Learning Curve Based Sigma Level Determination in Interrupted Non-Production Processes

V. Molnar, G. Metszosy

University of Miskolc, Faculty of Economics, Institute of Management Science, szvmv@uni-miskolc.hu

Abstract. The philosophy and methods of six sigma process development have been applied successfully since mid-1980s, and the application of the six sigma concept in non-production processes has increased significantly in the last decade. In this paper processes that can be characterized by learning curves are modeled. The quality of such processes can be analyzed on the basis of the six sigma concept. In this paper two back office processes are analyzed. The processes are built up of simple repeated steps and incorporate some interruptions. The application of the model allows the calculation of the maximally permitted number of interruptions in the process if the preliminary determined norm is to be kept.

Introduction

The application of the six sigma process management concept goes back about thirty years. Since then numerous practical papers and professional reports have been published and the method has appeared to some extent in almost all industrial branches. Six sigma requires a high level of system orientation and complex organizational operation. This means that its adaptation and successful application depend on several factors, the center of which is human resources in most cases. Some powerful companies adapt six sigma and the advantages which can be observed in their achievements remain even long after the adaptation. Above this, six sigma affects mainly the achievement of employees and not the productivity of resources [1]. According to the six sigma approach the improvisation is relayed by the professional engineering approach, the guesses and subjective point of views by the objective data and the fictive results by money. And the application success of it depends on the personnel, their consistent work, cooperation and professionalism [2]. However, the interaction of work performance and motivation [3] can also be critical because 'better motivation of employees results in an efficient workforce and it eventually increases the overall efficiency of the organization' [4].

Unfortunately there are only a few research results that focus on successful application of the concept. Reports of empirical research are published now and then but the literature provides mainly only the success factors of single enterprises (case studies). Some examples of such success factors are summarized in Table 1. The scientifically appropriate summary of success and the reliable generalization are topics requiring further work. It is important to highlight that the adaptation of not only six sigma but other modern process development concepts needs the support of several organizational factors, because the effect of globalization requires new ways of organizing work and

new approaches to human resource management [5]. Beyond that, companies that are able to successfully manage changes have to react to the challenges of the information society and the turbulent market environments [6].

Success factors	Study
Involvement of employees; culture change; communication; infrastructure; training; connecting six sigma clearly to enterprise's goals, customers, employees and suppliers; understanding the methods; project managerial skills; adequate prioritization of projects.	[7], [8]
Managerial commitment and participation; corporate strategy built up to customer needs; existing six sigma framework; project implementation and monitoring; investment in resources; education framework; bonus system; collecting and analyzing available data; reaching both short- and long-run goals; knowledge management system; project formation on the basis of corporate strategy; cooperation and communication; proper application of six sigma tools.	[9]
Managerial support; exact connection to corporate strategy; exact quantification and monitoring of results; clear financial results; efficient human resource allocation; proper knowledge of six sigma concept.	[2]

Table 1. Critical success factors of six sigma adaptation

A number of reports have published on applications of six sigma since the mid-eighties. In the last decade the number of them has substantially increased. The published reports, case studies and application models can basically be analyzed by several aspects and this diversity sometimes makes a proper summary of the literature difficult. In one study, 82 papers dealing with the application of six sigma were analyzed to determine the share of application fields [10] (Fig. 1). The sample was obtained through the database ScienceDirect. It covered the period 2000-2015. Most of the publications were connected to industrial production (discrete or continuous) (42.7%). Beyond that, the results of six sigma developments in the service industry (healthcare, education and other services) formed a significant share (23.3%). The reason for the relatively high share of these areas is that the number of successful six sigma applications has increased significantly in the past years.

