Quality Tools and Their Applications in Industry

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ABSTRACT

Almost all quality improvement methods require data collection and analysis to solve quality problems. The combination of six sigma and agile creates a six sigma agile methodology that aims to reach quality levels according to the Six Sigma requirements of 3.4 defects per million measurements. In order to achieve these objectives, it is necessary to know the industry well and implicitly the product or the analysed process. Thus, the correctness of these analyses depends on the collection of the data that will be analysed. The use of data analysis methods at each stage, especially in the measurement and analysis stages, is critically important for making strong decisions. The purpose of this article is to present the added value of the integration of six sigma and agile methodologies for IT projects. Thus, the integration of the two methodologies will lead to faster decision-making without the risk of an increase in the number of failures.

KEYWORDS

Agile, Process Performance, Six Sigma, Statistical Indicators

INTRODUCTION: QUALITY TOOLS AND THEIR APPLICATIONS IN INDUSTRY

Companies strive to develop and be sustainable in order to face all challenges (Stojcic et al., 2018). Thus, they implement effective continuous improvement methodologies such as Six Sigma or Agile, which assume the improvement of the existing model at the company level and lead to an increase in the company’s ability to reduce the number of timely responses to possible risks that may arise.
The concept related to the process model starts from the very simple principle that the organization itself represents a process or, rather, a series of coherent and interconnected processes, which allow the creation of a product that satisfies the client and other interested parties (Womack & Jones, 2006; Schwab, 2016).

Based on the definition of the process, presented in Figure 1, the raison d’être of an organization is to transform with the help of coordinated activities, and input data into output data at the same time as bringing added value to each individual process.

LITERATURE REVIEW

Six Sigma is a systematic approach based on data that aims to perfect the existing process. In Six Sigma, the DMAIC methodology (define, measure, analyze, improve, control) is used, and for the development of new products, the Six Sigma DFSS design method is used. (GE, 2004)

Statistical tools are systematically used in each stage of DMAIC and DFSS in order to find the root cause of the problem and eliminate it by applying effective improvement solutions. Among all these, the following tools are considered most important: SIPOC, Statistical Process Control, Process Capability Analysis, Measurement System Analysis, Experiment Design, Quality function deployment, Fault Tree Analysis, Statistical Regressions, Analysis of means and variances, Root cause analysis, Process mapping (Wanga & Chen, 2020; Pyzdek, 2003).

The application of the tools used in Six Sigma and Agile in cloud-based intelligent production is an element of novelty through the integrated approach of the two methodologies. Cloud-based intelligent manufacturing facilitates a new variety of applications and services to analyze a large volume of data and enable large-scale collaboration in manufacturing (Qinglin & Tao, 2019).

RESEARCH METHODOLOGY

The main objective of the proposed model is the integration of the concepts of Six Sigma and Agile. The proposed research methodology, from a quantitative but also a qualitative point of view, requires

Figure 1. The general model of a process
Quantitative methods were applied for statistical calculations of process performance measurement during the application of Six Sigma projects and the interpretation of the data from the collected questionnaires. Qualitative methods were applied to analyze a wide range of specialized literature in order to propose a new model that integrates Six Sigma and Agile methodologies (Black & Revere, 2006; Chang et al., 2012; Chen et al., 2005).

Six Sigma is a strategy for continuous process quality improvement used in many fields of activity. In general, Six Sigma is a process improvement methodology that reduces product defects, minimizes process variations and improves capabilities in manufacturing processes. Six Sigma offers two major perspectives: One is the statistical perspective, and the other is the managerial perspective. From a statistical point of view, the term Six Sigma is defined as having less than 3.4 defects per million products made or a success rate of 99.9997% (Figure 2) (Pande & Holpp, 2002; Pande et al., 2000; Pande et al., 2002).

Six Sigma is a systematic approach based on data that uses the DMAIC methodology in order to perfect the existing process and the Six Sigma DFSS (Design for Six Sigma) design method for the development of new products (GE, 2004). As a structured approach, the DMAIC model (Table 1) can provide an organization with a series of pragmatic solutions from the point of view of the evolution of a process or product (Parast, 2011; Popescu & Mandru, 2016; Psomas et al., 2018).

