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The propagation of variability of polymer processing parameters in production lines

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Analysis and modelling

ABSTRACT

Purpose: Analysis the propagation of the variability of polymer processing in production lines is the aim of the article. It is unprofitable occurrence. It contributes to an increase in the time of the production cycle and the volume of work in process.

Design/methodology/approach: For the measurement of the variability of polymer processing parameters the time Shewart′s card were used. The technique of the timing was applied for the registration of the production cycle time and the volume of stocks. The computer simulation was used for the analysis of the propagation of the variability in the production line at different values of the variability coefficient.

Findings: The Shewart's card permit to control the random variability of processes and eliminate the negative results of this occurrence. The computer simulation allowed to the investigate a lot of screenplays assuming different sizes of the variability. Prediction of the variability of polymer processing parameters gives possibility for the correction of the manufacturing process organization and against wastage.

Research limitations/implications: The next step of research will be. Determinations of relation between the variability of polymer processing parameters and coefficient of machines utilization and quality of the final product will be the next stage of the research. The validation simulation models and estimation of their usefulness in undertaking of the decision concerning production process.

Practical implications: The analysis of the propagation of variability of polymers processing parameters permits for better are understanding of reasons delays and excessive work in progress materials in the production of a particular article. The inspection of the variability permits better to manage the materials flow in the production system.

Keywords: Statistic methods; Engineering polymers; Variability parameters; Productivity and performance management

1. Introduction

The knowledge of the variability theory permits to make efficient the organization of the production and creates possibilities of the constant improvement. Necessary is the description and the control of the manufacturing process.

All measured parameters of the manufacturing process are characterized with the variability. Not always the method of the measurement permits to detect the variability, because it is too small or one used the inadequate tool of the measurement. It is not possible to avoid the variability in the realization of manufacturing processes. Additionally the variability from first stages of the production is transferred on following stages.

The large variability makes for the growth of the materials costs, costs of machines maintaining, cost of salaries etc. The reduction of this occurrence is, so, a necessity. The recognition of the variability nature is necessary. An advance in the way to control the process and decrease in its variability, is the distinction between general and special reasons.

A not as usual helpful tool is the statistical and dynamic control of the process [1,2]. The statistical control can be realized by control cards. The dynamics of the occurrence of the variability one can investigate at the use of the computer simulation. Received results permit to identify sources of the variability and to undertake suitable decisions on of realized process.

2. Investigation methodology

One described the production line in which one of stages was the process of the polymer materials processing and following the assembly of the semimanufactured product into the finished article. Analysis of production system was done. The information on the current state of the production system were assembled going with paths of the flow of materials and the information. The analysis was begun from the market board, that is to say from processes connected with the customer. These processes set the seed of processes up of the stream.

In the process of information about production processes receiving one used the timing. This is the technique of time measurement by means of the stop-watch, consisting in registration of the time the operation duration and the speed of the realization of each element of the process manufacturing.

Collected data were worked out statistically. Mean values of each parameter were calculated and the statistical distribution of the investigated occurrence was determined.

Quantities on which the significant influence of principle has an occurrence of the variability were calculated. To favour here one ought [3]:

- expected time value for processing the material in a particular workstation *CT* (i.e. machine work centre)
- expected material amount value for the material processed on the workstation *WIP*,
- relative utilization of the injection moulding machine *u*.

Accordingly one used the queueing theory [4,5]. Analyzed production line was considered as the network with service places. Hoop and Spearman proposed the use of following equations for the service system *G/G/m* [6,7]:

$$u = \frac{r_a}{r_e} = \frac{r_a \cdot t_e}{m} \tag{1}$$

$$CT \approx \left(\frac{c_a^2 + c_e^2}{2}\right) \cdot t_e \cdot \frac{u^{\sqrt{2\cdot(m+1)}-1}}{m\cdot(1-u)} + t_e \tag{2}$$

and

$$WIP = \left[\left(\frac{c_a^2 + c_e^2}{2}\right) \cdot t_e \cdot \frac{u^{\sqrt{2\cdot(m+1)}-1}}{m\cdot(1-u)} + t_e\right] \times r_a \tag{3}$$

where:
u – relative injection moulding machine duty
r_a - frequency of new orders,
r_e - frequency of completion of the orders,
m - number of machines in workstation,
t_e - effective time of the material processing,
c_a^2 - square variability coefficient of new jobs,
c_e^2 - square variability coefficient for effective processing time.

