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# THE ANALYSIS OF DEPENDENCIES BETWEEN EXTRACTION AND RESOURCE CONSUMPTION IN 2008-2014 ON THE EXAMPLE OF GLIŚNO GRAVEL PIT

# ANALIZA ZALEŻNOŚCI POMIĘDZY WYDOBYCIEM A ZUŻYCIEM ZASOBÓW W LATACH 2008-2014 NA PRZYKŁADZIE ŻWIROWNI GLIŚNO

The article presents research on the relationship between mining and used resources on the example of Gliśno gravel pit. As regards to resources, the following issues were analyzed: employees' working time, time of running machines, fuel consumption and electricity consumption. The aim of the publication is to examine the dependencies that exist between the analyzed variables. KPI's (Key Performance Indicators) were calculated for individual resources. The analysis presented in the publication contains data from 2008-2014.

**Keywords:** KPI, Key performance indicators, mining resources, production management

Artykuł przedstawia badania dotyczące zależności pomiędzy wydobyciem a zużytymi zasobami na przykładzie żwirowni Gliśno. W zakresie zasobów analizowano kwestie takie jak: czas pracy pracowników, czas pracy maszyn jezdnych, zużycie paliwa, zużycie energii elektrycznej. Celem publikacji jest zbadanie zależności, jakie istnieją pomiędzy analizowanymi zmiennymi. Dla poszczególnych zasobów obliczono wskaźniki KPI (Kluczowe wskaźniki wydajności). Prezentowana w publikacji analiza zawiera dane z lat 2008-2014.

**Słowa kluczowe:** KPI, Kluczowe wskaźniki wydajności, zasoby wydobycie, zarządzanie produkcją

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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. 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 Gliśno gravel pit for the years 2008-2014.

# 2. KPI indicators in the case of extraction and consumption of resources

Key Performance Indicators (KPIs) are tools to achieve the organization's goals. When they are properly designed and implemented can bring three main benefits (Nawrocki, 2015; Olkiewicz et al., 2015): 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 & Armand, 2013; Allaoui & Choudhary, 2015; Amzat, 2017; Carlucci, 2010; Chae, 2009; Chan & Chan, 2004; Wolniak et al., 2018; Xu et al., 2012):

- 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 & Ligarski, 2017;Gulledge & Chavusholu, 2008; Olkiewicz, 2018; Ugwu & Haupt, 2005; Wandogo et al., 2010).

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 (Kosierdzka, 2012; Loska, 2013; 2017; Malindžák et al., 2017; Nawrocki, 2015; Olkiewicz et al., 2015; 2017)) make it necessary to implement preventive or remedial actions, in particular in the sphere of:

a) product – in terms of expectations of quality, cost of production, time of creation as well as security, including environmental protection,
b) 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,

c) 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.,
d) 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),
e) 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",
f) the market – monitoring and analyzing the needs and expectations of stakeholders, business cycles, mega trends,
g) natural resources – as part of proper use of raw materials (natural resources) and implementation of environmental policy,
h) 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) (Anand & Grover, 2015; Bai & Sarkis, 2014; Bluszcz, 2017; Enoma & Allen, 2007; Enshassi & 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, e.g. (Haponava & Al-Jibouri, 2009; Jonek-Kowalska, 2017; Jonek-Kowalska, 2017a; Katamba et al., 2016; Pacana et al., 2014; Pacana & Ulewicz, 2017; Skotnicka-Zasadzień & Biały, 2011; Smith & Heiden van der, 2017; Sojda, 2014):

- 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 (Lafarge, 2005), the most frequently analyzed group of indicators is quoted:

**Employee productivity [t/h]**

$$PRS = \frac{PT}{HMO}$$

where:

PT — processed tones
HMO — total working time of people

**Performance of mobile machines [t/h]** $$MI = \frac{PT}{HME}$$

where:
PT — processed tones
HME — total working time of mobile machines

**Fuel consumption indicator [l/t]** $$FI = \frac{I}{PT}$$

where:
I — fuel consumption in liters
PT — processed tones

**Electricity consumption indicator [kWh/t]** $$EII = \frac{E}{PT}$$

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 & Dahlgaard, 2007; Shohet, 2003).

