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# Measures of the Synchronisation of the Work of a Processing Team

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**Abstract**
*The aim of the paper is to present indices of an assessment of the synchronisation of a sewing team used at the stage of process design. Assessment was made of a universally used coefficient for the synchronisation of the work of a team based on the average deviation of the sample. The use of a relationship based on the mean square deviation, which demonstrated its greater usefulness, is proposed.*

**Key words:** *team organization, work synchronisation, cooperation of work stations.*

## Inroduction

A clothing production process consists of two basic technological phases: cutting and confectioning. Special emphasis should be placed on the confectioning phase for the following reasons: the cutting process is dependent on the sewing process – the cutting unit must secure the production capacity of the sewing unit (the measure of the efficiency of a plant is the number of garments made). The confectioning process, on the other hand, is much more complex than the cutting of materials.

When designing a sewing team, one should solve the basic problem of the assignment of tasks to particular work stations. One should take into account that, on the one hand, a product manufacturing process boils down to performing a definite number of technological operations characterised by diverse labour-consumption and different tools necessary for their accomplishment. Moreover, particular operations must be performed in a specific order. On the other hand, the rule stating that the particular employees in a team should be uniformly burdened should be obeyed so that the course of the production process will be smooth.

Therefore, a designer has the serious task of properly dividing labour amongst operators, which is very complicated, and in operational studies it is counted among the group of NP-complete problems.

Traditionally, during the design of a processing team (a new one or the modification of an already existing one), one must first determine the planned rhythm of the team, which constitutes a basis for the grouping of indivisible operations into organisational ones.

An open problem would be what value a team's rhythm should assume. This rhythm depends on many factors: the labour-consumption of a product, the planned effectiveness of the team, and the level of their qualifications. A process designer must balance the rhythm value so that it will be optimal for the conditions in which the team will be working. There are two solutions:

The first is traditional: the rhythm of a team is determined on the basis of the quotient of the labour-consumption of a product and the size of the team, or the quotient of the duration of a work shift and the planned effectiveness per shift. Tasks are allocated to work stations so that the work station rhythm (the time of performance of a task) will be the closest to the team rhythm or its multiple as much as possible. A negative feature of this solution is that indivisible operations are not always grouped into organisational ones according to the order required by the technology of manufacturing a given product, resulting in the occurrence of "reversals", which complicates the flow of the components being processed between work stations.

The other solution, proposed by Więźlak [6], is as follows: first one should group indivisible operations into organisational ones according to technological requirements and then seek the rhythm magnitude, taking into account the minimisation of time lost in the team. From a technological point of view, this method is definitely more favourable.

However, the question arises as to how deftly the magnitude of the team rhythm was chosen, since the consequences of an improper choice at the design stage will affect the efficiency of the work of the whole processing team. Thus one should consider determining indices which will enable one to estimate how much the synchronisation of the team being designed differs from an ideal solution (when all the work stations perform their tasks in the same period of time), that is to say, the indices that will allow a designer to take proper decisions at the stage of designing a team.

## Assessment of the synchronisation of the work of a processing team

The correctness of design activities is verified by the level of the synchronisation of the work of processing work stations in a team. The formation of hold-ups, the accumulation of semi-finished products or elements being processed at work stations or passages are obvious evidence of a lack of synchronisation. These perturbations require taking appropriate counter-measures on a current basis. The better the organisation of the team, the fewer they will be. The securing of synchronisation in a flow team is an easier task, since a team made up of a large number of workers allows the rhythm

