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The Analysis of Dependencies Between Extraction and Resource Consumption in 2008-2014 on the Example of Ostrowite Gravel Pit

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Abstract:

Purpose: *The aim of the article is to examine dependencies between production-related indicators (extraction, processing) and indicators related to resource consumption. The analysis was made on the basis of data from the Ostrowite gravel pit for 2008-2014.*
Design/Methodology/Approach: *The study focuses on the research of KPIs conducted in the Ostrowite Gravel Pits located in the south-western part of the Pomeranian Voivodship, in the Lipnica commune, the Bytów Poviat. We use the KPIs analysis method in the paper.*
Findings: *The article presents research on the relationship between mining and used resources on the example of Ostrowite gravel pit. In modern industry, the method of monitoring the consumption of resources is to calculate the so-called KPIs (Key Performance Indicators) and to study the relationships between them. The presented study focuses on the research of KPIs conducted. As regards to resources, the following issues were analysed, employees' working time, time of running machines, fuel consumption and electricity consumption. It was found that in the case of fuel and energy consumption, there is no greater opportunity for improvement within the given technology, because the consumption of these resources is directly proportional to the production indicators.*
Practical Implications: *The articlee provides recommendations for organizations in the field of counteracting this situation.*
Originality/Value: *We have found that there is an increase in productivity in proportion to the increase in processed tonnage and production. This is due to better use of machines and human work, reducing the number of downtime and improving the work system.*

Keywords: *Key performance indicators; mining resources; production management; Industry 4.0.*

JEL Codes: *L23, M11, D2.*

Paper type: *Research article.*

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1. Introduction

Each production process consumes resources, human and material (machines and resources and materials). From an economic point of view, the improvement of the production process depends on organizing it in such a way as to ensure the lowest possible level of resource consumption allowing for the improvement of the efficiency in the production process (Wolniak *et al.*, 2020; Miśkiewicz and Wolniak, 2020). In modern industry, the method of monitoring the consumption of resources is to calculate the so-called KPIs (Key Performance Indicators) and to study the relationships between them.

The aim of the presented publication is to examine dependencies that exist between production-related indicators (extraction, processing) and indicators related to resource consumption. The analysis was made on the basis of data from the Ostrowite gravel pit for the years 2008-2014. Key Performance Indicators (KPIs) are tools to achieve the organization's goals. When they are properly designed and implemented can bring three main benefits (Parameter, 2016; Pilcher, 2005), adjusting daily activities to critical factors of organizational success (CSF), improving efficiency and deepening the sense of responsibility, empowerment and fulfillment.

It is essential for organizations to identify groups of indicators (Aleksander and Armand, 2013; Allaoui and Choudhary, 2015; Amzat, 2017; Carlucci, 2010; Chae, 2009; Chan and Chan, 2004; Wolniak, and Skotnicka-Zasadzień, 2014; Jonek-Kowalska, 2019; Wolniak *et al.*, 2019; Olkiewicz *et al.*, 2018; Gajdzik and Wolniak, 2021; Stecuła, 2018):

- result (Key Result Indicators - KRI) and result indicators (Result Indicators - RI),
- performance (Key Performance Indicators - KPI) performance indicators (PI).

Developed indicators should to cover the assessment of the actual state of all areas of the organization's functioning, correlation of achieved parameters also in relation to the adopted strategy and the possibility of creating the future (implementing pro-quality activities), within the dominant forces of influence (Gruszka and Ligarski, 2017; Gulledg and Chavusholu, 2008; Ugwu and Haupt, 2005; Wandogo *et al.*, 2010; Olkiewicz, 2018; Wolniak and Jonek-Kowalska, 2020; Wolniak, 2020).

