Using Industry 4.0 Concept – Digital Twin – to Improve the Efficiency of Leather Cutting in Automotive Industry

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Miroslava Horváthová, Roman Lacko, Zuzana Hajduová

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ABSTRACT

Purpose: The aim of this study is to propose alternatives of increasing the efficiency of material selection and processing in the selected company and reduce costs and leather sustainability as a result.

Methodology/Approach: In this case study, an automotive company processing a natural leather material that enters the process of a large-scale production was explored. For this purpose, the internal documents of the firm selected including its internal database and know-how of its employees were used. The ways of improving the efficiency of the material processing were proposed and tested in a digital environment. In the proposed solutions, Industry 4.0 principles were implemented.

Findings: By the use of Digital twin and other Industry 4.0 principles and solutions in the process of material selection and processing in the company selected, the increased efficiency and cost savings were achieved.

Research Limitation/implication: The solutions proposed in this paper were based on exploration of the chosen data set of the selected company. For the future research, testing of the given proposals in other companies should be conducted.

Originality/Value of paper: Although there is an increasing number of publications describing the concept Industry 4.0, the research providing evidence of its benefits for business entities is still scarce. This paper offers such a research in the enterprise selected.

Category: Case study

Keywords: cloud computing; Internet of Things; efficiency; big data; Industry 4.0; sustainability

1 INTRODUCTION

Meeting specific clients' requirements and needs has become more and more challenging for companies. The reason lies in ever-rising customers' demands on the quality of the purchased goods and services, time needed for processing requests, as well as after-sales service, what results from ever more spreading globalization and fast development in the field of IT. This trend is generally called fourth industrial revolution, also known as Industry 4.0.

According to Kamble, Gunasekaran and Gawankar (2018), the issue of sustainable growth connected with sustainability should be more discussed in accordance with Industry 4.0 literature. They also claim that there is a direct connection since Industry 4.0 concept can significantly reduce the waste during the manufacturing process. This reduction in waste should be weighted to costs connected with the implementation of Industry 4.0 tools. The application of Industry 4.0 tools could result in environmentally sustainable manufacturing (De Sousa Jabbour et al., 2018) but it could be more obvious when connected with UN Sustainable Development Goals (Bonilla et al., 2018). Based on literature review in the field of Industry 4.0 (Oztemel and Gursev, 2018), authors argue that incorporating new methods could bring important sustainable competitive advantage and improve several industrial areas, e.g. monitoring, automation, energy efficiency. From the point of view related to managerial implications (Piccarozzi, Aquilani and Gatti, 2018), the concept and strategy of Industry 4.0 should be implemented regarding to sustainability issues and the application of such strategies could improve sustainable social welfare growth. In another review conducted by Saucedo-Martínez et al. (2018), it was stated that Industry 4.0 environment should be included in company in two areas, both socio-technical area and physical objects virtualization. Industry 4.0 is still emerging in research field, but the results from past research are strongly encouraging the incorporation of selected methods in managerial practice (Schneider, 2018). The main drivers of Industry 4.0 implementation are strategic, operational, as well as environmental and social opportunities as presented in Müller, Kiel and Voigt (2018) and application of cyber physical systems results in more efficient processes which could be connected to increasing of economic sustainability (Nagy et al., 2018).

Industry 4.0 has several tools, which could be implemented in real companies. One of them is Big data analysis, one of the most frequently used method (Sivarajah et al., 2017). There are also other approaches e. g. Internet of Things (IoT), cyber physical system and many others (Tamás and Illés, 2016; Zhong et al., 2017). According to Roblek, Meško and Krapež (2016), cyber physical systems will integrate computation, networking, and physical processes. The aim of this study is to propose a way of improving the efficiency of the material selection and manufacturing process in the selected company in line with the Industry 4.0 concept. This could be done, according to the character of the process researched, by approach called "digital or cyber twin" which is defined in Negri, Fumagalli and Macchi (2017) as the virtual and computerized part of a physical system, able to simulate it by conducting a real-time data synchronization by the use of Industry 4.0 technologies. This approach could reduce time needed for commissioning of machines but requires a higher level of planning (Ayani, Ganebäck and Ng, 2018), while 74% of time assigned to planning is needed for multimodal data acquisition and evaluation (Uhlemann, Lehmann and Steinhilper, 2017). The benefits of automated data acquisition, such as automated derivation of optimisation measures and capturing of motion data are presented in Uhlemann et al. (2017). The concept of digital twin can be used e. g. in CNC programs designed for punching machines (Moreno et al., 2017) in order to make the process of cutting more efficient (Botkina et al., 2018), into cyber-physical cloud manufacturing (CPCM) systems (Hu et al., 2018; Kunath and Winkler, 2018), into manufacturing cyber-physical system (MCPS) (Leng et al., 2018), in the cloud assisted cyber-physical systems (CPPS) (Nagy et al., 2018; Wan and Xia, 2017; Zhang, Zhang and Yan, 2018) in the smart process planning of the construction of the diesel engine parts (Liu et al., 2018), or could be helpful to support job scheduling in cyber-physical production systems. Many other applications of digital twins are mentioned in Kritzinger et al. (2018), Negri, Fumagalli and Macchi (2017), Padovano et al. (2018).

2 METHODOLOGY

As primary sources, internal documents of the firm selected including its internal database as well as the knowledge of its employees were used. The study was conducted based on the analysis of an automotive company located in Slovakia, processing a natural leather material that enters the process of a large-scale production. Since the material explored is of a natural origin, it contains various defects. Hence, it is used only to a certain extent, i.e. there is always some inefficiency which could be decreased by proper management and change in the way the processes are conducted. Some studies conducted by Pringle, Barwood and Rahimifard (2016), Stepanov et al. (2015) proposed a new point of views connected with leather processing. Some of them are directly connected to leather cutting for the needs of automotive industry (Grieco, Pacella and Blaco, 2017).

Testing the ways of improving the efficiency of a material processing is very costly, if carried on a real production line. Therefore, a solution for the company lay in providing the “offline testing”, realized outside the real production process, in our case in a digital environment. The concept of Industry 4.0 – Digital twin was implemented.

The objective of the study was to provide the answer to the following question: Could the efficiency of the material selection and processing in selected company be increased in case of different processes settings? Due to the complexity of this question, three partial objectives were defined.

The first partial objective was to find out if the yield changes in case of changing the order in which the material enters the production process. The efficiency of that process was watched and expressed through the indicator "*yield of the material*" defined as follows:

$$Yield(\%) = \frac{UMA}{TMA} \tag{1}$$

where *UMA* is Usable Material Area, *TMA* is Total Material Area, where the "*usable material area*" represents the material area which is suitable for being used in a given process.

In order to achieve the first partial objective, the sample of 22 material pieces was chosen, which were processed by selected company in specific period in past, using "First In - First Out" (FIFO) order. By each piece, a certain yield was achieved, as recorded from the firm's internal database. In the virtual experiment, the material was arranged in ascending and then in descending order according to the Internal Quality Control Index (IQCI), which represents a quality of the material detected at the entrance check and the value of yield observed.

The second partial objective was to find out if the yield changes in case of changing the strategy used for material processing. In the company, there is a software used for finding out the suitable way of the use of defect-free parts of the material, with the overall aim to reduce waste. The software decides what shapes should be cut from the defect-free parts of the material in order to satisfy customer needs. The software has currently 15 strategies programmed. For the selected material sample, the strategy No. 1 was used. In the virtual experiment, all available strategies were applied for each material piece and the achieved yield was recorded.

The third partial objective was to find out if the efficiency changes in case of providing a significant system change – a transition from online to offline process flow.

During the online process flow, material received from the supplier is registered and it is subject to entrance check. Then, natural material errors are detected and marked manually. Later, the material is scanned and its suitable use is determined by the firm's software. Finally, material proceeds to the process of cutting and other operations. All these processes are running online, i.e. they are a part of a real production process.

In the third experiment, the offline process flow was proposed, during which the material is scanned and its optimal use is determined by the firm's software offline, i.e. outside real production process (even before the production starts). Material scans are saved on cloud since it is commonly used method to process the data (Hu et al., 2018; Thames and Schaefer, 2016; Wan and Xia, 2017; Zhang, Zhang and Yan, 2018; Zhong et al., 2017), while the material is physically placed in warehouse. After the customer order is known, the software explores the scans on the cloud and determines a suitable strategy of further use of the material, with the aim to select material samples which achieve the highest efficiency if used for that specific order. At the time of their real need, material samples are transferred into the production process, where they undergo other operations, including cutting.

In order to achieve the third partial objective, the sample of 4 customer orders were chosen, and for each of them, 20 material pieces were processed by a company in a specific period in past with a certain level of efficiency achieved. For the third experiment, we proposed to take all those 80 material scans into consideration and proceed the following way: firstly, the first customer order will be managed. Hence, the software explores all 80 digital scans and chooses 20 of them, which will be processed with the highest efficiency if chosen for the first order. Then, from the remaining 60 scans, the software chooses other 20 ones, which will be processed with the highest efficiency if chosen for the second order, etc. In the third experiment, the efficiency of each customer order is measured. The assumption was, that since the material is selected in a more sophisticated way than by using FIFO, the achieved efficiency would be higher. Moreover, that assumption was also driven by the fact, that a variability of the material was higher due to a bigger sample used.

3 RESULTS

The first experiment proved that by changing the order in which the material enters the production process, the yield changes. Obtained results from measurement are stated in the Tab. 1.

Table 1 – Yield by Different Material Pieces Order

Material piece number (M_{No})	Yield FIFO order	Yield IQCI ascending order	Yield IQCI descending order	Material piece number (M_{No})	Yield FIFO order	Yield IQCI ascending order	Yield IQCI descending order
1	41.81	24.29	20.626	13	20.423	26.536	13.877
2	18.27	22.455	21.901	14	21.473	19.02	16.423
3	22.265	21.612	19.473	15	31.931	26.661	26.303
4	33.373	29.535	29.511	16	13.393	18.48	16.862
5	38.34	41.438	56.513	17	19.5	24.07	21.693
6	17.999	15.003	17.181	18	14.708	28.973	15.723
7	26.834	23.659	23.659	19	24.454	21.955	21.414
8	28.108	20.006	23.659	20	28.32	42.314	41.705
9	13.241	13.241	8.672	21	45.2345	37.935	50.935
10	24.771	27.073	23.828	22	19.709	27.616	20.734

Material piece number (M_{No})	Yield FIFO order	Yield IQCI ascending order	Yield IQCI descending order	Material piece number (M_{No})	Yield FIFO order	Yield IQCI ascending order	Yield IQCI descending order
11	17.583	13.776	18.101	*Weighted average*	24.90	25.101	23.472
12	24.738	19.182	21.915				

If the selected material sample had entered the process in ascending order according to IQCI criterion, there would have been an increase in yield by 0.2012% on average, in comparison with FIFO order. In order to make a conclusion that ascending order tends to affect the efficiency only in a positive way, more experiments with a bigger sample and a higher variety of material and types of customer order, ought to be conducted.

The second experiment exhibited that by changing the strategy used for material processing, the yield changes. If the selected material sample had been processed by the strategy No. 14, there would have been an increase in yield by 0.13% on average, in comparison with strategy No. 1, as depicted in the Tab. 2.

Table 2 – Yield (%) from Selected Material Pieces by Individual Strategies

M_{No}	Strategy														
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}
1	40.70	44.03	40.73	44.03	44.03	40.73	44.03	44.03	44.68	43.58	44.68	43.58	44.68	43.58	44.03
2	38.16	42.94	36.72	42.94	38.38	36.00	38.38	39.82	29.60	34.73	29.60	34.73	29.60	34.73	42.94
3	21.62	21.11	21.62	21.11	21.07	21.62	21.43	21.43	23.22	21.47	23.22	21.47	23.22	21.47	21.11
4	24.30	25.25	24.30	25.25	25.25	22.22	25.25	25.25	21.90	24.16	21.90	24.16	21.90	24.16	25.25
5	37.05	35.29	37.05	35.29	41.84	41.84	41.84	41.84	42.27	42.27	42.67	42.27	42.67	42.27	35.29
6	19.70	15.40	19.70	18.97	13.61	15.40	13.61	13.61	21.49	19.70	21.49	19.70	21.49	19.70	15.40
7	22.66	17.75	22.66	16.39	18.04	19.64	21.80	20.99	21.51	22.55	21.51	22.90	21.51	22.90	17.75
8	20.99	16.96	20.28	16.96	17.47	18.16	17.47	14.12	19.77	19.41	19.77	19.05	19.77	19.5	16.96
9	10.10	14.63	10.10	14.63	14.63	12.43	14.63	14.63	13.60	10.07	13.60	10.07	13.60	10.07	14.63
10	21.81	19.40	19.40	17.46	21.35	20.69	21.35	17.46	18.60	22.25	18.97	21.89	18.97	22.62	19.40
11	23.62	23.62	23.62	23.62	15.37	17.99	21.00	23.62	18.50	22.43	18.90	22.82	18.90	23.22	23.62
12	23.92	23.51	23.92	23.51	23.51	23.92	23.51	23.51	17.83	22.69	17.83	23.51	17.83	23.51	23.10
13	18.78	13.88	18.78	13.88	13.88	18.78	13.88	13.88	13.88	18.78	13.88	18.78	13.88	18.78	13.88
14	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.73	14.30	14.73	14.30	14.73	14.30	14.73
15	32.45	32.05	32.85	32.48	32.05	32.45	32.45	32.45	31.65	32.05	31.65	32.05	31.65	32.45	32.05

M_{No}	Strategy														
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}
16	18.25	17.48	18.25	17.48	17.48	13.68	17.48	17.48	17.09	17.48	17.09	17.86	17.09	17.86	17.48
17	32.16	31.37	32.16	31.37	27.51	32.16	27.51	27.51	30.98	30.59	30.98	30.59	31.37	30.59	27.12
18	15.72	15.28	15.72	15.28	15.28	15.72	15.28	15.28	15.28	15.72	15.28	15.72	15.72	15.72	15.28
19	27.26	22.98	27.65	22.98	22.98	27.26	22.98	22.98	27.26	26.87	27.26	27.26	27.26	27.26	22.19
20	43.79	38.51	43.79	38.51	47.84	43.79	48.25	48.25	37.70	42.56	37.70	43.38	37.70	43.38	42.56
21	47.63	45.95	47.20	45.95	41.23	49.37	45.08	45.08	45.95	49.37	45.95	48.93	45.95	50.23	45.95
22	19.71	20.92	19.71	20.92	20.92	19.71	19.71	19.71	20.92	20.31	20.92	20.31	20.92	20.31	20.92
Yield (%)	*26.16*	*25.14*	*25.96*	*25.16*	*24.94*	*25.36*	*25.56*	*25.36*	*24.92*	*26.07*	*24.97*	*26.16*	*25.01*	*26.29*	*25.07*

The third experiment confirmed that by providing a significant system change from online to offline process flow, the efficiency changes. If the selected material sample had been processed in a proposed offline way, there would have been an increase in efficiency by 0.55% on average, in comparison with the online way.

Table 3 – Efficiency by Customer Orders O1 – O4

Customer order number	Material number	Efficiency (%) Online process	Efficiency (%) Offline process
O1	1 – 20	54.90	56.46
O2	21 – 40	55.70	56.01
O3	41 – 60	55.60	55.91
O4	61 – 80	55.40	55.41
Average		*55.40*	*55.95*

4 DISCUSSION

The first and the second experiment proved that by changing the order in which the material enters the production process, as well as the strategy used for material processing, a higher yield could be achieved, which would save the company a significant amount of money in the long run, depending on company's specifics. Therefore, it is important to choose the right order and strategy at right time. Due to the natural origin of the material explored, more sophisticated methods have to be used for that purpose. Hence, we suggest the implementation of machine learning in the future.

