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# STATISTICAL PROCESS CONTROL AS A FAILURE REMOVAL IMPROVEMENT TOOL

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Continuous improvement should be a part of the strategy of every modern company that wishes to meet the requirements posed by the demanding, competitive market. The article presents a concept of applying a tool known from quality engineering, i.e. Shewhart control charts, for the improvement of the maintenance process in a small company providing services for the agricultural and construction industries. The improvement of the process included the reducing of the downtime of belt conveyors due to failures. Using control charts allowed the detection of interferences in the process and defining of their nature. Using other tools such as 5 WHY allowed the identification of the root causes of overly long downtimes and, consequently, formulation and implementation of improvements and preventive measures that were optimal for the organisation. The verification of actions taken has shown their positive impact on the process, which was reflected in the shortening of downtime and, subsequently, streamlining the failure removal process. The paper presents a possibility and validity of utilising quality engineering tools, such as Shewhart's charts, 5 WHY or Ishikawa diagram, for improving the maintenance processes.

**Keywords:** improvement; maintenance; statistical process control; quality; Shewhart; 5 WHY

Processes connected with maintaining the machine fleet in working order are some of the most important auxiliary processes in every company, regardless of the industry. The application of modern maintenance management concepts does not, however, guarantee that the machines and equipment will be usable throughout their entire life cycle (Brodny et al., 2016; Galamboš et al., 2017). Despite risk minimising, the failures of the machine fleet elements cannot be avoided. In an event of a breakdown, the staff responsible for maintaining the machine fleet should aim to remove the failure as quickly as possible, reducing the downtime to a minimum.

## Material and methods

Continuous improvement should be a part of the strategy of every modern company that wishes to meet the requirements posed by the demanding, competitive market. The term "continuous improvement" was promoted by W. E. Deming in 1982 (the PDCA cycle, i.e.: Plan – Do – Control – Act) and refers to "continuous and perpetual improvement of the production process and services which cause the quality and productivity improvement and cost reduction" (Wojtaszak and Biały, 2013; Andrássyová et al., 2013).

As per the assumptions of Deming's cycle, the improvement of an already functioning production or service process in a company should be conducted according to the following scheme:

1. Identification and hierarchisation of problems.
2. Selection of problems, the removal of which will be the most beneficial from the perspective of process improvement and capability (resources) of the organisation.
3. Finding the root causes of the problems and where in the process do they occur.
4. The development and implementation of improvement measures that will limit or completely eliminate the problems.
5. The development and implementation of preventive measures in order to stop the problem from occurring in the future.
6. The implementation of control measures that will test the efficiency and effectiveness of the introduced changes.
7. Possible corrections of the measures as a result of the control measures taken.

An expansion of the above scheme is an algorithm proposed by the authors for solving the problem described in this paper, presented in Fig. 1.

The first stage of the process lies in identification of problems, i.e. interferences present in the process. Since failure is considered a one-time event, the Xi-MR type chart should be used, that is the single observation moving range chart used for studying single-point samples, e.g. in cases when testing the product would be very expensive or when there would be no possibility of gathering samples in larger quantity in a low-volume production. A properly maintained control chart shows anomalies (interferences) in the process that should be eliminated in the later stages of improvement.

When an anomaly is observed in a chart, it is possible to proceed to the second step, i.e. recognising the causes of the problem. The simplest tool used for finding the root causes of a problem is the 5 WHY. The creator of 5 WHY is



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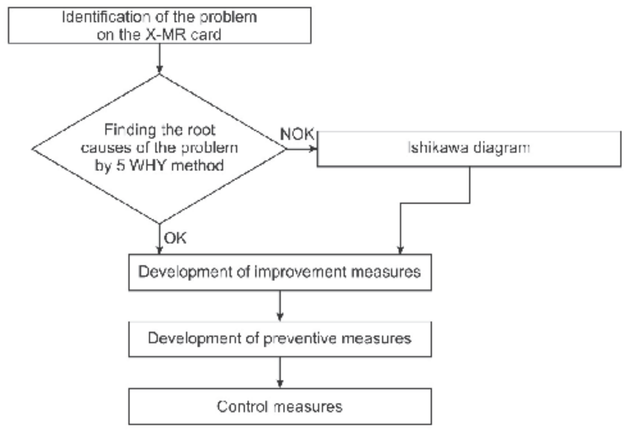


**Fig. 1** Process improvement algorithm (own study)

Sakichi Toyoda (Hino, 2005). The 5 WHY tool was quickly implemented and improved in the Toyota corporation. It is simple to use and requires no special training. It identifies the problem and, subsequently, asks "why" questions until a satisfying answer has been achieved. Therefore, it is a systematised cause-and-effect analysis, and when one question is answered, another one automatically arises, which creates a coherent whole until the root cause of the problem has been found. Tool's creator assumed that the learning of problem cause should occur after answering to 5 questions – hence the name – but by means of this method, the sought answer might be obtained after 3 or 7 questions (Zasadzień and Midor, 2015).

