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QUANTIFICATION AND MUTUAL INTERDEPENDENCE OF THE COMPONENTS OF THE POTENTIAL OF THE ENERGY MODEL OF A PRODUCTION SYSTEM

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Abstract The subject of considerations in this paper are the components of the potential of the energy model of a production system. In the literature dealing with this problem, the components of the potential of the production system are not defined more precisely. Also, the problem of the relationship between components of the potential has not been considered. In this paper, concrete expressions for the potentials relating to the human resources, material resources and the potential regarding the means of work has been derived. Also, based on the derived formulas, the relationship between the aforementioned potentials of a production system was considered. The conducted analysis shows that in order to optimize business, one should not aim at simultaneously reducing the investment in all three mentioned resources. The key to business success is to synchronize investment into the potentials of human, material and technical resources.

Keywords: models of a production system; energy model of a production system; potentials of a production system; components of the potential of a production system.

1. ENERGY MODEL OF A PRODUCTION SYSTEM

According to Planck and Päsler, energy is intrinsic ability of a system to generate external impact [1]. Energy transparency in factories nowadays have great significance [2]. Therefore, the studies about characterizing manufacturing processes from energy aspect is of great interest to all parties including manufacturers, consumers, government and others [3].

The subject of this paper is the determination of usable expressions for the potentials of certain components, which are an integral part of the total potential of the production system. In addition, the mutual relationship between these components will be analyzed. To this end, it is necessary to briefly present the energy model of the production system. This model has its starting basis in [4]. According to this model, the production process is viewed as a whole, in which the transformation process takes place in two directions, matter and energy. This is symbolically shown in Figure 1. With PS (t) a production system is marked, whose condition is observed during time t. The following variables are observed as input quantities in the production system [4]:

$\sum M(t)$ - sum (set) of material resources
$\sum R(t)$ - a set of people engaged in the production
$\sum G(t)$ - means of work used in the production process
$\sum E_r(t)$ - the sum of other used sources of energy (electricity, heat, water, etc.).

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All the above quantities have the appropriate potential:

P∑M(t) - potential of material resources
P∑R(t) - potential of human resources
P∑G(t) - potential of the means of work
P∑E_r(t) - potential of other used energy sources.

Output quantities from the production system are:

∑Q(t) - realized quantity of products
∑E(t) - spent (released) energy during the production process.

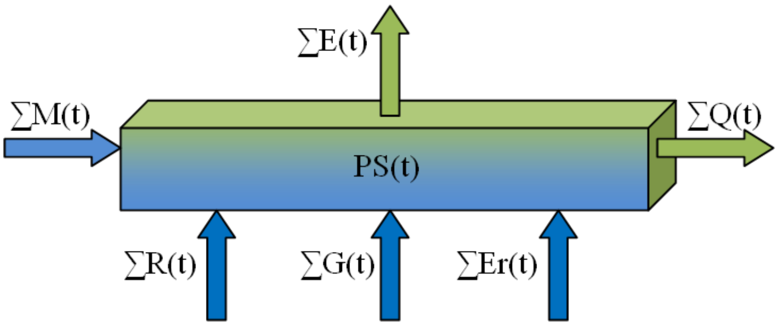

Figure 1. The symbolic representation of the energy model of the production system.

In the material-energy sense, the basic condition for the realization of a business can be expressed in the form of the following inequality $\Sigma M\ (t) + \Sigma R\ (t) + \Sigma G\ (t) + \Sigma E_r\ (t) \geq \Sigma Q\ (t) + \Sigma E\ (t)$. The production system in this context should be seen as a set of processes that enable the mentioned transformation [4]. Business systems mutually differ in terms of production processes (used methods and procedures), as well as in the above-mentioned available potentials.

2. PROBLEM

In the literature that deals with this issue [4], the notions of potentials of the mentioned resources are used in further considerations, although they are not more specifically defined. In order to concretize and quantify the potential of the production system, it is necessary to consider and identify concrete indicators of the potential of material and human resources, including the potential of the means of work. The potential of other energy sources used here will not be the subject of special consideration because, although important for the overall state of the production system, it is primarily in function of the time and extent of using the aforementioned resources. This approach to the problem, the precise record of the potentials of the used energy sources as an essential component for the functioning of the production systems, as well as the representation of the inequality that reflects the basic condition of the business, as a whole, contribute to the creation of a more complete picture of the energy model of the production system than previously presented in [4].

