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Analysis of Six Sigma Tools Utilization in Phases of DMAIC Cycle

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Abstract. Six Sigma has been developed and successfully used in many organizations for many years. The use of Six Sigma in process-improvement requires the systematic and disciplined use of specific tools and techniques in the DMAIC cycle. The DMAIC cycle includes five phases: Define, Measure, Analyze, Improve, and Control; this is one of the most popular Six Sigma improvement cycles that are used in improving existing processes. When improving processes in accordance with the DMAIC cycle, it is important to have knowledge of the tools and techniques that are used and the ability to select them for the specifics of a project and the appropriate phases of the cycle. This article critically reviews the literature on the use of individual tools in the appropriate phases of the DMAIC cycle and uses a semi-structured interview method with specialists in the field of using Six Sigma. The obtained results of the analyses can contribute to the study of the validity of using individual tools and techniques for the effective use of Six Sigma and provide a useful comparative review for theoreticians and practitioners who want to use the appropriate tools in the DMAIC cycle.

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1. INTRODUCTION

The skills and knowledge that are related to creating high-quality products and services are currently the main element of building a competitive advantage. In order to meet these requirements, companies are implementing various concepts and methods of improvement; among these, Six Sigma plays a significant role.

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Six Sigma is a comprehensive and flexible system for achieving, maintaining, and maximizing business success (Pande et al., 2000); it is guided by a close understanding of customer needs, reliance on facts, the use of data and statistical analysis, and attention to the management and improvement of business processes. Six Sigma has its origins in the USA; it was created by Motorola in the 1980s. It was then significantly developed by General Electric (GE) and other companies (including Allied Signal), which began to successfully use it in their business strategies.

Six Sigma is considered to be one of the most important concepts that have been used in the quality-improvement process over the last two decades (Garza-Reyes, 2015). It has been adopted as a major continuous improvement initiative by many world-class manufacturing and service companies (Sreedharan et al., 2018) in order to increase competitive advantage, process efficiency, and productivity or to improve customer service (Anthony & Karaminas, 2016). When properly implemented, Six Sigma brings a number of benefits to a company; these are not only financial in nature but can also include the following: increased customer satisfaction, culture change, product/service development, increased productivity and process efficiency, cost reduction, and many other benefits that result from using the full potential of a company's infrastructure and human resources. The result is products and services that are made cheaper, better, and in a shorter amount of time.

Six Sigma is still being developed and successfully used in the largest organizations in the world. Alongside concepts such as lean management and the theory of constraints (ToC), it has become a global standard for process improvement.

In principle, Six Sigma has been defined in many ways – both in the literature on the subject and in the nomenclature that is used by the companies that adapt and use it in practice: a strategy, initiative, concept, program, method, technique, etc. It is a method for improving and striving for perfection with customers and making their requirements centrally embedded by creating the set of tools and techniques that are used in the structured DMAIC cycle (Define – Measure – Analyze – Improve – Control) (Soliński, 2019).

In order to achieve success, the use and implementation of Six Sigma requires the systematic and disciplined use of specific tools (Anthony et al., 2007). The significant impact of the tools and techniques that are used in Six Sigma was also pointed out by (Yang & El-Haik, 2003), who stated that "Six Sigma is a method that provides companies with tools to improve the efficiency of their business processes," and (Harry & Schroeder, 2000), who stated that "Six Sigma focuses on the aspect related to basing on facts (data) and using the appropriate set of tools in order to identify sources of errors and how to eliminate them."

It seems that the key to the success of Six Sigma lies in the rigorous use of the appropriate tools in the DMAIC cycle. Six Sigma is a comprehensive set of tools and techniques; it is, therefore, important to have appropriate knowledge of most of the tools and techniques as well as the ability to apply them correctly in the appropriate phases of the DMAIC cycle. Despite the numerous theoretical contributions, there is still a lack of comparative studies and limited empirical validations.

The conducted research was based on the methods of critical review of the subject literature on the use of the individual tools and techniques in the appropriate phases of the DMAIC cycle and the method of semi-structured interviews with spe-

cialists in the field of using Six Sigma. The obtained results of the analyses can be a contribution to the research on the validity of using individual tools for the effective use of Six Sigma and also constitute a useful comparative review for practitioners who want to use the appropriate tools and techniques in the DMAIC cycle.