The third experiment was designed in a simplified way in order to test its functionality in a firm environment. However, since it proved the assumed increase in efficiency, we propose to conduct more extended experiments in the future, by which a bigger material sample will be used. Moreover, we suggest the creation of a consignment stock in the firm's premises, where the supplier will have an online access to the information about the stock level and, thus, will be able to replenish the stock as soon as they leave the warehouse. That way, the software could always choose from 80 digital material scans, which could lead to the increase of the efficiency even more. Furthermore, the software should incorporate a feature alerting the presence of the material pieces in the warehouse, which have not been selected over a longer period to prevent them from expiration.

However, it is necessary to consider, that there should not be big differences in the efficiency achieved by processing the material for single customer orders. The aim is to achieve the highest possible efficiency in the selection and processing process of the material while preserving its sustainability (Wolf, Meier and Lin, 2013/2014; Zgodavová et al., 2019). Therefore, we propose to define the maximum level of efficiency which can be achieved for a specific customer order. In case of a higher efficiency level, material samples with the highest usability should be kept for a different customer order. For this purpose, the software should become familiar with the potential upcoming customer orders for a reasonable period. That step could prevent a high efficiency variability as well as can increase the overall average efficiency achieved.

5 CONCLUSION

All those three experiments were conducted in a virtual environment using computing capacities, since the cost savings linked to the increase in efficiency would be useless if conducting them in a real environment, using the real production capacities. Industry 4.0 brings about solutions which allow finding more efficient ways of conducting processes without blocking the real production capacities. Considering a relatively high price of the input raw material, which is a subject to exploration in this study, as well as more demanding customer requests, the reasonable way for companies to achieve competitive advantage is to focus on decreasing the costs. For this purpose, the use of the Industry 4.0 principles becomes a must.

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ABOUT AUTHORS

Miroslava Horváthová – Department of Quantitative Methods, Faculty of Business Economics with seat in Košice, University of Economics in Bratislava, Tajovského 13, 041 30 Košice, Slovakia. E-mail: miroslava.horvathova@student.euke.sk, Author's ORCID: 0000-0002-7673-4444.

Roman Lacko – Department of Economy, Faculty of Business Economics with seat in Košice, University of Economics in Bratislava, Tajovského 13, 041 30 Košice, Slovakia. E-mail: roman.lacko@euke.sk, Author's ORCID: 0000-0002-5801-1998.

Zuzana Hajduová – Department of Business Finance, Faculty of Business Management, University of Economics in Bratislava, Dolnozemská cesta 1, 852 35 Bratislava, Slovakia. E-mail: zuzana.hajduova1@gmail.sk, Author's ORCID: 0000-0002-9381-776X.

Possibilities of Using Graphical and Numerical Tools in the Exposition of Process Capability Assessment Techniques

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Josef Tošenovský, Filip Tošenovský

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ABSTRACT

Purpose: The paper focuses on how the problem of process capability assessment can be handled when taught, using convenient numerical and graphical means. The contents of the paper results from the authors' own academic and practical experience, which suggested that many important steps are overlooked in the process of selecting and using capability indices.

Methodology/Approach: Selected problems in capability assessment are illustrated with suitable examples and graphs.

Findings: The authors' experience is reflected in the paper, aiming to emphasize what matters and how, and what does not. Also, a new capability index is introduced.

Research Limitation/implication: The style in which the problems are analysed may serve as a guide for further studies in the field and capability index applications.

Originality/Value of paper: The paper also contains, aside from specific examples, some more advanced techniques, and is therefore accompanied by software readouts, since computer support is required in such cases.

Category: Conceptual paper

Keywords: process capability; capability index selection; process robustness

1 INTRODUCTION

This paper presents our experience with education in the field of process capability assessment. It is intended for everyone who plans to dedicate their career to process evaluation and is willing to practise it credibly in the future. During courses run in a selected corporate sector, we encountered many imperfections, ambiguities and problems that we tried to clarify in the paper in an illustrative way, using computational examples and graphical tools. We would like to pass on some of what we have learnt in this process to the interested reader. The paper consists of several sections that cover both univariate and multivariate capability indices. Since univariate indices are more popular, the emphasis is placed on them, and diverse practical situations are dealt with based on how the problem at hand is defined. The text begins with conditions that should be met in order for a capability index to work properly, and then moves on to the problem of selection of an appropriate index. The latter, in particular, has to do with the specific situation the index user happens to find himself in. Further, the paper also pays attention to the evaluation of capability indices and the term “robustness” that has its place in the theory of process capability assessment for all those who seek excellence (Zgodavova and Slimak, 2008).

2 PROCESS CAPABILITY ASSESSMENT AND CONDITIONS

capability index formula being applied without seeing the broader picture of doing so. We shall therefore start our pedagogical journey with the interpretation of formulas. Each capability index is given by a formula that can only be used under certain conditions. If B denotes such a formula, we can view its use as a result of the implication $A \Rightarrow B$, where A stands for the conditions. If the conditions A hold, the formula B is true. The formula will certainly work when the conditions are met. It may also happen to work when the conditions fail to hold, but it may not work, so it is advisable to avoid using it when the conditions are not met because we are not certain what will happen. Thus, knowing the conditions is fundamental to putting the indices to use.

The practice, it appears, is such that only one specific capability index is applied, whatever the process, or such usage is even required in this context. These situations usually concern the C_{pk} capability index. But an application of C_{pk}, or any other index, is linked to the conditions for its use, as we already know. Let us start with the conditions. To make them systematic and facilitate orientation within their framework, we now divide them into two categories. We work with:

- general conditions,
- specific conditions.

The general conditions are those that must *always* be met, regardless of the capability index used. If they do not hold, one cannot continue to assess process capability with an index. The problem must be removed before any capability assessment takes place.

The specific conditions are index-specific extra conditions which must hold in addition to the general conditions. These conditions usually accompany the definition of a capability index. Both the general and specific conditions should be verified with statistical tests, or also in combination with suitable graphical methods. Nowadays there are capability indices suitable basically for any situation, so there is no reason to improvise and use a specific index outside the conditions that define its application. In this context, it is perhaps necessary to say that when an organization strictly requires that its suppliers calculate a specific index, such as C_{pk}, regardless of whether the index matches the suppliers' production environment, it does not boost its credibility. In these cases, one may ask what good such an index is and how serious the customer is about it. Since, as is known, the customer must be complied with, one way of proceeding is to present the required index with a supplementary explanation what the specific environment of the organization is, and what adequate index should be applied. Such an index should be announced, and the attention should be drawn to the potential discrepancy between the two indices and the unreliability of the required index. Companies often do not comply, if assessed by the required index, but do comply with the standards set by the proper index!

The *general conditions* are related to the evaluated *process*, *data* and *tolerance*. They are:

- The *process* is stable.
- The *data* on the process are independent, without outliers, sufficient in size.
- The *tolerance* is specified correctly.

If any of the conditions fails, it is advisable not to calculate the capability index. Otherwise, the resulting value is unreliable. It is overestimated or underestimated, depending on which condition failed to hold. The value of the index can also be meaningless. Note that *normality* of the data is not among the general conditions. Process capability can be evaluated without normality. In relation to these conditions, many questions arise that the user of an index should ask, such as how to verify the validity of the conditions, what exactly happens when they do not hold, or how to proceed in the less favourable situation when they fail. Comparing various scholarly publications on capability assessment, we find out that the set of conditions differs slightly among the authors, however there is definitely a consensus regarding the condition of process stability. This condition is crucial.

A process is stable in the statistical sense of the word when all its monitored quality characteristics lie within the control limits of the corresponding control charts. Of course, this means that control charts must be an established tool in organizations. This, however, can be a problem. It seems that many organizations do not know that when control charts are not available, it is possible to verify the process stability easily, fast and reliably with a statistical test. This is true even when more than one quality characteristic is observed for a process. The truth is that such a test is not commonly implemented in statistical software packages, but the situation is not hopeless. The interested reader may find a theoretical exposition of the tests in Holmes and Mergen (1995), its practical use is implemented, for instance, in the computer program *Capa* (Tošenovský, 2006).

When analysing a process, defining the tolerance for its quality characteristic(s) and gathering data on the process is how the capability assessment begins. What then follows is the selection of an appropriate capability index.

3 SELECTION OF A CAPABILITY INDEX

When selecting a univariate index (one quality characteristic observed), verifying normality of the data should be the first step. If the data come from a normal distribution, the next step is to further narrow down the selection so that it is in line with the type of tolerance worked with. Tab. 1 shows the situation, including the selection procedure in the case of non-normal data.

Table 1 – Capability Index Selection Scenarios

One quality characteristic observed			
Normal distribution – tolerance:		**Non – normal distribution:**	
Symmetric	$C_p, C_{pk}, C_{pm}, C_{pmk}$ (Kotz and Johnson, 1993)	Mass production	Special indices (Pearn and Kotz, 1995; Clements, 1989)
Asymmetric	C^*_{pm} (Chan, Cheng and Spiring, 1988)	Unit production	Q, C_{pT} (Schneider, Pruett and Lagrange, 1996)
One-sided	C_{pp}, C_{pT} (Phillips, 1995; Schneider, Pruett and Lagrange, 1996; Krishnamoorthi, 1990)	Attributes	(Bothe, 2000)
Unbounded	Modified C_{pm}, C_{pk}		

3.1 Symmetric Tolerance

The procedure of assessing capability for the case of symmetric (and asymmetric) tolerances is well-known. Let us note that all the frequently applied indices C_p, C_{pk}, C_{pm}, C^*_{pm} and C_{pmk} have data normality as their specific condition of use, and for C_p, there is an additional condition $\mu = T$, i.e. the process must be centred. Unlike other indices, C_p does not reflect the extent to which the expected value μ of the quality characteristic complies with the defined target T. Thus, it can happen that an uncentered process with small σ can have a better C_p than a centered process with far higher variability σ: for the specifications LSL = 10, USL = 16, T = 13, for instance, the process for which:

a) $\mu = T = 13$ (a perfectly centered process), $\sigma = 1$, the index equals 1;

b) $\mu = 19$ (a process off the target), $\sigma = 0.5$, the index equals 2.

Regarding C_{pk}, where data normality is the only specific condition, a lack of centralization can be offset by a reduction in the variability of the quality characteristic, if this is possible (see the example below). It can be used for technologies where there is no problem to adjust both the expected value μ of the quality characteristic and its variance σ^2. If it is convenient for the producer to keep μ near one of the tolerance limits, it will follow this strategy. To give an example, for a supplier of sand, for the humidity of which the target value is T and the lower and upper tolerance limits are LSL and USL, respectively, it is convenient to keep the average humidity μ close to USL (the weight of sand pays) and keep σ^2 at the same time at such a level that the required value of C_{pk} will be fulfilled. In the documentation provided by the customer, it is therefore not enough to state the intended value of C_{pk}. The requirement $\mu = T$ should be mentioned, as well. To use specific values, let us assume $USL = 65$, $LSL = 35$ and $T = 50$. The expected value is pushed away from the target value, but σ is being reduced at the same time (see the values below for the two characteristics). In all the cases, $C_{pk} = 1$.

a) $\mu = 50$, $\sigma = 5$,

b) $\mu = 53$, $\sigma = 4$,

c) $\mu = 56$, $\sigma = 3$,

d) $\mu = 59$, $\sigma = 2$.

We shall now comment on other situations listed in Tab. 1.

3.2 Unbounded Tolerance

This is the case when one of the tolerance limits is unbounded. In tis case, we arrive at the modified versions of C_{pm} and C_{pk}. The modified C_{pm} is:

for the case $LSL = -\infty$

$$C^*_{pm} = \frac{\min\{USL - T, T - (-\infty)\}}{3\tau} = \frac{USL - T}{3\tau} \tag{1}$$

and for the case $USL = +\infty$

$$C^*_{pm} = \frac{\min\{+\infty - T, T - LSL\}}{3\tau} = \frac{T - LSL}{3\tau} \tag{2}$$

where

$$\tau^2 = n^{-1}\sum_i (x_i - T)^2 \tag{3}$$

If no T is defined, one may modify the C_{pk} index. The modified index is calculated as follows:

for the case $LSL = -\infty$

$$C_{pk} = \frac{USL - \mu}{3\sigma} \tag{4}$$

and for the case $USL = +\infty$

$$C_{pk} = \frac{\mu - LSL}{3\sigma} \tag{5}$$

3.3 One-sided Tolerance

There are situations when the target value T equals one of the tolerance limits $T = USL$ or $T = LSL$. In technical documentation, the situation is denoted as T^{-0}_{+d} or T^{-d}_{0}, when T = LSL or T = USL, *d* being the tolerance (Schneider, Pruett and Lagrange, 1996). Strictly speaking, this is not an asymmetric tolerance. It is not reasonable to use C_{pk} for this type of tolerance, as we shall see. The situation is illustrated in Fig. 1 and Fig. 2. Let us recall that the objective of capability assessment is to make a judgement on process centralization and variability. Fig. 1 shows the case $T = LSL$.

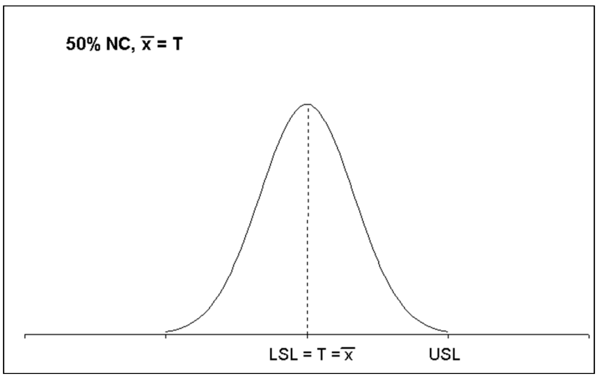

Figure 1 – $\bar{x} = T$ but NC = 50%

Assuming that the process is centred, or the sample average of the observed quality characteristic is equal to the target value, then fifty per cent of the process output will be flawed, in other words, it will represent nonconforming products (NC). If the process is not centred, but its output is within the tolerance limits (no flawed products), the target value will never be achieved, as shown in Fig. 2.

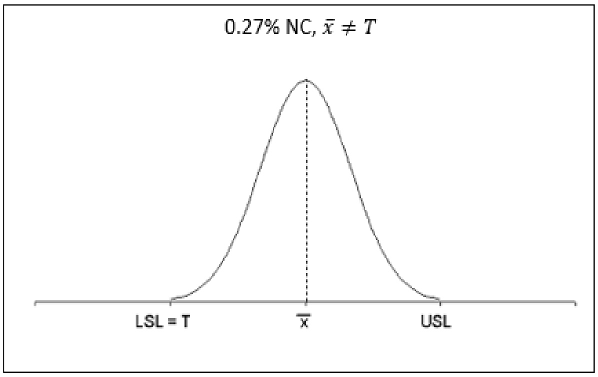

Figure 2 – NC = 0.27%, but $\bar{x} \neq T$

It is not possible to comply with both requirements – being centred and minimize NC. Producers proceed in such cases logically – their process follows the center of the tolerance interval. This explains why there is no point in using C_{pk}, which evaluates the amount of centralization, purposefully violated in this case. The C_{pp} and C_{pT} indices, on the contrary, seem very suitable here (Schneider, Pruett and Lagrange, 1996). They can be applied to both the two-sided and one-sided tolerances, regardless of whether the data the indices are calculated from come from a normal distribution. For non-normal data, one can proceed in more than one way. Special indices can be used, or the data may be transformed so that their true distribution is brought closer to normality. A separate category is represented by non-measurable quality characteristics (attributes) and the so-called unit production.

4 ROBUSTNESS AND ITS SIGNIFICANCE

After an index is calculated, it should be evaluated (Tab. 2), i.e. a judgement should be made as to whether its value is high enough for the given amount of data, from which it was calculated, and whether there is enough room for a potential process deterioration, i.e. how robust the process is.

