# Possibilities of Maintenance Service Process Analyses and Improvement Through Six Sigma, Lean and Industry 4.0 Implementation

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**Abstract.** The paper deals with problems concerning a maintenance process realized by maintenance service companies. In the paper the concept of wastes identification in such companies is presented. Then, a case study company is analysed. The company designs, manufactures, implements and performs maintenance processes of installations used in products control, sorting and packing in clients' factories. The analysed problems concern data collection as well as their analysis in order to improve the maintenance company efficiency. The authors propose to implement the Six Sigma methodology to collect and analyse data, elements of the Lean concept to identify wastes and Industry 4.0 concept in order to improve the maintenance service processes.

**Keywords:** Maintenance · Six Sigma · Lean concept · Industry 4.0
Efficiency improvement

## 1 Introduction

Maintenance processes play a significant role in maintaining the efficiency of technical equipment. Maintenance processes can be realized by different participants: by a user of equipment (1), by a manufacturer (2), by a company which delivered the service of an equipment installation (3), by an external company on the principle of outsourcing (4), in a mixed way (5). A maintenance process depends on many factors such as: selection of the right maintenance strategy [1], ensuring a certain technical infrastructure for a maintenance process [2], selection of the qualified employees [3] and, the most important, gathering the right data for a decision making in the maintenance process planning [4]. In order to manage a maintenance process correctly, it is essential to identify factors critical to quality (CTQ) from the point of views of clients as well as a company which delivers a maintenance service. Then, it is necessary to identify these factors which have real influence on CTQs. To do it Six Sigma methodology can be applied [5]. On the basis of the knowledge coming from the analyses performed in Six Sigma project, the maintenance information systems can be developed to be used in a decision making process. In the work [6] maintenance information systems were highlighted as one of the six important research areas in maintenance processes. Additionally, the work [7] shows how the collected data can be converted into


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information, and then into knowledge in maintenance processes. A decision making system in maintenance can be supported by different methods and tools. The systems such as: CMMS (Computerized Maintenance Management Systems) [7, 8] or ERP (Enterprise Recourse Planning) [9] allow to store the data from a maintenance process, and then use them in analyses in many different ways. Different decision scenarios can be analyzed [10]. The works [11, 12] present the use of fuzzy logic in the analyses of the data gathered from a maintenance process, and then the prioritization of the maintenance activities. Additionally, the work [13] shows the use of a genetic algorithm in optimizing an aircraft maintenance plan. It is advantageous for companies to use such solutions in maintenance processes. Considering the fact that software might be expensive, analyses might be too complex and time consuming, the mentioned solutions are not very popular in small and medium enterprises (SME). However, in the light of Industry 4.0 concept it is predictable that more and more data which can be used for maintenance planning will be available [14]. Therefore, a cyber-physical system (CPS) can be proposed to support a maintenance process. A holistic approach for the quality oriented maintenance planning presented in the work [15] and an approach which uses historical data presented in the work [16] can be taken into consideration in CPS development.

Another important issue is connected to the wastes which may exist in a maintenance process. In order to identify wastes and then to eliminate them Lean concept can implemented [17]. Therefore, in this paper, the authors propose a methodology which uses Six Sigma and Lean concepts for a problem definition and identification of important factors influencing a decision making in a maintenance service process (MSP). It also combines a lot of data and analyses together, as well as the concept of Industry 4.0 to propose a direction for CPS development. The proposed methodology was developed for a case study company and it is currently implemented in this company.

In Sect. 2, the research problem and work methodology are presented. Section 3 describes a business organization in the case study company. Section 4 presents description of the MSP. In Sect. 5 the adopted the Six Sigma methodology is presented. Section 6 describes a company problem. Section 7 specifies the data which are collected. Section 8 presents the proposed statistical tests to be conducted to verify the research hypotheses. Section 9 indicates proposals for improvements and it presents a concept of MSP monitoring with the support of CPS. The last section concludes the work and identified limitations as well as the future research.

## 2 The Research Problem and Work Methodology

The research problem the authors deal with is that a simple methodology which can be applied in an SME maintenance service company and leads to the key factors identification and maintenance process improvement is not presented in the literature.

In order to develop such a methodology, the authors first analysed the business organization in the case study company and the activities undertaken in an MSP, then they adopted the Six Sigma methodology and Lean concept to the case study.

