TECHNICAL TRANSACTIONS 6/2017
CZASOPISMO TECHNICZNE 6/2017
CIVIL ENGINEERING
DOI: 10.4467/2353737XCT.17.095.6571

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The algorithm for the evaluation of construction workers' labour productivity

Algorytm oceny wydajności pracy robotników budowlanych

Abstract

The paper presents an algorithm that allows to calculate the potential productivity of construction workers, including the factors that influence them. Its development involves one of the classifications of factors. In the next step, the elements of fuzzy logic were used for the parameterization of factors. Subsequently, a survey was applied to specify the gradation of individual factors with regard to their impact on productivity. The paper as a whole presents a mathematical algorithm, the practical application of which was presented too.

Keywords: algorithm, labour productivity, construction workers

Streszczenie

Artykuł przedstawia algorytm pozwalający na obliczenie potencjalnej wydajności pracy robotników budowlanych uwzględniający czynniki na nich oddziałujące. Do jego budowy wykorzystana została jedna z klasyfikacji czynników. W kolejnym etapie przedstawiono sposób wykorzystania elementów logiki rozmytej do parametryzacji czynników. Następny krok polegał na wykorzystaniu badań ankietowych do określenia gradacji poszczególnych czynników pod kątem ich stopnia wpływu na wydajność. Całość publikacji prowadzi do zaprezentowania matematycznego algorytmu, którego możliwości zastosowania w praktyce również zostały przedstawione.

Słowa kluczowe: algorytm, wydajność pracy, robotnicy budowlani

1. Work environment of the construction worker

Construction works have a dynamic character. Apart from the diversity of the works, a great significance is given to the instability of factors related to the influence of the environment. In literature [3, 4, 7], there were attempts to describe this dynamicity by means of algorithms. However, their scope of operation was related only to a mathematical relationship between the algorithm and schedule building [15, 17, 19]. The basic problem of the procedure described is the lack of a detailed analysis of the reasons for the occurrence of the differences. Apart from the technological issues, labour productivity of construction workers, depending on the influence of a variety of factors [13], is an important element. Therefore, a comprehensive approach to the subject should include information about the work environment of the construction worker. An indispensable element is the identification and evaluation of the factors that influence his work.

Previous research already concerns various classifications of factors influencing the labour productivity of construction worker [9, 14, 16]. It is worth emphasizing that they all specify which aspects should be analysed when performing an evaluation of labour productivity of a construction worker. The authors of the present paper chose publication [14] to analyse which factor, in their opinion, describes construction works in the most universal way. The factors included there are presented in Table 1. A characteristic feature of this classification is

Table 4. Classification of the factors affecting labour productivity

Factor group	Factors
Time spent outside work	▸ suitable length of rest ▸ worker's absence ▸ time spent with the family (WLB)
Weather conditions	▸ biometeorological conditions ▸ temperature ▸ humidity ▸ rainfall ▸ extreme work conditions (temp. and humidity)
Psychophysical conditions	▸ stress ▸ fatigue ▸ health ▸ age ▸ recovery
Organization and management of the worker	▸ ergonomics ▸ noise ▸ duration of work shift ▸ salary ▸ organization of work and workstations
The remaining factors	▸ day of the week ▸ experience ▸ adaptation to new operating conditions or a new technology

Source: [14].

the lack of relationship between individual factors with a particular construction work. This feature allows to make an attempt to develop a mathematical algorithm, including the factors that surround the worker, to describe the productivity of the work that he attains.

2. The premises of the algorithm describing labour productivity of construction workers

The classification described in the previous section serves as input data for the development of the algorithm, which makes the workers' labour productivity dependent on the factors that influence it. According to the authors, the factor itself needs to be described by at least two variables:

- influence on labour productivity – that is, a measure of the degree of positive/negative impact on labour productivity;
- degree of significance of the factor – the parameter differentiating individual factors among each other due to the strength of the impact on labour productivity,

Within the framework of the presented concept, it appeared necessary to introduce one, very important rule. The description of the factor impact should be brought to a common unit, since only in this way can the parameters presented be compared. For instance, it is difficult to use the day of the week, for example. Wednesday with a temperature of 12°C and noise of 77 dB, in one mathematical algorithm. To standardize the descriptions of factor impact on the work productivity, the basic tenets of the theory of fuzzy sets [10] were used. This mathematical method allows to define the space in which a factor fully influences labour effectiveness. Here, it is necessary to provide a definition, which states that fuzzy set A in a certain non-empty space $X = \{x\}$, written down as $A \subseteq X$, is a set of pairs [2] (1, 2):

$$A = \{(\mu_A(x), x)\}, \forall x \in X \tag{1}$$

where:

$$\mu_A : X \to [0, 1] \tag{2}$$

is a membership function of a fuzzy set [18]. The function assigns to each element $x \in X$ its degree of membership in fuzzy set A. The subsequent parts of the paper describes the scope of the positive influence of the factor on the labour productivity of construction workers, which is called the set of high efficiencies.

