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THE ATTRACTION OF DIGITAL PERSONNEL AND CORPORATE TRAINING IN QUALITY MANAGEMENT IN INDUSTRY 4.0 WITH A BALANCE BETWEEN SUSTAINABILITY AND COMPETITIVENESS

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A B S T R A C T

The purpose of the article is to develop a systematic scientific vision of the quality assurance process in industry 4.0 through HRM of digital personnel. This vision is based on a new ("broad") interpretation of quality in industry 4.0, which can maintain a balance between sustainability (the support of the SDGs) and global digital competitiveness and most completely take into account the characteristics of product quality in industry 4.0. In accordance with the authors' interpretation based on international experience for 2021-2022, the article presents an econometric model that mathematically describes the impact of HRM of digital personnel on product quality in industry 4.0. The key conclusion of the study is that the attraction of job-ready digital personnel makes a much greater contribution to improving quality in industry 4.0 and is therefore preferable as compared to corporate training of digital personnel. For the fullest disclosure of the potential of quality improvement in industry 4.0, the authors have developed a program-target approach to HRM of digital personnel with a balance between sustainability and competitiveness of quality in industry 4.0. The theoretical significance of the research results is due to the fact that they have allowed for the first time to develop an approach to HRM of digital personnel that ensures high quality in industry 4.0 in accordance with its innovative interpretation – with a balance between sustainability and competitiveness. The practical significance of the authors' recommendations lies in the fact that the proposed program-target approach to quality assurance in industry 4.0, with a balance between sustainability and competitiveness, will increase the efficiency of HRM of digital personnel and comprehensively take into account the interests of stakeholders in ensuring product quality in industry 4.0.

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1. INTRODUCTION

The quality of products determines its competitiveness and position in the market. Although perceptions and approaches to human resource management (HRM) have changed with the development of socio-economic systems, these resources have always been important for ensuring product quality. In the conditions of a consumer society, when the first industrial revolutions made it possible to overcome the total deficit due to mass production and the “effect of scale”, the most important and in fact the only quality criterion was the compliance of products with the current quality standards. This criterion made it possible to comprehensively take into account the interests of two interested parties.

On the one hand, the interests of the manufacturer: standardization and quality control ensure a consistently high sales rate with a minimum share of product returns and minimal costs for resolving disputes with consumers. On the other hand, the interests of consumers: standardized products most fully meet the expectations and needs of the needs of consumers. In this regard, HRM assumed such patterns of perception of employees as “interchangeable parts”, and included a requirement for employees to accomplish the production plan and meet current quality standards of products.

Social progress has caused a change in market conditions, an increase in the number of stakeholders, as well as the complexity of product quality requirements. The production of products, taking into account the interests of employees, is assumed to be socially responsible, i.e. corporate social responsibility is one of the quality requirements. In this regard, HRM involves improving working conditions in a broad sense, covering not only work safety, but also the psychological atmosphere in the workforce, as well as motivation and stimulation of work.

The aggravation of global environmental problems, in particular caused by climate change and environmental pollution, has triggered a new wave of social progress, which has led to the formation of environmentally responsible communities. This new category of stakeholders has its own requirements for quality, which are related to the environmental friendliness of products. This requirement is fully in line with "green" products that comply with specially introduced environmental standards. In this regard, HRM assumes the creation of “green” jobs.

The formation of a “knowledge society” and an innovative economy has contributed to the emergence of requirements for innovation, which are a new dimension of product quality. New product properties, as well as the use of new production and distribution techniques, largely determine the competitiveness of products. In this regard, HRM involves attracting creative personnel, creating knowledge-intensive jobs and stimulating the innovative activity of employees.

The Fourth Industrial Revolution transformed the interests of all stakeholders, adding to them a new requirement for product quality. This new universal requirement has become the use of high technologies, which determines the digital competitiveness of products - the ability of products to withstand competition in a new, digital form. In industrial and manufacturing engineering 4.0, HRM involves the management of digital personnel – employees with digital competencies.

The problem is that the Fourth Industrial Revolution, which has begun recently and is still going on, has not yet passed a sufficient scientific discussion, which is why the issue of HRM in industry 4.0 remains open. The divergence between the listed quality requirements causes uncertainty in both its scientific interpretation in the context of industry 4.0 and the choice of the most preferred approach to HRM to ensure the quality of products in industry 4.0. This is a gap in the literature that this article seeks to fill.

The purpose of the article is to develop a systematic scientific vision of the quality assurance process in industry 4.0 through HRM of digital personnel. To achieve this goal, the article solves three tasks. The first task is to conduct a factor analysis of quality assurance in industry 4.0 through HRM of digital personnel. The second task is to develop alternative scenarios for quality management in industry 4.0 from the perspective of HRM of digital personnel. The third task is related to the development of a program-target approach to quality assurance in industry 4.0 through HRM of digital personnel.

2. LITERATURE REVIEW

2.1. Systemic interpretation of quality in industry 4.0 with a balance between sustainability and competitiveness

The theoretical basis of the research in this article is the concept of quality in industry 4.0. In accordance with the existing concept, quality in industry 4.0 includes two components. The first component is the main one, it is widespread in the existing literature and is sometimes found in the formulation “quality 4.0” (Đapan et al., 2019; Popkova, 2019; Popkova and Giyzov, 2021, Arsovski 2023). This component reflects the engineering complexity of the product, its suitability for use in subsequent links (in high-tech industries) of the value chain in industry 4.0, as well as compliance with the current quality standards applied to these products (no defects) (Handayani et al., 2022; Misita and Milanovic, 2019; Sharma, 2023; Stefanović et al., 2019, Ceko 2023).

The second component is considered additional, is considered separately and is often not taken into account when studying the quality of products in industry 4.0.

