M. STOICA

Economic Considerations on Methods of Establishing Standard Work Time

The selection of the work measuring method must be as sensible as possible, such as to ensure an acceptable accuracy concomitantly avoiding excessively arduous analyses.

1. INTRODUCTION

Practical problems of production management imposed the improvement of work-time measuring and analyzing methods. Simple duration estimates have been replaced by statistic data processing. Yet even for an elementary rational organization according to foreman's, worker's or supervisor's understanding, statistic reports did not furnish, in all circumstances, sufficient elements. Thus the need of effecting timekeepings and data processing on statistico-mathematical bases arouse. In the condition of a scientific management, when the study of ergonomic methods and principles is applied with the technical help of a complex experts team, not even timekeepings through the agency of classical apparatus are sufficient. Thus the necessity appears of using improved apparatus (cinematograph cameras, oscillographs, tape recorders, etc.). Measurements may be carried out for each studied case and they can be analytically processed, once for all, making up pre-determined time standards; these standards can be used — according to certain rules — in establishing work standards for a large variety of work processes, any time it is necessary.

2 PRE-DETERMINED TIME SYSTEMS AND DEVELOPMENT OF PRE-DETERMINED TIME SYSTEMS GENERATIONS

Taylor was the first to advocate the use of pre-determined times and he stated that, for the majority of studied tasks, most of the composing elements were identical or similar.

The techniques of stating and using pre-determined times were presented in a new outlook in Gilbreth's work. On the basis of the decomposition principle and due to the cinematographic technique, it was stated that human work activities in the industry form 17 fundamental motions or "therbligs". The motion study cuts out the necessity of working with elements which can be timed, whose duration is of the order of seconds, as time measuring accuracy surpasses by far the accuracy of a common timekeeper.

The elementary pre-determined times are frequently called "standard data". Yet the establishing of a universal system failed, because practical needs lead to the appearance of various pre-determined time systems. It can be said, similarly to electronic computers, that the pre-determined time systems also knew, during their historical development, several generations. The first pre-determined time systems appeared a few years before World War II. Among the pre-determined time systems of the first generation the best known are: M.T.A. (Motion Time Analysis) system, Work Factor system, M.T.M. (Method Time Measurement) system and B.M.T. (Basic Motion Time) system.

While applying these elementary time systems, it was stated that some motions occur under the form of the same grouping. By adding the times of a certain frequent grouping, a new motion time was obtained, with a longer duration, depending on a more limited number of influence factors, but having a more reduced accuracy (error by about $\pm 5\%$ greater).

In the last few years second-generation pre-determined time systems made their appearance and developed. These systems are characterized by a grouping of the most frequent first-generation motions and by a greater applying opperativity. The most widely spread second-generation system is the M.T.M.$_2$ system, originating in the M.T.M. system. Also from M.T.M. system is derived the M.S.D. (Master Standard Data) system. The M.S.D. system goes on with the grouping by concrete, long lasting operations, e.g., assembling works. It comprises four parts: standards for fastening (fixing), standards for screwing up (inferred on the basis of the M.T.M. system and of times, timed or computed with the help of technological parameters), grouped standards for the body motions and standards for specific assembling operations.

In the developing process of pre-determined time systems generation, third-generation systems made their appearance (M.T.M.$_3$ system, worked out by the Renault Works in France), as well as fourth generation systems (M.T.M.$_4$ system and U.M.S. system, i.e. Universal Maintenance Standards), and presently fifth-generation systems appear.

3. ECONOMIC LIMITS OF PRE-DETERMINED TIME SYSTEMS APPLICABILITY

The applying of a certain pre-determined time system is economically efficient only to the extent in which the obtained effect exceeds the respective expenses. Thus, it is obvious that it would be unefficient to apply the Work-Factor method with work time standards for effecting a one-off, for which a workman works only a few hours, even if the obtained accuracy is very big. In the mean time, in order to select one or another of the systems, the economic criterion is made up by the small expenses brought about by

its applying (of course, with the condition of obtaining satisfactory results as concerns the use of the resulting time standards).

