New Statistical Approach "Six Sigma" as a Solution for Improving Plastic Quality Products

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The concern for quality assurance and improvement of the manufacturing processes of plastic materials is of great interest to industry companies offering the guarantee to ensure the conformity, performance, competitiveness and profitability. This paper addresses the importance of improving the quality of plastics manufacturing processes, on high (flow) performance. It illustrates the application of the "Six Sigma" statistical method for injected products that have certain defects / nonconformities, especially dimensional manufacturing.

Keywords: plastic products, quality, six sigma, manufacturing process, efficiency

The rapid development, in the last years, of plastics processing industry accounted the emergence of advanced machines and equipment of process (especially, for injection / extrusion – the most used), with computerized command and the tendency of eliminating the human factor from the entire technological process, with favorable consequences for economic efficiency. Also the introduction of automation and robotisation in order to increase processing efficiency, intends to improve the quality of produced products, respectively, reducing or eliminating their manufacturing errors (nonconformities).

The quality of plastic products is influenced by both the quality of the process as well as the processing equipment. Previous research mainly targeting the most common processing methods, extrusion and injection, revealed the correlation between quality and flow for polymer products, optimization of process or of the main components or equipment etc. [1-5].

Quality can be defined by melt quality represented as thermomechanical uniformity and dimensional conformity/precision of the finished product, with consideration of phenomena such as swelling due to viscoelastic behaviour of processed melt, rupturing the melt, the contraction for the cooling of the product from the processing temperature at ambient temperature. Also, optimal design of extrusion head, injection forms, as well as automating the manufacturing processes are the basis of obtaining quality plastic products [6-9].

The use of modern methods to improve product quality (by optimizing manufacturing processes, modeling and simulation of manufacturing processes for plastics) has reduced nonconformities (defects).

In case of injected products; for example, the non-compliance can sometimes be represented by: local contraction (surface draw), a lack of injected material, burrs, black points, internal bubbles (Blister effect), line welding, burning of material (Diesel effect) etc.

The concern for quality control of polymeric materials has led to the adoption of modern investigation techniques (noncontact nondestructive measurements: laser spectroscopy, NMR, etc.) [15, 16].

Implementation of the several organizations in the plastics processing industry (SMEs, industrial companies) of the quality management system in accordance with the 9001 standards, required the use of a whole toolbox of modern methods and techniques of quality improvement (reengineering, flexible manufacturing, "zero defects" and, "Just in Time" techniques and advanced compensation strategies / quality assurance by monitoring active processes or automatic control of manufacturing systems [17].

In recent years, the "zero defects" technique is increasingly used (introduced by Singeo Shingo in Japan), which is the highest possible conformance level of a product to specifications. This technique is based on the idea that carrying out statistical quality control can lead to absolute ideal situation, "zero defects", but especially to reduce the number of defects still without their complete elimination. Also mentioned technique means inspection on source in 100% and consists in using sensors or observations of operator, in self successively control to detect when, where and whether abnormalities are happening and then their correction per unit of current output and full system [17].

Thus, the concept "zero defects" has been the starting point in creating the method "Six Sigma", originally defined by Bill Smith for Motorola in 1986 and applied for six decades ago to other top companies (General Electric, Honeywell International, ABB, Lockheed Martin, Polaroid, Sony, Honda, American Express and Solectron). Then, "Six Sigma" method was released around the world, many organizations could prove, in figures, its pivotal role in their success [19].

Firstly, this method at the beginning, "new on the market" and "unknown" for Total Quality Management (TQM), later proved many companies, so-called "suspicious", a guaranteed success thanks to generating a substantial profit on the basis of the gained results. For example, for the company Motorola, the "Six Sigma" method was in 2006 a recorded service of the brand and of the company's market, reporting a profit of 17 billion dollars as a result of its implementation at the organizational level [19].

The first "Six Sigma" project was intended to improve manufacturing processes and eliminate defects / non-conformities, and then "Six Sigma" method was improved by focusing on achieving measurable and quantifiable financial results from any project aimed at improving the

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quality, imposing it as a powerful "quality tool" in the field of statistical techniques, at the same time being presented in an innovative manner [19, 20].