## 3. Description of the plant and technology

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 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 approx. 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, 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 & Korzeniowski, 2005):

- 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.

## 4. Analysis of dependencies and their discussion

Table 1 summarizes the basic values of indicators related to mining and consumption of resources in the Gliśno 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.

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. It can be noticed that in years 2008-2010, the efficiency of using human labor continued to increase, and

TABLE

KPI indicators for the Gliśno gravel pit in terms of extraction and consumption of resources

| Gliśno gravel pit | 2014 | 2013 | 2012 | 2011 | 2010 | 2009 | 2008 |
|---|---|---|---|---|---|---|---|
| **Extraction [kt]** | 2156,2 | 1829,3 | 2007,7 | 2305,7 | 1875,9 | 2218,1 | 1904,5 |
| **Processed tones [kt]** | 483,6 | 441,488 | 463 | 532,1 | 548,868 | 445,546 | 419,4 |
| **Production [kt]** | 390 | 331 | 326,5 | 368 | 382,8 | 377,7 | 347,9 |
| **The total working time of people [h]** | 47802 | 44514 | 47644 | 56385 | 48226 | 49046 | 45132 |
| **Employee productivity [t/h]** | 10,1 | 9,9 | 9,7 | 9,4 | 11,4 | 9,1 | 9,3 |
| **The total operating time of the drivng machines [h]** | 11331 | 9942 | 12072 | 13341 | 10352 | 8467 | 8181 |
| **Efficiency of driving machines [t/h]** | 42,7 | 44,4 | 38,4 | 39,9 | 53,0 | 52,6 | 51,3 |
| **Fuel – amount used [l]** | 290938 | 259385 | 285560 | 312415 | 235984 | 272348 | 260870 |
| **Fuel consumption indicator [l/t]** | 0,60 | 0,59 | 0,62 | 0,59 | 0,43 | 0,61 | 0,62 |
| **Electricity – amount used [kwh]** | 2496365 | 2269450 | 2233300 | 3116825 | 2654074 | 2503471 | 2116062 |
| **Electricity consumption indicator [kwh/t]** | 5,16 | 5,14 | 4,82 | 5,86 | 4,84 | 5,62 | 5,05 |

*Source:* Own study

then in the years 2011 there was a slight correction and next from 20011 up till 2014 the efficiency of using human labor is rising.

Analysis of Pearson's correlation coefficient between indicators related to extraction and working time of people at the level of statistical significance $\alpha = 0{,}1$ allows to conclude that there is a positive strong correlation at the level of 0.81 between extraction and total working time of employees. It's obvious that when there is bigger extraction there is needed more employers working time. But analysis shows no statistical significance relation between extraction and productivity of employees. We cannot say that increase of production level has an impact on employee performance in researched gravel pit. The differences between employee performances year to year are rather small regardless to bigger differences in extraction.

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. Fig. 1 presents the indicators of running machines for the Głośno 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 2010 (53 t/h), and then it was reduced in the following years to the lowest level of 38.4 t/g in 2012. In subsequent years, the value of the ratio rose again to 42.7 t/h however, it has not yet reached the level of 2010.

