INCREASING THE ENERGY EFFICIENCY OF MANUFACTURING INDUSTRIAL SYSTEMS USING CRITICALITY ASSESSMENT METHODS

Dejan BRANKOVIĆ [1*], Zdravko MILOVANOVIĆ [1], Darko KNEŽEVIĆ [1], Jovan ŠKUNDRIĆ [1], Saša LALOŠ [1]

[1]Faculty of Mechaical Engineering University of Banja Luka, Banja Luka, Bosnia and Herzegovina

[*] Corresponding author; E-mail: dejan.brankovic@mf.unibl.org

Production industrial systems are large consumers of energy, which within their technical systems and technological processes hide numerous opportunities for improvement. Process optimization aims to reduce production and maintenance costs. The most significant positive financial effects arise from the increase in energy efficiency and sustainability of the system, because today we are faced with the high price, unavailability and high demand of energy sources. The paper presents a case study of the application of the developed algorithm for assessing the criticality of a part of an industrial plant for the production of hygienic paper, which significantly facilitated the analysis, definition and selection of plant elements with the greatest potential for possible improvements. The theoretical bases of possible savings in energy consumption are related to the heat balance and calculation of the dryer, which give a realistic estimate of the reduction of specific steam consumption for drying hygienic paper in relation to the expected increase in the dryness of the paper web during the dewatering process. The experimental results of the research refer to the comparison of energy consumption results, maintenance costs and the quality of the final product before and after the implementation of the modification of a part of the technical system. The percentage reduction in specific steam consumption obtained by comparing data and records of energy consumption in the boiler plant corresponds to an increase in the degree of dryness of the paper web sample after the dewatering process, which justifies the value of the investment.

Key words*: energy efficiency, sustainability, energy consumption, maintenance, criticality algorithm, industrial system*

1. Introduction

Industrial systems are the basis of every social community because they ensure the creation of products of new use value of high quality that serve to satisfy the needs of end users, that is, customers. The technology and maintenance sectors are direct participants in production processes, and with their activities, they strive to positively influence the increase in the effectiveness of the production system, which at the same time determines the effectiveness of the maintenance service. Maintenance represents the joint action of a set of segments or elements with the aim of ensuring the functional state of the industrial system in accordance with the set requirements and criteria, [1], [2]. According to [3] maintenance activities control or prevent possible failures or malfunctions of the equipment as much as possible. Extending the life of the equipment is possible by properly organizing maintenance activities, which increases the quality of the process, which simultaneously improves the output results in production [4].

A good understanding of the processes within production along with an appropriate level of knowledge about the technical characteristics of the equipment and machines used are the basic prerequisites for achieving a positive impact of maintenance on the effectiveness of production. Within production systems, not all integral technical parts of the system are equally important for the smooth running of the process. There are certain parts, the so-called critical elements of the system whose malfunction or failure results in a complete stoppage in the functioning of parts of the system or the system as a whole and are regularly accompanied by large purchase costs and maintenance costs. Improvements and modifications of these parts of the system have great potential for optimizing production and maintenance processes. To analyze the criticality of parts of technical systems, it is first necessary to identify potential critical points and perform their classification. After identifying a critical element, the task of maintenance can be its analysis by some of the criticality assessment methods (e.g., Failure Method Effects and Criticality Analysis - FMECA, Fault Tree Analysis and others - FTA) and the proposal of activities for possible improvements (optimization) [5].