Study	Year	Analyzed variable	Current value	Value after development
[11]	2005	Average number of infections in a hospital per day	11	1.7
[12]	2011	More than 10 minutes wait to surgery admission (%)	42	10
[13]	2014	Increasing σ-level	3.31	4.5
[14]	2015	Employee satisfaction (%)	48	73
		Waiting time (min)	105	47
		Lead time(min)	135	66.5
[15]	2017	Increasing σ-level	2.45	3.16
[16]	2016	Increasing σ-level (short-run)	2.9	5.2
		Increasing σ-level (long-run)	1.4	3.7

Table 2. Results of six sigma process development projects

One of the main rules of six sigma projects is that one should designate what has to be developed, how that can be quantified, and the concrete goal value of this factor. In Table 2 a short summary about development results of case-study type papers is given as an example.
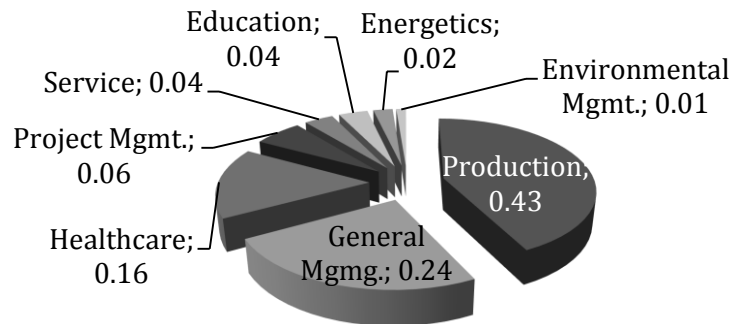
Figure 1. Distribution of application areas of six sigma [10]

1. Application of six sigma in processes characterized by learning curve

There are several methods for modeling production processes. From a morphological point of view most of the processes show a sequential form, i.e. they have determined start and finish points. Some characteristics of different, non-conventional processes are [17]:

- indefinite number and time interruptions,
- stochastic lead time,
- ad hoc content.

Some non-production processes can be characterized by one or by a combination of these. A back office worker receives their wage on the basis of the time spent in the office and not their achievement, in most cases. The tasks – ad hoc, regular or standard– performed in working hours can also be characterized by their lead time. Therefore, though with certain limitations, the costs of the work elements can easily be calculated [18]. The model introduced in this paper allows the determination of performance norms as well [19].

Similarly to standardized machine assembly processes, for example, several non-production processes can be characterized by learning curves. When performing a certain task, in the initial phase the time of the repeated steps is still relatively high and this time decreases with the increase of number of repetitions and eventually reaches a stabilized level. In case of the learning curve defined in this manner, the time values higher than the stabilized level are times of learning or 'attunement'. This phase is natural in several types of work. However, if the process is interrupted by shorter or longer periods, the process becomes one that incorporates several phases characterized by several learning curves. Due to the learning phases, the time of all the repeated steps will higher compared to the same process without interruptions. From this point of view all the time values over the stabilization level of the learning curves located after the first interruption can be considered as waste. This waste can be reduced or eliminated by the elimination of interruptions, which can be realized by rational work organization.

2. Mathematical model

To introduce the model, let a process be characterized by an indefinite number of interruptions and stochastic activity time. A typical learning curve can be described by an exponential function. In Fig. 2 the process is demonstrated. The process contains m work phases, therefore m learning curves. There are m-1 interruptions in the whole process. The last steps directly before the interruptions are designated by n, x is the number of repetitions and t is the realization time of a step. The average of all the steps of the whole process is t_Σ and the deviation is s_Σ. It is supposed that the stabilized values of all the learning curves are equal.
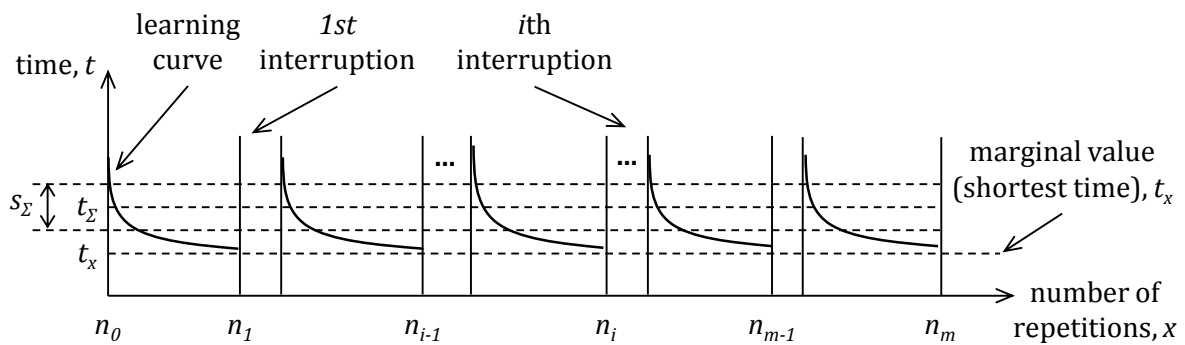