This component includes all the characteristics of products of industry 4.0 that are not related to its consumer properties (technical characteristics). Among these additional characteristics of products of industry 4.0, firstly, social responsibility towards digital personnel involved in the production of products in industry 4.0, manifested in the creation of favorable conditions for the disclosure of their human potential and social justice of labor collectives (Lepore et al., 2022; Meng et al., 2022).

Secondly, the environmental friendliness of products of industry 4.0, achieved through corporate environmental responsibility in the process of industrial and manufacturing engineering 4.0 (Zhang and Zhao, 2023). "Green" jobs contribute to the greening of cities and the creation of environmentally sustainable territories with a favorable environment (Ning et al., 2022). For example, artificial intelligence (AI) allows for "smart" sorting and environmentally safe waste disposal, as well as the development of circular production in industry 4.0 (Chen et al., 2023; Pan et al., 2022).

The energy efficiency of industry 4.0 deserves special attention. Automated, especially robotic, production is characterized by high energy intensity (Li and Wang, 2023; Zhao et al., 2022). The introduction of innovations that reduce energy consumption in production of industry 4.0 or allow industrial and manufacturing engineering 4.0 to switch to "clean" energy is important for quality in terms of environmental friendliness of products (Gao and Peng, 2023). Due to such innovations, the high-tech nature of products of industry 4.0 is preserved, and its quality is complemented by improved energy properties (Nizam et al., 2020). Energy innovations that contribute to the development of energy-efficient manufacturing and consumption practices are of great importance (Xin et al., 2023; Zhao and Qian, 2023).

It is noteworthy that all these characteristics not only determine the competitiveness of industry products 4.0 and, in particular, their digital competitiveness, but are also reflected in the Sustainable Development Goals (SDGs) (Beier et al., 2021). Thus, innovation and high-tech (quality 4.0) are enshrined in SDG9. Socially responsible HRM of digital personnel implies decent employment (SDG 8), reduction of inequality (SDG 10) and gender neutrality of workplaces (SDG5). The creation of "green" jobs based on corporate environmental responsibility contributes to environmentally sustainable development (SDG11), energy efficiency improvement and the development of "clean" energy (SDG7) in the territories where production of industry 4.0 is located.

In the existing literature, the most common is a "narrow" interpretation of quality in industry 4.0, limited by global digital competitiveness (Arsovski, 2019; Thach et al., 2021; Woźniak et al., 2022; Zimon et al., 2022). The disadvantage of the current interpretation is that it is limited to the first, the main component of product quality in industry 4.0. In order to fully take into account the characteristics of product quality in industry 4.0 in the unity of both highlighted components, this article proposes a new – systemic ("broad") interpretation of quality in industry 4.0 with a balance between sustainability (the support of the SDGs) and global digital competitiveness.

2.2. Alternative approaches to quality assurance in industry 4.0 through HRM of digital personnel

In accordance with the existing ("narrow") interpretation of product quality in industry 4.0, in the available works of Capasso and Umbrello (2022), Kee et al. (2023), Kiener et al. (2023), Stofkova et al. (2022), the role of HRM of digital personnel in quality assurance in industry 4.0 is reduced to the creation and implementation of breakthrough technologies, as well as the use of advanced automation tools to gain and strengthen digital competitive advantages. The noted role of personnel management makes it possible to bring the products of industry 4.0 in line only with the main component of quality, while the possibility to take into account both (main and additional) components of product quality in industry 4.0 remains unknown.

The lack of a well-formed approach to HRM of digital personnel, which ensures high quality in industry 4.0 with a balance between sustainability and competitiveness, is a gap in the literature. This raises the following research question. RQ: How to ensure high quality in industry 4.0 through HRM of digital personnel with a balance between sustainability and competitiveness? To date, there have been two alternative approaches to HRM of digital personnel, which form alternative answers to the RQ posed in thy article.

The first approach assumes the involvement of job-ready digital personnel. The essence of this approach is that the government places a state order to universities 4.0 for the training of digital personnel in accordance with national standards of higher education (Rocha et al., 2022). It is also possible to train digital personnel based on paid higher education services. This allows graduates of universities 4.0 to develop a wide range of digital competencies, but most of them are theoretical ones (Hernandez-de-Menendez et al., 2020a).

The advantage of this approach is that enterprises of industry 4.0 receive job-ready digital personnel and do not incur expenditures associated with their training (Motyl and Filippi, 2021). The disadvantage of this approach is that the lack of applied digital competencies that are in demand in industry 4.0 complicates the employment of graduates of universities 4.0. At the same time, enterprises of industry 4.0 are experiencing a shortage of digital personnel with the necessary applied competencies (Dao et al., 2023).

The second approach is related to corporate training of digital personnel. At the same time, enterprises of industry 4.0 attract professional industry personnel to their workplaces, most of whom already have work experience in their profession, and then continue to develop the digital competencies of these employees in the learning process. For this purpose, targeted (narrowly focused, employer-funded) university training or advanced training is used, as well as on-the-job skills training, for example, through mentoring (Sein-Echaluceet al., 2022).

The advantage of this approach is that industry specialists get the opportunity to avoid the release of personnel due to automation and find a job in industry 4.0. Enterprises of industry 4.0 give employment to those specialists who have a targeted set of applied digital competencies that are in demand in this particular production. The disadvantage of this approach is that corporate training provides the development of only a narrow set of digital competencies, which may not be sufficient, and this, in turn, will certainly affect the quality of products. Another disadvantage is that enterprises of industry 4.0 incur the costs of corporate training of digital personnel. The transition from one production of industry 4.0 to another naturally leads to an increase in the shortage of digital competencies, which especially affects the quality of products (Roll and Ifenthaler, 2021).