The main influence factors which determine the applicability economic limits of pre-determined time systems are:

— production process nature;
— repetitivity or frequence of the studied element;
— volume of the product series;
— duration of the analyzed elements;
— accuracy to be carried out;
— urgency of applying results.

The presented influence factors are not independent, and this allows to make the decision of applying a certain method of measuring time, even when only part of them are known. For instance, it is known that, as the product series volume increases, the duration of the analyzed elements diminishes, and the pursued accuracy increases. That is why it is sufficient to state whether the production is one-off, in order to be able to fix the most adequate method of measuring time. Hence, for this it is necessary to determine the production volume (which reflects the product series size). The index used to estimate this production level is the number of cycles of the studied elements, occurring during a year in the selected work process. If we admit, as a mean, 280 working days a year, the level index (I_N) is computed by relation:

$$I_N = 280\, n_c = \frac{2800 \times m \times nl}{t} \tag{1}$$

where: n_c represents the mean cycle number per day;
n_1 — number of work places to which the studied element is applied (by the same mean cycle number per day);
m — mean number of minutes in a day, during which the respective element is worked with;
t — cycle duration of an element in minutes (per cycle of one element).

Taking into account the cost of expenses for time measuring and processing of results (C_p) and the cost of the expenses produced by errors (C_e), the total cost (C_t) to be optimized is

$$C_t = C_p + C_e \tag{2}$$

The test of time measuring and processing of results (C_p) is proportional to the duration of the analysis by the respective method and the cost of this time (C_s) (the salaries of the specialists who are measuring times and processing data and the due indirect expenses). This cost decreases as the order number (k) of the pre-determined time system generation increases. It was settled by experience that, with the Work-Factor system, 300 — 600 analyzing minutes are necessary for one minute of the studied operation element. With the M.T.M. system, 100 — 200 analyzing minutes are necessary for one minute. It results that the processing time length reduces, on the average, in the ratio 1 : 3. Also, the M.T.M.$_2$ system is built such as a processing expeditivity of 2.5 — 3 times results. If we take into consideration that the pro-

cessing durations reduce, in this cases, approximately in geometric progression, as against the order (k) of the pre-determined time system generation ($k = 0$ for Work-Factor system, $k = 1$ for M.T.M. etc.), and that C_s is considered 0.25 lei/minute, the time analyse costs by a pre-determined time system of the k-generation ($k = 0, 1, 2, 3$) is:

$$C_p = \frac{C_s \times 600t}{3^k} = \frac{0{,}25 \times 600 \times 280 mn_l}{3^k} = \frac{42000 mn_l}{3^k I_N} \tag{3}$$

Errors are produced by the fact that the more recent pre-determined time analyses allow, for more expeditious applications, a bigger deviation, as a consequence of the various mergers which reduce the number of versions. Thus, the M.T.M.$_2$ system allows a deviation by $\pm 5\%$ bigger than the M.T.M. system. The cost of these errors (C_e) is proportional to the product of the allowed time deviation and the cost of this time (a cost, denoted by C_1, was admited, of 0.10 lei for every minute having a plus deviation as against the value given by the most accurate system, i. e. the Work-Factor system; equally, for minus deviations, a cost denoted by C_2, of 0.01 lei/minute, was considered).

The distribution $f(x)$ of errors x was considered parabolic, namely of the form:

$$\begin{aligned} f(x) &= 0 && \text{for } x < -0.05 \\ f(x) &= 15 - 60000x^2 && \text{for } -0.05 \leqslant x \leqslant +0.05 \\ f(x) &= 0 && \text{for } x > +0.05 \end{aligned} \tag{4}$$

The average plus error is, in this case:

$$\bar{x} = \frac{\int_0^{0{,}05} x(15 - 6000x^2)\,dx}{\int_0^{0{,}05} (15 - 6000x^2)\,dx} = \frac{0.009375}{0.50} = 0.01875 \tag{5}$$

