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Modelling of the Process of Working Activities Training

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The article gives brief information on solving the basic problem connected with managing the process of acquisition of working activities. The application of the evolution law and quantitative results of psychological research enabled us to use several mathematical models. Through analysing and measuring the performance of different working activities differently strong cross correlation between empirical and theoretically calculated values of relevant regressive functions was established together with calculation forms of parameters of regressive functions. Two of the models have shown such close dependence that they can be considered equal descriptions of the process.

The preference of one of them was caused above all by the possibility of easy approximation of a relatively complicated calculation by graphical interpolation.

1. INTRODUCTION

Effectiveness of working activities training depends in a high degree on managing the process. Examining its quantitative side assumes construction of a general model covering training of all (or at least as many as possible) activities.

The acquisition of working activities belongs to evolution processes, i.e. it can be described in time progression of changes of a certain variable (in this case determined as the measure of acquisition of an activity). The aim of research was to determine the nature of changes and introduce the variable as a quantity.

2. THEORETICAL BASIS OF THE RESEARCH

The dynamism of changes of any phenomenon is in most common form grasped by the evolution law, the mathematic formula of which is:

$$\frac{\mathrm{d}y}{\mathrm{d}t} = f(t)\,,$$

where y is a variable, the evolution of which is observed in time t.

The nature of function $f(t)$ is principially arbitrary, but in this case it is known from psychology (e.g. [1]) that:

a) with increasing length of training (t) the degree of acquisition of an activity (y) is also increasing, i.e. for $t_2 > t_1$ is $y_2 > y_1$;

b) relative increments of the degree of acquisition of a working activity (y) descend with growing time, i.e.

$$\frac{dy_1}{dt_1} > \frac{dy_2}{dt_2} > \frac{dy_3}{dt_3} \text{ etc.}$$

Revealed curves of learning (e.g. [2]; [3]; [4] and others), which are very numerous, correspond with this general characterization. But in comparative studies – after generalizing concrete forms given by different authors and after unification of parameters – we found only four different types:

$$y = a\,e^{-bt}\ \text{(I)} \qquad y = at^{-b}\ \text{(II)}$$
$$y = a - b \ln t\ \text{(III)} \quad y = a - b/t\ \text{(IV)},$$

where y represents assumed (expected, planned) measure of acquisition of a working activity, t is the time of training (instruction), a; b are parameters. The above mentioned functions can also be demonstrated graphically as the dependence of the degree of acquisition of certain activity values on independently variable time of training. The beginning of the curve in coordinate system and steepness of its course are expressed by parameters a; b.

Functions I–IV are formulated as failling, because we suppose it to be more convenient from the point of view of interpretation. For functions III and IV it is also necessary to take no account of measuring quantity y in time $t = 0$.

3. SELECTION OF DATA FOR ANALYSING AND BRINGING VARIABLES TO A STANDARD

For verification of the type of function best modelling the process of acquisition of working activities it was necessary to gather data on:

a) very different activities,
b) differently complicated activities,
c) activities at different stages of acquisition.

At the same time it was necessary for the data to be as far as possible the results of exact measuring, realized independently of the research under description. That is why some introductory data were taken from the following extraneous sources:

a) from records on filing tests organized by Institute of Human Labour in Prague with apprentices who were trained by various engineering firms in 1942–1946 (cf. [5])

b) from the publication by Z. Škuta et al. [6] summarizing empirical data gathered in measuring the apprentices' performance during their acquisition of the following activities: reversing a tractor without a trailer, chucking the lathe tool, setting up Diesel engine valves, flame welding, grafting fruit-trees by coupling, filing square holes, setting up a milking unit and riveting,

c) from the quoted article by M. Buchalkov and A. Petrov [4], in which there are published results of the research of the performance of apprentices in the lathe operator line during the two years of their apprenticeship,

d) from the publication by S. J. Batyšev [7], which is summing up calculations of correction factors for standartization of the apprentices' work in the lathe operator line for whole two-year apprenticeship period.