Research into the process optimization of technical systems and processes is numerous and all of them are aimed at showing possible improvements with the aim of opening new perspectives on solving specific situations and finding better technical-technological solutions in industrial practice. The most important factors that affect the effectiveness of production systems are the hours of operation (or downtime) of production, energy costs, as well as effectiveness and maintenance costs. The issue of critical points in technical systems hides numerous possibilities for improvement in terms of increasing energy efficiency and sustainability. Saving energy today, when we live in a time of increased demand and lack of energy, represents an imperative and support for the initiation and implementation of project activities. Requirements for the continuous provision of energy needs in sufficient quantities for industrial plants, transportation and the standard of living of people require the development of new technologies based on fossil fuels, as well as increasing energy efficiency, [6]. The connection between the use of certain energy sources and savings and more efficient use has a double importance. On the one hand, the rational use of energy is a direct means of reducing the total energy consumption and thus the impact on the environment, and on the other hand, special designs of devices and plants for energy use increasingly enable the participation of unconventional or new renewable energy sources, [7]. In the work [8], an example of the optimization of the construction of a chain conveyor of a production machine and its influence on the change (reduction) of energy that is spent on overcoming dissipative effects is given. The verification of the measurement results and the analytical approach show significant savings in energy consumption with a small increase in energy efficiency. An example of the analysis of the interdependence of energy consumption and surface roughness values within the self-propelled rotary tool turning (SPRT) process is presented in [9]. The result of the research shows the possibility of optimizing the process and reducing the total energy consumption by adjusting the inclination angle, depth of cut, feed rate and turning speed. The paper [10] presents the results of the implementation of a new approach called the supercritical organic Rankine cycle (S-ORC), which uses extraction steam compression regeneration in a supercritical state. The results of applying the new approach represent a structural optimization with a significant improvement in the thermal efficiency of the system. Ways of overcoming the energy crisis in Pakistan by researching the possibility of using renewable energy sources are presented in the paper [11]. The optimization model HOMER (Hybrid Optimization Model for Electric Renewables) was applied. Different cases of microgrid sizing, techno-economic exploration, sensitivity analysis and environmental effects were analyzed. The results of the analysis show that the cost of energy and environmental emissions have been significantly reduced for the proposed system. In paper [12], a hybrid static economic dispatch (HSED) model was presented with the aim of improving the economic efficiency of electricity dispatch after the integration of wind energy. An improved pathfinder algorithm (IPFA) was introduced within the model with the aim of improving the economic efficiency of power dispatch. The results of applying this algorithm show lower operating costs by 1.8% when wind energy is integrated. The proposed model and method provide the power system economic feasibility and stability, encouraging the use of renewable energy sources at the same time.

2. Developed algorithm for evaluating the criticality of system

Defining the critical elements of the system and finding optimal solutions and improvements should be supported by a universal methodology that can be applied in various applications in industrial practice. In this sense, we will create an algorithm for evaluating the criticality of elements of technical systems, Fig.1.

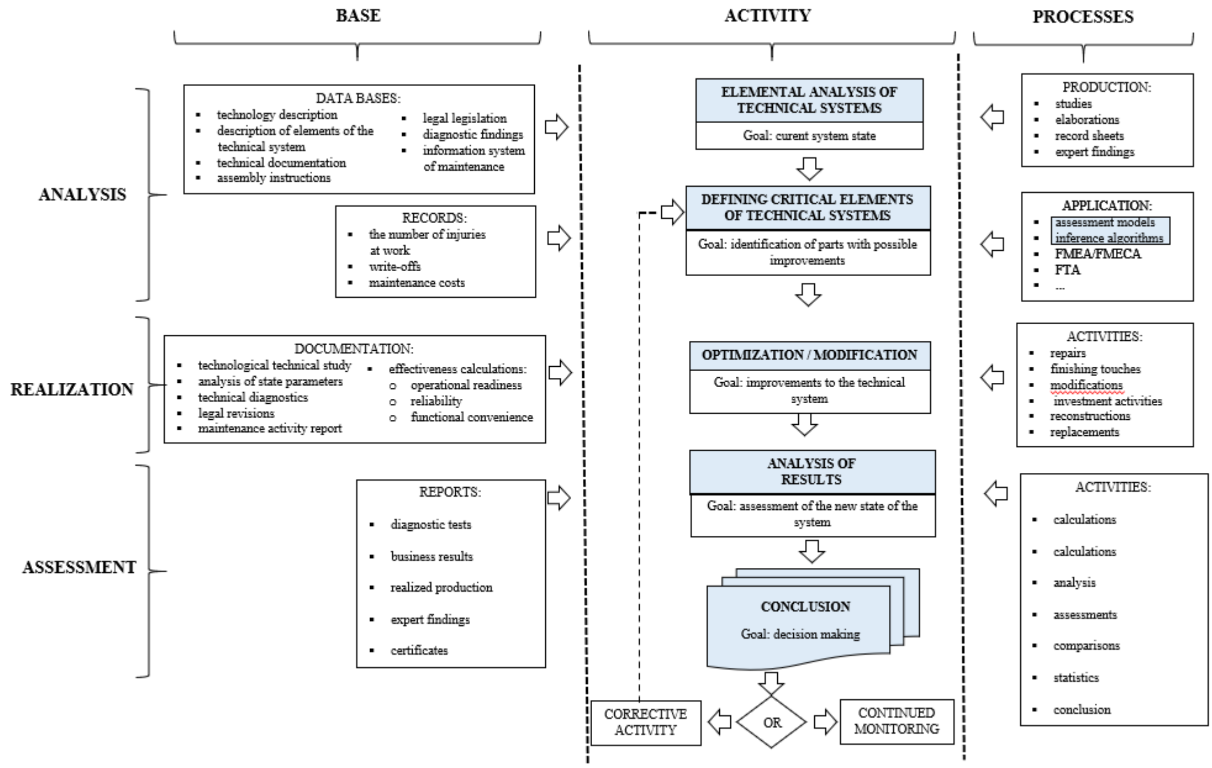

Figure 1. Algorithm for evaluating the criticality of elements of technical systems

The algorithm is focused on data collection, analysis, proposal of solutions and their valorization. By applying the algorithm, it is possible to arrive at more favorable technical-technological solutions in a systematic way, which achieve better production results. As part of the algorithm, Fig. 2 shows a model for assessing the criticality of parts of the production system with regard to maintenance criteria.