The expression *G/G/m* represents, in the David G. Kendall's notation [8], the system of the service with the general, defined by the researcher, statistical distribution of the random variable with which productive orders are obtained, and with the statistical distribution with which productive orders on defined (*m*) number of stands are realized. Above-expressions are supplemented by the equation the describing the square variability coefficient [7].

$$c_e^2 = c_0^2 + 2 \cdot A \cdot (1-A) \cdot m_r \cdot \frac{1}{t_0} \tag{4}$$

$$c_e = \sqrt{c_0^2 + 2 \cdot A \cdot (1-A) \cdot m_r \cdot \frac{1}{t_0}} \tag{5}$$

where:
c_0^2 - natural square variability coefficient
A - machine's accessibility

$$A = \frac{m_f}{m_f + m_r} \tag{6}$$

m_f - mean time to failure
m_r - mean time to repair,
t_0 - time of the material processing i.e. injection cycle time

On base of collected data, the variability coefficient of the production cycle time and utilization of stands were determined for every element of the manufacturing process – polymeric materials processing and assembly into the finished product. Control cards were also worked out.

The utilization of work stands was in the range 70 - 80%. It means that the manufacturing process has a certain steady state. However it does not mean that the process does not characterize it by high variability.

The production cycle time consists of mechanical times and technological times. In this investigation these times were consider together. [9-11].

3. Statistical methods for process variability control

While looking for the values of the processing parameters, mainly the stand duty, production capability and capacity the statistical tool in form of a control card has been used. The applied control card is a process card for the polymer processing on the given machine (e.g. injection moulding machine, drying machine, knife mill and the assembly time card etc.)

The advantage of the control card application is the fact that it is difficult to define the variability nature of a given parameter and unambiguously state if it is high of low. This information is obtained after completion of a measurement of particular parameter in certain period of time by determining square variability coefficient. The control card should serve mainly to control the variability of the production system in progress. The purpose of the control card is signalizing of the deviation from the state which is found stabile $(c_i^2 \approx 1)$. Using the cards the following activities can be defined:

- start activities after detection of a change,

- restrain from activities in case of lack of changes.

The described activities are the basis for statistical control of the material flow process. The impulse for taking appropriate activities can be the systematic components and the random components. It is justifiable to assume that the registered process shows randomness as a result of "common" reasons called also the natural ones but also as a result of the occurrence of "special" reasons. The purpose of the control card is to trace and define these reasons.

To the inspection of the variability of productive parameters one can use tools such of SPC (*statistic process control*) as the Shewart's card or the CuSum card [12, 13, 14]

In research the Shewart's cards were used. One performed 15 measurement of the number of cycles per minute every after 5 tests.

Analysis of 5 tests from observations enabled to estimate the short-time variability around the mean value. Each registered test made up its own mean value estimator and the standard deviation. In the Fig. 1a and 1b. the diagram of the value of plastic processing cycle time registered in the individual observations and assembly cycle time is shown.

To measure and control the injection cycle time the control cards $\overline{X} / R$ were used. It was assumed that the injection cycle time variability characteristics have a normal distribution. The analysis of the normality by Shapiro-Wilk ((*SW-W = 0.96780341, p = 0.0531*) and the designed diagram of normality proved this assumption.

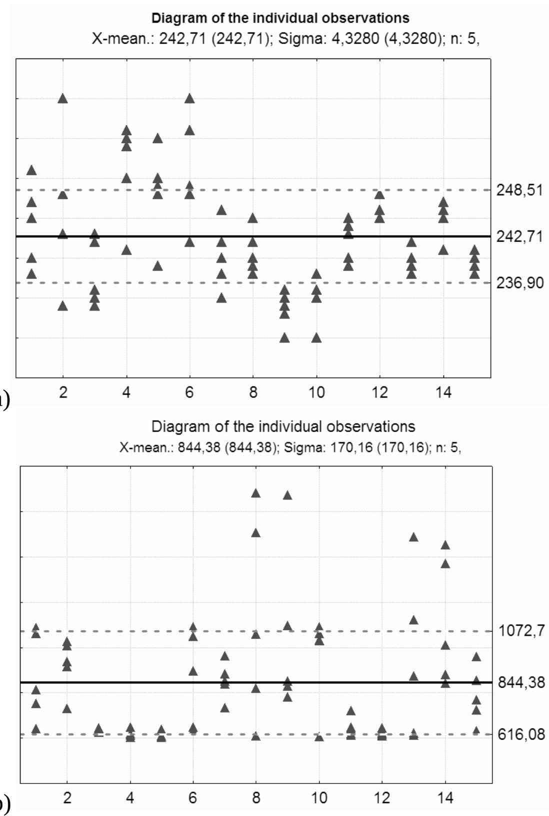


Fig. 1. The graph of individual observations in 15 measurement: a) injection moulding room; b) assembly room