The property that when the average of a process quality characteristic deviates from the target value, yet it doesn't lead to a higher number of NC products, is called process robustness. It can be quantified by the equation:

$$R = 3\sigma(C_p - 1) \tag{6}$$

R describes the distance by which the average μ can move away from the target value T without the process losing its capability. The distance is expressed as a multiple of σ. To give an example of this interpretation, let $C_p = 1.33$. Then $(USL - LCL)/6\sigma = 1.33 \Rightarrow USL - LSL = 7.98\sigma \cong 8\sigma$. The length of the tolerance interval, a multiple of σ, is roughly 8σ. The length containing for a normally distributed quality characteristic 99.73% of its values is 6σ. Calculating the robustness, we have $R = 3\sigma(1.33-1) = \sigma$. Looking at Fig. 3, we see the average can shift from T by σ without increasing palpably NC.

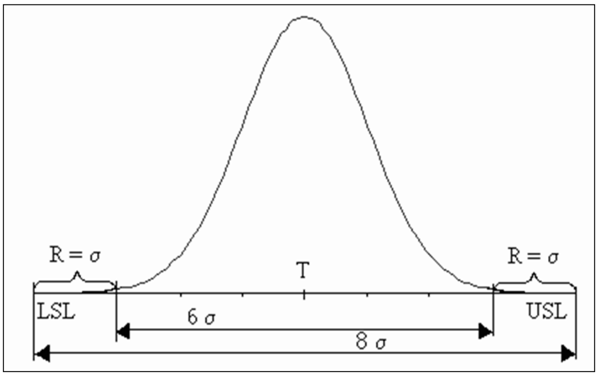

Figure 3 – Robustness R = σ

To give another example, if $C_p = 1.67$, then $(USL - LCL)/6\sigma = 1.67 \Rightarrow USL - LSL = 9.96\sigma \cong 10\sigma$ and $R = 3\sigma(1.67-1) \approx 2\sigma$.

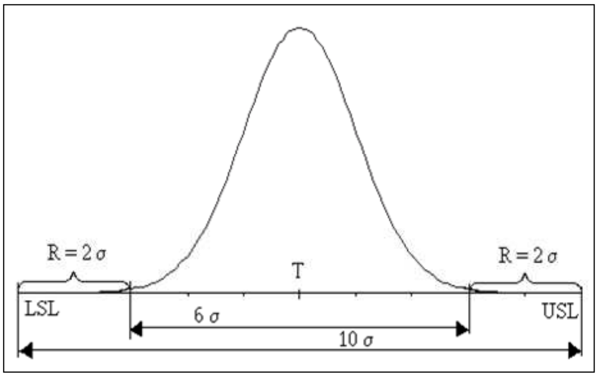

Figure 4 – Robustness R = 2σ

For $C_p = 1$, $R = 3\sigma(1-1) = 0$ (Fig. 5). R = 0 means that even a very small deterioration leads to process incapability (to exceeding the tolerance limits).

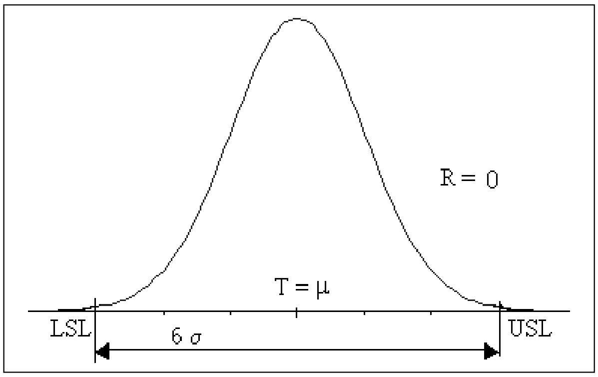

Figure 5 – Robustness R = 0

Aside from robustness, there are other reasons why the capability index should be well above 1. To give an example, let us assume that an aggregate is made up of 400 components, each of which is produced with the philosophy that it is enough to lie within the tolerance limits, i.e. $C_{pk} = 1$. Then *NC*, or the probability that a part is outside the tolerance, is 0.0027, but the probability of *at least* one part being outside the tolerance is, under the binomial model:

$$P = 1 - \binom{400}{0} \cdot 0.0027^0 \cdot (1 - 0.0027)^{400} = 0.6609$$

There is a 66.09 per cent chance that at least one component will be an *NC*, and the aggregate will not function properly! By comparison, for $C_{pk} = 1.33$, the *NC* is 0.000066 and the probability of having at least one of the 400 components malfunctioning is:

$$P = 1 - \binom{400}{0} \cdot 0.000066^0 \cdot (1 - 0.000066)^{400} = 0.026$$

The probability of having a defective aggregate is only 0.026 in this case!

5 EVALUATION OF A CAPABILITY INDEX

Denoting by $\hat{c}_{pm}$ the estimate of the population index C_{pm}, the two indices are naturally not the same, generally speaking. The customer demands the C_{pm}, the supplier can offer only the estimate unless it checks the whole production, which is something that usually exists only in theory. When testing significance of the estimate, given a probability *p* and a number of measurements n, we ask the question what its value must be so that the C_{pm} attains a required level *C*. Thus, we are looking for a certain value $\hat{C}_{pm}$(min). For the most frequently used indices C_p, C_{pk}, C_{pm}, C^*_{pm} and C_{pmk}, this problem is tackled in various ways. For instance, Tošenovský (2006) with the help of *Capa* follows the procedure described in Tab. 2. The table shows different ways of evaluation of the five indices. In practice, such an evaluation is unfortunately seldom performed.

Table 2 – Evaluation of Significance for Selected Capability Indices

Index	**Evaluation**
C_p	Correction (Lewis, 1991)
C_{pk}	Correction (Lewis, 1991)
C_{pm}	Test + $\hat{C}_{pm}$(min) (Chan, Cheng and Spiring, 1988)
C^*_{pm}	Test + $C^*_{pm}(\min)$ (Chan, Cheng and Spiring, 1988)
C_{pmk}	Test (Pearn and Lin, 2002)

If an index is not calculated from the population, it is overestimated. The smaller the data sample, the more severe the overestimation, as shown in Tab. 3 and Fig. 6. To correct such an index means to remove the overestimation. The corresponding procedure is described in Lewis (1991).

Table 3 – Overestimation of the Indices C_p and C_{pk}

Sample Size	**Overestimation (%)**	
	C_p	C_{pk}
40	19	24
50	17	21
60	15	19
70	14	18
80	13	17
90	12	16
100	12	15
150	10	12

For instance, for n = 150, the amount of overestimation is 10% for C_p and 12% for C_{pk}.

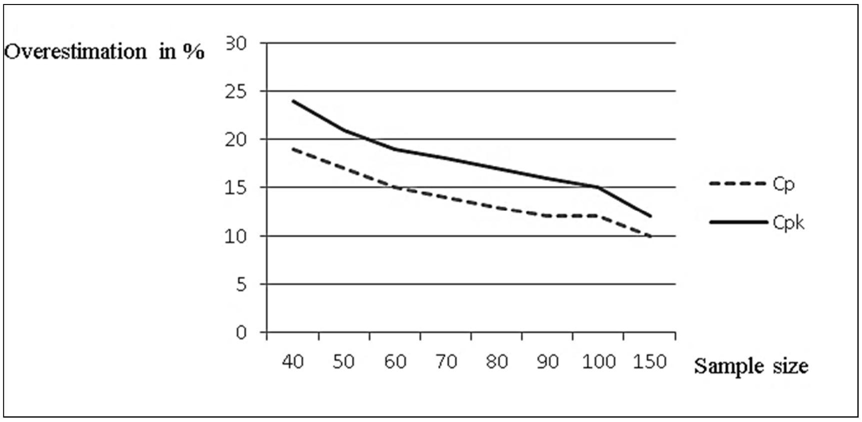

Figure 6 – Overestimation in per Cent of C_p *and* C_{pk} *with Respect to n*

To make a more exact judgement about the significance of the sample indices, one should perform a statistical test. Nevertheless, such a test only gives information on whether the estimated index is or is not sufficiently high, and so, as mentioned earlier, it is also useful to calculate $\hat{C}_{pm}(\min)$ or similar characteristics.

Tab. 4 shows how $\hat{C}_{pm}(\min)$ depends on the sample size *n,* significance level *p* and the required value of C_{pm}.

Table 4 – Values of $\hat{C}_{pm}(\min)$

	Required values of the population index					
	Cpm = 1.0		*Cpm = 1.33*		*Cpm = 1.67*	
n	*p = 0.95*	*p = 0.99*	*p = 0.95*	*p = 0.99*	*p = 0.95*	*p = 0.99*
10	1.56	1.97	2.11	2.62	2.66	3.28
50	1.19	1.29	1.59	1.72	2.00	2.15
75	1.15	1.23	1.53	1.63	1.93	2.04
100	1.13	1.19	1.50	1.58	1.89	1.98

For instance, given the sample size of 10, the required value of 1.33 and the degree of reliability 0.95, the estimated index must attain or exceed the value 2.11, whereas for *n* = 100, the value 1.50 will suffice. If the tables on $\hat{C}_{pm}(\min)$ are available, they will only list specific options for C_{pm}, as shown in Tab. 4. The tables are also given for *n* ranging from 3 to 100 and for *p* = 0.9 or *p* = 0.95 or *p* = 0.99. To make similar calculations of $\hat{C}_{pm}(\min)$ for any *n*, *p* and C_{pm}, a special software must be used (Tošenovský, 2006).

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6 MULTIVARIATE INDICES

The multivariate indices are used if:

a) more operations are performed on a product, so that when evaluating the process (or the sequence of operations), more quality characteristics are observed, or
b) a product is made up of several components, each of which possesses a quality characteristic, and the product is evaluated as a whole.

When more quality characteristics are observed, it is not recommended to evaluate them separately with the aforementioned indices. When they are evaluated separately, then:

a) the process is not assessed as a whole, individual operations or components are evaluated instead,
b) if the characteristics are dependent, then not even a single operation is assessed, as the effect of the other operations is not factored into such a calculation.

In these cases, special multivariate capability indices were designed as well as graphical methods. The multivariate indices are denoted MC_p, MC_{pk}, MC_{pm}. For an index to be selected for use, it must satisfy proper conditions (see Tab. 5).

Table 5 – Conditions to Be Met by Multivariate Indices

MC_p, MC_{pm}	MC_{pk}
Normally distributed quality characteristics with two-sided tolerances. They do not have to be independent.	Independent quality characteristics X_i (this also concerns attributes) with any type of tolerance. Normality is not necessary.

To get the idea about the indices, we illustrate the situation with the bivariate version of the MC_p index. Let there be two observed quality characteristics X_1, X_2, and let the corresponding random vector (X_1, X_2) has the normal distribution $N(\mu, V)$. Further, let T_i be the target value for X_i, LSL_i be its lower specification limit and USL_i be its upper specification limit. The region of admissibility is then represented by a tolerance rectangle defined by the values LSL_1 and USL_1 on the X_1– axis and the values LSL_2 and USL_2 on the X_2– axis in the plane (Fig. 7, Fig. 8).

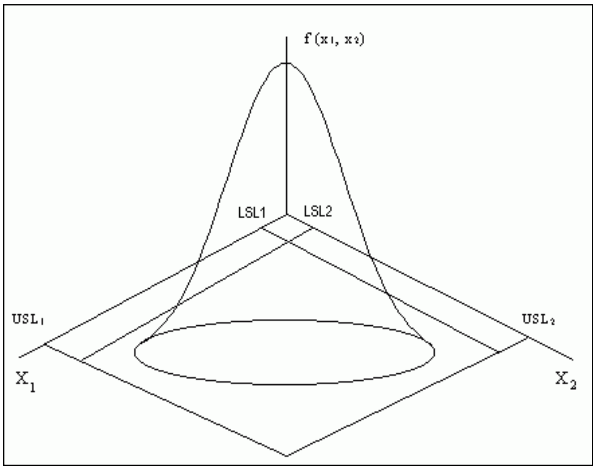

Figure 7 – A Bivariate Normal Distribution for (X_1, X_2)

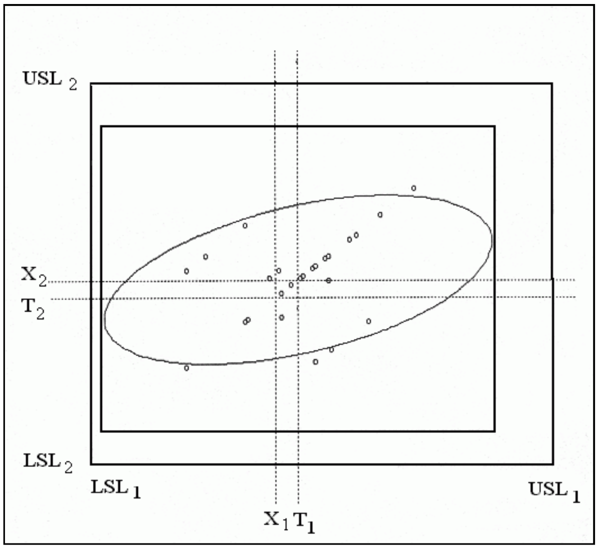

Figure 8 – A View of the Plane $X_1 \times X_2$

The target values T_1 and T_2 are the coordinates of the *center of specification* T, the actually achieved average values $\overline{X}_1, \overline{X}_2$ are the coordinates of the point $\overline{X}$. The distance between T and $\overline{X}$ suggests the amount of process decetralization. Fig. 8 shows measurements and the *ellipse* attained by making a cut through the graph of the bivariate normal density $f(x_1, x_2)$ (Fig. 7), the cut being parallel to the plane $X_1 \times X_2$.

The sets of points at which the density is constant satisfy the equation:

$$(\overline{X}-T)^T V^{-1}(\overline{X}-T)=\chi_2^2(\alpha) \tag{7}$$

where $\overline{X}=\begin{pmatrix}\overline{X}_1\\ \overline{X}_2\end{pmatrix}$, $T=\begin{pmatrix}T_1\\ T_2\end{pmatrix}$ and $V=\begin{pmatrix}\sigma_1^2 & \sigma_{12}\\ \sigma_{12} & \sigma_2^2\end{pmatrix}$ is the variance matrix of (X_1, X_2).

When working with three quality characteristics X_1, X_2, X_3, the formula represents a *rotational ellipsoid.*

Fig. 10 and Fig. 11 are analogies. The figures represent the projection of the tangent parallelepiped of the ellipsoid onto a selected plane $X_i \times X_j$. The plane is depicted as a rectangle together with the specification rectangle for the variables X_i and X_j. The depicted ellipse is not a projection of the ellipsoid. It is a projection of its cut through the plane which is parallel to the plane $X_i \times X_j$ and runs through the center of the ellipsoid $\overline{X}=(\overline{X}_1,\overline{X}_2,\overline{X}_3)$. Since the cut is led through the center, the tangent parallelepiped may not touch the ellipse. In the case of three quality characteristics, the projection can be made onto the planes $X_1 \times X_2$, $X_1 \times X_3$ and $X_2 \times X_3$.