If the problem cannot be solved using the 5 WHY tool, more comprehensive tools should be used, such as Ishikawa diagram, also known as the 5M method, which divides all potential causes into 5 groups: manpower, machinery, management, materials and methods (Gajdzik and Sitko, 2016; Zasadzień, 2014).

After identification of the problem root cause, preventive and improvement measures should be developed and implemented.

The research and implementation of the methods and tools described above were carried out in a company dealing with renting and leasing machinery for agriculture and construction industry. These are mainly: trailers, belt and auger conveyors, sowing machines, ploughs, tractors, diggers, loaders and others. In majority of cases, machine failures are removed by the company's employees.

Belt conveyors were selected for the analysis; the company has 20 belt conveyors at its dispose. These are mobile conveyors with a length ranging from 3 to 20 m intended for both horizontal and inclined transport (up to

**Table 1** Belt conveyor breakdown times

| Failure | Mean downtime – MDT (h) | Standard deviation of MDT | Number of failures | Total downtime (h) |
|---|---|---|---|---|
| **Damaged motor** | 27.68 | 9.48 | 29 | 803 |
| **Broken belt** | 26.12 | 4.95 | 19 | 496 |
| **Damaged transformer** | 13.75 | 3.50 | 7 | 96 |
| **Damaged contactor** | 8.75 | 3.02 | 8 | 70 |
| **Damaged cable** | 9.79 | 4.23 | 6 | 59 |
| **Damaged gearshift** | 19.50 | 3.54 | 2 | 39 |
| **Fuse replacement** | 5.00 | 1.77 | 5 | 25 |

**Table 2** Downtime due to motor failure

| Failure No. | Duration (h) | Failure No. | Duration (h) | Failure No. | Duration (h) |
|---|---|---|---|---|---|
| **1** | 12 | 15 | 32 | 29 | 27 |
| **2** | 20 | 16 | 37 | 30 | 10 |
| **3** | 27 | 17 | 47 | 31 | 30 |
| **4** | 32 | 18 | 27 | 32 | 25 |
| **5** | 32 | 19 | 22 | 33 | 32 |
| **6** | 37 | 20 | 37 | 34 | 27 |
| **7** | 22 | 21 | 22 | 35 | 50 |
| **8** | 48 | 22 | 25 | 36 | 17 |
| **9** | 20 | 23 | 22 | 37 | 27 |
| **10** | 35 | 24 | 20 | 38 | 27 |
| **11** | 25 | 25 | 46 | 39 | 30 |
| **12** | 27 | 26 | 22 | 40 | 35 |
| **13** | 22 | 27 | 20 | | |
| **14** | 20 | 28 | 12 | | |