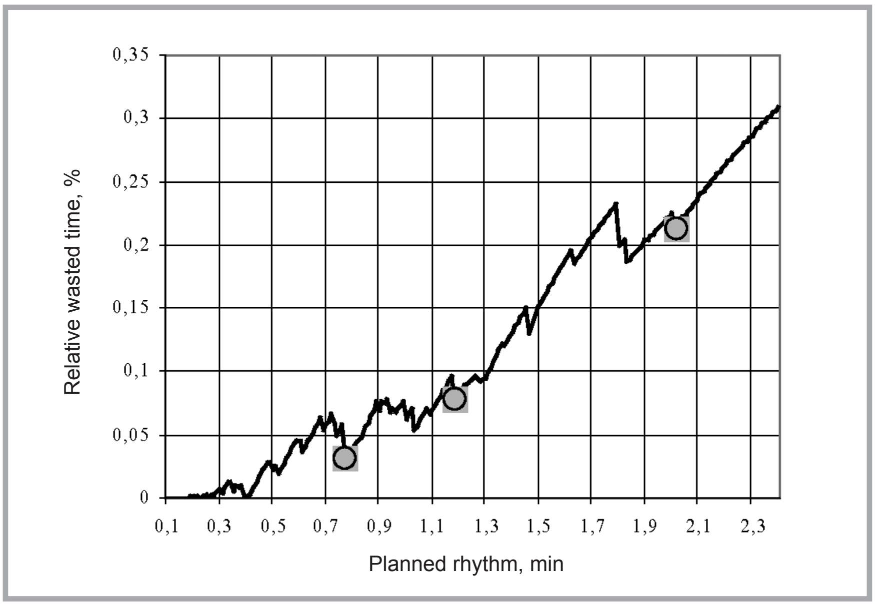


***Figure 1.** Dependence of the relative time wasted in a team on the rhythm magnitude [9].*

size to be reduced, and consequently an organisational operation is composed of fewer technological operations[1)]. On the other hand, the synchronisation of a team can be achieved thanks to supplies between work stations or passages. It is much more difficult to synchronise work in an assembly-line team, which are very popular in the present economic situation (creating short-run production in short execution times).

The level of synchronisation can be estimated at the stage of designing an organisational team and in the course of the realisation of a production process. At the design stage, the production rhythmicity coefficient, proposed by Meinhardt [1], or its modified version called the synchronisation coefficient [5] can be a measure of synchronisation. This coefficient is universally used in industrial practice.

A measure of the synchronisation of a team's work (at the process design phase) can also be the proportion of waiting times of particular workstations for components to be processed in relation to the labour consumption of the product. In the 1960s, Więźlak [6] introduced an index called the relative time wasted in a team, which is expressed by the dependence:

$$\beta = \frac{\sum_i p_i}{R_z * \sum_i n_i} \qquad (1)$$

where:
$p_i$ – the magnitude of stoppage at the i-th workstation, $p_i = \frac{1}{2}\left[\left|x_i - \tau_i\right| + (x_i - \tau_i)\right]$,
$x_i$ – the time at the team's disposal for performing the i-th operation $x_i = n_i * R_z$,
$\tau_i$ – the longest permissible time for performing the i-th operation $\tau_i = t_i + \varepsilon * t_i$,
$\varepsilon$ – the permissible deviation of the performance time from the rhythm magnitude.

An example curve of the relative wasted time as a function of the planned rhythm is shown in ***Figure 1***.

The local minima of the function present permissible variants of a solution. However, the criteria for the selection of the rhythm magnitude from a set of permissible values are unclear.

To assess the synchronisation of the work of a team, one can also use computer simulation, which illustrates the functioning of a team before the production process is started. A number of simulation programs can be used for this purpose, e.g. Arena or Witness. The necessity to develop appropriate assumptions simplifying real conditions, construct a simulation model and acquire the skill of handling the simulation program make it a tool scarcely used in industrial practice.

In the course of the realisation of a production process, a convenient tool for the assessment of the synchronisation of the work of workstations are entry/exit diagrams, developed by Bass [3]. In a rectangular coordinate system, the time is marked on the axis of abscissa, while the number of elements supplying and leaving a workstation (a group of workstations) is given by the axis of ordinates. The graphs present two lines: the line of entry, illustrating changes in the number of items supplying a worksta-