Due to the distribution curve symmetry, the minus error has the same absolute value. The probability of getting a positive error is, for the same reason, equal to the probability of getting a negative error, hence it is $\frac{1}{2}$. It results that the function expressing the mathematical expectation of error cost is of the form:

$$C_e = \frac{1}{2}[(1+x)^k - 1]\,280\,C_1\,mn_l + \frac{1}{2}[(1+x)^k - 1]280\,C_2\,mn_l =$$

$$= \frac{1}{2}(1.01875^k - 1)\,280 \times 0.10\,mn_l + \frac{1}{2}(1.01875^k - 1)\,280 \times 0.01\,mn_l =$$

$$= 15.4\,(1.01875^k - 1)\,mn_l \tag{6}$$

The total cost becomes:

$$C_t = \frac{42\,000 mn_l}{3^k I_N} + 15.4\ (1.01875^k - 1)\ mn_l =$$

$$= \left[\frac{42\,000}{3^k I_N} + 15.4\ (1.01875^k - 1)\right] mn_l = \left[\frac{a_k}{I_N} + b_k\right] mn_l \qquad (7)$$

where we denoted:

$$a_k = \frac{42\,000}{3_k} \qquad (8)$$

$$b_k = 15.4\ (1.01875^k - 1) \cong 15.4 \times 0.01875\ k = 0.289\ k \qquad (9)$$

In order to determine the economic limits it is necessary to compare costs for two consecutive generations k and $k + 1$.
In the case when:

$$\left(\frac{a_k}{I_N} + b_k\right) mn_l > \left(\frac{a_{k+1}}{I_N} + b_{k+1}\right) mn_l \qquad (10)$$

we shall, obviously, prefer the method of generation $k + 1$, and in the opposite case — the k-order method. If costs are equal, it is immaterial what method is adopted.

If we make equal the cost for two successive generations (k and $k + 1$), it results:

$$I_N = \frac{a_k - a_{k+1}}{b_{k+1} - b_k} = \frac{a_k - \frac{a_k}{3}}{0.289(k+1) - 0.289} = \frac{2a_k}{3 \times 0.289} = \frac{2 \times 42000}{3 \times 0.289 \times 3^k} =$$

$$= \frac{100000}{3^k} \qquad (11)$$

By logarithmation we obtain

$$\log I_N = 5 - 0.47712\ k \qquad (12)$$

To find the minimum, differentiation of relation (7) and its equalling to zero is not correct. Yet the result obtained by this procedure is very close to the correct expression (12):

$$\log I_N = 5.22146 - 0.48519\ k \qquad (12')$$

Taking into account that the purpose is to find the order of magnitude of the optimum level index for a given generation of the pre-determined time system, following relation can be considered:

$$\log I_N = 5 - 0.5\ k \qquad (13)$$

This relation is valid in the assumption that the studied elements have about the same importance, hence there is no "bottleneck". Relation (13) also supposes an analysis carried out with the help of the "traditional"

techniques of work studies (interrogative method, graph of both hands, etc.). When using modern, mathematical methods, as for instance, numerical simulation, the game theory etc., which need electronic computers, it is necessary to apply a more analytical one-step system, hence relation (13) becomes:

$$\log I_N = 5 - 0.5\,(k - 1) = 5.5 - 0.5\,k \qquad (14)$$

By giving to order (k) various values from oto 4, various level indices, expressed in number of cycles per year, are obtained. In this manner, for each predetermined time systems generation, the range is delimited where applying gets economical. These limits can be put down in the following table, in which a single work place and a single shift a day are assumed, a third of the shift being allotted to work at the studied element:

No. of cycles per year	Element duration	Economic method		
		Generation		Symbolic designation of method (corresponding to the version without computer)
		without computer	with computer	
over 500,000	under 25 sec.	—	0	
100,000—500,000	under 25 sec.	0	1	WF
35,000—100,000	25 sec.—70 sec.	1	2	MTM
10,000—35,000	70 sec.—250 sec.	2	3	MTM2, MSD, GPD
3,500—10,000	250 sec.—700 sec.	3	4	MTM 3
under 3,500	over 700 sec.	4	4 or 5	MTM 4, UMS