The bivariate index MC_p is defined similarly as C_p, i.e. as the ratio of the area that should contain measurements of the observed quality characteristics (the tolerance area) and the area that actually contains the measurements. While the interval of the length 6σ stands for the true location of measurements in the C_p case, the bivariate index MC_p utilizes the ellipse or rectangle skirting the edges of this ellipse in the plane $X_1 \times X_2$ (the tangent rectangle). In the formula (8) for the bivariate index, it is defined by the points L_1, U_1, L_2, U_2:

$$MC_p=\frac{(USL_1-LSL_1)(USL_2-LSL_2)}{(U_1-L_1)(U_2-L_2)} \tag{8}$$

Similarly, for the k-dimensional index MC_p, $k>2$, we observe and evaluate:

a) the process centralization, using the so-called Hotelling's statistic (Hubele, Shahriari and Cheng, 1991),

b) the multivariate capability index (Pearn and Lin, 2002):

$$MC_p=\frac{\Pi_{i=1}^k(USL_i-LSL_i)}{\Pi_{i=1}^k(U_i-L_i)} \tag{9}$$

While, for instance, Kotz and Johnson (1993) use in the denominator of MC_p the volume of the rotational ellipsoid, (9) calculates the volume of the tangent parallelepiped, defined by the numbers U_i, L_i. The required limits U_i, L_i can be read from Fig. 10 and Fig. 11 (software *Capa* used in this example):

c) the characteristic *M* that identifies outliers (Hubele, Shahriari and Cheng, 1991) is $M = \max\left\{1, \frac{|U_1 - LSL_1|}{USL_1 - LSL_1}, \frac{|L_1 - USL_1|}{USL_1 - LSL_1}, ..., \frac{|U_k - LSL_k|}{USL_k - LSL_k}, \frac{|L_k - USL_k|}{USL_k - LSL_k}\right\}$

M should be less than one. For two variables X_1, X_2, we have:

$$M = \max\left\{1, \frac{|U1 - LSL1|}{USL1 - LSL1}, \frac{|USL1 - L1|}{USL1 - LSL1}, \frac{|U2 - LSL2|}{USL2 - LSL2}, \frac{|USL2 - L2|}{USL2 - LSL2}\right\} \tag{10}$$

Fig. 9 shows various limits used to calculate the characteristic.

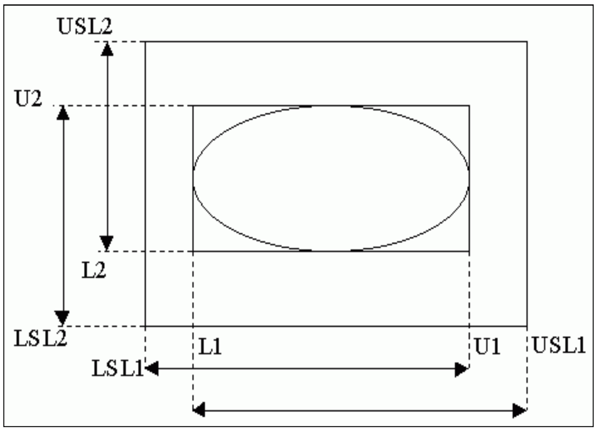

Figure 9 – Parameters for the M Characteristic

To give an example, if we are to calculate the MC_p index for a process with three quality characteristics X_1, X_2, X_3, obtaining the data by examining the graphs, the procedure will be as follows:

Process Specifications:

$USL_1 = 240$, $LSL_1 = 100$, $USL_1 - LSL_1 = 240 - 100 = 140$;

$USL_2 = 80$, $LSL_2 = 20$, $USL_2 - LSL_2 = 80 - 20 = 60$;

$USL_3 = 24$, $LSL_3 = 11$, $USL_3 - LSL_3 = 24 - 11 = 13$.

The limits U_i, L_i, necessary for the calculation of MC_p, can be found in Fig. 10 and Fig. 11. For X_3 and X_1, we have from Fig. 10:

$L_3 = 11.311$, $U_3 = 24.128$;

$L_1 = 114.03$, $U_1 = 240.36$;

$U_3 - L_3 = 24.128 - 11.311 = 12.817$.

For X_1 and X_2, we have from Fig. 11:
$L_1 = 114.03$, $U_1 = 240.36$;

$L_2 = 32.447$, $U_2 = 72.217$;

$U_1 - L_1 = 240.36 - 114.03 = 126.33$;

$U_2 - L_2 = 72.217 - 32.447 = 39.77$.

The numerator of MC_p contains the multiplication of the differences $USL_i - LSL_i$, the denominator involves the multiplication of the differences $U_i - L_i$, therefore:

$$MC_p = \frac{140 \cdot 60 \cdot 13}{126.33 \cdot 39.77 \cdot 12.82} = 1.695$$

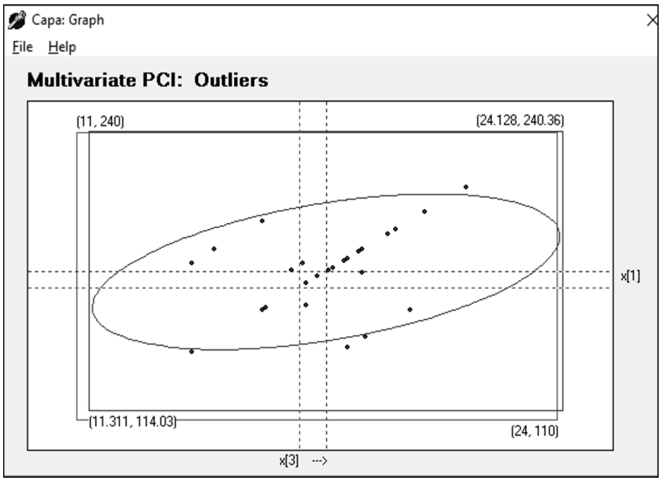

Figure 10 – A Cut for given Values of X_1 and X_3

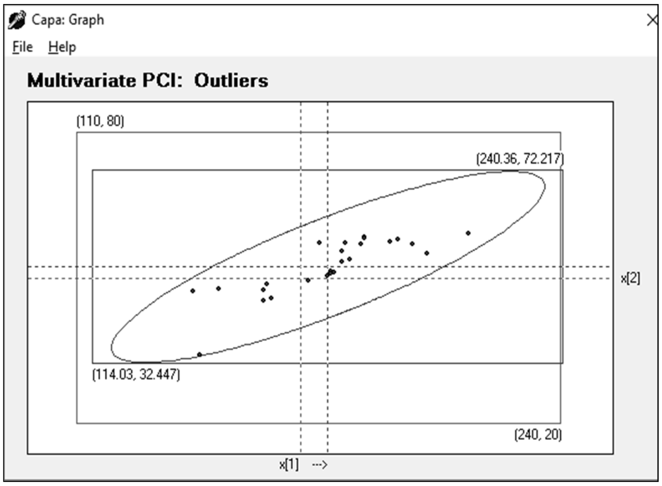

Figure 11 – A Cut for given Values of X_1 *and* X_2

The graphical representation shown in Fig. 10 and Fig. 11 enables us to get the idea about:

a) the extent of centralization,
b) the extent to which the specification rectangle is exploited,
c) the location of the ellipse inside the rectangle,
d) the specification and tangent rectangles, needed for MC_p,
e) whether any measurements happen to be outside the specification rectangle.

Working with a multivariate index, Fig. 11 can be used to assess three attributes: MC_p, centralization and outliers (Hubele, Shahriari and Cheng, 1991). Fig. 12 represents different views of the plane $X_1 \times X_2$: the minus sign means the observed criterion is not compliant, the plus signs means it is compliant (the criteria are: MC_p, $\bar{X} = T$, inequality $M < 1$).

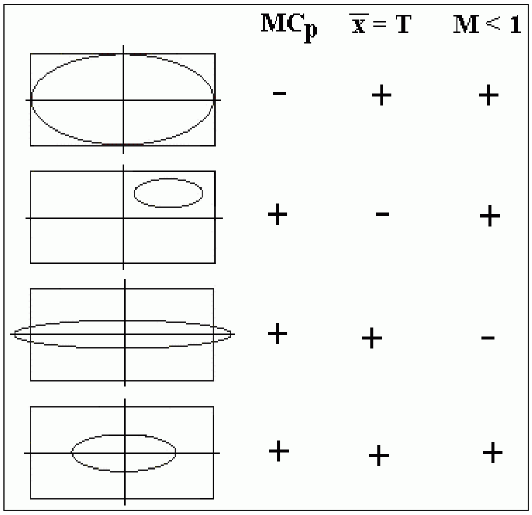

Figure 12 – Different Scenarios for Three Observed Criteria

7 A ROBUST VERSION OF THE CPK INDEX

Although data are analysed for possible outliers prior to capability index calculation, the data can be subsequently wrongly inserted in a computer, which can significantly alter the capability index being calculated. When calculating a univariate or multivariate capability index, the sample average and variance are also calculated. If the data is contaminated with outliers, moment characteristics will be biased, and so will the capability indices. This can be prevented with the following (robust) adaptation of C_{pk}: the median M is used instead of the average and the median of absolute differences MAD instead of variance, in other words MAD = med($|x_i$ – med $x_i|$).

RC_{pk} will then be calculated according to the formula:

$$RCpk = \min\left(\frac{USL - M}{3.MAD}, \frac{M - LSL}{3.MAD}\right) \tag{11}$$

We shall now illustrate the use of this robust version. For the data 12, 15, 14, 11, 10 and the specification USL = 18.61, LSL = 6.19, T = 12.4, let us calculate C_{pk} and RC_{pk} as follows:

a) C_{pk} in the standard way;

b) C_{pk} with the false value x_5 = 1.0 instead of 10;

c) RC_{pk} for flawless data;

d) RC_{pk} for flawed data: x_5 = 1.0 instead of 10.

The results are:

a) C_{pk} = 0.998 (calculated with *Capa*);

b) C_{pk} = 0.26 (average is 10.6; standard deviation equals 5.59);

c) M = 12, MAD = 2,

$$RCpU = \frac{USL - M}{3.MAD} = \frac{18.61 - 12}{3.2} = 1.102; \quad RCpL = \frac{M - LSL}{3.MAD} = \frac{12 - 6.19}{3.2} = 0.968$$
$$RCpk = 0.968;$$

d) M = 12 and MAD = 2, i.e. the same values as for the correct data, and so the index remains the same.

For the correct data, C_{pk} and RC_{pk} do not differ significantly. For the wrong data, RC_{pk} keeps its value attained for the correct data.

Knowledge of multivariate data is also used in other calculations, such as regression, where robust techniques are exploited, as well Kutner, Nachtsheim and Neter (2014). A simple and efficient procedure is, for instance, that of obtaining regression coefficients with the generalized-least-squares formula $\mathbf{b} = (X^TWX)^{-1} X^TWY$, where W is a matrix of weights. It is a diagonal matrix with elements w. Two widely used weight functions are the Huber and bisquare weight functions. According to Huber, w = 1.345/u, u = e/4.6683, where e is a residual from the classical least-squares estimation method. These techniques, studied in students' SGS projects, for instance, proved to be robust.

8 CONCLUSION

The aim of the paper was to show how educational process in the field of process evaluation can be complemented with graphical and numerical illustrations of selected chapters on this subject. We believe that visualization and numerical examples are a way to make statistical methods more popular. It is also very convenient to provide students with enough material for their self-training, with a software that provides quick solutions, is up to date in the field and can be used for real-life problems, if possible. We have prepared a 380-pages long training manual with the most frequently occurring real-life problems, illustrated with graphs and solutions. The solutions can also be obtained with the software Capa that is part of the manual (Tošenovský, 2006). Our experience is such that knowledge of modern methods of capability evaluation is needed not only for producers, but also for customers. In the latter case, lack of knowledge often leads to situations when customers require inadequate means of capability assessment.

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ABOUT AUTHORS

Josef Tošenovský – The author is a full professor at VŠB-Technical university of Ostrava, specializing in probability, statistics and econometrics. In 1988 he became an associate professor in mathematics and in 2001 a professor in Management of Industrial Systems. E-mail: josef.tosenovsky@vsb.cz, Author's ORCID: https://orcid.org/0000-0003-4684-1369.

Filip Tošenovský – The author is an assistant professor at VŠB-Technical university of Ostrava, specializing in probability, statistics, econometrics and operations research. E-mail: filip.tosenovsky@vsb.cz, Author's ORCID: https://orcid.org/0000-0003-3946-7815.

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An Empirical Study of Root-Cause Analysis in Automotive Supplier Organisation

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Anna Nagyová, Hana Pačaiová, Anna Gobanová, Renáta Turisová

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ABSTRACT

Purpose: The paper aims to introduce the practical application of using Root-cause analysis (RCA) by chosen methods of continual improvement in solving non-conformity occurrence in an organisation operating in the automotive field.

Methodology/Approach: The chosen tools of (RCA), which includes an extended version of 5W2H and 5Whys were applied. Both tools were systematically applied step by step in case of claim solving, which occurred in automotive production.

Findings: Non-conformity, which occurred in this case, was analysed through RCA and helped not only to identify the problem but also solve it and find adequate preventive measures to avoid occurrence non-conformity in the future.

Research Limitation/implication: Practical application of chosen tools shows how problems and non-conformities should be solved using systematic steps of a different tool. In some cases, if it is needed, other methods and tools can be added, as well as metrology verifications.

Originality/Value of paper: The innovative element of these tools application is the introduction of the extended version of the 5W2H method from the customer's perspective as well as from the organisation perspective. It is also clear that to solve customer's claim, it is necessary to use a combination of more tools to make sure that that kind problem is not going to occur in the future.

Category: Case study

Keywords: method; non-conformity; continual improvement

1 INTRODUCTION

Beneath every problem is a cause for that problem. In order to solve a problem, one must identify the cause of the problem and take steps to eliminate the cause. If the root cause of a problem is not identified, then one is merely addressing the symptoms, and the problem will continue to exist (Dogget, 2006). RCA is a step-by-step method that leads to the discovery of faults or root cause. Wilson, Dell and Anderson (1993) have defined the RCA as an analytic tool that can be used to perform a comprehensive, system-based review of critical incidents. He also states that a root cause is the most fundamental reason for an undesirable condition or problem. Dew (1991) and Sproull (2001) state that identifying and eliminating the root causes of any problem is of utmost importance. According to them, RCA is the process of identifying causal factors using a structured approach with techniques designed to provide a focus for identifying and resolving problems. According to Duggett (2004), several RCA tools have emerged from the literature as generic standards for identifying root causes. As problems have increased in complexity, more tools have been developed to encourage employees to participate in the problem-solving process Zgodavova, Hudec and Palfy (2017). Some of the most common are the 5 Why Analysis (5WHY), Multi-Vari Analysis, Cause-and-Effect Diagram (CED), the Interrelationship Diagram (ID), and the Current Reality Tree (CRT). He has added that 5 WHY is the most simplistic RCA tool whereas current reality tree is used for possible failures of a system and it is commonly used in the design stages of a project and works well to identify causal relationships. DOE Guideline RCA Guidance Document February (1992) says that immediately after the occurrence identification, it is important to begin the data collection phase of the root cause process using these tools to ensure that data are not lost. The data should be collected even during an occurrence without compromising with safety or recovery. Anderson and Fagerhaug (2000) have simplified the RCA. They provide a comprehensive study of the theory and application of metrics in RCA. It it emphasises the difficulty in achieving process capability in the software domain and is cautious about SPC implementation. They mention that the use of control charts can be helpful for an organisation, especially as a supplementary tool to quality engineering models such as defect models and reliability models. However, it is not possible to provide control as in manufacturing since the parameters being charted are usually in-process measures instead of representing the final product quality. Arcaro (1997) has presented various tools for identifying root causes. He describes that RCA techniques are constrained within the domain and give a detailed tutorial by supporting theoretical knowledge with practical experiences. He states that all RCA techniques may not be applicable to all processes. Brown (1994) has used the root cause technique to analyse the assembly of commercial aircraft. He has concluded that it is the most effective tool to eliminate the causes in most vital assemblies like aircraft, where utmost safety and reliability is needed. Brassard (1996) and Brassard and Ritter (1994) have put their emphasis on continuous improvement and effective planning. They have pointed out that RCA tools give management to think ahead about failures

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and plan accordingly. They emphasise that process improvement models implicitly direct companies implement RCA as a crucial step for project level process control and organisational level process improvement purposes. Cox and Spencer (1997) have advocated that RCA tools effectively give solution to handle constraints and arrive at an appropriate decision. Like Cox and Spencer (1998) and Dettmer (1997) have also used RCA on the management of constraints. He presents one of the earliest studies on the debate of applying RCA to processes. Lepore and Cohen (1999), Moran, Talbot and Benson (1990), Robson (1993) and Scheinkopf (1999) move ahead. The foundations of their studies are pioneering one as they question an accepted practice for RCA and the results of the example studies are encouraging. However, the studies are far from being a practical one, as they include too many parameters and assumptions. Smith (2000) has explained that Root Cause Tools can resolve conflicting strategies, policies, and measures. The perception is that one tool is as useful as another tool. While the literature was quite complete on each tool as a stand-alone application and their relationship with other problem-solving methods. There are very few works of literature available on the comparative study of various RCA tools and methods. Gano (2011) has presented some insight into the comparison of standard RCA tools and methods. He indicates that there are some comparative differences between tool and method of a RCA. He has added that tools are included along with methods because tools are often touted and used as a full-blown RCA.

