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QUALITY MANAGEMENT IN INDUSTRY 4.0 BASED ON EDUCATIONAL AND LABOR MIGRATION: PROSPECTS OF RUSSIA AND OTHER CIS COUNTRIES

Abstract: *The article reveals the unique experience of Russia and other CIS countries, which are fast-growing digital economies with a dynamically developing industry 4.0, as well as free migration. The purpose of this article is to study the prospects for improving quality management in Industry 4.0 based on educational and labor migration in Russia and other CIS countries. It is proved using econometric modeling of the experience of Russia and other CIS countries using regression analysis based on data for 2021 that immigration does not allow attracting highly qualified personnel for industry 4.0, but emigration does not lead to the loss of highly qualified personnel for industry 4.0.Alternative scenarios of quality change in industry 4.0 in Russia and other CIS countries have been created, which are based on the flows of educational and labor migration in the "Decade of Action" (in the period up to 2030). The scenario of filtration of incoming and freedom of outgoing migration flow has proved to be the best, since the optimization of educational and labor migration flows provides the highest rates of qualitative growth of industry 4.0 in Russia and other CIS countries by 223.96% with a probability of 46.5%.To implement this scenario, a promising model of migration flow management has been proposed to improve the quality of Industry 4.0 products in Russia and other CIS countries. The theoretical significance of the results obtained in the articleis that they clarified the role that the migration mechanism has on the quality management of Industry 4.0 products, taking into account the unique experience of Russia and other CIS countries.The practical significance of the authors' conclusions and recommendations is that they make it possible to improve the effectiveness of quality management in industry 4.0 based on educational and labor migration in Russia and other CIS countries.*

Keywords: *quality, educational migration, labor migration, russia, cis, quality management, industry 4.0.*

1. Introduction

Product quality determines its digital competitiveness and therefore is the most important benchmark for the development of industry 4.0. Summarizing the numerous available definitions of Łukasiński and Łukasiński and Nigbor-Drożdż (2022), Thach et al. (2021), Woźniak et al. (2022), Zimon et al. (2022), this article interprets industry 4.0 as the most advanced high-tech segment of the digital economy that emerged and is dynamically developing under the influence of the Fourth Industrial Revolution. The role of human resources in industry 4.0 is specific and therefore the subject of ongoing scientific discussion (Safonova & Konyukhov, 2023; Nestorov et al., 2023).

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Goyal et al. (2023), Margherita and Braccini (2021), Martell et al. (2023)note in their works the decline in the importance of human resources in the digital economy in the course of the development of industry 4.0, in which the automation of business processes is of universal scope and is becoming more and more widespread. In contrast, Ahmad et al. (2022), Burnett et al. (2022), Ramos et al. (2022), Tapasvi et al. (2023) in their writings indicate that although industry 4.0 does demand fewer human resources than in less technologically advanced sectors of the modern economy, the quality requirements for human resources in industry 4.0 are much higher.

This is due to the fact that the design of technically complex products, which industry 4.0 specializes in, requires highly qualified personnel with pronounced creative abilities and high innovation activity. Digital personnel capable of using advanced automation tools and breakthrough technologies are needed to perform production processes that are not subject to automation. Thus, the quality of human resources largely determines the quality of products in Industry 4.0.

The migration mechanism of product quality management has a contradictory interpretation in the context of industry 4.0. On the one hand, the incoming migration flow (immigration) can potentially provide an influx of highly qualified specialists into the economy and overcome their deficit, if it arises.On the other hand, the outgoing migration flow (emigration) can lead to a brain drain, including industry 4.0 personnel, and, as a result, to the loss of valuable knowledge, to a shortage of specialists, the paralysis of industry 4.0 productions and a decrease in their digital competitiveness.

In the aspect of quality management based on the migration mechanism in industry 4.0, first of all, labor migration is of the greatest interest. For Industry 4.0 enterprises, labor migration allows attracting the necessary human resources on a temporary (for example, in case of seasonal employment) or permanent (to fill gaps in the staff) basis. The benefit of labor migration for workers is that, in case of unemployment due to the insufficient level of development of industry 4.0 or an excess of industry 4.0 personnel in one country, they get the opportunity to find employment by profession and build a career in another country.

Secondly, educational migration. The benefit of educational migration for employees is that they can fill in the gaps in competencies, including digital ones, by studying abroad with the possibility of subsequent employment. That is, educational migration creates social elevators for industry 4.0 workers. For Industry 4.0 enterprises, educational migration makes it possible to place an order at local universities to train the necessary personnel with a certain set of competencies for a specific enterprise, taking into account its unique needs.An additional advantage of educational migration is the development of universities and territories that serve as training centers for industry 4.0.

The Commonwealth of Independent States (CIS) is a progressive socio-economic and legal space for the free movement of goods and all types of resources on mutually beneficial terms for all its participants. The unity of historical roots, multiple points of contact of cultures, the almost complete absence of language barriers, as well as the mutual recognition of higher education diplomas determines favorable conditions for migration. In this regard, the basis of the migration flow of Russia and other CIS member countries is internal migration - the movement of human resources among the CIS countries. In addition, Russia and other CIS countries represent fast-growing digital economies with a dynamically developing industry 4.0. This makes the experience of Russia and other CIS countries remarkable and especially useful for studying in the context of this research.

The purpose of this article is to study the prospects for improving quality management

in Industry 4.0 based on educational and labor migration in Russia and other CIS countries. The originality of the study consists in rethinking the role of the migration mechanism in the product quality management of industry 4.0, taking into account the specifics of the realities of Russia and other CIS countries.This predetermined the sequence of this study.