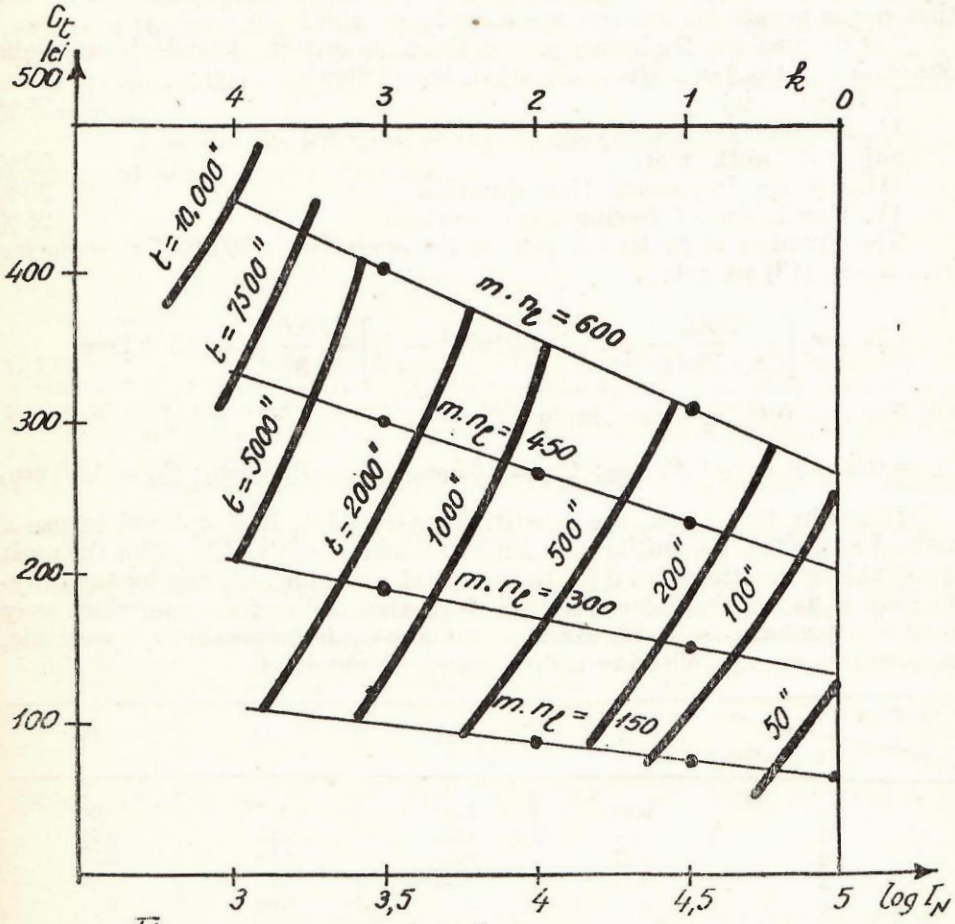
Note. With elements whose duration is over 70 sec. timekeepings can be also used.

In order to take into account the frequencies leading to an average occupation degree, of the shift, for a studied element, of 400 min. per shift, and also to take into account a variable number of work places, it is necessary to plot nomograms.

In the practice of the work norming it is necessary to take into consideration the importance of each element by the agency of its frequency within the process. For instance, when laying parquetry, one element as "marking parquetry blocks, cross-cutting and cutting out by chisel" has a reduced number of cycles, hence it can be measured by time keeping. In exchange," fixing parquetry" has a number of cycles per year of the order of tens — or even hundreds of thousands, hence it is suggested to make the study by M.T.M. analysis or even by Work Factor.