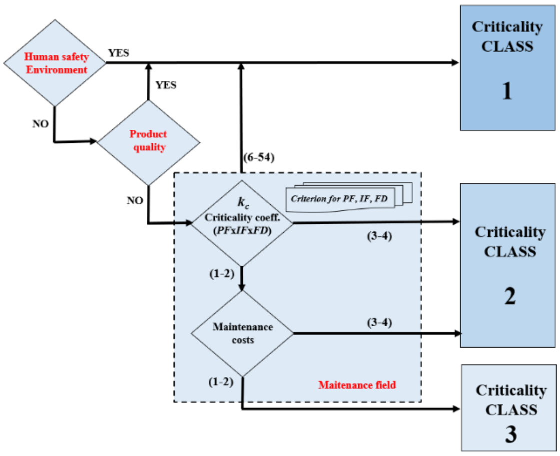

Figure 2. Model of assessment of the criticality of system parts

The values of the coefficients (PF, IF and FD) related to the maintenance criteria are given in Tabs 1 to 3. Level 1 criticality refers to all parts of the observed system when there is an impact of the work of the observed part of the technical system on the safety of workers participating in the work process, but also when there is a significant impact on the quality of the finished product.

Table 1. Criticality coefficient – PF

Criticality coefitient – PF Probability of failure		
Explanation	Level	Value
Failure is unlikely and can occur remarkably. Maintenance dynamics are poor.	Small	1
The failure has already appeared in the past. Sometimes a failure of an irrelevant meaning may occur. Failure can be assumed on the basis of experience.	Medium	2
Failures are very common, they are repeated. It is almost sure that the failure will occur.	High	3

Table 2. Criticality coefficient – IF

Criticality coefitient – IF Influence of failure on production process		
Explanation	Level	Value
Failure does not affect the production process, it does not limit production. There is an alternative facility i.e. parallel production.	Irrelevant	1
Failure limits the production process. Loss in production is expected.	Medium	4
Loss of loop functionality will suspend or interrupt the production process - high production losses.	Serious	6

Table 3. Criticality coefficient – FD

Criticality coefitient – FD Detection of the failure		
Explanation	Level	Value
Detection of the failure and its causes is problematic and it is likely to be easily identified.	High	1
Detection of failure and its causes is problematic. Detection is difficult and requires special diagnosis. Proving failure can be difficult to identify.	Medium	2
Failure detection and its causes is not possible or incredible. Failure of the reliability of the facility or its causes cannot be confirmed (hidden failure), the manifestation of failure is not noticeable.	Small	3

3. Application of algorithms for the assessment of criticality in the industrial system

The application of any method of analysis and evaluation of process parameters is possible if there is a good knowledge of the technological process and the technical capabilities of the system elements that are in the chain of realization of the production process. From the aspect of maintenance effectiveness, the dominant parameters are the time of total plant operation and total production costs. A particularly significant item in the total costs of production is the energy consumption for obtaining products of new use value, so the research of the conditions for increasing energy efficiency is one of the basic goals of analyzing the criticality of parts of the observed system.

3.1. Description of the real production system

The process industry is an example of a system with a large consumption of energy that needs to be invested in order to realize the production process. One such example is the industry for the production of hygienic paper. Testing of the algorithm for criticality assessment and analysis of the possibility of optimizing the process in production and maintenance as well as increasing energy efficiency will be shown on the example of the paper machine production plant in the industrial system for the production of hygienic paper in Banja Luka, Bosnia and Herzegovina.