2. DMAIC CYCLE IN SIX SIGMA

There is no single definition of Six Sigma; many authors have presented their own, very different, attempts to define it by looking at it from different perspectives. This is not surprising, because Six Sigma can take on various individualized forms in each organization, combining with the strategy and culture of a company or becoming one of many methods for solving problems. A relatively often-cited definition in the literature is the one that was proposed by Pande et al. (2000), which stated that "Six Sigma is a comprehensive and flexible system for achieving, maintaining and maximizing business success. It is guided by a close understanding of customer needs, based on facts, the use of data and statistical analysis, and paying attention to the management, improvement and discovery of business processes." This definition shows the fundamental principles that have led to the release of the potential of Six Sigma in every organization.

The use of Six Sigma requires the use of a structured and logical cycle of activities. The main and dominant cycle that is used in Six Sigma is the DMAIC cycle, which is used to solve problems and improve processes, products, and services. It was proposed by Motorola and GE in the 1980s. One can see some similarity between this cycle and the most popular improvement cycle (PDCA), which was proposed by Shewhart and Deming. DMAIC consists of five phases and was built in such a way that it can be used for more-complex problems and improvement projects in which there is a large amount of data. Each phase was designed to ensure the consistency of the implemented improvement projects with the business goals of the company and to focus on the factors that are key to customer satisfaction; it requires the involvement of one's employees as well as the allocation of time and resources for continuous improvement. The DMAIC cycle is used to improve existing processes; in order to design new processes and adapt them to customer requirements, the *Design for Six Sigma* approach is used, which distinguishes itself with IDOV and DMADV cycles, among others.

Table 1 presents a brief description of the individual Six Sigma DMAIC phases that have been proposed by the author.

Table 1. *Characteristics of DMAIC cycle phases*

Phase	Characteristics and purpose of each phase
Define	Identifying and clearly describing a problem, and defining the key customer requirements and goals to be achieved within a defined project scope.
Measure	Identifying and measuring the key process characteristics in order to define the current situation (baseline).
Analyze	Analyzing the data on the key process characteristics in order to identify any sources of variations as well as their root causes.

Table 1 cont.

Phase	Characteristics and purpose of each phase
Improve	Generating solutions that reduce variability and eliminate root causes, selecting them, implementing them, and assessing their impacts on the process.
Control	Standardizing the work methods, processes, and applied solutions, confirming and evaluating the achieved effects, and providing the mechanisms for monitoring and maintaining the effects over time.

3. TOOLS AND TECHNIQUES THAT ARE USED IN DMAIC CYCLE

An extremely important role in the success of Six Sigma projects is played by the use of the appropriate tools and techniques that have become key elements of Six Sigma's success. It is the use of the appropriate tools and techniques in appropriate manners that affects the effectiveness and efficiency of Six Sigma projects, which contributes to solving existing problems and achieving measurable business effects.

The size and complexity of the tools that are used can also become a problem, as was indicated by Firka (2010); he stated that the teaching and training that require a lot of time often go beyond the actual requirements for the use of the appropriate tools that are related to the specificity of the Six Sigma project. It is therefore important to focus on the most important Six Sigma tools.

The variety of tools often causes anxiety among team members and their leaders – especially if these are among the first initiatives of this type that are undertaken in companies. It seems that it would be useful to determine which tools are more frequently used by other practitioners or other companies with similar specifics. It can be risked to say that the most frequently used tools can be considered to be the most practical tools that can be easily understood and applied in Six Sigma projects.

Six Sigma Black and Green Belt training includes Six Sigma toolkits, which include the most commonly used tools and are often associated with the body of knowledge of global organizations such as ASQ (American Society for Quality). The participants of any training should be familiarized with these tools. Both theoreticians and practitioners should be interested in determining which tools are used in the appropriate phases of the DMAIC cycle. Hahn et al. (2000) also pointed out that, very often, the skills that are acquired during training in advanced tools (such as DOE, SPC, regression analysis, and variance analysis) are only temporary and that employees very often forget about them and do not use them in their Six Sigma projects.