Further, the article provides a literary review, which serves as a basis for gap analysis. After that, the materials and research methodology are described. Then the results of the study are presented: 1) the consequences of educational and labor migration for quality in industry 4.0 in Russia and other CIS countries; 2) scenarios of quality change in industry 4.0 in Russia and other CIS countries depending on the flows of educational and labor migration; 3) a promising model of migration flow management to improve the quality of industry 4.0 products in Russia and other countries CIS. In the discussion section, the received answers to research questions are formulated in contrast with the existing literature.The findings of the study and their significance for science and practice, as well as the limitations of the article, along with the prospects for future research, are given in the conclusion section.

2. LiteratureReview

The fundamental basis of this research is the concept of product quality management in Industry 4.0 (Popkova et al., 2021; Popkova and Giyazov, 2021; Popkova and Sergi, 2022; Sergi et al., 2022; Sergi and Popkova, 2022), in which the critical importance of human resources for achieving high quality of these products is noted (Pajpach et al., 2022; Santos et al., 2021). Thus, Mohamed Imhmed Abuazoom et al. (2019) in their work based on evidence from the construction industry, proved that human resource management (HRM) methods can improve product quality, in particular, when implementing high-tech projects related to industry 4.0.

In turn, Alkhallidy (2020) conducted an applied study at an electrical industry enterprise and based on its results proved the important role of human resource management in achieving competitive advantages using the requirements of total quality management (TQM).Nizamidou et al. (2019) proved the close and stable relationship between security and personnel management in the implementation of anti-crisis business management, on the one hand, and the quality of its products, on the other.

The problem of quality management of services in healthcare (the most high–tech of which belong to industry 4.0), as well as in pharmaceutical products related to high-tech industries and, in some cases, industry 4.0 has worsened against the background of the COVID-19 pandemic.Padula et al. (2021) proved that investments in qualified specialists, including digital personnel, contribute to improving the quality of medical services through the development of hospital infrastructure.

Verma et al. (2020), using the example of small and medium-sized businesses, proved that progressive HR management practices based on big data improve the innovative competence of businesses and thereby increase the quality of services. Kerdpitak and Boonrattanakittibhumi (2020) proved that staffing and personnel management can improve not only the overall operational efficiency of a business, but also the quality of its products in the case of high human intensity of its production, which, in particular, is characteristic of industry 4.0.

The conducted literature review allows us to conclude that the issues of product quality management in industry 4.0 are sufficiently well elaborated.Nevertheless, the role of the migration mechanism in this management process has been poorly studied, and it is unclear, therefore it is a gap in the literature. In this regard, the following two research questions (RQs) arise.

RQ_1: Does immigration allow attracting highly qualified personnel for Industry 4.0? Duarte and Rodríguez (2021), Janaviciute et al. (2017), Lim (2021), Mendoza (2022), Samuk et al. (2023) note in the writings that immigration in developed countries contributes to attracting highly qualified personnel and ensuring the influx of the best specialists from around the world. However, most of the CIS countries belong to developing countries, as a result of which the generalized experience of developed countries cannot be extended to them. It should also be noted that personnel for industry 4.0 constitute a special category of the labor market, in relation to which any special retention tools can be applied. In this regard, this category needs to be studied separately, which leaves the RQ_1 open.

RQ_2: Does emigration lead to the loss of highly qualified personnel for industry 4.0? In the works of Alili et al. (2022), Bhardwaj and Sharma (2023), Lee et al. (2021), Mittelmeier et al. (2022), it is indicated that in developing countries emigration leads to the loss of highly qualified personnel, that is, it causes a brain drain.The economic meaning of this process is that the host countries of the developed world offer more comfortable and favorable working conditions, which stimulates the influx of the best personnel to them (Meister et al., 2023). At the same time, an important prerequisite in this case is a poorer level of working conditions, as well as a significant level of unemployment among highly qualified personnel in the sending countries (Sargent, 2023).

That is, the reason for emigration is not so much in the commercial interest of highly qualified personnel, as in their fundamental inability to realize their human potential in the country of residence -forced emigration (Iqbal et al., 2020; Mao et al., 2022). However, this is not typical for dynamically developing countries, for example, for Russia, where highly qualified personnel are widely in demand (for example, unique working conditions and social elevators for IT specialists have been created).

Since highly qualified Russian personnel have the opportunity to fully unleash their human potential in their own country, the meaning of emigration disappears, which does not allow them to mechanically transfer the experience of other developing countries to Russia. In this regard, emigration in Russia and other CIS countries needs a separate study, which leaves the RQ_2 open.

To fill the identified gap in the literature and answer the RQs posed in this article, econometric modeling and forecasting of quality changes in Industry 4.0 in Russia and other CIS countries, depending on the impact of educational and labor migration, was carried out.

3. Materials and methodology

The article successively solves the following three research tasks. The first task is to determine the consequences of educational and labor migration for qualityin Industry 4.0 in Russia and other CIS countries. To do this, the authors conducted economic and mathematical modeling using regression analysis to identify the dependence of the results of quality management in industry 4.0, measured using such indicators as:“high-tech manufacturing”, “knowledge-intensive employment” (WIPO, 2023), “knowledge capital” and “educational enabling environment” (Knowledge for all, 2023) on the following migration factors: number of immigrants and number of emigrants (World population review, 2023).

The sample includes the current members of the CIS (10 countries), according to the materials of the Interstate Statistical Committee of the Commonwealth of Independent States (2023). The study is conducted according to data for 2021, its statistical base is shown in Table 1.