The literature review conducted by the authors shows that both existing alternative approaches to HRM of digital personnel have been studied in sufficient detail and are widely represented in the available literature. Nevertheless, the applicability of existing approaches to quality assurance in industry 4.0 through HRM of digital personnel has not been sufficiently developed and remains unknown, which is why the RQ remains unanswered.

The authors of most literature sources, guided by the “narrow” interpretation of quality in industry 4.0 (Liu et al., 2023), note that this quality is ensured through corporate training aimed at developing a narrow range of digital competencies that are in demand at the enterprise of industry 4.0 (Lepore et al., 2022; Patiño et al., 2023). In contrast to this position, authors such as Hernandez-de-Mendez et al. (2020b), Li (2022) note the advantage of digital personnel trained in universities 4.0, associated with their broader set of competencies. On this basis, the following hypothesis is put forward in this article.

H: the attraction of job-ready digital personnel makes a much greater contribution to improving quality in industry 4.0 than corporate training of digital personnel. To test the hypothesis put forward in this article, econometric modeling is carried out based on the latest international experience, revealing the impact of alternative approaches to HRM of digital personnel – attracting job-ready personnel and corporate training – on the product quality in industry 4.0 in its authors' systemic interpretation with a balance between sustainability and competitiveness.

3. RESEARCH DESIGN AND METHOD

To achieve the purpose of this study, it consistently solves the following three tasks. The first task: to conduct a factor analysis of quality assurance in industry 4.0 through HRM of digital personnel. This task is solved using the regression analysis method. Using the chosen method, the regression dependence of product quality characteristics in industry 4.0 in its systemic interpretation is determined with a balance between sustainability and competitiveness on HRM factors of digital personnel.

To quantitatively measure the characteristics of product quality in industry 4.0, the following indicators are used:

- “Global competitiveness score” (QLT4.01) as an indicator of global digital competitiveness embodying the main component of quality (from the standpoint of quality standardization 4.0), calculated by IMD (2023);
- “Goal 9 Score” (QLT4.02) as an indicator of quality 4.0, reflecting both digital competitiveness and compliance with the SDGs, calculated by UN (2023);
- “Goal 8 Score” (QLT4.03) as an indicator of the disclosure of human potential through corporate social responsibility, calculated by UN (2023);
- “Goal 10 Score” (QLT4.04) as an indicator of social justice in the workplace achieved through corporate social responsibility, calculated by UN (2023);
- “Goal 5 Score” (QLT4.05) as an indicator of gender neutrality of workplaces achieved through corporate social responsibility, calculated by UN (2023);
- “Goal 11 Score” (QLT4.06) as an indicator of "green" jobs that ensure environmental sustainability of territories, calculated by UN (2023);
- “Goal 7 Score” (QLT4.07) as an indicator of energy efficiency and the use of "clean" energy, calculated by UND (2023).

All these indicators are measured in scores from 1 to 100 (best), which ensures comparability of data and guarantees the reliability of interpretation of the results of factor analysis. The following indicators are used to quantify the HRM factors of digital personnel:

- “Digital/Technological skills” (DHRM1), score 0-10 (best) as an indicator of attracting job-ready digital personnel, calculated by IMD (2023);
- “Firms offering formal training” (DHRM2), score 0-100 (best) as an indicator of corporate training, in particular, digital personnel, calculated by the WIPO (2023).

In accordance with the entered designations, the research model has the following form:

$$QLT4.0=a+b_1*DHRM_1+b_2*DHRM_2, \quad (1)$$

where a –a constant;
b – a regression coefficient.

The reliability of the regression model (1) is checked using correlation analysis, Fisher’s F-test, Student’s t-test and standard errors for factor variables. Hypothesis H is considered proven if in the research model (1) $b_1 > b_2$, which will mean a greater contribution of attracting job-ready digital personnel to improving quality in industry 4.0 compared to corporate training of digital personnel.

The study sample includes all 43 countries for which data are available in the materials of official statistics MD (2023), UN (2023) and WIPO (2023), that is, for which there are no data gaps. The time frame of the study covers 2021-2022, the data for which are combined into a common array, including 86 observations. The economic and geographical structure of the study sample (in the classification of countries used by UN, 2023) is reflected in Fig. 1.

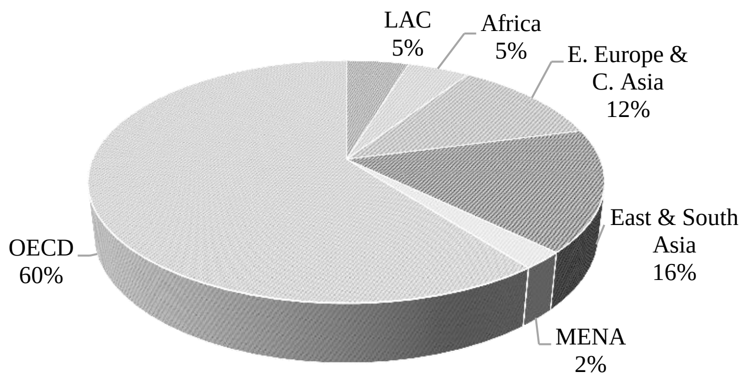


Figure 1. Economic and geographical structure of the study sample
Source: calculated and constructed by the authors.

As shown in Figure 1, the sample is dominated by OECD countries (26 countries, 60%). The sample also includes countries from East & South Asia (7 countries, 16%), from E. Europe & C. Asia (5 countries, 12%), LAC countries (2 countries, 5%), Africa countries (2 countries, 5%) and MENA countries (1 country, 2%). The diversified economic and geographical structure of the sample ensures its representativeness and applicability in this study. The sample of the study is attached to this article as a separate file with a table of Microsoft Excel.

