021). The result of this work was the development of tools to justify the strategic development of the railway system, to assess the possible interaction between the economy and the railway transport. The work (Myslyakova, 2021) notes that for the effective operation of an industrial region during significant external shocks, it is important to determine the connectivity of the region as an indicator of the integrity of socio-economic relations, taking into account the peculiarities of infrastructural inter-subject interaction.

According to P.A. Minakir, at the stage of 2015-2017, the reorientation of Russia's exports to the East was justified by the dynamics of opportunities in Eastern markets with their expanding demand for Russian raw materials and energy, and opportunities for Russia to increase export rents (Minakir, 2017; Wirth, 2014). The radical change in world economic relations observed in 2022 essentially makes the reversal of the largest export flows to the East a no-regret option. China, Indonesia, Vietnam, and a number of other Asian countries are, to a large extent, Russia's current and, to an even greater extent, future strategic partners. The countries of the East and, in the future, of the South will form a new geo-economic and geopolitical center of development, with which Russia will have to build relations in foreign trade, capital movement, technology exchange and humanitarian contacts, as shown in the article (Akaha, 2014). Therefore, the processes of increasing economic potential in eastern Russia will also accelerate, which may cause or increase the need for certain transport infrastructure facilities in the Greater Urals area. Thus, of the four projects we selected for fuzzy analysis, projects A, B and D can be classified in this category.

This analysis is based on the apparatus of fuzzy sets (Limbu, 2007) and fuzzy logic (Hu Zhaoguang, 2002; Sasaki, 1999).

Methods and data

One of the promising decision-making tools in the context of sanctions policies by unfriendly countries is the theory of multiple-criteria decision-making, which received further development in accordance with the development of fuzzy sets theory (Bellman, 1976).

As noted in the Introduction, a fuzzy multi-criteria project analysis procedure to compare different ways of prioritizing the construction of trunk rail lines served as an example. This procedure is part of the fuzzy decision-making methodology according to the Bellman-Zadeh scheme (Bellman, 1976).

Fuzzy logic operates with fuzzy sets, which provide a mathematical way of representing uncertainty and fuzziness, particularly in the economic and social sciences. Formally a fuzzy set Θ is defined (Shtovba, 2007) as a set of ordered pairs of the form $< x, \mu_{\Theta}(x) >$, where x is an element of some universal set X, and $\mu_{\Theta}(x)$ – is a degree of membership which puts in correspondence to each element of $x \in X$ some real number from the interval [0, 1]. Thus, a fuzzy set – is a set of elements with different degrees of memberships. In this case, the comparison of each element of its degree of belonging to a fuzzy set is carried out with the help of the membership function (MF).

The proposed article uses the indirect method for determining the values of MF (Leonenkov, 2005), since there are no measurable properties that can be used to construct a fuzzy set of the subject area under consideration. For this purpose, the method of pairwise comparisons, based on intuition or on performing certain logical actions, formalized by constructing a symmetric diagonal matrix with reciprocal elements of the same name, is used. In this case, the problem of constructing the MF is reduced to finding such a vector w, which is a solution of the equation:

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$$A \cdot \mathbf{w} = \lambda_{max} \cdot \mathbf{w}, \ \mathbf{w} = (w_1, w_2, ...w_n), \quad w_1 + w_2 + ...w_n = 1, \tag{1}$$

where λ_{max} is the largest eigenvalue of the matrix of pairwise comparisons A, n – is the number of elements of the fuzzy set.

The process of pairwise comparison of elements is based on intuition or on performing some sequence of logical actions. Note that it is the indirect method of determining the MF used by the authors in the proposed article.

Formalized procedure of fuzzy multi-criteria analysis as applied to the task of comparing different methods of ordering of the construction of the main directions of railway lines consists of the following steps.

1. Setting a set of trunk projects that are subject to multicriteria analysis : $\boldsymbol{P} = \{P1, P2, \ldots, P4\}$.