Figure 2. Modeling of process incorporating interruptions with learning curves

Notations of Fig. 3 are applied to describe the process located directly before the ith interruption. In this phase k_i-n_i is the section in which only stochastic fluctuation can be found (further decrease of time is not possible in the given circumstances). This means that in the continuous approach the learning curve holds for the marginal value (shortest time). These values of the curve are located in a sufficiently small δ environment. Value t_i^* designates the ith repeated step. The k_i is determined by the appropriately chosen δ. The average time of the repeated steps before k_i is t_i^{**}. The time loss resulted from the initial learning is designated by V_i.
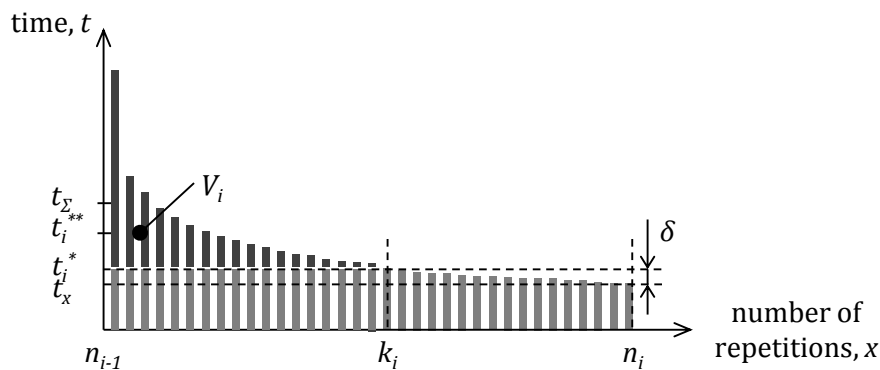

Figure 3. Model of the phase before the first interruption

Applying the notations of Fig. 3, the calculation of time loss can be constructed. This loss and the marginal value (t^*) of the stabilization section (k_i-n_i) for the ith phase can be calculated by Eqs. (1-2).

Total time loss of the process can be calculated by Eq. (3). Average time and empirical deviation of the repeated steps can be calculated by Eq. (4) and Eq. (5), respectively.

$$V_i = \sum_{x=n_{i-1}}^{k_i} t_x - (k_i - n_{i-1})t_i^* \tag{1}$$

$$t_i^* = \frac{1}{n_i - k_i} \sum_{x=k_i}^{n_i} t_x \tag{2}$$

$$V = \sum_{j=1}^{m} V_j \tag{3}$$

$$t_\Sigma = \frac{1}{m} \sum_{x=n_0}^{n_m} t_x \tag{4}$$

$$s_\Sigma = \sqrt{\frac{\Sigma(t_x - t_\Sigma)^2}{n_m - 1}} \tag{5}$$

Let the process be developed by simple work organization methods where the interruptions and therefore the relearning times are eliminated. Applying the notations of Fig. 2, the developed process is demonstrated in Fig. 4. The area above the curve (T - total time of work) demonstrates the state after process development and can be calculated by Eq. (6).
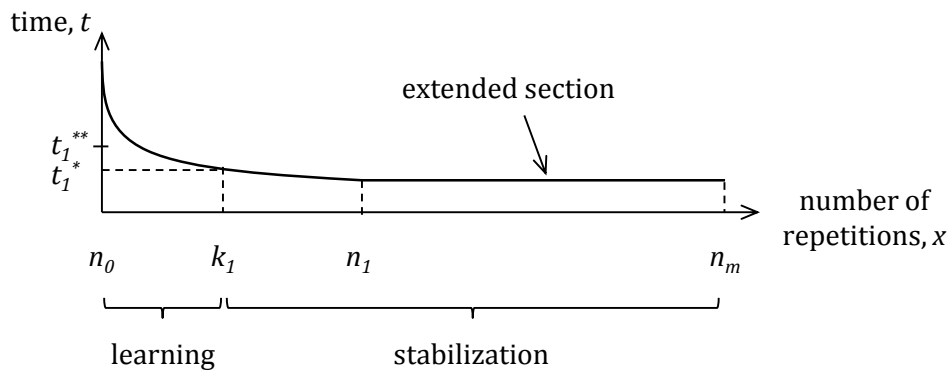