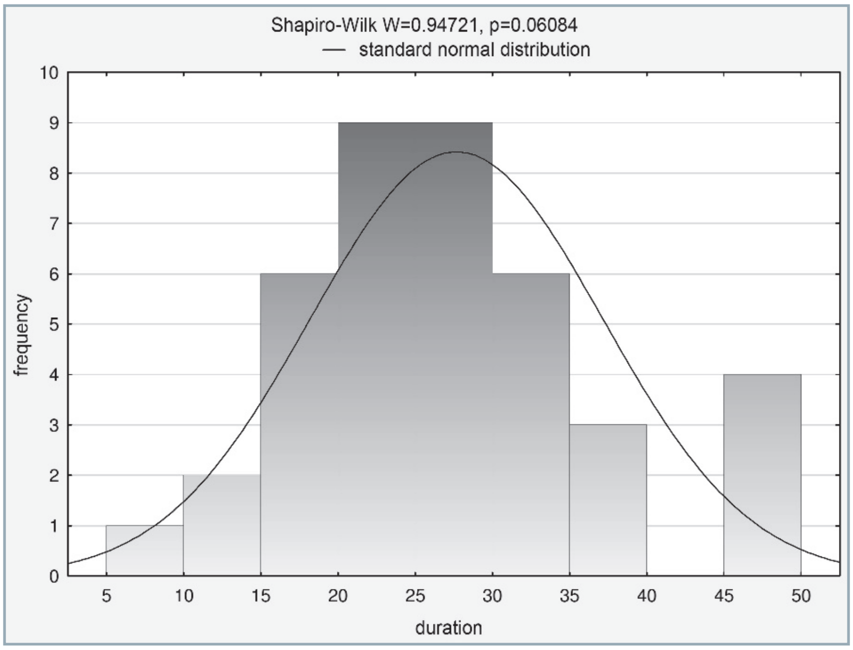


**Fig. 2** Shapiro-Wilk test

30°). Over a period of 18 months, data pertaining to the time of downtimes caused by belt conveyor failures were gathered; these gathered data are shown in Table 1.

The failure which resulted in the longest total downtime during the analysed period turned out to be the replacement of a damaged motor of the conveyor (803 hours). Downtime due to a broken belt lasted 496 hours, while the other downtimes took 289 hours. The problem of overly long downtime due to motor failure was selected for further analysis. Forty such breakdowns were observed during the analysed period. All the observed downtimes are shown in Table 2.

Shapiro-Wilk test was chosen to test the hypothesis of the normal distribution of variables, which is usually used for low-quantity samples (Romão et al., 2010). For the purposes of the test, a hypothesis states that the studied data set has a normal distribution. The STATISTICA 13.1. software was used to test the hypothesis, and the results are presented in Fig. 2.

As shown in Fig. 2, the hypothesis about the normal distribution of data points was confirmed ($p$ = 0.06>0.05) and, consequently, a control chart could be drawn up. The following values necessary for drawing up the Xi-MR chart were calculated:

- mean record value:

$$X' = \frac{x_i}{n} = 27.67\,\text{h} \tag{1}$$

- moving range value:

$$MR_i = \left| x_i - x_{i-1} \right| \tag{2}$$

- mean range value:

$$M'R = \frac{MR_i}{n} = 10.79\,\text{h} \tag{3}$$

- upper limit value of the $X$ control chart:

$$UCL_X = X' + (2.66 \cdot M'R) = 56.37\ \text{h} \tag{4}$$

- upper limit value of the $MR$ control charts:

$$UCL_{MR} = 3.27 \cdot M'R = 35.26\ \text{h} \tag{5}$$

where:

$i$ – failure number
$x$ – downtime
$n$ – number of failures
2.66 and 3.27 – table values dependent on the number of measurements

The Xi-MR chart consists of a chart plotting the duration of individual downtimes and a chart of moving ranges calculated for these downtimes. In addition to these, the charts also plot the mean values of downtime and range, as well as control limits. The obtained results are presented in Fig. 3.

Improving the process on the basis of Shewhart charts should begin with:

1. Determining the $Cp$ and $Cpk$ indicators in order to determine the capacity of the process.
2. Identifying the cause of very long downtimes (points exceeding or located very close to the $UCL_X$ line – e.g. failures no. 8, 17, 25 and 35 (Fig. 3).
3. Identifying the causes of very big fluctuations in the downtimes (points exceeding or located very close to the $UCL_{MR}$ line – e.g. failures no. 8 and 35).

Following that, when all causes of the aforementioned cases have been eliminated, attention should be paid to other anomalies in the Xi-MR charts such as: trends (rising or falling), large alternating fluctuations in the results, or series of points laying above or below the central line. Aforementioned anomalies may also be indicative of the presence of special interferences in the process, e.g. tool wear and tear or insufficient engagement of employees in their duties.