2. Setting a set of criteria, according to which trunk projects are evaluated $\boldsymbol{G} = \{G1, G2, \ldots, G6\}$.

3. Based on the expert comparisons of projects by criteria, paired comparison matrices are determined on the Saati scale.

4. Finding the coordinates of the eigenvector of the matrix of pairwise comparisons, corresponding to the maximum eigenvalue. Obtaining fuzzy sets for each criterion, each element of which corresponds to a certain project. The number of fuzzy sets is equal to the number of criteria. The sum of degrees of memberships must be equal to one.

5. Based on the pairwise comparisons of the relative importance of the criteria, the matrix of pairwise comparisons of the importance of the criteria is formalized and, in accordance with equation (1), quantitative estimates of the coefficients of relative importance of the criteria are obtained.

6. Raising each element of the set obtained at the fourth stage to the degree corresponding to the coefficient of the relative importance of the criteria, we obtain fuzzy sets of criteria, using their relative importance.

7. The intersection of these fuzzy sets (minimization procedure) allows you to determine the degree of membership of the fuzzy solution, the maximum value of which corresponds to the best trunk project.

8. Based on the degrees of memberships found in the eighth step, an membership function is constructed (indirect method of constructing the MF).

As a result of performing the described procedure, you can not only choose the best option for the criteria of the project, but also to analyze the different options. That is, to find the answer to the question "What should be changed in some alternative to make it the best? To do this, you need to change one of the pairwise comparisons and monitor the resulting solutions.

Results

As noted in the Introduction, the proposed queues of transport rail support are based on four main line projects: $\boldsymbol{P} = \{P1, P2, \ldots, P4\}$, where $P1$ element corresponds to the Middle Urals Latitudinal Railway on the N-Tagil – Perm section, $P2$ – to the Troitsko-Pechorsk – Ivdel section, $P3$ – to the Perm – Chernushka section, and $P4$ – to the Ust – Aha – Uray – Khanty-Mansiisk – Salym section.

Accordingly, the set of criteria, in accordance with which projects are evaluated, includes six elements $\boldsymbol{G} = \{G1, G2, \ldots, G6\}$, where the element $G1$ corresponds to the degree of diversification of industries in the territory of the trains passing, $G2$ – cargo base, $G3$ – expansion of "bottlenecks" (the capacity of the main directions), $G4$ – transport accessibility of points of passing lines, $G5$ – total investments, $G6$ – total operating costs of existing traffic flows.

The expert comparisons of the projects $\boldsymbol{P} = \{P1, P2, \ldots, P4\}$ according to the six $\boldsymbol{G} = \{G1, G2, \ldots, G6\}$ criteria were conducted on the basis of the benefits assessment scale (Saaty scale (Saaty, 1993)) shown in Table 1. Six pairs of projects were compared for each criterion. These expert comparisons are shown in Table 2.

The expert statements shown in Table 2 correspond to the following matrices of pairwise comparisons of 4x4 for each criterion (written in string form).

Table 1

Evaluating the advantage of projects

№	Type of advantage	Evaluation
1	No advantage	1
2	Weak advantage	3
3	Significant advantage	5
4	Absolute advantage	7

Source: the authors' calculations.