Figure 4. Process model after elimination of interruptions

$$T = \sum_{x=n_0}^{k_1} t_x + (n_m - k_1)t_d^* \tag{6}$$

To determine the sigma level of the process calculation of some deviation value is necessary. It can be supposed that the deviation of the section between k_i and n_i (stabilization section) equals that of the rest of the process. But the number of considered values is different, therefore the square summing of s_{k1n1} (Eq.(7)) deviation of the k_1-n_1 section is necessary for the whole k_1-n_m section. The modified s_m empirical deviation (Eq.(8)) refers to a section that generally is not necessarily an integer multiple value of the section k_1-n_1.

$$s_{k1n1} = \sqrt{\frac{\sum(t_x - t_d^*)^2}{n_1 - k_1 - 1}} \tag{7}$$

$$s_m = \sqrt{\frac{n_m - k_1}{n_1 - k_1}(s_{k1n1})^2} \tag{8}$$

To describe the process formally the section n_0-k_1 has to be considered as well. The deviation of this section can be calculated by Eq. (9). The empirical deviation of the whole process (learning and stabilization sections) can be determined by Eq. (10).

To interpret sigma level let p [%] be defined. The meaning of this parameter is that what percent is allowed for exceeding the planned time of work (T). Then the acceptance range of the whole work time can be designated by L (Eq. (11)). Sigma level can be calculated by Eq. (12).

$$s_{n0k1} = \sqrt{\frac{\sum(t_x - t_d^{**})^2}{k_1 - n_0 - 1}} \tag{9}$$

$$s = \sqrt{(s_{n0k1})^2 + s_m^2} \tag{10}$$

$$L: \left[T; \left(1 + \frac{p}{100}\right)T\right] \tag{11}$$

$$l = \frac{pT}{100s} \tag{12}$$

In this method, due to the learning curve the distribution of time values is lognormal. Its density function is asymmetric; the minimum value of the probability variable is the marginal value (stabilization section). The method allows the amount of time loss to be determined, similarly to the determination of scrap rates of manufacturing processes. If previously determined learning curve parameters are available, determining the sigma level can provide information about the maximum number of interruptions, which is connected to the acceptable extra time. Application of the method can be necessary if the analyzed process contains only the extra times of relearning. Elimination of other problems and waste generally has to come before that of the relearning waste, because they tend to be on a larger scale, e.g. in case of problems like raw material availability or non-time-related errors of work or scrap.

3. Application example 1 – class schedule entry of a university department

In our analysis the steps of class schedule completion were measured course by course. In this analysis we measured time spent for each step in the process of entering data into an electronic system for a subject to be offered during the semester. The person who was traced is experienced in this activity. These steps incorporate the following elementary tasks: choosing the lecturer's name from a list;

checking possibilities of combining classes; registering the time load of lectures and seminars. Two very similar processes were analyzed. The first is the above activities connected to the class schedule for full-time students. In this process there were some interruptions. The second process was the same for the schedule for part-time students, in which there was no interruption. In the first analysis interruptions were intentionally built into the process. The first interruption lasted 3 hours and the second 1 hour. In both processes the processing time of 53 subjects were measured. The measured data of the two processes are summarized in Table 3. The higher values of learning sections can be observed easily.

To calculate the parameters of the model first the k values (number of the repeated step which can be considered as the starting point of stabilization) were designated. In the three phases of the interrupted process these are 10, 9 and 5, respectively. The calculated values for the phases (t_i^*, s), the t_Σ and s_Σ values connecting to the whole process, the modified s_m deviation and the s deviation of the process are summarized in Table 4.