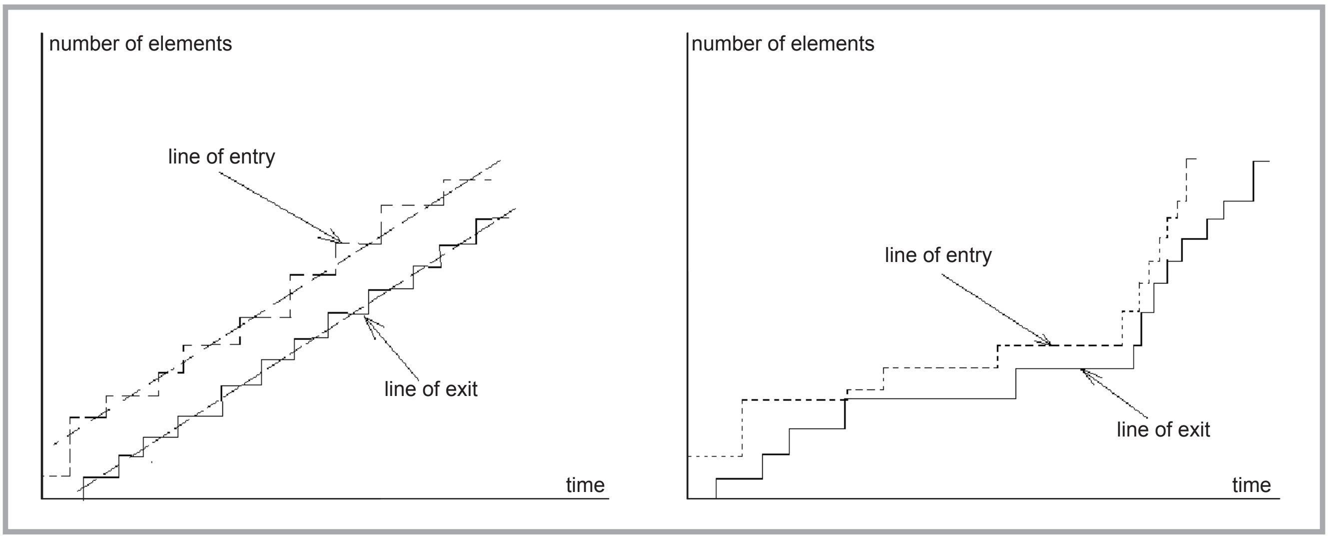


***Figure 2.** Entry/exit diagrams [3].*

*Table 1. Juxtaposition of example processing teams [own elaboration]*

| Quantity | Team A | Team B | Team C |
|---|---|---|---|
| Times of organisational operations, min | 1.10 | 1.10 | 0.70 |
| | 1.30 | 1.30 | 1.30 |
| | 1.50 | 1.50 | 1.50 |
| | 1.50 | 1.50 | 1.50 |
| | 1.60 | 1.60 | 1.60 |
| | 1.80 | 1.80 | 1.80 |
| | 1.80 | 1.80 | 1.80 |
| | 1.80 | 1.80 | 1.80 |
| | 1.90 | 1.90 | 1.90 |
| | 2.10 | 2.50 | 2.10 |
| Medians, min | 1.70 | 1.70 | 1.70 |
| Mean value, min | 1.64 | 1.68 | 1.60 |
| Team rhythm, min | 1.64 | 1.64 | 1.64 |
| Average deviation, min $op = \frac{1}{n}\sum \lvert t_i - R_z \rvert$ | 0.24 | 0.28 | 0.28 |
| Root mean square deviation, min $s = \sqrt{\frac{1}{n}\sum (t_i - R_z)^2}$ | 0.28 | 0.36 | 0.37 |

tion with time, and the line of exit, depicting changes in the number of items leaving the workstation. Two criteria are used for the assessment of synchronisation: "constant stock" and "simultaneity". According to the first criterion, synchronisation is correct if the size of the stock is constant. According to the other criterion, synchronisation will be complete if the entry of an element to a workstation occurs when it is processing the previous element. Example graphs are shown in ***Figure 2*** (see page 81).

The first Figure presents an ideal situation: the lines of entry and exit are parallel to each other, which, on the one hand, means that there are no hold-ups, while on the other, that no stocks are being accumulated. The other Figure, in which the lines approach or recede from each other, points to a breakdown in the cooperation between workstations.