The second task: to create alternative scenarios for quality management in industry 4.0 from the perspective of HRM of digital personnel. To do this, the values of factor variables are substituted into the research model (1) in accordance with alternative scenarios. The scenario of more active recruitment of digital personnel involves maximizing the value of the indicator “Digital/Technological skills” (increasing $DHRM_1$ to 10 scores). At the same time, the value of the indicator “Firms offering formal training” remains unchanged (at the level of 2022).

An alternative scenario of the development of corporate training involves maximizing the value of the indicator “Firms offering formal training” (increasing $DHRM_2$ to 100 points). At the same time, the value of “Digital/Technological skills” remains unchanged (at the level of 2022). Using the trend analysis method, the trend is calculated – the direction and scale of changes in the values of the dependent variables in the research model (1) are estimated under the influence of the indicated change in the values of factor variables for each of the selected scenarios.

The third task: to develop a program-target approach to quality assurance in industry 4.0 through HRM of digital personnel. The approach is developed using a program-target method of management in relation to HRM. To ensure the clarity of the authors’ approach, the method of graphical representation of information is used. The approach reflects the “tree of goals”, that is, it reveals the purpose, tasks, tools for achieving them and the result provided by the implementation of the approach associated with improving the quality of products in industry 4.0.

4. RESULTS

4.1. Factor analysis of quality assurance in industry 4.0 through HRM of digital personnel

As part of solving the first task of this study and determining the HRM factors of digital personnel that affect quality assurance in industry 4.0, the authors define the dependence of characteristics of product quality in industry 4.0 in its systemic interpretation with a balance between sustainability and competitiveness on the HRM factors of digital personnel through regression analysis. In accordance with the research model (1), the following system of equations is obtained:

$$\begin{cases} QLT4.0_1=-9.3898+10.5863*DHRM1+0.0880*DHRM2, \\ QLT4.0_2=43.0564+4.7883*DHRM1+0.0088*DHRM2, \\ QLT4.0_3=-1.9375+10.2837*DHRM1+0.0243*DHRM2, \\ QLT4.0_4=-10.6218+11.5813*DHRM1-0.0328*DHRM2, \\ QLT4.0_5=50.1886+2.2385*DHRM1+0.1475*DHRM2, \\ QLT4.0_6=56.8771+3.6590*DHRM1+0.0228*DHRM2, \\ QLT4.0_7=52.3679+4.3997*DHRM1-0.0393*DHRM2. \end{cases} \quad (2)$$

The econometric model (2) indicates that an increase in the level of development of digital/Technological skills by 1 point is accompanied by an increase in global competitiveness score by 10.5863 points, Goal 9 Score – by 4.7883 points, Goal 8 Score – by 10.2837 points, Goal 10 Score – by 11.5813 points, Goal 5 Score – by 2.2385 points, Goal 11 Score – by 3.6590 points, Goal 7 Score – by 4.3997 points.

An increase in firms offering formal training by 1 point contributes only to a slight increase in global competitiveness score (by 0.0880 points), Goal 9 Score (by 0.0088 points), Goal 8 Score (by 0.0243 points), Goal 5 Score (by 0.1475 points) and Goal 11 Score (by 0.0228 points) and does not have a positive impact on Goal 10 Score (regression coefficient negative: -0.0328) and on Goal 7 Score (regression coefficient negative: -0.0393). The assessment of the reliability of the econometric model (1) is illustrated in Tables 1-7.

Table 1. Regression analysis of the dependence of global competitiveness score on HRM of digital personnel

Regression statistics	
Multiple R	0.7300
R-Square	0.5329
Adjusted R-Square	0.5216
Standard Error	10.4835
Observations	86

ANOVA

	df	*SS*	*MS*	*F*	*Signifi-cance F*
Regression	2	10405.7856	5202.8928	47.3400	$1.9*10^{-14}$
Residual	83	9122.0917	109.9047		
Total	85	19527.8773			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	-9.3898	7.8552	-1.1954	0.2354	-25.0136	6.2339
$DHRM_1$	10.5863	1.1488	9.2151	$2.4*10^{-14}$	8.3014	12.8712
$DHRM_2$	0.0880	0.0433	2.0316	0.0454	0.0018	0.1741

Source: calculated and compiled by the authors.

The results obtained in Table 1 indicate that the global competitiveness score is 73.00% determined by the influence of HRM factors of digital personnel. The significance of F=1.9*10-14, therefore, the regression statistics under consideration corresponds to the highest level of significance: 0.001. Critical F=7.5159 with two factor variables (k_1=m=2) and 86 observations (k_2=n-m-1=86-2-1=83). The observed F=47.3400 – it exceeds the critical value. Therefore, the Fischer’s F-test has been passed.

Critical t=2.6349 at a given level of significance at 85 degrees of freedom. The observed t exceeds the critical value only with the factor variable $DHRM_1$ and is 9.2151. Consequently, Student’s t-test has been passed only for digital/technological skills, which is the only of the two factors considered that have a statistically significant impact on the dependent variable. The standard error for this factor variable is small: 1.1488, which indicates a small error in the results of regression analysis.

Table 2. Regression analysis of the dependence of Goal 8 Score on HRM digital personnel

Regression statistics	
Multiple R	0.5205
R-Square	0.2709
Adjusted R-Square	0.2533
Standard Error	7.9767
Observations	86

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	1962.0357	981.0179	15.4181	$2*10^{-6}$
Residual	83	5281.0815	63.6275		
Total	85	7243.1172			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	43.0564	5.9769	7.2038	$2.4*10^{-10}$	31.1687	54.9441
$DHRM_1$	4.7883	0.8741	5.4780	$4.5*10^{-7}$	3.0497	6.5268
$DHRM_2$	0.0088	0.0329	0.2667	0.7903	-0.0567	0.0743

Source: calculated and compiled by the authors.