The paper machine is a complex technical system that works in a continuous work process, the output of which produces hygienic paper with a weight of 15 to 40 gr/m2. The previously prepared paper mass is brought to the system of drive rollers and driven rollers by a system of pipelines, pumps and cleaners, through which the movement of the endless belt of sieves and felt transfers the paper mass from the input part (the so-called wet part) to the pressing part (press rollers) and the part for drying the paper mass (drying cylinder). The complex process of dewatering by pressing and drying the paper strip on the drying cylinder takes place precisely on the pressing section and the drying section of the paper strip with significant energy transfer via dry saturated steam inside the drying cylinder and the drying hood on the outside of one side and the amount of water content in the paper mass that needs to be extracted in a certain percentage to obtain paper of a certain dryness. The efficiency of the paper machine production plant dominantly determines the production results. In this sense, there is a constant need to monitor the operation of system components and find even the smallest improvement opportunities that would contribute to better business results. Along with the proper and responsible work of the technological staff, the engagement of the maintenance service certainly plays a key role in maintaining a high hourly capacity utilization of the paper machine.

3.2. Assessment of the criticality of parts of the technical system of the paper machine

Applying the criticality assessment algorithm means an initial review of all available information about the technical parts of the system and their role in the technological process. In the case of the observed paper machine system, the maintenance service as well as the technological staff possess an enviable archive of the behavior of the system parts, failure history, production results, energy consumption in the process and previous analyzes that additionally describe the behavior of the complete system

Defining critical positions means finding places (elements in the technical system) with a high potential for process optimization and achieving real savings, both in maintenance and in production.

Based on long-term monitoring and experience of the production and maintenance sector, the position of suction press roll and blind drilled press roll has been defined as one of the critical positions of the paper machine with great potential for improvements and optimization in terms of saving maintenance costs and saving on the consumption of total energy required for drying the paper strip, Fig.3. Presses are driven rotary rollers that are used to do the process of dewatering the water content from the paper pulp. Extraction of water from the paper mass is carried out by vacuum and pressing through the mutual contact of the press with the drying cylinder. A number of factors affect the quality of dewatering such as roll geometry, value and distribution of line pressure loads during pressing, age of roll lining, etc.

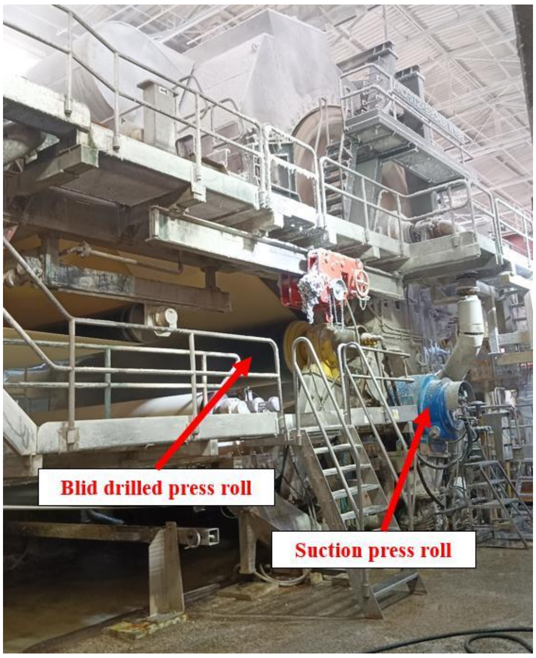

Figure 3. Critical positions of the paper machine

However, one of the very important factors that has a direct impact on the amount of steam needed for paper drying, i.e., value of the energy used is the quality of the coating of the rollers, i.e. the type of material from which the lining of the press is made.

In relation to maintenance, press positions are very important in terms of providing high-value spare parts (e.g., bearings, suction chambers, etc.) but also providing regular press services that include periodic grinding or complete replacement of press linings. Considering the costs of regular service, they are one of the most important items in the planning of maintenance funds. These facts can be evaluated within the application of the criticality assessment model, Fig. 4.

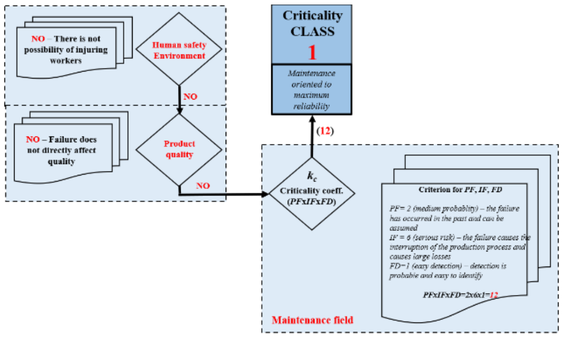

Figure 4. Assessment of the criticality coefficient of the position of the paper machine press

Considering the maximum reliability of the plant, the analysis of the criticality coefficient classifies the position of the press in the category of criterion 1. The fact is that a failure of the press leads to a complete stoppage of the paper machine and interruption of production.