## Coefficient of the synchronisation of a team

The basic measure allowing to estimate the correctness of setting up a sewing team at the design stage is the coefficient of the synchronisation of a team.

Meinhardt [1] proposed calculating the magnitude of the planned production process as an average deviation of operation times with respect to the rhythm magnitude. He defined the complementing of this quantity to one as a coefficient of production rhythmicity. This coefficient was modified and – as a sum of the absolute deviations of organisational operation times from the multiple of the rhythm in relation to the time for product execution at the disposal of the team – is universally used as a synchronisation coefficient [5].

$$\eta = \frac{\sum_{i=1}^{k} \lvert t_i - n_i * R_z \rvert}{R_z * \sum_{i=1}^{k} n_i} * 100\% \qquad (2)$$

where: $t_i$ – duration of the i-th organizational operation, $n_i$ – the number of workstations performing the i-th operation, $k$ – the number of operations, $R_z$ – the team rhythm.

In practice it has been arbitrarily assumed that this coefficient should be smaller than 5%; higher values are permissible, but they should not exceed 10%.

Analysis of the above dependence shows that the coefficient of synchronisation can be interpreted as a mean deviation of operation times from the rhythm multiple in relation to the rhythm magnitude. The average deviation reaches its smallest value if the quantity of the reference is a median (the middle value of a sample) [2]. A median is the position index in a sample, which, as an "average value", is far more resistant to "protruding elements" than the arithmetic mean, for the determination of which all the values of the sample are used. Therefore, it seems that the mean square deviation or, to be more precise, its root is a better parameter for analysis of the spread of averages.

Let us consider an example of three 10-person teams differing in the duration of the first or last operation (***Table 1***). When team A is treated as a base, changes in the duration of operation execution at the workstations result in greater changes in the root mean square deviation (an increase of 30%) than in the average deviation (an increase of 17%).

It results from the above example that the root of the mean square deviation is

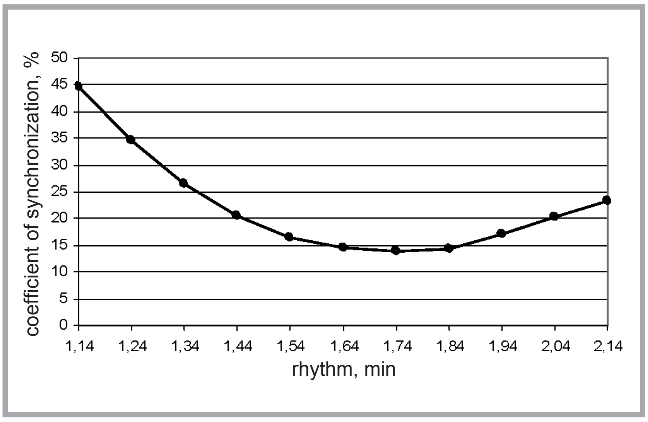


***Figure. 3.*** *Dependence of the coefficient of synchronisation on the rhythm magnitude [own elaboration].*

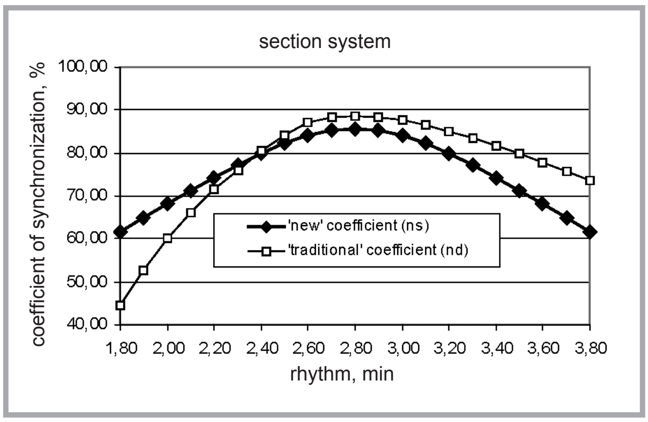


***Figure. 4.*** *Changes in the coefficient of synchronisation as a function of the team rhythm [own elaboration].*

*Table 2. Juxtaposition of operation times for a section team [own elaboration].*