The results obtained in Table 2 show that Goal 8 Score by 52.05% is determined by the influence of HRM factors of digital personnel. The significance of F=2*10-6, therefore, the regression statistics under consideration corresponds to the highest level of significance: 0.001. The observed F=15.4181 – it exceeds the critical value (7.5159). Therefore, Fischer's F-test has been passed.

The observed t exceeds the critical value (2.6349) only with the factor variable $DHRM_1$ and amounts to 5.4780. Consequently, Student's t-test has been passed only for digital/technological skills, which is the only of the two factors considered that have a statistically significant impact on the dependent variable. The standard error for this factor variable is small: 0.8741, which indicates a small error in the results of regression analysis.

Table 3. Regression analysis of the dependence of Goal 9 Score on HRM digital personnel

Regression statistics	
Multiple R	0.5546
R-Square	0.3075
Adjusted R-Square	0.2909
Standard Error	15.7056
Observations	86

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	9092.9046	4546.4523	18.4316	$2.4*10^{-7}$
Residual	83	20473.2788	246.6660		
Total	85	29566.1834			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	-1.9375	11.7681	-0.1646	0.8696	-25.3438	21.4687
$DHRM_1$	10.2837	1.7210	5.9753	$5.5*10^{-8}$	6.8607	13.7068
$DHRM_2$	0.0243	0.0649	0.3743	0.7091	-0.1047	0.1533

Source: calculated and compiled by the authors.

The results obtained in Table 3 indicate that Goal 9 Score is 55.46% determined by the influence of HRM factors of digital personnel. The significance of F=2.4*10-8, therefore, the regression statistics under consideration corresponds to the highest level of significance: 0.001. The observed F=18.4316 – it exceeds the critical value (7.5159). Therefore, Fisher's F-test has been passed.

The observed t exceeds the critical value (2.6349) only with the factor variable $DHRM_1$ and is 5.9753. Consequently, Student's t-test has been passed only for digital/technological skills, which is the only one of the two factors considered that has a statistically significant impact on the dependent variable. The standard error for this factor variable is small: 1.7210, which indicates a small error in the results of regression analysis.

Table 4. Regression analysis of the dependence of Goal 10 Score on HRM digital personnel

Regression statistics	
Multiple R	0.4067
R-Square	0.1654
Adjusted R-Square	0.1453
Standard Error	26.0783
Observations	86

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	11189.1230	5594.5615	8.2263	0.0006
Residual	83	56446.5345	680.0787		
Total	85	67635.6576			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	-10.6218	19.5403	-0.5436	0.5882	-49.4866	28.2431
$DHRM_1$	11.5813	2.8577	4.0527	0.0001	5.8975	17.2652
$DHRM_2$	-0.0328	0.1077	-0.3041	0.7618	-0.2470	0.1815

Source: calculated and compiled by the authors.

The results obtained in Table 4 indicate that Goal 10 Score by 40.67% is determined by the influence of HRM factors of digital personnel. The significance of F=0.0006, therefore, the regression statistics under consideration corresponds to the highest level of significance: 0.001. The observed F=8.2263 – it exceeds the critical value (7.5159). Therefore, Fisher's F-test has been passed.

The observed t exceeds the critical value (2.6349) only with the factor variable $DHRM_1$ and is 4.0527. Consequently, Student's t-test has been passed only for digital/technological skills, which is the only one of the two factors considered that has a statistically significant impact on the dependent variable. The standard error for this factor variable is small: 2.8577, which indicates a small error in the results of regression analysis.

Table 5. Regression analysis of the dependence of Goal 5 Score on HRM of digital personnel

Regression statistics	
Multiple R	0.3885
R-Square	0.1509
Adjusted R-Square	0.1305
Standard Error	11.3123
Observations	86

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	1887.7739	943.8870	7.3759	0.0011
Residual	83	10621.4273	127.9690		
Total	85	12509.2013			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	50.1886	8.4762	5.9211	$7*10^{-8}$	33.3297	67.0475
$DHRM_1$	2.2385	1.2396	1.8058	0.0746	-0.2270	4.7041
$DHRM_2$	0.1475	0.0467	3.1568	0.0022	0.0546	0.2404

Source: calculated and compiled by the authors.

The results obtained in Table 5 show that Goal 5 Score is 38.85% determined by the influence of HRM factors of digital personnel. The significance of F=0.0011, therefore, the regression statistics under consideration corresponds to the highest level of significance: 0.005. The observed F=15.4181 – it exceeds the critical value (5.6514). Therefore, Fischer's F-test has been passed.

The observed t exceeds the critical value (1.6630) with the factor variable $DHRM_1$ at a significance level of 0.10 and is 1.8058. The observed t exceeds the critical t (2.6349) with the factor variable $DHRM_2$ at a significance level of 0.10 and is 3.1568. Consequently, Student's t-test has been passed for both factor variables, which has a statistically significant impact on the dependent variable. The standard errors for factor variables are small: 1.2396 and 0.0467, respectively, which indicates a small error in the results of regression analysis.

Table 6. Regression analysis of the dependence of Goal 11 Score on HRM digital personnel

Regression statistics	
Multiple R	0.3525
R-Square	0.1243
Adjusted R-Square	0.1032
Standard Error	10.1119
Observations	86

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	1204.4797	602.2398	5.8899	0.0041
Residual	83	8486.7832	102.2504		
Total	85	9691.2629			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	56.8771	7.5768	7.5068	$6.2*10^{-11}$	41.8072	71.9470
$DHRM_1$	3.6590	1.1081	3.3021	0.0014	1.4551	5.8629
$DHRM_2$	0.0228	0.0418	0.5454	0.5869	-0.0603	0.1058

Source: calculated and compiled by the authors.