3.3. Assessment of the possibility of optimization of paper machine parts

The theoretical basis of research into the possibility of optimizing the critical positions of the paper press is based on the theory of drainage, which defines the influence of several important factors that determine this process, such as: contact pressure between the press and the drying cylinder, profile of the contact surface (nip profile), value of the open area of the press cover (total area of openings in the casing and their arrangement), cooling method of the press lining, etc. The description of the pressing model was developed back in 1968 and still gives reliable results to this day. The development of pressure during the passage of the paper web and the press fabric through the press nip is described in [13], which was later confirmed in laboratory tests. Fig. 5 describes the pressing process and the pressure distribution profile in a press nip within 4 characteristic phases.

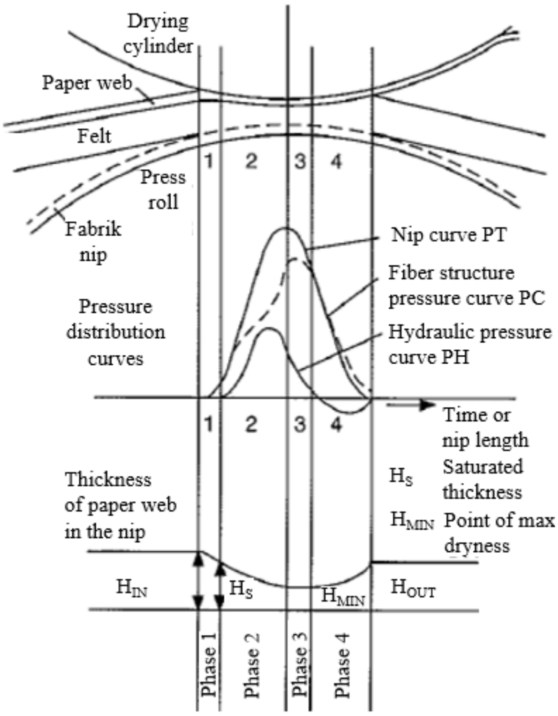

Figure 5. Pressure distribution in a press nip, [14]

Changing the press cover material significantly changes the characteristics of the dewatering process and the pressure value. Until the time of optimization, the covers of the paper machine press were made of a special type of rubber, which certainly has a number of advantages for the specific construction of the paper machine (well-known technology of rubberizing the cover of the roller, good compensation of vibrations during operation and satisfactory quality of the produced paper).

Today's technology and the development of new types of materials provide the possibility of changing the type of press cover, which is particularly pointed out by the manufacturers of covers, stating the huge potential in terms of better working characteristics and significant energy savings. A special development trend relates to the production and use of polyurethane (PU) covers, which have significant advantages over rubber covers. The most significant advantage of using single-layer polyurethane covers is the possibility of working with higher pressures in the press nip zone compared to the currently preferred competitive double-layer rubber coverss, which can achieve better results in the dewatering process, which means a lower amount of energy used per ton of paper produced.

Energy saving is based on the heat balance of the energy required for the evaporation of the water part from the total content of the paper mass within the dewatering process. The expected saving of energy needed for drying the paper tape is based on the calculation of the heat balance and the comparison of the energy needed to evaporate a certain content of water from the total content in the case of working with the old (rubber) cover of the suction press and working with the new (PU) cover of the suction press. Thermal flux for evaporation of material according to [15] is:

$$\dot{Q}_s = \dot{m}_s \cdot \left[\left(u_m^{in} - u_m^{out}\right) \cdot r + c_m^{out} \cdot \left(t_m^{in} - t_m^{out}\right)\right] \tag{1}$$

where:

- $\dot{m}_s$ is mass flow of absolutely dry material
- c_m is specific mass heat capacity of material

- u_m is absolute humidity of material (inlet/outlet)
- r is heat of evaporation taken for the mean value of material temperature.

In case of evaporation of a certain amount of water from the total content of the paper mass ($\dot{W}_{evap}$) exchanged energy for evaporation of water is obtained as:

$$\dot{Q}_{exc} = \dot{W}_{evap} \cdot (h_{st} - h_w) \tag{2}$$

where:

- h_w is specific enthalpy of water at inlet temperature
- h_{st} is specific enthalpy of superheated steam at outlet temperature.

That is:

$$\dot{Q}_{exc} = \dot{W}_{evap} \cdot (r_0 + c_{st} \cdot t_{out} - c_w \cdot t_{in}) \tag{3}$$

where:

- r_0 is entalphy of evaporation
- c_w is specific heat capacity of water
- c_{st} is specific heat capacity of steam
- t_{in} is inlet temperature (temperature after pressing)
- t_{out} is outlet temperature (at outlet drynes).

