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Миссия журнала «R-Economy» — обеспечить публикацию исследований в области региональной экономики. Мы считаем сотрудничество с экономистами из стран БРИКС нашим главным приоритетом. «R» в названии журнала ссылается на три его базовых направления – Region (региональное развитие), Rating (сравнительные исследования) и Regulation (государственное регулирование).

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Original Paper

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The role of e-government systems in ensuring government effectiveness and control of corruption

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ABSTRACT
E-government systems are a part of the general process of digital transformation in the public sector: countries with efficient e-government manage to reduce the administrative burden on private citizens and businesses and to improve government performance, transparency and accountability. This article brings to light the connection between the development of e-government systems and such factors as the rule of law and control of corruption. The study relies on a path model, which was built and statistically tested by using linear regression analysis to authenticate the veracity of the model's components. The model uses three indicators adopted from the World Bank's Governance Indicator project – the rule of law, control of corruption, and government effectiveness. The data to measure the e-Government Development Index (EGDI) in fifteen countries was provided by the e-Government 2016 Survey conducted by the United Nations. The findings reveal a positive complementary relationship between the rule of law in a country and the development of an e-government system, which enhances the government's effectiveness. The article describes a shift towards a more citizen-centric e-government implementation strategy, which can be recommended in particular to policy-makers in developing economies. The proposed model can be recommended as a measurement tool to assess effective governance in any given country.

KEYWORDS
government effectiveness, e-government, rule of law, control of corruption, citizen-centric governance, government policy

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Роль систем электронного правительства в обеспечении эффективности государственного управления и контроля коррупции

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АННОТАЦИЯ
Системы электронного правительства являются частью общего процесса цифровой трансформации в государственном секторе: странам с эффективным электронным правительством удается снизить административную нагрузку на частные лица и предприятия, а также повысить эффективность, прозрачность и подотчетность правительства. Эта статья раскрывает связь между развитием систем электронного правительства и такими факторами, как верховенство закона и борьба с коррупцией. Исследование опирается на модель роста, которая была построена и статистически протестирована с использованием линейного регрессионного анализа для проверки достоверности элементов модели. В модели используются три показателя, рассчитываемые Всемирным банком: верховенство закона, борьба с коррупцией и эффективность правительства. Данные для измерения индекса развития электронного правительства (EGDI) в пятнадцати странах были предоставлены в рамках Обзора электронного правительства 2016 года, проведенного ООН. Полученные данные свидетельствуют о позитивной взаимодополняющей взаимосвязи между верховенством закона в стране и развитием системы электронного правительства, которая повышает эффективность правительства. В статье описывается сдвиг в сторону более ориентированной на граждан стратегии внедрения электронного правительства, которая может быть рекомендована, в частности, лицам, определяющим политику в развивающихся странах. Предложенная модель может быть рекомендована в качестве инструмента оценки эффективности государственного управления в любой стране.

КЛЮЧЕВЫЕ СЛОВА
эффективность правительства, электронное правительство, верховенство закона, борьба с коррупцией, гражданское управление, государственная политика

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Introduction

Just as technological innovation is aimed at optimizing the business process or the work of enterprises and at giving them a competitive advantage, e-government is aimed at improving the efficiency, effectiveness and transparency of governance and public service delivery [1]. The aim of innovation in the public sector, that is, electronic government (or e-government), is to provide quality public service delivery, reduce stress and bureaucracy in accessing public services, build trust in government and government accountability to its citizens and users [2]. Apart from improving citizens' access to public services and being a transformative tool [3], e-government also makes it possible to promote business to business (B2B) networking, acting as a link between businesses and enabling resource flow and efficient communication [4].

In recent years, e-government research and implementation has transitioned into the phase of citizen-centric or citizen-centered e-government, which seeks to put citizens at the core of these public service innovations [5; 6]. For a long period, most governments have focused on infrastructure provision rather than on satisfying the citizens/users (the main reason why these implementations exist) [7; 8]. That being said, if citizen-centric e-government is fully embraced and implemented effectively, it will enhance user satisfaction and increase government effectiveness.

For e-government to successfully fulfil its purpose in any given environment, the following factors are necessary: citizen satisfaction, security, privacy and trust, support from the government, ICT skills, facilities offered, efficiency, innovative thinking, strategic ICT thinking within government, rule of law, availability of ICT infrastructure and ICT amenities [9; 10].

This study investigates e-government and its influence on government effectiveness by building a model which takes into account certain factors and tests them.

This paper is organized as follows. The next section provides a review of the research literature on this problem. After that, in the methodology section, we are going to describe our research model and postulate the hypotheses we are going to test. Then, we are going to discuss the findings, and the final section concludes and discusses the policy implications of the results.

Literature Review

This study is centered on effective governance, which is achievable when e-government is citizen-centric. A citizen-centric e-government system encourages users to interact more freely and effectively with their governments and thus leads to enhancement of the quality of public services [5]. A citizen-centric e-government involves participation of users/citizens [6] before, during and after the delivery of e-government services. Governments must fully transform from agency-centric to citizen-centric in order for e-government capabilities to be fully realized [11].

Eger & Maggipinto pointed out that e-government does not encompass technology alone but also includes rules and procedures. Thus, their study concludes that "e-government operates under the Rule of Law, protecting general principles such as equality, administrative transparency, rights protection for all citizens" [12, p. 23]. This assertion indicates the significant role played by the rule of law in any successful e-government endeavor. The rule of law is a powerful anti-corruption predictor and e-government has the potential of curbing corruption [13].

When the rule of law is upheld and followed, it leads to development and prosperity. The rule of law contributes to the protection of such core values as human freedom, which, in its turn, fosters an environment for economic development [14]. Socio-economic development policies are at the heart of e-government initiatives [15]. Thus, e-government development and economic development are interdependent. This means that in an environment where the rule of law is supported by institutions, e-government systems can flourish. E-government cannot be successful in chaotic systems (primarily where the rule of law is violated), which can be illustrated by an example of corruption in developing economies, which leads to the failure of e-government projects [16].

Previous studies failed to examine the effect of e-government on government effectiveness. For example, Ifinedo [17] theorized models yet did not provide sufficient evidence to demonstrate the positive influence of the rule of law on e-government growth in transition economies of Central and Eastern Europe. Krishnan & Teo [18] focused on e-government maturity, using the growth model to determine the value of good governance on e-government maturity. Another study [19] focuses on government efficiency and e-government growth.

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Our study focuses on another aspect – on the impact of e-government development on effective governance. We are going to address the following research questions:

1. Does the rule of law influence the development of e-government and corruption control?
2. Does e-government development influence corruption control?
3. Does e-government development enhance government effectiveness?

The next section outlines the research model and posits the hypotheses.

Research Model and Hypotheses

To answer the research questions and test the hypotheses, we need to develop a viable methodological framework [20]. Model validation and model development are necessary for research because they enhance our knowledge base and also provide the empirical basis for the construction of a comprehensive theory for further studies [21].

The research model for this study consists of the following components: the rule of law, corruption control, e-government development, and government effectiveness.

Rule of law

According to the World Justice Project, the rule of law is defined by these four universal principles: accountability, just laws, open government, and accessible and impartial distribution of justice[1]. In other words, the strong adherence to formal procedures and requirements is crucial [22]. The factors considered in the Rule of Law Index include: (1) constraints on government powers, (2) absence of corruption, (3) open government, (4) fundamental rights, (5) order and security, (6) regulatory enforcement, (7) civil justice, (8) criminal justice and (9) informal justice. Thus, the rule of law index is considered in this study as a representation of the rule of law in any given country.

Corruption control

Mungiu-Pippidi and Dadašov [23] describe corrupt activities as a result of individual behavior by self-seeking agents (bureaucrats), who abuse their position for personal gains and thereby betray top-level policy-makers' interests. Furthermore, the researchers highlighted the fact that corruption is a function of monopoly power over a good or service, the discretion to decide who receives it, and the degree of accountability of public authorities [23]. Our study uses the World Bank Group's World Governance Indicator – control of corruption, which captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as exploitation of the state by elites and private interests[2].

As such, anti-corruption policies are used by policy-makers to ensure effective governance. Corruption control is an important component to be included into our model.

E-government development

Research on e-government has investigated monitoring and evaluation of public sector e-services and infrastructure maturity over different periods. Benchmarking of e-government maturity performed by the United Nations[3] is a comprehensive assessment of the distribution of e-government in various governments across all nations. The 2016 UN report highlighted the following key points as factors which determine the development of e-government: the existence of Whole-of-Government Approaches (WGAs), e-participation, open government data or electronic and mobile services. Hence, e-government development requires strong political commitment, government-wide vision, collaborative leadership, as well as appropriate legislation and holistic institutional frameworks[4]. E-government development influences national progress [24].

This study associates e-government development with the UNDESA's e-Government Development Index (EGDI).

Government effectiveness

Government effectiveness encompasses the ability of the government to provide quality public services and its ability to formulate credible and quality policies [25]. Government effectiveness has a positive impact on innovation and so-

[1] *What is the Rule of Law?* Retrieved from: https://worldjusticeproject.org/about-us/overview/what-rule-law (Accessed 10 August 2018)

[2] World Bank (2016). *The Worldwide Governance Indicators (WGI) project*. Retrieved from: http://info.worldbank.org/governance/WGI/ (Accessed 10 August 2018)

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[4] United Nations (2016). *United Nations e-government survey 2016: e-government in support of sustainable development*. New York. Retrieved from: http://workspace.unpan.org/sites/Internet/Documents/UNPAN97453.pdf (Accessed 10 August 2018)

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cio-economic activities of companies and enterprises, creating perfect conditions for economic prosperity [26].

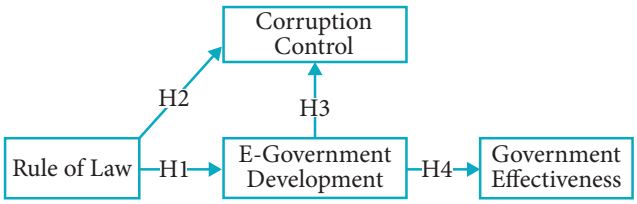

Figure 1. *Proposed research model*

Figure 1 illustrates the proposed research model. The rule of law influences e-government development and the control of corruption. E-government development has a significant impact on the control of corruption and, most importantly, on government effectiveness.

The next section expounds on the methodology of the study.

Methodology

For the purpose of this study, we used three (3) governance indicators for 2016 from the World Bank's Governance Indicator project – the rule of law, control of corruption, and government effectiveness[5]. The e-Government Development Index (EGDI), the indicator which measures e-government performance country-wise, was derived from the UN's e-Government 2016 Survey [25]. The reason for selecting 2016 was due to the fact that these are the most recent data available for the EGDI indicator on the current state of e-government in all countries.

In selecting the countries for our comparative analysis, we chose three countries from each continent. One country was selected for each of the EGDI ranges: 0–0.39 (low), 0.4–0.59 (medium), and 0.60–1 (high). The countries and their respective indicators are shown in Table 1.

For the purpose of this study and due to the numerical nature of variables, a linear regression analysis was performed on the presented data set in the R programming language. The study explored the relationship between the dependent and independent variables for each scenario (hypothesis) of the model (see Figure 1).

The regression analysis was chosen for this study because it allows us to identify mathematical relationships between dependent and independent variables as well as describe the impact that an independent variable has on a dependent variable [28]. Thus, a simple linear regression analysis was used to verify the association between each interconnected component of the proposed model.

The results were expressed as the quality of the adjusted model called R-squared (R^2). R^2 ranges from 0 to 1 and describes the amount of variation in the response that is explained by the least squares line [29].

[5] World Bank (2016). *The Worldwide Governance Indicators (WGI) project*. Retrieved from: http://info.worldbank.org/governance/WGI/ (Accessed 10 August 2018)

Table 1

Countries and selected indicators for 2016

Region	Country	E-government development index	Government effectiveness	Rule of law	Control of corruption
Africa	Mauritius	0.6231	1.0	0.8	0.3
	Ghana	0.4182	–0.2	0	–0.2
	Guinea	0.1226	–1.0	–1.3	–0.9
Americas	USA	0.8420	1.5	1.7	1.3
	Cuba	0.3522	–0.1	–0.4	0.1
	Bolivia	0.4821	–0.6	–1.2	–0.7
Asia	Republic of Korea	0.8915	1.1	1.1	0.4
	Jordan	0.5123	0.1	0.3	0.3
	Pakistan	0.2583	–0.6	–0.8	–0.9
Europe	Finland	0.8817	1.8	2.0	2.3
	Belarus	0.6625	–0.5	–0.8	–0.3
	Albania	0.5331	0	–0.3	–0.4
Oceania	Australia	0.9143	1.6	1.8	1.8
	Papua New Guinea	0.1882	–0.7	–0.8	–0.9
	Samoa	0.4019	0.5	0.8	0.3

Source: World Bank (2016). *The Worldwide Governance Indicators (WGI) project*. Retrieved from: http://info.worldbank.org/governance/WGI/ (Accessed 10 August 2018); United Nations (2016). *United Nations e-government survey 2016: e-government in support of sustainable development*. New York. Retrieved from: http://workspace.unpan.org/sites/Internet/Documents/UNPAN97453.pdf (Accessed 10 August 2018).

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Research Findings

This section presents the results of the analysis performed on the given data (see Table 2) by using the selected linear regression test. In the sub-sections below we describe the results of the relationship test.

Rule of Law and E-Government Development (RoL → EGDI)

First, we tested the following hypothesis:

H1: The presence and effectiveness of the rule of law has a positive and significant effect on e-government development in any country.

Table 2

Regression coefficients on e-government development (EGDI)

Independent Variable	*β*	*t*	*Pr(>|t|)*	Result
RL.EST	0.05306	3.607	0.00319**	Supported (H1)
	Significance codes: * $p<0.05$, ** $p<0.01$; *** $p<0.001$ Adjusted *R*-squared: 0.4618			

Rule of Law and Corruption Control (RoL → CoC)

The second hypothesis to be tested was as follows:

H2: The presence and effectiveness of the rule of law has a positive and significant effect on control of corruption in any country.

Table 3

Regression coefficients on corruption control (CC.EST)

Independent Variable	*β*	*t*	*Pr(>|t|)*	Result
RL.EST	0.1546	3.188	0.00781**	Supported (H2)
	Significance codes: * $p<0.05$, ** $p<0.01$; *** $p<0.001$ Adjusted *R*-squared: 0.7948			

E-Government Development and Corruption Control (EGDI → CoC)

The third hypothesis looked the following way:

H3: E-Government development (effectiveness and quality of service delivery) has a positive and significant effect on the level of corruption control in any country.

Table 4

Regression coefficients on corruption control (CC.EST)

Independent Variable	*β*	*t*	*Pr (>|t|)*	Result
EGDI	1.6445	2.544	0.02575*	Supported (H3)
	Significance codes: * $p<0.05$, ** $p<0.01$; *** $p<0.001$ Adjusted *R*-squared: 0.7948			

As it can be seen from Table 4, the results prove the hypothesis that e-government development has a positive and significant effect on corruption control in any country.

E-Government Development → Government Effectiveness (EGDI → GE)

H4: E-Government development (effectiveness and quality of service delivery) has a positive and significant effect on government effectiveness in any country.

Table 5

Regression coefficients on government effectiveness (GE)

Independent Variable	*β*	*t*	*Pr(>|t|)*	Result
EGDI		3.795	0.00223**	Supported (H4)
	Significance codes: * $p<0.05$, ** $p<0.01$; *** $p<0.001$ Adjusted *R*-squared: 0.4891			

As Table 5 illustrates, the results of our analysis prove the hypothesis that e-government development has a positively significant influence on government effectiveness. Our results thus agree with those of the studies referenced in the preceding sections, which assert that e-government contributes to people's trust in the government and the government's accountability (characteristics of an effective government).

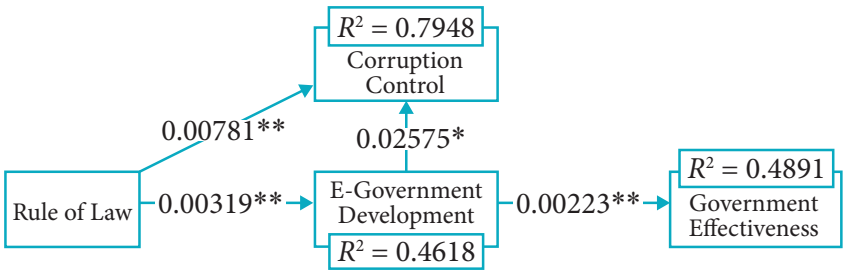

Figure 2. *Path diagram of the conceptual model of government effectiveness based on the development of e-government*

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Our observations agree with the study of Kim [13], who concludes that the rule of law is a fundamental precondition of government effectiveness and an important tool in fighting corruption (see Figure 2).