This means that key indicators (KPIs) must be universal (applicable to various organization units), monitored, supervised, etc., as they are to support planning activities in a significant way, leading to the desired effect in both the production and organizational sphere, social or environmental. The growing and changing stimuli of the organization's functioning and development -external and internal (Kosieradzka, 2012; Loska, 2013; Loska, 2017; Nawrocki, 2015; Olkiewicz *et al.*, 2015; Xu *et al.*, 2012; Olkiewicz *et al.*, 2018, Olkiewicz, 2020) make it necessary to implement preventive or remedial actions, in particular in the sphere of:

1. product - in terms of expectations of quality, cost of production, time of creation as well as security, including environmental protection,
2. human resources - employees directly related to production, administration, logistics, but also subcontractors, in at least two levels:
   - professional suitability - that is, qualifications combined with individual abilities to perform a given job,
   - employee performance - measurable quantitative and qualitative effect,
3. fixed assets - as part of proper development and full use of fixed assets of the organization, i.e., machinery, equipment, buildings, means of transport, infrastructure, etc.,
4. material and energy management - reduction of unproductive consumption of fuel materials, electricity and production materials, as well as increasing the use of production waste (recycling),
5. management - implementation, improvement of the management system should use the organization's policy, objectives for implementation and the vision of the "future of the organization",
6. the market - monitoring and analyzing the needs and expectations of stakeholders, business cycles, mega trends,
7. natural resources - as part of proper use of raw materials (natural resources) and implementation of environmental policy,
8. legal and economic regulations - in the way of monitoring the changes of fast (flexible) adjustment to the policy of economic development, covering all areas of the organization's functioning.

Therefore, the efficiency of using key performance indicators will be possible when measured in a 24/7 (or weekly) system, and applying the 10/80/10 rule (10 should be key result indicators (KRI) / 80 result and performance indicators (RI, PI) / maximum of 10 key performance indicators (KPIs) (Olkiewicz *et al.*, 2017; Anand and Grover, 2016; Bai and Sarkis, 2014; Bober *et al.*, 2017; Enoma and Allen, 2007; Enshassi and Shorafa, 2015).

Creating a system of key performance indicators for a company as part of the process management (based on twelve steps of KPI implementation), one should be guided by two criteria that are consistent with respect to interrelationships and dependencies, (Haponava and Al. Jibouri, 2009; Jonek-Kowalska, 2017; Katamba *et al.*, 2016; Skotnicka-Zasadzień and Biały, 2011; Smith and Heiden, 2017; Sojda, 2014; Mačala, 1997; Rybar *et al.*, 2015; Driner and Pavelek, 2016):

- work efficiency per hour for one employee;
- average elimination time of the defect;
- the amount of defective products for total production;

- the number of complaints for total sales;
- percentage of untimely and incomplete deliveries;
- fuel and energy consumption for single production.

The selection of measures takes place in accordance with the requirements and expectations of the organization as well as with the processes existing in it, where the reporting system must be open to changes when expanding or decreasing the number of indicators. For the purposes of this study, i.e., the aggregate industry production area, the most frequently analyzed group of indicators is quoted:

1. Employee productivity [t/h]
where: PT – processed tones; HMO – total working time of people;
2. Performance of mobile machines [t/h]
where: PT – processed tones; HME – total working time of mobile machines;
3. Fuel consumption indicator [l/t]
where: I – fuel consumption in liters; PT – processed tones;
4. Electricity consumption indicator [kWh/t]
where: E – electricity consumption in kWh; PT – processed tones.

Most organizations, report the most important KPIs at least once a week. The need for continuous monitoring of processes forces organizations to create models that, based on various sets of indicators, allow to evaluate effectiveness on an ongoing basis. In the era of digitization, organizations are supported by various IT solutions, thanks to integration with production systems allowing for the creation of reports in the desired format, time and "time window - time range" (Grabowska, 2017; Pun *et al.*, 2012; Setijono and dahlgaard, 2007; Shohet, 2003).

2. Material and Methods

The study focuses on the research of KPIs conducted in the Ostrowite Gravel Pits located in the south-western part of the Pomeranian Voivodship, in the Lipnica commune, the Bytów Poviat. The plant was founded in 1976, and from the very beginning was involved in the mining and processing of minerals. At present, the Gravel Pit is located in the Mining Plant Trzebielsk and Ostrowite III and their records are subject to the same in the mining and processing part. Natural aggregates in the form of gravels and sands are extracted in the Ostrowite Gravel mine.

Exploration takes place in a land-based way in a deep-hole excavation from VI-class agricultural lands and from coniferous forests. Mining is carried out using open pit method in a longwall system with one extraction floor. For this purpose, caterpillar bulldozers are used to remove the overburden over the deposit, wheeled loaders with one bucket for loading of spoil and conveyor belts for tipping and transporting the mineral for further processing. The organization of production process of aggregates in the gravel pit is divided into two parts.