To define the degree of impact of the factor on labour productivity of construction workers, a survey was prepared, as described in [12, 14]. The results served to build a preliminary database of coefficients. At this stage, some of the factors identified in Table 1 were aggregated and each was assign a number. The result is presented in Table 2.

Table 1. Assignment of numbers to factors

Factor number	Factor name
c_1	Ergonomics
c_2	Noise
c_3	Duration of work shift
c_4	Salary
c_5	Organization of the workstations
c_6	Stress
c_7	Fatigue
c_8	Health
c_9	Age of the worker
c_{10}	Recovery of strength
c_{11}	Rainfall
c_{12}	Air temperature
c_{13}	Wind
c_{14}	Time spent with the family
c_{15}	Worker's absence
c_{16}	Day of the week
c_{17}	Adaptation to new operating conditions

Source: own study.

On this basis, using survey results and the Likert scale [6] individual factors were assigned to one of the four groups. The effect of the assignment is presented in Table 3.

Table 2. The division of the degree of factor influence on individual groups

Name of the group – impact on labour productivity of construction workers	Low	Average	High (Important)	Very high (very important)
Factors assigned	$c_3, c_{10}, c_{14}, c_{15}$	$c_2, c_6, c_9, c_{11}, c_{12}, c_{13}, c_{16}, c_{17}$	c_1, c_5, c_7, c_8	c_4
Weighting factor	0.25	0.5	0.75	1

Source: own study.

The authors consider the assignment in Table 3 as preliminary and allow the possibility of differentiating the weighting factors due to the nature of works. For example, in the case of external works, it is necessary to increase the importance of factors associated with weather

conditions. There exist a number of mathematical methods, which allow to calculate the value of the degree of impact coefficients.

The last element of the algorithm is the computational module. It allows to perform calculations on the basis of parameterized factors. The following formula (3) was adopted:

$$Wp = \left[\left(\frac{\sum_{i=1}^{17} \mu_A(c_i) \cdot w(c_i)}{\sum_{i=1}^{17} w(c_i)} \right) + 0.5 \right]^y \quad (3)$$

where:

- Wp – labour productivity,
- $\mu_A(c_i)$ – the value of the membership function of the set of high productivities for the i-th factor,
- $w(c_i)$ – the value of the function of the degree of the impact of the i-th factor on labour productivity,
- y – coefficient correcting the interval width of the possible occurrences of the Wp function values.

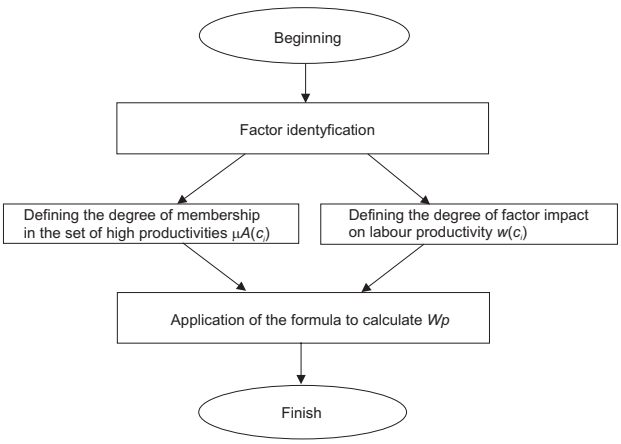

Fig. 1. Operating diagram of the algorithm – own study

The thus obtained value of labour productivity of construction workers is a non-individual value. The value $W_p = 1$ means average productivity. $W_p < 1$ below average, while $W_p > 1$ indicates a value above the norm assumed. The assumption about defining labour productivity corresponds to the way data are published by the Central Statistical Office [8]. In formula (3), the value of the quotient of the sum in each case is in the interval of <0, ..., 1>, hence the necessity to move the centre of the interval by 0.5 so that for the average quotient value, interpreted as average productivity, the result obtained equalled 1, meaning 100% of productivity, or accomplishment of the assumed norm. The exponential form of the function is related to the possibility of adjusting the width of the interval of possible results. Example intervals $<z_1, \ldots, z_2>$, depending on the value of the power of y are presented in Table 4.

Value z_1 means a minimum theoretical value of function W_p, while z_2 is the maximum. The authors analysed the sensitivity of formula (3) to the change of exponent y and, as a result of the conducted simulations, the calculated correlation coefficient was only slightly changed by +/–0.02. This proves that exponent y serves to adjust the value of function (3) with the actual results and it only takes into account the degree of sensitivity of the tested construction work on the interaction of all the factors.

To illustrate the operation of the algorithm describing labour productivity of construction workers, a block diagram was created (Fig. 1).