2 METHODOLOGY

Two similar tools, such as 5WHY a 5W2H, were used in this case study as a part of RCA. 5WHY is an iterative interrogative technique used to explore the cause-and-effect relationships underlying a particular problem. The primary goal of the technique is to determine the root cause of a defect or problem by repeating the question "Why?". Each answer forms the basis of the next question. The technique was originally developed by Sakichi Toyoda and was used within the Toyota Motor Corporation during the evolution of its manufacturing methodologies. It is a critical component of problem-solving training, delivered as part of the induction into the Toyota Production System. The architect of the Toyota Production System, Taiichi Ohno, described the 5WHY as "the basis of Toyota's scientific approach" by repeating why five times the nature of the problem, as well as its solution, becomes clear (Taichi, 2006). The tool has seen widespread use beyond Toyota and is now used within Kaizen, lean manufacturing and Six Sigma. 5W2H is an already recognised methodology that aims to assist in the creation of efficient Action Plans. With Action Plans created by this method, it is possible to make better decisions and better understand what needs to be done to solve a problem or implement a new process (Fonseca, Limaand Silva, 2015). 5WHY and 5W2H may help to identify the problem but to find a solution is necessary to use other systematic tool or approach for nonconformity management.

Those mentioned tools were directly applied as a part of problem solving. The company that makes keys and locks for the automotive industry was informed of its nonconforming product that was the subject of customer complaints. Within this complaint, it was necessary to apply RCA, where the tools of improvement creating together a unified logical system, by means of which a cause of non-conformance was identified and utilizing which corrective and preventive measures were determined, were used. RCA includes the following tools:

- 5W2H (extended version),
- 5 WHYs.

The claim mentioned above made by the customer was related to the key, namely the separated blade of the key from its chrome head of the key (Fig. 1), while it was clear that the cause for its break-down was a missing pin connecting these two parts.

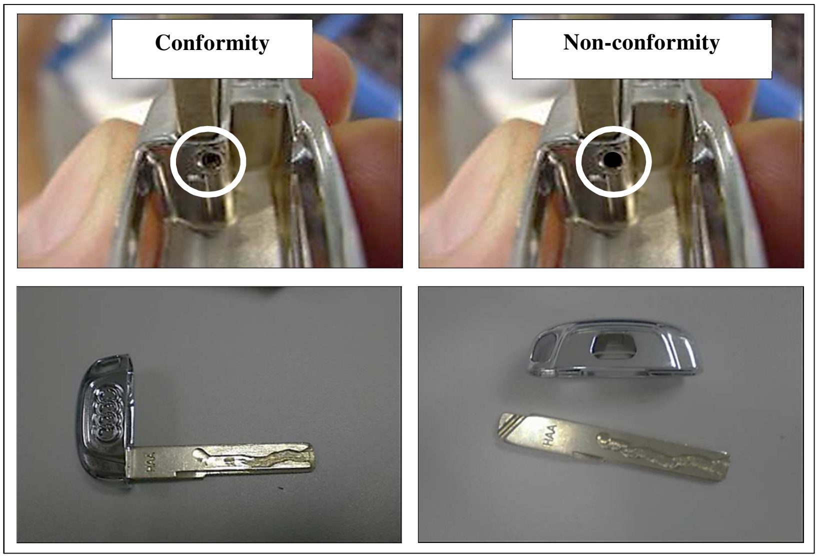

Figure 1 – Visualization of Missing Pin

2.1 5W2H Application

The first step was to identify this problem as a whole using the 5W2H tool in two separate views:

1. Customer's view,
2. Internal specialist's view.

Table 1 – Comparison of the 5W2H Method Application

1. Customer's view	**2. Internal specialist's view**
1. What is the problem? Missing pin in a chrome head of the key.	*1. What is the difference conformity and non-conformity?* *Conformity*– the pin is not present in a chrome head of the key, there are residual traces of adhesive in a head of the key, and a trace after the pin pre-loading. *Non-conformity*– pin as well as an adhesive are present, the blade is firmly fixed in a head of the key without the possibility of falling out, the blade and the head make a right angle.
2. Why is this problem? Blade of the key is separated from a chrome head of the key (loss of required function).	*2. Was the piece under a complaint made in a standard process?* Yes, no approved deviation in the standard process was valid at that time.
3. When did the problem arise? 11/01/2010	*3. When was the piece under a complaint made?* The date and time are not specified due to lack of traceability from the customer.
4. Who revealed the problem? The operator of the customer helpline	*4. Who made the piece under complaint?* Company premises, assembly line, chrome head and metal key blade riveting post.
5. Where was the problem revealed? Customer assembly line.	*5. What, if the product under complaint is being also used in another process?* No, the key type (with chromium head) is specific only to this project.
6. How was the problem revealed? Visually.	*6. How are we able to capture the product with the defect in a standard process?* Yes, checking the presence of the pin is part of the standard output control from the process.
7. How many non-conformity components were found? One.	*7. How did we deal with a similar problem internally or externally in the past?* Yes, the complaint came on 15 June 2009 when 1 non-conformity component was found. The permanent measure was implemented in the form of a mechanical poka-yoke lever of the pin preload.

Since the missing pin poses a problem for all products on a given assembly line, they were immediately physically suspended in the warehouse and also blocked in SAP. Exactly 1480 pieces of key sets were included. In addition, a temporary instruction for sorting was made, on the basis of which the suspended products were checked and the compliant ones were released to the customer, as well as a temporary control instruction for supercontrol of the presence of pins on the line after starting the production. Regarding the method of control, a repeated visual inspection was ordered that is a standard part of the workflow.

2.2 Problem Analysis

The RCA was added by comparison of the "conformity" and the "non-conformity" (component) and the comparison of the obtained results with the specification (drawing documentation). A good piece as conformity is a component that is randomly selected from the current series, and the component returned by the customer is considered to be a non-conformity.

2.2.1 Dimensional Analysis of the Components

The key is composed of three components – the key blade, the chrome head of the key and the pin. The factors for these components that could lead to the problem rise were defined:

1. *Key blade* – on the key blade, the dimensions were taken into account: the groove depth for the pin and the groove angle for the pin.
2. *Chrome head of the key* – the following parameters were identified: hole diameter for the pin, hole depth for the pin and hole angle for the pin.
3. *Pin* – the diameter and the length of the pin were taken into account.

In the dimensional analysis, the dimensions of the conformity component and non-conformity were compared for all the factors and their parameters. The measurements were carried out with a sliding scale and all randomly selected pieces ranged within the specified tolerance, confirming that the components used in the production of the piece claimed did not affect the defect produced since all dimensions were in accordance with the drawing documentation.

2.2.2 Analysis of the Assembly Process

As part of the initial analysis, it was possible to conclude that the problem was due to the absence of a pin, that is to say, in the process of ripping it. As in the previous case, as well as in the analysis of the riveting process, factors were identified which could influence the absence of a pin in the chrome head of the key, and in particular the following factors: the depth of the pin preload, the stroke of the roller at the workload and the position of the chrome head in the carriage bed during riveting.

1. *Depth of pin preload* determines the fixation of the pin in the chrome head prior to the riveting process itself. The preload depth is not a default parameter, and its measurement can only be done based on the trace that the pin in the head will leave when preloaded. Measurement was performed using an optical measuring device, a camera on a coordinate measuring device. A piece from the customer and a piece from the serial process were compared again. In this case, it was found that the pin on the piece under complaint was preloaded to 0.9 mm and a conformity component to 2 mm, so the difference in preload is 1.1 mm. The preloaded pin on a non-conformity component is not firmly fixed in the chrome head

and may be dropped when the carriage is moved. The depth of the pin preload is given by the step of the mechanical lever. The lever was designed in such a way that the preload depth of the pin was constant so that the operator could not influence the depth of the preload. This is a modifiable mechanical lever which allows the release of the piece with the preloaded pin until the lever is pushed to the lower position. However, when testing a conformity component, it was found that the lever was damaged and lost its function. The depth of pin preload is not constant, and this factor was determined as a factor with a direct impact on the occurrence of a defect.

2. *Compaction roller allowance at workload.* The examined roller was without any sign of the allowance when it was fully inserted and disengaged. This factor did not affect the occurrence of the defect.
3. *Position of the chrome head* in the carriage bed determines the position of the pin against the compaction *when riveting*. The examined beds of the carriage on the machine were free of wear and tear, and the chrome head was seated firmly and steadily in them.

The analysis of the assembly process selected the cause that was insufficient pin preload and thus in the process of moving the carriage or compaction itself, the pin dropped out of its position.

2.2.3 Analysis of Failure to Fix the Defect

The analysis of failure to fix the defect consists of verification of those process factors that are related to control in this process and are designed to detect any undesirable condition on the product and thus prevent it from being transported to the customer. Control points in the process are based on a control plan, which is also approved as a document for customers and is a direct connection with the process FMEA.

2.3 Application of 5WHY

In the case of this claim, we proceeded from the factors directly affecting the defect, namely: the insufficient depth of the pin preload and the inappropriate location of the presence of the pin in the process.

Insufficient depth of the pin:

1. Why?

   The step of the pin preload lever was not met.

2. Why?

   The device to prevent the lever from returning to the extreme position is not working properly.

3. Why?

   The device was damaged during its use – loose fastening screw (Fig. 2).

4. Why?

   No maintenance need was identified.

5. Why?

   There is no record of checking the mechanical lever before it is used.

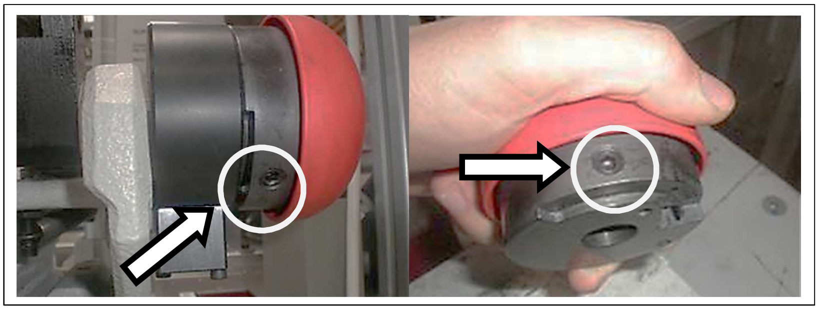

Figure 2 – Fixing Screw on Device

Inappropriate position of detection of the presence of the pin in a process:

1. Why?

   Check of the pin presence is performed by the machine at the beginning of the operation.

2. Why?

   The output from the process is a visual check of the presence of a pin.

3. Why?

   The process FMEA, used in the company did not take into account the risk of a visual check of the presence of a pin.

4. Why?

   Possibility of the pin falling out during operation was not taken into account.

5. Why?

   Insufficient information during the machine creation (the machine was developed and created independently of other line machines and similar projects).

The 5Whys analysis concludes that the absence of the pin in a chrome head of the key was caused by a long-term failure of device for blocking the lever return move prior to reaching the edge position at the pin preload. Since the failure of the device was detected only when the defect was reproduced, the root cause of its occurrence is the inability to detect a defect on the machine. The result of the analysis is also that the fact that the piece with the defect left the line and was sent to the customer significantly contributed to the absence of detection of the presence of the pin during the assembly process itself.

3 RESULTS AND CONCLUSION

The way how the organisation faces customer complaints significantly affects the organisation's loss of customer or changes the customer's initial dissatisfaction to renewed customer's confidence regarding the company, product, and so forth.. To have a complaint handling procedure that includes complaint evidence, assignment of competencies and responsibilities to competent persons, use of quality management methods and tools to identify root causes of nonconformity, including the proposal and implementation of effective measures is, therefore, an important condition for this success. Methods, used in this complaint are standard for issues solutions, especially for RCA. In this case, was an extended version of the 5W2H method used, which helped to identify the source of the cause (Fig. 3).

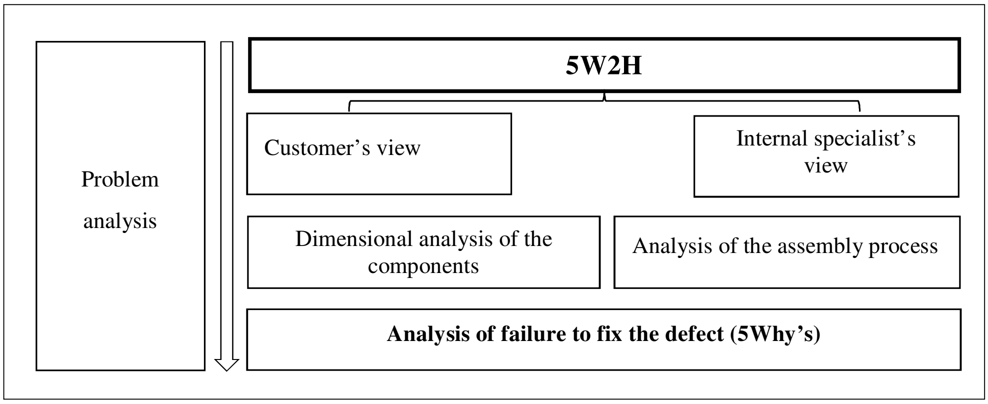

Figure 3 – Steps of 5W2H Analysis

According to analysis, it was clear that the source of the problem was the insufficient depth of the pin preload and the inappropriate location of the presence of the pin in the process. The analysis of failure to fix the defect showed that a piece without a pin could leave the process if a visual check of the presence of a pin failed and also because the proposed machine detection in the process does not provide a 100% finding of non-conformance since the pin can fall out after detecting its presence even before or during the pushing of the compaction roller. Since the failure of the device was detected only when the defect was reproduced, the root cause of its occurrence is the inability to detect a defect on the machine. The result of the analysis is also that the fact that the piece with the defect left the line and was sent to the customer significantly contributed to the absence of detection of the presence of the pin during the assembly process itself. Corrective and preventive measures are a response to identified root causes resulting from the conclusions of the cause analysis and the use of the 5Whys method. Measures must be designed to fully eliminate the possibility of repeating a defect.

In the case of a missing pin, the following measures were defined:

- Repair of a device for the pins preloading into the chrome heads.
- Adding the frequency control of the device functionality.
- Implementation of the detection of the presence of a pin during the pushing process directly on the pushing cylinder.
- Adding a frequency check of the pin presence detection functionality on the to the compaction roller.
- P FMEA updating – for the identified riveting process, pin presence detection was added directly to the compaction cylinder and therefore the risk of absence of the pin had to be reassessed. By adding detection, it was reduced from 98 to 48.

In this case study, the customer has taken the proposed measures. The effectiveness of these measures was monitored one month after their implementation, and none non-conformity component was discovered in the reference period with the described defect in the production process and was also not recorded by the customer, so we can state that the proposed measures are maximally effective and not only prevent a defect occurrence with the customer, but also a defect in the production process itself.

Generally, it must be clear that any non-conformities must be solved step by step with a systematic approach using chosen tools or also the combination of different methods to make sure that non-conformity is identified and also the appropriate measures are taken to avoid occurrence in the future.