The results obtained in Table 6 show that Goal 11 Score is 35.25% determined by the influence of HRM factors of digital personnel. The significance of F=0.0041, therefore, the regression statistics under consideration corresponds to the highest level of significance: 0.005. The observed F=5.8899 – it exceeds the critical value (5.6514). Therefore, Fischer's F-test has been passed.

The observed t exceeds the critical t (2.6349) only with the factor variable $DHRM_1$ and amounts to 3.3021. Consequently, Student's t-test has been passed only for digital/technological skills, which is the only one of the two factors considered that has a statistically significant impact on the dependent variable. The standard error for this factor variable is small: 1.1081, which indicates a small error in the results of regression analysis.

Table 7. Regression analysis of the dependence of Goal 7 Score on HRM digital personnel

Regression statistics	
Multiple R	0.3555
R-Square	0.1264
Adjusted R-Square	0.1053
Standard Error	11.6732
Observations	86

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	1635.7787	817.8894	6.0022	0.0037
Residual	83	11309.9249	136.2642		
Total	85	12945.7036			

	Coeffi-cients	*Standard Error*	*t-Stat*	*P-Value*	*Lower 95%*	*Upper 95%*
Constant	52.3679	8.7467	5.9872	$5.2*10^{-8}$	34.9711	69.7646
$DHRM_1$	4.3997	1.2792	3.4395	0.0009	1.8555	6.9439
$DHRM_2$	-0.0393	0.0482	-0.8148	0.4175	-0.1352	0.0566

Source: calculated and compiled by the authors.

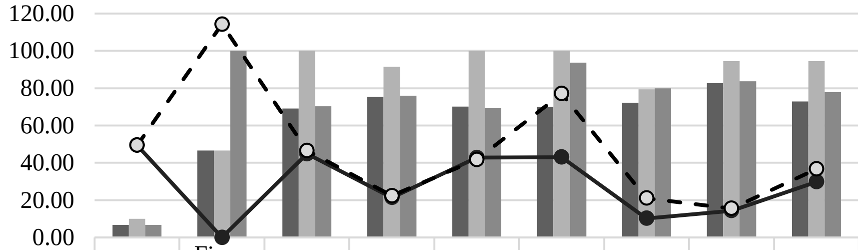
The results obtained in Table 7 indicate that Goal 7 Score is 35.55% determined by the influence of HRM factors of digital personnel. The significance of F=0.0037, therefore, the regression statistics under consideration corresponds to the highest level of significance: 0.005. The observed F=15.4181 – it exceeds the critical value (5.6514). Therefore, Fischer's F-test has been passed.

The observed t exceeds the citical t (2.6349) only with the factor variable $DHRM_1$ and is 3.4395. Consequently, Student's t-test has been passed only for digital/technological skills, which is the only one of the two factors considered that has a statistically significant impact on the dependent variable.The standard error for this factor variable is small: 1.2792, which indicates a small error in the results of regression analysis.

Thus, the results obtained show that $b_1>b_2$ in all regression equations in the econometric model (2), as well as the factor variable $DHRM_2$ is statistically insignificant in most cases, unlike $DHRM_1$. This indicates that the attraction of job-ready digital personnel makes a much greater contribution to improving quality in industry 4.0 compared to corporate training of digital personnel, which proves the hypothesis *H*.

4.2. Alternative scenarios of quality management in industry 4.0: attracting digital personnel vs corporate training

In order to solve the second task of this study and to develop alternative scenarios for quality management in industry 4.0 from the perspective of HRM of digital personnel, the values of factor variables in accordance with alternative scenarios were substituted into the econometric model (2). The trend of changes in the values of the dependent variables for each scenario is also calculated. The scenarios are shown in Fig. 2.



	Digital/Technological skills, score 0-10	Firms offering formal training, score 0-100	Global competitiveness score, 0-100	Goal 8 Score	Goal 9 Score	Goal 10 Score	Goal 5 Score	Goal 11 Score	Goal 7 Score
Baseline values in 2022,	6.70	46.68	69.06	75.26	70.05	69.90	72.11	82.66	72.85
Values according to the scenario of more active attraction of digital personnel, points	10.00	46.68	100.00	91.35	100.00	100.00	79.46	94.53	94.53
Values according to the scenario of the development of corporate training, points	6.70	100.00	70.28	75.99	69.34	93.64	79.92	83.65	77.90
Growth according to the scenario of the development of corporate training, %	0.00	114.24	1.77	0.97	-1.03	33.96	10.83	1.20	6.94
Growth according to the scenario of more active attraction of digital personnel, %	49.36	0.00	44.81	21.38	42.74	43.06	10.19	14.36	29.77

Figure 2. Attracting digital personnel and corporate training as alternative scenarios for quality management in industry 4.0

Source: calculated and constructed by the authors.

In Fig. 2, the scenario of more active attraction of digital personnel involves maximizing the value of the indicator "Digital/Technological skills" (an increase in DHRM1 by 49.36% compared to 2022). At the same time, the value of "Firms offering formal training" remained unchanged (at the level of 2022). According to this scenario, the following advantages for product quality were achieved in industry 4.0:

- Increase in Global competitiveness score by 44.81% (from 69.06 points in 2022 to 100 points);
- Increase in Goal 8 Score by 21.38% (from 75.26 points in 2022 to 91.35 points);
- Increase in Goal 9 Score by 42.74% (from 70.06 points in 2022 to 100 points);
- Increase in Goal 10 Score by 43.06% (from 69.90 points in 2022 to 100 points);
- Increase in Goal 5 Score by 10.19% (from 72.11 points in 2022 to 79.46 points);
- Increase in Goal 11 Score by 14.36% (from 82.66 points in 2022 to 94.53 points);
- Increase in Goal 7 Score by 29.77% (from 72.85 points in 2022 to 94.53 points).