Table 3. Examples of interval values dependent on exponent *y*

y	0	0.25	0.5	0.75	1	2	3	4	5
z_1	1	0.84	0.71	0.59	0.5	0.25	0.13	0.06	0.03
z_2	1	1.11	1.22	1.36	1.5	2.25	3.38	5.06	7.59

Source: own study.

3. Applications of the algorithm

This section presents four basic applications of the algorithm for labour productivity of construction workers:

- prediction of the amount of labour per worker,
- assessment of the possibility to meet the deadline,
- indication of factors the correction of which may increase productivity,
- reliable assessment of the worker's individual potential.

The most intuitive way of using formula (3) is for the specification of the amount of the labour performed by the worker. In order to do so, one needs to account for the effect of the labour, which can be either retrieved from the Contractors Estimator or defined on the basis of own observation. The calculations also require the specification of the time in which the worker is to perform a given activity. Due to the variable values $\mu_A(c_i)$ the time should not exceed the duration of a single work shift. Applying the formula (3) of labour productivity of construction workers to predict the amount of the labour performed can be defined by the following formula (4):

$$V_p = W_p^{(')} N_j T_i \tag{4}$$

where:

V_p – amount of labour performed,
$Wp^{(')}$ – labour productivity on the basis of the basic formula (simplified),
N_j – individual labour effect [j.m./r-g],
T_i – duration of the labour performed [r-g].

Another potential benefit resulting from the application of the algorithm (Fig. 1) is the assessment of the possibility of meeting the deadline for the completion of the construction tasks. After evaluating the degree of membership of individual factors to the set of high

productivities $\mu_A(c_i)$ and establishing the degree of the influence of individual factors on productivity $w(c_i)$, one receives the value of function W_p, for which the value lower than one means a combination of factors that negatively influence productivity. This means that it is likely that the worker or the whole team under consideration will not perform the average amount of labour. A value greater than 1 means such combination of factors, which give the possibility of achieving a more than average amount of labour. The evaluation of the factors alone and applying formula (3) do not require any specification of the value of the base unitary effect, then the results obtained present combinations of factors beneficial and adverse for productivity. Due to such an application of the mathematical model, one can prepare a simulation of the workstation and its surroundings before the works begin to achieve the assumed target quantity of the planned work.

Another benefit of the algorithm (Fig. 1) is the ability to react to the quantitative results of the labour achieved by workers. After a couple of days, assessment with the use of the productivity model. Then, by simulating changes in work conditions and correcting the value of the degree of the impact for these factors that can be influenced (such as noise, ergonomics or salary), one is able to predict the potential productivity value.

This will allow to predict whether the change of the conditions and working environment, especially by their improvement, will boost the chances to implement a task on time with unchanged personnel resources available, and whether it will be necessary to increase employment [5]. Thus, the productivity model can be used in the process of scheduling construction works, in the selection of work teams and in the specification of the necessary minimum staffing to implement the task on time [11].

The mathematical model presented here may also become an auxiliary tool to evaluate construction workers with reference to their productivity and industriousness [1]. Taking into account the factors influencing them, one receives a more rounded picture of their work, thus the feedback provided by the analysis of work time is fuller too. For instance, out of two workers, *X* and *Y*, performing the same type of tasks on different construction sites, worker *X* achieved an example productivity $W_p = 0.92$ on his first day on the construction site. While this value is below average, the worker was exposed to unfavourable weather conditions, collaborated with incompetent staff supervision, received faulty tools and the analysis of his productivity took place on Friday. On the other hand, worker *Y*, on the 23rd work day, achieved the value of productivity of $W_p = 1.13$. This result is, theoretically, above average, yet worker *Y* performed in very good weather conditions, was supervised by a well-organized and communicative works manager, had new and fully functional tools and the productivity analysis took place on Wednesday. For the sake of simplification, the remaining factors were the same for both workers. The example shows that a comparison of the same values of the productivity function without the comparison of work conditions for individual workers is biased and should not remain the only source of information about the productivity achieved by workers.

4. Summary

The paper presented a novel approach to the issue of labour productivity of construction workers. The authors chose one of the existing classifications of factors influencing the productivity of workers, and then they used it for a further analysis of the problem. The strength of the study is its universality. In the subsequent steps of the proceedings, the issue of comparison of various factors were analysed. As a solution, the basic assumptions of the fuzzy set theory were applied. The main advantage proved to be the standardization of factors by describing them without the presence of natural entities. In this way, the development of a mathematical algorithm was enabled. The assessment of the degree of the impact of individual factors on the labour productivity of construction workers involved a survey, which became the basis of the preliminary database of coefficients. They allowed the gradation of individual factors in relation to their strength of influence on the subject of the research. In effect, a mathematical algorithm for proceedings has been constructed to calculate labour efficiency of construction workers. The paper also presented the potential applications of the solution under consideration. The possibilities of its implementation depend on the following: prediction of the amount of labour, assessment of the possibility of meeting the deadlines, identification of factors that need to be corrected and an individual assessment of labour productivity of a construction worker.

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