One of the preconditions of the research was comparing very different activities, mastering of which took differently long time. Besides, the level of mastering them was measured through different quantities of incommensurable values. For these reasons it was necessary to pass from nominal variable values to indexes originated in relating actually established speed or quality of performance to given standard.

The degree of acquisition of a working activity (y) was then defined as:

$$y = \frac{\text{standard quality}}{\text{quality achieved}} \text{ (in measuring the quality of performance).}$$

$$y = \frac{\text{standard performance}}{\text{performance achieved}} \text{ (in measuring the speed of performance).}$$

The index of the speed of performance can also be expressed in time units:

$$\frac{\text{time achieved}}{\text{standard time}} \text{ (the standard is in this case in the denominator of the fraction).}$$

4. CALCULATION FORMS OF REGRESSIVE FUNCTIONS AND MEASURING OF TIGHTNESS

Propositions of all modelling functions are based on the assumption of functional dependence between the measured degree of acquisition of a working activity and the time of training. Scattering of empirical values round the regressive curve is put to the account of the influence of difference of conditions, under which the dependence is persued. Under strong dependence the difference of conditions can cause only small variability round the regressive curve and vice versa.

The result of the process of mastering the analysed working activities is a dot diagram with different amount of points (according to the number of exercises in training), each of which is the arithmetic mean of empirical values scattered around it (according to the number of persons in the examined group and its homogenity).

By means of the square method parameters a; b for all modelling functions (I–IV) were calculated. For their calculation forms it holds:

$$\log a_{\mathrm{I}} = \frac{\sum_{i=1}^{n} \log y_i + 0{,}4343 b_{\mathrm{I}} \sum_{i=1}^{n} t_i}{n} ; \quad b_{\mathrm{I}} = \frac{n \sum_{i=1}^{n} [(\log y_i)\, t_i] - (\sum_{i=1}^{n} t_i)(\sum_{i=1}^{n} \log y_i)}{0{\cdot}4343[(\sum_{i=1}^{n} t_i)^2 - n \sum_{i=1}^{n} t_i^2]}$$

$$\log a_{\mathrm{II}} = \frac{\sum_{i=1}^{n} \log y_i - b_{\mathrm{II}} \sum_{i=1}^{n} \log t_i}{n} ; \quad b_{\mathrm{II}} = \frac{n \sum_{i=1}^{n} (\log t_i \log y_i) - \sum_{i=1}^{n} (\log y_i) \sum_{i=1}^{n} (\log t_i)}{(\sum_{i=1}^{n} \log t_i)^2 - n \sum_{i=1}^{n} (\log t_i)^2}$$

$$a_{\mathrm{III}} = \frac{\sum_{i=1}^{n} y_i + (\sum_{i=1}^{n} \ln t_i) \,.\, b_{\mathrm{III}}}{n} ; \quad b_{\mathrm{III}} = \frac{n \sum_{i=1}^{n} (y_i \ln t_i) - (\sum_{i=1}^{n} \ln t_i)(\sum_{i=1}^{n} y_i)}{(\sum_{i=1}^{n} \ln t_i)^2 - n \sum_{i=1}^{n} (\ln t_i)^2}$$

$$a_{\mathrm{IV}} = \frac{\sum_{i=1}^{n} y_i - b_{\mathrm{IV}} \sum_{i=1}^{n} \frac{1}{t_i}}{n} ; \quad b_{\mathrm{IV}} = \frac{n \sum_{i=1}^{n} \frac{y_i}{t_i} - \left(\sum_{i=1}^{n} \frac{1}{t_i}\right)\left(\sum_{i=1}^{n} y_i\right)}{n \sum_{i=1}^{n} \frac{1}{t_i^2} - \left(\sum_{i=1}^{n} \frac{1}{t_i}\right)^2}$$

The tightness of correlation between empirically established and theoretically calculated values of the examined curves was established by means of the index of correlation I. Other criteria of suitability of modelling functions were also the index of determination I^2, the standard deviation S and coefficient of variation V, defined in accordance with ČSN (Czechoslovak State Regulation) 01 0250 [8].