Table 1. Migration factors and quality management results in Industry 4.0 in Russia and other CIS countries in 2021

Country	Migration factors, people		Quality management results in Industry 4.0, points 1-100			
	Immigrants	Emigrants	High-tech manufacturing	Knowledge-intensive employment	Knowledge capital	Educational enabling environment
	imm	em	HTM	KIE	KNC	EEE
Azerbaijan	252228	1163922	13,8	34,0	68,51	61,45
Armenia	190349	958190	5,7	27,6	43,15	66,94
Belarus	1079708	1897128	38,9	63,1	80,10	90,97
Kazakhstan	3732073	4203899	19,2	56,5	72,82	69,97
Kyrgyzstan	199011	774377	1,2	28,4	76,71	79,82
Moldova	104438	1159443	25,4	47,4	75,49	69,15
Russia	11636911	10756697	29,4	71,1	86,10	79,87
Tadjikistan	276031	586851	1,9	-	65,34	72,80
Turkmenistan	194920	242554	-	-	-	-
Uzbekistan	1162007	2027823	35,6	-	79,01	82,01

«-» – the data is not available in the source, so these cells are assigned zero values to eliminate gaps in the data during regression analysis.

Source: compiled by the authors based on the materials of Knowledge for all (2023), WIPO (2023), World population review (2023).

Taking into account the designations of the indicators introduced in Table 1, the research model has the following form:

$$\begin{cases} HTM=a_{htm}+b_{htm1}imm+b_{htm2}em, \\ KIE=a_{kie}+b_{kie1}imm+b_{kie2}em, \\ KNC=a_{knc}+b_{knc1}imm+b_{knc2}em, \\ EEE=a_{eee}+b_{eee1}im+b_{eee2}em. \end{cases} \quad (1)$$

Model (1) allows to find the answer to RQ_1. Positive values of regression coefficients at imm (b_{htm1}, b_{kie1}, $b_{knc1}$and b_{eee1}) indicate that immigration allows attracting highly qualified personnel for industry 4.0, and negative values of these regression coefficients indicate that it does not. Model (1) also allows to find the answer to RQ_2. Negative values of regression coefficients at imm (b_{htm2}, b_{kie2}, $b_{knc2}$and b_{eee2}) indicate that emigration leads to the loss of highly qualified personnel for industry 4.0, and positive values of these regression coefficients indicate that it does not.

The second task: to identify scenarios of quality change in industry 4.0 in Russia and other CIS countries depending on the flows of educational and labor migration. To solve it, a scenario analysis using the Monte Carlo method is conducted. Based on the arithmetic mean and standard deviations of the number of immigrants (average: 1882768, standard deviation: 3600594) and the number of emigrants (average: 2377088, standard deviation: 3148279), forecasts of their values in the "Decade of Action" (in the period up to 2030) are made, histograms of their normal distribution are constructed. The predicted values of the factor variables are substituted into the regression equations in the model (1) and the growth rate of the resulting variables is determined.

The third task: to develop a promising management model for migration flows to

improve the product quality in industry 4.0 in Russia and other CIS countries.To do this, the best scenario is determined, in which the optimization of educational and labor migration flows provides the highest rate of quality growth in industry 4.0 in Russia and other CIS countries. The model is aimed at strengthening scientific and methodological support for the implementation of this scenario through improving the management of migration flows in Russia and other CIS countries in the "Decade of Action" (until 2030).

4. Results

4.1 Consequences of educational and labor migration for quality in Industry 4.0 in Russia and other CIS countries

To solve the first research problem, which consists in determining the consequences of educational and labor migration for quality in industry 4.0 in Russia and other CIS countries, the authors used the regression analysis method to carry out economic and mathematical modeling of the dependence of quality management results in industry 4.0 on migration factors: the number of immigrants and the number of emigrants.The analysis was based on statistics from Table 1, and its results are reflected in Table 2-5.

Table 2. Regression analysis of the dependence of high-tech manufacturing on migration factors in Russia and other CIS countries in 2021

Regression statistics	
Multiple R	0,7946
R-Square	0,6313
Adjusted R-square	0,5260
Standard Error	10,1581
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	1236,8850	618,4425	5,9935	0,0304
Residual	7	722,3040	103,1863		
Total	9	1959,1890			

	Coefficients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Y-intercept	-9,1815	8,5219	-1,0774	0,3170	-29,3326	10,9696
Immigrants	-0,00003	0,00001	-2,8453	0,0249	-0,00005	-0,000004
Emigrants	0,00003	0,00001	3,0341	0,0190	0,00001	0,0001

Source: calculated and compiled by the autors

Results from Table 2 indicate that the change in high-tech manufacturing in Russia and other CIS countries in 2021 by 63.13% (R^2) is determined by the influence of migration factors (Multiple R=0.7946). The significance of F=0.0304.Therefore, the regressionstatistics under consideration corresponds to the significance level of 0.05. At this level of significance, with 2 factor variables and 10 observations, the critical F=4,7374. The observed F=5.9935 – it exceeds the critical one, therefore, the F-test has been passed, and the regression statistics are reliable at a given level of significance.

Table 3. Regression analysis of the dependence of knowledge-intensive employment on migration factors in Russia and other CIS countries in 2021

Regression statistics	
Multiple R	0,7724
R-Square	0,5966
Adjusted R-square	0,4813
Standard Error	19,2576
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	3839,1957	1919,5978	5,1761	0,0417
Residual	7	2595,9933	370,8562		
Total	9	6435,1890			

	Coefficients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Y-intercept	-5,5983	16,1558	-0,3465	0,7391	-43,8007	32,6042
Immigrants	-0,00003	0,00002	-1,7999	0,1149	-0,0001	0,00001
Emigrants	0,00004	0,00002	2,0661	0,0777	-0,00001	0,0001

Source: calculated and compiled by the autors

The results from Table 3 indicate that the change in knowledge-intensive employment in Russia and other CIS countries in 2021 by 59.66% (R^2) is determined by the influence of migration factors (Multiple R=0.7724). The significance of F=0.0417.Therefore, the regression statistics under consideration corresponds to the significance level of 0.05. At this level of significance, with 2 factor variables and 10 observations, the critical F=4.7374. The observed F=5.1761 -it exceeds the critical one, therefore, the F-test has been passed, and the regression statistics are reliable at a given level of significance.