If we adopt the precondition that the dry part of the total content of the paper mass is constant, evaporated water in the case of work with a rubber cover of the suction press can be calculated as:

$$\dot{W}_{evap}^{rub} = \dot{m}_m \cdot \frac{1 - x_{1in}}{x_{1in}} \tag{4}$$

where:

- $\dot{m}_m$ is dry matter
- x_{1in} is absolute content of dry matter when working with rubber cover.

In the case of work with PU cover, analogously to the previous one, evaporated water is calculated according to:

$$\dot{W}_{evap}^{PU} = \dot{m}_m \cdot \frac{1 - x_{2in}}{x_{2in}} \tag{5}$$

where:

- x_{2in} is the absolute content of dry matter when working with PU cover.

By equating equations (4) and (5), taking into account the condition of equal mass of the dry part in both cases, we get the ratio of energy exchanged for evaporeted water from the paper web during drying precess:

$$\dot{Q}_{exc}^{PU} = \dot{Q}_{exc}^{rub} \cdot \frac{x_{1in} \cdot (1 - x_{2in})}{x_{2in} \cdot (1 - x_{1in})} \tag{6}$$

In the case of working with rubber cover, the usual percentage of humidity, i.e., dryness of the paper strip after the pressing process, obtained by taking a sample from the total paper mass, is approximately 45%. The guarantees of the manufacturer of PU coverings related to the expected decrease in humidity, i.e., the increase in the dryness of the paper strip after pressing is up to 1%. In that case, the ratio from equation (6) would be:

$$\frac{\dot{Q}_{exc}^{PU}}{\dot{Q}_{exc}^{rub}} = \frac{0{,}45 \cdot (1 - 0{,}46)}{0{,}46 \cdot (1 - 0{,}45)} \approx 0{,}96 \tag{7}$$

which means an expected reduction of specific energy consumption by approx. 4%.

Another possibility of savings is related to the analysis of maintenance costs in case of working with PU cover: longer cover lifetime, longer time between two grindings, less downtime and production loss caused by press replacements, etc.

The process of changing the type of cover and switching to work with PU cover was approached very cautiously considering the specifics of the technological process and the influence of a large number of additional factors that can affect the final results and thus the quality of the produced paper. Compared to the previous rubber, the relatively more expensive new PU cover has a significantly longer service life, which, along with better mechanical characteristics, was one of the main arguments for replacement. It should also be emphasized the rather high risk and uncertainty considering that in this particular case there were no previous experiences of replacing the press cover material on this type of paper machine, which in the early eighties of the 20th century was one of the 4 pilot projects of paper machine construction in Europe.

3.4. Realization of the optimization - replacement of the cover material of the suction press roll

Based on the assessment of the project team and the decision of the management, the replacement of the cover material of the suction press was approved and implemented, which is also the first step in the implementation of the optimization. The new PU cover on the suction press roll of the paper machine is a product of a renowned manufacturer of paper machines from Austria. The installation of the press roll with a new cover was carried out during the planned replacement of the felt (technological stoppage of production) in the winter period (mid-January), since the company has two suction press rolls (one in operation and the other in reserve).

4. Results and discussion

The first results of the implementation of the replacement of the cover of the suction press roll were noticed immediately after the start of production and related to a significant reduction of splashing water in the area around the press rolls. Relevant results and confirmation of a significant impact on energy consumption were obtained by analyzing two weeks of work in the winter period, which from the point of view of comparison is more relevant because it is a matter of higher energy consumption due to lower temperatures of the work space and the environment.

A comparison was made of the average production of paper on the paper machine and the consumption of produced steam for drying the paper strip in equal monitoring time intervals in the calendar month of the realization of the optimization. Precise recording and monitoring of the balance of steam consumption is possible because the company owns its own boiler room with a separation of energy consumption for the operation of the paper machine, its own consumption of the boiler room, part of the energy for space heating and external consumers. In the analysis of the results of the modification's impact on the total energy consumption, only the consumption of the produced steam, which is realized on the paper machine for the purposes of drying the paper strip, was taken.

Records of steam consumption for drying the paper tape in relation to the produced amount of paper with a new PU cover and with an old (rubber) cover for the same time period before and after the replacement of the cover is shown in Fig. 6.