The parameter for estimation of the normality of the distribution is a *SW-W* parameter. The value *p* which relates to the obtained *SW-W* is higher than 0.05 therefore there is no basis to reject the hypothesis of a distribution normality.

In the case of the assembly cycle time, it did not succeed to confirm the hypothesis about the normal distribution. Both the observation of the graph of the normality and the histogram evidences the large irregularity of the assembly time. This confirms the Shapiro-Wilk's test. Very difficult to conclude which character has this occurrence. However one can it control within limits.

Figure 2.a presents the estimation of the mean value and the standard deviation for the processing cycle time. Non-linearity highlights the deviation from the normality. In this case the linearity is visible. In the case of the assembly time one ought to suppose that it can be characterized by him other distribution probably exponential(Fig. 2.b).

Normal distribution for the processing cycle time is not the demanded form. However, the convenience of using it results from the fact that its character is understandable and tabled. Figure 3 represents the histogram. Only in the case of the drawing 3a well describes the normal probability distribution.

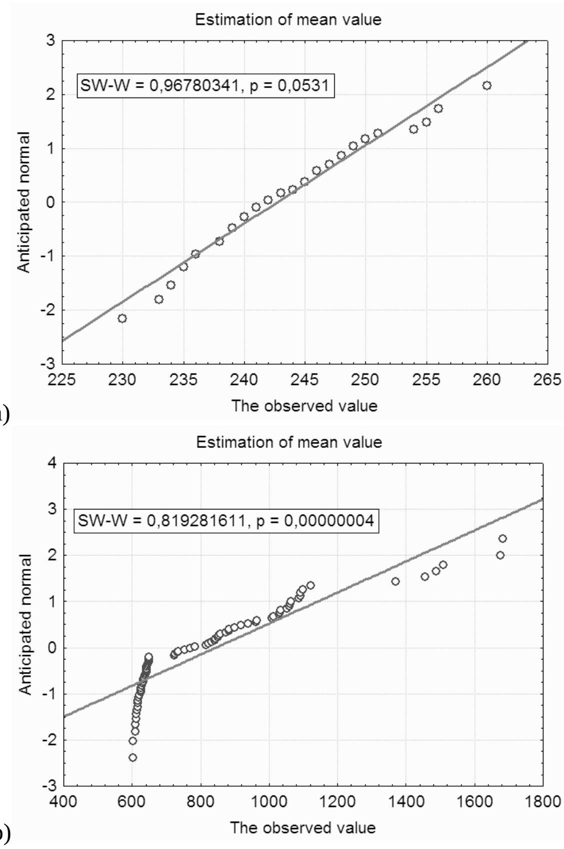


Fig. 2. Estimation of mean value and standard deviation for cycle time of polymer processing (a) and assembly (b)

The results of injection cycle time monitoring are presented in the Fig. 4. The applied card enables simultaneous controlling of the mean value and the spread level. The diagram for the mean values from the measurements showed in 4 cases crossing the boundary values. The warning lines are located within the distance of ± 2 statistical errors from the target line.

Injection cycle mean time was around mean value, however, during a few measurements crossing of the boundary lines was observed. The fundamental influence on the increase in cycle time was from the machine's operator's experience and knowledge. In several cases moulded cooling time was shortened due to the variable mould temperature [15].

In the attempt 9 and 10 it was needed to shorten of the cycle time of the injection moulding due to the necessity of leveling of delays in the realization of the process. In fig. 4. one represented the control card of the assembly time. It is easy to noticed that mean values and dispersion often have values near boundary ones at which process can be seen as correct.

Variability of the injection cycle time took lower or average values and did not prove any progressing changes.

However in the second test one observed the exceed of control limits. Due this was a probably small experience of the worker serving the machine.