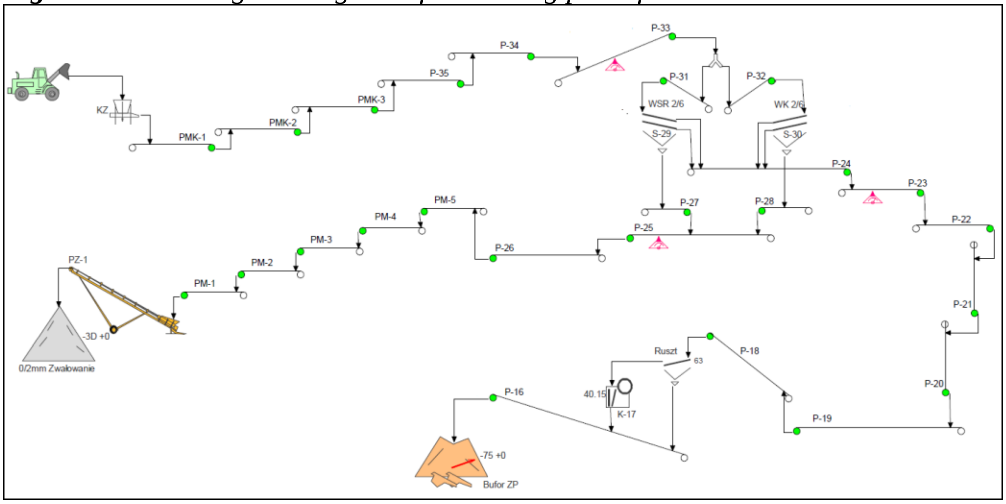
The first part presented in Figure 1 is the mining process, where the spoil is taken from the wall by the loader and fed through the hopper and conveyor belts to the pre-screen. The main task is to separate part of the sand (fraction 0-2 mm) from the gravel (fraction above 2 mm) and transport it to the excavation for later reclamation. Sieved sand, treated as waste, accounts for approximately 65-70% of the production level. The pre-screened aggregate is conveyed via conveyor belts to the intermediate tank, where it is stored before proceeding with further processing. If there is a stone of size over 80 mm in the spoil, it goes to the jaw crusher before the crushing, which crumbles its size.

The second part, presented in Figure 2, is a processing plant powered by pre-sieved and crushed output from the intermediate tank. The whole is subjected to classification on specific fractions with the help of screens and is rinsed using a shower system. The technological system of the plant allows dehydration of the washed aggregate and save it on the cones separately for each fraction. The system also includes a cone crusher, secondary material recessing to the size of 0-31,5 mm, later distributed to specific fractions. The presented production process leads to obtaining a specific product with the assumed parameters, but the variety of products offered leads to the diversification of processes. Differences arise in the complexity and course of the process over time and the organization of production, which is why they can be divided according to different criteria (Glapa and Korzeniowski, 2005; Szatkowski, 2012):

- the criterion of continuity and progress over time, dividing processes into discrete and continuous ones;
- criterion of applied technologies, i.e., mining, processing, assembly and disassembly, natural and biotechnological;
- criterion of participation of human work in the case of work and natural processes;
- the criterion of using the means of work, i.e. manual, manual-machine, machine, automated, computer-integrated;
- criterion of the complexity of processes in the case of division on simple and complex.