## 3 The Business Organization in the Case Study Company

The case study company designs, manufactures, implements and performs maintenance processes of the installations used in products control, sorting and packing in clients' factories. In order to create an installation, the company uses different kinds of elements: (1) elements which are manufactured in the company, (2) elements which are bought as standard elements (e.g. engines) and (3) elements which are delivered to order by other companies (e.g. industrial robots).

When an installation is started, the case study company takes responsibility for the maintenance process of the installation, if included in the contract. If not, the company takes responsibility only for hidden defects during the warranty period. In this work, only the cases in which a maintenance process is included in the contract are discussed.

The strategy of maintenance activities is presented in Fig. 1. A supplier of the elements delivered on order, which are composed into an installation, takes responsibility for a maintenance process of these elements (e.g. industrial robots). An installation supplier, i.e. the case study company, takes responsibility for the rest of the installation elements as well as for a trouble-free operation of the entire installation. Additionally, a user of the installation should plan internal maintenance processes to the necessary extent, of which the frequency depends on the installation utilization.

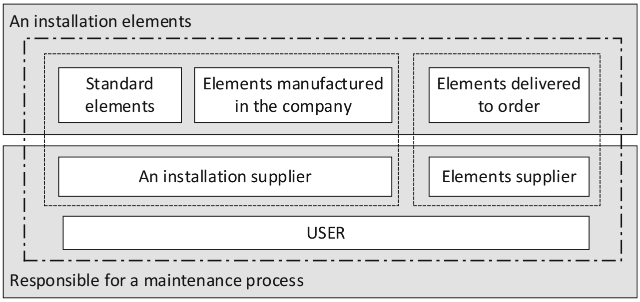


**Fig. 1.** A maintenance strategy.

In order to avoid failures, a preventive maintenance process is recommended. This kind of maintenance activities is undertaken by an installation supplier and elements suppliers in accordance with the provisions of the contracts, as well as by a client (user). Unfortunately, clients very often do not plan and do not undertake any preventive maintenance activities what causes the installation failures and increases the costs of the maintenance process undertaken by an installation supplier and elements suppliers. Therefore, in order to find the possibilities to decrease the costs of a maintenance process, this problem will be discussed in this work.

## 4 Description of a Maintenance Service Process

The MSP analysis is started from the identification of the steps of the process (Fig. 2). The process begins when a problem is reported or a company orders a preventive MSP. Then, a report is registered and a preliminary diagnosis or analysis of the activities that should be undertaken in a preventive MSP is performed. At this point, the kind of activities that should be done on the installation have to be pre-decided.

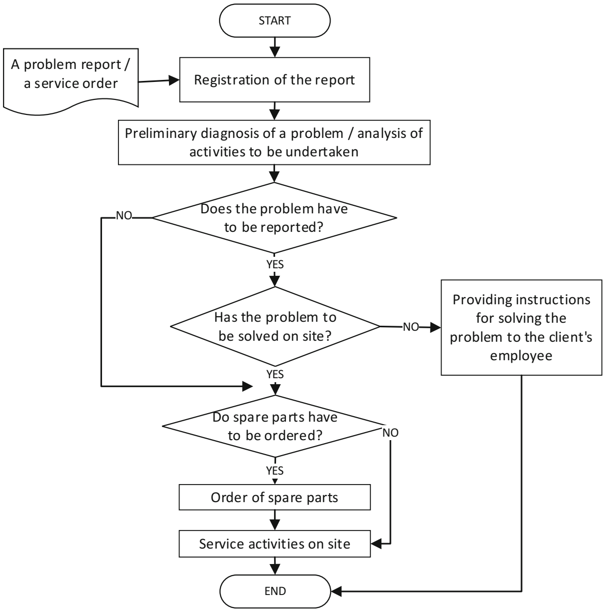


**Fig. 2.** A flowchart of the service process.

There are situations, related to problems reporting, when a problem can be solved remotely. It means that an employee can solve the problem based on the instructions of a supplier's maintenance employee, given by phone. Then, the MSP is finished. If a problem cannot be solved remotely, a maintenance employee or employees have to go to the installation place to perform a diagnosis and undertake maintenance service activities on site. Spare parts are sometimes needed. If this is the case, spare parts are ordered. Sometimes they have to be manufactured by the supplier. It takes time. When the spare parts are available, the MSP on site begins. One or more service employees (depending on the needed skills) have to go to the client's to undertake any necessary activities. If both an elements supplier and an installation supplier have to undertake service activities connected to the same reported problem, a client wants them to do it at the same time, because the running process must be stopped for the time of repair. Many factors have a potential influence on an MSP on each step of the process.