From the theoretical standpoint, our conceptual model affirms the fact that adherence to the rule of law influences corruption control and e-government development; e-government development, in its turn, influences corruption control and government effectiveness.

Discussion

This study presents e-government as a key factor that shapes government effectiveness. The model we built and the analysis of the available data indicate that the rule of law is significant in controlling corruption and creating room for e-government development. E-government development also significantly influences the control of corruption and enhances government effectiveness.

The results obtained are in line with the study of Diez et al. [29], who found that states which adhere to the rule of law have an enabling environment for e-government to flourish because it encourages e-participation. Following this line of reasoning, it can be concluded that the development of e-government creates transparency in governance and enhances trust among citizenry and, therefore, helps fight corruption [30; 31]. Moreover, our results agree with those of Smith [32], who pointed out that e-government helps the state address vital questions and needs of citizens.

This study's findings contribute to the theoretical discussion of e-government development by highlighting its role in ensuring effective governance. The model is highly recommended as a measurement tool to assess effective governance in any given country. The constituents of the model have proven to be important indicators, thus their combination may be useful for policy-and decision-makers.

Conclusion

The above-described study involved the analysis of selected development indicators (factors) – the rule of law, corruption control, e-government development, and government effectiveness – and the role they play collectively in ensuring government effectiveness (with e-government as the core component). We found that the rule of law together with promotion of e-government systems enhances the efficiency of public services. Thus, creation of a citizen-centric e-government environment becomes one of the crucial tasks for modern states in the digital era.

Just as every research has certain hindering factors, this study is no exception. To begin with, for our model, we used a limited number of factors, so further research is needed to expand the model and test other contributing factors. Moreover, 52 it would be productive to use cross-sectional panel data for different time periods.

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Sino-Russian environmental cooperation: past, present, and future

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ABSTRACT
In order to address vital environmental issues, China and Russia have established a set of cooperation mechanisms, such as the Sub-Committee on Environmental Protection of the Regular Meeting of the Prime Ministers of China and Russia. There is currently a multi-level environmental cooperation system between the two countries. In recent years, China and Russia have strengthened their ecological cooperation and have achieved certain results in the conservation of cross-border water resources and establishment of transboundary nature reserves. There are still, however, many problems to handle such as the discrepancies in legislation and the limited character of investment each of the countries is willing to make into environmental protection. Therefore, as the article shows, it is necessary to formulate a unified regulatory framework; to establish a resource protection zone; to enhance joint monitoring of the water quality in transboundary rivers as well as soil and air quality in adjacent areas; and, finally, to raise public awareness in both countries of environmental security and nature conservation. In 2017, Russia hosted the Year of Ecology, which was a good opportunity for both countries to promote information exchange and cooperation in the sphere of joint monitoring and governance, environmental legislation, and ecological education.

KEYWORDS
China, Russia, environmental cooperation, Year of Ecology

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Китайско-Российское экологическое сотрудничество: прошлое, настоящее и будущее

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АННОТАЦИЯ
Для решения насущных экологических проблем Китай и Россия создали ряд механизмов сотрудничества, таких как Подкомитет по охране окружающей среды Регулярной встречи премьер-министров Китая и России. В настоящее время между двумя странами существует многоуровневая система экологического сотрудничества. В последние годы Китай и Россия укрепили свое экологическое сотрудничество и достигли определенных результатов в сохранении трансграничных водных ресурсов и создании трансграничных природных заповедников. Однако все еще остается много проблем, таких как несоответствия в законодательстве и ограниченный характер инвестиций, которые страны готовы внести в охрану окружающей среды. Поэтому, как показано в статье, необходимо сформулировать единую нормативно-правовую базу; создать ресурсную охранную зону; усилить совместный мониторинг качества воды в трансграничных реках, а также качества почвы и воздуха в прилегающих районах; и, наконец, повысить осведомленность общественности в обеих странах об экологической безопасности и сохранении природы. В 2017 году в России прошел Год экологии, который стал для обеих стран хорошей возможностью содействовать обмену информацией и сотрудничеству в области совместного мониторинга и управления, экологического законодательства и экологического образования.

КЛЮЧЕВЫЕ СЛОВА
Китай, Россия, экологическое сотрудничество, год экологии

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Introduction

China and Russia are currently experiencing the best period of history in their relationship, both in terms of political and economic cooperation. China and Russia have a common border separated by the Amur, Songhua River and Wusuli River and Xingkai Lake. Shared water resources determine the need for cooperation between the two countries in the sphere of environmental protection. In addition, there is also a land boundary, which is more than 4,300 kilometers long. Therefore, both countries face a number of environmental problems associated with the conservation of forests, protection of wildlife and plant life, prevention of air pollution and so on. These problems are a part of large-scale global issues such as the global warming and resource depletion.

Like in many other countries in the world, the environmental conditions in China and Russia leave much to be desired. According to the 2017 Bulletin on the State of Ecological Environment, 239 cities in the country's 338 prefecture-level cities or 70.7% do not meet the air quality requirements[1]. In Russia, the amount of recycled and neutralized waste increased by 1.9 times compared to 2010. In 2017, the total amount of solid chemical waste exported from Russia was 274.4 million cubic meters, 16.6% more than in 2010. In 2017, the amount of municipal solid waste exported to waste treatment plants reached 27.9 million cubic meters, accounting for 10% of the total municipal solid waste[2]. Thus, it can be seen that both China and Russia are facing severe environmental pressures.

Methodology

The study uses methods of comparative analysis, by focusing on both quantitative and qualitative indicators to show the similarities and differences in China's and Russia's approach to environmental protection.

It should be noted that comparative studies on ecology and environmental protection in China consider cases of other countries trying to solve similar problems. For example, much attention is paid to water issues in the studies of Liya Su, Jingling Liu, Per Thorsø Christensen [1], Shaofeng Jia, Yuanyuan Sun, Jesper Svensson, Maitreyee Mukherjee [2]. Kai-Yi Zhouand and William R. Sheate compare Chinese legislation with that of Northern European countries [3]. It should be noted here that similar studies on Russian environmental problems were conducted by Russian researchers.

After the end of the Cold War, the traditional geopolitical pattern and political relations underwent tremendous changes. The security issue has expanded from the traditional military and political spheres to economic, social, and environmental fields [4]. Environmental security, especially cross-border environmental security issues, is particularly prominent in geopolitical relationships. As geopolitical and economic relations between China and the neighbouring country were developing, more and more attention started to be given to cross-border environmental security as a part of national environmental security, for example, protection of cross-border water resources [5–7] and joint construction and coordination management of cross-border nature reserves [8; 9].

China's environmental problems are discussed both nationwide [10], and across entire Asia [11], since they greatly affect the neighboring countries. Some studies consider a range of tools to address these problems, in particular by changing taxation [12; 13].

Environmental issues faced by Russia are discussed by Russian and European researchers [14; 15]. Russian researchers often approach environmental problems by focusing on questions of sustainable development and conduct their analysis on the national and interregional levels rather than on the level of international cooperation.

This study compares the Russian and Chinese approaches to solving environmental problems and discusses the prospects of interstate cooperation. The purpose of the study is to outline the prospects for Russian-Chinese cooperation and propose measures to strengthen this relationship. In order to achieve this goal, we need to analyze the current state of Sino-Russian environmental cooperation; identify the possible impediments; and devise recommendations for handling them. The hypothesis behind this study is that the environmental policies of China and Russia should be based on cross-border cooperation.

[1] 2017 China Ecological Environment Bulletin (2018). Retrieved from: http://www.mee.gov.cn/gkml/sthjbgw/qt/201805/t20180531_442212.htm (Accessed 1 October 2018)

[2] Ministry of Natural Resources of the Russian Federation: State Report "On the condition and protection of environment in the Russian Federation in 2017" (December 2018). Retrieved from: https://nangs.org/analytics/minprirody-rossii-gosudarstvennyj-doklad-o-sostoyanii-i-ob-okhrane-okruzhayushchej-sredy-rossijskoj-federatsii-pdf (Accessed 1 October 2018)

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The structure of the article is based on the "point-by-point" scheme, that is, for each of the given parameters, information about one country is first provided, followed immediately by the description of the other country. After discussing the parameters, the findings are presented and suggestions are made to address the problems.

Natural resources of Russia and China

Russia is known to be a rich country, abundant in resources such as oil, natural gas, timber, minerals and fresh water. Although China's resources can also be sufficient, due to the rapid economic development in recent years, the environment has suffered from serious pollution and damage. For example, if we consider water resources, China's per capita freshwater resources are much lower than Russia's, but the average annual water consumption is significantly higher than that of Russia (see Table 1). It can be said that compared with Russia, China faces more serious problems in environmental protection and sustainable development. On October 18, 2017, Chinese President Xi Jinping emphasized in his report that "constructing ecological civilization is a millennium plan for the sustainable development of the Chinese nation. It is necessary to establish and practice the concept of green mountains. The basic national policy of conserving resources and protecting the environment treats the ecological environment as life"[3] China has turned sustainable development into a basic national policy and decided to contribute to the world's environmental security.

Table 1

Russia's and China's freshwater resources and their use

	Freshwater reserves per capita, m^3	Annual average fresh water consumption, billion m^3	Freshwater use (%)		
			agriculture	industry	household consumption
Russia	29.013	47,9	15	69	16
China	2.062	594,2	64	22	13

Source: *The table is based on the data of the National Statistics Office of the Russian Federation*. Retrieved from: http://www.gks.ru/bgd/regl/b18_39/Main.htm (Accessed 1 October 2018)

At present, the comprehensive strategic partnership between China and Russia has entered the "best period in history". The integration of the Belt and Road Strategy and the Eurasian Economic Alliance has become a top priority in the comprehensive strategic partnership between China and Russia. It will promote social and economic development of the two countries and their neighbours. As regional powers, China and Russia have always been committed to maintaining regional security and promoting regional development. Cooperation in the field of environmental conservation is among the most important areas.

History and the current status of Sino-Russian environmental cooperation

Sino-Russian environmental cooperation began in the 1980s (see Table 2 below). This cooperation first focused on the protection of the boundary rivers. On October 23, 1986, China and the Soviet Union signed the Agreement on Water Resources Management. On May 27, 1994, China and Russia signed the cooperation agreement in the field of conservation, utilization and reproduction of aquatic resources in the Heilongjiang and Wusuli Rivers; on April 25, 1996, the Agreement on the Establishment of a Forbidden Fishing Area between China and Russia in Xingkai Lake was signed [16]. The cooperation between China and Russia began to expand when in May 1994, the Agreement on Environmental Protection Cooperation between the Government of the People's Republic of China and the Government of the Russian Federation was signed. In November 1997, China and Russia signed the "Joint Statement", which emphasized the importance of environmental cooperation and described the responsibilities of the two countries to prevent cross-border pollution and ensure rational and economical use of natural resources (including transboundary water resources)[4].

A turning point in the Sino-Russian environmental cooperation became the Songhua River water pollution incident in 2005. On November 13, 2005, the explosion of the double-benzene plant of Jilin Petrochemical Company in China caused an environmental disaster on the Songhua River, which seriously affected the residents' living conditions in the adjacent areas of the two countries. In order to protect people from pollution, the two countries decided to further strengthen

3 Xi Jinping. (2017-10-28) *Decisive victory to build a well-off society in an all-round way to win the great victory of socialism with Chinese characteristics in the new era*. People's Daily, 001.

4 *China Environmental News reporter talks Li Ping, director of the Environmental Protection Department of Heilongjiang Province – wins understanding and trust by hard work* (2010). Retrieved from: http://www.hljdep.gov.cn/zmhd/zxft/2010/02/10271.html (Accessed 1 October 2018)

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their cooperation in monitoring of the water quality in the rivers. Since then, the two governments have begun to address and pay more attention to the importance of environmental cooperation. In 2006, China and Russia signed the "Sino-Russian Joint Monitoring Plan for Water Quality of Transboundary Waters", which expanded joint monitoring to cross-border water in the Ergun, Heilongjiang, Wusuli River, Suifenhe and Xingkai Lakes. Thus, water monitoring was raised from the local to national level: the corresponding national departments of the two countries started to exchange information about their monitoring results.

The two countries also established the Environmental Protection Subcommittee within the Chinese-Russian Prime Ministers' Regular Meeting Committee in the same year. Thus, the highest level of environmental cooperation between the two countries was established. Since then, the countries have been taking turns to hold meetings of the Sub-Committee. Within the framework of the Sub-Committee, the two countries are now closely cooperating in the three core areas, including emergency response to pollution and environmental disasters; establishing transboundary nature reserves and biodiversity conservation; cross-border water monitoring and protection.

In addition, cooperation is now realized on the level of research organizations and research groups: since 2008, in Heihe City, Heilongjiang Province, there has been held "Heilongjiang Heihe Sino-Russian Forestry Ecological Construction Academic Forum". In 2013, the "Russian-Chinese Forum on the Conservation and Rational Use of Forest Resources" was held for the first time in the Amur region. These two local forums are aimed at enhancing scientific research in the sphere of environmental conservation[5].

China and Russia have launched environmental cooperation programs within the framework of international organizations such as the SCO and BRICS. In September 2013, the China-Shanghai Cooperation Organization Environmental Protection Cooperation Center was established. The center is committed to implementing the consensus of the Shanghai Cooperation Organization Leaders Meeting and promoting environmental protection cooperation and exchanges between China and Shanghai Cooperation Organization member states. China and Russia rely on China-Shanghai Cooperation Organization Environmental Protection Cooperation Center to carry out multilateral ecological cooperation under the framework of the SCO and BRICS and work together to solve global environmental problems.

Both countries have established a mechanism of environmental cooperation between Chinese and Russian enterprises. In 2015, the China-Russia Friendship Peace and Development Commit-

[5] *Heihe Daily*, June 13, 2013, version 001.

Table 2

Regulations and agreements on the environmental cooperation between Russia and China

Regulations and agreements	Content
Sino-Russian Cooperation Agreement on the Protection, Utilization and Reproduction of Aquatic Resources in the Heilongjiang and Ussuri Rivers (signed on 27 May, 1994)	Protecting the aquatic resources of the Heilongjiang and the Wusuli River; promoting utilization and reproduction of aquatic resources in the two boundary rivers
Sino-Russian Agreement on Xingkai Lake Nature Reserve (signed on 25 April, 1996)	Protecting flora and fauna in nature reserves; promoting bilateral cooperation in the sphere of environmental conservation and sustainable use of natural resources; monitoring and research of natural ecosystems; raising awareness of the purpose and meaning of nature conservation among citizens of both countries
Sino-Russian Joint Statement (signed in November 1997)	Prevention of cross-border pollution; Promotion of sustainable use of natural resources (including transboundary water resources)
Joint Monitoring Plan for Sino-Russian Transboundary Water Quality (signed on 2 June, 2006)	Joint monitoring of the Ergun River, Heilongjiang River, Wusuli River, Suifen River and Xingkai Lake; Monitoring of water quality in Sino-Russian transboundary waters on the national level; Monitoring to be carried out by the corresponding national departments
Sino-Russian Transboundary Water Use and Protection Cooperation Agreement (signed on 29 January, 2008)	Defining the use, protection and detection of transboundary water bodies; Stipulation of the relevant responsibilities of the two governments, including responsibilities to inform each other about the situation in the boundary river waters, facts of water pollution and so on, and the responsibilities to take measures when necessary

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Table 3

Joint Chinese-Russian events in the field of environmental protection in 2017

Area	Event description
Bird protection and wildlife survey work (April, 2017)	Bagua Island National Nature Reserve and Russia's Basdak Nature Reserve monitored endangered birds, such as the Oriental white stork and great egret
Bird and fish protection	Researchers from China and Russia jointly conducted wildlife inspections in Honghe Nature Reserve
Bird protection (April, 2017)	The First Xingkai Lake International Love Bird Festival
Environmental protection (October, 2017)	Honghe Reserve and Bastak Reserve jointly published the album "People and Nature"
Protection of biodiversity and promotion of environmental security (29 May – 3 June, 2017)	"Belt and Road"Baikal Eco-Forum
Research of fauna and flora	Background survey of animals and plants in Xingkai Lake and the Song Acha River Basin

tee added an ecological council, which provided an important communication channel for civil cooperation in this sphere.

Achievements in Sino-Russian environmental cooperation

Within the multi-level Sino-Russian environmental cooperation system, both countries have managed to achieve certain results in protecting cross-border water resources, establishing transboundary nature reserves and ensuring biodiversity conservation[6]. In 2013, experts from the Chinese Academy of Sciences and Changbai Mountain Reserve visited the "Far East Leopard Habitat" Nature Reserve in Russian Primorye and planned to sign an agreement with the Russian partners to protect the north-eastern tiger. Russia and China's future plans include the establishment of protected areas for protection of the far eastern leopard the north-eastern tiger. At the moment, most of the cooperation is realized in the form of information exchange[7].