| A Section system, Planned rhythm 2.80 min | |
|---|---|
| No. of organisational operations | Operation time, min |
| 1 | 2.57 |
| 2 | 2.71 |
| 3 | 3.03 |
| 4 | 2.70 |
| 5 | 2.63 |
| 6 | 2.71 |
| 7 | 2.51 |
| 8 | 1.99 |
| 9 | 2.85 |
| 10 | 2.82 |
| 11 | 2.57 |
| 12 | 2.64 |
| 13 | 3.28 |
| 14 | 3.52 |
| 15 | 3.50 |
| 16 | 3.00 |
| 17 | 3.30 |
| 18 | 2.12 |
| 19 | 2.45 |
| 20 | 3.10 |
| Total | 56.00 |

more "sensitive" to changes carried out in a team and, as a result, allows a more detailed analysis to be made of the effects of the activities of the process designer. Let us, in turn, consider the curve of changes in the coefficient of synchronisation as a function of a team's rhythm. Since in dependence (2) the quantity of a team's rhythm $R_z$ occurs both in the numerator and denominator, the curve of changes is asymmetrical, an example of which is shown in ***Figure 3***.

For the example presented (team A), a decrease in the rhythm magnitude from 1.64 min (the mean value of operation times) to 1.14 (decrease of 30%) caused an increase in the coefficient of 200%; in turn, an increase in the rhythm magnitude from 1.64 min to 2.14 min (increase of 30%) caused an increase in the coefficient of 60%.

Hence, the following statements can be made:

1. Intuition suggests that an increase in the coefficient of synchronisation is favourable, testifying to better cooperation within a team. Yet dependence (2) shows the magnitude of disturbance of a planned production course in relation to the time that a team has for manufacturing a product. Consequently, a higher value of the coefficient corresponds to lower synchronisation. Therefore, it appears that making use of the well-known and widely used dependence above is not particularly beneficial.

2. There is no justification for the fact that higher values of the rhythm should be more favourable than lower ones (when organisational operation times remain unchanged). In the first case there are unjustified time losses and overrated work norms, and in the other, workstations are not able to accomplish the tasks in time (underrated work norms). Thus both cases are equally unfavourable.

3. A team's rhythm is determined on the basis of the times of technological operations (indivisible), not organisational ones.

The examples shown above and the resulting conclusions indicate the usefulness of developing a new index for the synchronisation of a team's work. As a basis, it appears that it will be more favourable to take the mean square deviation than the average deviation .

For the population from the sample ($t_1$, $t_2$,….., $t_n$), the mean square deviation of a set number C can be written as:

$$s_c{}^2 = \frac{1}{n}\sum_{i=1}^{n}\left(t_i - C\right)^2 \qquad (3)$$

Introducing the arithmetic mean into the equation, we obtain:

$$s_c{}^2 = \frac{1}{n}\sum_{i=1}^{n}\left(t_i + t_s - t_s - C\right)^2 \qquad (4)$$

Making simple transformations, we get:

$$s_c{}^2 = \left(t_s - C\right)^2 + \frac{1}{n}\sum_{i=1}^{n}\left(t_i - t_s\right)^2 \qquad (5)$$

It results from this dependence that the mean square deviation will assume the smallest value when the value of constant C is equal to the arithmetic mean. Furthermore, we can write:

$$s_c = \sqrt{\left(t_s - C\right)^2 + \frac{1}{n}\sum_{i=1}^{n}\left(t_i - t_s\right)^2} \qquad (6)$$

A measure of the synchronisation of a team can be the root of the mean square deviation referred to the value of the arithmetic mean. However, this will be the non-uniformity of the distribution of times, i.e. the quantity signifying a lack of synchronisation. Thus, the level of synchronisation will be the complementation of the non-uniformity to one. Therefore it is proposed that the coefficient of synchronisation be written in the following form (after substituting the value of the planned rhythm $R_z$ after constant C):

$$\eta_s = 1 - \frac{s_c}{t_s} = 1 - \frac{\sqrt{\left(t_s - R_z\right)^2 + \frac{1}{n}\sum_{i=1}^{n}\left(t_i - t_s\right)^2}}{t_s} \qquad (7)$$

According to this dependence, a higher value of the coefficient will correspond to the better synchronisation of a team.