The term "Six Sigma" (or "6 σ") is derived from the field of mathematical statistics, known originally as the ability to create short-term quality entities (products, processes), in accordance with the specifications, in order to obtain long-term effects at all levels, respectively 3,4 defects per million opportunities (DPMO). Implicit goal of the "Six Sigma" method is to improve the quality of all entities considered at the best level [19, 21].

Therefore, the novelty of statistical methods "Six Sigma", specific to quality engineering, lies in the possibility of its application to the many organizations, regardless of their specific activity. So, for organizations in the plastics processing industry, the method "Six Sigma" refers to obtaining good results in the manufacturing process, improving product quality, reducing non-conformities in the system and the cost of poor quality or increase organizational profitability.

Experimental part

The main purpose of this paper is to synthesize the methodology of a project to improve the quality, based on the application of new statistical approach called „Six Sigma", by presenting, explaining and extrapolating it in the field of industrial companies for the processing of the plastic materials by injection.

Using the results of some actual evaluations of the quality characteristics specific to some injected plastic pieces in an industrial specialized organization, the paper aims to prove that the methodology of this statistical approach „6σ", identifies as one application guide, able to lead by default, to improve performance, efficiency and quality at the organizational level, as well as to reducing of defects / the nonconformities from the manufacturing processes in the specified limits, by ensuring a maximum efficacy .

In figure 1, below, graphically are highlighted the performance of the method "6σ" (Six Sigma), by comparison with the method „3σ", taking into account the standard deviation "σ" which represents the basic metric in statistical analysis of the data of some evaluated/ measured characteristic, respectively, the value of a variable that shows the distribution of the process output characteristic. A higher value for *sigma* (σ), indicate a more stable process, having a lower risk for flawed events (scraps/major non-conformities) and reduced costs.

At the level of an industrial company in the field of injection processing of the plastic materials, the "*Six Sigma*" strategy represents a statistical step, having the purpose of improving the quality of the injected products, starting from defining the opportunities (problems, defects / nonconformities), respectively of the specific data of the evaluated characteristics (measured, quantified) that characterize the current level of performance and continuing with the other specific phases of this method (*DMAIC*), as in figure 2.

Defining opportunities of quality improvement and establishing the mission of the "Six Sigma" project must consider, in the first place, the identification through brainstorming the flawed opportunities (deficiencies, nonconformities, obstacles and so.), from theoretical, cultural and material point of view, regarding quality assurance of manufacturing processes, namely:

-absence/insufficient knowledge/skills in quality management to individuals involved in quality assurance (OD_1);

-insufficient techniques and specific tools of quality management (OD_2);

-absence/insufficiency/inadequacy of objectives, policies and strategies in the quality field in the short, medium and long term (OD_3);

-existence of some mentalities, counterproductive attitudes and behaviours instead of proactive (OD_4);

-existence of insufficient/inadequate training of the staff involved in quality management (OD_5);

-non-involvement of managers (the top one, assistant and execution managers) of the concerned institution (OD_6);

-the priority granting to quantitative targets at the expense of qualitative ones (OD_7);

-ineffective/inefficient communication with trade partners within hierarchical pyramid and between departments of the institution (OD_8);

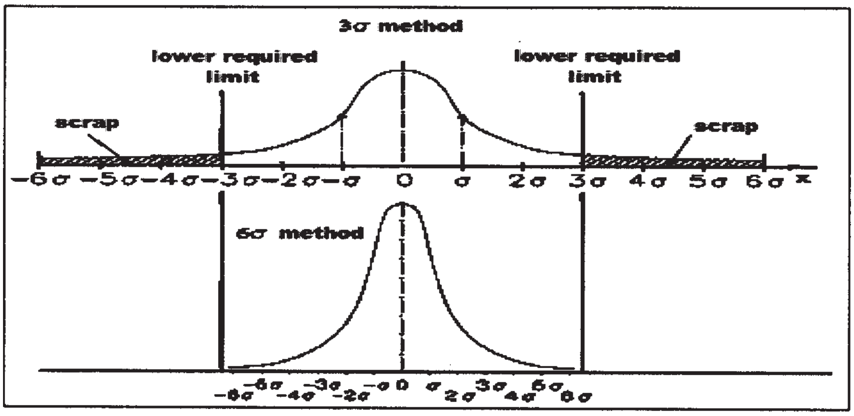

Fig. 1. Performances of the „Six Sigma" Method [17]