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Table 2

Paired comparisons of projects on the Saati scale

№	Projects	Best project	Advantage	Evaluation
		*G*1		
1	1–2	2	Significantly	1/5
2	1–3	3	Weak	1/3
3	1–4	4	Absolutely	1/7
4	2–3	2	Significantly	5
5	2–4	4	Significantly	1/5
6	3–4	4	Significantly	1/5
		*G*2		
1	1–2	2	Significantly	1/5
2	1–3	1	Significantly	5
3	1–4	4	Weak	1/3
4	2–3	2 = 3	No	1
5	2–4	2	Weak	3
6	3–4	3 = 4	No	1
		*G*3		
1	1–2	1	Significantly	5
2	1–3	1	Significantly	5
3	1–4	1	Weak	3
4	2–3	3	Weak	1/3
5	2–4	4	Significantly	1/5
6	3–4	4	Significantly	1/5
		*G*4		
1	1–2	1 = 2	No	1
2	1–3	1	Weak	3
3	1–4	4	Significantly	1/5
4	2–3	2	Significantly	5
5	2–4	4	Weak	1/3
6	3–4	4	Significantly	1/5
		*G*5		
1	1–2	1	Weak	3
2	1–3	3	Significantly	1/5
3	1–4	1	Weak	3
4	2–3	3	Absolutely	1/7
5	2–4	2 = 4	No	1
6	3–4	3	Absolutely	7
		*G*6		
1	1–2	1	Weak	3
2	1–3	3	Weak	1/3
3	1–4	1	Significantly	5
4	2–3	3	Significantly	1/5
5	2–4	2	Significantly	5
6	3–4	3	Significantly	5

Source: the authors' calculations.

Given the limited size of the article, we specify only the matrix of pairwise comparisons, corresponding to the criterion *G*1

$$A(G1) = \begin{bmatrix} 1 & 1/5 & 1/3 & 1/7 \\ 5 & 1 & 5 & 1/5 \\ 3 & 1/5 & 1 & 1/5 \\ 7 & 5 & 5 & 1 \end{bmatrix}.$$

In the given matrices all elements correspond to pairwise comparisons of Table 2 and the conditions of diagonality and inverse symmetry of matrices. Based on equation (1) we obtain fuzzy sets of all criteria, the elements of which are shown in Table 3.

Table 3

Elements of fuzzy sets for each criterion

	***P*1**	***P*2**	***P*3**	***P*4**
*G*1	0.0490	0.2482	0.0944	0.6078
*G*2	0.2116	0.4219	0.1544	0.2122
*G*3	0.5283	0.0610	0.1057	0.3050
*G*4	0.1633	0.2124	0.0655	0,5588
*G*5	0.1911	0.0760	0.6570	0.0760
*G*6	0.2655	0.1427	0.5354	0.0564

Source: the authors' calculations.

These fuzzy sets are given without using the relative importance of the criteria for evaluating energy supply projects. To take into account the relative importance of the criteria, we again use the expert method based on linguistic statements regarding pairwise comparisons of the importance of the criteria. Based on the linguistic statements, all project evaluation criteria are ranked on a six-point scale, shown in Table 4.

Table 4

Ranking the criteria according to their importance

Criterion	Rank
1. Diversification	2
2. Cargo base	1
3. Bottlenecks	5
4. Transport accessibility	3
5. Total capital investment	4
6. Operating costs	6

Source: the authors' calculations.

Comparing the values of the criteria given in Table 4, we can conclude that the criteria related to operating costs and throughput capacity of trunk routes are the most important for making

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decisions on the projects. The criterion assessments given in Table 4 correspond to the following matrix of pairwise comparisons of dimension 6x6 (written in string form).

$$A = \begin{bmatrix} 1 & 2 & 2/5 & 2/3 & 1/2 & 1/3 \\ 1/2 & 1 & 1/5 & 1/3 & 1/4 & 1/6 \\ 5/2 & 5 & 1 & 5/3 & 5/4 & 5/6 \\ 3/2 & 3 & 3/5 & 1 & 3/4 & 1/2 \\ 2 & 4 & 4/5 & 4/3 & 1 & 4/6 \\ 3 & 6 & 6/5 & 2 & 6/4 & 1 \end{bmatrix}.$$

Based on equation (1), the normalized degrees of relative importance of the criteria are determined:

$$a1 = 0.0952;$$
$$a2 = 0.0476;$$
$$a3 = 0.2381;$$
$$a4 = 0.1421;$$
$$a5 = 0.1905;$$
$$a6 = 0.2857,$$

where $a1$, $a2$, ..., $a6$ – the relative importance of the criteria $\boldsymbol{G} = \{G1, G2, \ldots, G6\}$. To find the degrees of membership of fuzzy sets, considering the importance of the criteria, it is necessary, according to (Awasthi, 2018; Khorasani, 2018), each element of these sets to a power with the index equal to the relative importance of the criteria. As a result, we obtain the following final fuzzy sets of criteria, considering their importance. (Table 5).