Table 4. Regression analysis of the dependence of knowledge capital on migration factors in Russia and other CIS countries in 2021

Regression statistics	
Multiple R	0,7741
R-Square	0,5992
Adjusted R-square	0,4847
Standard Error	18,3673
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	3530,3974	1765,1987	5,2324	0,0408
Residual	7	2361,5102	337,3586		
Total	9	5891,9076			

	Coefficients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Y-intercept	20,1085	15,4089	1,3050	0,2332	-16,3278	56,5448
Immigrants	-0,00004	0,00002	-2,6878	0,0312	-0,0001	-0,00001
Emigrants	0,0001	0,00002	2,8595	0,0244	0,00001	0,0001

Source: calculated and compiled by the autors

The results from Table 4 indicate that the change in knowledge capital in Russia and other CIS countries in 2021 by 59.92% (R2) is determined by the influence of migration factors (Multiple R=0.7741). The significance of F=0.0408.Therefore, the regression statistics under consideration corresponds to the significance level of 0.05. At this level of significance, with 2 factor variables and 10 observations, the critical F=4.7374. The observed F=5.2324 – it exceeds the crital one, therefore, the Fisher F-test has been passed, and the regression statistics are reliable at a given level of significance.

Table 5. Regression analysis of the dependence of the educational enabling environment on migration factors in Russia and other CIS countries in 2021

Regression statistics						
Multiple R	0,7024					
R-Square	0,4934					
Adjusted R-square	0,3487					
Standard Error	20,3024					
Observations	10					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	2	2810,5324	1405,2662	3,4093	0,0925	
Residual	7	2885,3193	412,1885			
Total	9	5695,8518				
	Coefficients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Y-intercept	26,3482	17,0323	1,5470	0,1658	-13,9269	66,6233
Immigrants	-0,00004	0,00002	-2,3637	0,0501	-0,0001	0,00000002
Emigrants	0,0001	0,00002	2,4658	0,0431	0,000002	0,0001

Source: calculated and compiled by the autors

The results from Table 5 indicate that the change in knowledge-intensive employment in Russia and other CIS countries in 2021 by 49.34% (R^2) is determined by the influence of migration factors (Multiple R=0.7024). The significance of F=0.0304.Therefore, the regression statistics under consideration corresponds to the significance level of 0.10. At this level of significance, with 2 factor variables and 10 observations, the critical F=3.2574. The observed F=3.4093 – it exceeds the critical one, therefore, the F-test has been passed, and the regression statistics are reliable at a given level of significance.

The regression analysis results obtained in Table 2-5 make it possible to refine the research model (1) and set up the following system of equations:

$$\begin{cases} HTM=-9,1815-0,00003imm+0,00003em, \\ KIE=-5,5983-0,0003imm+0,00004em, \\ KNC=20,1085-0,00004imm+0,0001em, \\ EEE=26,3482-0,00004imm+0,0001em. \end{cases} \quad (2)$$

The system of equations (2) provided answers to both RQs. The obtained results indicate that with an increase in the number of immigrants in Russia and other CIS countries, the quality in industry 4.0 decreases: high-tech manufacturing decreases by 0.00003 points, knowledge-intensive employment – by 0.0003 points, knowledge capital – by 0.00004 points, educational enabling environment – by 0.00004 points. Consequently, immigration does not allow attracting highly qualified personnel for industry 4.0.

With an increase in the number of emigrants from Russia and other CIS countries, the quality in industry 4.0 increases: high-tech manufacturing increases by 0.00003 points, knowledge-intensive employment – by 0.00004 points, knowledge capital – by 0.0001 points, educational enabling environment – by 0.0001 points. Consequently, emigration does not lead to the loss of highly qualified personnel for industry 4.0.

4.2 Scenario analysis of quality changes in Industry 4.0 in Russia and other CIS countries depending on the flows of educational and labor migration

To solve the second research task of identifying scenarios of quality change in industry 4.0 in Russia and other CIS countries depending on the flows of educational and labor migration, a scenario analysis using the Monte Carlo method was carried out. Based on the arithmetic mean and standard deviations of the number of immigrants (mean: 1882768, standard deviation: 3600594) and the number of emigrants (mean: 2377088, standard deviation: 3148279), forecasts of their values in the “Decade of Action” (in the period up to 2030) are made. In Fig. 1-2, histograms of their normal distribution are constructed.

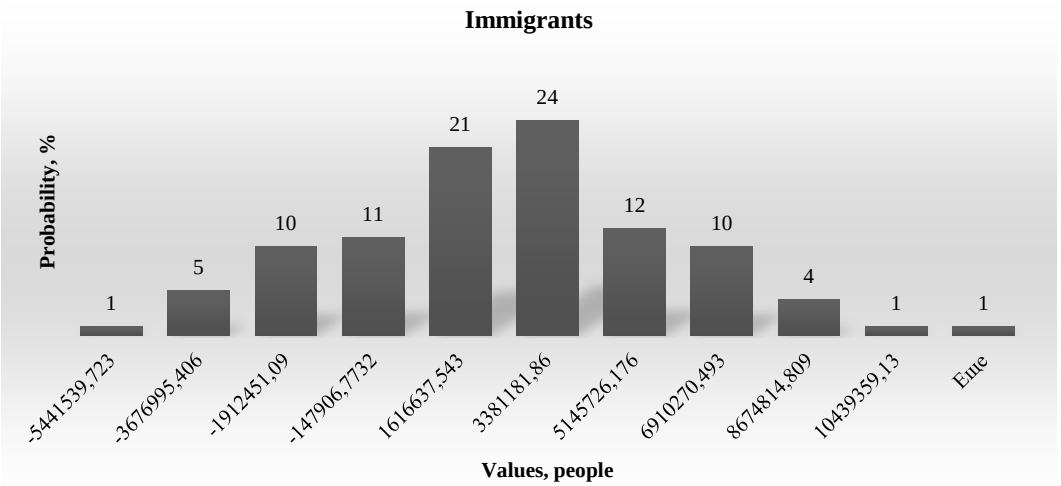

Figure 1. Histogram of the normal distribution of the forecast of changes in the number of immigrants in Russia and other CIS countries until 2030
Source: calculated and constructed by the autors

As can be seen from Figure 1, with a probability of 21%, the number of immigrants in Russia and other CIS countries will remain at the level of 2021 (about 1882768 people) in the period up to 2030.).