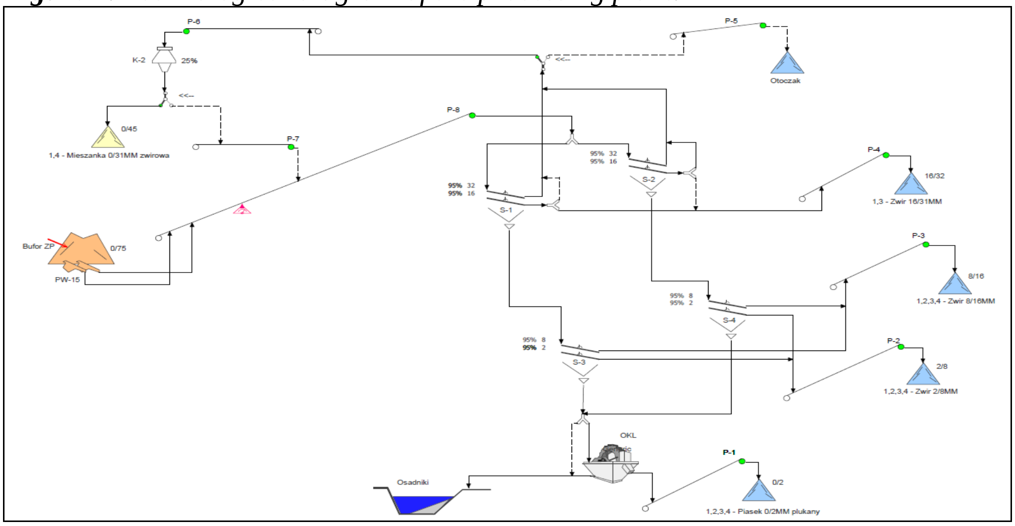
Aggregate production in a three-shift system, six days a week, from February to December is supported by the safety and health departments, resource management, the environment, financial controlling and geological and surveying services. An important area of the production process is quality control that is valuable and qualitative. In order to maintain the highest quality, the process of testing of finished products is outsourced to an external accredited laboratory. Process verification can be done by the Factory Production Control (ZKP). Everything is implemented in accordance with the quality management system and the requirements of the ISO 9001 standard. Ready and tested products reach customers through the B2B (business to business) and B2C (business to client) channels implemented within the organization.

Figure 1. *Technological diagram of the mining part of the Ostrowite Gravel Pit.*



Source: *Own study.*

Figure 2. *Technological diagram of the processing plant.*



Source: *Own study.*

3. Results and Discussion

Table 1 summarizes the basic values of indicators related to mining and consumption of resources in the Ostrowite gravel pit in 2008-2014. Individual indicators have been calculated in accordance with the formulas given in the previous section of this publication. Four resources were selected for the analysis of resource consumption in the surveyed enterprise (for which the relevant indicators can be found in Table 1):

- people's working time,
- time of running machines,
- fuel consumption,
- electric energy usage.

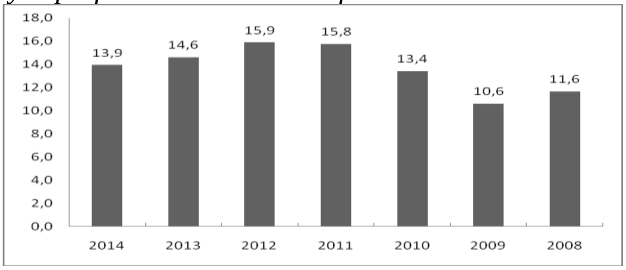
Table 1. *The main data years 2008-2014*

Ostrowite gravel pit	2014	2013	2012	2011	2010	2009	2008
Extraction [kt]	2231,6	2079,2	1991,5	1996,6	1662,876	1479,1	1866,1
Processed tones [kt]	606	655,0	671,1	811,7	561,072	447,853	711,8
Production [kt]	285,8	301	328,26	400,15	323,14	429,62	606,85
The total working time of people [h]	43501	44834	42241	51522	41831	42298	61115
Employee productivity [t/h]	13,9	14,6	15,9	15,8	13,4	10,6	11,6
The total operating time of the drivng machines [h]	9994	10825	11822	16384	9812	7675	9248
Efficiency of driving machines [t/h]	60,6	60,5	56,8	49,5	57,2	58,4	77,0
Fuel - amount used [l]	253987	324523	330428	439751	249832	201816	286542
Fuel consumption indicator [l/t]	0,42	0,50	0,49	0,54	0,45	0,45	0,40
Electricity - amount used [kwh]	2150320	1991420	2036650	2496996	2074879	1417193	2328466
Electricity consumption indicator [kwh/t]	3,55	3,04	3,03	3,08	3,70	3,16	3,27

Source: *Own study.*

The first resource to be analyzed in this publication is the working time of people. The resource is measured in hours, while the employee productivity rate in tones per hour. Fig. 3 shows the change in the value of the employee performance indicator in the following years. It can be noticed that in years 2008-2012, the efficiency of using human labor continued to increase, and then in the years 2013-2014 there was a slight correction.