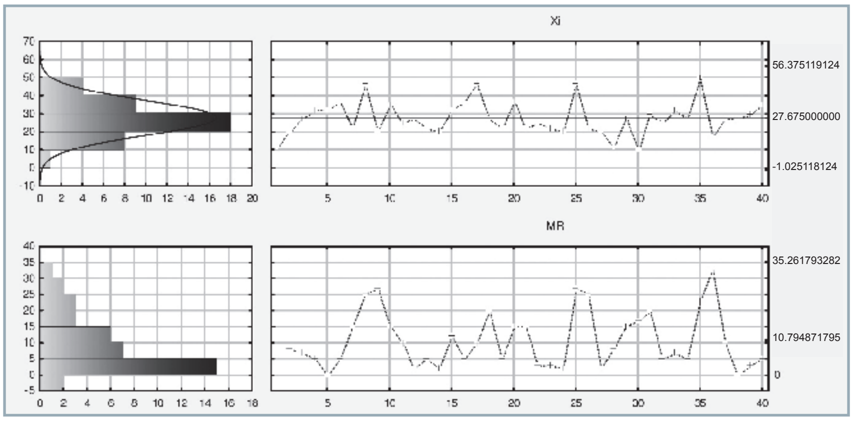


**Fig. 3** The Xi-MR chart

## Results and discussion

### Control charts

No nominal value or tolerance for downtime has been defined for the process. On the basis of data shown in Shewhart chart (downtime) and working time measurements, it was determined that the aim of process improvement would be achieving a downtime caused by motor failure of 24 hours with a tolerance of ±5 hours. Working time measurement included observation of time required for the workshop employees to dismount the damaged motor and mount a new one along with auxiliary activities, such as: breaks, administrative tasks, searching for parts, materials and tools in the warehouse. Delay resulting from renovation works and removing other breakdowns was also taken into consideration. By defining the nominal value and tolerance, it was possible to determine the process performance indicators *Cp* and *Cpk*, which were calculated using the following formulas:

$$Cp = \frac{USl - LSL}{6\sigma} \qquad (6)$$

$$Cpk = \min\left(\frac{|USl - X'|}{3\sigma};\frac{|X' - LSL|}{3\sigma}\right) \qquad (7)$$

where:

*USL*, *LSL* – upper and lower specification limit (tolerance), with respective values of: *USL* = 29 hours, *LSL* = 19 hours

*Cp* – process capability

*Cpk* – process capability index

Šibalija and Majstorović (2009) recommend using the process performance indicators *Pp* and *Ppk* alongside the *Cp* and *Cpk* indicators, which are more sensitive to changes in the distribution of process results; however, the authors decided to forgo the use of these indicators at such an early stage of study and control. In the discussed case, the *Cp* indicator is 0.17, which means that the process has too large a spread of individual results, i.e. it is imprecise (the width of the tolerance area is much smaller than the value of 6σ = 59, Eq. 6). Desired value of the *Cp* indicator should be at least 0.89, at which the number of downtimes, the times of which lie outside the tolerance limits, will be approx. 1% (Dudek-Burlikowska, 2005). The determined value of the *Cpk* indicator is 0.04; indicating the preciseness of the process or whether the mean measured value lies close to the value defined as nominal. In this particular case, this is not true – the vast majority of the results is higher than the nominal value.

### 5 WHY

This control chart is the starting point for controlling the failure removal process. Using this chart, the results can be gathered from the process on an ongoing basis. Presented paper focuses only on the measures aimed at reduction of the duration of very long downtimes. In the fourth week of monitoring the process, a failure occurred which caused a downtime that lasted for 48 hours. Consequently, actions were taken aimed at identifying the causes of the anomaly using the 5 WHY tool. The analysis is shown in Fig. 4.

The analysis showed that the main problem with the long downtimes of the belt conveyors was due to time spent waiting for the motor, resulting from the difficulty of finding a fitting motor in company's warehouses and stockpiles. In many cases, a new motor is ordered from the supplier despite the fact that the company has one at its disposal. As a result of the analysis, four main problems were pointed out:

1. The lack of personnel with knowledge of the location of a fitting motor.
2. Unintelligible and ambiguous motor markings. Motors are located in a closed warehouse and in roofed carports, so the nameplates on the parts are rusty and dirty, making it difficult for the employees to quickly find the necessary information. In many cases, the employee selects a motor only to discover that it is of an improper type when mounted or started.
3. Replacement motors placed in various storage spaces. In the company, replacement motors are stored in various places: in a warehouse and in two carports. There is no correlation between the type and appropriation of a motor and the place where it is stored. This causes time losses when searching for an appropriate replacement motor.

| | | | |
|---|---|---|---|
| name: | John Smith | description of failure: | corrective actions: |
| device: | belt conveyor FUGOR | drive motor does not work | replacement of damaged motor |
| date: | 15.09.2016 | | |
| begining: | 7:50 | | |
| end: | 15:20 +1D | | |
| duration: | 1890 | | |