5. RESULTS OF THE RESEARCH

5.1. Summing up the results of the analysis

The results of analysis can be briefly summed up in three tables. Table 1 shows the values of the indexes of correlation for each of the modelling functions ($I_{\mathrm{I}}, I_{\mathrm{II}}, I_{\mathrm{III}}, I_{\mathrm{IV}}$) and each examined example of the process of the quality of performance. Besides, it shows also the average value of the indexes of correlation $\bar{I}$ for each of the examined functions, the size of the standard deviations S and the coefficient of variation V.

Table 2 brings values of the same quantities for the process of the speed of performance, and besides average values of the index of correlation, the standard deviation and the coefficient of variation, calculated from all the examples (the quality and the speed of performance).

Table 1.

The tightness of empirically established and theoretical values of indexes of the quality of performace

Example No	I_I	I_{II}	I_{III}	I_{IV}	Notes
1a	0·910	0·821	0·869	0·692	reversing a tractor
2a	0·843	0·984	0·959	0·995	chucking the lathe tool
3a	0·791	0·766	0·767	0·734	setting up the valves
4a	0·832	0·974	0·946	0·997	flame welding
5a	0·994	0·994	0·998	0·982	grafting by coupling
8a	0·994	0·974	0·985	0·935	riveting
9	0·918	0·884	0·904	0·612	filing
10	0·780	0·915	0·889	0·969	filing
11	0·854	0·931	0·922	0·955	filing
12	0·889	0·971	0·969	0·930	filing
I	0·880	0·921	0·922	0·880	arithmetic mean
S	0·071	0·073	0·064	0·136	standard deviation
V	8·11	7·90	6·99	14·45	coefficient of variation

Note:

Two cases of working activities were not incorporated into the analysis of the quality of performance — filing the square holes and setting up the milking unit. The criteria of the evaluation of performance were not sufficiently objective. In these cases only the speed of performance has been analysed (see Table 2).

Table 3 presents indexes of detetmination expressed in percentage ($I^2 . 100$) and calculated from the indexes of correlation that in single examples reach the highest values (see the numbers in frames in Table 1 and 2).

5.2. Interpretation of the results of the analysis

Among all the analysed examples of working activities and examined modelling functions a strong correlation dependence has been established, which in case of model II and III is approaching functional correlation.

From Table 1 and 2 is evident that, besides 3 exceptions, for all the examined functions and examples the index correlation is higher than 0,7, while in 73 per cent of cases I it is higher than 0,9. In one third of cases the index of correlation is even higher than 0,98, and in 14 cases it is higher than 0,99.

For all the examined functions without any exception the arithmetic mean of all the indexes of correlation (both in quality and speed of performance) is higher than 0,9. The values of the standard deviation and the coefficient of variation are also favourable. From average and minimum values of the indexes of determination ($100\, I^2$) can be derived that the degree of mastering the analysed working activities in more than 90 per cent (and minimum in 60 per cent) depends on the length of training (see Table 3).

From the results summed up in Tables 1 and 2 follows that the process of mastering working activities is most truthfully modelled by regressive functions:

$$y = a - b \ln t \text{ (III)} \quad \text{and} \quad y = at^{-b} \text{ (II)}.$$

Owing to very near values of all chosen criteria it is difficult to prefer any of them. It even has come out that at the extrapolation of values (besides the examined interval) of variables t; y both the functions have equal course around the point $y = 1$; i.e. for cases when the achieved performance is approaching the standard.

Table 2.

The tightness of empirically established and theoretical values of the speed of performance

	Example No	I_{I}	I_{II}	I_{III}	I_{IV}	Notes
	1b	0·884	0·825	0·865	0·699	reversing a tractor
	2b	0·899	0·989	0·981	0·964	chucking the lathe tool
	3b	0·926	0·969	0·954	0·974	setting up the valves
	4b	0·984	0·955	0·976	0·868	flame welding
	5b	0·991	0·994	0·995	0·991	grafting by coupling
	6	0·963	0·986	0·982	0·979	filing the square hole
	7	0·977	0·993	0·994	0·981	setting up the milking unit
	8b	0·911	0·978	0·971	0·991	riveting
	13	0·849	0·939	0·949	0·895	metal turning
	14	0·988	0·987	0·997	0·981	metal turning (coefficients)
	I	0·937	0·962	0·966	0·932	arithmetic mean
	S	0·048	0·049	0·037	0·087	standard deviation
	V	5·10	5·05	3·85	9·39	coefficient of variation
For the whole set	I	0·909	0·941	0·944	0·906	arithmetic mean
For the whole set	S	0·067	0·065	0·057	0·117	standard deviation
For the whole set	V	7·37	6·90	6·06	12·94	coefficient of variation

Table 3.