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ABOUT AUTHORS

Anna Nagyová – The lecturer as well as the internal auditor for the quality management system (QMS) at Technical University of Košice. Her main topic is project management as well as different management systems. She was a team member of several national and international projects and author of more than 80 publications. E-mail: anna.nagyova@tuke.sk, Author's ORCID: https://orcid.org/0000-0003-3936-4517.

Hana Pačaiová – Deputy Head of the Department of Safety and Quality at Faculty of Mechanical Engineering, Technical University of Košice. Her professional orientation is focused on Risk Management, Quality and Safety management systems, Machinery safety, Asset and Maintenance management (RCM, TPM, RBI). She is a team leader and member of several national and international projects and author of more than 20 scientific books and 300 publications. E-mail: hana.pacaiova@tuke.sk, Author's ORCID: https://orcid.org/0000-0002-0308-1980.

Anna Gobanová – Quality manager in the company, which provides metrological service. Her professional orientation is focused on quality tools in the automotive industry. E-mail: nagyovaanna@hotmail.com, Author's ORCID: https://orcid.org/0000-0003-0040-7997.

Renáta Turisová – Associate professor at the Faculty of Mechanical Engineering, Department of Safety and Quality, Technical University of Kosice. She is engaged in integrated management with the focus on quality and safety as well as statistical and quantitative methods. E-mail: renata.turisova@tuke.sk, Author's ORCID: https://orcid.org/0000-0003-3333-0914.

Corporate Social Responsibility and Inter-Organisational Trust in a B2B Context

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Egle Staniskiene, Zivile Stankeviciute, Asta Daunoriene

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ABSTRACT

Purpose: The purpose of the paper to reveal the linkage between the customer perception of the supplier's CSR and inter-organisational trust in a B2B context.

Methodology/Approach: The paper conceptualises the customer perception of CSR activities as a latent second-order factor composed of three dimensions: CSR towards environment and community; CSR towards employees; and CSR towards customers. Three-dimensional understanding of inter-organisational trust, is applied in this paper. A quantitative study was conducted.

Findings: As it was expected, the findings revealed that the customer perception of supplier's CSR, namely CSR towards environment and community, towards employees and customers, generates inter-organisational trust that could be divided into competence trust, benevolence trust and integrity trust.

Research Limitation/implication: Seeing that the paper uses a sample from a single country, it has a limitation due to its restrictive generalisability (especially having in mind that the research was done in a low-trust societal context). Moreover, the paper does not incorporate the characteristics of organisations, and the future research could elaborate on the issues of how the perceived CSR and its impacts on inter-organisational trust vary depending on organisational financial performance, market share, and so forth.

Originality/Value of paper: The paper challenges the researchers and managers to move towards more sophisticated assessments concerning the way the customer perception of CSR affects inter-organisational trust in a B2B context, which might lead to improved organisational performance and sustainability.

Category: Research paper

Keywords: corporate social responsibility; inter-organisational trust; B2B context; customer; supplier

1 INTRODUCTION

Despite the earlier scepticism prevailing in business about its duty to balance the organisation's financial performance and its impact on the society and environment (Dyllick and Hockerts, 2002), corporate social responsibility (CSR) has lately become of strategic importance for numerous organisations (Kiron et al., 2012). The fact that Fortune 500 companies currently spend more than $15 billion a year on CSR activities (Novick O'Keefe, 2017) confirms the salient place of CSR in the strategic goals of organisations. The growing number and enhanced quality of CSR reports (KPMG, 2017) also serve as evidence that being socially responsible is getting increasingly more relevant. In general, motives of businesses behind the engagement in CSR could be twofold: normative and economic ones. The normative case for CSR argues that it is a moral duty for a business to engage in CSR ("doing good"), while the business case for CSR is based on the expected returns that organisations may receive from CSR ("doing better") (Maignan and Ferrell, 2004; Bhattacharya and Sen, 2004). Generally speaking, the business case for CSR relies on the notion that CSR elicits organisation-favouring responses from the stakeholders. It seems that positive responses are evident in the business world, as the survey of 2,874 managers and executives from 113 countries revealed that about 31% of organisations are benefitting from sustainable business practices (Kiron et al., 2012). Actually, CSR can be applied, and returns from CSR can be expected in both contexts: business-to-business (B2B) and business-to-consumer (B2C). However, to date, studies about the returns from CSR in the B2C sector are prevailing (Öberseder et al., 2014; Kim, 2019), meanwhile the research addressing CSR in a B2B environment is scarce (Kubenka and Myskova, 2009; Homburg, Stierl and Bornemann, 2013; McKnight et al., 2017).

CSR has its roots in the stakeholder theory (Asif et al., 2013). Drawing on this theory, CSR could be defined as "a firm's voluntary consideration of stakeholder concerns both within and outside business operations" (Homburg, Stierl and Bornemann, 2013). Despite various stakeholder classifications schemes introduced in the literature, customers are always included among other stakeholders (Rodrigo and Arenas, 2008; Parmar et al., 2010). Referring to the B2B context, customers are highly salient stakeholders as suppliers need them in order to operate (Parmar et al., 2010). Supporting the notion that CSR in the B2B context really matters and treating customers as highly important to suppliers in the B2B context, the paper deals with the customer perception of supplier CSR expecting positive reactions of customers as a response to supplier engagement in CSR.

The previous research, mainly in the B2C context, on the reactions of consumers to business CSR, revealed organisation-favouring responses on an array of cognitive and affective as well as behavioural outcomes (Sen, Bhattacharya and Korschun, 2006; Sen and Bhattacharya, 2001; Ng, Yam and Aguinis, 2019). For instance, Li, Liu and Huan (2019) demonstrated that renewing the CSR strategy can increase Starbucks' consumer loyalty by increasing customer-company identification. In supporting this, Arrive at al. (2019) found a dependency relationship between CSR and customer satisfaction and employee loyalty.

Previous literature on CSR in the B2B environment has generally focused on one of the two areas. First, some studies analysed the way the organisations implement the CSR issues within their business operations (Homburg et al., 2013). Second, the drivers of CSR in the B2B context were examined by involving the purchasing function in CSR, which has been labelled as Purchasing Social Responsibility (Carter and Jennings, 2004). However, researchers have largely neglected to study the effects of supplier's CSR on customers in terms of customer responses (Lai et al., 2010; Homburg, Stierl and Bornemann, 2013). The paper tries to close this gap by analysing inter-organisational trust as the outcome of customer engagement in CSR seeing that the previous studies identified trust as a central customer benefit arising from the supplier's CSR (Homburg, Stierl and Bornemann, 2013). More specifically, the argumentation behind choosing the inter-organisational trust is twofold. First, trust is important in exchange relations; referring to the B2B context, inter-organisational trust reduces problems that may arise from information asymmetries between the supplier and customer (Pavlou, 2002; Homburg, Stierl and Bornemann, 2013). Second, it is well established from multiple literature streams (strategy and marketing literature; economic literature; organisational literature) that inter-organisational trust is associated with fundament positive outcomes, namely competitive advantage, firm performance, conflict reduction, etc. (Pavlou, 2002; Zaheer and Jared, 2006).

This paper aims to reveal the linkage between the customer perception of supplier CSR and inter-organisational trust in the B2B context. In doing this, the paper seeks to answer the following: how can CSR be defined, and why is it important to take the customer perspective into consideration? How can organisational trust be defined? Will customer perception of CSR foster inter-organisational trust in the B2B context?

The paper contributes to the literature of CSR in several ways. First, contrary to the previous studies that have been conducted in the B2C sector, examining the consumer reactions, the current paper focuses on customer reactions in the B2B setting. Second, the paper analyses customer perception underlying the difference between the people's perception and awareness of concrete CSR activities. Third, the paper analyses inter-organisational trust as a reward for the supplier for its engagement in CSR. Thus, the paper enriches not only the CSR literature but also the literature of the trust domain. Finally, the paper contributes to the literature by signifying the importance of inter-organisational trust in exchange relations where uncertainty is present, as the research was carried out in Lithuania, which is treated as an example of a post-socialist society where trust is quite low (Pučėtaitė, Lämsä and Novelskaitė, 2010).

The paper begins by examining the literature on CSR and inter-organisational trust and developing the hypotheses. The research methodology is then outlined.

Following this, the results of the research are presented and discussed. Last, the paper provides several general conclusions before indicating some future research avenues.

2 THEORETICAL BACKGROUND

Stakeholder Approach, CSR and customer Perception of CSR

Nowadays is almost unthinkable to discuss CSR without referring to stakeholders (Rodrigo and Arenas, 2008; Turker, 2009a; Costa and Menichini, 2013; Gallardo-Vázquez and Sanchez-Hernandez, 2014; Singh, Sethuraman and Lam, 2017; Moneva and Hernández-Pajares, 2018). The European Commission (2011) in the renewed EU strategy 2011-14 for CSR also highlighted the close collaboration of enterprises with their stakeholders. Generally speaking, the stakeholders in an organisation are "individuals and constituencies that contribute, either voluntarily or involuntarily, to its wealth-creating capacity and activities, and who are therefore its potential beneficiaries and/or risk bearers" (Post, Preston and Sachs, 2002, p.8). Referring to the provided definition, in contemporary society and business environment, stakeholders are perceived much broader than shareholders; different interest groups such as employees, customers, suppliers, NGOs, the whole community etc. are all defined as stakeholders (Mitchell, Agle and Wood, 1997; Jamali, 2008).

Addressing the question of why and how a particular stakeholder is relevant to the organisation, scholars have introduced various stakeholder classification schemes (Rodrigo and Arena, 2008). According to Mitchell, Agle and Wood (1997), groups of stakeholders can be identified by their possession or attributed possession of one, two, or all three of the following attributes: the stakeholders' power to influence the organisation; the legitimacy of the stakeholders' relationship with the organisation; and the urgency of the stakeholders' claim on the organisation. Following this view, the supplier in the B2B environment should consider the importance of each customer according to their power, legitimacy and urgency. However, generally speaking, each customer and the pool of all customers are crucial for starting and sustaining the business in the long-term. This leads to the conclusion that suppliers need to serve the needs of customers as well as behave in a socially responsible way. Campbell (2007) argues that organisations are acting in a socially responsible manner when they do two things. First, they must not knowingly do anything that could harm their stakeholders, such as their employees, customers, investors, suppliers, or the local community within which they operate. Second, if organisations do cause harm to their stakeholders, they must then rectify it whenever the harm is discovered and brought to their attention. This corresponds to Carroll's (2015) idea that there are two active aspects of CSR, namely protection and improvement. Protection refers to the idea that companies need to avoid their negative impacts, meanwhile improving welfare means that organisations need to create positive benefits for stakeholders.

CSR is a multi-dimensional concept, usually categorised by two aspects: the type of responsibilities and the type of stakeholders groups (Park and Levy, 2014; Lee, Lee and Li, 2012). Building on the aspects of responsibility, Carroll (1991) suggested four dimensions of CSR, namely economic, legal, ethical and philanthropic. The economic dimension is about the organisation's economic responsibilities to its stakeholders, for instance, in terms of operational efficiency or competitiveness. Legal responsibilities reflect a view that organisations are expected to pursue their economic missions within the framework of the law. The ethical dimension refers to the organisation's responsibility to be fair and just in making decisions and performing, beyond its legal obligation. Philanthropic dimension includes the actions of an organisation that are carried out in response to social expectations. The second categorisation of CSR is based on the notion "to whom" the organisation is responsible. Actually, the scope of responsibility seems to be the hot issue in the CSR debates (Lee, Lee and Li, 2012; Van Marrewijk, 2003). The underlying idea is that in business, "socially responsible behaviour should focus on meeting expectations of its stakeholders rather than the society as a whole" (Lee, Lee and Li, 2012). In mainstream literature, the CSR dimensions by stakeholders groups mostly encompass employees, suppliers, customers, community and shareholders (Öberseder et. al., 2014; Turker, 2009a, 2009b). This paper supports the second stream of the CSR dimensions by analysing in the empirical part the CSR dimensions based on stakeholder types.

The assumption of the mismatch between the actual engagement of an organisation in CSR and awareness of different stakeholders about the CSR activities is an important aspect when analysing CSR (Sen, Bhattacharya and Korschun, 2006; Bhattacharya, Korschun and Sen, 2009). Referring to the B2B context, customers may not know about certain initiatives implemented by the supplier. Thus, customer evaluations of supplier activities may be entirely different from the absolute level of CSR at the supplier's organisation. The current paper does not aim at finding such dissonance and measuring the customer perception of CSR. Following Lee, Park and Lee (2013), the customer perception of CSR activities is the degree to which customers perceive that the supplier supports the CSR activities. Park and Levy (2014) argue that previous studies suggest that CSR activities are better understood theoretically and tested empirically when they are organised by stakeholder types (e.g. customers, employees, etc.) rather than by responsibility types (e.g. economic, legal, etc.). Hence, the paper conceptualises the customer perception of CSR activities as a latent second-order factor composed of three dimensions organised by stakeholder types (CSR-environment and community; CSR-employees; CSR-customers).

2.1 Interorganisational Trust

Already two decades ago, inter-organisational trust was seen as a means to achieve advantageous outcomes of economic performance (Zaheer and Jared, 2006). More recently, inter-organisational trust has been recognised as a key component for maintaining a successful long-term relationship between various stakeholders (Lee, Lee and Li, 2012). According to Boström (2015), trust is a crucial dimension in the customer and supplier relationship. Referring to Park, Lee and Kim (2014), trust from the customer perspective can be defined as the customer's belief that the organisation "will perform in a manner consistent with expectations regarding its expertise, integrity, and goodwill" (p.296). Homburg, Stierl and Bornemann (2013) define trust as "comprising the customer's expectancy that the supplier organisation is competent and can be relied on <…> and the belief that the supplier's organisation has beneficial intentions and motives" (p.58). According to Pavlou (2002), inter-organisational trust is "the subjective belief with which organisational members collectively assess that a population of organisations will perform potential transactions according to their confident expectations, irrespective of their ability to fully monitor them" (p.218). Organisational trust can be perceived as a unidimensional construct; however, as suggested by McKnight, Choudhury and Kacmar (2002), the paper adopts the three-dimensional understanding of trust, which includes expertise (competence), benevolence and integrity.

Competence refers to the ability of the trustee to do what the truster needs (McKnight, Choudhury and Kacmar, 2002). According to Mayer, Davis and Schoorman (1995), expertise is a group of skills, competencies, and characteristics that enable one party to influence within some specific domain. Referring to the B2B context, expertise trust is the customer's belief that the supplier has the competence and technical skills to produce or deliver a particular product (Park, Lee and Kim, 2014).

Benevolence refers to the trustee's caring and motivation to act in the truster's interests (McKnight, Choudhury and Kacmar, 2002). Benevolence is "the extent to which a trustee is believed to want to do good to *the trustor,* aside from an egocentric profit motive" (Mayer, Davis and Schoorman, 1995, p.718). Thus, benevolence includes the customer's belief that the supplier is genuinely concerned with the preservation and enhancement of customer welfare (Park, Lee and Kim, 2014).

Integrity means that trustee is honest and keeps promises (McKnight, Choudhury and Kacmar, 2002). Integrity is about the customer's belief that the supplier demonstrates the consistency of their value and behaviour (Park, Lee and Kim, 2014).

2.2 Corporate Social Responsibility and Inter-Organisational Trust: Hypothesis Development

The notion that organisations reap the rewards from their CSR activities is well established in the literature (Bhattacharya, Korschun and Sen, 2009) and supported by survey data (Kiron et al., 2012). Wang et al. (2016) argue that recently, CSR has become increasingly prevalent and visible within corporations as a mechanism to energise and motivate the stakeholders. Accordingly, motivation efforts are dedicated to creating a positive stakeholder response in terms of cognitive, effective or behavioural outcomes (Peloza and Shang, 2011; Sen, Bhattacharya and Korschun, 2006), including trust between the customer and supplier.