By analyzing the literature on the subject regarding the most frequently and least frequently used tools, several authors have distinguished the following sets of tools that are used in Six Sigma:

- Antony and Banuelas (2002):
  - Most frequently used tools: cause-effect analysis, Pareto analysis, control charts, and run charts.
  - Least frequently used tools: DOE, QFD, FMEA, 5S, Poka-Yoke, and SPC.

- Curry and Kadasah (2002):
  - Most frequently used tools: checklists, process maps and brainstorming, sampling, and control charts.
- Bayazit (2003):
  - Most frequently used tools: Pareto analysis, SPC, cause-effect diagrams, and process maps.
- Antony et al. (2005):
  - Most frequently used tools: process maps, histogram, cause-effect analysis, run chart, SPC control charts, FMEA, process capability analysis, and Poka-Yoke.
  - Least frequently used tools: nonparametric tests (e.g., Mann–Whitney Test), affinity diagram, project charter, SIPOC, quality cost analysis, run charts, measurement system analysis (MSA), and QFD.
- Antony and Desai (2009):
  - The most commonly used (statistical) tools are histogram, control charts, and process capability analysis (SPC). The most commonly used problem-solving tools are brainstorming, cause-effect analysis, Pareto analysis, process mapping, and project charter.
  - The least frequently used tools (statistical) are nonparametric tests (Mann–Whitney test), Taguchi, and DOE methods. The least frequently used tools for solving problems are affinity diagrams, force-field analysis, and matrix analysis.
- Cauchick-Miguel et al. (2012):
  - The ten most commonly used tools by companies are data-collection sheet, histogram, Pareto analysis, brainstorming, control charts, process capability analysis (SPC), process map, and measurement system analysis.
  - The ten least commonly used tools are OCAP, PDPC, EVOP, operational testing, PERT/CPM, market testing, stakeholder analysis, FTA, and accelerated life-testing.

It should be noted that the studies that were presented above were conducted in different industries and countries, so the specifics of a given project may slightly distort the overall picture of the tools that are used. Another aspect that was argued by Linderman et al. (2006) was that, when project goals are very ambitious and difficult to achieve, increasing the use of more-advanced Six Sigma tools resulted in higher project performance. On the other hand, Antony et al. (2005) stated that easier-to-use tools are used more often and, therefore, attract more users as compared to more-sophisticated and -complex statistical tools. Hahn et al. (2000) stated that more-advanced tools become more important as organizations move to more-complex problems. From these statements, it can be concluded that the more-complex tools are, unfortunately, less frequently used in organizations, which may result in significantly smaller benefits for companies than they could be.

Given these findings, the need to know the tools and techniques that can be used in Six Sigma seems to be crucial for achieving better results in Six Sigma projects.

In order to systematize this knowledge, matrices have been published that show the individual tools in the DMAIC cycle. These tools are most often assigned to one or more phases of the DMAIC cycle.

One of the attempts to systematize this issue is the matrix that was presented by Hagemeyer et al. (2006), which showed the use of 34 tools in the individual phases of the DMAIC cycle. Similar matrices were also proposed by Cauchick-Miguel et al. (2012), in which 58 tools were shown in the individual phases. An important element of the guidelines for the use of the appropriate tools that are used with interest by Six Sigma project leaders are the lists that have been presented by large organizations that deal with quality, such as the previously mentioned ASQ or the popular guides from The Six Sigma Memory Jogger (Table 2).

Table 2. *DMAIC Phase Tools Matrix*

Tool	D	M	A	I	C
Affinity diagram	×				
Brainstorming			×	×	
Capacity indices		×	×		×
Cause-and-effect analysis			×		
Charter (project charter)	×				
Commitment scale				×	
Communication plan	×				×
Control chart	×	×		×	×
CTQ tree	×				
Data-collection techniques	×	×			
Data types		×			
Designs of experiments			×		
Flow chart (process map)	×	×	×	×	
FMEA			×	×	
Focused-problem statement			×		
Gantt chart	×			×	
Histogram		×	×	×	
Hypothesis testing			×		
Interrelationship graph			×		
Involvement matrix				×	
Kano model	×				
MSA		×			
Operational definitions		×			

Table 2 cont.