*Table 3. Juxtaposition of operation times for a section team [own elaboration].*

| B Section system | | | | |
|---|---|---|---|---|
| No. of organisational operations | Operation time, min | No. of persons executing an operation | Rhythm of the workstation / passage | Number of passages |
| 1 | 2.57 | 1 | 2.57 | 1 |
| 2 | 2.71 | 1 | 2.71 | 1 |
| 3 | 5.73 | 2 | 2.86 | 1 |
| 4 | 2.63 | 1 | 2.63 | 1 |
| 5 | 2.71 | 1 | 2.71 | 1 |
| 6 | 2.51 | 1 | 2.51 | 1 |
| 7 | 4.84 | 2 | 2.42 | 1 |
| 8 | 2.82 | 1 | 2.82 | 1 |
| 9 | 2.57 | 1 | 2.57 | 1 |
| 10 | 5.92 | 2 | 2.96 | 1 |
| 11 | 3.52 | 1 | 3.52 | 1 |
| 12 | 3.50 | 1 | 3.50 | 1 |
| 13 | 3.00 | 1 | 3.00 | 1 |
| 14 | 5.42 | 2 | 2.71 | 1 |
| 15 | 5.55 | 2 | 2.78 | 1 |
| Total | 56.00 | 20 | 42.27 | 15 |

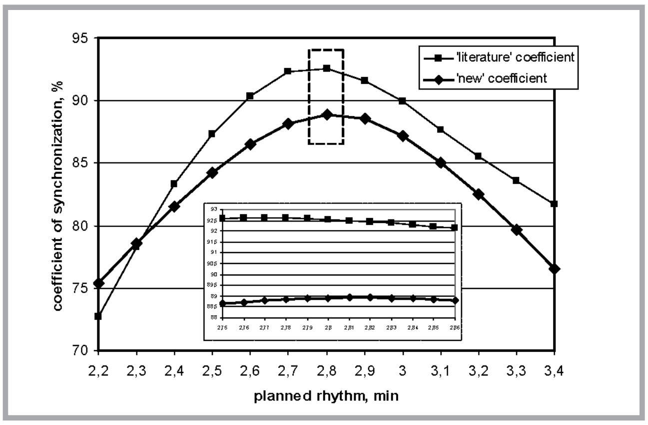


***Figure. 5.*** *Changes in the coefficient of synchronisation as a function of the team rhythm [own elaboration].*

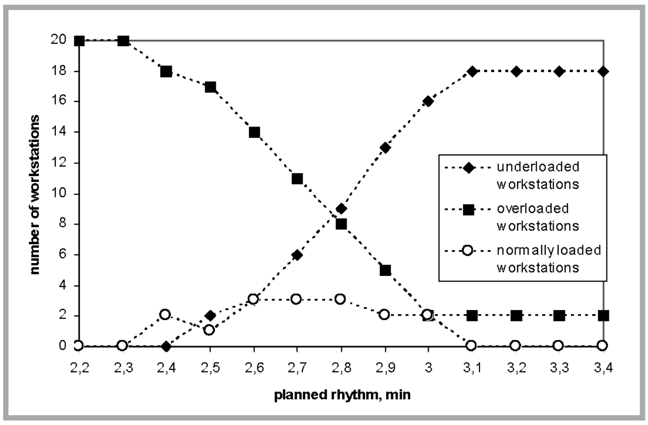


***Figure. 6.*** *Number of underloaded, overloaded and normally loaded workstations depending on the rhythm magnitude [own elaboration].*