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3. RELATION OF THE POTENTIALS OF HUMAN, MATERIAL AND TECHNICAL RESOURCES

Guided by the need to specify the relationship between the potentials of the resources that are the subject of consideration, it is necessary to define these potentials first. In that regard, we will start from the potential of human resources, which is in the literature often imprecise determined, although it is widely used as an entity that is almost exclusively by its name determined and sufficiently clear. In addition, the human factor is often neglected when considering the application of different technologies [5], which can lead to failures in different business segments. The following analysis will point out the significance that human resource potential has for the entire production system, and it will be revealed its impact on the remaining two resources.

The potential of human resources can be expressed in the form of a function that includes the following parameters: number of workers ΣR (t), productivity PR, the total time of workers' work and the quality of workers' work. In [6], a formula is given for the calculation of the required number of workers for the production process

$$\sum R(t)=\frac{\sum_{j=1}^{p}\sum_{i=1}^{m}(T_{PFij}+Q_j \cdot t_{Pij}+EWN_{STij})}{dy \cdot hs-L_{st}} \quad [\frac{workers;day}{year}] \tag{1}$$

All quantities in the above formula basically have a time dimension. The symbols used in the previous formula are:

T_{PF} - preparatory-final time for the production of a product predicted by norms of work
t_P - time per piece for making one product predicted by the norms of work
Q - the planned quantity of products of a certain type
dy - number of working days in a year
hs - number of hours in one shift of the working day
EWN_{st} - standard execution of work norms - below or above
L_{st} - standard losses in empoyee use
j=1,....,p - number of different types of products
i=1,....,m - number of types of workplaces.

There are a number of formula for determining the productivity PR of workers. Here the formula will be given according to [6]

$$PR=\frac{Q}{\sum R(t)} \tag{2}$$

As an indicator of the total working time of workers, the so-called degree of execution of the time norm of work of workers will serve, which according to [6] represents the ratio of the normed and realized working time. It is determined by the formula

$$i_{nr}=\frac{\sum_{j=1}^{p}\sum_{i=1}^{n}(T_{PFij}+Q_j \cdot t_{Pij})}{\sum_{j=1}^{p}\sum_{i=1}^{n}RT_{ij}} \cdot 100\ [\%] \tag{3}$$

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where
RT - achieved time per operation
i=1,...,n - number of operations
j=1,...,p - number of different types of products.

As an indicator of the quality of work of workers, it will serve the indicator of the level of defective products caused by the work of workers K_d. It represents the percentage of faulty parts generated as a consequence of worker error in the total quantity of defective parts Q_d (which are the result of various errors in the functioning of the technical components, including the technological process, etc.). This indicator of the quality of work of workers can be considered more precise and more direct than other indicators of a similar nature that can be found in the literature. It is determined by the formula

$$K_d = \frac{Q_{dw}}{Q_d} \cdot 100 \ \ [\%] \tag{4}$$

where
Q_{dw} - the total amount of defective products caused by workers' faults $[\frac{pieces}{year}]$
Q_d - the total quantity of defective products $[\frac{pieces}{year}]$.

In this way, if the value of this indicator is low, then the quality of work of the workers is high, which is largely due to their qualifications and training, as well as other human factors. In view of the above, the human resource potential PΣR (t) can be described by the following function

$$P\sum R(t) = F(\sum R(t), PR, i_{nr}, K_d) \tag{5}$$

In this way, it is emphasized that the potential of human resources is not merely a term that is only mentioned or taken into account in a limited measure in different considerations, but rather a concrete quantity that can be explicitly determined based on the calculation of the parameters that make up the above function.

The potential of material resources is determined by the quantity and quality of materials that a company has at its disposal. It can be determined in several ways, and one of them is over the amount of money invested in the procurement of a certain quantity of material, which is necessary for the realization of the production process. In view of this, the costs of material CM that indicate the level of potential of the material resources can be determined from the relation

$$C_M = C_{MP} \cdot Q + C_{ML} \tag{6}$$

where
C_{MP} - the cost of purchasing the materials for the production of a unit of a particular product
C_{ML} - costs due to losses in the material (defects, handling losses, depreciation, waste materials, etc.).