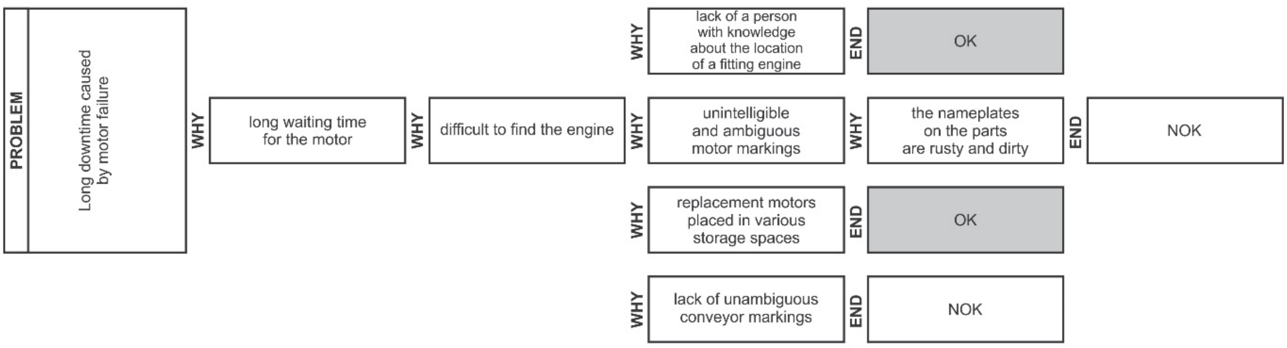


**Fig. 4** The 5 WHY analysis of the overly long downtime caused by the motor failure

4. The lack of clear conveyor markings. The conveyors are produced according to individual orders from the clients (arm length, carrying capacity, inclination angle, etc.) and not supplied from a catalogue. Therefore, the majority of conveyors owned by the company has no markings regarding the type or model, but merely the brand name, causing the selection of motors to be based on a comparison of parameters or employees' knowledge.

## Process improvement

Unintelligible motor markings and a lack of such markings on the conveyors were pointed out as the key causes of the problem, and consequently, improvement measures were developed for these causes.

A team – consisting of employees participating in the process and senior management staff – developed improvement measures as a result of applying heuristic methods. Proposed measures were put into an evaluation sheet and subsequently assessed (Fig. 5 and 6).

Three solutions were proposed to solve the unintelligible motor marking problem (Fig. 4): introducing the RFID (Radio-Frequency Identification) technology (Finkenzeller, 2010); introducing barcode markings; and using durable, colourful plates. The team considered all the three solutions as comparably efficient; however, the first two were rejected due to high costs of implementation. It was recommended that plastic (foamed PVC) plates in various colours with legible markings indicating the motor type should be attached to the motors.

Two solutions were proposed to solve the problem of a lack of markings on the conveyors related to type and model: the introduction of stickers with barcodes; and introduction of "internal" conveyor markings that would be painted on the machine casings. The first solution was rejected due to its low efficiency. Barcodes in the forms of stickers could be easily worn out during the conveyors' operation under working conditions. A solution proposing the painting of markings on the conveyor casing with a colour corresponding with the colour of marking plate on a replacement motor was selected.

After implementation of the described improvement measures, preventive measures aimed at maintaining the solutions in the future were developed. These are:

1. Introducing the control of type markings and their renewal to the conveyor by inspection procedure (position on the checklist).
2. Monthly inspections of the plates placed on replacement motors. The inspections are confirmed with employee's signature.

Introduced changes were solidified in the company, which is confirmed by the results obtained over the next 6 months of observation. The results of measurement downtime caused by failures of conveyor's motor are shown in Fig. 7.