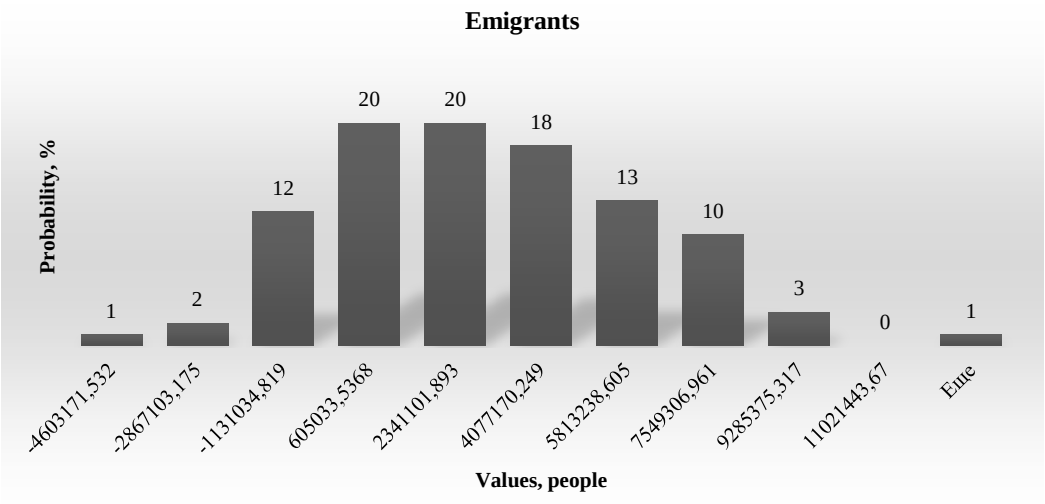

Figure 2. Histogram of the normal distribution of the forecast of changes in the number of immigrants in Russia and other CIS countries until 2030
Source: calculated and constructed by the autors

As can be seen from Fig. 2, with a probability of 20%, the number of emigrants from Russia and other CIS countries will remain at the level of 2021 (about 2377088 people)in the period up to 2030. This article discusses the following four alternative scenarios:

1. Scenario of growing the incoming and outgoing migration flows. This scenario assumes the deregulation of migration and the continuation of the free movement of its flows under the influence of globalization. According to the forecasts in Fig. 1-2, in this case, with a probability (p) of 52%, the number of immigrants in Russia and the CIS countries will increase to 3381182 people or more. At the same time, with a probability of 45%, there will be an increase in the number of emigrants from Russia and other CIS countries to 4077170 people or more.

2. Scenario of active recruitment and retention of personnel. This scenario assumes tighter state regulationsassociated with limiting the outgoing flow of migration, as well as stimulating the influx of migrants. According to the forecasts in Fig. 1-2, in this case, with a probability of 52%, there will be an increase in the number of immigrants in Russia and CIS countries to 3381182 people or more. At the same time, with a 35% probability, there will be a reduction in the number of emigrants from Russia and other CIS countries to 605033 people or less.

3. The scenario of retention (migration restriction). This scenario also assumes stricter government regulations associated with limiting the outgoing flow of migration, but unlike the previous scenario - limiting the influx of migrants, that is, protecting society and the economy of Russia and other countries from incoming new residents, workers and students. According to the forecasts in Fig. 1-2, in this case, with a probability of 48%, there will be a decrease in the number of immigrants in Russia and CIS countries to 1616637 people or less. At the same time, with a 35% probability, there will be a reduction in the number of emigrants from Russia and other CIS countries to 605033 people or less.

4. The scenario of filtration of incoming and freedom of outgoing migration flow. This scenario also involves limiting the influx of migrants, that is, protecting society and the

economy of Russia and other countries from the influx of new residents, workers and students, but the deregulation of exit from the country. According to the forecasts in Fig. 1-2, in this case, with a probability of 48%, there will be a decrease in the number of immigrants in Russia and CIS countries to 1616637 people or less. At the same time, with a probability of 45%, there will be an increase in the number of emigrants from Russia and other CIS countries to 4077170 people or more.

The predicted values of the factor variables for each scenario are substituted into the regression equations in the model (2) and the growth rate of the resulting variables is determined (Table 6).