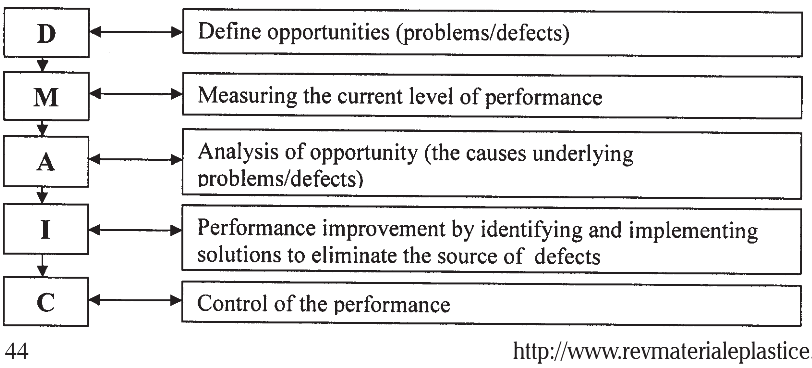

Fig. 2. The phases of the "Six Sigma" method [1]

Defective opportunities (nonconformities) (OD_i)	Evaluating and recording data									Total	Percentage of total [%]
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9		
OD_1	2	3	4	2	3	2	2	4	3	25	0.049
OD_2	3	4	3	2	3	5	4	3	4	31	0.061
OD_3	4	4	4	3	3	4	2	2	3	29	0.057
OD_4	3	4	3	4	5	4	3	2	4	32	0.062
OD_5	4	5	5	4	4	4	4	4	4	38	0.074
OD_6	4	5	5	3	4	5	3	4	4	37	0.072
OD_7	3	4	3	3	3	4	3	3	4	30	0.059
OD_8	3	4	4	5	3	4	5	4	3	35	0.068
OD_9	4	3	4	4	3	4	4	3	4	33	0.064
OD_{10}	5	4	4	5	5	4	5	4	4	40	0.078
OD_{11}	4	4	5	4	4	5	4	5	4	39	0.076
OD_{12}	4	4	3	4	4	5	4	4	4	36	0.070
OD_{13}	3	3	3	4	3	4	2	3	3	28	0.055
OD_{14}	3	4	3	3	4	3	5	4	5	34	0.066
OD_{15}	5	5	4	4	5	4	5	4	5	41	0.080
										508	1.000

Table 1

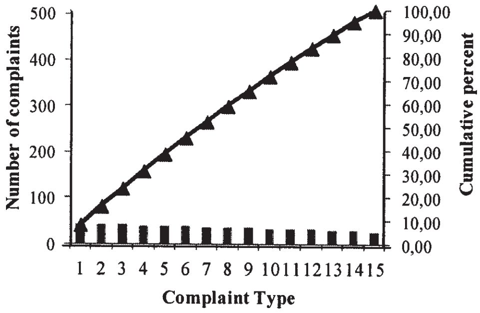

Fig. 3. PARETO diagram

-ignoring the reticence, the resistance to change and methods/techniques to reduce them (OD_9);

- the existence of stops / stagnations of production (OD_{10});

- the impossibility of deliveries to timelines (OD_{11});

- the existence of disturbance variables in the manufacturing process regarding the optimization of the parameters that have influenced the technological process (the plastic material, dimensional tolerances of the product, specifications relating to the manufacturing equipment, adjusting SDV and so.) (OD_{12});

- timely failure to identify the problems related to quality and respectively, to stability of manufacturing (maintaining under statistical control of all the manufacturing processes) (OD_{13});

- absence / insufficiency / inadequacy of the financial resources available for investments in advanced process equipment, as well as in ensuring of consumable materials and of the general maintenance (OD_{14});

- obtaining a low level of qualitative performance in account of manufacture errors (nonconformities) and in the percentage of scraps (OD_{15}).

In order to achieve and sustain the success of such a "*Six Sigma*" project, is necessary to ensure a comprehensive and flexible system, focused strong on deep knowledge of opportunities which are improving the quality, and are leading to decrease those that are defective in the system and of the costs of non-quality that are necessary to implement a quality management.