Dependence of the degree of acquisition of a given working activity on the time of training

Example No		i	I_i	$I^2 . 100$	Notes
The quality of performance	1a	I	0·910	82·8%	reversing a tractor
	2a	IV	0·995	99·0%	chucking the lathe tool
	3a	I	0·791	62·6%	setting up the valves
	4a	IV	0·997	99·4%	flame welding
	5a	III	0·998	99·6%	grafting by coupling
	8a	I	0·994	98·8%	riveting
	9	I	0·918	84·3%	filing
	10	IV	0·969	93·9%	filling
	11	IV	0·955	91·2%	filing
	12	II	0·971	94·3%	filling
	I	—	0·950	—	arithmetic mean
	$(I^2 . 100)$	—	—	90·6%	arithmetic mean
The speed of performance	1b	I	0·884	78·1%	reversing a tractor
	2b	II	0·989	97·8%	chucking the lathe tool
	3b	IV	0·974	94·9%	setting up the valves
	4b	I	0·984	96·8%	flame welding
	5b	III	0·995	99·0%	grafting by coupling
	6	II	0·986	97·2%	filling the square hole
	7	III	0·994	98·8%	setting up the milking unit
	8b	IV	0·991	98·2%	riveting
	13	III	0·949	90·1%	metal turning
	14	III	0·997	99·4%	metal turning (coefficients)
	I	—	0·974	—	arithmetic mean
	$(I^2 . 100)$	—	—	95·0%	arithmetic mean
For the whole set	I	—	0·962	—	arithmetic mean
	$(I^2 . 100)$	—	—	92·8%	arithmetic mean

6. CONCLUSION

Total results of the research prove the assertion that the process of working activities acquisition depends to a large extent on the length of training and that it can be, with sufficient exactness, directed according to modelling functions:

$$y = a - b \ln t \,, \quad \text{or} \quad y = at^{-b} \,,$$

in which y represents the assumed degree of acquisition of working activities (measured by means of the index of quality or the index of the speed of performance) in the training time t; and a; b are parameters.

Besides it was proved that the speed of performance at the given moment of training can be used as the simplest and the same time sufficiently objective and exact factor of the degree of acquisition of working activities. This finding is especially valuable because measuring of the speed of performance is easier, quicker and more objective than measuring of the quality of performance.

An important assumption for using modelling functions in practice is maximum simplification of calculation. That is why we suppose that function III is especially suitable. In regressive equation

$$y = a - b \ln t$$

natural logarithms are replaced by common ones and complicated calculation of parameters a; b and theoretical values y is eliminated by the construction of a nomogram. The graphical picture of modelling function III in semilogarithm coordinates is a line, which can easily be constructed through consecutive graphical interpolation of measured values.

In several chosen examples of working activities the calculations have proved that the values of criteria of tightness of empirical and theoretical values of indexes of performance calculated from all the measured values, when compared with the values read from nomograms, deteriorated in such an imperceptible extent that, for practical use, it is quite neglectable. The values of chosen criteria (according to Table 2) for recommended modelling function III are as follows:

$$I = 0{\cdot}966\,; \quad S = 0{\cdot}037\,; \quad V = 3{\cdot}85\,.$$

The values of these criteria according to nomograms are:

$$I = 0{\cdot}944\,; \quad S = 0{\cdot}08\,; \quad V = 8{\cdot}47\,.$$

In the original research report [9] it was also proved that modelling function III can successfully be applicated also at polyphase course of training. In these cases the regressive curves are constructed for each phase independently.

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