Tool	D	M	A	I	C
Pareto diagram	×	×		×	
PDCA				×	×
Prioritization matrix				×	
Process-management chart					×
Six Sigma Level		×		×	
Scatter diagram			×		
SIPOC	×				
Six Sigma Storyboard					×
Taguchi loss function		×			
Tollgate review	×	×	×	×	×
Tree diagram			×		
$Y = f(x)$ formula	×	×	×		

Source: own study based on (Brassard et al., 2017)

4. OWN RESEARCH AND DISCUSSION OF RESULTS

The research was conducted on a purposefully selected group of experts by taking their knowledge and experience in the field of Six Sigma into account. The experts that took part in the research were people from the automotive and household appliances industries who had certified training in the field of Six Sigma Black Belt and had completed at least three improvement projects using the DMAIC cycle in the previous three years.

In order to show the use of the individual tools in the DMAIC cycle, a semi-structured interview was conducted with Six Sigma Black Belt experts on the subject of their implemented Six Sigma projects and the tools that they used in them. For this purpose, a set of questions and a survey questionnaire with answers were prepared in order to collect the research material. Based on a literature research and the author's experience, 115 specific tools and techniques were identified that could be used during the implementation of a Six Sigma project. The interview technique also allowed for the easy addition of a given tool if it was reported by any experts during the interviews. The interviews were conducted; then, the interview results were developed using the completed questionnaire, thus making a critical analysis of the experts' statements. This allowed for obtaining a set of tools that have been used in Six Sigma projects in the automotive and household appliances industries in the Polish economic reality (which are presented in Table 3).

In the analysis of the tools and techniques that were used, their names were standardized, and some tools were gathered into groups:

– graphical analysis – includes all kinds of presentation charts (pie, scatter, bar, etc.);

– descriptive statistics – include location measures (mean, mode, and median), dispersion measures (range, standard deviation, and variance) and shape measures (kurtosis and skewness);
– normality of distribution test – includes matching statistical distribution to empirical data, its analysis using nonparametric statistical tests (Shapiro-Wilk, Chi^2 and Anderson-Darling);
– control charts – contains cards for continuous features (X-R, X-S, and Xi–MR) and attributive features (p, np, c, and u).

Table 3. *Tools and techniques that have been used in DMAIC phases in automotive and household appliances industries*

D	M	A	I	C
Project charter Risk matrix Stakeholder analysis Pareto CTQ tree Process map SIPOC	Data-collection plan Data collection sheet Graphical analysis Descriptive statistics Six Sigma Level Measurement system analysis (MSA)	Brainstorming Ishikawa diagram 5 Whys Pareto Descriptive statistics Histogram Test of distribution normality Statistical hypothesis testing Correlation and regression analysis Process capability analysis Graphical analysis FMEA	Brainstorming Benchmarking Ranking method Process map Action plan Poka-Yoke	Standardized operating procedure One-point lesson Out-of-control-action plan Descriptive statistics Six Sigma level Histogram Test of distribution normality Statistical hypothesis testing Graphical analysis Process capability analysis SPC - control charts

Based on the research, 31 tools and techniques that were used during the implementations of Six Sigma projects were identified. As already mentioned, some of the tools were aggregated into homogeneous groups. Taking each individual tool that was indicated in the study into account, the number of tools increased to 38. According to the experts, using the right tools and techniques in appropriate ways affects the effectiveness and efficiency of Six Sigma projects. Their effective use significantly contributes to solving existing problems and achieving measurable business effects. As can be seen in the list, selected tools and techniques can be used in several phases depending on a team's needs. The experts also drew attention to this aspect during their interviews. The research also indicated that the use of the

appropriate tools and techniques depended on the specificity of a project and the specificity of an industry.

Then, the research results regarding the tools that were used in the DMAIC cycle (Table 3) were compared with the most frequently used tools lists that had been presented in various scientific publications (which were described earlier in the publication). From this group of the most frequently used tools in Six Sigma, all were among the tools that were given by the experts in the study that was conducted by the author.

The obtained results were also compared with the set of tools that were presented in one of the most popular Six Sigma books – The Six Sigma Memory Jogger II (Table 2). The tools and techniques that were indicated in the research constituted about 70% of all of the Six Sigma tools that were indicated there.