1st process 1st phase				1st process 2nd phase				1st proc. 3rd ph.		2nd process							
Repetition #	Time [s]	Repetition #	Time [s]	Repetition #	Time [s]	Repetition #	Time [s]	Repetition #	Time [s]	Repetition #	Time [s]	Repetition #	Time [s]	Repetition #	Time [s]	Repetition #	Time [s]
1	74	15	50	1	81	15	51	1	72	1	75	15	52	29	52	43	48
2	70	16	45	2	74	16	54	2	70	2	70	16	50	30	48	44	49
3	61	17	49	3	71	17	47	3	59	3	71	17	53	31	43	45	47
4	53	18	48	4	72	18	50	4	52	4	62	18	45	32	48	46	49
5	46			5	63	19	44	5	55	5	55	19	50	33	49	47	43
6	52			6	60	20	45	6	46	6	53	20	52	34	49	48	45
7	54			7	52	21	50	7	45	7	53	21	49	35	51	49	48
8	51			8	58	22	51	8	47	8	51	22	48	36	45	50	47
9	47			9	51			9	52	9	49	23	49	37	50	51	48
10	50			10	47			10	52	10	48	24	49	38	48	52	50
11	51			11	53			11	46	11	52	25	51	39	49	53	44
12	50			12	45			12	49	12	52	26	50	40	47		
13	48			13	54			13	52	13	52	27	47	41	50		
14	49			14	52					14	51	28	47	42	49		

Table 3. Time measurement data of time schedule completion process [17]

The average times of the stabilization sections are between 48.89 and 49.57 sec and the deviations are between 1.76 and 3.54 sec. These values can be considered similar. The averages prove the supposition that with a similar physical and mental load similar values can be measured in the

stabilization sections. The reason for the relatively higher differences among the deviation values is the difference in the number of repetitions.

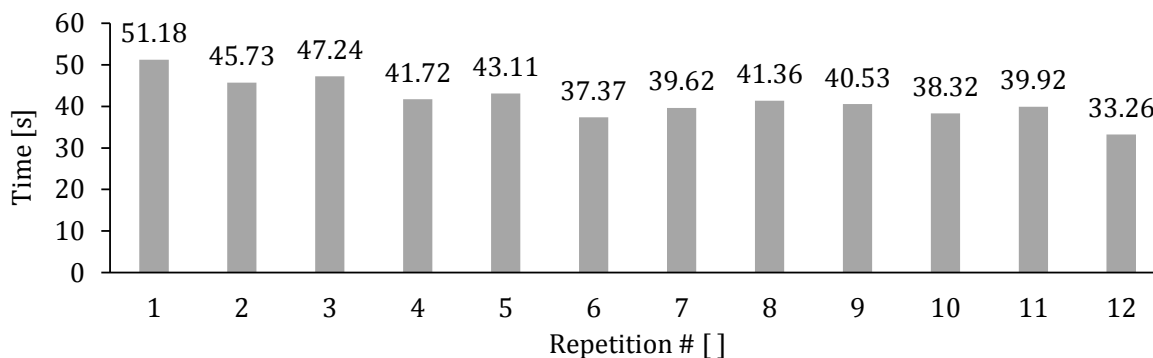| Parameter	Value	Parameter	Value
t_1^* $(k_1\text{-}n_1)$	48.89s	t_Σ $(n_0\text{-}n_3)$	54.15s
s_{k1n1}	1.76s	s_Σ $(n_0\text{-}n_3)$	9.09s
s_{n0k1}	9.86s	s_m	3.9s
t_2^* $(k_2\text{-}n_2)$	49.57s	s	10.61s
s_{k2n2}	3.39s		
t_3^* $(k_3\text{-}n_3)$	49.33s		
s_{k3n3}	3.54s		

Table 4. Calculated values of the first measurement (full-time class schedule)

The reason for the relatively high value of the calculated s is that the first 10 points of the first learning curve show a great fluctuation. The total time of the interrupted process is 2870 sec. After the process development (elimination of interruptions) the value of T identifies to what extent the whole process time can be decreased. Substituting the corresponding parameters in Eq. (6), this value is 2659 sec, which is a 7.4% reduction in time. If a 1% limit is available for exceeding the planned T time of work, the sigma level of the process without interruptions is 2.51 (Eq. (12) is applied).

In the next step let us consider the second process, which contains no interruptions (the part-time class schedule). The total time of the process is 2682 sec, which is 6.5% lower than that of the first process. In this process the average time of the stabilized section (starts at the 15th repeated step) is 48.42 sec and the deviation is 2.38. Considering the 1% limit again, these values lead to a 11.26 sigma level, which is 4.49-fold of the first process which included interruptions. The meaning of this is that although the lead time did not decrease radically, the stability of the process shows a relatively significant improvement.