Figure 2 The normal distribution in the context of six sigma

<table>
<thead>
<tr>
<th>Phases</th>
<th>Definition</th>
<th>Measure</th>
<th>Analysis</th>
<th>Improve</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity</td>
<td>Defining the current situation</td>
<td>Identification of potential causes</td>
<td>Analysis of possible causes</td>
<td>Identification of potential solutions</td>
<td>Effectiveness control over time</td>
</tr>
<tr>
<td></td>
<td>Defining the desired situation</td>
<td>Quantifying the problem</td>
<td>Selection of initial causes</td>
<td>Selection / implementation of solutions</td>
<td>Implementation of means of control</td>
</tr>
<tr>
<td>Result</td>
<td>Defining the problem. Potential advantages</td>
<td>The origin of the problem and the list of causes</td>
<td>Quantified causes and selected initial causes</td>
<td>Pilot solutions and their final implementation</td>
<td>Process control and monitoring</td>
</tr>
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<td></td>
<td></td>
<td></td>
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<td>Confirmed benefits</td>
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</tbody>
</table>

Source: Six Sigma Institute https://www.6sigma-institute.org/.
Being a process optimization methodology, Six Sigma can be integrated with other improvement methodologies. The integration of the Six Sigma methodology in the Agile methodology leads to the creation of a fairly powerful tool that can bring added value to any process. The Agile model first appeared in the software development industry, wanting to be a Code of Good Practice to which practitioners in this industry adhere.

Since the Agile methodology emphasizes the inclusion of the client’s representative in the project implementation team, the integration of this methodology in the Six Sigma methodology helps to obtain meaningful results throughout the entire process. The quality and predictability of the process is increased within the Agile methodology because at any moment of the project it is known what functionalities existed at the end of the previous moment and what functionalities will be at the next moment.

If we analyze the Agile methodology from the point of view of the PDCA cycle in quality management as shown in Figure 1, this can be integrated with other improvement methodologies and can have the graphic form presented in Figure 3 (El Manzani et al., 2019; Troshkova & Levshina, 2018; West & Cianfrani, 2015; SR EN ISO 9000:2015; SR EN ISO 9001:2015).

The main objectives of the proposed model are: (i) the integration of the concepts of Agile and Six Sigma, (ii) the execution of integrated projects, and (iii) recommended tools in order to improve the performance of the process. The new model is an integrated conceptual model, which is developed based on the Six Sigma Methodology (by default DMAIC) integrated with the conceptual requirements of the Agile methodology (Nonaka & Takeuchi, 1995; Pamfilie & Procopie, 2013).

The set of tools used within the DMAIC methodology (Figure 4) will also adapt to the new methodology in such a way that the approach oriented towards concrete results of Six Sigma can also be found in the new model.

In the process of optimizing the activity of an organization, Agile was introduced in all phases of the DMAIC model (Hellman & Liu, 2013; Juhani et al., 2016; Luburić, 2019). This is how the model called DMAICA was developed (the DMAICA model—Integration of Six Sigma, Agile methodologies). This model is presented in Table 2.

As shown in the Table 2, the proposed model is composed of seven stages described as follows:
Figure 4. Tools used within the DMAIC methodology

Table 2. The DMAICA model: integration of agile, six sigma methodologies

<table>
<thead>
<tr>
<th>Stages</th>
<th>Activities</th>
<th>Tools and approaches used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>Planning the realization of the phases of the AS Methodology</td>
<td>Agile Six Sigma concept&lt;br&gt;Development of the communication methodology within the organization&lt;br&gt;Development of the communication methodology with clients&lt;br&gt;Development of the strategic plan&lt;br&gt;Development of a training plan for the executive management and members of the work teams</td>
</tr>
<tr>
<td>Stage 2</td>
<td>Identification of activities for each AS phase</td>
<td>Development of the list of activities for each phase of the analyzed methodology</td>
</tr>
<tr>
<td>Stage 3</td>
<td>Using work tools for each activity</td>
<td>Six Sigma tools used for each phase—the use of statistical tools in the context of the need to clarify the analyzed data</td>
</tr>
<tr>
<td>Stage 4</td>
<td>Gathering new knowledge and ideas to improve the process</td>
<td>Involvement of the entire team and clients in the process of collecting and identifying new ideas through workshops, brainstorming sessions, priority matrix, histograms, and Pareto</td>
</tr>
<tr>
<td>Stage 5</td>
<td>Innovation in the context of Six Sigma and Agile</td>
<td>Establishing the results regarding the sustainability of the organization&lt;br&gt;Innovation project control in the context of Six Sigma and Agile&lt;br&gt;Modifications of the innovation project in the context of Six Sigma and Agile</td>
</tr>
<tr>
<td>Stage 6</td>
<td>Use of acquired knowledge</td>
<td>The launch of the project&lt;br&gt;Constantly informing the client about the results of the project</td>
</tr>
<tr>
<td>Stage 7</td>
<td>Project performance evaluation</td>
<td>Evaluation of process results&lt;br&gt;Process analysis&lt;br&gt;The impact of project results on the organization&lt;br&gt;Calculating the added value of the organization through project implementation&lt;br&gt;Conclusions regarding the impact the project has on the organization</td>
</tr>
</tbody>
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Source: Authors’ own contribution

- **Stage 1**: Planning the realization of the phases of the ASI Methodology. The purpose of the first stage is to develop a common framework in order to implement the proposed methodology according to the recommendations of the Six Sigma standard (Vujović et al., 2017).
In this stage, the context of the implementation of the methodology must be defined, emphasizing the development of a common approach within the implemented projects.