4. UTILITY THEORY APPLIYING POSSIBILITIES WHEN SELECTING THE WORK-TIME MEASURING METHOD

In order to take into account a larger number of influence factors than those in relation (13) a complex model can be found, with the help of the utility theory. Thus, if certain repetitive operations have a reduced frequency, such that they do not need an analytic system, but make up "bottlenecks" within a certain technological succession, it is still possible that the apply-



The nomogram of economic costs for work time processing

ing of an analytic system gets economical. In this case, it is necessary to introduce at least one more criterion for selecting the measuring and analyzing method, namely the possibility of satisfying the conditions imposed by the adjacent work places. It is obvious that, from this point of view, analytic systems are preferable to upper generation systems. Another criterion could be the possibility to free some workers as a result of labour rationalization. But other criteria may lead to opposite results. For instance, if system implementation duration, for a certain operation, is taken into account, it results that upper generation systems are more favourable.

Let us consider, for instance, that the main criteria, for which we make our choice (option) in a given situation, have following weights:

I. Repetitivity 25%
II. Possibility of satisfying conditions imposed by the adjacent work place 30%
III. System implementation duration 20%
IV. Possibility of freeing some workers 25%

The number of cycles per year of the operation is 70,000. By replacing in relation (13) we get:

$$C_t = mn_l\left[\frac{42000}{3^k \times 70000} + 15.4\,(1.01875^k - 1)\right] = \left[\frac{0.6}{3^k} + 0.289\,k\right]mn_l$$

For $k = 0,1, \ldots, 4$ we obtain

$$C_{to} = 0.6\,mn_l \quad C_{t1} = 0.49\,mn_l;\quad C_{t2} = 0.64\,mn_l;\quad C_{t3} = 0.89\,mn_l;\quad C_{t4} = 1.16\,mn_l$$

It results that, from the repetitivity viewpoint, it is optimal to use a method of the first generation. Conferring to each criterion utility 1 for the most favourable generation, and 0 for the most defavourable one, and for the intermediary situation the value resulting from the utility function (which may have a linear form, as in this example, but also could be parabolic, hyperbolic, exponential a.s.o.), following utility matrix is obtained:

Criterion / Generation	I	II	III	IV
0	0.84	1.00	0	1.00
1	1.00	0.75	0.25	0.75
2	0.77	0.50	0.50	0.50
3	0.41	0.25	0.75	0.25
4	0	0	1.00	0

The vector of utility U is obtained by multiplying the utility matrix by the column-vector of criterion importance:

$$U = \begin{Vmatrix} 0.84 & 1.00 & 0 & 1.00 \\ 1.00 & 0.75 & 0.25 & 0.75 \\ 0.77 & 0.50 & 0.50 & 0.50 \\ 0.41 & 0.25 & 0.75 & 0.25 \\ 0 & 0 & 1.00 & 0 \end{Vmatrix} \times \begin{Vmatrix} 0.25 \\ 0.30 \\ 0.20 \\ 0.25 \end{Vmatrix} = \begin{Vmatrix} 0.76 \\ 0.71 \\ 0.58 \\ 0.40 \end{Vmatrix}$$

It results that, if several criteria are taken into account, the decision making may change, as against what is obtained by relation (13), in which a single criterion is considered, the applying of Work-Factor system being, from this point of view, more useful than that of M.T.M. system.

Thus the problem of selecting the most economical work measuring method can be treated by the decision-making theory.

In conclusion, it is necessary that, in the present context of the extending action of applying scientific methods to the labour norming, both the dispersion of the concerns of the speciality staff for intricate and costly studies regarding operations of feeble importance, and the neglecting of minute analysis of certain elements of the work process, having a significant weight, must be avoided.

The exposed optimizing relations allow a reasonable selection of studying methods of work process elements.