Analysis of the correlation coefficient between variables concerning the efficiency of the driving machines allows concluding that there is not a correlation in the case of the relation between the running time of the driving machines and the number of processed tons. The growth of the production level is not correlated amount of time of driving machines used in the gravel pit. The variables are independent and there could be other factors influencing the extraction amount. Also is not correlation at statistically significant level between efficiency of driving machines and extraction and production indicators. Efficiency of using this equipment is also independent from production. This could be a problem and on the basis of the results we can think that there is not development of using of machines in the company. Gravel pit use old machines and not

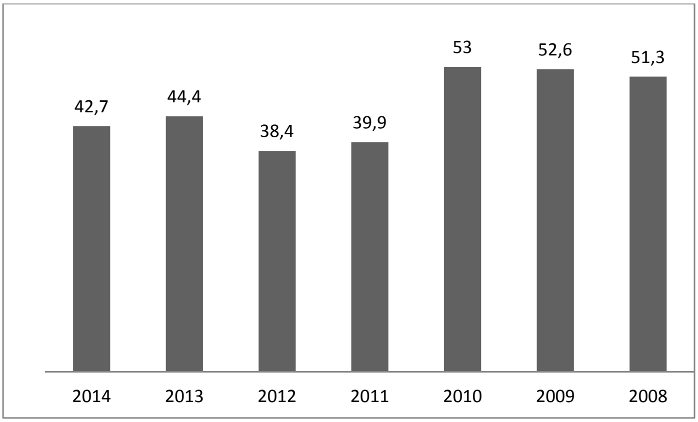


Fig. 1. Performance indicators of mobile machines for Gliśno Gravel pit [t/h]
*Source:* Own study

improve used technology through years. because of that the level of efficiency in this case is not rising and not correlated to production.

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 (Fig. 2). They oscillate around 0.6 i/t and decreased only in 2011 (in this year fuel consumption efficiency ratio was 0,43 l/t.

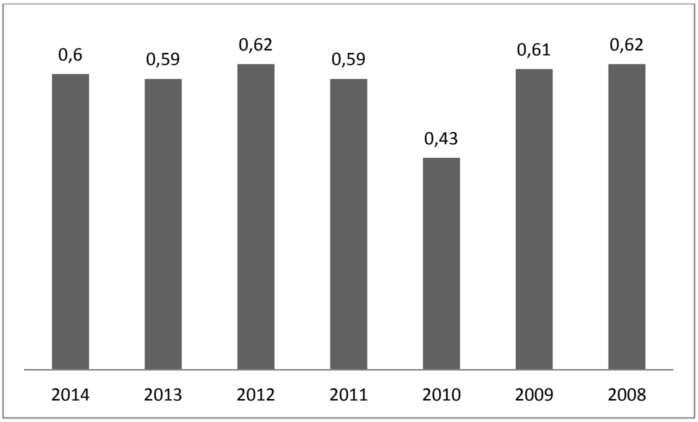


Fig. 2. Fuel consumption efficiency ratios for Gliśno Gravel Pit [l/t].
*Source:* Own study

The analysis of the correlation between the indicators regarding fuel consumption and the indicators regarding the extraction at the assumed level of correlation allows concluding that there is a statistically significant relationship between fuel consumption and the number of processed tons. The correlation is strong and is 0.81. 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. The interesting correlation is between fuel efficiency consumption indicator and the amount of processed tones. The correlation is statistically significant and negative on the level of –0,73. The obtained value mean that when we preceded more tones of gravel in the pit the whole process is less fuel-efficient. There are problem with fuel efficiency and we can observe, that organization should analyze their process because it's not fuel efficient and if the level of processing product is big the efficiency of the process is worse. The case can be old machines used by the gravel pit which are low efficient when the production level is bigger.

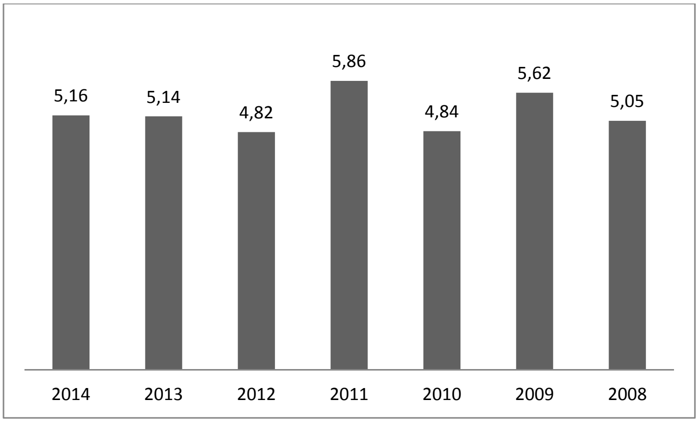


Fig. 3. Electricity consumption efficiency indicators for Gliśno Gravel Pit [kwh/t].
*Source:* Own study