Figure 3. *Employee performance indicators for the Ostrowite Gravel Pit [t/h].*

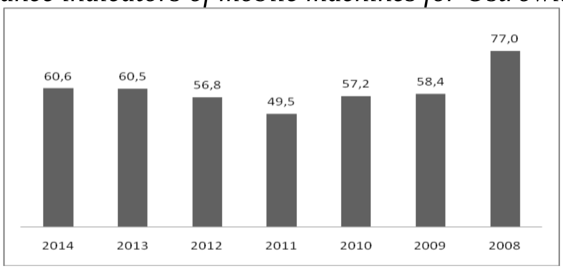


Source: *Own study.*

Analysis of Pearson's correlation coefficient between indicators related to extraction and working time of people at the level of statistical significance α = 0,1 allows to conclude that there is a positive correlation at the level of 0.68 between extraction and productivity of employees. On this basis, it can be stated that the higher the level of extraction, the better the use of resources in the examined gravel pit. With the increase in the production level, the number of machine and equipment downtime is reduced and we are dealing with a more effective use of human labor. The total working time of people, however, is correlated with the level of production - the correlation coefficient is 0.85.

The next resource used by the tested gravel pit is time of use driving machines. The time of running machines counted in h was analyzed. Figure 4 presents the indicators of running machines for the Ostrowite Gravel Pit. The analysis of the data shows that the efficiency of the mobile machinery is an aspect of the functioning of the examined gravel pit, which has been deteriorated. The highest level was reached in 2008 (77 t / h), and then it was reduced in the following years to the lowest level of 49.5 t / g in 2011. In subsequent years, the value of the ratio rose again to 60.6 t / h however, it has not yet reached the level of 2008.

Figure 4. *Performance indicators of mobile machines for Ostrowite Gravel pit [t/h]*



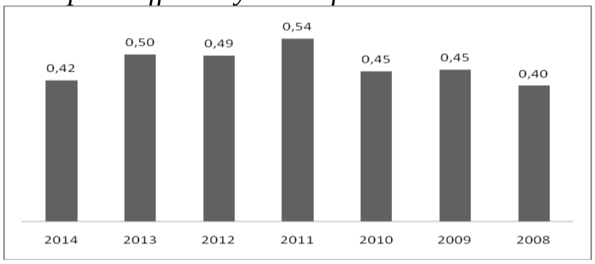
Source: *Own study.*

Analysis of the correlation coefficient between variables concerning the efficiency of the driving machines allows concluding that there is a correlation in the case of the relation between the running time of the driving machines and the number of processed tons (the value of the correlation coefficient is 0.82). Correlation results from the fact that mobile machines are used in the processing of the extracted gravel.

This is the reason why the higher the number of processed tons in the enterprise, the higher the operating time of the mobile machines. In the case of the efficiency of the mobile machinery, a correlation between the coefficient and the production level was found. The correlation coefficient is 0.67. In this case, the greater the production of gravel pit the more effective is the use machines.

The third resource, examined in this publication, is the fuel consumption measured in liters. In the case of fuel consumption indicators, within the analyzed period of years 2008-2014, major changes cannot be observed in their scope (Figure 5). They oscillate around 0.4 l / t and increased only in 2011.

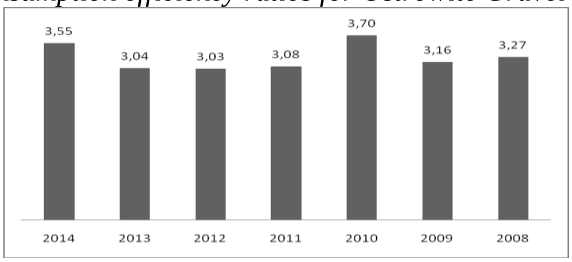
Figure 5. *Fuel consumption efficiency ratios for Ostrowite Gravel Pit [l/t]*



Source: *Own study.*

The analysis of the correlation between the indicators regarding fuel efficiency and the indicators regarding the extraction at the assumed level of correlation allows to conclude that there is a statistically significant relationship between fuel consumption and the number of processed tons. The correlation is strong and is 0.91. The increase in the amount of processed tons requires the work of machines and these consume fuel, which can be seen in the case of the correlation coefficient. The fuel efficiency indicator is not correlated with extraction.