Table 6. Scenarios of quality change in Industry 4.0 in Russia and other CIS countries depending on the flows of educational and labor migration

Indicators	Basic values (2021)	Values under alternative scenarios			
		Increasing the incoming and outgoing migration flow (globalization)	Active recruitment and retention of personnel	Retention of personnel (migration restriction)	Filtration of incoming and freedom of outgoing migration flow
Immigrants,people	1882768 (p=21%)	3381182 and more (p=52%)	3381182 and more (p=52%)	1616637 and less(p=48%)	1616637 and less (p=48%)
Emigrants, people	2377088 (p=20%)	4077170 and more (p=45%)	605033 and less(p=35%)	605033 and less(p=35%)	4077170 and more (p=45%)
High-tech manufacturing , points 1-100	17,11	31,98 (+86,93%)	-553,37%	-286,55%	77,64 (+353,76%)
Knowledge-intensive employment, points 1-100	32,81	55,57 (+69,36%)	-361,70%	-194,83%	100,00 (+236,23%)
Knowledge capital, points 1-100	64,72	89,92 (+38,93%)	-249,53%	-129,05%	100,00 (159,41%)
Educational enabling environment, points 1-100	67,30	90,06 (+33,82%)	-230,60%	-117,96%	100,00 (146,46%

Source: calculated and compiled by the autors

The scenario of increasing the incoming and outgoing migration flow (globalization) allows significantly (on average by (86,93+69,36+38,93+33,82)/4=57,26%) to improve quality in industry 4.0. According to this scenario, the growth of high-tech manufacturing is achieved by 86.93% from 17.11 points in 2021 to 31.98 points; an increase in knowledge-intensive employment by 69.36% from 32.81 points in 2021 to 55.57 points; increase of knowledge capital by 38.93% from 64.72 points in 2021 to 89.92 points; growth of educational enabling environment by 90.06% from 67.30 points in 2021 to 90.06 points. The probability of this scenario: (52+45)/2=48,5% – this is the most likely of the four scenarios considered.

The scenario of active recruitment and retention of personnel does not contribute to improvement, but on the contrary is associated with a high risk of reducing the product quality of industry 4.0 in Russia and other CIS countries (on average by (553,37+361,70+249,53+230,60)/4=348,8%)

According to this scenario, the decline of high-tech manufacturing is -553.37%, the reduction of knowledge-intensive employment: -361.70%, the decrease of knowledge capital: -249.53, the decline of educational enabling environment: -230.60%. The probability of this scenario: (52+35)/2=43,5%.

The personnel retention scenario (migration restriction) also does not contribute to an increase, but on the contrary is associated with a high risk of a decrease in the product quality of industry 4.0 in Russia and other CIS countries (on average by (286,55+194,83+129,05+117,96)/4=182,10 %). According to this scenario, the decline of high-tech manufacturing is -286.55%, the reduction of knowledge-intensive employment: -194.83%, the decrease of knowledge capital: -129.05, the decline of educational enabling environment: -117.96%. The probability of this scenario: (48+35)/2=41,5% – this is the least likely of the four scenarios considered.

The last (fourth) of the considered scenarios has proved to be the best.The probability of this scenario: (48+45)/2=46,5%. In this scenario, the optimization of educational and labor migration flows provides the highest rate of quality growth in industry 4.0 in Russia and other CIS countries (Fig. 3).

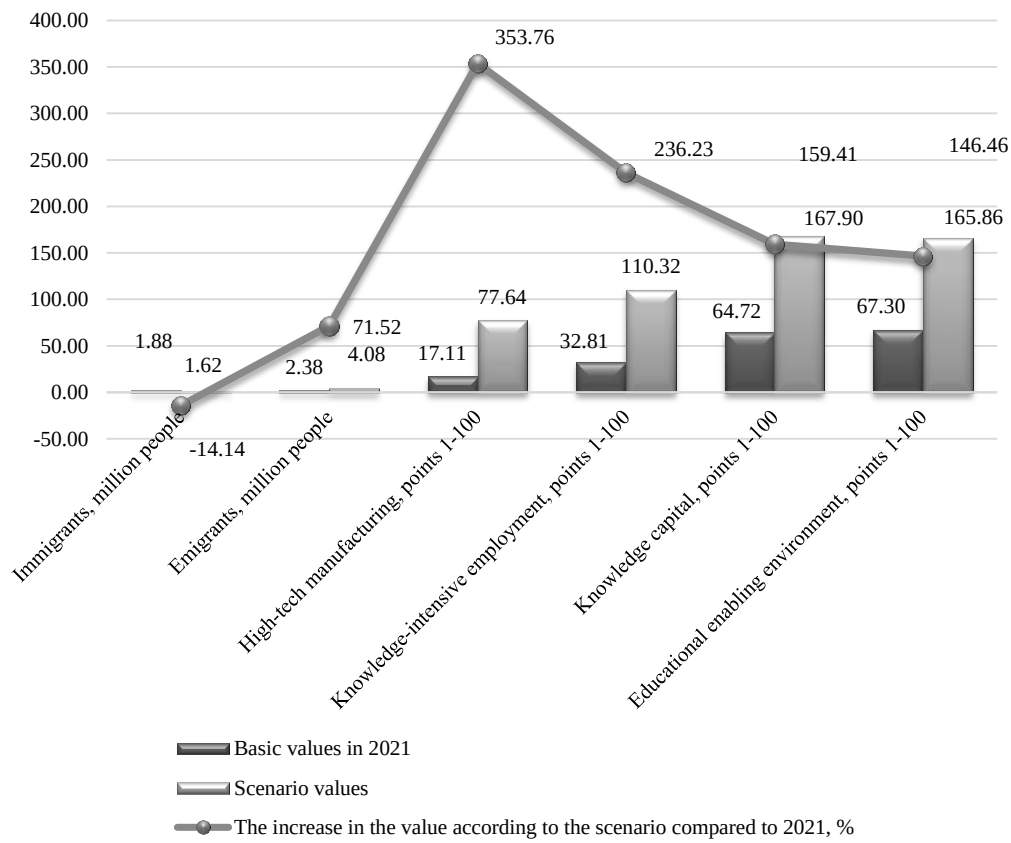

Figure 3. The scenario of filtration of incoming and freedom of outgoing migration flow in Russia and other CIS countries until 2030.
Source: calculated and constructed by the authors

According to this scenario, the growth of high-tech manufacturing is achieved by 353.76% to 77.64 points; an increase in knowledge-intensive employment by 236.23% to 100 points; an increase in knowledge capital by 159.41% to 100 points; an increase in educational enabling environment by 146.46% to 100 points. Therefore, the chosen best scenario allows significantly (on average by (353,76+236,23+159,41+146,46)/4=223,96 %) to improve the product quality of industry 4.0 in the "Decade of Action" (in the period up to 2030) in Russia and other CIS countries.