As for biodiversity conservation, the two countries have established four cross-border nature reserves: Xingkai Lake Nature Reserve, Sanjiang Nature Reserve, Bagua Island Nature Reserve and Honghe Nature Reserve [17]. The Sino-Russian cross-border nature reserve cooperation plan is to meant to intensify the information exchange and improve the level of cooperation for protection of rare animals and plants. Table 3 shows some of the joint environmental activities in 2017.

Problems in Sino-Russian environmental cooperation

Russia and China have a number of similar problems of economic development, they also have comparable goals and conditions and can, therefore, build their interaction in all areas on a solid foundation of good neighbourly relations [18]. In recent years, the rapid economic development and industrialization have put enormous pressure on the environment of the neighboring regions of the two countries. The intensity of ecological protection measures and the ability of ecological restoration do not compensate for the deterioration of the natural environment.

The *first problem* to be considered here is the limited investment both countries make into environmental protection**.** According to the experience of developed countries, the national environmental protection investment generally accounts for more than 2% of GDP, and 3% can bring about significant improvements in the sphere of environmental conservation. For nearly ten years, China's environmental protection investment has been below 2% of GDP, and it was below 1.5% for a long time. Russia's environmental protection investment accounts for less than 1% of GDP. Therefore, there is a huge gap between Chinese and Russian investment and that of developed countries.

The *second problem* concerns water resources**.** The Heilongjiang, Wusuli River, Xingkai Lake and Suifen River in Heilongjiang Province are adjacent to Russia. The deterioration of water resources will affect the living conditions and socio-economic development in the region and have a serious impact on the climate and ecosystem. In November 2005, the water pollution incident occurred on the Songhua River; in September 2006, yet another incident of water pollution occurred

[6] *China Environmental News reporter talks Li Ping, director of the Environmental Protection Department of Heilongjiang Province – wins understanding and trust by hard work* (2010). Retrieved from: http://www.hljdep.gov.cn/zmhd/zxft/2010/02/10271.html (Accessed 1 October 2018)

[7] *Russia and China agreed to protect tigers together* (2013). Retrieved from: http://www.cntour2.com/viewnews/2013/01/25/xCv0qEO4XrigDVK1MBd30.shtml (Accessed 1 October 2018)

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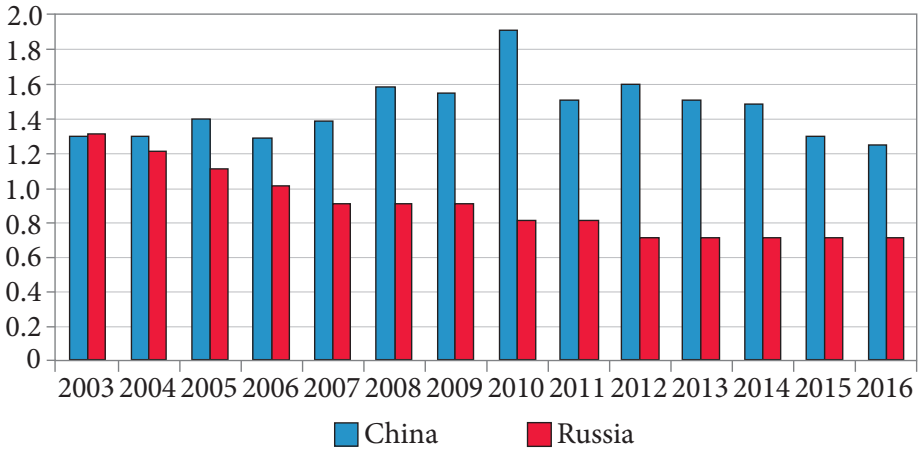

Figure 1. *Investment into environmental protection, percentage of GDP, % (The chart uses the daa of the China Environmental Statistics Yearbook and the National Statistics Office of the Russian Federation)*

on the Niuhe River in Jilin; in November 2006, the Russian side found that water near the villages in Khabarovsk regions was contaminated with camphor and requested the Chinese side to analyze the concentration of camphor in the waters of the Songhua River and Tongjiang, and to inform the Russian side of the results[8]. These incidents show how vulnerable is the natural environment in the region. After that, China and Russia took some steps to establish joint monitoring of water quality in the boundary rivers and achieved certain results.

Russia and China formulated the "Sino-Russian Joint Monitoring Plan for Cross-border Water Quality". This plan proposes to conduct joint monitoring of the transboundary waters of the Heilongjiang, Wusuli River, Erguna River, Suifen River and Xingkai Lake. Joint monitoring has been realized since 2007 [19]. However, there are still some problems in the cooperation between the two countries: the number of water tests is insufficient; the water quality related data and boundary river water database need to be improved; the water quality testing standards of the two countries lack uniformity; there is also a lack of a unified information platform and management supervision platform; the differences in management departments and management systems between the two countries lead to a lack of understanding on the responsibilities of the sides and so on.

The *third problem* is the conservation of forest resources**.** Forestry resources in the adjacent areas of China and Russia are extremely rich. According to the data of the National Forest Register as of January 1, 2018, the total area of the Russian Federation with forest distribution is 184.45 million hectares, and the forest area is 1,147 million hectares. The areas with the highest forest coverage are the Far Eastern Federal District and the Siberian Federal District. In China, Heilongjiang Province is the main national forest area and a source of timber. As of 2017, the province's forest coverage rate was 47.07%, and forest accumulation was 1.994 billion cubic meters[9].

The problem of illegal logging in the adjacent regions of China and Russia is really serious and involves severe violations of operating procedures in timber harvesting. The Russian forest area mainly develops logging and paper industries, and the paper industry also causes some serious water pollution and air pollution to the region. Nikola Smatakov, Director of the forest project of the Russian branch of the WWF, said that the Russian timber prices are extremely low: for example, the cost of logging 1 cubic metre of eucalyptus wood in the Far East is only 41 rubles, while the market price may exceed 10 thousand rubles, which leads to inefficient use of resources and people being unwilling to restore the forest area. The ecologist also added that because the regulatory authorities often have incomplete information about forest

[8] *China Environmental News reporter talks Li Ping, director of the Environmental Protection Department of Heilongjiang Province – wins understanding and trust by hard work* (2010). Retrieved from: http://www.hljdep.gov.cn/zmhd/zxft/2010/02/10271.html (Accessed 1 October 2018)

[9] *Bulletin on the State of the Environment of Heilongjiang Province in 2017* (2018). Retrieved from: http://www.hljdep.gov.cn/hjgl/hjjc/hjzkgb/2018/06/19044.html (Accessed 1 October 2018)

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resources and that there is a risk of deforestation, with the amount of illegal harvesting of some valuable tree species (eucalyptus, oak, ash) being twice or more than the legally allowed amount of forest harvesting [8].

The *fourth problem* is protection of rare animal and plant species. In addition to forest resources, a large part of wetland is located in the area of the Wusuli River Basin and Xingkai Lake. The flora and fauna are very rich, and it is the main habitat of many endangered species and the stopover of migratory birds. So far, Heilongjiang Province has established 250 nature reserves of various types and levels, including 40 at the national level, 84 at the provincial level, 55 at the municipal level, and 71 at the county level, with the total area of 7.9 million hectares. The total area of nature reserves accounts for 16.7% of the province's total area, and the area of the Heilongjiang River Basin Conservation Area accounts for about 40% of the total area of the province's nature reserves[10].

In recent years, the demand for rare animals and plants has increased due to the eating habits of the people of Northeast Asian countries and the improvement of people's living standards. The problem of reduced income and unemployment in the Russian Far East will lead people to take risks and steal rare animals and plants. The old laws and regulations cannot prevent illegal poaching, and the relevant law enforcement departments lack the necessary power and resources, which leads to illegal hunting and theft. There are transfer channels between China and North Korea and rare animals and plants, such as ginseng, the far eastern leopard, lynx, camphor, and leeches, are in a lot of danger.

Therefore, it is imperative to improve environmental cooperation between China and Russia. The environmental problems of China and Russia, especially the problems in the adjacent areas, will inevitably require the two countries to work together to enhance the existing environmental cooperation system and maintain the ecological harmony shared by the two countries.

Prospects for Sino-Russian environmental cooperation

China and Russia have established a robust system for cooperation in the sphere of environmental protection. At the same time, the urgency of environmental issues requires that the two countries should maximize the efficiency of this cooperation.

In 2017, Russia held the Year of Ecology, which included such activities as improvement of environmental legislation, promotion of environmentally friendly technologies, improvement of solid waste treatment methods, establishment of special nature reserves, protection of water, forests, rare animals and other resources, and popularization of ecological education. As a result, 7,000 activities at the federal and regional levels are scheduled to be completed by 2025, and emissions of air pollutants and river networks have decreased by 284,000 tons per year. A state registry of objects that have a negative environmental impact was created with 87,953 of such objects registered. The national parks Sengileevsky Mountains (Ulyanovsk Region) and Kislovodsky (Stavropol Territory) were established. A large number of events focused on Lake Baikal, including "Eco-Generation" flash mob and the Baikal Ecological Water Forum, attended by more than 1,000 people[11]. The Russian experience of the Year of Ecology has set a good example for China.

1. Expanding cooperation

There are a number of areas in which Russia and China can expand their cooperation: for example, the protection of the boundary river and the boundary lake. It is necessary to control the pollution of industrial and agricultural wastewater and domestic sewage; prevent pollution accidents; protect vegetation and wetlands; organize restoration or reforestation projects to guarantee the recovery of forests and grassland in former agricultural areas; enhance joint monitoring and control over the quality of water; improve the database on the quality of water in boundary rivers; organize regular updating and harmonization of water quality testing standards; facilitate information exchange on the state of border rivers; establish a unified information platform and a coordinated supervision platform. There should be created transnational authorities with clearly defined rights and responsibilities, in charge of the protection and control over the environment in the boundary areas.

As for the establishment of transboundary nature reserves and biodiversity conservation,

[10] *Report on the Sino-Russian Transboundary Nature Reserve and Biodiversity Conservation in Heilongjiang Province in 2016* (2017). Retrieved from: http://www.hljdep.gov.cn/hjgl/zrbh/swdyxbhyswaqgl/2017/04/15484.html (Accessed 1 October 2018)

[11] (2017) *Results of the Year of Ecology in Russia*. Moscow, p. 14.

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under the supervision of the Sino-Russian Environmental Protection Sub-Committee, Sanjiang, Honghe, Bagua Island and Xingkai Lake National Nature Reserves in Heilongjiang Province are engaged in active cooperation with Russia. The Sanjiang National Nature Reserve has signed an agreement with Khabarovsk and Jewish Autonomous States to jointly protect the natural environment between the Wusuri River and Heilongjiang River Basin. The Honghe National Nature Reserve promotes Sino-Russian ecological cooperation through the GEF Wetland Project and is committed to the task of biodiversity conservation in protected areas[12]. The two countries can continue to expand their cooperation in testing, scientific research, publicity, resource conservation, eco-tourism, cross-border nature reserves, and so on.

2. Environmental education

The Russian government has always attached great significance to the building of ecological culture by focusing on environmental education, especially among younger generations, environmental awareness, and mass communication of environmental information. It is largely this experience that China can learn from. According to the regulations of the Russian Ministry of Education, the environmental education curriculum is compulsory for Russian schools. However, at this stage, China is experiencing serious shortages of qualified teachers, specializing in environmental education and the quality of such education still leaves much to be desired. Therefore, the secondary education system in China should include environmental education in the list of its top priorities, start to provide high quality courses and teaching materials, and guide students to implement the ecological civilization concepts in their daily lives.

Russia also invests into popularization of environmental action and raising environmental awareness. The "Russian Federal Environmental Protection Law" stipulates that "environmental protection legislation and ecological security legislation should be popularized among residents" [20]. The same should be done in China: a flexible and diverse approach should be applied to popularize and publicize relevant laws and policies, to enhance public environmental awareness and public engagement. Chinese citizens should learn about the eco-friendly technologies and sustainable consumption.

3. Enforcing environmental legislation

In Russia, the main principles of environmental legislation are established by the Constitution. The "Russian Federal Environmental Protection Law" adopted in 2002 has the status of the basic law and forms the foundation for other normative documents. The country's environmental policy is described in such documents as "Environmental Protection for 2012–2020", "Strategy of Environmental Security until 2025", and the 'Russian National Environmental Strategy. In addition, there are annual reports issued by the Russian Ministry of Natural Resources and Environmental Protection. The purpose of these reports is to ensure that state authorities, social organizations and the public should be aware of the state of environmental protection, which includes ensuring the rational use of natural resources, restoration of natural resources and implementation of the country's sustainable development strategy [20].

The Chinese side also has some relevant policies. The report of the 19th National Congress pointed out that the reform of the ecological civilization system would be accelerated. The reform includes promotion of "green" development, protection of ecosystems, changes in the system of environmental supervision and measures to address some specific environmental problems. The report also incorporates the principle of "harmonious coexistence of man and nature" into the basic strategy of the country's development. It is planned that by 2035, "there would be some fundamental improvements of the environment and the goal of beautiful China would be realized".

The newly revised Environmental Protection Law of the People's Republic of China came into force on January 1, 2015. Although Russia's Environmental Law has some differences from China's Environmental Protection Law, they also have quite a lot in common: for example, both laws establish some basic rules and principles of environmental protection, appoint specific government agencies in charge of environmental management. However, many places in the "Environmental Protection Law of the People's Republic of China" are not as comprehensive as the Russian law. For example, unlike its Russian counterpart, the Chinese law provides no description of the basic system of environmental protection, instead some

[12] *China Environmental News reporter talks to Li Ping, Director of the Environmental Protection Department of Heilongjiang Province* (2010). Available at: http://www.hljdep.gov.cn/zmhd/zxft/2010/02/10271.html (Accessed 1 October 2018)

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parts dealing with this topic are scattered across different articles of the law. In addition, China's law does not mention ecological identification, international cooperation and other relevant topics. Therefore, China can learn from Russia's experience of environmental legislation.

Conclusion

In today's rapidly developing world, air, water and soil pollution is becoming one of the most serious global problems. Many countries are now trying to develop and implement various strategies in the sphere of environmental cooperation. China and Russia share a borderline of more than 4,000 kilometers and have common rivers, which means that there are some mutual expectations and responsibilities concerning nature conservation and sustainable development.

As regional powers, China and Russia have been committed to maintaining regional security and promoting regional development. Environmental protection is one of the key areas of cooperation between the two countries. Some significant results have already been achieved in the sphere of protection of cross-border water resources, creation of transboundary nature reserves and ensuring biodiversity conservation, for example, the two countries have established twelve transboundary protected areas. Various types of cooperation agreements at the national and local levels have been signed, cooperation institutions for information exchange and monitoring have been founded. Of course, there are still many problems that need to be addressed such as the lack of a unified information platform and supervision platform, relevant databases, protection of rare animal and plant species. The 2017 Year of Ecology in Russia provides China with some valuable lessons to learn from.

In recent years, the Chinese government has attached great importance to environmental protection. Under the guidance of Xi Jinping, China is putting a lot of effort into promotion of sustainable development methods, prevention and control of air, water and soil pollution. There are hopes that in the future, the cooperation between China and Russia will be carried out under the framework of the "Belt and Road" Initiative and the Eurasian Economic Union.

In summary, we believe that although the cooperation between China and Russia in the sphere of environmental protection is not as close as their economic cooperation, it has made certain progress in recent years. There is a growing awareness in both countries that this cooperation is mutually important.

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Cluster approach to organization of special economic zones in Russia and Kazakhstan

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ABSTRACT
The article aims to study the theoretical and empirical foundations of combining free economic zones with industrial clusters. The theoretical foundation is provided by the concept of a cumulative and circular process and the theory of "new economic geography". The empirical part deals with the creation of cluster-type economic zones in Russia and Kazakhstan. The symbiosis of special economic zones (SEZs) and clusters is expected to enhance export potential and act as a powerful catalyst for national innovative development. Establishment of clusters within the framework of the existing SEZs can bring to these zones highly efficient projects for manufacturing export-oriented products. Methodologically, the research relies on systemic and structural-functional approaches, the logical method and the method of formalization as well as on the comparative and grouping methods applied to analyze SEZs. The study also provides a general overview of the SEZs and clusters operating in Russia and Kazakhstan and indicates their main types and characteristics. The practical significance of this research is that its findings can be used to devise recommendations for improving economic performance of both countries, attracting new technologies and investments and addressing social and economic problems of the regions.