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The quantity C_{MP} is expressed in the money per piece, while the C_M and C_{ML} quantities are determined in monetary units. As mentioned above, Q represents the planned amount of product for the realization [pieces]. In order to determine the potential impact of human resources on the potential of material resources, it is necessary to perform certain mathematical operations. From equation 2 it follows that Q = PR • ΣR (t). By changing this expression for Q in (6) we obtain

$$C_M = C_{MP} \cdot PR \cdot \sum R(t) + C_{ML} \quad (7)$$

If we assume that the costs of the material for the production of a given product and the number of workers engaged in their realization are approximately constant for the established production regime, then the product $C_{MP} \cdot \sum R(t)$ can be marked with φ and adopted for a constant value. Accordingly, from (7) follows

$$C_{ML} = C_M - \varphi \cdot PR \quad (8)$$

Equation (8) indicates that the productivity of workers also reflects on the material domain. From the relation (8) it follows that the losses in the material are smaller, if the productivity of the workers is greater and vice versa. In this way, through equality (8), it has been shown that the human factor emanating from the domain of the human resource potential has an influence on the variable from the domain of potential of material resources.

The potential of the means of work can also be determined in several ways. For this analysis, a formula will be used that determines the potential of the means of work from the energy aspect. Accordingly, the calculation of the potential of the engaged capacities (from the aspect of the available power) can be made according to [6] using the formula

$$CP_r = \sum_{i=1}^{m} n_i \cdot p_{ui} \cdot cp_{ri} \quad (9)$$

where
p_u - maximum available power installed in the machine (kW)
n - number of machines of the same type
cp_{ri} - available capacity of a certain type of machine (hours/year)
i=1,...,m - number of different machines.

The relation (9) indicates that the potential of the means of work can be expressed in a concrete form. In order to determine the impact of human resources potential on the potential of the means of work with E_p $[\frac{kWh}{year;piece}]$ will be marked the power required to produce one product over a period of one year. Considering this, the equation (9) can be written in the form $Q \cdot E_p = \sum_{i=1}^{m} n_i \cdot p_{ui} \cdot cp_{ri}$. Given that according to (2) Q = PR · ΣR (t), we have that

$$E_p = \frac{1}{PR \cdot \sum R(t)} \cdot \sum_{i=1}^{m} n_i \cdot p_{ui} \cdot cp_{ri} \quad (10)$$

From the equality (10), it can be seen that with the increase in productivity and the number of engaged workers, the required power for the production of products is reduced. Consequently, the

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need for procurement of means of work of high production performances is reduced. This means that it is possible to install the technical capacities of less power, if at the same time it is working on increasing the productivity or the number of workers. In this way, through the relationship (10) it has been shown in a concrete manner that the potential of human resources has a large share in designing the potential of the means of work.

However, elements that characterize the potential of material resources also have an impact on the potential of the means of work. This can be noticed if the relation (7) we write in the form $PR \cdot \sum R(t) = (C_M - C_{ML})/C_{MP}$ and then replace into equality (10). Then we get

$$E_p = \frac{C_{MP}}{C_M - C_{ML}} \cdot \sum_{i=1}^{m} n_i \cdot p_{ui} \cdot cp_{ri} \qquad (11)$$

Relation (11) indicates that in the case of the increase of costs for the purchase of certain material resources, it is necessary to invest less power to produce the product, ie in the case of the use of higher quality materials, it is possible to invest less power in the production process. This indicates that the potential of material resources also has an impact on the design of the potential of the means of work.

All previously presented points to the fact that the potentials of human resources, material resources and the potential of the means of work are mutually connected and conditioned. As a result, the potential of a production system in the energy sense can be expressed in the form of the equation

$$P_{PS} = P\sum M(t) + P\sum R(t) + P\sum G(t) + P\sum E_r(t) \qquad (12)$$

If we consider the production system in the energy sense as a complete entity that has a certain potential at the observed moment, then a company with a low level of human resource potential (a small number of workers, a low labor productivity) can maintain a competitive advantage on the market primarily by using higher quality materials and more modern assets for work, which is based on equation (12). Similarly, if the firm has the low potential of its available technics, then it is necessary exploitation of more quality materials while increasing the productivity of workers, as well as improving other factors that define the potential of human workforce. Finaly, if the company uses low-quality materials, its survival on the market is only possible based on the improvement of the means of work, in parallel with the engagement of highly qualified and efficient human resources.

4. CONCLUSION

Based on the previous analysis, it can be concluded that the tendency towards simultaneous minimization of investments in terms of human and material resources, including the means of work that is often present in theory [3], and also in practice does not lead to optimization of business, but contrary to its failure. The core of the successful business is in the harmonization and synchronization of the three analyzed resources under specific conditions, in order to achieve the maximum business effect.

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