The last resource studied in the publication, used in the Gliśno Gravel Pit, is electricity (measured in kwh). In the analyzed years 2008-2014 (Fig. 3), the electricity consumption indicator shows slight changes. In general, in the years 2008-2014 was recorded an upward trend from 5.05kW / t to 5.16 kWh / t, however, in particular analyzed years it fluctuated considerably below and above this level. The best efficiency level of electricity consumption was in the year 2011 – 5.86 kWh/t, and the worse in the year 2012 when it was 4.82 kWh/t.

Correlation analysis shows a statistically significant strong correlation between electricity consumption and the number of processed tones. The correlation coefficient in this case is 0.81. The strong correlation is due to the fact that the processing of the extracted gravel requires the consumption of electricity in a proportional relationship. Electricity consumption indicator is correlated to extraction on the level of 0.8. The correlation means that when is bigger extraction there is better value of electricity consumption efficiency. When more tons are processed, the size of the production lot increases, the number of machine reversions decreases and the process efficiency increases because machines needs small energy for the production unit.

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:

- ++ – strong correlation,
- + – 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]** | ++ | no connection | no connection |
| **Employee productivity [t/h]** | no connection | no connection | no connection |
| **Total time of running machines [h]** | no connection | no connection | no connection |
| **Efficiency of drive machines [t/h]** | no connection | no connection | no connection |
| **Fuel – amount used [l]** | ++ | no connection | no connection |
| **Fuel consumption indicator [l/t]** | no connection | + | no connection |
| **Electricity – amount used [kwh]** | ++ | no connection | no connection |
| **Electricity consumption indicator [kwh/t]** | no connection | ++ | no connection |

*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 extraction of gravel and the consumption of a given resource (total time of people, fuel consumption, electricity consumption). In the case of fourth resource – time of running machines there is no correlation with extraction level. Because there is linear correlation of many resources with the extraction, there is not easy to increase efficiency indicators, and improvement of the whole production process. The method can be implementation of the new technology, which can add new possibility to the process and allow increasing efficiency of machines used in the company. Certain reserves also exist in the scope of human resources, because their productivity can be improved along with the increase in production, when we implement new technology.

The analysis also shows that there are correlation between tone processed and two variables: fuel consumption efficiency (negative correlation) and electricity consumption efficiency (positive correlation). The use of electricity is the advantage of the researched gravel pit, while the use of fuel is its disadvantage.

The next table 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 employee productivity, where indicators have increased in recent three years. On the other hand, it is dangerous that the performance indicator of driving machines efficiency in the last years of analysis have decreased. This is particularly disadvantageous in that, as it was written above, it is the productivity of driving machines is the area that should be improved and whose improvement brings the best results especially in the case of implementing new technology. The company should take action to deal with this unfavorable trend, for example by:

- implementing new production technology,
- buying new driving machines,
- detailed analysis of the causes of problems in the case of worst results in fuel efficiency (negative correlation with tone processed).

TABLE 3

KPI indicators for the Gliśno 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]** | + | – | + | + | – | – |
| **Electricity consumption indicator [kwh/t]** | + | + | – | + | – | + |

*Source:* Own study

# 5. 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 working time of people, 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. The new machines or technology can boost efficiency of the company and allow increasing its performance indicators. The strong point of the company is the use of electricity because its efficiency indicator is correlated with amount of processed tones. The main disadvantage is fuel consumption, where exist negative correlation between efficiency indicator and amount of processed tones. The publication also provides recommendations for organizations in the field of counteracting this situation.

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