REFERENCES

1. LEHMAN, J. T.: *La mesure des temps alloués.* Les Editions d'organisation, Paris, 1965.
2. MAYNARD, H. B.: *Industrial Engineering Handbook.* Ed. Mc. Graw Hill, 1960.
3. QUICK J. H., DUNCAN J. H. and MALCOM J. A. jr. *Work Factor Time Standards. Measurement of Manual and Mental Work.* Ed. Mc. Graw Hill Book Company, New York, 1962.
4. ISAC P.: *Normarea muncii pe baza sistemelor de normative pe mişcări.* Studiu documentar, I.D.T., 1968.
5. STOICA M.: *Metode de studiul muncii aplicate în construcţii.* Sinteză documentară, I.D.T., 1969.
6. ISAC P.: *Sistemele de normative de timp pe mişcări, elemente iniţiale ale informaticii economice referitoare la stabilirea volumului real de muncă în cadrul întreprinderilor.* Studii şi cercetări de calcul economic şi cibernetică economică, nr. 6, 1969.
7. BOLDUR GH.: *Asupra metodelor de estimare a proprietăţilor utilităţii.* Studii şi cercetări de calcul economic şi cibernetică economică, nr. 1, 1969.

CONSIDERATIONS ECONOMIQUES SUR LES METHODES D'ETABLIR LE TEMPS ALLOUE

Les systèmes de temps prédéterminés peuvent être classifiés par plusieurs générations de systèmes, selon le degré des détails de l'analyse des éléments composants du temps de travail. A chaque génération on accorde un rang K de telle façon que la plus analytique méthode (Work Factor) reçoit le rang O. Ensuite on attribue le rang 1 au système M.T.M1, le deuxième au M.T.M2 et ainsi de suite. Lorsqu'on effectue une étude concrète de l'analyse du temps de travail, il est nécessaire de choisir une méthode suffisament exacte, mais qui, en même temps, ne soit pas par trop laborieuse.

A cet effet on recommande l'existence de la relation:

$$\log I_N = 5 - 0{,}5\ K$$

entre le rang K de la génération des systèmes de temps prédéterminé et le nombre de cycles de l'élément de travail étudié au cas où l'on n'emploie pas les ordinateurs électronique et

$$\log I_N = 5{,}5 - 0{,}5\ K$$

au cas de l'utilisation des ordinateurs électroniques.

Pour obtenir les limites économiques d'applicabilité des méthodes d'évaluation du temps, on peut utiliser, en dehors des relations mentionnées, les tableaux et les nomogrammes.

Si, dans le choix de la méthode d'analyse, on envisage aussi d'autres critères, l'applicabilité de la théorie de l'utilité devient impérieusement nécessaire.

Les principes avancés assurent un choix rationnel de la méthode d'étude du temps de travail, permettant une précision acceptable et évitant les analyses qui nécessitent un nombre exagéré de calculs.

ЭКОНОМИЧЕСКИЕ СООБРАЖЕНИЯ О МЕТОДАХ ОПРЕДЕЛЕНИЯ НОРМИРОВАННОГО РАБОЧЕГО ВРЕМЕНИ

В зависимости от степени детализации анализа составных элементов рабочего времени, системы предопределенного времени могут быть разделены на несколько поколений систем. Каждому поколению придается ранг K, таким образом, чтобы наиболее аналитический метод (Work Factor) получил ранг 0. Затем системе MTM_1 придается ранг 1, системе MTM_2 — ранг 2 и т.д. При конкретном изучении анализа рабочего времени необходимо выбирать достаточно точный метод, который не был бы однако в то же время слишком трудоемким. С этой целью рекомендуется, чтобы между рангом K поколения систем предопределенного времени и числом циклов рассматриваемого элемента труда существовало соотношение:

$$\log I_N = 5 - 0{,}5\,K$$

без применения электронных калькуляторов,

$$\log I_N = 5{,}5 - 0{,}5\ K$$

в случае применения электронных калькуляторов.

Для нахождения экономических пределов применяемости методов измерения времени можно использовать, помимо вышеуказанных соотношений, таблицы или номограммы.

В случае, если при выборе метода анализа учитываются и другие критерии, становится абсолютно необходимым применение теории полезности.

Изложенные принципы обеспечивают правильный выбор метода изучения рабочего времени, приемлемую точность и избежание слишком трудоемких анализов.