Figure 6. *Fuel consumption efficiency ratios for Ostrowite Gravel Pit [l/t].*



Source: *Own study.*

The last resource studied in the publication, used in the Ostrowite Gravel Pit, is electricity (measured in kwh). In the analyzed years 2008-2014 (Fig. 6), the electricity consumption indicator shows slight changes. In general, in the years 2008-2014 was recorded an upward trend from 3.27kW / t to 3.55 kWh / t, however, in particular analyzed years it fluctuated considerably below and above this level.

Correlation analysis shows a statistically significant strong correlation between electricity consumption and the number of processed tones. The correlation coefficient in this case is 0.9. The strong correlation is due to the fact that the processing of the extracted gravel requires the consumption of electricity in a proportional relationship. The research did not show any dependence between the electricity consumption indicator and mining. Table 2 presents a summary of extraction indicators and indicators related to resource consumption when particular correlation occurs. The following designations were used in this case:

1. ++ - strong correlation,
2. + - weak correlation.

Table 2. *Correlations between extraction rates and resource consumption*

Resource consumption	Extraction [kt]	Tone processed [kt]	Production [kt]
The total working time of people [h]			++
Employee productivity [t/h]	+		
Total time of running machines [h]		++	
Efficiency of drive machines [t/h]			+
Fuel - amount used [l]		++	
Fuel consumption indicator [l/t]			
Electricity - amount used [kwh]		++	
Electricity consumption indicator [kwh/t]			

Source: *Own study.*

The analysis of the collected data shows that for the majority of resources there is a direct proportional relationship between the number of processed tones and the consumption of a given resource (machine operation time, fuel consumption, electricity consumption). Only in the case of one resource - human labor, the phenomenon of productivity growth can be observed along with the increase in production. In this case, it can be noticed that with the increase in production in the following years, the production process was improved, so that the use of human labor was ever smaller per unit of extraction. The analysis allows us to state that the largest reserves in a production enterprise are still related to human resources. With a given technology, it is very difficult to limit the consumption of material resources, which is correlated with the level of extraction, while the consumption of human labor can be limited. Considering that human labor today is a relatively expensive resource, it is the best path to improve production processes. Certain reserves also exist in the scope of applied technology in the field of machine use, because their productivity can be improved along with the increase in production.

The next Table 3 presents a comparison of changes in the value of performance indicators in the analyzed years (starting from 2009). The following markings were used in the table:

- „+” – when the index increased compared to the previous year,
- „-:,when the value of the indicator decreased as compared to the value adopted in the previous year,
- „0” – when the value of the indicator remained unchanged compared to the previous year.

The analysis of the data allows us to state that the best situation is in the case of the efficiency of mobile machines, where indicators have increased in recent years. On the other hand, it is dangerous that the performance indicators of employees in the last two years of analysis have decreased. This is particularly disadvantageous in that, as it was written above, it is the productivity of employees that is the area that should be improved and whose improvement brings the best results. The company should take action to deal with this unfavorable trend, for example by:

- increasing the number of training in the knowledge of machine operation and production processes by employees,
- detailed analysis of the causes of problems.

Table 3. *KPI indicators for the Ostrowite gravel pit in terms of extraction and consumption of resources.*

Osowite gravel pit	**2014**	**2013**	**2012**	**2011**	**2010**	**2009**
Employee productivity [t/h]	-	-	+	+	+	-
Efficiency of driving machines [t/h]	+	+	+	-	-	-
Fuel consumption indicator [l/t]	-	+	-	+	0	+
Electricity consumption indicator [kwh/t]	+	+	-	-	+	-

Source: *Own study.*

4. Conclusion

The issue of the analysis of dependence between extraction indices and consumption indicators for gravel pits described in the publication is very important from the point of view of the efficiency of the organization. Data analysis enabled the realization of the sated goal. As a result of the research it was found that in the case of fuel and energy consumption, there is no greater opportunity for improvement within the given technology, because the consumption of these resources is directly proportional to the production indicators. However, improvement opportunities arise in the case of machine efficiency and employee productivity. It can be seen that there is an increase in productivity in proportion to the increase in processed tonnage and production. This is due to better use of machines and human work, reducing the number of downtime and improving work system in organization. In this context, the threat may be the fact that in years 2013-2014 the employee performance ratio decreased. The publication provides recommendations for organizations in the field of counteracting this situation.

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