An alternative scenario for the development of corporate training involves maximizing the value of "Firms offering formal training" (an increase in DHRM2 by 114.24%). At the same time, the value of "Digital/Technological skills" remains unchanged (at the level of 2022). Under this scenario, the Global competitiveness score increases by only 1.77% (from

69.06 points in 2022 to 70.28 points). At the same time, Goal 8 Score increases by only 0.97% (from 75.26 points in 2022 to 75.99 points).

It is worth noting that Goal 9 Score is reduced by 1.03% (from 70.06 points in 2022 to 69.34 points). Goal 10 Score increases by 33.96% (from 69.90 points in 2022 to 93.64 points). Goal 5 Score also increases by 10.83% (from 72.11 points in 2022 to 79.92 points). At the same time, Goal 11 Score increases by only 1.20% (from 82.66 points in 2022 to 83.65 points). Goal 7 Score increases by 6.94% (from 72.85 points in 2022 to 77.90 points).

Thus, the scenario of more active attraction of digital personnel is more promising, since it allows to improve the quality of products in industry 4.0 by an average of 29.47%, while the alternative scenario for the development of corporate training is only 7.81% on average with a decline in the values of individual indicators.

4.3. A program-target approach to quality assurance in industry 4.0 through HRM of digital personnel with a balance between sustainability and competitiveness

As part of solving the third task of this study and determining the prospects for quality assurance in industry 4.0 through HRM of digital personnel using a program-target management method in relation to HRM, a program-target approach has been developed (Fig. 3).

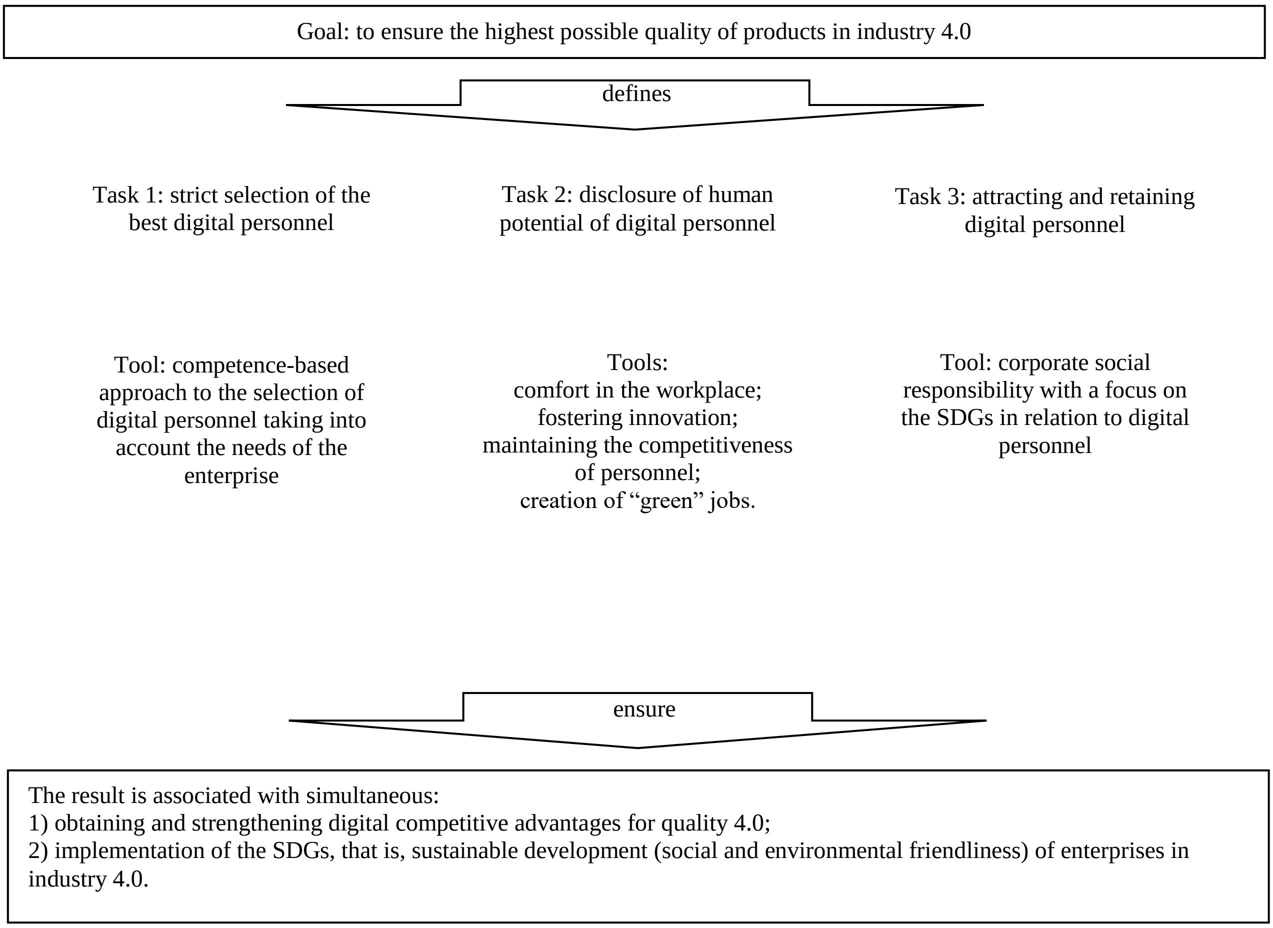


Figure 3. Program-target approach to quality assurance in industry 4.0 through HRM of digital personnel with a balance between sustainability and competitiveness

Source: developed by the authors.

In the authors' approach in Fig. 3, the goal is to ensure the highest possible quality of products in industry 4.0. The goal is achieved using a set of three tasks. Task 1: strict selection of the best digital personnel. The tool for achieving it is the competence-based approach to the selection of digital personnel, taking into account the needs of the enterprise.