Optimization	**Boiler plant data**				**Paper machine energy consumption**		Average specific steam consumption
	January	Production	Heavy oil	Steam consumption	Steam consumption	Specific steam consumption	
	Day	t	t	GJ	GJ	GJ/t	GJ/t
Before	1.	102,3	20,9	847,26	636,08	6,23	**6,13**
	2.	91,5	19,6	794,21	560,77	6,13	
	3.	123,3	21,1	855,36	655,75	5,33	
	4.	109,9	21,2	859,01	619,01	5,63	
	5.	102,3	20,5	831,87	616,80	6,03	
	6.	98,7	21,5	872,37	635,49	6,44	
	7.	109,9	20,9	845,64	616,595	5,61	
	8.	103,1	20,1	814,05	605,02	5,87	
	9.	87,5	17,2	695,39	495,47	5,66	
	10.	98,6	22,2	898,70	657,59	6,67	
	11.	90,9	21,1	855,77	619,66	6,82	
	12.	110,6	24,1	977,27	691,12	6,25	
	13.	118,5	23,9	967,55	701,63	5,92	
	14.	83,5	19,7	897,26	566,82	6,76	
	15.	107,3	23,3	944,87	698,84	6,51	
	16.	Shutdown of paper machine					
After	17.	116,6	21,0	850,50	612,47	5,33	**5,48**
	18.	123,1	20,2	868,32	699,66	5,44	
	19.	131,2	21,1	853,74	679,61	5,18	
	20.	109,3	19,6	791,78	598,96	5,48	
	21.	121,9	22,2	897,89	655,82	5,38	
	22.	91,1	18,5	749,66	549,33	6,03	
	23.	122,0	21,4	867,11	660,02	5,41	
	24.	112,6	19,9	807,98	604,66	5,37	
	25.	121,1	21,2	858,20	662,41	5,47	
	26.	105,9	19,8	801,90	588,80	5,56	
	27.	107,4	20,2	819,72	622,92	5,80	
	28.	119,2	20,2	816,48	618,64	5,19	
	29.	118,5	21,5	870,35	655,30	5,53	
	30.	116,1	20,6	833,90	655,96	5,65	
	31.	112,5	19,8	801,50	623,25	5,54	

Figure 6. Boiler plant data - energy consumption before and after optimization

The data clearly indicate a reduction in steam consumption by 0.65 GJ/t, which is a percentage reduction in drying energy by approx. 10.60%. The basic energy used for the production of steam in the observed factory is heavy oil with a monthly consumption of approx. 600 t. In this particular case, the achieved energy saving of 10.60% results in a reduction of fuel oil consumption by approx. 63.6 t/month. Based on the current average price of heavy oil of approx. 620 EUR/t cost saving (C_S) can be represented by the following equation:

$$C_S = 63{,}6\ \frac{t}{month} \cdot 620\,\frac{EUR}{t} = 39\ 432\,\frac{EUR}{month} \tag{8}$$

The obtained monthly savings represent a significant positive economic result created by increasing the energy efficiency of the industrial-process system. According to equation (7), an increase in dryness, i.e., a decrease in humidity of the paper strip by 1% results in a decrease in specific energy consumption by approximately 4%. The result of reducing the specific steam consumption of the paper machine by 0.65 GJ/t caused an increase in the percentage of dryness of the paper mass after the pressing process by approximately 2.65%, which is shown schematically in Fig. 7.

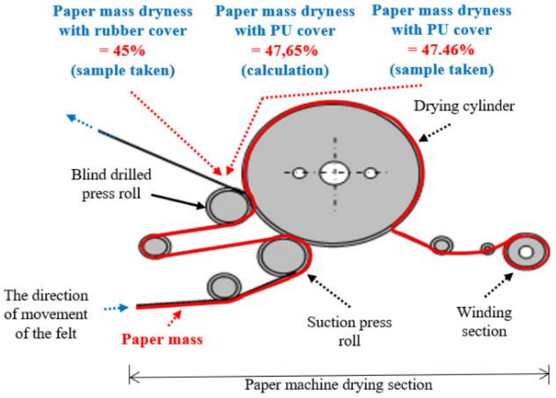

Figure 7. Paper mass dryness comparison

Subsequent sampling and measurement of the dryness of the paper pulp in the case of work with PU coating showed a value of 47.46%, which is in correspondence with the results of the measurement of specific energy consumption.

The most significant positive effect from the maintenance point of view is the extension of the grinding interval of the new PU cover of the suction press roll. The new PU cover was grinded for the first time after 14 months of continuous work, which is a much longer working period than the manufacturer's guarantee of 9 months. This results in annual savings on grinding costs of approx. 7,800 EUR. From the point of view of the technological process, in addition to the increase in the available time for the realization of production, a more even distribution of the grammage and moisture profiles along the section of the paper strip was observed.