- **Stage 2**: Identification of activities for each AS phase. In this stage, all the specific tasks of the different DMAIC phases should be identified according to the recommendations of the Six Sigma standard (ISO 13053 - 1 & 2, 2011). This standard describes the Six Sigma methodology, which usually includes five phases:

- **Stage 3**: Using the work tools for each activity. The use of statistical tools in the context of the need to clarify the analyzed data is done in order to bring an added value to the process. Thus, concepts such as variation, mean, dispersion, standard deviation, distribution, ANOVA, regression analysis, correlation analysis, adjustment analysis, normality tests, and hypothesis tests will be used.

- **Stage 4**: Gathering new knowledge and ideas to improve the process. Involvement of the entire team and clients in the process of gathering and identifying new ideas through workshops and brainstorming sessions. The specific elements of the Agile methodology will be integrated into the Six Sigma methodology in order to ensure traceability regarding the development and implementation of the project using the new methodology.

- **Stage 5**: Innovation management in the context of Agile Six Sigma. In this stage, emphasis will be placed on the development of the innovation process, the establishment of results regarding the sustainability of the organization, the control of the innovation project in the context of Agile Six Sigma, and changes to the innovation project in the context of Agile Six Sigma. Specific monitoring and control tools will be used in order to identify the possible risks that may appear in the innovation process. The tools used are: SWOT Analysis, Probability - Impact Matrix, AMDE - Fault Tree Analysis and decision trees, Priority Matrix, Cause-Effect Diagram.

- **Stage 6**: Using the acquired knowledge. During this stage, the emphasis is on project execution and permanent communication with the client, which implies that there will be constant feedback from the client. This stage will take place in accordance with the PDCA cycle applied for processes as follows:

  Where:
  
  **“PLAN”** establishes the objectives and processes necessary to obtain results in accordance with the client’s requirements and the organization’s policies;
  
  **“DO”** implements the processes;
  
  **“CHECK”** monitors and measures processes and products against the policies, objectives, and requirements specified for the product and reports the results;
  
  **“ACT”** applies actions for the continuous improvement of process performance.

- **Stage 7**: Evaluation of project performance. In the framework of this last stage, there is an evaluation of the process results, and the analysis of the process and the impact of the results on the organization are followed. All this is analyzed from the perspective that the added value of the organization will be calculated by analyzing the efficiency and effectiveness indicators and establishing conclusions regarding the impact the project has on the organization.

**RESULTS**

The application of a DMAIC model within a company whose activity is centralized in the cloud transforms traditional production models into intelligent models, adaptable to each situation. Cloud-based production applications can be shown in Figure 5. The physical production system covers all physical devices as well as all users. The upper layer represents data processing, process control, and
service management in the cloud environment that provides non-physical services and applications for users in the production life cycle.

The integration between physical devices, users, and the cloud is possible by introducing data and functions within services. In addition, data is collected from the physical manufacturing system and transmitted through the network. Through cloud-based solutions, manufacturing companies are able to develop better integrated and more efficient processes with lower costs.

The intelligent production system involves several levels. The base layer is represented by smart devices, which are the data sources. The middle layer is the data transmission network. The upper layer is the cloud, where big data is stored and analyzed. Through the computing, storage, and network capabilities of nearby nodes, edge computing and fog computing reduce the data sent to the cloud and the probabilities of service interruption, ensuring the robustness of the intelligent production system. Edge computing, fog computing, and cloud computing cooperate with each other, better fulfilling the requirements of intelligent production applications.

In this sense, the application of the DMAICA methodology is essential in the process of data collection and interpretation in the case of intelligent production applications. The use of statistical tools helps us in the analysis of process variation, which can have two causes: a common cause or a special one. Common cause is given by any unaccepted source as part of random inputs to processes. The special cause is seen as any unaccepted external source that influences the process. The use of statistical tools is essential in the context in which the capacity of the process can be discussed in order to identify its stability. The variation index is used to represent the process capability. There are two indices that help to analyze process capacity: $C_p$ - called process capacity and $C_{pk}$ - sometimes called process performance precisely to be distinguished from process capacity. $C_p$ can be used if the average of the process is centered on the target value, being a measure of the width of a distribution, of the outputs from the process. $C_p$ shows how close the new measurements can be to the characteristics of the product or service. $C_{pk}$ shows the same thing, but also how the average value is compared to the target value.

Also, $C_p$ and $C_{pk}$ suppose that the process is statistically stable and that the data are approximately normally distributed (the normal distribution is one of the most important distribution laws and is known as Gauss’s law or Gauss-Laplace—Figure 6).