To select the best transport supply project in terms of the set of criteria, a maximization approach is used (Nazari, 2018), which consists in minimizing the fuzzy sets for each criterion for each project and then maximizing the resulting fuzzy set to select the best project.

Table 5

Elements of fuzzy sets for each criterion given their importance

	P1	*P2*	*P3*	*P4*
G1^a1	0.7396	0.8699	0.7898	0.9514
G2^a2	0.9253	0.9578	0.9108	0.9254
G3^a3	0.8580	0.5111	0.5831	0.7250
G4^a4	0.7759	0.8050	0.6828	0.9218
G5^a5	0.7302	0.6129	0.9233	0.6129
G6^a6	0.6807	0.5686	0.8343	0.4344

Source: the authors' calculations.

The minimization operation of the criteria is to intersect the above final fuzzy sets of criteria for each project. As a result, we get the following fuzzy set:

$$G_{\min} = \{0.68,\ 0.51,\ 0.58,\ 0.43\}$$
$$\text{P1}\quad \text{P2}\quad \text{P3}\quad \text{P4}$$

This fuzzy set indicates a clear advantage of the project A, i.e., the advantage of the project to continue the Middle Urals Latitudinal Railway on the Nizhny Tagil – Perm section. This project satisfies all the criteria considered better than others.

A comparison of the examined projects based on the membership functions is shown in Figure 2. The figure shows that the distance between the projects for the most important criteria *G3, G6* and the other criteria is much more significant compared to the distance between the projects for unimportant project criteria. From the membership functions shown in Figure 1, you can also analyze which projects are more or less preferred by which criteria.

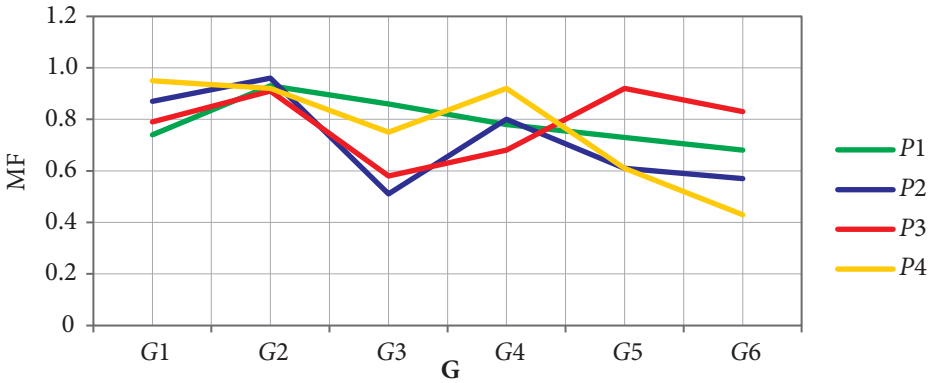

Figure 2. *Membership functions (MF) of P = {P1, P2, ..., P4} projects with regard to the importance of criteria G = {G1, G2, …, G6}*

Source: the authors' calculations.

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Thus, the following hierarchy of projects in order of importance and priority was obtained as a result of the experiment: 1) Sredneuralsky Latitudinal Railway on the N.-Tagil – Perm section (project *P1*); 2) Perm – Chernushka section (project *P3*); 3) Troitsko-Pechorsk – Ivdel section (project *P2*); 4) Ustye – Aha – Uray – Khanty-Mansiisk – Salym section (project *P4*).