Task 2: disclosure of the human potential of digital personnel. The instruments of its achievement are: comfort in the workplace, fostering innovation, maintaining the competitiveness of personnel and creating "green" jobs. Task 3: attracting and retaining digital personnel. The tool of its achievement is corporate social responsibility with a focus on the SDGs in relation to digital personnel.

The result of the implementation of the program-target approach is associated with the simultaneous: 1) obtaining and strengthening digital competitive advantages for quality 4.0; 2) implementing the SDGs, that is, sustainable development (social and environmental friendliness) of the enterprise of industry 4.0 and its products.

5. DISCUSSION

The article contributes to the literature through the development of scientific provisions of the concept of quality in industry 4.0 by clarifying the scientific interpretation of product quality in industry 4.0, as well as the preferred approach to HRM to maximize the quality of these products. The results obtained in the article are compared with the existing literature in Table 8.

Table 8. Comparison of the results obtained in the article with the existing literature

Aspects for comparison	Provisions of the existing literature	New scientific provisions substantiated in this article
Interpretation of quality in industry 4.0	from the perspective of global digital competitiveness (Arsovski, 2019; Đapan et al., 2019; Handayani et al., 2022; Misita and Milanovic, 2019; Popkova and Giyzov, 2021; Popkova, 2019; Sharma, 2023; Stefanović et al., 2019; Thach et al., 2021; Woźniak et al., 2022; Zimon et al., 2022).	from the perspective of balance between sustainability (the support of the SDGs) and global digital competitiveness
The role of HRM in quality assurance in industry 4.0	creation and implementation of breakthrough technologies, as well as the use of advanced automation tools to gain and strengthen digital competitive advantages (Capasso and Umbrello, 2022; Kee et al., 2023; Kiener et al., 2023; Stofkova et al., 2022)	− Unlocking the human potential of digital cadres (SDG8); − Creating and implementing innovations to improve quality 4.0 (SDG9); − Ensuring "healthy" competition in the workplace (SDG5 and SDG10); − Stimulating environmental (SDG11) and energy (SDG7) innovations in "green" workplaces in industry 4.0.
What is it that ensures quality in industry 4.0 with HRM of digital personnel?	due to corporate training aimed at developing a narrow range of digital competencies that are in demand at the enterprise of industry 4.0 (Dao et al., 2023; (Hernandez-de-Menendez et al., 2020a; (Lepore et al., 2022; (Motyl and Filippi, 2021; Patiño et al., 2023)	by attracting job-ready digital personnel with a wide range of digital competencies and by unlocking their human potential

Source: developed by the authors.

As shown in Table 8, unlike Arsovski (2019), Đapan et al. (2019), Handayani et al. (2022), Misita and Milanovic (2019), Popkova and Giyzov (2021), Popkova (2019), Sharma (2023), Stefanović et al. (2019), Thach et al. (2021), Woźniak et al. (2022), Zimon et al. (2022) for the most reliable definition of quality in industry 4.0, instead of a "narrow" interpretation from the standpoint of global digital competitiveness ("quality 4.0"), a new – systemic ("broad") interpretation from the standpoint of balance between sustainability (the support for the SDGs) and global digital competitiveness has been proposed.

Unlike Capasso and Umbrello (2022), Kee et al. (2023), Kiener et al. (2023), Stofkova et al. (2022), it has been proved that the role of HRM in quality assurance in industry 4.0 is not limited to the creation and implementation of breakthrough technologies, the use of advanced automation tools to obtain and strengthen digital competitive advantages, but includes: 1) unlocking the human potential of digital personnel (SDG8); 2) creating and implementing innovations to improve the quality of 4.0 (SDG9); 3) ensuring "healthy" competition in the workplace (SDG5 and SDG10); 4) stimulating environmentally friendly (SDG11) and energy (SDG7) innovations in "green" workplaces in industry 4.0

Unlike Dao et al. (2023), Hernandez-de-Menendez et al. (2020a), Lepore et al. (2022), Motyl and Filippi (2021), Patiño et al. (2023), it has been proved that the quality in industry 4.0 with HRM of digital personnel is provided more effectively by attracting job-ready digital personnel who possess a wide range of digital competencies, as well as through the disclosure of their human potential, than through corporate training.

6. CONCLUSION

So, the purpose has been achieved – the article has developed a systemic scientific vision of the process of quality assurance in industry 4.0 through HRM of digital personnel. This vision is based on a new ("broad") interpretation of quality in Industry 4.0 with a balance between sustainability (SDG support) and global digital competitiveness, which most comprehensively takes into account the characteristics of product quality in industry 4.0. In accordance with the authors' interpretation, based on international experience for 2021-2022, the article presents an econometric model that provides mathematical proofs that the attraction of job-ready digital personnel makes a much greater contribution to improving quality in industry 4.0 compared to corporate training of digital personnel (hypothesis H has been proved).

Based on the econometric model, it has been revealed that the scenario of more active attraction of digital personnel is preferable, since it allows to improve the quality of products in industry 4.0 by an average of 29.47%, while the alternative scenario for the development of corporate training improves the quality of products in industry 4.0 by only 7.81% on average with a decline in the values of individual indicators (Goal 9 score).

The theoretical significance of the research results is due to the fact that they have allowed for the first time to form an approach to HRM of digital personnel that ensures high quality in industry 4.0 in accordance with its innovative interpretation – with a balance between sustainability and competitiveness. The practical significance of the authors' recommendations lies in the fact that the proposed program-target approach to quality assurance in industry 4.0, with a balance between sustainability and competitiveness, will increase the efficiency of HRM of digital personnel and comprehensively take into account the interests of stakeholders in ensuring product quality in industry 4.0.

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