Therefore, the matrix of selecting the alternatives for the improvement quality project, (table 1) takes into account 9 criteria (C_j), according to which the project team will give notes from 1 to 5, corresponding to the 15 faulty opportunities (OD_i), mentioned above. The following criteria are:

-chronicity (C_1): to correct a frequently problem that occurs;

-the importance (C_2): which characterizes the appearance of the final results that clearly justifies the effort;

-time (C_3): provided for a period less than 1 year;

-the potential impact (C_4): must be quantified;

-urgency (C_5): occurs by addressing the issues that make the vulnerable organization to competition;

-potential risk (C_6): can lead to a long project, or failure of expected results;

-possible resistance to change (C_7): has a major impact on the choice of the project;

-the success of the project (C_8): attests nonexistence of obstacles in the path of positive results;

-quantification/measurement (C_9): is required to start of any project in order to ensure the necessary evaluation data.

From the graphical representation of Pareto diagram, as shown in figure 3, below, in which it was taken into consideration the ordering of evaluation data and the cumulated percentages (table 2), it results that the major flawed opportunities are those related to presence of manufacturing errors and respectively, in the percentage of scraps (OD_{15}).

Next, carrying out the project to improve the quality on the opportunity side which targets the strategy of detection, quantification and eliminate manufacturing errors, and that of the percentage of scraps, in order to obtain high quality.

Measuring the current level of performance is based on the nonconformities results (Xi) gained from the examination of quality characteristics of a sample taken from a number of samples (Ki = 10) belonging to a batch of products constant injected volume (NK = 600 pcs / sample), which are presented centralized in table 3.

For the graphical representation of probability density, in the case of a normal distribution (Gaussian) of the results

Table 2

	Total	Percent from total [%]	Cumulative percent [%]
OD_{15}	41	0.080	0.080
OD_{10}	40	0.078	0.158
OD_{11}	39	0.076	0.234
OD_5	38	0.074	0.308
OD_6	37	0.072	0.380
OD_{12}	36	0.070	0.450
OD_8	35	0.068	0.518
OD_{14}	34	0.066	0.584
OD_9	33	0.064	0.648
OD_4	32	0.062	0.710
OD_2	31	0.061	0.771
OD_7	30	0.059	0.830
OD_3	29	0.057	0.887
OD_{13}	28	0.055	0.942
OD_1	25	0.049	1.000

The total volume of products (N) / representative sample (K_i)	Number products with manufacturing errors / nonconformities (X)		Number conformities products	The percentage of the level of current performance [%]
	major /higher	minor /lower		
600	85	115	400	0.666

Table 3

Nonconformities resulting from the statistical control (600 pcs = 30 groups x 20 pcs/group)										I	II	III	IV	V	VI
1	15	5	13	18	2	6	20	5	2	1	2	2	5	9	13
10	2	13	1	2	17	8	1	10	12	1	2	3	5	10	15
5	3	2	9	5	1	2	5	4	1	1	2	4	5	10	17
$X_{min} = 1$; $X_{max} = 20$; $R = X_{max} - X_{min}$; $K = 1 + 3.22\ \lg 30 \approx 6$; $\delta = R / K = 3.166$										1	2	5	6	12	18
										1	2	5	8	13	20

Table 4

No. item	Interval of grouping of the nonconformities $x_i \div x_{i+j}$	Central value x_{ic}	Frequency of the nonconformities				$\overline{X} = f_i \cdot x_{ic}$
			simple		cumulated		
			a_i	f_i	A_i	F_i	
1	0 - 3	1.5	20	0.100	20	0.100	0.15
2	4 - 7	5.5	35	0.175	55	0.275	0.962
3	8 - 11	9.5	37	0.185	92	0.460	1.758
4	12 - 15	13.5	53	0.265	145	0.725	3.577
5	16 - 19	17.5	35	0.175	180	0.900	3.063
6	20 - 20	0	20	0.100	**200**	**1.000**	0
Σ			**200**	**1.000**			**9.51**