KEYWORDS
economic regulation, special economic zones, cluster approach, industrial cluster, Kazakhstan, Russia

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Кластерный подход к организации особых экономических зон в России и Казахстане

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АННОТАЦИЯ
Целью статьи является изучение теоретических и эмпирических основ объединения свободных экономических зон с промышленными кластерами. Теоретическая основа обеспечивается концепцией кумулятивного и кругового процесса и теорией «новой экономической географии». Эмпирическая часть посвящена созданию экономических зон кластерного типа в России и Казахстане. Ожидается, что симбиоз особых экономических зон (ОЭЗ) и кластеров усилит экспортный потенциал и станет мощным катализатором национального инновационного развития. Создание кластеров в рамках существующих ОЭЗ может принести в эти зоны высокоэффективные проекты по производству экспортно-ориентированной продукции. Методологически исследование опирается на системный и структурно-функциональный подходы, логический метод и метод формализации, а также на сравнительный и групповой методы, применяемые для анализа ОЭЗ. В исследовании также приводится общий обзор ОЭЗ и кластеров, фунционирующих в России и Казахстане, и указываются их основные типы и характеристики. Практическая значимость этого исследования заключается в том, что его результаты могут быть использованы для разработки рекомендаций по улучшению экономических показателей обеих стран, привлечению новых технологий и инвестиций и решению социальных и экономических проблем регионов.

КЛЮЧЕВЫЕ СЛОВА
экономическое регулирование, особые экономические зоны, кластерный подход, промышленный кластер, Казахстан, Россия

ДЛЯ ЦИТИРОВАНИЯ
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Introduction

The Russian Federation and the Republic of Kazakhstan are united by a common history, conditions of economic development, cultural traditions and geographical boundaries. Similarity of initial characteristics of the national socio-economic and political systems determines the commonality of the key tasks both countries have to address. One of the main priorities for both countries is diversification of economy, stimulation of innovations and attraction of investments. In his message to the Federal Assembly in 2018, Russian President Vladimir Putin pointed out that to ensure a further structural change of national economy and to enhance its competitiveness it is necessary to use the available "sources of growth" at a fundamentally different level. These include labor productivity, increased investment and development of non-commodity exports[1]. The message of President Nursultan Nazarbayev to the people of Kazakhstan emphasizes that the fourth industrial revolution requires profound technological, economic and social changes as well as new management tools[2].

Therefore, in both countries, there is a need for full support of regional development and cluster initiatives in the form of various legislative, administrative, managerial and financial-economic measures. In this respect, the key institutional link between these measures may become zones with special conditions for economic activity or special economic zones (SEZs). Such zones make it possible, on the one hand, to make the economy more open, guarantee economic security and stimulate economic growth on the regional level. On the other hand, it gives new impulses to territorial economic systems, activates development potential of territorial clusters and enables the government to launch new large-scale projects using positive effects of scale.

Taking into account the above-mentioned considerations, in this article we are going to compare the experience of creating and SEZs in Russia and Kazakhstan, including the peculiar characteristics of such zones and mechanisms of their operation.

We compared zones with special conditions of economic activity by applying the cluster approach and providing recommendations as to how adjust the priorities for SEZs in order to foster knowledge-intensive economy and to stimulate the development of high-tech industries and services.

Methodology

Most studies of the available international experience of SEZs and the possibilities of their use in Russia and Kazakhstan were conducted after 1990 [1–10]. The cluster approach, which has been actively developing since the 1990s, offers considerable opportunities of modernizing SEZs. The cluster theory was introduced and popularized by Nobel laureate Michael Porter, who identified such key features of clusters as territorial specialization, competition and cooperation [11].

Alfred Marshall laid the foundations of the geographical clustering theory of firms [12]. According to Marshall, the geographical proximity of firms ("industrial district") creates external effects ("benefits of agglomeration (or localization)"), which stem from the unification of the labor market, flow of knowledge, and specialization. Firms within Marshallian industrial districts gain advantages in the form of access to specialized human resources and skills, lower costs, knowledge transfer and increased productivity. Porter emphasizes the role of these advantages in increasing productivity and competitiveness of firms, regions and countries in their theory of industrial clusters. Porter puts the main emphasis on "competitiveness" (of firms, industries, regions and countries) in global economy. Openness of firms and industries to foreign competition is considered as a driving force for formation and development of the cluster. The concept of SEZs has much in common with Porter's concept of clusters.

Theoretical foundations of the cluster approach in organization of SEZs are described by D. Peter [13], M. Amiti, B. S. Javorcik [14], J. A. Mathews [15], and P. R. Krugman [16] (see Table 1).

The heterodox approach ignores the role of agglomeration savings, suggesting that free economic zones themselves provide a platform for attracting export-oriented foreign direct investment, creating a favorable investment climate. Therefore, there is no need to combine it with clusters.

SEZs are, in fact, geographically concentrated, state-supported agglomerations of internationally competitive enterprises. They have a number of advantages such as efficient infrastructure, favorable business environment, few regulatory restrictions and a minimum of bureaucracy. The role of SEZs in shaping the savings from agglomeration and its advantages is ignored in the existing literature largely due to the assumption that SEZs

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Table 1

Theoretical foundations of the cluster approach in organization of special economic zones

Approaches, concepts and theories	Description
Heterodox approach (M. Amiti, B. S. Javorcik)	The heterodox approach ignores the role of agglomeration savings, suggesting that the free economic zones provide a platform for attracting export-oriented foreign direct investment, thus creating favorable investment climate. Therefore, there is no need to combine free economic zones with clusters
Concept of a cumulative and circular process (J. A. Mathews)	Internationally competitive clusters in host countries act as a factor in attracting foreign direct investment, which triggers the process of "circular and cumulative causality" or a chain reaction. Clusters begin to expand, trying to settle near SEZ, the latter serving as growth poles for regional development
Theory of "New Economic Geography" (D. Peter, P. R. Krugman)	Concentration of production in one region can lead to even greater concentration of production in this region due to international trade. Thus, it can be assumed that SEZs, which are agglomerations of trade-oriented, highly competitive firms, have better prospects for attracting investment to the rest of the host country than inward-oriented clusters. Therefore, they can act as a "big push" by the government or growth poles. Trade benefits are higher when agglomerative savings are applied to goods, since concentration of world production in one place provides substantial benefits

Source: [13–16]

are commercial enclaves with small internal connections, where cheap labor is used to implement poor-quality production. But global experience shows that such zones are evolving and their characteristics change over time. They are getting bigger, and now zones are better integrated into economy, produce more technological and capital-intensive products. In this regard, it is necessary to move to a new theoretical paradigm based on clustering and agglomeration savings in order to capture the potential benefits of SEZs. This new approach, drawing from the cluster theory, will expand our understanding of their benefits and their underlying mechanisms [17].

The cluster approach is, first of all, a new management technology which enhances competitiveness of a particular region or industry and the state as a whole. The cluster approach is a natural stage in economic development and its widespread distribution can be considered as a main feature of all highly developed economies.

As international practice shows, free economic zones can be a part of a cluster. In turn, interacting clusters may be a part of special economic zones. A similar merging process can serve as the beginning of formation of a new type of zones – cluster zones. China uses the cluster approach to create zones (open cities, "Chinese titanium valley") aimed at developing manufacturing industry. The UAE achieved a positive effect by combining territorial clusters into zones and, conversely, dividing SEZs into clusters. They established 15 SEZs on the basis of seaports and airports and thus managed to ensure an increase in export and import of goods and services, an increase in foreign direct investment, which led to intensification of international economic relations [15; 18–27].

Today, clusters are recognized as one of the most important tools of enhancing innovative industrial development, competitiveness and efficiency of national economy.

The scheme for assessing the potential of clustering in SEZs may be as follows: first, it is necessary to identify the companies and firms that manufacture goods and provide services for export, taking into consideration their location and the share of exported goods in their production. Second, we should identify large firms which produce or are able to organize production of competitive goods. Analysis of the value chain reveals the firms that provide services and/or that are engaged in supplying semi-finished products. Moreover, it is important to look at the horizontal and vertical chains connecting various firms. Third, we need to identify organizations that can provide information, R&D and education services and organizations that can provide financial support to potential cluster members. Finally, we should consider those governmental organizations that can facilitate the development of the cluster in question by attracting companies of all the above-mentioned types to the SEZ.

Possibilities of integrating SEZs and clusters in Russia and Kazakhstan

Today, the governments of Russia and Kazakhstan are searching for new tools of economic development that would allow these countries to ensure a competitive advantage in domestic and

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global markets. One of such tools is the integration of SEZs and clusters.

In Russia, creation and development of clusters should follow the guidelines for implementation of the cluster policy in the constituent entities of the Russian Federation, developed by the Ministry of Economic Development of the Russian Federation dated December 26, 2008 No. 20615-ak / d19.

Table 2 shows the mechanism for combining clusters and SEZs in Russia.

One of the most successful SEZs of the industrial production type is "Alabuga" located on the territory of Tatarstan. The main factor of its efficiency is the interest of regional officials.

Special attention should be paid to "Titanium Valley" – an IPT special economic zone in Sverdlovsk region. Its success is determined by the fact that titanium production has no competitors in Russia and this zone offers the most attractive conditions for taxing profits and customs privileges.

SEZ "Kaluga" in Kaluga region is a highly developed zone due to the competent management system and the fact that its residents produce consumer goods, including automobiles.

As for tourist and recreational areas, one of the most effective SEZs is 'Birch Katun' located in Altai. Its effectiveness is largely due to the experimental tourism approach.

To creating a SEZ of the cluster type, it is important that the cluster SEZ should be divided into several cluster formations in order to develop the neighboring regions and territories and it is also necessary to distribute benefits within the SEZ according to differentiated (individual) approach, to stimulate various activities depending on their priority level [28].

In Kazakhstan, the idea of cluster development was identified as the main method of diversifying the economy. For Kazakhstan, the cluster approach is a fairly new tool, which has recently started to play an increasingly important role in the country's innovative development. Mechanisms for cluster stimulation and control are being developed at the state level. In general, it should be noted that cluster initiative is being implemented in accordance with the President's Message to the People of Kazakhstan – "Towards Competitive Kazakhstan, Competitive Economy, Competitive Nation" of March 19th, 2004[3]. The main objectives of the cluster initiative are to create the necessary conditions to maximize the country's competitive advantages in order to develop the non-commodity sector of economy by involving private business structures and improving the performance of enterprises.

In March 2005, Kazakhstan launched the project "Competitiveness Assessment of the Existing and Potential Sectors of Kazakhstani Economy and Elaboration of Recommendations for their Development". This project received the status of a Kazakhstani cluster initiative. This project was implemented by the Center for Marketing and Analytical Research in cooperation with JE Austin, an American consulting company.

Table 2

Clusters and SEZs in Russian regions

Region	SEZ*	Cluster**
Kaluga	IPT "Kaluga"	Pharmaceuticals, biotechnology, biomedicine
Republic of Buryatia Altai region	TRT "Birch Katun"	Biopharmaceutical cluster
Tomsk	TIT "Tomsk"	Complex processing of coal and industrial waste
Territory of Zelenograd, administrative district of Moscow	TIT " Zelenograd"	Micro- and nanoelectronic products; electronic devices and equipment; integrated technical IT systems based on electronic devices and devices
Sverdlovsk	IPT "Titanium Valley"	Manufacturing of titanium products; production of components and equipment for metallurgy; engineering; aircraft industry; medical equipment and supplies; oil and gas equipment
Republic of Tatarstan	IPT "Alabuga"	Automotive industry; automotive parts; instrument-making; petrochemistry; composite and building materials; construction materials; consumer goods
St. Petersburg	TIT "St. Petersburg"	IT technologies and telecommunications; pharmaceuticals and medical technologies; instrument making; energy efficiency

Source: * *Russia. Special economic zones. JSC "Special Economic Zones".* Retrieved from: http://www.eng.russez.ru/ (Accessed 14 February 2019); ** *Map of clusters in Russia. Russian Cluster Observatory Institute for Statistical Studies and Economics of Knowledge.* Retrieved from: http://map. cluster.hse.ru/about/ (Accessed 14 February 2019)

Note: "IPT" stands for the industrial production type of SEZs; "TRT", tourist and recreational type; "TIT", technical-innovative type.

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At the first stage, the selection was based on such indicators as the share in GDP, GDP growth and export in comparison with the growth of similar indicators in the country, employment rate and potential market attractiveness. The selection segments were those sectors in which Kazakhstan had competitive advantages: these sectors belong to attractive markets and their development is expected to lead to diversification in the short or medium term. Thus, 24 sub-sectors were identified.

At the second stage, markets (global, regional, and national) were analyzed and the potential of industries was assessed. Moreover, forecasts concerning the estimated supply and demand for the next 5–10 years were made. In addition, the analysis focused on structures of the already existing clusters and their cost-efficiency. As a result, 11 clusters were selected[1].

The final selection stage dealt with the assessment of the possibility of clustering and its outcomes, according to such parameters as leadership, structure, and readiness for work.

This multi-stage selection process resulted in the choice of seven "pilot" clusters (Table 3).

Table 3

"Pilot" clusters in Kazakhstan

Sector	Cluster	Region
Basic	metallurgical	Karaganda region
	petrochemical	Mangistau region
Market-oriented	textile industry	Pavlodar region
	production of building materials	Atyrau region
	transport logistics	Zhambyl Region
Innovative	tourist	Southern Kazakhstan
	intellectual and innovative	Almaty region, Astana

Within the framework of the "SP FIID" program and the Strategy "Kazakhstan – 2050", clusters are planned to be created in the already existing SEZS (Table 4).

The following SEZs in Kazakhstan can be used as a basis for creating high-tech manufacturing clusters (Table 5).

Table 4

SEZ and clusters in Kazakhstan and their specialization

SEZ	Specialization	Timeframes	Cluster
Saryarka	metallurgy, metalworking	2011–2036	metallurgical
Seaport Aktau	metalworking, instrument engineering	2002–2028	metallurgical
Pavlodar	petrochemistry	2011–2036	petrochemical
National Industrial Petrochemical Technopark	petrochemistry	2007–2032	petrochemical
Chemical Park Taraz	chemistry	2012–2037	chemical
Ontustic	textile	2005–2030	textile industry
Astana-New City	construction, industry	2001–2027	production of building materials
Horgos – Eastern Gates	trade, logistics	2011–2035	transport logistics
Burabai	tourism	2008–2017	tourist
Technology Innovation Park	IT-innovations, instrument engineering	2003–2028	intellectual and innovative

Source: Special economic zones in the Republic of Kazakhstan. Official site of the National Agency for Export and Investment "KAZNEX INVEST". Retrieved from: http://www.kaznexinvest.kz (Accessed 25 April 2019)

Table 5

Potential clusters of high-tech industries based on SEZs

Cluster specialization	Territory	Integrator
Information and communication technologies, advanced technologies ("green" technologies, smart industry, smart environment, e-commerce and media)	SEZ "Technology Innovation Park"	JSC TIT Management Company, National Agency for Technological Development
Production of new materials, advanced technologies (energy-saving, 3D printing, biotechnology) and design	AEO "Nazarbayev University", SEZ "Astana-New City"	Nazarbayev Research and Innovation System (NURIS)
Alternative energy	SEZ "Astana-New City"	JSC "Samruk Energo"
Metallurgy	SEZ "Saryarka"	AO "Tau Ken Samruk"
Mechanical Engineering	SEZ "Saryarka", SEZ "Seaport Aktau"	JSC "Kazakhstan Engineering"
Chemistry	SEZ "Taraz", SEZ "Pavlodar"	LLP "United Chemical Company"

Source: Decree of the Government of the Republic of Kazakhstan of October 11, 2013 No. 1092 "On the Approval of the Concept for the Formation of National Clusters of the Republic of Kazakhstan until 2020"

[1] *Special economic zones in the Republic of Kazakhstan. Official site of the National Agency for Export and Investment "KAZNEX INVEST".* Retrieved from: http://www.kaznexinvest.kz (Accessed 25 April 2019)

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The use of SEZs is expected to provide favorable opportunities for the development of knowledge-based industrial clusters. For cluster development, it is necessary to organize a complete production cycle of high-tech finished products in strategically important sectors of the national economy with high added value. The pre-requisite for creating a high-tech cluster is to combine advanced research and hi-tech manufacturing. Another pre-requisite is the development of detailed "road maps" (or implementation schedules) for launching cluster projects.

Conclusion

A special economic zone with a cluster form of organization is a group of economic entities united by priority logistical links. Viewed from the governmental perspective, it is a self-contained autonomous unit in which the necessary range of production, infrastructure and social functions are performed.

Application of the cluster approach allows the government to stimulate the activity of business entities, improve the investment climate and business environment in the region, develop economic, social, information and integration systems and thus intensify the development of entrepreneurship, attract investment and enhance economic growth. For example, in Kazakhstan, "pilot" clusters were created in the following industries: metallurgy (Central Kazakhstan); oil and gas engineering (Western Kazakhstan); textile production (South Kazakhstan); food industry (agricultural areas); production of building materials (Almaty region); tourism (Almaty); and transport logistics (transport corridor between China and Europe). At the same time, many Kazakhstani scientists believe that the country has a potential to create clusters in other sectors of economy such as oil and gas industry, biotechnology, pharmaceuticals, chemical industry, mechanical engineering, and IT.