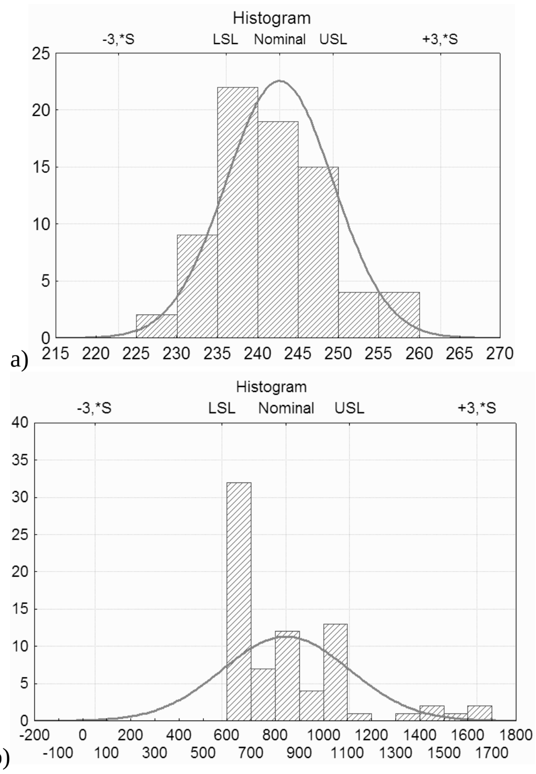


Fig. 3. Histogram the observations value a) Pressroom; b) Assembly

The control card of the assembly process of the received semimanufactured product, evidences large divergences during the realization of each assembly-acts. Because the assembly process was carried on manually the change of productivity time was probably caused by a tiredness of workers, their less precession work and an lower efficiency.

While undertaking the attempt to control processing cycle time for the polymeric materials the possibility to occurrence of the "out of control" state should be predicted, other than as a result of the deviation of processing cycle time mean value from the target value. It is of great importance to detect each increase in variability over the level characteristic for the process. As the analysis showed, this increase may appear without change in the mean value during process. The statistics which enable measuring of variability through tests is a range statistics. These mean the difference between the highest and lowest observation in an analysed test.

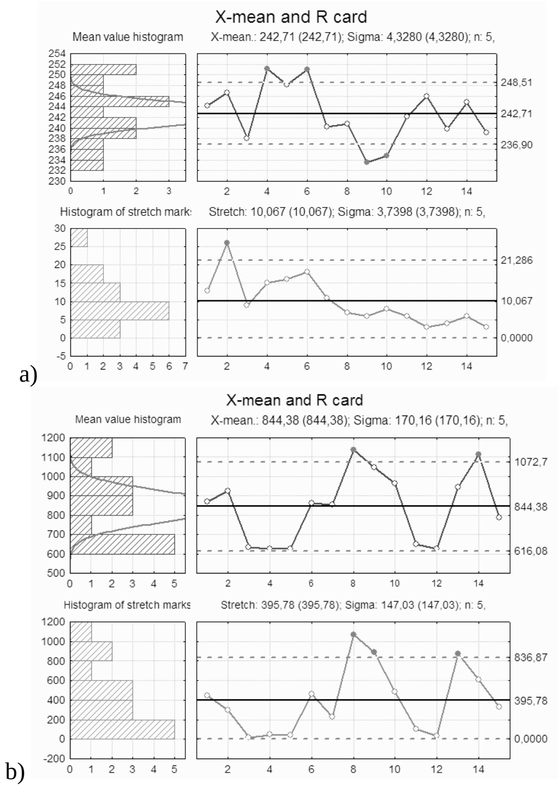


Fig. 4. Monitoring of the injection cycle time and assembly cycle time by means of Shewart's card

The analyzed values do not always oscillate within control boundaries. Range probability distribution in a test is not a normal distribution. It is an asymmetric distribution, which excludes application of the $\pm$ rule. Coefficients for the ranges control lines are determined in Polish standards of PN/EN 03014 or the British one BS 5700, 1984.

One ought to give himself the question, whether observed faultinesses have an influence on other processes , and if so in which degree. In publications one can find the information on the character of the variability [7]:

- $c_e^2 < 0.5$ - low variability,
- $0.5 < c_e^2 < 1.75$ - average variability,
- $c_e^2 > 1.75$ - high variability.

The influence of the variability on manufacturing processes and the spread of this occurrence in production lines was examined at the utilization of the computer simulation.