Table 5

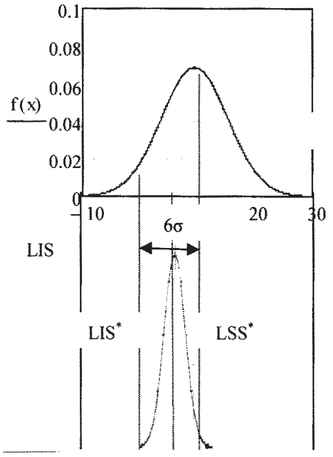

Fig. 4. Normal distribution curves

corresponding to the precise detection strategy of the manufacturing errors, of quantification and respectively, of the percentage of scraps, it is necessary their situation, presented in table 4 (by grouping of the lot with the total volume N_T = 6000 pcs. parts of the same type, in 10 samples having 600 pcs. parts each), as well as the situation of statistical distribution, prezented in table 5.

By using of the"*Six Sigma*" architecture, are represented in figure 4, the normal distribution curves, relating both the of the specific values for quantification the current performance (corresponding to of level *1.9*σ, equivalent to 33.33 defects per 666,666.7 opportunities), what are presented in table 3 - 5, as well as for maximum performance (corresponding to of level *6*σ, equivalent to 3.4 defects per one million opportunities).

Therefore, follows the need for a "Six Sigma" deviation calculated from the mean value $\overline{X}$ = 9.51 (with limits specification values between *LIS**= 0 and *LSS* = 20), to the value $\overline{X}$* = 5, which must be within the normal range of predefined specifications, respectively *LIS**= 0 and *LSS** = 10 (σ* = 1.66; 6σ = 10).

Analysis of quality improvement opportunities must begin by removing or reducing the cause/causes of quality problems, respectively precisely detection / identification of manufacturing errors, their quantification and respectively, eliminating the percentage of scraps. The stage is carried out through the following activities: evaluation of alternatives; improvements design; changing the culture; proving efficacy; implementation [18].

Improving the performance should require rigorous implementation of an algorithm that includes the following *steps* [17]:

a) involving the entire organization through a series of activities that will be taken and implemented continuously;

b) initiating the quality improvement activities for entire organization by establishing a program of activities and allocation of adequate resources;

c) investigating the possible causes of nonconformities in order to increase understanding of the process nature that will be improved by collecting, validating and analyzing data;

d) establishing the cause-effect relationships, both for identifying in-depth nature of the process that will be improved and for formulating possible cause-effect relationships;

e) initiate the preventive or corrective actions on the processes, in order to obtain satisfactory results and/or reduce the frequency of unsatisfactory results;

f) confirmation the improvements after implementation of preventive or corrective actions;

g) maintaining in time of the improvements by involving usually some changes of specifications and/or operational and administrative procedures and practices, education and training of personnel;

h) continuing improvement with the possibility of repetition based on the new options.

Performance control means the control of quality that can be identified with the measurement process of the real performance and comparing them with the desired performance. The control should prevent reappearance of nonconformities and maintain achievements through improvement. For maintaining these results, there should be implemented *four types of activities*: design elements for effective control; perfecting improvements; auditing control elements; developing an effective quality control [18].

Results and discussions

The implementation of the quality improvement project, where falling within the normal range of pre-established specifications, as shown in figure 3 above, could represent a good example to be followed by other similar organizations, at the same time identifying new improvement projects that can be approached and started.

Introducing the deviations "*Six Sigma*" from an average value calculated X at another average value X*, in order to achieve compliance of the distribution values within the normal range of specifications (lower, *LIS** and higher, *LSS**) attests obtaining index of effectiveness, equal to 3,4 defects per million opportunities (*DPMO*), which corresponds to an efficiency of 99.9997%, synonymous with the successful completion of the project to improve the quality.

Conclusions

By applying the statistical method "Six Sigma" in the industrial companies in the plastics processing industry, it can be met target function defined by improving the quality of manufacturing processes. Although it is a method that is based on mathematical statistics, "Six Sigma" does not provide tools that are difficult to use and thus represents a guaranteed success for such organizations which targets achieving outstanding results and providing higher performance levels.

Therefore, the statistical method "Six Sigma" is addressed equally to all industrial companies to improve performance, efficiency and quality manufacturing processes as well as for reducing defects / non-conformities within the limits specified by providing satisfactory stability and maximum effectiveness.

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Manuscript received: 17.10.2014