Obtained results show a clear reduction in the duration of downtimes. The maximum time was 34 hours and on MDT (Mean Downtime) lasted 25.7 hours. As other elaborations (Oakland, 2007) show, after a successful introduction of improvement measures, the limit values of control lines should be recalculated, since it will allow more efficient observation of interferences, and thus further improvement of the process.

| TEAM: | 1. | | PROBLEM: | CAUSE: |
|---|---|---|---|---|
| | 2. | | long downtime caused by motor failure | unintelligible and ambiguous motor markings |
| | 3. | | | |
| | 4. | | | |
| APPROVED BY: | | | | |
| DATE: | | | | |

| Improvement actions | | Rating (1-5) | | TOTAL | Recommendation |
|---|---|---|---|---|---|
| | | cost | effectiveness | | |
| 1. | introducing RFID technology | 1 | 4 | 4 | - |
| 2. | introducing barcode markings | 3 | 3 | 9 | - |
| 3. | using durable, colourful plates | 5 | 4 | 20 | + |

**Fig. 5** Measure evaluation sheet for the problem of unintelligible markings

| TEAM: | 1. | | PROBLEM: | CAUSE: |
|---|---|---|---|---|
| | 2. | | long downtime caused by motor failure | lack of unambiguous conveyor markings |
| | 3. | | | |
| | 4. | | | |
| APPROVED BY: | | | | |
| DATE: | | | | |

| Improvement actions | | Rating (1-5) | | TOTAL | Recommendation |
|---|---|---|---|---|---|
| | | cost | effectiveness | | |
| 1. | introduction of bar codes on all conveyor belts | 3 | 2 | 6 | - |
| 2. | introduction of conveyor markings which would be painted on the casings of the machines | 2 | 5 | 10 | + |

**Fig. 6** Measure evaluation sheet for the problem of a lack of conveyor markings

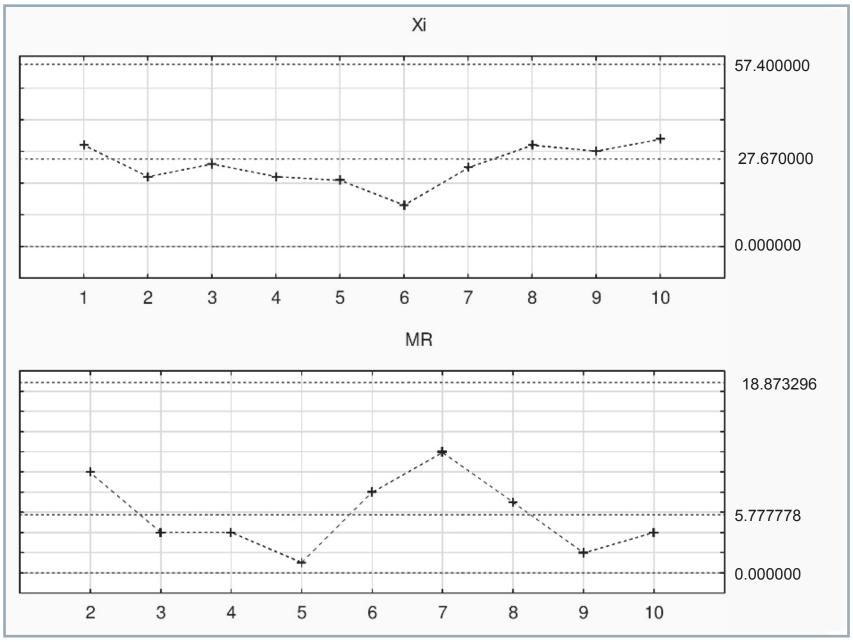


**Fig. 7** The Xi-MR chart for the results obtained after implementation of changes

## Conclusion

Summing up the previous considerations, we can conclude that:

1. Using the continuous improvement methodology allowed shortening of the duration of downtimes caused by the failure of the motor in belt conveyors.
2. As also pointed out by other authors (Šibalija and Majstorović, 2009; Truscott, 2003), using statistical process control is a very effective method of observation of interferences occurring in the process despite the fact that it does not enable process improvement.
3. Skilful use of other quality engineering tools, such as 5 WHY or Ishikawa diagram, allows effective recognition of the type of anomaly and the identification of its root cause is the starting point for effective improvement.
4. Developed improvement and preventive measures should be consulted with concerned employees at all levels so that implemented changes would be achievable and would not generate excessive loads in terms of human and financial resources.
5. The introduction of improvement measures must be connected with preventive measures so that it would be possible to maintain the beneficial changes to the process structure in the future.
6. Another path indicated by Šibalija (2004) would be a comprehensive application of methods known from e.g. the Six Sigma methodology, which include the DMAIC (Define, Measure, Analyze, Improve and Control) method or the 8D, commonly used in the automotive industry (Sokovič et al., 2010; Wojtaszak and Biały, 2013). In authors' opinion, using such complex and formalised methods is possible in large organisations with high technical and organisational culture.

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