As for Russia, in order to improve competitiveness of different regions and their production, the following options could be considered, involving creation of SEZs and clusters and their subsequent integration:

1. SEZ "Lotos" in Astrakhan region and a new cluster for construction of modern offshore facilities (ships and platforms, underwater infrastructure designs), special equipment for oil and gas fields development on the Arctic shelf, including underwater robotic complexes and special equipment.

2. Cluster of innovative technologies ZATO Zheleznogorsk, Krasnoyarsk and a new SEZ in the field of space and nuclear technologies. This will increase reliability and quality of GLONASS spacecraft, make it possible to develop new types of fuel for the power unit, and create new ways to store irradiated nuclear fuel and tools for its processing.

3. Cluster Technopolis "New Star" and a SEZ in the field of rocket and aircraft engine engineering to consolidate Russia's leading position in the aircraft market.

In the future, such "symbioses" of the already existing or evolving SEZs and clusters will enhance the growth of the innovation sector of economy and stimulate exports of goods and services produced within this sector. Moreover, such projects will lead to an increase in the number of small and medium enterprises; ensure the growth of direct domestic and foreign investment; increase the level of labor productivity due to specialization and outsourcing of non-core activities; raise the level of employment by attracting and forming new companies in related and supporting industries. The cluster approach activates socio-economic development of the regions where clusters are based and boosts the territory's competitiveness.

When considering different options for SEZ-cluster integration, we should keep in mind that we cannot afford to make inefficient investment in the current economic situation. Projects aimed at invention and introduction of new types of goods and services should be encouraged to create a temporary "monopoly of production" on the world market.

Today, two groups of industries can become points of growth: those that are able to compete on the domestic market and have certain export opportunities (automotive, engineering and special shipbuilding industries) and those that are able to compete on international markets such as aerospace, nuclear energy and isotope production, instrument engineering, software development.

The proposed SEZ-cluster integration mechanism should become a hothouse for the development of knowledge-based industries. Such mechanism will make it possible to manufacture products that are competitive on world markets, primarily in the sectors strategically important for Russia and Kazakhstan. The governments of Kazakhstan and Russia should consider creating interstate clusters, which can be implemented within the framework of the Customs Union.

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Methodology for comprehensive assessment of regional innovative development

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ABSTRACT
Innovative development of territories is strategically important for the prosperity of any country. This article aims at describing original methodology for comprehensive assessment of innovative development of Russian regions. The proposed model takes into account specific features of innovative activity of regions and identifies growth potential and resources of territories, taking into account not only the innovation environment, but also areas of innovative activity. The study relies on the statistical data provided by the Central Statistical Database and the Unified Interdepartmental Information and Statistical System. In the course of processing and analyzing data, the index method, the multidimensional average method, factor-index analysis and other statistical data processing methods are used. The research involves ranking Russian regions according to their levels of innovative development and further dividing them into groups of powerful, strong, medium and weak innovators. We also analyzed the dynamics of innovation in the regions by looking at the changes in their ranking positions. The research findings brought to light the uneven development of Russian regions. The proposed assessment toolkit can be further used for drawing individual profiles for regions and formulating recommendations and guidelines for these regions' development by taking into consideration their strengths and weaknesses. The results of this study have theoretical and practical significance and can be used as a tool for management of innovative activities both at the level of individual territories and at the national level.

KEYWORDS
innovative climate, innovative potential, innovation, regional development, Russian regions

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Практические аспекты оценки и анализа инновационного развития регионов

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АННОТАЦИЯ
Инновационное развитие территорий является стратегически важным для процветания любой страны. Целью данной статьи является описание оригинальной методики комплексной оценки инновационного развития российских регионов. Предложенная модель учитывает особенности инновационной активности регионов и определяет потенциал роста и ресурсы территорий с учетом не только инновационной среды, но и направлений инновационной деятельности. Исследование опирается на статистические данные, предоставленные Центральной статистической базой данных и Единой межведомственной информационно-статистической системой. В процессе обработки и анализа данных используются индексный метод, метод многомерного среднего, факторный индексный анализ и другие статистические методы обработки данных. Исследование включает в себя ранжирование российских регионов по уровням инновационного развития и дальнейшее разделение их на группы наиболее сильных, сильных, средних и слабых новаторов. Мы также проанализировали динамику инноваций в регионах, посмотрев на изменения их рейтинговых позиций. Результаты исследования выявили неравномерность развития российских регионов. Предлагаемый инструментарий оценки может быть далее использован для составления отдельных профилей для регионов и разработки рекомендаций и руководящих принципов для развития этих регионов с учетом их сильных и слабых сторон. Результаты данного исследования имеют теоретическое и практическое значение и могут быть использованы в качестве инструмента управления инновационной деятельностью как на уровне отдельных территорий, так и на национальном уровне.

КЛЮЧЕВЫЕ СЛОВА
инновационный климат, инновационный потенциал, инновации, региональное развитие, российские регионы

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Introduction

Innovation is an important indicator of regional development and development of the country as a whole. Modernization has a significant impact on the country's economic stability and competitiveness on the international arena.

In our study, innovative development is understood as the process of continuous development of science, technology, methods of production, technological processes as well as the creation of conditions to stimulate innovation[1]. Innovative development is a complex process which has two main objectives: to realize innovative projects (sustainable innovative activity) and to develop innovative potential. Innovative activity comprises a complex system of interconnected elements and there is a perceived lack of comprehensive methodologies for assessing innovative activity since the vast majority of the existing tools focus only on individual aspects. Therefore, our research is aimed at designing a tool for integrated assessment and analysis of innovative development in Russian regions by taking into account the shortcomings of the existing assessment methods.

Review of theoretical and methodological approaches to assessment of innovative development

In Russia, methods for assessing innovative potential, innovative activity and the state of innovative environment are developed by such researchers as L. V. Shabaltina [1], S. A. Novikov [2], S. E. Tikhonova [3], T. N. Kosheleva [4], I. V. Shlyakht [5], Yu. P. Anisimov [6], E. A. Lapteva [7], and by various associations and research teams such as the Russian Research Institute of Economics, Politics and Law in the scientific and technical sphere[2]; Higher School of Economics and Management[3]; Center for Research and Statistics of the Russian Federation; Association of Innovative Regions of Russia and the Ministry of Economic Development[4]; National Association of Innovation and Information Technology[5]; and the Institute of Innovative Economics of the Financial University under the Government of the Russian Federation[6].

In our previous studies, we systematized and classified the approaches to assessment of innovative development proposed by Russian researchers [8]. We found that there is currently no agreement among Russian researchers as to how define different categories of innovative development and assess them. The main drawback of these assessment methodologies is that they use a large number of qualitative indicators and, therefore, expert and score assessments (for a more detailed analysis of these approaches see [9]).

International studies are aimed at assessing innovative development of countries (world economies) and individual territories (states or regions). To assess innovation, these studies use specialized competitiveness indices developed by the World Economic Forum (see Table 1).

The above-described indices are used by rankings of world economies and innovation territories. Our analysis has shown, however, that foreign indices are either not applicable for Russia (complex and specialized indices) or require substantial adaptation (specialized indices of innovative development). Thus, while the methodological toolkit proposed by Russian researchers is based on the conceptual apparatus and the interrelationship between the main innovative development categories, in international methodologies, assessment of innovative development of territories is mainly based on the results of innovation implementation and the effects of their use in related areas and industries.

Our research is aimed at developing a methodology for integrated assessment of regional innovative development, which will allow us to take into account the interrelation between the main categories of the innovation environment [8] and the internal and external conditions for innovation [11; 12]. Moreover, such methodology should enable us to assess the impact of

[1] *Russian Federation Government Decree of 08.12.2011 N 2227-r "On approval of the Strategy of Innovative Development of the Russian Federation for the period till 2020"* (2017). Retrieved from: http://innovation.gov.ru/ru/node/5320 (Accessed 10 August 2018)

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regional innovation on the country's overall economic development. This tool can be also used for designing strategies of regional innovative development.

Methodology for assessing regional innovative development

The point of departure for our study is the assumption that innovative development is a complex and continuous process of improving the conditions of innovative environment [13–15]. Therefore, we need to design an assessment model that will allow us to take into account a complex system of factors. Our methodology is based on a qualitatively new approach, involving the assessment of the innovation component in certain categories (innovative climate, innovative potential, innovative activity) in the context of the main areas of innovation activity.

We identified the following areas of innovation:

– socio-economic (social and economic indicators of the region's development);

– production and technology;

– investment (innovation financing, funding of reconstruction and modernization);

– R&D (development of science and strategies for innovative development in Russian regions);

– human resources for R&D;

– R&D funding.

Table 1

International studies of innovative development

1. Complex competitiveness indices			
Growth Competitiveness Index, GCI (Macroeconomic Competitiveness Index)	Business Competitiveness Index, BCI (Microeconomic Competitiveness Index)	Technology Achievement Index, TAI	Networked Readiness Index, NRI
The aggregated competitiveness index consists of 113 variables combined into 12 blocks, determining the national competitiveness of the countries that are at different levels of economic development. 2/3 of the variables are the result of the global survey of business leaders, 1/3 variables are taken from publicly available sources (statistics and research results of international organizations)[1]		To calculate the integral index, indicators divided into indices that have the same weight are used: the technology creation index, the distribution index of modern innovations, the distribution index of old innovations, the human ability index. There is no specific set of indicators, because it is impossible to cover the whole range of technologies	The index characterizes the close correlation between economic well-being and the development of innovation. It is calculated by using 53 parameters divided into 3 main groups: the presence of conditions, readiness for use and the level of use of ICT. The basis of calculation is the statistical data of the United Nations, the International Telecommunication Union, the World Bank and surveys of top executives[2]
2. Specialized competitiveness indices			
Innovation Capacity Index			
It characterizes the innovation infrastructure (ability of the national economy to develop and commercialize the flow of new technologies). To calculate this index, it is necessary to select indicators, determine the scores and calculate the integral indicator [10]			
3. Specialized competitiveness indices (regional level)			
Regional Innovation Scoreboard, RIS (European Union)[3]		Portfolio Innovation Index, PII (USA)[5]	
Index evaluates innovative activity by 11 indicators divided into 3 blocks: factors of innovative development, data on performance of companies, effectiveness of innovative activities of companies[4]		The composite index of innovation development includes 20–30 indicators divided into 4 blocks with different weight factors: human capital (30%), economic dynamics (30%), productivity and employment (30%), and well-being (10%)[6]	
Indices combine resources and results of innovative activity			

Source:

[1] *Analytical portal by the main directions and humanitarian technologies markets. The Global Competitiveness Index*. Retrieved from: https://gtmarket.ru/ratings/global-competitiveness-index/info (Accessed 27 January 2019)

[2] *Analytical portal by the main directions and humanitarian technologies markets. Networked Readiness Index*. Retrieved from: https://gtmarket.ru/ratings/networked-readiness-index/networked-readiness-index-info (Accessed 27 January 2019)

[3] The Regional Innovation Scoreboard. (2018). Retrieved from: https://ec.europa.eu/growth/industry/innovation/facts-figures/regional_en (Accessed 27 January 2019)

[4] *European Innovation Scoreboard*. (2018). European Commission. Retrieved from: http://ec.europa.eu/growth/industry/ innovation/facts-figures/scoreboa rds_en (Accessed 27 January 2019)

[5] *Portfolio innovation index*. (2018). Source or supplier information. Retrieved from: http://www.statsamerica.org/innovation/reports.html (Accessed 27 January 2019)

[6] *Innovation Index in American regions*. (2018). U. S. Economic Development Administration. Retrieved from: http://www.statsamerica.org/innovation/innovation_index/methodology.html (Accessed 27 January 2019)

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Our model for the assessment of regional innovative development is shown in Figure 1 and reflects the matrix structure of the main innovation categories used for assessment [9]:

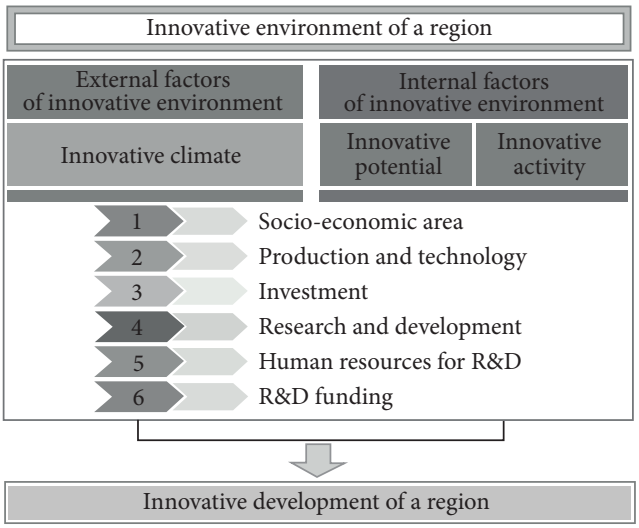

Figure 1. *Matrix structure of the innovative development assessment model [9]*

Assessment results are represented in the form of a ranking. For our model, we combined two methodologies: the methodology proposed by the Higher School of Economics and Management, which evaluates indicators according to areas of innovation implementation, and the methodology of the Association of Innovative Regions of Russia and the Ministry of Economic Development, which evaluates indicators according to innovation categories. The algorithm for calculating the integral index of innovative development is a complex multi-step process.

The stages of assessment reflect the analysis procedure which involves selected indicators and calculation of the integral index used to rank regions according to their level of innovative development.

These steps are as follows:

1. Data normalization

We have managed to achieve homogeneity and comparability of indicators with the help of transition from absolute to weighted values. We propose to normalize the indicators for a mini-max formula (1). This method of rationing the source data is optimal, since it allows to fill a range of values tihtly and evenly. The range of values is, determined by the empirical magnitude of the data from 0 to 1.

$$\tilde{X}_{ij} = \frac{x_{ij} - x_{\min i}}{x_{\max i} - x_{\min i}}, \quad (1)$$

where $\tilde{X}_{ij}$ is the transformed value of the i^{th} indicator in the j^{th} region; x_{ij} is the initial value of the i^{th} indicator in the j^{th} region; $x_{\min i}$ is the minimum value of the i^{th} indicator among Russian regions; $x_{\max i}$ is the maximum value of the i^{th} indicator among Russian regions.

2. Significance of factors and calculation of region-specific indices

In order to assess innovative development of regions, we first need to decide whether our methodology should take into account certain factors or not. The role of these factors can be determined by using expert assessments. To calculate partial indices, it is proposed to use the multidimensional average formula (2). This is a generalized characteristic of a certain phenomenon built on the basis of converging its individual characteristics into a single indicator, which is calculated from the interrelation of attribute values for a unit of aggregate to average values of these attributes.

$$PIs = \frac{\sum_{i=1}^{m} \frac{\tilde{X}_{ij}}{\tilde{X}_{iaver}}}{m}, \quad (2)$$

where PIs is the region-specific index of the region by quantity by the block of indicators (area of implementation // innovation category); $i = 1 \ldots m$ is reduced partial indicators; m is the number of reducible indicators; $\tilde{X}_{ij}$ is the numerical value of the ith indicator for the jth region in each block of indicators (area of implementation // innovation category); $\tilde{X}_{iaver}$ is the average value of the i^{th} indicator among all regions in the block of indicators.

3. Calculation of the Integral Index

We applied three-factor and six-factor models of factor analysis to calculate the final indices for the areas of implementation and innovation categories and to calculate the integral index of innovative development.

Due to the fact that the assessment model has a matrix structure (Figure 1), we need to solve the problem of classifying the indicators which must simultaneously belong to one of the six implementation areas and characterize one of the three categories of innovation environment. Thus, innovation climate characterizes external conditions of the region's environment, that is, how favourable are the existing scientific, technological, industrial and socio-economic conditions for innovation in the region [8].

In its turn, innovative potential characterizes the conditions and reflects the dynamics of in-

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ternal factors of the region's innovative environment – a set of financial, human, scientific and technical, organizational and managerial, informational, methodological and marketing resources that make the region capable of fulfilling a set of innovative tasks [8].

Innovative activity characterizes effectiveness of innovation. The level of innovative activity is an indicator of economic development.

The assessment model uses 54 indicators, which are divided into 3 innovative categories and 6 areas of innovative activity, thus forming 18 region-specific indices. Indicators are taken from such sections of the state statistics as population; labor market, employment and wages; science, innovation and information society; macroeconomic indicators. The proposed approach allows us to calculate not only the integral index, but also to determine development factors, growth drivers, and bottlenecks of innovation activity in regions and specific territories.

For example, in the socio-economic block, the indicators that form the region-specific index by climate category include the index of physical volume of GRP; production and technology includes the coefficient of renewal of fixed assets; the investment activity block, the volume of investment in fixed capital per capita and the growth rate of investment in fixed assets in GRP; R&D, the coefficient of inventive activity; the block of human resources for R&D, the proportion of doctoral candidates and candidates in the total economically active population and the growth rate of researchers' average salary; and, finally, for R&D funding, we used such indicators as the share of domestic expenses on R&D in the expenses of the consolidated budgets of Russian regions and the growth rate of organizations' expenses on technological innovation.