## 5 The Six Sigma Methodology with Additional Indicators

The authors proposed a project to be realized in the case study company. It involves the Six Sigma methodology and Lean tools in order to identify problems and factors which have an influence on the MSP outputs. The methodology consists of 5 steps based on DMAIC: Define, Measure, Analyse, Improve, Control, and it is presented in Table 1.

**Table 1.** Steps of the analysis

| Step | Description | Results |
|---|---|---|
| Define | Identification of important outputs | Identified *Y*s |
| | Identification of inputs which can have a potential influence on the outputs | Identified *X*s |
| Measure analysis | Data collection | *Y*s and *X*s |
| | Analysis of *Y*s distributions | Normality test results |
| | Selection of statistical tests (for continuous data and attribute data) | Chosen tests |
| | Performing statistical tests | Test results |
| | Calculation of additional indicators | Values of indicators |
| | Qualitative analysis – identification of high costs and long lead time causes with the use of the quality and Lean tools (VSM) | Problems causes |
| Improve | Proposals for MSP improvements based on Industry 4.0 concept | Improvements |
| Control | Process monitoring based on Industry 4.0 concept | Stable processes |

In order to evaluate the effectiveness of machines, devices and the MSP, the following performance indicators will be calculated: *MTBF* (Mean Time Between Failures), *MTTR* (Mean Time To Repair), *OA* (Operational Availability) calculated with the use of Eq. (1) and *MLD* (Mean Logistic Delay).

$$OA = \frac{MTTM}{MTTM + MMT + MLD} \tag{1}$$

where: *MMT* – Mean Maintenance Time, *MTTM* – Mean Time To Maintenance.

In order to perform the presented analyses, the company needs to gather a lot of different data. Then, detailed analyses of the values of the presented indicators have to be performed to show the problems as well as the directions of improvements in a MSP.

Additionally, for the assessment of the quality and flexibility of an MSP, the following analysis, among other, are planned to be performed: (1) the analysis of the frequency of emergence of particular types and (potential) causes of failures; (2) the analysis of the frequency of emergence of individual ways to eliminate failures; (3) the analysis of the number and specialization of the employees involved in a maintenance process; (4) the analysis of the type and costs of the spare parts used; (5) the analysis of the waiting time for the spare parts. Then, the Lean tool, such as Value Stream

Mapping (VSM), will be used to analyse the details of a single MSP and to identify additional problems which can cause, for example, delays or which can increase the maintenance service costs, as done in the work [18]. The detailed VSM methodology will not be presented in this work. In order to recognise the causes of the identified problems, the Ishikawa diagram can be applied. The results of the analysis will be taken into consideration in proposing improvements.

The project is established to be realized in the period of six months. The initial steps of the project are presented in this paper as well as the whole methodology developed to realize the project.

## 6 Define: Description of the Problem and SIPOC Development

The case study company is struggling with the problem of failures. These failures cause high costs of maintenance activities. Additionally, the lead time of failures elimination is long what, in consequence, causes customer's dissatisfaction. Therefore, the following problem has been defined.

*Identification of the factors influencing the number of failures, maintenance service costs and lead time of a maintenance service process (MSP), and determination of activities which should be undertaken to minimize the costs and lead time.*

In order to analyse the problem, first SIPOC was developed and it is presented in Fig. 3. There are several suppliers for a maintenance process such as: a client who provides the installation to be maintained; elements suppliers who perform a maintenance process of the chosen installation elements; and spare parts suppliers.