The sequence of infrastructure projects selected for analysis at the beginning of the article is based on the intuitive assumption that they are arranged in descending order of importance. All of these projects correspond to the paradigm of the formation of a large transport grid and rely on serious factors of their justification. At the same time, they are very dissimilar network projects. Their direct technical and economic comparison is ambiguous, including because the regions and stakeholders involved in them compete. And the projects themselves, although they do not replace each other in any way, compete for development resources. When moving from the pre-project stage to the preparation of supporting materials for each of these projects, each time it is necessary to carefully adapt the overall methodological scheme of evaluation. Namely, it is always important to choose a system of reference of costs and results and take into account the interests of indirect beneficiaries.

According to the results of the study, we see that on the basis of the applied method it is possible to rank directly non-comparable projects on the basis of the formalization of the expert procedure. And the obtained ranks of significance in this case only partially confirmed our implicit hypothesis about the sequence of projects in terms of their significance.

In this article, we did not set out to perform justifications, but explained the motives for selecting projects for analysis by formalizing fuzzy logic and performed the corresponding calculations to simulate and summarize expert evaluations. The experts involved in different aspects of the development of the railway transport network arranged our intended criteria by importance and gave relative pairwise preferences for the proposed four projects. Thus, a multi-criteria expert evaluation of the projects was made, which shows another undoubted advantage of the applied procedures. The principle of multi-criteria is the most difficult to observe in a specific justification. In this case, according to the applied methodology, the nuances of expert motivation of preferences are not important, but the result of the aggregate expert evaluation is important. For this purpose, we converted linguistic variables into quantitative values and constructed membership functions, which gave the desired result.

Turbulent times can unexpectedly bring some projects, not widely promoted in the previous period, to the top of the priority list. Our initial assumption is that the Perm – Chernushka line is not a priority, but experts put it in second place. Delving deeper into the content analysis of the latest situation around it, one can see additional arguments in favor of its relevance. They may be related to the prospect of routing a much larger linear transportation project – bringing the Moscow-Kazan-Yekaterinburg high-speed highway to the Urals just through the south of the Perm region, via Chernushka. In this case, Chernushka is likely to become a transportation hub, from which lines will be needed both to the north, toward Perm and Solikamsk, and to the south, to Bashkiria.

With the help of the simulation expert model, the uncertainty in the assessment of the subsequent similar, including relatively unextended links between the regions of the Greater Urals is reduced.

Conclusion

At present, due to the sanctions period affecting the delivery of goods, the development of the transport rail network is a particularly urgent issue. Due to the turbulence of economic processes in this period, decisions must be made that are effective, first and foremost, from a nationwide perspective. For this purpose, it is necessary to justify them taking into account multi-criteria and all available information, which at the initial stages is fundamentally incomplete, insufficiently reliable and sometimes weakly formalized. In such cases, it is advisable to use special methods that allow evaluating decisions under conditions of uncertainty, in particular methods of fuzzy logic and mathematics.

With the help of fuzzy logic methods, it is possible to find compromise options that satisfy the various interests of those affecting the decisions, regardless of the structural organization of the backbone industries, one of which is undoubtedly the transport industry.

An important conclusion of our study is that by including the most significant technological

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and economic criteria, reflecting the national priority, the order of priority of transport rail support on the most important in the federal and regional scale main lines was assessed.

In accordance with the objectives of this study, the article implements a process of pairwise comparison of elements of sets (projects and criteria) based on the most significant technological and economic requirements, reflecting the nationwide priority. The formalized procedure of fuzzy multi-criteria analysis applied to comparison of different ways of priority of constructions of the main railway lines directions enabled to estimate the priority of transport railway provision on the investigated most important in federal and regional scale main lines. The best project out of all those considered, which satisfies all the criteria considered, is the continuation of the Middle Ural Latitudinal Railway on the N.-Tagil – Perm section.

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