4. The propagation of the variability of parameters in the production line

From practical and economic reasons one cannot pass the exact analysis of the propagation occurrence of the variability of parameters in the production line. First of all it was assumed that such situation took place. Mathematical model of the production line was worked out. Its schematic diagram was represented in Fig. 5.

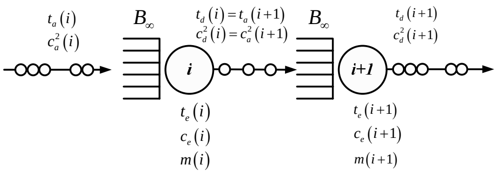


Fig. 5. The propagation of the variability in the production line

where:
i - machine number
t_a – mean arrival raw material flow
t_d - mean time between completion of each order,
$1/t_d = r_d$ - frequency of completion of each order, productivity
c_d^2 - square variability coefficient of completion of each order.

$$c_d^2 \approx 1 + \left(1-u^2\right)\cdot\left(c_a^2-1\right) + \frac{u^2\left(c_e^2-1\right)}{\sqrt{m}} \quad (7)$$

The production line consist of the injection moulding department and the assembly department. On the entry to the system and between departments there are magazines of the safety about not normalized volume of stocks. It this an essential assumption which allow to analyze impromptu free the occurrence of the variability propagation. The interoperating-magazine levels adverse effect of the process variability on condition that its capacity is enough large. In effect one aims to the support of low warehouse-states. The low magazine level and the large coefficient of its rotation cause propagation of the variability in the production line.

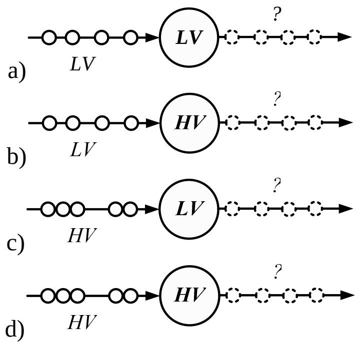
Orders flow to the injection molding department. This occurrence can by described by the exponential distribution. The variability of the polymers processing on the injection molding department one graded from small to large values. It was assumed that machines would be very loaded, that is to say the coefficient of the utilization will be in the range 0,8 - 1.

As it should be to suppose the variability of parameters at the entry and the service influences parameters at the exit. Processed material is translocated in the production line. On the ground of the observation of the real manufacturing process one infers that the flow of the material is accompanied by negative results of the too high variability of each processes parameters.

5. The simulation of the production line

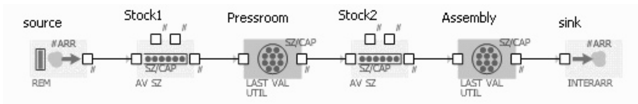
For the check of the accepted hypothesis one worked out the simulations model of the production line using *AnyLogic 5.4.1* program of the firm *XJ Technologies Company Ltd*, with the utilization of the queuing theory [16,17]. To develop the model in the simulator the suitable blocks representative the given element of the productive system. Then values describing magazines, matched together polymer processing and the assembly of elements from polymer materials were determined.

It was assumed that both the variability of the time of the affluence of new notifications to the realization and the time of the injection moulding will change with duration of the simulation, but the variability of the assembly time will be on the same level 845 seconds. Cases at the high charge of machines on the injection moulding department were examined (Fig. 6)



LV (law variability) – 0,4; HV (high variability) – 2

Fig. 6. The value of the variability of the output rate



Figs. 7. The simulation model of the production line

The computer simulation permitted to known what influence the injection cycle time on the assembly process has. (Fig. 7)

Cases with the limited capacity of magazines were also examined. Predictably, the simulation showed that at a very low level of interoperating-stock the production process can be stopped because of machine blocking or assembly-works breaking arising from the lack of sufficiency amount of the semimanufactured product in the magazine in a particular [18,19].

The amount of processed material was established on the average level - 50 kg/h. In the table one represented boundary cases of the variability of the time of the new orders inflow and variability of polymer processing time and their influence on the square coefficient of the variability of the following orders execution in the injection molding department. It has mean values, within the range 0,68 - 1,54.

		Arrival Rate Variability	
		LV	HV
Process Time Variability	LV	0,68	1,09
	HV	1,13	1,54

In fig. (8) the influence of the variability of following notifications inflow to the polymer processing and variability of processing time on assembly cycle time is presented.