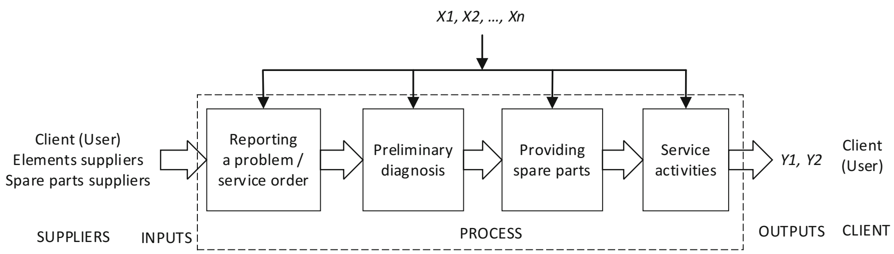


**Fig. 3.** The factors influencing the service process.

The input is the installation which will be the object of a maintenance process. The process consists of the following steps: registration of a report (a problem/a service order), a preliminary diagnosis, spare parts provision and service activities. From the client's point of view, the lead time (*Y1* [days]) of a service process is crucial. From the supplier's point of view, the cost (*Y2* [Euro]) of an MSP is also important. Therefore, these factors will be treated as the outputs of the process (CTQs). A customer is a user of the installation. The process can be influenced by different factors (*X1, X2,..., Xn*). In order to identify these factors, first an MSP has to be carefully analysed.

## 7 Measure: Data Collection

Among the factors which can have a potential influence on the steps of a service process, these presented in Table 2 were identified. These data are currently being collected in the case study company and they will be used in further analyses. There are two kinds of data: attribute data and continuous data. The attribute data are coded as presented in Table 2. The outputs of the process might depend on some or on all of the inputs. However, in order to discover which inputs have a real influence on the outputs, further statistical analyses are indispensable.

**Table 2.** Factors having potential influence on the service process

| Group of factors | Kind of factor | Symbol | Kind of data |
|---|---|---|---|
| Factors depending on a client | Kind of agreement with a client | *X16* | S, NS |
| | Kind of installation | *X3* | S, W, P, L, O |
| | Time since the installation of the work stand | *X17* | [days] |
| | Duration of the client's employees' training | *X23* | [hrs.] |
| | Time since the last preventive actions | *X21* | [days] |
| | Time since the last failure | *X22* | [days] |
| | Time since the installation of the oldest robot | *X18* | [days] |
| | Manufacturer of the robot | *X19* | M1, M2 |
| | Number of collaborating equipment elements | *X20* | [pcs] |
| | People responsible for preventive actions | *X24* | S, C |
| | Day of the week when a problem was reported | *X32* | M, T,… |
| Reporting a problem/service order | Client | *X1* | C1, C2,… |
| | Industry | *X2* | I1, I2,… |
| | Way of reporting | *X15* | M, P |
| | Kind of an order | *X26* | P, F |
| | Comment of a client | *X27* | Descript. data |
| Preliminary diagnosis | Type of failure | *X4* | M, A, E, O |
| | Causes of failure | *X5* | C1, C2,… |
| | Distance to the client's site | *X11* | [km] |
| | Timeliness of preventive maintenance activities | *X25* | Y, N |
| Providing spare parts | Type of spare parts | *X8* | T1, T2,… |
| | Cost of spare parts | *X29* | [Euro] |
| | Waiting time for spare parts | *X31* | [days] |
| | Availability of spare parts | *X30* | A, NA |
| Service activities | Way of failure elimination | *X6* | W1, W2,… |
| | Additional actions | *X7* | T, D, R |
| | Way of the order realization | *X12* | C, S, SS |
| | Elements supplier | *X13* | SS1, SS2,… |
| | Number of employees engaged in the process | *X9* | [persons] |
| | Time for repairs | *X14* | [h] |
| | Specializations of employees | *X10* | S1, S2,… |

## 8 Analyse: Proposed Statistical Tests

When the data are complete, first of all, statistical tests will be performed to identify the factors which have an influence on *Y1* and *Y2*. Therefore, the hypotheses were developed, taking into account the identified CTQs. Table 3 shows statistical tests which can be used in the presented hypotheses verification. In case of GLM application for H1 hypothesis testing, all *X*s can be tested in one GLM test, what is possible if *Y*1 distribution is normal. In case when *Y*1 distribution is not normal the Kruskal-Wallis test can be applied and each *X* has to be tested separately.