In the conducted study, the experts came from the automotive and household appliances industries. Expanding the sample with additional experts from other industries as well as using a random sample may contribute to increasing the representativeness of the results.

Taking this into account, it was possible to recommend additional tools for Six Sigma practitioners that were additionally based on the literature research and the author's own research (who is a certified Lean Six Sigma Master Black Belt). In the author's opinion, these would help in the effective and efficient implementation of Six Sigma projects. The set of tools that were presented in Table 3 (own research) should be supplemented with the following:

1. Project-management tools:
   - communication plan used to develop communication strategy with project stakeholders (Define phase);
   - Gantt chart – used to develop and manage project schedule (Define phase);
   - gate review – so-called review of Six Sigma project phases, performed after each DMAIC phase (all phases);
   - Impact-Effort Matrix – a decision-making tool for prioritizing and selecting the most appropriate solutions.
2. Statistical tools:
   - box plot – used to show distribution of studied feature (Measure, Analyze, and Control phases);
   - ANOVA and MANOVA – analysis of variance used to assess influences of studied factors (Analyze and Control phases).
3. Modeling tools:
   - DOE – design of experiments (Analyze and Improve phases).
4. Project-closure tool:
   - Six Sigma Storyboard – presents key analyses, decisions, and results that are obtained during DMAIC improvement cycle in simple graphical form (Control phase).

The final results (with supplemented tools and techniques in the Polish economic reality) are presented in Table 4.

Table 4. *Tools and techniques used in DMAIC phases*

D	M	**A**	**I**	**C**
Project charter Risk matrix Stakeholder analysis Communication plan Gantt chart Pareto CTQ tree Process map SIPOC	Data-collection plan Data collection sheet Graphical analysis Descriptive statistics Six Sigma level Measurement system analysis (MSA)	Brainstorming Ishikawa diagram 5 Whys Pareto Descriptive statistics Histogram Box plot Test of distribution normality Statistical hypothesis testing Correlation and regression analysis ANOVA and MANOVA Process-capability analysis Graphical analysis FMEA	Brainstorming Benchmarking Ranking method Impact-Effort matrix Process map Action plan Poka-Yoke DOE	Standardized operating procedure One-point lesson Out-of-control-action plan Descriptive statistics Six Sigma level Histogram Test of distribution normality Statistical hypothesis testing ANOVA and MANOVA Graphical analysis Process capability analysis SPC control charts Storyboard

5. CONCLUSIONS

Six Sigma is a comprehensive set of tools and techniques that can be used during the implementations of improvement projects. These are used in the appropriate DMAIC phases, which play extremely important roles in running Six Sigma projects and become key elements of its success. From this point of view, it is important for a team that implements a Six Sigma project to focus on the most important tools and techniques in order to effectively and efficiently implement it.

The conducted research allowed us to obtain a set of tools that have been used in Six Sigma projects in the automotive and household appliances industries in the Polish economic reality. It should be noted that the use of the appropriate tools and techniques depends on the specifics of a project and the specifics of an industry; therefore, factors such as industry type, organizational differences, project complexity, and the level of one's Six Sigma maturity may influence the selections of the tools and should be carefully considered.

In this study, the tools and techniques were assigned to the individual phases of the DMAIC cycle.

Based on the research, 31 tools and techniques were identified that were used in the individual phases of DMAIC. Additionally, the author suggested nine additional tools and techniques for use, which allowed for the identification of a total of 40 tools. The review of the literature on the subject allowed for the conclusion that the tools

and techniques that were indicated in the study included a set of the most frequently used tools that had been presented in various scientific publications and overlapped by 70% with the tools that had been indicated in the popular Six Sigma tools books.

From this point of view, it is important for a team that implements a Six Sigma project to focus on the most important tools and techniques in order to effectively and efficiently implement it.

Based on the presented research results, Six Sigma project leaders (Green and Black Belts) and their teams can refer to the information that was provided in Table 4 and apply the listed tools in the corresponding phases of the DMAIC cycle (bearing in mind that the industry in which they operate may determine the use of additional specialized tools).

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