Table 2

Ranking of Russian regions according to the value of the integral index of innovative development for 2014–2016

Regional ranking by the value of the ID index for 2014		Regional ranking by the value of the ID index for 2015		Regional ranking by the value of the ID index for 2016	
No.	Region	No.	Region	No.	Region
1	Moscow	1	Moscow	1	Moscow
2	St. Petersburg	2	Moscow region	2	St. Petersburg
3	Republic of Tatarstan	3	St. Petersburg	3	Moscow region
4	Moscow region	4	Tomsk region	4	Nizhny Novgorod region
5	Nizhny Novgorod region	5	Krasnoyarsk region	5	Krasnoyarsk region
6	Kaluga region	6	Nizhny Novgorod region	6	Tomsk region
7	Perm region	7	Republic of Tatarstan	7	Republic of Tatarstan
8	Tomsk region	8	Perm region	8	Tyumen region without autonomous districts
9	Novosibirsk region	9	Sverdlovsk region	9	Tula region
10	Yaroslavl region	10	Voronezh region	10	Ulyanovsk region
	…		…		…
20	Lipetsk region	20	Novosibirsk region	20	Belgorod region
21	Samara Region	21	Ulyanovsk region	21	Rostov region
22	Republic of Bashkortostan	22	Chelyabinsk region	22	Chelyabinsk region
23	Volgograd region	23	Lipetsk region	23	Lipetsk region
24	Belgorod region	24	Krasnodar region	24	Leningrad region
25	Chelyabinsk region	25	Orenburg region	25	Khabarovsk region
	…		…		…
75	Kostroma region	75	Tyva Republic	75	Chechen Republic
76	Karachay-Cherkess Republic	76	Mari El Republic	76	Republic of Khakassia
77	Amur region	77	Chechen Republic	77	Sevastopol
78	Sevastopol	78	Republic of Khakassia	78	Jewish Autonomous Region
79	Jewish Autonomous Region	79	Sevastopol	79	Karachay-Cherkess Republic
80	Nenets Autonomous Okrug	80	Jewish Autonomous Region	80	Nenets Autonomous Okrug
81	Republic of Ingushetia	81	Nenets Autonomous Okrug	81	Pskov region
82	Republic of Crimea	82	Republic of Ingushetia	82	Republic of Ingushetia
83	Tyva Republic	83	Republic of Crimea	83	Sakhalin region
84	Chukotka Autonomous Okrug	84	Chukotka Autonomous Okrug	84	Chukotka Autonomous Okrug
85	Yamalo-Nenets Autonomous Okrug	85	Yamalo-Nenets Autonomous Okrug	85	Yamalo-Nenets Autonomous Okrug

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Table 3

Groups of regions by value of the integral index of ID for 2014–2016

Group	Group name	Distribution of the regions				
		Value of the integral index of ID	Regions' actual value of the integral index of ID	Number of regions in groups		
				2014	2015	2016
I	"Alpha regions" or powerful innovators	> 100	122.70–44,800.07	2	3	3
II	"Beta regions" or strong innovators	10–100	13.14–96.80	3	5	4
III	"Gamma regions" or medium innovators	1–10	1.07–9.94	16	9	12
IV	"Delta regions" or weak innovators	0–1	0.00–0.82	64	68	66

The integral index of innovative development, calculated with the help of the above-described indicators, allows us to assess continuous development of economy, science, technology, production as well as the development of conditions necessary for innovation. Innovative development is a complex process which has two main objectives: realization of innovation projects (ensuring sustainable innovative activity) and development of innovative potential in the existing innovative environment [8].

Results

The assessment method we propose is a multifunctional tool that has several *levels of possible practical results*.

At *the first level*, this method allows us to form a ranking of Russian regions by the value of the integral index of innovative development (ID index) (see Table 2).

At *the second level*, the regions are divided into four groups according to the value of the integral index of innovative development (ID) (see Table 3).

Regions of the first group – "alfa regions" – have the highest value of the integral index of innovative development: more than 100. This group of powerful innovators includes regions with the highest level of innovation development of the territory.

Regions of the second group – "beta regions" – have the value of the index from 10 to 100 and are called strong innovators.

Regions of the third group – "gamma regions" – have the value of the index from 1 to 10 and are called medium innovators.

Regions of the fourth group – "delta regions" – are weak innovators with an index value from 0 to 1.

In addition, at this level, our methodology allows us to analyze the distribution of regions by the value of the integral index of ID and to analyze the structural shifts in the distribution of regions (see Figure 2).

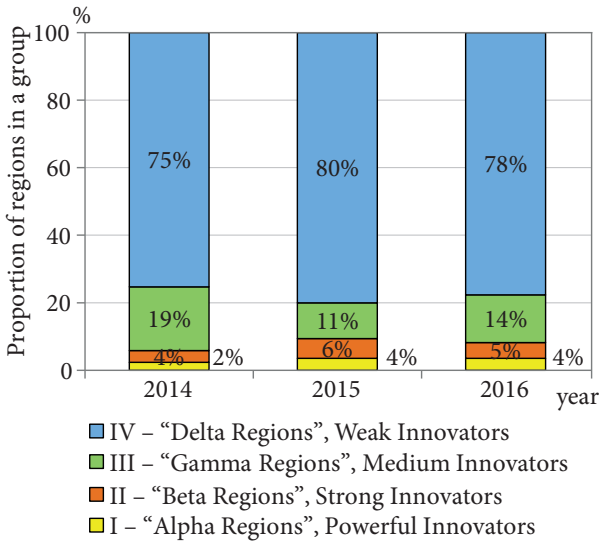

Figure 2. *Groups of regions according to the integral index of ID*

We found that Moscow, the city of federal significance, ranked first and, accordingly, was a member of the alfa-group with the maximum value of the calculated index. The leading positions in 2014 were also held by St. Petersburg; in 2015 and 2016 the group of powerful innovators also included Moscow region.

The second group, "beta regions", in 2014, 2015 and 2016 included 3, 5 and 4 regions respectively such as Nizhny Novgorod region and Tatarstan. Tomsk region, Krasnoyarsk region, Perm region were listed in this group in 2015 and 2016.

As part of the third group, "gamma regions", in 2014 there were 19% of regions; in 2015, 11%; and in 2016, 14%. Kaluga, Sverdlovsk and Voronezh regions as well as Perm region ranked among medium innovators.

The fourth group, "delta regions", with the lowest value of the index were the most numerous – 75% (64 regions), 80% (68) and 78% (66) of all regions in 2014, 2015 and 2016, respectively. It

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Table 4

Structural shifts of regions by value of the integral index of ID

		I Group		II Group		III Group		IV Group		ID per year
		n	average ID	*n*	average ID	*n*	average ID	*n*	average ID	
Comparison 2014 → 2015	2014	2	2,554.83	3	91.95	16	3.92	64	0.08	64.16
	2015	3	15,027.38	5	27.61	9	3.37	68	0.09	532.43
	Remained in the same group	2		2		5		60		Number of regions
	Moved up	1		3		4		–		
	Moved down	-		0		0		8		
Comparison 2015 → 2016	2015	3	15,027.38	5	27.61	9	3.37	68	0.09	532.43
	2016	3	3,343.62	4	45.15	12	3.84	66	0.06	120.73
	Remained in the same group	3		4		4		61		Number of regions
	Moved up	0		0		7		–		
	Moved down	–		0		1		5		

is possible to explain such a high proportion of regions in the group (caused by the decrease in the calculated indicators) by the economic crisis of 2014, its causes and consequences. Stagnation, slowdown, and then sharp weakening of the national currency due to the significant decline in oil prices and economic sanctions led to a rise in inflation, a decline in real incomes of the population and a change in consumer behavior. These factors affected all aspects of regional performance including innovative development, which is illustrated by the changes in regions' ranking positions.

The analysis of the structural shifts focuses on regions' positions in the rankings. For example, sometimes regions remained within one group, moved to an upper group or to a lower group (see Table 4).

Figure 3 below illustrates changes in the number of regions in groups for 2014–2016.

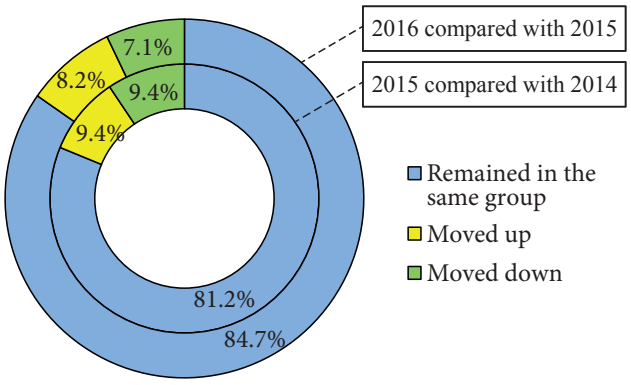

Figure 3. *Changes in the number of regions in groups for 2014–2016*

Thus, 81.2% of the regions (69) remained in the same groups in 2015 in comparison with 2014. Eight regions moved up (9.4%) and Moscow region entered the group of "alfa regions"; three regions joined the group of "beta regions" – Tomsk, Perm and Krasnoyarsk regions; and four regions – Penza, Kaliningrad, Krasnodar and Magadan regions – moved up and joined the group of "gamma regions"; eight regions (9.4%) moved down the ranking – Novosibirsk, Yaroslavl, Ulyanovsk, Sakhalin, Vladimir, Tyumen, Lipetsk regions and the Republic of Komi. All of them joined the group of weak innovators with low values of the innovative development index.

In 2016 compared to 2015, 84.7% of the regions (72) remained in the same groups. Seven regions moved to the group of "gamma regions" and 8.2% of the regions improved their position. Thus, in 2016, among the regions classified as medium innovators, Novosibirsk, Yaroslavl, Ulyanovsk, Tyumen, Kursk, Tver regions and the Republic of Sakha (Yakutia) retained their positions. Six regions (or 7.1%) moved down. Perm region moved from the group of strong innovators to medium ones. Five regions entered the group of weak innovators: Rostov, Samara, Magadan, Penza and Kaliningrad regions.

Division of regions into groups according to the value of the index of ID can be represented in the form of fields or matrices. We compiled distribution fields of the four groups of regions for the period 2014–2016. Thus, in the study we received 12 distribution fields, reflecting the full range of values of the index. The distribution fields of regions by groups for the whole period under review look similar to the field of group I distribution in 2016. This field is presented in Figure 4 (the first group of regions) as an example. The regional distribution matrixes compiled by the fields complete this level of results.

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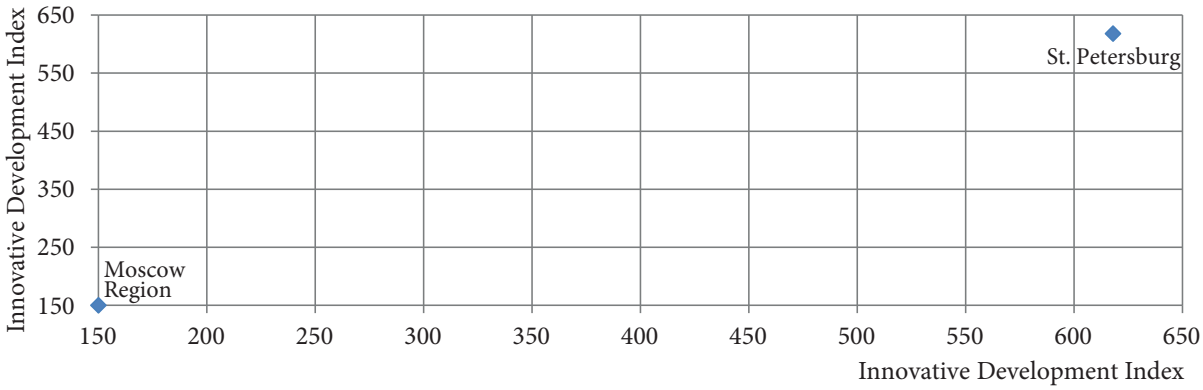

Figure 4. *The field of group I distribution ("alpha region" or powerful innovators), according to the value of the innovative development index in 2016*

The matrix of the distribution of regions for 2016 shows the regions included into selected groups: group I – "alpha regions" or powerful innovators; group II – "beta regions" or strong innovators; group III – 'gamma regions' or medium innovators; and group IV – "delta regions" or weak innovators (see Table 5).

Table 5

Matrix of the distribution of regions in groups, 2016

Groups	Regions
Group I	Moscow, St. Petersburg, Moscow region (3)
Group II	Nizhny Novgorod region, Krasnoyarsk region, Tomsk region, Tatarstan (4)
Group III	Tyumen region without autonomous districts, Tula region, Ulyanovsk region, Republic of Sakha (Yakutia), Kursk region, Sverdlovsk region, Tver region, Novosibirsk region, Kaluga region, Voronezh region, Perm region, Yaroslavl region (12)
Group IV	Belgorod region, Rostov region, Chelyabinsk region, Lipetsk region, Leningrad region, Khabarovsk region, Republic of Mordovia, Republic of Bashkortostan, Novgorod region and others (66)

At this level, it is also possible to analyze the dynamics of average values of the integral index of ID by focusing on specific groups of regions.

The dynamics of average values of the integral index reveals the factors that have the greatest influence on innovative development in different groups of regions. For example, let us consider Figure 5, which reflects the dynamics of the average value of the index in regions of the first group.

The high average value of the index in group I in 2015 was almost 6 times higher than in 2014 and 4.5 times higher than in 2016. The rise in 2015 was caused by a significant increase in indicators (10 times) of Moscow region, which is the leader and which determines the innovative potential of this group. If we look at another region – St. Petersburg, we shall see a simultaneous fivefold decrease in the indicators' values in 2015 and their subsequent fivefold increase in 2016, which generally caused a strong jump in the average value of the index for the whole group in 2015. The same changes in indicators brought the average value of the innovative development index in 2014 and 2016 to a comparable value. Thus, the maximum average index value of the first group was reached in 2015 and the minimum, in 2014.

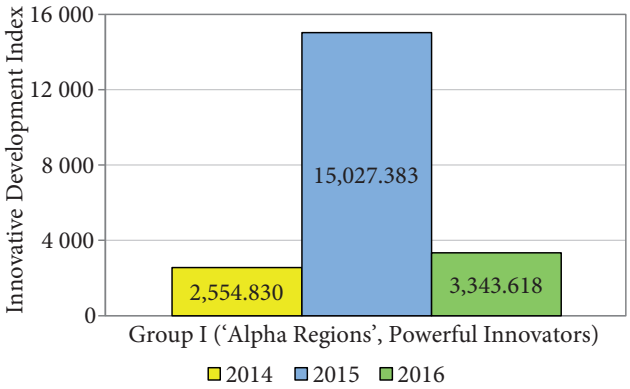

Figure 5. *Dynamics of the average value of the innovative development index in group I for 2014–2016*

At the *third level*, we are going to analyze the dynamics of the rankings positions of the regions.

The regional rankings based on the innovative development index for 2014, 2015 and 2016 allow us to draw a number of conclusions, tracking how the region's position changed and how they either moved up or dropped in the ranking depending on their levels of innovative development.

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For example, in 2014, Novosibirsk region ranked 9th and was a part of the third group with the index value of 5.935, which almost twice exceeded the average index value of this group in the give period. In 2015, the region dropped in the ranking by 11 positions and moved to group IV, "delta regions", with the index value below the average of this group. By 2016, Novosibirsk region regained its position in the group of "gamma regions", after having improved its position by 5 points compared with the previous period. At the same time, it still lagged behind the average indicator level for the group 1.6 times.

Thus, we can rank the regions according to the intensity of changes in their ranking positions for the period 2014–2016. Regions that improved their positions in 2016 compared to 2015 are presented in Table 6, regions that moved down the rankings in 2016 compared to 2015 are presented in Table 7.