**Table 3.** Hypotheses to be tested and proposed statistical tests

| | Hypotheses | Input | Output | Statistical test |
|---|---|---|---|---|
| H1 | There is a significant difference in the lead time when *X*s take different attributes | *X1–X7, X10, X12, X13, X15, X16, X19, X24–X26, X30, X32* | *Y1* [days] | GLM or Kruskal-Wallis test |
| H2 | There is a significant difference in the costs of an MSP when *X*s take different attributes | *X1–X7, X10, X12, X13, X15, X16, X19, X24–X26, X30, X32* | *Y2* [Euro] | GLM or Kruskal-Wallis test |
| H3 | There is a significant difference in the lead time when *X*s take different values | *X9, X11, X14, X17, X18, X20–X23, X29, X31* | *Y1* [days] | Regression analysis |
| H4 | There is a significant difference in the costs of an MSP when *X*s take different values | *X9, X11, X14, X17, X18, X20–X23, X29, X31* | *Y2* [Euro] | Regression analysis |
| H5 | There is a significant difference in the types of failures (*X*4), failures causes (*X*5) and in additional actions (*X*7) in different kinds of installations | *X3* | *X4, X5, X7* | $Chi^2$ |
| H6 | There is a significant difference in the ways of an order realization within a different distance from the clients' site | *X11* (data have to be transformed into attribute data) | *X12* | $Chi^2$ |
| H7 | There is a significant difference in the number of employees engaged in different kinds of the installations maintenance process | *X3* | *X9* | Anova one way or Kruskal-Wallis test |

The same situation occurs for hypothesis H2. For H3 and H4 regression analyses can be performed. For the next hypotheses, H5 and H6, we propose to use $Chi^2$ tests, however in case of H6, first the data (*X11*) have to be transformed into attribute data. In order to test H7 hypothesis, we recommend to use Anova one way or Kruskal-Wallis test depending on the distribution of *X9*.

On the basis of the results of the presented analysis, significant factors which have an influence on the outputs will be identified.

## 9 Improve and Control

The results of the above analyses will show the strengths and weaknesses of the MSP realized in the case study company. Additionally, the results will show the directions and ways of the MSP improvements. In order to improve the MSP on-line monitoring of the chosen installations' parameters such as: a number of working hours of the chosen elements of the equipment (1), vibration of the chosen elements of the equipment (2), work temperature of the chosen elements of the equipment (3), power consumption of the chosen elements of the equipment (4) and environmental working conditions (5) can be performed. Then, a decision making process that uses artificial intelligence, neutral networks or fuzzy logic, which on the basis of the data will suggest preventive maintenance activities on the grounds that a failure can appear, can be implemented [11, 12]. Other improvements can be proposed on the basis of the results of the analysis.

In order to control the MSP, the data concerning the process realization should be collected. Until now, the data concerning a certain client's order were registered partly in a database and partly on paper forms. The authors propose to implement a Cyber Physical System (CPS) with mobile devices which will allow to input the data concerning a maintenance process on site, where the installation functions, without a necessity of filling paper documents. This way, all the necessary data will be available just after the MSP completion and they will be the inputs for a decision making process supported by the developed algorithms.

## 10 Conclusions and Future Research

This paper presents a Six Sigma project which is currently run in a maintenance service company. The finished stages of the project concerned the problem definition, recognition of the current situation (flowchart of the service process), SIPOC development, identification of the factors which can have a potential influence on the maintenance process lead time (*Y1*), the costs of the maintenance service (*Y2*) and selection of statistical tests which can be used in further analysis to test the developed hypotheses. This allowed to understand the problem and plan further steps of the Six Sigma project.

The paper shows that the efficiency of an MSP depends on a number of factors. The realization of the process can be supported by different methods and tools. In order to support the MSP, more or less complex solutions can be applied in the same company. The main problem is data collection and integration, and then adequate responding to the performed analyses results. The presented approach shows the way of integrating the Six Sigma methodology, Lean philosophy and Industry 4.0 concept in order to increase the quality, efficiency and flexibility of an MSP.

The proposed methodology presents types of data and the way of data collecting as well as the possibilities of their statistical and qualitative analyses. the implementation of this methodology may allow companies to identify the possibilities of improvements, especially in the reduction of costs and lead time of an MSP.

The proposed methodology has its limitations which are connected to the fact that the methodology was developed on the basis of one company, and it has not been fully applied in practice yet. Therefore, in the future publications, the authors will present analyses which will be performed on the basis of the data which are currently being collected.

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