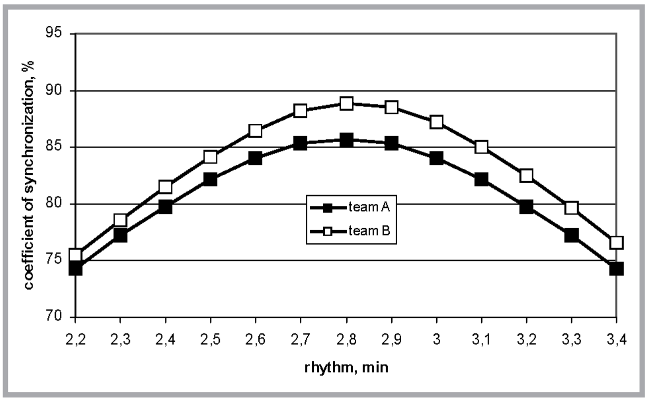


***Figure 7.*** *Coefficient of synchronisation as a function of the team rhythm for both teams analysed [own elaboration].*

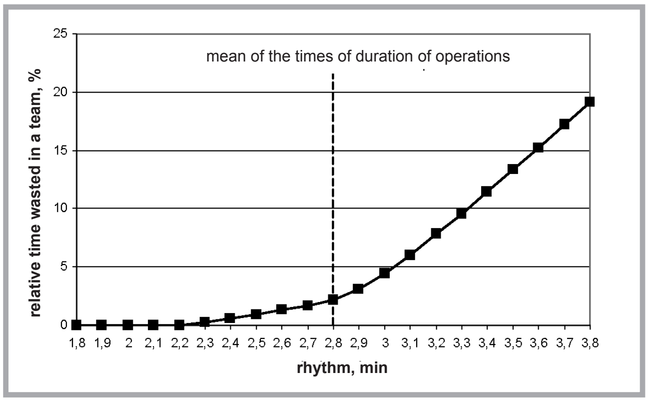


***Figure 8.*** *Relative time wasted in a team as a function of the team rhythm magnitude [own elaboration].*

The value of the coefficient must assume positive values, consequently:

$$\sqrt{(t_s - R_z)^2 + \frac{1}{n}\sum_{i=1}^{n}(t_i - t_s)^2} < t_s \qquad (8)$$

Since both sides of inequality (8) are positive, after simple transformations it turns out that the mean square deviation is:

$$\frac{1}{n}\sum_{i=1}^{n}(t_i - t_s)^2 < R_z(2t_s - R_z) \qquad (9)$$

The square deviation can assume only non-negative values, and hence it results from the above inequality that the magnitude of the rhythm of a team must be smaller than the doubled arithmetic mean of the organisational operation times.

An analysis of the synchronisation of a team, with the inclusion of the newly created coefficient of synchronisation ($\eta_s$) and the coefficient according to the literature ($\eta$), was made for a team manufacturing men's trousers.

To make a comparison of both coefficients possible, it was assumed that the coefficient of synchronisation (2) is a complementation of the quantity $\eta$ to one, denoted as $\eta_d$:

$$\eta_d = 1 - \frac{\sum_{i=1}^{k}|t_i - n_i * R_z|}{R_z * \sum_{i=1}^{k} n_i} \qquad (10)$$

Analyses were carried out for a team arranged in a sectional system, in which one workstation operation occurs. In ***Table 2*** the times of organisational operations are presented.

All the indivisible operations were grouped into 20 organisational operations. The labour consumption of the product was 56 minutes. The arithmetic mean of the times of an operation was 2.8 minutes, which is the time assumed as the magnitude of the planned rhythm. The level of team synchronisation was estimated by means of the index of synchronisation (10), amounting to 88.57%; the newly developed index (7) amounted to 85.74%.

For both indices the level of their changes was determined as a function of the planned rhythm of the team, which is shown in ***Figure 4*** (see page 82).

It results from the graphs presented that the extreme values for both functions of changes in the coefficients of synchronisation occur for the same value of the rhythm (equal to the arithmetic mean of operation times R = 2.80 min). Significant differences occur in the intervals of changes in the rhythm values set by the extreme. A change in the rhythm in the range from 1.8 min to 2.8 min caused the range of the value of the "traditional" coefficient to be at a level of 44.1% and the "new" one – 24.2%.

In turn, a change in the rhythm in the range from 2.8 min to 3.8 min caused the range of the coefficients to be 14.9% and 24.2%, respectively.