Compared with 2015, fifteen regions improved their positions in 2016 by more than 10 points. As it can be seen from Table 5, five regions moved to the group with a higher value of the index of ID, from "delta regions" to "gamma regions". The Republic of Sakha (Yakutia) rose in

Table 6

Regions with a significant change in their ranking positions in 2015–2016 (improved positions, fragment)

No.	Region	2015		2016		2015–2016	
		Rank	Group	Rank	Group	Rank change	Group change
1	Republic of Sakha (Yakutia)	48	IV	11	III	37	+1
2	Kursk region	42	IV	12	III	30	+1
3	Tyumen region without autonomous districts	34	IV	8	III	26	+1
4	Kabardino-Balkaria	73	IV	51	IV	22	0
5	Republic of Crimea	83	IV	62	IV	21	0
6	Republic of Karelia	49	IV	30	IV	19	0
7	Tver region	31	IV	14	III	17	+1
8	Udmurtia	64	IV	48	IV	16	0
9	Belgorod region	35	IV	20	IV	15	0
10	Vologda region	59	IV	45	IV	14	0
11	Komi Republic	56	IV	42	IV	14	0
12	Omsk region	47	IV	35	IV	12	0
13	Khanty-Mansi Autonomous Okrug – Ugra	44	IV	32	IV	12	0
14	Khabarovsk region	36	IV	25	IV	11	0
15	Ulyanovsk region	21	IV	10	III	11	+1

Table 7

Regions with a significant change of their ranking positions in 2015–2016 (lost positions, fragment)

No.	Region	2015		2016		2015–2016	
		Rank	Group	Rank	Group	Rank change	Group change
1	Rostov region	11	III	21	IV	–10	–1
2	Perm region	8	II	18	III	–10	–1
3	Kemerovo region	50	IV	61	IV	–11	0
4	Kostroma region	61	IV	73	IV	–11	0
5	Samara Region	17	III	31	IV	–15	–1
6	Tambov Region	32	IV	47	IV	–15	0
7	Vladimir region	18	IV	34	IV	–16	0
8	Karachay-Cherkess Republic	62	IV	79	IV	–16	0
9	Pskov region	63	IV	81	IV	–18	0
10	Caliningrad region	12	III	40	IV	–22	–1
11	Orenburg region	25	IV	55	IV	–30	0
12	Penza region	16	III	52	IV	–36	–1
13	Magadan Region	13	III	58	IV	–46	–1
14	Sakhalin region	19	IV	83	IV	–65	0

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the ranking by 37 points: in 2016 it ranked 11th and in the previous year, 48th by achieving significant improvements in all areas: socio-economic area, production and technology, investment, R&D, human resources for R&D, and funding. The transition of Kursk region to the group of medium innovators is explained by a significant increase in indicators characterizing production and technology, investment and funding for R&D as well as the factors shaping the innovative potential and innovative activity of the region. Tyumen region closes the top three leading regions in 2016 ranking. It moved to the 8th position from the 34th in the previous period due to its improved performance in R&D, human resources for R&D and funding, which is directly related to the growth in indicators of innovative environment – innovative potential and innovative activity.

Table 6 shows 14 regions and the change in their ranking positions in 2016 compared to 2015, which was more than 10 points. Sakhalin region did not leave the group of "delta regions" in 2016 and led the top three outsider regions with a significant loss of 65 positions. From the 19th place in the 2015 ranking, in 2016, it dropped to the 83rd place due to a very low level of innovative activity and low rates of research and investment activity. Penza region closes the top three, it dropped from the 36th place to the 52nd in 2016. The decline in production and technology, investment activity and R&D funding, affected the indicators of innovative activity in the region, which resulted in the region's joining the group of weak innovators.

At *the fourth level*, we are going to divide regions according to the values of the final indices in innovative categories and areas of implementation. This level allows us to analyze the relationship between innovative development and the factors of external and internal environment as well as the relationship between the areas of implementation of innovation activities.

Thus, the fields reflect the direct relationship between innovative development and innovative potential in 2016 (Figure 6) and between innovative development and funding for R&D in 2016 (Figure 7).

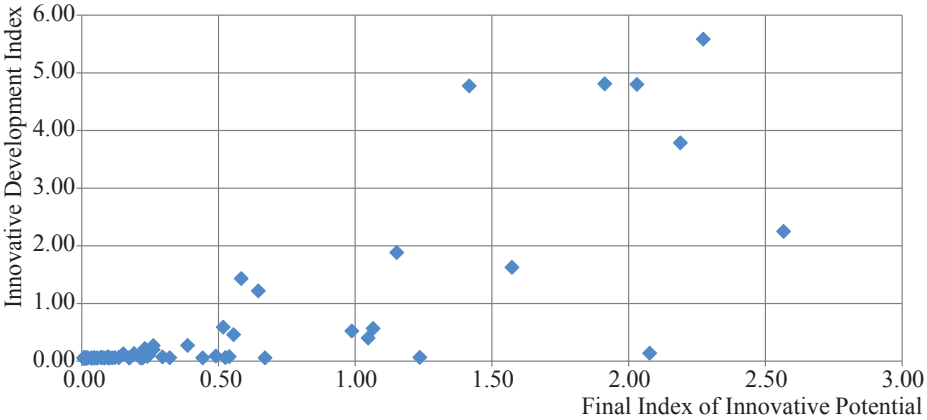

Figure 6. *The field of dependence between innovative development and innovative potential of regions in 2016*

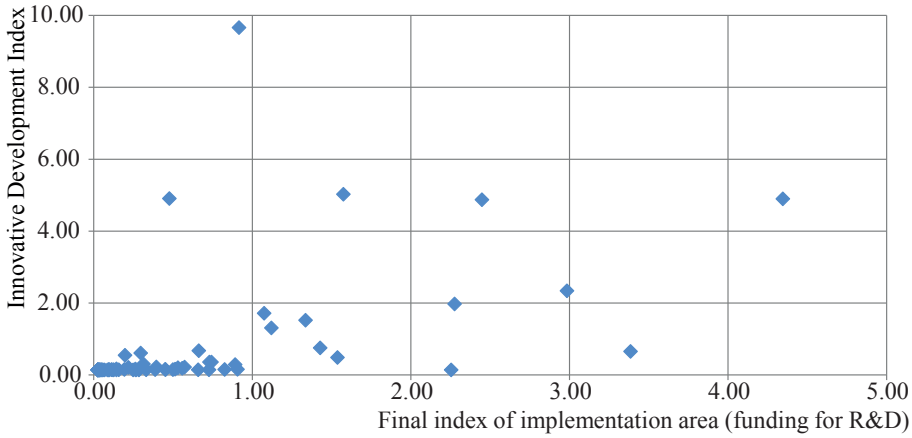

Figure 7. *Field of dependence between innovative development and funding for R&D for 2016*

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At *the fifth level*, we are going to draw a profile of a region depending on its innovative development. The innovative profile relies on the results of region-specific assessment, which allow us not only to reveal the change in the integral index of ID, but also the impact of final indices. The dynamics of changes in the final indices according to innovative categories and implementation areas is presented in Figures 8–9.

The dynamics of the values of region-specific indices, which form the final indices according to implementation areas and innovative categories, are shown in Figure 10 ("Socio-economic area") and Figure 11 ("Innovative climate").

A similar presentation has the dynamics of region-specific indices in the following areas of implementation: production and technology, investment activity, R&D, human resources and funding for R&D.

A similar presentation has the dynamics of region-specific indices in the categories "potential" and "activity".

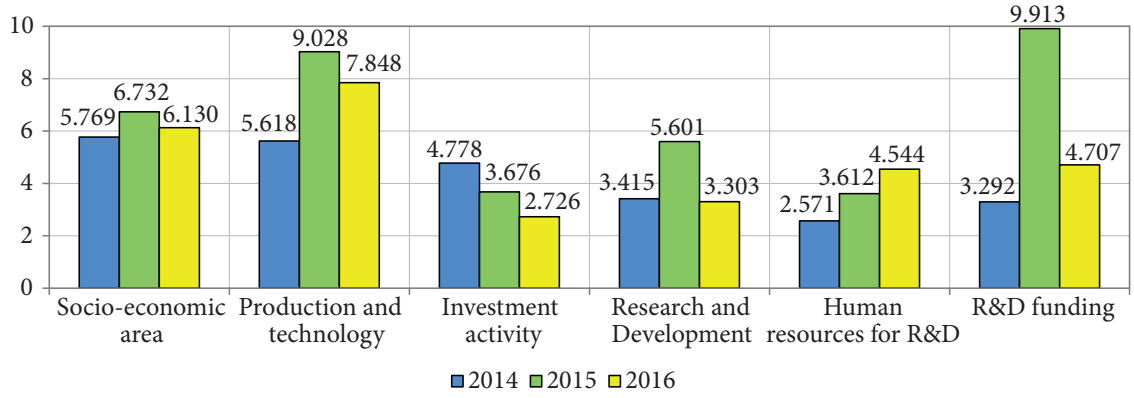

Figure 8. *Dynamics of the values of the final indices by areas of implementation for 2014–2016*

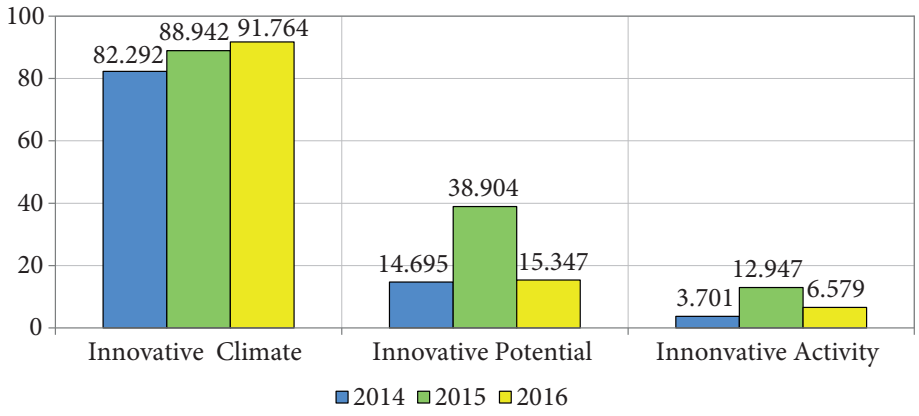

Figure 9. *Dynamics of the values of final indices by innovative categories for 2014–2016*

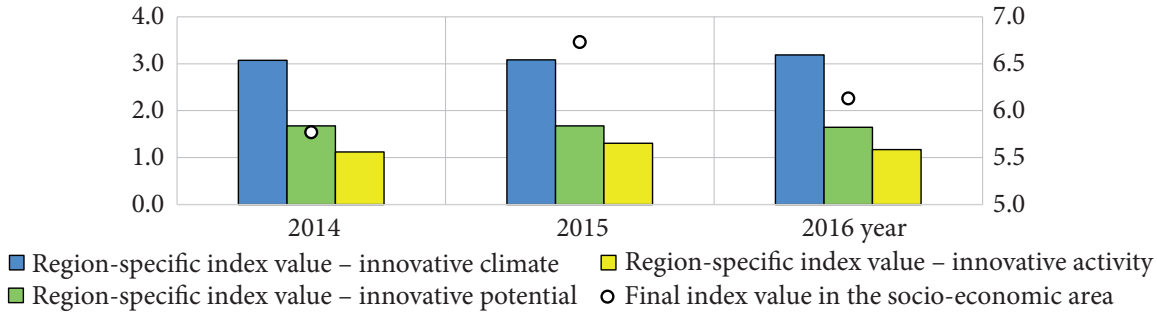

Figure 10. *Dynamics of the values of region-specific indices in the socio-economic area for 2014–2016*

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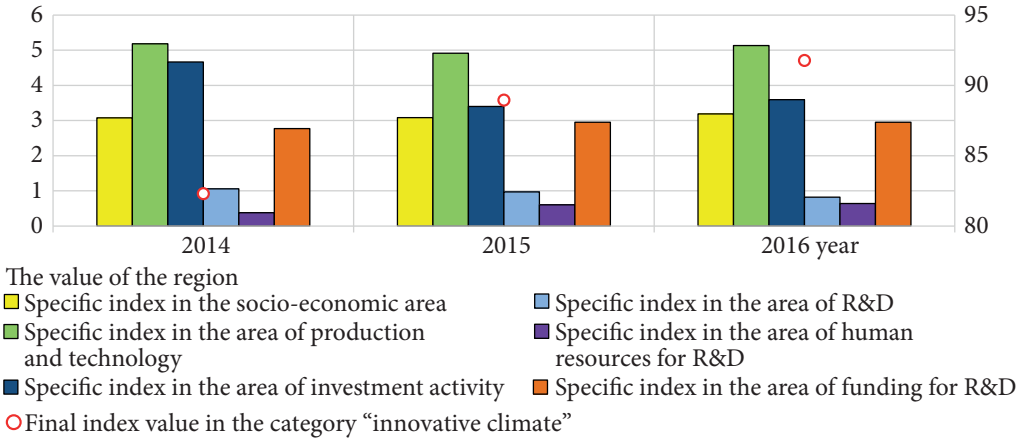

Figure 11. *Dynamics of the values of region-specific indices in the category "innovative climate" for 2014–2016*

Analysis of the results at this level allows us to rank regions according to the final indices – innovative climate, innovative potential and innovative activity in the regions. Similarly, it is possible to rank regions according to the level of development of the implementation areas of innovation activities. Thus, we can make an overall assessment of regions' innovative development. The integral index of ID is calculated on the basis of final indices of innovative categories and implementation areas, and final indices are calculated on the basis of region-specific ones. The latter can be also used to create a profile for each region. The innovative profile of a region reflects the results of the analysis of its innovative environment and show the region's strengths and weaknesses, growth drivers and resources. Therefore, profiling can be useful to devise recommendations and guidelines for further innovative development of the region.

Conclusion

In this research, we were trying to address the problem of the lack of a generally accepted conceptual and terminological apparatus for studying innovation as well as a toolkit for a comprehensive assessment of innovative development.

The proposed methodology is suitable for assessment of innovative development of territories taking into account such characteristics as innovative environment and innovation activities. The methodology comprises a set of indices including the integral index and region-specific indices; criteria for ranking regions according to their level of innovative development and further classification of regions according to their ranking positions; fields and matrixes of regions' distribution according to their innovative development; fields of dependence that show the relationship between innovative development and different categories of innovative environment (external and internal factors); and tools for creating individual profiles of regions.

A limitation of this study is the use of official statistics in calculations: these data are published with a time lag, which may affect the picture we get when assessing the regions' innovative development.

The results described in this article may be further used for studying innovation potential of Russian regions and devising strategies and policies for enhancing innovation in these regions and in the whole country. Further research in this area may involve creation of profiles of innovative development for specific regions, highlighting their strengths and weaknesses. Moreover, the proposed assessment toolkit may be applied in the context of other countries.

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Transport system modelling based on analogies between road networks and electrical circuits

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ABSTRACT
This article describes a probabilistic mathematical model which can be used to analyse traffic flows in a road network. This model allows us to calculate the probability of distribution of vehicles in a regional road network or an urban street network. In the model, the movement of cars is treated as a Markov process. This makes it possible to formulate an equation determining the probability of finding cars at key points of the road network such as street intersections, parking lots or other places where cars concentrate. For a regional road network, we can use cities as such key points. This model enables us, for instance, to use the analogues of Kirchhoff First Law (Ohm's Law) for calculation of traffic flows. This calculation is based on the similarity of a real road network and resistance in an electrical circuit. The traffic flow is an analogue of the electric current, the resistance of the section between the control points is the time required to move from one key point to another, and the voltage is the difference in the number of cars at these points. In this case, well-known methods for calculating complex electrical circuits can be used to calculate traffic flows in a real road network. The proposed model was used to calculate the critical load for a road network and compare road networks in various regions of the Ural Federal District.

KEYWORDS
probabilistic mathematical model, traffic flows, Ohm's Law, Kirchhoff's First Law, regional road network, traffic management

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Моделирование транспортной системы на основе аналогий между дорожными сетями и электрическими цепями

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АННОТАЦИЯ
Предложена вероятностная математическая модель, позволяющая анализировать транспортные потоки в дорожной сети. Эта модель позволяет рассчитать вероятность распределения транспортных средств по дорожной сети региона или улично-дорожной сети города. В модели движение автомобилей трактуется как марковский процесс. Это позволяет сформулировать уравнение, определяющее вероятность нахождения автомобилей в ключевых точках дорожной сети. В качестве таких ключевых точек можно рассматривать, например: пересечение улиц в городах, парковки или другие места скопления автомобилей. В региональной сети автомобильных дорог в качестве таких ключевых точек можно рассматривать города. С помощью этой модели была показана, в частности, возможность использовать аналоги первого закона Кирхгофа (закона Ома) для расчета транспортных потоков. Этот расчет основан на эквивалентности реальной дорожной сети электрическим цепям сопротивлений. Транспортный поток является аналогом электрического тока, сопротивление участка между контрольными точками - это время, необходимое для перехода из одной ключевой точки в другую, напряжение - это разница в количестве автомобилей в этих точках. В этом случае для расчета транспортных потоков в реальной дорожной сети могут использоваться общеизвестные методы расчета сложных электрических цепей. Предложенная модель использовалась для расчета критической нагрузки в дорожной сети и сравнения дорожной сети в различных областях Уральского Федерального округа по этому показателю.