The justification of the replacement results in this position provides a basis for thinking about the possibility of replacing the cover and other, blind-drilled press rolls. Considering the sensitivity of the technological process and the presence of numerous influential factors, as well as the possibility of further saving energy and maintenance costs, this activity is in the focus of the project team and may be the subject of the continuation of this research.

5. Conclusion

Increasing energy efficiency is the primary goal of industrial processing systems because energy costs make up a significant share of total business costs. The economic stability of the society provides a prerequisite for the sustainability and well-being of the population. Process-industrial systems hide numerous possibilities of modifying system elements and improvements because they represent the integration of technological and technical systems, each of which significantly affects the achievement of the goal function - the production of goods of new utility value. The presented algorithm for criticality assessment with the application of the criticality assessment model for parts of the production system methodologically facilitates access and analysis of the system and indicates possible sources of process improvement. The universality of the application of the algorithm provides the possibility of analyzing system elements in various areas of the process industry and facilitates the research of project teams in charge of process optimization in production and maintenance. A concrete example of the application of the algorithm confirms the positive results of the combination of methodological research and positive industrial practice.

References

[1] Branković, D., Milovanović, Z., *Maintability of Industrial Systems* (in Serbian language), The Research Center of Dependiability and Quality Management DQM, Prijevor, Serbia, 2021

[2] Papić, LJ., Milovanović, Z., *System Maintability and Reliability* (in Serbian language), The Research Center of Dependiability and Quality Management DQM, Prijevor, Serbia, 2007

[3] Torman, S., System Reliability Analysis of Large Capacity Electric Mining Trucks Used in Coal Mining, *Journal of Reliability and Statistical Studies, 16* (2023), 1, pp 81-89, https://doi.org/10.13052/jrss0974-8024.1614

[4] Norman M. A., *et al.*, A Model for Maintenance Planning and Process Quality Control Optimization Based on EWMA and CUSUM Control Charts, *Transactions of FAMENA, 45* (2021), 1, pp. 95-116, https://doi.org/10.21278/TOF.451021920

[5] Pryanta, D., *et al.*, The Application of OREDA (Offshore Reliability Data) in Developing Valve Criticality Analysis Criteria. *IOP Conference Series: Earth and Environmental Science, 1298* (2024), 1, pp. 1-12, https://doi.org/10.1088/1755-1315/1298/1/012015

[6] Milovanović, Z., *et al.*, *Sustainable Energy Planning: Technologies and Energy Efficiency* (in Serbian language), DQM Monograph Library Quality and Reliability in Practice, Prijevor, Serbia, 2011

[7] Milovanović, Z., *Optimization of Power Plant Reliability* (in Serbian language), University of Banja Luka, Faculty of Mechanical Engineering Banja Luka, Banja Luka, Bosnia and Herzegovina, 2003

[8] Langerholc, M., *et al.*, Conveyor Design Optimization as the Provision of Sustainability, *Tehnički vjesnik*, *20* (2013), 5, pp. 837-846, https://hrcak.srce.hr/109793

[9] Van, A., *et al.*, Optimization of Rough Self-Propelled Rotary Turning Parameters in terms of Total Energy Consumption and Surface Roughness, *Tehnički vjesnik, 30* (2023), 6, pp. 1728-1736, https://doi.org/10.17559/TV-20230202000308

[10] Enhui, S., *et al.*, Thermodynamic Study of Organic Rankine Cycle Based on Extraction Steam Compression Regeneration in the Supercritical State, *Energy Conversion and Management, 293* (2023), 117546, https://doi.org/10.1016/j.enconman.2023.117546

[11] Javid, Z., *et al.*, Hybrid-Microgrid Planning, Sizing and Optimization for an Industrial Demand in Pakistan, *Tehnički vjesnik, 27* (2020), 3, pp. 781-792, https://doi.org/10.17559/TV-20181219042529

[12] Li-Nan, Q., et al., A Hybrid Static Economic Dispatch Optimization Model With Wind Energy: Improved Pathfinder Optimization Model. *Energy Reports*, *10* (2023), pp. 3711-3723, https://doi.org/10.1016/j.egyr.2023.10.033

[13] Wahlstrom, B. Opportunities in Pressing, Part I. *Tappi Jornal, 64* (1981), 1, 75

[14] Pandey, R. S. D. *Theory and Design of Paper Machines*, Vol. 1. Tara, Book Agency, Varnasi, India, 1983

[15] Topić, M. R. *Designing plants and process and energy systems* (in Serbian language), University in Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbian, 2013

Paper submitted: July 7, 2025

Paper revised: August 2, 2025

Paper accepted: August 6, 2025