4.3 The promising model ofmigration flow management to improve the quality of Industry 4.0 products in Russia and other CIS countries

To solve the third research task in order to strengthen scientific and methodological support for the implementation of the chosen best scenario, a promising model of migration flow management has been developed to improve the product quality of industry 4.0 in the "Decade of Action" (until 2030) in Russia and other CIS countries (Fig. 4).

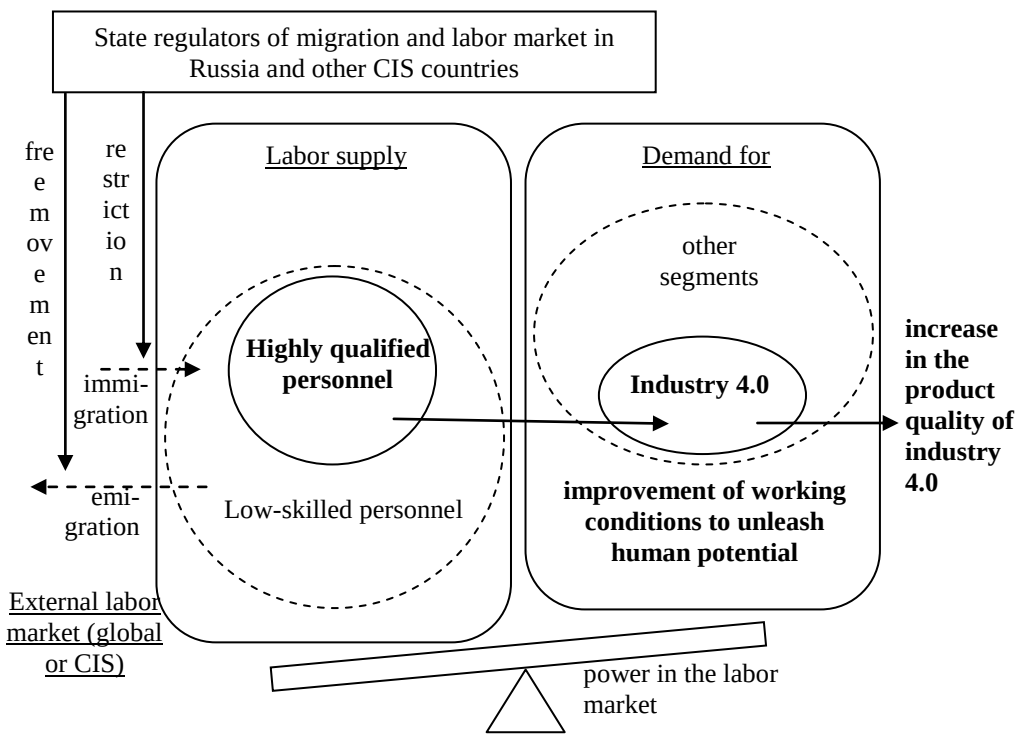

Figure 4. The promising model of migration flow management for improving the product quality of industry 4.0 in Russia and other CIS countries
Source: developed and constructed by the authors

The authors' model presented in Fig. 4 provides optimization of migration flows based on state regulation. In this regard, the subjects of migration flow management in the model are state migration regulators, on the one hand, and the labor market in Russia and other CIS countries, on the other.The core of the labor supply is highly qualified personnel who do not participate in the movement of the migration flow (remain

unchanged).

The following two measures related to managing migration are recommended for implementation. The first measure is to restrict immigration (incoming migration flow) to prevent the destabilization of the labor market due to an overabundance of low-skilled personnel.

The second measure is to ensure the free movement of emigration (outgoing migration flow) in order to allow low-skilled personnel who cannot withstand high competition in the local labor market to voluntarily leave this market and find work outside it - in the external labor market: global or CIS.

As a result, the overall level of competition of sellers in the local labor market decreases, thereby increasing the power of sellers (workers) in this market. This corrects the demand for labor: in Industry 4.0, working conditions are improving to fully unleash the human potential of local highly qualified personnel. As a result, this contributes to improving the quality of products in industry 4.0.The proposed perspective model of migration flow management for improving theproduct quality of industry 4.0 has the following additional advantages:

– it orients highly qualified personnel towards successful employment by profession and building a career in industry 4.0;

– it shows low-skilled personnel a real picture of their competitiveness in the labor market, thereby avoiding false expectations and excessive demands on working conditions on the part of these personnel;

– it maintains the psychological background among the economically active population at a normal level, giving them the freedom to emigrate, which serves as a natural (market) mechanism for retaining the best staff.

5. Discussion

The contribution of the article to the literature is to develop the scientific provisions of the concept of product quality management in industry 4.0 by strengthening the evidence base of the critical importance of human resources to achieve high quality of these products (in support of Alkhallidy, 2020; Kerdpitak and Boonrattanakittibhumi, 2020; MohamedImhmedAbuazoom et al., 2019; Nizamidou et al., 2019; Padula et al., 2021; Pajpach et al., 2022; Santos et al., 2021; Verma et al., 2020). The received answers to the RQs are presented in Table 7 in contrast with the existing literature.