It should be stressed that a change in the rhythm magnitude of ± 36% caused substantial differences in the values of the "traditional" coefficient of synchronisation (asymmetry of the function).

As results from the above, the curve of the dependence of a newly determined coefficient is symmetrical and assumes the maximum value for a rhythm that is the arithmetic mean of operation times. This is logical and conveys the sense of a coefficient synchronisation intuitively.

In the case of a passage of workstations (several workstations performing a given operation in parallel), the rhythm of the passage is related to the rhythm of the workstations through the relationship:

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + .... + \frac{1}{R_n} \qquad (11)$$

where: $n$ – the number of workstations in the passage (section).

Assuming a two-workstation section and an identical rhythm at both workstations (the same qualifications of the operators), we can write:

$$R_p = \frac{R}{2} \qquad (12)$$

The coefficient of synchronisation of such a team will be described by relationship (7), after the substitution of the value of the section's rhythm $R_p$ with the organisational operation time $t_i$ and the number of passages in a team with the number n[2)].

The juxtaposition of times for a team is presented in ***Table 3*** (see page 83).

For a team thus organised, coefficients of the team synchronisation for different magnitudes of the planned rhythm were determined. To facilitate the comparison of the results, the values of the "literature" coefficient in ***Figure 5*** have been presented as a complementation to one (equation 10).

For the coefficient of synchronisation developed (7), the extreme of the function occurs for a planned rhythm equal to the value of the mean of the passage rhythm. For the coefficient determined according to relationship (10), the extreme is moved towards lower values of the rhythm.

For particular rhythm values, the number of underloaded and overloaded workstations in a team were determined. It was found that the smallest number of this type of workstation occurs with a rhythm equal to the arithmetic mean of the operation times (***Figure 6***). In this case, the number of underloaded workstations is close to that of overloaded workstations, which also confirms the usefulness of assuming the value of the mean of operation times as the team rhythm.

Analysis of the synchronisation of both teams (A and B) demonstrates that the introduction of parallel workstations in a passage improves cooperation between operators. Irrespective of the planned rhythm magnitude, the coefficient of team synchronisation is higher for the variant containing more than one workstation in a passage. The dependence of the coefficient of synchronisation on the rhythm magnitude is illustrated for both teams in ***Figure 7***.

For the data presented in ***Table 2*** (see page 83), the relative time wasted in a team was determined for definite magnitudes of rhythms (with a constant number of operators), the results of which are presented in ***Figure 8*** in graphical form.

The relationship presented above clearly demonstrates that when the rhythm is equal to the arithmetic mean of the times of the duration of organisational operations, the relative time wasted in a team rises sharply.

It results from the above considerations that during the organisational design of a team, one should estimate the rhythm magnitude on the basis of the value of the arithmetic mean of the times of the duration of organisational operations.

## Conclusions

On the basis of the considerations presented above, one can state that:

1. To assess the cooperation of workstations in a team, one should use a coefficient of synchronisation based on the mean square deviation. This deviation, calculated from the mean value, assumes the minimum value, whereas that calculated from a selected value of the rhythm can constitute an estimate of how far the choice made differs from the "ideal".
2. The planned rhythm of a team should be as close as possible to the arithmetic mean of the times of the duration of organisational operations. The coefficient of synchronisation proposed can constitute a criterion for the aptness of the choice of the team rhythm. However, it is not a basis for the selection of the rhythm magnitude.
3. It appears that during the design of a processing team, one should first – according to the statement by Więźlak [6] – join indivisible operations into organisational ones and determine a set of permissible planned rhythms. Then one should constrain this set using appropriate criteria, for example the clothing assortment (complexity of the product), the length of the production batch, or the staffing of the sewing team. The correctness of the selection of the rhythm magnitude can be estimated by means of the coefficient of synchronisation.

## Editorial notes

*1) A technological operation (indivisible) is a basic part of a technological process performed continuously at one workstation (from the beginning to the end without a break). An organizational operation is one or several indivisible operations constituting the content of a task assigned to one work station.*

*2) For a one-workstation passage $R_p$=$t_i$.*

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