4. Application example 2 – registering data from invoices

In the second example the time needed to register data contained in invoices in an electronic system is analysed. We examine whether a certain extent difference experienced in the parameters of the phases limits the application of the model. Times of repeated steps of a process were measured. There were two interruptions in the process (1 and 3 hours), so the process contained three phases. The time values are summarized in Fig. 5. Registration of 21 invoices was measured.
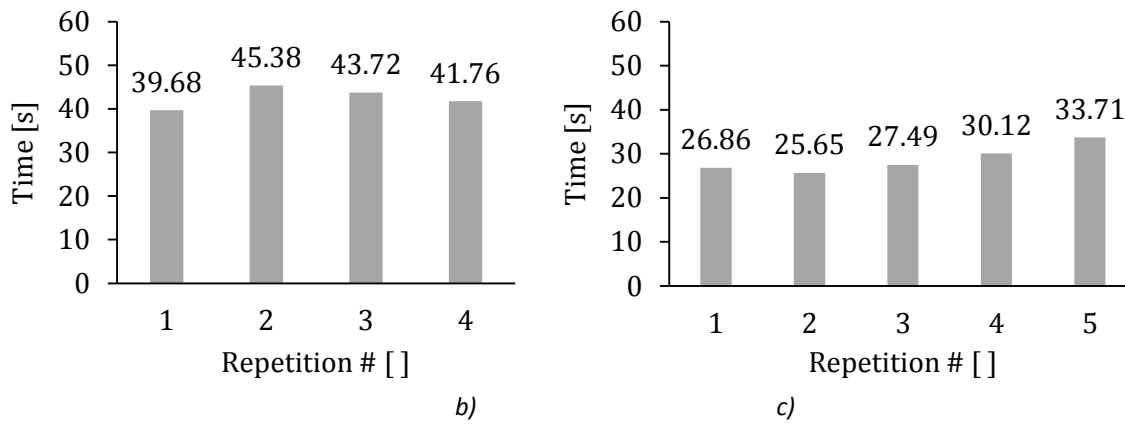

a)

Figure 5. Time measurement data of invoice registration process

On the basis of these data the calculated values of the model parameters are summarized in Table 5. The k values of the three phases are 5, 2 and 3, respectively. In this case we were unable to collect data for an uninterrupted period of entering data, so no comparison can be made. The total time of the original process is 813.83 sec. Eliminating the interruptions the calculated value of T is 856 sec. It can be observed that the average values of the second and third phases, with relatively low deviation values, greatly differ from each other.

Parameter	Value	Parameter	Value
t_1^* $(k_1$-$n_1)$	39.19s	t_Σ $(n_0$-$n_3)$	38.75s
s_{k1n1}	2.97s	s_Σ $(n_0$-$n_3)$	6.95s
s_{n0k1}	3.91s	s_m	4.33s
t_2^* $(k_2$-$n_2)$	43.62s	s	5.84s
s_{k2n2}	1.81s		
t_3^* $(k_3$-$n_3)$	30.44s		
s_{k3n3}	3.12s		

Table 5. Calculated values of the filing process

The extent of this difference means that development on the basis of the introduced model is no longer realistic because the T value whose improvement was desired happens to have a higher value than the original one. This type of discrepancy can be experienced if the work intensity of an analyzed person is altered to a great extent after an interruption. To eliminate this problem, it is necessary to register more data. A similar distorted case could be experienced if the work of different persons were modeled. In this example it can be observed that in the third phase a fatigue section appears, i.e. the time values after a certain number of repetition start increasing slowly.

5. Summary

The aim of the simple mathematical model introduced in this paper is to give advice to decision-makers interested in six sigma process development by quantified data. The model can help to determine process parameters that connect to the time values of repeated simple work steps. In the model exceeding a preliminary determined norm is considered as an error. In the model the sigma level is considered by lognormal distribution of time values of the exponential learning curve. The

sigma level provides information about the stability of the process. A case study was used to show the possibilities for application of the model. A second case study highlighted an important instance when the result of the model is distorted. It is supposed in the model that after each interruption a certain level of relearning starts in the same process. However, the model does not yet account for at the fact that at the end of long processes the time of repeated steps can increase, due to the load on the worker and worker fatigue.

Acknowledgement

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