Table 7. The received answers to RQs in contrast with the existing literature

Research questions (RQs)	Answers in the existing literature	New answers received in the article
RQ_1: Does immigration allow attracting highly qualified personnel for industry 4.0?	yes: in developed countries, immigration makes it possible to attract highly qualified personnel (provides an influx of the best specialists from all over the world) (Duarte and Rodríguez, 2021; Janaviciute et al., 2017; Lim, 2021; Mendoza, 2022; Samuk et al., 2023)	no: in Russia and other CIS countries, immigration causes an influx of low-skilled personnel, which reduces the power of sellers in the labor market
RQ_2: Does emigration lead to the loss of highly qualified personnel for industry 4.0?	yes: in developing countries, emigration leads to the loss of highly qualified personnel (causes brain drain) (Alili et al., 2022; Bhardwaj and Sharma, 2023; Lee et al., 2021; Mittelmeier et al., 2022)	no: low-skilled personnel emigrate to Russia and other CIS countries, whose departure increases the power of sellers in the labor market

Source: deeloped and compiled by the autors

As can be seen from Table 1, contrary to Duarte and Rodríguez (2021), Janaviciute et al. (2017), Lim (2021), Mendoza (2022), Samuk et al. (2023), the article proves that, unlike developed countries where immigration allows attract highly qualified personnel (provides an influx of the best specialists from all over the world), immigration in Russia and other CIS countries causes an influx of low-skilled personnel, which reduce the power of sellers in the labor market.

In contrast to the position of as authors as Alili et al. (2022), Bhardwaj and Sharma (2023), Lee et al. (2021), Mittelmeier et al. (2022), the article proves that unlike the general category of developing countries, where emigration leads to the loss of highly qualified personnel (causes brain drain), in Russia and other CIS countries, on the contrary, there is an emigration of low-skilled personnel, whose departure increases the power of sellers in the labor market.

6. Conclusion

In the course of the study, the following results have been obtained:

1) The consequences of educational and labor migration for quality in industry 4.0 in Russia and other CIS countries have been revealed.Using econometric modeling of the experience of Russia and other CIS countries based on data for 2021, it has been proved that immigration does not allow attracting highly qualified personnel for industry 4.0, but at the same time emigration does not lead to the loss of highly qualified personnel for industry 4.0. On average, migration determines the quality of products in industry 4.0 by 58.01% ((63.13+59.66+59.92+49.34)/4).

2) Alternative scenarios of quality change in industry 4.0 in Russia and other CIS countries have been created, depending on the flows of educational and labor migration in the “Decade of Action” (in the period up to 2030). The scenario of increasing the incoming and outgoing migration flow (globalization) allows improving the quality in industry 4.0 by 57.26% with a probability of 48.5%. The scenario of active recruitment and retention of personnel does not contribute to improvement, but on the contrary is associated with a high risk of reducing the quality of industry 4.0 products in Russia and other CIS countries: 348.8% with a probability of 43.5%.

The most dangerous, but least likely scenario of staff retention (migration restriction) also does not contribute to an increase, but on the contrary is associated with a high risk of a decrease in the product quality of industry 4.0 in Russia and other CIS countries: by 182.10% with a probability of 41.5%. The scenario of filtration of incoming and freedom of outgoing migration flow has proved to be the best. In this scenario, the optimization of educational and labor migration flows provides the highest rate of quality growth in industry 4.0 in Russia and other CIS countries by 223.96 with a probability of 46.5%.

3) In order to strengthen scientific and methodological support for the implementation of the chosen best scenario, a promising model of migration flow management has been developed, aimed at improving the quality of industry 4.0 products in Russia and other CIS countries. Migration management in the authors’ model assumes, on the one hand, the restriction of immigration (incoming migration flow) to prevent the destabilization of the labor market due to an overabundance of low-skilled personnel.

On the other hand, ensuring the free movement of emigration (outgoing migration flow) in order to allow low-skilled personnel who cannot withstand high competition in the local labor market to voluntarily leave this market and find work outside it - in the external labor market: global or CIS. Due to this, the model generates natural (market) incentives to retain the best local highly qualified

personnel.

The useful effect of the model is that it reduces the overall level of competition of sellers in the local labor market, thereby increasing the power of sellers (workers) in it. This has a corrective effect on the demand for labor. As a result, in industry 4.0, working conditions are improving to fully unleash the human potential of local highly qualified personnel.

The key conclusion of the study is that labor migration is associated with the highest risks in Russia and other CIS countries, as it saturates local labor markets with low-skilled personnel, while limiting opportunities for both employment and disclosure of the human potential of highly qualified personnel.Educational migration can be useful provided that university graduates are highly qualified personnel and prefer to stay in the country where they receive higher education for employment and career building in industry 4.0.

The theoretical significance of the results obtained in the article is that they clarified the role of the migration mechanism in the process of product quality management of industry 4.0 and took into account the unique experience of Russia and other CIS countries. The practical significance of the authors' conclusions and recommendations is due to the fact that they make it possible to improve the efficiency of quality management in industry 4.0 based on educational and labor migration in Russia and other CIS countries.

The social significance of the article is related to the fact that the results have enriched knowledge and expanded the horizon of implementation, provided a systematic approach to their implementation in practice in the "Decade of Action" of such Sustainable Development Goals (SDGs) as SDG 4 (in terms of optimizing educational migration flows),SDG 8 (in terms of optimizing labor migration flows, ensuring decent employment for personnel for industry 4.0 and accelerating the growth rate of the digital economy),SDG 9 (in terms of improving the staffing of Industry 4.0), SDG 16 (in terms of improving the efficiency of the migration institute) and SDG 17 (in terms of using the migration mechanism to strengthen the partnership of the CIS countries).

The limitation of the results obtained in the course of this study is that they are based on the experience of 2021, since more recent data have not yet been presented in official statistics. The aggravation of the international sanctions crisis in 2022 could potentially bring significant changes to the scale and nature of the movement of migration flows in Russia and other CIS countries. Therefore, in future studies, as statistics become available, it is advisable to rethink the conclusions obtained in the article taking into account the latest experience of Russia and other CIS countries in 2022-2023.

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