With the increase of the variability of the new notifications inflow and with the increase of the variability of the polymer processing time the assembly cycle time increases linearly in spite of the assembly process has the small variability.

The simulation confirmed the assumption about the influence of the variability of the injection cycle time on the entire time of the following operation, that is to say the assembly of the semimanufactured product into the finished one.

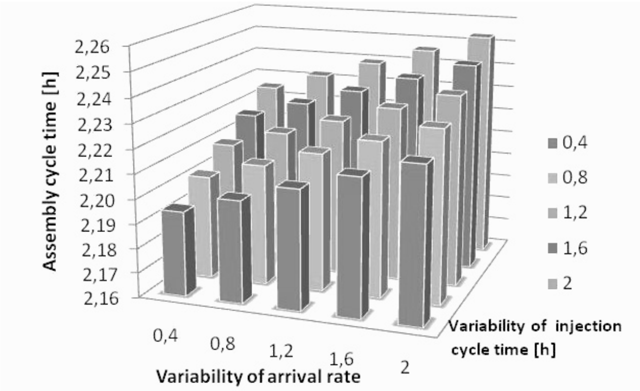


Fig. 8. Influence of injection cycle time variability and raw materials arrival rate on assembly time

In the case of the fully balanced line values of the injection cycle times and the volume of production in progress should be the same every time. Such situation takes place when diagnosing low variabilities of injection cycle time. Together with the increase of the first machine process variability values of each analysed magnitudes increase. The dynamics of this increase is dependent on the value of each process machines variability and the degree of their utilization.

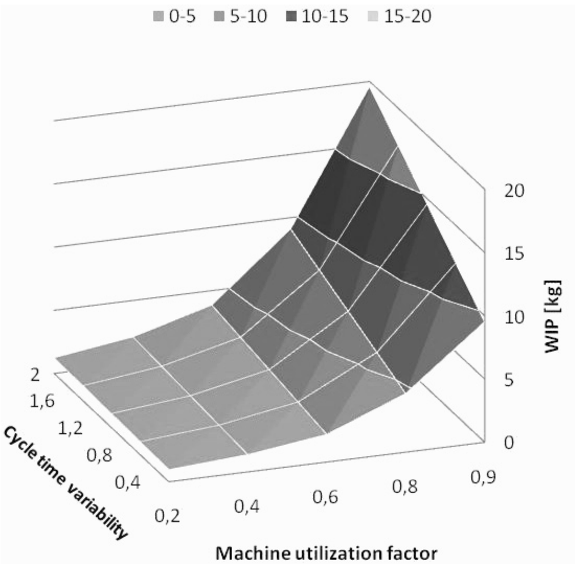


Fig. 9. Influence of cycle time variability on value of work in progress (*WIP*) on the workstation

On the ground of production line simulation it can be noticed that the variability in first workstations has a greater influence on the volume of production in progress than the analogous variability in stations realizing final manufacturing processes. Very often workstations of the high variability of processing parameters determine so called productive bottle-necks [20].

In steady-state the increase in injection cycle time caused the increase in the average production cycle and the level of production in progress.

Simulation investigation showed that increasing machines utilization factor *u*, without introducing other changes, the average production cycle and the volume of production in progress increase exponentially (Fig. 9). The volume of production in progress depends on the injection cycle time linearly.

6. Summary

Firms should unceasingly aim at the decrease in the variability of production parameters, because high variability causes extensions of material processing cycles time, enlargement of production stock, low utilization of production capacities and decrease in productiveness. All these lead to increase in cost of production.

Decreasing the variability is a difficult and long-term process but due to that it is possible to learn how to better use available production stocks and limit the waste. There are a few stages that lead to reduction in variability of injection cycle time:

- Identification of the reasons variability in polymeric material processing cycle times (technical failures of tools and machines, staff breaks, re-assembly, absence level, trial runs, execution of urgent orders)
- reduction of the causes of variability
- acceleration of the production processes through control of input/output type
- repeatable evaluation of possibilities to reduce material processing cycle time
- application of newest polymeric material processing technologies and production organization methods.

The variability of processing parameters influences not only the extension of the task realization time but also the quality of the received product [21]. Substantially it sizes up the production cycle and the volume of production and also determines the elasticity of the system in the reaction on variable ambient conditions eg. on the variable demand on final goods.

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