As mentioned before, the paper conceptualises the customer perception of CSR activities as a latent second-order factor composed of three dimensions: CSR towards environment and community; CSR towards employees; and CSR towards customers. Three-dimensional understanding of trust, which includes expertise (competence), benevolence and integrity, is applied in this paper.

2.2.1 CSR towards Environment and Community

Both initiatives, protecting the environment and caring about the local community, reflect the supplier engagement in CSR. The customer can be proud of buying goods or products from such supplier. The customer can feel that the supplier cares about the present and future of the world, even though is not a lucrative decision for the supplier, at least in the short term (Turker, 2009b). Therefore, the customer can conclude that the supplier who cares about the environment and society will act more in the interest of the customer: it will use its competence and technical skills to produce or deliver products (competence); will care of the interest of supplier (benevolence) and will be honest and keep promises (integrity) (McKnight, Choudhury and Kacmar, 2002; McKnight et al. 2017). Accordingly, the customer will demonstrate a higher level of trust in the supplier. In supporting the mentioned assumptions, Park, Lee and Kim (2014) found that trust, in terms of competence, benevolence and integrity, was fostered by CSR initiatives. Further, Flammer (2015) highlighted that studies on relationships in the B2B context suggested that the extent to which suppliers showed responsibility and concern for their stakeholders in the form of charity and other socially responsible practices towards the community could serve as a valuable signal of the supplier's quality and non-opportunistic behaviour. Based on theoretical insights and empirical evidence, the paper hypothesises the following:

H1. Customers perception of CSR towards environment and community will be positively related to their trust in supplier, including competence trust (H1a), benevolence trust (H1b), and integrity trust (H1c).

2.2.2 CSR towards Employees

Employees represent one of the most critical primary stakeholder group, as they determine the quality of service and goods (Lee, Lee and Li, 2012). Encouraging employees to develop their skills and careers; ensuring work-life balance; providing a safe and healthy working environment, and fairly treating employees indicate that the organisation (of the supplier) is socially responsible towards employees (Turker, 2009b; Park, Lee and Kim, 2014). Such initiatives serve as a sign for the customer to trust the supplier more. The supplier's encouragement to employees to develop their skills means that employees possess a high level of competence. Thus, the customer can feel a higher level of competence trust. The fact that the employees are treated fairly demonstrates the honesty of the supplier (McKnight, Choudhury and Kacmar, 2002) and this signals to customers to express a higher level of integrity trust. The supplier's caring about the work-life balance of employees serves as an argument for the customer to feel benevolence trust. Referring to theoretical expectation, the paper proposes the following hypothesis:

H2. Customers' perception of CSR towards employees will be positively related to their trust in supplier, including competence trust (H2a), benevolence trust (H2b), and integrity trust (H2c).

2.2.3 CSR towards Customers

CSR towards customers manifests itself in a variety of ways, such as incorporating the interest of customers in business decisions, providing high-quality services; or treating customer satisfaction as highly important (Park, Lee and Kim, 2014). Following Turker (2009b), CSR is seen as a "significant tool of influencing the feelings, thoughts, and consequently buying behaviours of their target customers" (p.192). The fact that the customers feel the care expressed by the supplier in corporate socially responsible initiatives can create inter-organisational trust environment and increase the customer trust in the supplier. Referring to the theoretical expectations, the paper proposes the following hypothesis:

H3. Customers perception of CSR towards customers will be positively related to their trust in supplier, including competence trust (H3a), benevolence trust (H3b), and integrity trust (H3c).

3 METHODOLOGY

3.1 Sample and Data Collection

The respondents chosen to gather the data and test the hypotheses were working-age employees in Lithuania. Lithuania was chosen due to the reason that the country belongs to a low-trust societal context (Pučėtaitė, Lämsä and Novelskaitė, 2010). The research was based on the criterion of convenience in order to obtain the data from the respondents who were easier to reach. The questionnaire was distributed online. Data collection took more than two months. At the end of the research, 384 questionnaires were collected and, according to the number of working people in Lithuania, a such number of responses reflects a 5.0% error, which indicated the reliability of the data. Tab. 1 provides the respondents' profile.

Table 1 – Respondents' Profile

Characteristics	Frequency (n)	Percentage (%)
Gender		
Female	359	93.50
Male	25	6.50
Age		
18-25	114	29.8
26-32	106	27.7
33-41	112	29.2
42-52	40	10.4
53-65	11	2.9
Working time in a particular organisation		
Up to 1 year	69	18.00
1-3 years	102	26,6
3-5 years	174	45.3
More than 5 years	39	10.1

3.2 Measures

Interorganisational trust was measured using the adapted scale of McKnight, Choudhury and Kacmar (2002), which includes three subscales: benevolence (3 items), integrity (4), and competence (4 items). Respondents were asked to indicate their agreement with each statement on a 5-point Likert scale, where 1 means strongly disagree, 5 – strongly agree. The subscales had a Cronbach's alpha of 0.652; 0.773 and 0.690 respectively.

Customer perceptions of organisational CSR were measured using the scale of Park and Levy (2014), which comprises 3 subscales: CSR practices towards environment and community (11 items), employees (6 items), and customers (5 items). Respondents were asked to indicate their agreement with each statement on a 5-point Likert scale, where 1 means strongly disagree, 5 – strongly agree. The subscales had a Cronbach's alpha of 0.714; 0.720 and 0.620 respectively.

4 RESULTS

The means, standard deviations for the scales and correlation matrix are provided in Tab. 2. Referring to Tab. 2, H1, H2, and H3 were confirmed.

Table 2 – Means, Standard Deviations and Correlations

Variable	Mean	SD	1	2	3	4	5	6	7	8	9	10
1. Gender	1.07	0.247										
2. Age	2.29	10.02	-0.051									
3. Working time in particular organisation	2.47	0.90	-0.093	0.024								
4. CSR towards environment and community	3.35	0.437	-0.006	0.039	-0.006							
5. CSR towards employees	3.86	0.314	0.113	0.001	-0.113	0.585**						
6. CSR towards customers	4.07	0.362	0.071	0.044	0.071	0.532**	0.591**					
7. Benevolence trust	3.64	0.304	0.015	0.031	0.015	0.452**	0.401**	0.489**				
8. Integrity trust	4.02	0.400	0.015	0.118*	0.015	0.498***	0.483**	0.404**	0.596**			
9. Competence trust	3.96	0.332	0.035	-0.082	-0.002	0.523**	0.518**	0.511**	0.528**	0.576**		
10. Inter-organisational trust	3.90	0.255	-0.019	0.038	0.030	0.529**	0.583**	0.549**	0.662**	0.678**	0.687**	

Notes: **p<0.01, *p<0.05

Concerning H1, the customers' perception of CSR towards environment and community was found to have a statistically significant positive effect on inter-organisational trust (r=0.523, p<0.01). Concerning the different components of inter organisational trust, CSR towards environment and community has the most significant positive effect on competence trust (r=0.523, p<0.01) and a less significant effect on benevolence trust (r=0.4527, p<0.01).

Concerning H2, it was confirmed in the same manner as in the case of H1. A positive relationship was found between the customers' perception of employees and inter-organisational trust (r=0.583, p<0.01). The most significant positive effect was detected on the competence trust (r=0.518, p<0.01) and a less significant effect on the benevolence trust (r=0.401, p<0.01).

H3 was confirmed as well. However, the most significant positive effect was established on the competence trust (r=0.511, p<0.01) and a less significant effect on integrity trust (r=0.404, p<0.01).

5 DISCUSSION

The research was designed to explore whether the customer perception of the supplier's CSR towards three stakeholders groups (environment and community, employees and customers) generates the inter-organisational trust, including competence trust, benevolence trust and integrity trust, in the B2B context.

Overall, all the hypotheses received some support. The results backed up all hypotheses raised concerning the inter-organisational trust, strengthening the fundamental premise that positive customer perceptions of CSR towards different stakeholders will result in higher customer trust directed at suppliers. To the best of the authors' knowledge, few studies in the B2B context have been conducted; consequently, the discussion is also based on examples concerning B2C.

As predicted, a positive relationship was found between the customer perceptions of CSR directed at environment and community and the trust in suppliers. However, the received results contradict the findings of Homburg, Stierl and Bornemann (2013), where the supplier's CSR engagement targeted at secondary stakeholders (community) had no significant effect on the customers' trust in suppliers. Turning to B2C context, the current findings support the study of Park, Lee and Kim (2014), where the consumers' perception of ethical responsibility generates consumer integrity trust and the perception of philanthropic responsibility generates the consumers' benevolence trust. Referring to employees as important stakeholders, Lee, Lee and Li (2012) found that employee perception of CSR will have a positive effect on organisational trust. Thus, the results from the B2C contexts and the current results provide a reliable message that the extent to which the suppliers show their concern for community and environment can serve as a valuable signal of the suppliers' trustworthiness (Flammer, 2015).

Consistent with the expectations, customer perceptions of the supplier's CSR directed at employees demonstrated the existence of a positive relationship with trust. Thus, it pays off to take care of the employees, as customers draw a parallel between the supplier behaviour towards employees and towards them. Based on the social exchange theory, if the supplier treats its employees fairly and respectfully, the customers expect to receive the same treatment (Homburg, Stierl and Bornemann, 2013). The current findings are in line with the study of Homburg, Stierl and Bornemann (2013) where the organisation's CSR engagement targeted at primary stakeholders (employees and customers) had a positive effect on trust. Generally, the current findings strongly support the overall notion that employees are highly important stakeholders of organisations and tackling the employee concerns seriously is a key target for each organisation willing to survive in the long-term (Guest, 2017).

As predicted, the findings revealed that the perceived CSR towards customers results in a higher level of trust. Since the organisational success in the B2B context depends to a great extent on customers, suppliers try to build and maintain good relationships with them (Turker, 2009b). As in the previous case, the current findings support the study of Homburg, Stierl and Bornemann (2013) where the organisation's CSR engagement targeted at customers had a positive effect on trust. Thus, customer decisions concerning the trustworthiness of potential suppliers when making the purchasing decisions and long-term relational commitment can be generated by the customers' perception of the supplier's engagement in CSR.

6 CONCLUSION

The paper aimed at exploring the relationship between the customer perception of CSR and their inter-organisational trust in suppliers in the B2B context. The results demonstrated that customer perceptions of suppliers implementing socially responsible practices towards environment and society, employees, and customers lead to a greater exhibition of customer trust (competence trust, benevolence trust and integrity trust) in suppliers.

The paper provides several practical implications. Firstly, practitioners will benefit from considering CSR seeking to foster the inter-organisational trust in the B2B context, seeing that the customer perception of the supplier acting in a socially responsible way towards various stakeholder groups results in higher competence, benevolence and integrity trust. This is extremely relevant for countries with the predominant low-trust societal context. Secondly, practitioners should employ the general notion that customer perceptions of CSR in the B2B context play a vital role in striving to obtain and sustain the competitive advantages in the long-term perspective. Customers may affect organisational vitality by not trusting the supplier and not buying their products or services due to low supplier engagement in socially responsible initiatives. Finally, the main practical implication for emerging from the current research is that businesses willing to reap the benefits from CSR should evaluate not only the actual engagement of the organisation in CSR, but also the awareness and perception of different stakeholders of the CSR activities. As mentioned before, a mismatch may emerge between the particular actions (results) of organisations and the specific perception of stakeholders concerning these actions (results).

The paper has several limitations to consider when interpreting the mentioned findings. The paper uses a sample from a single country; as a result, it has a limitation due to its restrictive generalisability (especially having in mind that the research was done in a low-trust societal context). To overcome this factor, future research could be extended to a whole region. Further, the unit of analysis is a customer-supplier relationship. However, the data was collected only from customer organisations. To obtain a complete picture, future research could deal with the data from supplier organisations and enrich the literature by providing a comparison. Next, as the paper does not incorporate the characteristics of organisations, future research could delve deeper into the issues of how the perceived CSR and its impacts on interorganisational trust vary depending on the organisational financial performance, market share, etc. Finally, seeing that the paper does not analyse the outcome of inter-organisational trust, the future research models could be enriched by examining the consequences of trust for both parties in the B2B context – for suppliers and customers.

In conclusion, this paper challenges the researchers and managers to move towards a more sophisticated assessment of the way the customer perception of CSR affects the inter-organisational trust in the B2B context, which might lead to improved organisational performance and sustainability.

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ABOUT AUTHORS

Prof. Egle Staniskiene, PhD. – Professor at School of Economics and Business. Kaunas University of Technology. E-mail: egle.staniskiene@ktu.lt.

Assoc. prof. Zivile Stankeviciute, PhD. – Associated professor at School of Economics and Business. Kaunas University of Technology. E-mail: zivile.stankeviciute@ktu.lt.

Assoc. prof. Asta Daunoriene, PhD. – Associated professor at School of Economics and Business. Kaunas University of Technology. E-mail: asta.daunoriene@ktu.lt, Author's ORCID: https://orcid.org/0000-0002-3471-3389.

The ISO 9001:2015 Quality Management System Standard: Companies' Drivers, Benefits and Barriers to Its Implementation

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Laura Bravi, Federica Murmura, Gilberto Santos

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ABSTRACT

Purpose: The aim of this study is to evaluate companies' perception of the latest version (2015) of ISO 9001 in terms of motivations that pushed companies to the implementation of a Quality Management System.

Methodology: The research was conducted through a questionnaire proposed to 3,975 ISO 9001 certified companies, making a simple random sampling among the 150,143 Italian companies certified in 2018. Among the companies contacted, 493 participated in the survey and gave shape to the reference sample.

Findings: The results of the study show that the "culture of quality" is rooted in Italy and mainly in the North, which represents the most economically advanced area. With regard to the evolution of the standard from ISO 9001:2008 to 2015, companies seem to have perceived the main changes introduced with the latest revision, that helps to easily adopt its principles in companies.

Research Limitation: The main limitation of the study lies in the fact that the focus of the research was based on Italian companies. It would be important for future research to consider also other European countries, and make a comparison between them, in order to consider if companies of different markets have different motivations for implementing the standard and perceive different benefits and barriers to its implementation.

Value of paper: Few researches have focused on the latest version of the ISO 9001 standard; therefore this study gives a broad vision of how companies that have had to deal with the new standard consider it in relation to the previous version, highlighting the main strengths and weaknesses.

Category: Research paper

Keywords: Quality Management System; ISO 9001; Total Quality Management

1 INTRODUCTION

Quality from a fundamental philosophical perspective can be defined as the summary of entity property manifestation in surrounding and time their characteristic functions (Zgodavová et al., 2002). Therefore the implementation of a Quality Management System (QMS), and its subsequent certification, is a voluntary process, supported by the motivations, objectives and policies of the organisation. Jones, Arndt and Kustin (1997), identified two types of organizations, based on the main purpose for which they decide to certify themselves, that is, the "non-developmental companies", which tend to implement a quality system only to obtain a certificate and the "developmental companies", which adopt the standard, because they believe they can get internal benefits from its implementation.

Based on a survey conducted in 2016 by the International Organization for Standardization (ISO) it emerges that, with 150,143 certified companies, Italy is at the top of the European classification of Quality Management System (QMS) certifications according to the ISO 9001 standard, and it is second in the world after China, which, for the year under review, presents 350,631 certified companies (www.accredia.it).

This research reported a total of 1,105,356 certificates valid for the ISO 9001 standard worldwide (including 80,596 issued for the 2015 version), with an increase of 7% compared to the previous year (2015). The first four industrial sectors by number of ISO 9001 certifications in 2016, based on the data, are the metal and metal products sector, with 116,457 valid certificates, followed by Electrical and optical equipment (88,482), construction (87,605) and wholesale & retail trade, repairs of motor vehicles (79,492) (www.iso.org).