КЛЮЧЕВЫЕ СЛОВА
вероятностная математическая модель, транспортные потоки, закон Ома, первые аналоги закона Кирхгофа, региональные дорожные сети, управление транспортными потоками

ДЛЯ ЦИТИРОВАНИЯ
Tolmachev, A. V., Sinitsyn, E. V., & Brusyanin, D. A. (2019) Transport system modelling based on analogies between road networks and electrical circuits. *R-economy*, 5(2), 92–98. doi: 10.15826/recon.2019.5.2.010

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Introduction

The task of modelling road network dynamics is a widely discussed topic in modern research literature [1–6]. Despite the availability of fairly complex software systems, such as VISUM, it is still quite difficult to build simple models that would allow us to analyse the distribution of traffic flows across the road network, without detailed information about the social, age and gender structure of the population. Such macro-analysis is necessary, for example, in strategic planning for the development of urban transport, an integrated transport service system and in dealing with other problems.

In all these cases, it is useful to analyse not the traffic flows that occur in specific periods of time in a specific socio-economic, demographic and transport context, but objective characteristics of the transport network itself determined by its technical, geometric and topological factors. It is of theoretical and practical interest to compare such objective characteristics of transport networks of various cities with other macro-parameters characterizing their economic and social development.

In a number of works (see, for example [1]), the authors used models based on analogies between the transport flow and the flow of electric current through resistance circuits. Such an analogy is justified by the fact that the movement of automobiles, which is to some extent similar to the movement of electrons in a conductor, can be measured by the number of corresponding units passing through a certain section per unit of time, while the movement itself is caused by the external electromotive force. In this case we can use the analogue of Ohm's Law for the road section between points 1 and 2 (Figure 1): [7]

$$I = \frac{U}{R} = \sigma U. \quad (1)$$

Here I is an analogue of electric current – traffic flow, defined as the number of cars passing through the road cross-section per unit of time. U is an analogue of voltage. It is natural to assume that the analogue of the electric field strength, the force causing the movement of electric charges, is the gradient of the number of cars going along the road in a certain direction. Thus, U is the difference of the number of cars between points 1 and 2.

The analogue of electric resistance for a highway section of the length – L (one row) with the allowed speed of movement v_0 – looks the following way:

$$R = \frac{L}{v_0}. \quad (2a)$$

Respectively:

$$\sigma = R^{-1} = \frac{v_0}{L}. \quad (2b)$$

The scheme for calculating "resistance" for a specific road section is shown in Figure 1. If we measure I as the number of cars passing per unit of time through the cross section of the road part 1 → 2, for example: [I] = Number of cars per second, we can enter the current density j: [8]

$$\vec{j} = \frac{I}{h}\vec{dl} = \lambda\vec{E} = \frac{\vec{E}}{\rho}, \quad (3a)$$

Here h is the width (cross section), $\vec{E}$ is an analogue of the "electromotive force", $\vec{dl}$ is the vector along the elementary section of the road, ρ and λ are the "resistivity" and "conductivity" of the road section, respectively. Comparing (3a) with the traditional expression for $\vec{j}$:

$$\vec{j} = n \cdot \vec{v_0}, \quad (3b)$$

where n is the surface density of cars, we obtain the following:

$$E = n \cdot h, \quad (3c)$$

$$\rho = h \cdot v_0. \quad (3d)$$

Dimensions of the values in (3) (we will assume that time is measured in seconds – [sec], length in meters – [m], number of cars in units – [units]) are as follows:

$$[I] = \frac{unit}{sec}, \quad (4a)$$

$$[j] = \frac{unit}{sec \cdot m}, \quad (4b)$$

$$[\rho] = sec, \quad (4c)$$

From (3c) we get:

$$[E] = \frac{unit}{m}. \quad (4d)$$

After taking an integral of both parts in (3a) along the road section between points 1 and 2, we find an analogue of Ohm's Law:

$$U = \oint_1^2 \vec{E} \cdot \vec{dl} = I \oint_1^2 \frac{\rho}{h} dl = I \cdot R_{12}. \quad (5)$$

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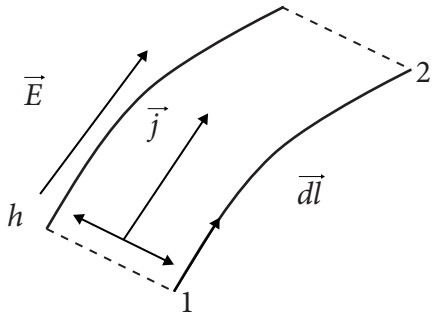

Figure 1. *Scheme for calculating the "resistance" of the road section*

R_{12} in (5) is the "resistance" of the road section between points 1 and 2. For the permanent velocity along the road section from (5) one can easily obtain formulae (1), (2). The analogy between the traffic flow and electrical current in conductors is described in more detail in the next section[1]. We are going to use the above-described formulae to compare regional transport systems (see Section 3).

The analogy mentioned above can be used for various purposes. Firstly, it is convenient to make calculations regarding traffic flows in systems of arbitrary complexity by applying standard approaches such as the methods used for the calculation of electrical circuits [7]. For example, two parallel roads between points 1 and 2 (or two rows of traffic on the same road) can be compared to a parallel connection of electrical resistances. In full accordance with the formulas for calculating electrical circuits, the "resistance" of such a road is two times less, and the conductivity is twice as high as that of a road with single-row traffic. Surely, the calculation of traffic flows in real road networks, taking into account all the existing interconnections and conditions, is a rather complicated computational problem, but methods for solving such tasks are well developed [7]. Secondly, this analogy can be used to compare transport systems of different regions. In this case, the "resistance" (or "conductivity") of a regional road network can be used for such a comparison (for more on this see Section 3).

[1] The laws describing the current flow in conductors can also be formulated so that the electric current will be the number of electrons flowing through a conductor cross section per unit of time (instead of its traditional definition – the amount of charge flowing per unit of time through the conductor cross section). In this case, in the SGS system, the resistivity will be measured in seconds [sec], and $|\vec{E}|$, in units per meter [unit / m].

Probabilistic mathematical model

Let us now focus on the proposed mathematical model. This model also has an independent value. It allows us to calculate the probabilities of distribution of vehicles along a road network and to estimate the risks of traffic collapses. Let us consider an equation describing the probability that in a road network containing n intersections[2], at intersection 1, there are X_1 cars, at intersection 2, X_2, ..., at intersection n, X_n. We will describe the distribution of cars at intersections by the following vector:

$$\vec{X} = \{X_1, X_2, \ldots, X_n\} = \boldsymbol{X}, \tag{6}$$

where

$$\sum_{i=1}^{n} X_i = M, \tag{7}$$

where M is the total number of the cars on the roads of the city. In this case, as it was shown in [9], the desired probability $P(\vec{X}\,|\,t)$ satisfies the equation:

$$\frac{\partial P(\vec{X}\,|\,t)}{\partial t} = P(\vec{X}|t)\{(1-z)\sum_{i=1}^{n} P_{ii} - \sum_{i=1}^{n} X_i\} +$$

$$+ z\sum_{i=1}^{n}(X_i+1)P(\ldots, X_{i+1}, \ldots|t) + \tag{8}$$

$$+(1-z)\sum_{i=1,j\neq i}^{n} P_{ij}(X_i+1)P(\ldots, X_{i+1}, \ldots, X_{j-1}, \ldots|t)\},$$

z is the probability of leaving the road, let $z = 0$ for the sake of simplicity, P_{ij} is the probability of moving a car from intersection i to intersection j. It is obvious that

$$\sum_{j=1}^{n} P_{ij} = 1, \tag{10}$$

Let us calculate the averages [10]:

$$\overline{X_i} = < X_i > = \int_0^M X_i P(\vec{X}\,|\,t)dX_i, \tag{11}$$

and dispersion:

$$\sigma_{ij} = \overline{(X_i - < X_i >)(X_j - < X_j >)} =$$

$$\int_0^M X_i \cdot X_i \cdot P(\vec{X}|t)dX_i \cdot dX_j - < X_i > \cdot < X_j > . \tag{12}$$

[2] Each intersection is a key point of the road network such as a real intersections of city streets, parkings, and other places of cars concentration. For regional road networks we can use cities as such key points.

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It can be shown that

$$\overline{X_i} \sim M,$$
$$\sigma_{ij} \sim \sqrt{M}. \quad (13)$$

Here M is the total number of cars. Thus, as the coefficients of variation tend towards zero:

$$C_V(ij) \sim \frac{1}{\sqrt{M}} \to 0, \quad (14)$$

Multiplying (4) by and carrying out some simple transformations, we get the following:

$$\frac{\partial < X_l >}{\partial t} = \sum_{k=1}^{n} [\widetilde{P_{kl}} \cdot < X_k > - \widetilde{P_{lk}} \cdot < X_l >], \quad (15)$$

here $\widetilde{P_{kl}} = 0$ for $k = l$; $\widetilde{P_{kl}} = P_{kl}$ for $k \neq l$. P_{kl} are defined in comments to equation (4) $k \neq$ l.

It can be easily seen that for

$$\frac{\partial < X_l >}{\partial t} = 0$$

(15) is equal to Kirchhoff's First Law for the electrical network [7]. Cars $< X_l >$ play the role of nodal potentials, and transition probabilities $\widetilde{P_{kl}}$ play the role of conductivities of sections of the road between intersections k and l. It is easy to see that the dimensions of and correspond to formula (1) introduced in Section 1.

It is well known that (15) is also equal to the problem of random walks through the oriented graph whose vertices correspond to points $\{X_1, X_2, \ldots, X_n\}$ and the transition probabilities between the vertices are [11 12]. It should be mentioned that despite the fact that methods of graph theory are very popular in transportation modelling [13–15], it is interesting to consider the application of (15) for analysis of transport systems on the basis of the graph theory approach and methods of machine learning [16]. This question will be addressed in our following articles.

Despite the analogy drawn between road networks and electric circuits, it is still quite difficult to solve equation (15). One of the problems is how to determine the probabilities P_{lk}. In the simplest case, we can assume that they are determined solely by the network infrastructure and traffic management rules (a system of road signs, traffic signal change intervals, etc). With a more complex and rigorous approach, it is necessary to take into account the dependence of parameters on quantities, which will significantly complicate the task.

Discussion

First let us consider in more detail the effects that occur when a traffic flow passes through a section of a road of length L, for example, a part of a street between two intersections. Let us assume that for safe driving the distance between cars should not be less than the stopping distance in case of emergency braking – l_s. According to[3]:

$$l_s(v) = \frac{3v}{10} + \left(\frac{v}{10}\right)^2, \quad (16)$$

where v is the speed of the vehicle in (km / h). In this case, the density of the traffic flow should not exceed the value:

$$j \leq \frac{v}{l_s(v)} \cdot \frac{1}{h}. \quad (17)$$

With the help of (1) and (2) we can find that the value of "voltage" satisfies the condition:

$$U_{cr} \leq \frac{L}{l_s(v)} = N_{cr}, \quad (18)$$

In (17), (18) L is the length and h is the width of the considered section of the road. It can be shown from (2), (3) and (5) that U_{cr} is numerically equal to the total number of cars in this section of the road.

Let us now compare critical quantities N_{cr} for different regions. We will use the data[4] on the total length of roads with a hard surface in the corresponding region and the fraction of the roads with improved surface. We will assume that on roads with improved surface, the speed is 90 km / h, and on roads with usual surface, 40 km / h. The exact value of these velocities is irrelevant for our comparison. These critical values N_{cr} (18) will be compared with the current total number of cars in the region (public buses and private cars). Figure 2 shows the data for Sverdlovsk region in recent years. As it can be seen, the available number of cars significantly exceeds the critical one. This means that even a fraction

$$f_{cr} = \frac{N_{cr}}{N}, \quad (19)$$

of the current number of cars on the region's roads will make normal movement impossible. The average value of fraction f_{cr} for Sverdlovsk region is equal to 26%.

It is interesting to compare f_{cr} for different regions of the Ural Federal District. This compari-

[3] Retrieved from: http://www.1gai.ru
[4] Retrieved from: http://www.gks.ru

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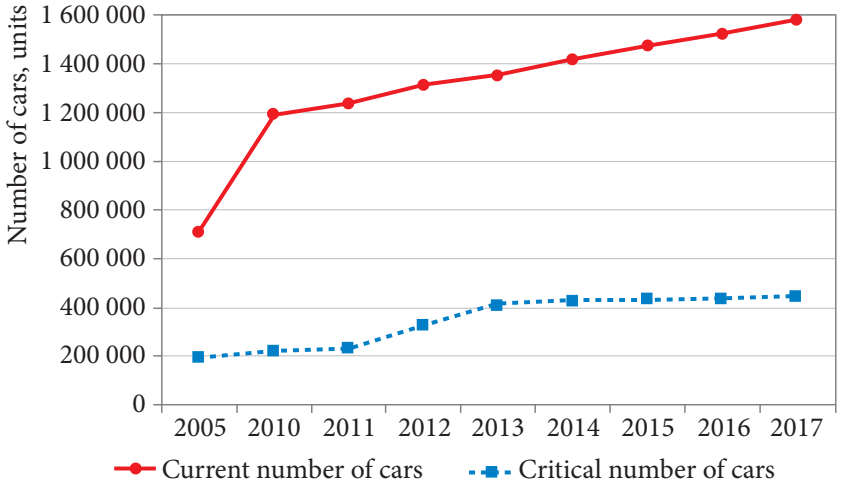

Figure 2. *Dynamics of changes in the current and critical number of cars for Sverdlovsk region. The calculations were made by the authors on the basis of the official statistical data (State Federal Statistics Service. Retrieved from: http://www.gks.ru/), by applying formulae (16)–(19)*

son is illustrated by Figure 3. The results show that the transport systems of the regions in the Urals Federal District are under considerable pressure (with the exception, perhaps, of Kurgan region). For example, the massive use of private vehicles due to any reasons (holidays, emergencies etc.) in most regions is bound to lead to a traffic collapse.

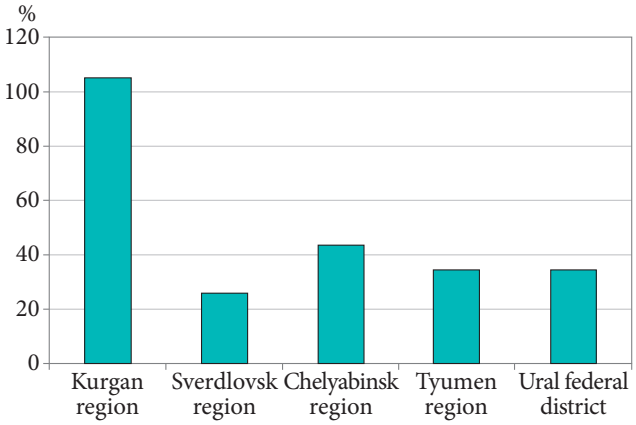

Figure 3. *Fraction (19) for different regions. The authors made calculations by applying formula (19) and using the available statistical data (Regions of Russia. Key Characteristics of Subjects of the Russian Federation (2018). Moscow)*

Conclusion

The above-described probabilistic mathematical model, which determines the distribution of cars along intersections of a road network, makes it possible to substantiate the analogy between the traffic flow and the electric current in an equivalent electric circuit where the resistances are the times needed for a car to travel along a certain road section.

At the same time, the main characteristics of effective electrical circuits that correspond to real road systems should be determined by taking into account the actual location of roads, their category, the number of traffic rows as well as the rules of traffic regulation.

In the cases when the road contains several rows, they can be considered as parallel resistances, the number of resistances corresponding to the number of rows. The described analogy makes it possible to reduce the task of calculating the traffic flow of the urban street-road network to the calculation of electric current in complex electrical circuits. Despite the fact that it is also a difficult task, it can be solved by using well-known methods and algorithms [17] implemented in various software applications.

In the future, we are planning to provide a detailed analysis of road networks in various regions, taking into account all the factors described above, as well as the social and economic characteristics of the regions (see below). However, in this article we limited ourselves to a comparative analysis of the critical capacity of the road network. The latter was understood as a critical number of cars that can simultaneously be on the roads of the region without violating traffic safety requirements.

Our analysis shows that in almost all of the given regions (Sverdlovsk, Chelyabinsk, and Tyumen regions) of the Ural Federal District, the

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number of the already existing personal vehicles and public buses significantly exceeds the critical throughput of the road network. The only exception is Kurgan region. It should be noted that cargo vehicles were not taken into account (partly, this was due to the lack of reliable data on the number of trucks on the roads of the Ural Federal District). Of course, if we took trucks into consideration, this picture would look even worse.

This situation indicates the potential instability of the work of road transport. Holidays, emergencies, bad weather conditions and so on may cause a significant increase in the use of motor vehicles or an increase in the "resistance" of road sections (for example, accidents, repair works) and cause traffic collapses.

In the future, we intend to present a more detailed system for comparison of regional transport systems by using the model described above. We are going to take into account the exact geographical location of the road network and traffic regulation rules; different types of transport; conditions of population settlements and their structure; and the location of economic objects and economic relations of territories.

We believe that this model can prove useful for strategic planning of transport systems and traffic management.

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