Figure 5. Cloud-based production applications
To calculate $C_p$ and $C_{pk}$ use the specifications and process widths. The specification width is the difference between the upper specification limit - $L_s$ and the lower specification limit - $L_i$, or the upper tolerance limit and the lower tolerance limit. If it is decreased, $L_s - L_i$, the width of the specifications is obtained.

The width of the process is the difference between the upper control limit $L_s$ and the lower control limit $L_i$, these two limits showing how the process works. If it is decreased, $L_s - L_i$ the width of the process is obtained. The width of the process can also be calculated by multiplying the standard deviation by 6.

Process capacity—$C_p$ is usually expressed as the specification width divided by the process width and shows the instantaneous capacity of the process.

$$C_p = \frac{\text{specification width}}{\text{process width}} = \frac{USL - LSL}{6\sigma}$$

Process capacity indicates the potential short-term performance level that a process can achieve.

If $C_p < 1$, the result of the process exceeds the specifications the process is incapable

If $C_p = 1$, the process hardly meets the existing specifications

If $C_p > 1$, the result of the process falls within the specifications, but defects may occur if the process is not centered towards the expected result.

Thus, the higher the $C_p$, the less variations there are in the process. $C_p$ is used for continuous data and is based on several assumptions.

As $C_p$ does not take into account the centering of the process, it is not used alone to describe the performance of the process, and together with $C_{pk}$ measures the ability of the process to fulfill the requirements or specifications established by the customers considering its short-term variant. $C_{pk}$ is the ratio of the measured distance between the process average and the specification/tolerance limit closer to half of the total process spread. The tolerance (T) is specified by specifying the upper limits $L_s$ and the lower limit $L_i$:

\[ C_{pk} = \frac{L_s - \bar{X}}{T} \]
\[ T = L_s - L_i \]

So that \( C_{pk} \) indicates the level of performance that a process can reach, taking into account its average. \( C_{pk} \) is interpreted as:

If \( C_{pk} = C_p \), the average of the process is the expected one
If \( C_{pk} = 0 \), the average of the process falls within one of the specification limits
If \( C_{pk} < 1 \), the process average is completely outside the specification limits

\( C_{pk} \) is used for continuous data and assumes that the process is statistically stable and that its data are normally distributed. If the data distribution is irregular, \( C_{pk} \) takes into account the central value of the process and the short-term variance; for this reason it is only used together with \( C_p \). All the statistical information analyzed helps us to identify the performance indicators of the process and implicitly the added value through the application of the methodology.

**CONCLUSION**

Effective understanding of these methodologies and their relationship will give companies a competitive advantage. Many organizations use one of the methods as a basis for continuous improvement. As such, the relationship between Six Sigma and Agile, as well as the development of an integrated model, is an opportunity for organizations to perform well.

It is known that successful organizations strive to stay ahead of their competition by effectively implementing continuous improvement methodologies. The application of the DMAICA methodology leads to the development of solutions in order to increase the efficiency, effectiveness, and implicitly the productivity of the organization.

**CONFLICT OF INTEREST STATEMENT**

Ana Maria Ifrim, Cătălin Ionuț Silvestru, Mihai-Alexandru Stoica, Cristina Vasilica Icociu, and Marian Ernuț Lupescu declare no conflicts of interest. Ionica Oncioiu is the Editor-in-Chief of the International Journal of Innovation in the Digital Economy.
REFERENCES


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Cristina Vasiliu Icociu graduated the Faculty of Law in 1996 with a Bachelor’s diploma at the Alexandru Ion Cuza Police Academy. She has held a Master’s diploma since 2001 and a PhD diploma since 2010, both in administrative sciences at the National School of Political Studies and Public Administration. In this respect, she has extensive experience in central administration field, mainly in education and research field, where she has occupied various management positions, from General Manager to Deputy Secretary-General, but also at a government level, as councillor to the vice prime-minister on economy and business environment. Alongside the activities carried out in the public administration sector, Mrs. Icociu has also been active in the academic field, first from 2006 as an associate at the Technical University of Civil Engineering of Bucharest/University Polytechnic of Bucharest and the National School of Political Studies and Public Administration. Since 2012, she has held the position of lecturer at the University Polytechnic of Bucharest, Department of Economical Engineering where she is teaching various subjects from the field of legal sciences relevant for engineers to contracts. She has also worked in the writing and implementing stages of several European financing projects as legal advisor or project manager. In 2021, she became Associate Professor to the robotics department, teaching law and ethics for students from level 6 to 8 EQF. She has co-authored seven books and fifteen articles. Like a law expert, she has also participated in the elaboration of several laws, ordinances, government decisions, and other central public administration acts. She is very diligent about the quality of the work, being interested in compliance to the human rights, equal opportunities, academic ethics, and integrity.

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