Currently, the globalisation has changed the way of doing business; customer's expectations have increased and are more articulated, and the ease of access to information by all stakeholders has lead companies to operate in a supply chain that is more complex than it was in the past. Therefore the ISO 9001 standard, in order to keep up with market changes began a review process in 2012 to make it compatible with the ongoing evolution of the market and with the standards related to other management systems. The path that led to the publication of the UNI EN ISO 9001:2015 standard began with a preliminary phase through the creation of a web survey aimed at identifying the weak points of the standard and then improving them within the process of reviewing.

The revision of the ISO 9001:2015 standard has introduced significant differences compared to the 2008 edition, which can be summarised in 9 points (Gigante and Ziantoni, 2015):

- the adoption of the High-Level Structure (HLS), a structure that is common to The ISO standards related to management systems and defined in Annex SL of the ISO Directives – Part I.

- An explicit requirement that requires the adoption of Risk-Based Thinking to support and improve the understanding and application of the process approach.
- Less prescriptive requirements.
- Greater flexibility in relation to documentation.
- Better applicability to services.
- The requirement to define the boundaries of the QMS.
- Increased emphasis on the organizational context.
- Increased leadership requirements.
- Increased emphasis on achieving process results to increase customer satisfaction.

Considered the above, the study aims to evaluate companies' perception of the latest version (2015) of ISO 9001 in terms of motivations that led companies to the implementation of a Quality Management System, and the subsequent benefits and barriers obtained from the adoption of the standard.

2 LITERATURE REVIEW

2.1 Main Drivers to ISO 9001:2015 Adoption and Benefits and Barriers to Its Implementation

Making a historical overview of the reasons cited in the literature, regarding the implementation of ISO 9001, the motivations can be classified according to two main categories: internal and external (Santos et al., 1996; Murmura and Bravi, 2017). With regard to internal motivations, these are linked to the objective of achieving an internal management improvement; while external motivations are mainly related to promotional and marketing issues, customer pressures and the improvement of market share (Santos and Barbosa, 2006; Prates and Caraschi, 2014; Santos and Milan, 2013).

Regarding the factors that influence the decision to adopt ISO 9001, various studies have shown the importance of the size of the company (Psomas and Pantouvakis, 2015; Feng, Terziovski and Samson, 2008). Larger companies are associated with more market shares and are more likely to operate in different markets or across different segments of the same market. For large companies, the ability to tackle tackle ISO 9001 is higher, leads to greater customer satisfaction, reduces information asymmetries between customers and other interested parties, is a allows further market penetration and increases barriers for competitors of smaller size (Boiral, 2011; Ilkay and Aslan, 2012).

As for the benefits that a company can receive developing a QMS, according to Douglas, Coleman and Oddy (2003) and Van der Wiele et al. (2005), these can also be classified into two categories: internal and external. As stated by Santos, Mendes and Barbosa (2011), there is a consensual opinion that the benefits of ISO 9001 are linked to the reasons why the organization achieves the certification; when companies are certified on the basis of internal motivations (productivity improvements, improvements in quality awareness, and internal organization improvements), the resulting benefits have a more global dimension (Douglas, Coleman and Oddy, 2003; Van der Wiele et al., 2005; Heras-Saizarbitoria, 2011; Fonseca and Domingues, 2018; Rosa, Silva and Ferreira, 2017; Caridade et al., 2017). On the contrary, when companies are certified on the basis of external motivations (access to new markets, customer satisfaction, and improvement of market share), the improvements obtained are mainly of an external nature (Tarì, Heras-Saizarbitoria and Pereira, 2013). Concerning the main barriers associated with the implementation of ISO 9001, these may be linked with various aspects such as lack of resources, or specific technical resources and capabilities, changes in corporate culture (Zgodavová, Hudec and Palfy, 2017), organisational idiosyncrasies, etc. Santos et al. (2016). Other important barriers identified by organisations are: high implementation and maintenance costs (Batista and Santos, 2015) and the bureaucratic management of the standard (Santos and Barbosa, 2006; Rebelo et al., 2016; Boiral, 2011; Ilkay and Aslan, 2012; Rebelo, Santos and Silva, 2015). The last revision of the standard ISO 9001 reviewed in 2015 gives greater importance to the concept of risk management (Rebelo, Santos and Silva, 2017; Ferreira, Santos and Silva, 2019). The implementation of QMS promotes the sustainability (Santos, Mendes and Barbosa, 2011; Barbosa, Oliveira and Santos, 2018) and Corporate Social Responsibility (Santos, Bravi and Murmura, 2018) for a better quality of life (Felix et al., 2018; Bravi, Murmura and Santos, 2018; Santos et al., 2019).

2.2 ISO 9004 Standard: A Guide to Excellence

The ISO 9004 standard provides a guideline for achieving the lasting success of an organisation in a complex, demanding and constantly evolving context. This standard is applicable to any organisation, regardless of the size and type of product or service provided. The ISO 9004 standard has not been designed for certification purposes but includes a self-assessment tool, which allows assessing the degree of maturity of an organisation's Quality Management System, as well as identifying and prioritising potential areas for improvement. If correctly implemented, its application should facilitate the transition to a complete Total Quality Management program, which requires a profound organisational change and a culture in which strong, committed and supportive leadership is present and employees are motivated (Boys, Karapetrovic and Wilcock, 2004; Ribière and Khorramshahgol, 2004).

The standard suggests to implement a process of measurement of the organisation as a tool to assess, in relation to all levels of the organisation, the degree of achievement of planned results and performance.

Once the factors that are critical to pursuing the lasting success of the organisation have been identified, they must be subjected to measurement using the most suitable indicators, defined by the same standard as Key Performance Indicators (KPI). These should be quantifiable and should depend on objectives, to identify and predict trends and take corrective and improvement actions.

The tools suggested by ISO 9004:2009 to fully implement the measurement process are represented by internal audits, benchmarking and self-assessment (to which the standard dedicates an entire appendix), which results must be analysed and become an important input of senior management review (Wilcock et al., 2006).

3 METHODOLOGY

The research was conducted through a questionnaire proposed to 3,975 ISO 9001 certified companies, making a simple random sampling among the 150,143 Italian companies certified in 2018. All the information necessary to contact the companies was obtained from the Italian Accreditation Body (ACCREDIA) database through its website (www.accredia.it). Among the companies contacted, 493 participated in the survey and gave shape to the reference sample. The questionnaire, sent using Computer Assisted Web Interviewing (CAWI), began on September, 5th 2018 and the replies were accepted until October, 27th 2018. The questionnaire was administered via e-mail, and exactly 3,834 e-mails were sent, as 141 e-mail addresses were not valid. A second submission was made 15 days after the first submission, as a reminder for those companies that had not previously considered the e-mail. The questionnaire was administered anonymously to encourage the sincerity of the answers.

The questionnaire was divided into two sections: in the first section, interviewees were asked the general questions, in order to obtain basic information necessary to define companies profile, while the second section considered the perception of companies about the ISO 9001 standard, investigating the evolution over time, the reasons that lead companies to obtain certification, the advantages and the barriers to its implementation.

Descriptive analysis was performed to describe the sample profile of respondent ISO 9001 certified companies. A five-point Likert scale (where 1 – "not at all important" and 5 – "A lot important was used to evaluate companies' motivations that led them to the certification and the main advantages and barriers to its implementation perceived. The coefficient of variation, that allows evaluating the dispersion of values around the average, calculated as the ratio between mean and standard deviation has been performed. It represents good results when it is equal or less than 0.5. The non-response bias was assessed by verifying that early and late respondents were not significantly different, considering therefore late respondents, who answered the questionnaire only after a reminder as those that refused to participate the first time (Armstrong and Overtyon, 1977). A set of tests compared respondents who answered the questionnaire during the first administration and those who answered when the survey was submitted for the second time. T-test comparisons performed between the means of the two groups showed insignificant differences (p-value <0.1).

4 RESULTS

Tab. 1 shows the profile of the 493 ISO 9001 certified companies. Considering the size of the companies in relation to the markets in which they operate, it can be noted that no large enterprises of the sample operate simultaneously both in Italy and in Europe, most operate only in Italy (15), even if a relevant number also works abroad; the Medium-sized companies operate mostly on the international markets (43); instead the Small and the Microenterprises work mainly on the Italian market only (200), although there are a few that operate on international markets (110).

Concerning the specific location of companies in Italy, most of them, that is 44.6% are located in the northern regions (220). Furthermore, from a further analysis of the data it emerged, that the Large companies are located mostly in the North, and so are the Medium-sized companies, while as regards the Small ones and the Microenterprises these are located almost equally between North and Center, although a relevant number is also concentrated in the South.

Table 1 – Profile of Respondent Companies

Respondents' Profile	**N**	**%**
Type of Companies	-	-
Manufacturing	493	44.8
Services	493	55.2
Dimension	-	-
Micro Companies (<10 employees)	493	29.2
Small Companies (10-49 employees)	493	48.1
Medium Companies (50-249 employees)	493	18.3
Large Companies (>250 employees)	493	4.5
Reference Market	-	-
Italy	493	51.3
Italy and Europe	493	16.2
International Markets	493	32.5

After outlining a general picture of the companies that make up the reference sample, the time in which companies adopted ISO 9001 certification was considered, in order to have an opinion from companies certified for many years, on the evolution of the standard from ISO 9001:2008 to the latest version ISO 9001:2015, to which companies, by September 15, 2018, have had to adapt.{avantgarde syntax}

It was found that most companies (355, or 72%) have been certified for over 7 years, (having been certified both with the version of the ISO 9001 standard of 2000 and 2008), thus showing the presence of a quality culture, especially among Medium-sized companies (87.7%), but also in Large companies (77.2%) and Small ones (74.6%). Finally, 56.9% of Micro companies have been certified according to the ISO 9001 standard for a long time. The 23.32% (or 115 companies) has been certified for a period ranging from 2 to 7 years; these companies have therefore been certified only with the ISO 9001:2008 revision of the standard, while 4.66% (23 companies) have been certified for a year or less, and therefore, they have not made any change from previous revisions of the standard, having certified directly according to the latest version of 2015.

Furthermore, it has been established that the companies certified for more than seven years are located mainly between North (144) and Center (126) of Italy. Later, companies that had experimented or were experimenting with the transition from ISO 9001:2008 to ISO 9001:2015 were asked, what was their opinion on the evolution of the Standard.

Most respondents noted that the new revision of the standard gives greater importance to the concept of "Risk management" (value 3, 4 and 5 of the Likert scale) (67.1%; mean value: 3.85), makes it easier to integrate with standards related to other issues (environment , health and safety, ethics...) (60.9%; mean value: 3.63), presents a greater propensity to the aspect of "continuous improvement" (57.4%; mean value: 3.54), allows the implementation of a more quality-oriented system (49.6%; mean value: 3.38) and it adapts more easily to the organizational structure (47.4%; mean value: 3.32). That is in line with what has been found in the literature (Gigante and Ziantoni, 2015).

According to the interviewees the transition to the new version of the Standard does not allow the achievement of a higher profit (56.4%), especially for Medium (53.3%) Small (49%) and Micro enterprises (45.8%), and at the same time the 42.1% says they are indifferent to the increase in the financial cost of implementing the standard (Tab. 2).

Table 2 – Changes Perceived by Companies in the Transition between ISO 9001:2008 and ISO 9001:2015

	N	Mean (μ)	St. Deviation (σ)
It requires less bureaucratization	470	3.13	1.11
It has become easier to understand	470	3.05	1.03
It adapts more easily to the organisational structure	470	3.32	1.06
It allows implementing a more quality-oriented system	470	3.38	0.99
It makes it easier to integrate with standards related to other issues	470	3.63	1.02
It has made conformation to the standard of easier implementation	470	3.22	1.01
The financial cost of implementing the standard has increased	470	2.75	1.03
It allowed the achievement of a greater profit	470	2.25	0.99
It provides guidance to project the company into the future	470	3.12	1.13
It presents a greater propensity to the aspect of “continuous improvement”	470	3.54	1.02
It leads to greater centrality of the leadership	470	3.26	1.11
It gives greater importance to the concept of “Risk management”	470	3.85	1.11

Initially, the survey focused on the reasons that led Italian companies to obtain ISO 9001 certification. Based on what can be observed in Tab. 3, the reasons that led companies to get the certification are mainly: the possibility of improving their own corporate image (89%; mean value: 4.36), obtaining internal organizational improvements (75.2%; mean value: 4.04) and the opportunity to use the standard as a marketing tool (51.3%; mean value: 3.30). The first two reasons are the most important for all companies in the sample, in fact for these items there is an average value higher than 4. Two out of three of the main reasons are linked to external factors and are in line with what was stated in previous research (Prates and Caraschi, 2014; Santos and Milán, 2013; Santos and Barbosa, 2006). Overall, the less important reasons seem to be: the reduction of costs (18.2%; mean value: 2.23), the benefits experienced by other companies (19.5%; mean value: 2.47), the improvement of relations with the communities (26.1%; mean value: 2.82) and, as previously stated, the possibility of avoiding potential obstacles to exports (23%; mean value: 2.23).

Table 3 – Motivations that Pushed Companies to ISO 9001 Standard

	N	Mean (μ)	St. Deviation (σ)	Coefficient of variation (σ/μ)
Reduction of costs	493	2.23	1.24	0.5
Pressures from customers	493	3.03	1.44	0.4
Use of the Standard as a marketing tool	493	3.30	1.19	0.4
Get internal organizational improvements	493	4.04	1.09	0.3
Keep up with its own certified competitors	493	3.17	1.32	0.4
By word of mouth from benefits experienced by other companies	493	2.47	1.17	0.5
Avoid potential export barriers	493	2.23	1.39	0.6
Improve relations with communities	493	2.51	1.33	0.5
Improve relations with government authorities	493	2.82	1.45	0.5
Improve the corporate image	493	4.36	0.86	0.2

Subsequently, the main advantages of implementing an ISO 9001 QMS were considered (Tab. 4). The main benefits perceived include an improvement in corporate image and reputation (77.7%; mean value: 3.98), a greater awareness of corporate opportunities (in terms of continuous improvement) (71.6%; mean value: 3.91) and the reduction of non-conformities (62.5%; mean value: 3.55).

Further perceived benefits are the greater customer satisfaction (58.6%; mean value: 3.52), an increase in corporate efficiency (56.4%; mean value: 3.43), followed by an improvement in customer relations (55.6%; mean value: 3.49), an improvement in internal communication (55.4%; mean value: 3.43), and a reduction in complaints (53.3%; mean value: 3.40).

However, there are also benefits that are not perceived by the companies in the sample, i.e. the 71% do not believe that certification leads to an improvement in delivery times (mean value: 2.78), and 72.6% believe that there is an increase in sales (mean value: 32.79).

Only a small percentage (27.3%) believes that the certification has contributed to the increase in sales, and these are mostly medium and small companies. Therefore this confirms various studies (Bravi, Murmura and Santos, 2018; Caridade et al., 2017) highlighting that for large companies, the possibility of tackling ISO 9001 is higher, thank their dimension.

Table 4 – Benefits Perceived from the Implementation of ISO 9001 Standard

	N	Mean (μ)	St. Deviation (σ)	Coefficient of variation (σ/μ)
Greater customer satisfaction	493	3.52	1.12	0.3
Improved image and reputation	493	3.98	0.89	0.2
Greater awareness of company possibilities	493	3.91	0.97	0.2
Improved relationship with customers	493	3.49	1.08	0.3
Improved delivery times	493	2.78	1.16	0.4
Increase of corporate efficiency	493	3.43	1.08	0.3
Reduction of non-conformities	493	3.55	1.09	0.3
Reduction of complaints	493	3.40	1.17	0.3
Improvement of internal communication	493	3.43	1.09	0.3
Increase in sales	493	2.79	1.12	0.4
Improvement of competitive advantage	493	3.17	1.15	0.4
Greater staff motivation	493	3.03	1.18	0.4

After analyzing the positive aspects related to the certification, the research focused on the analysis of the perceived barriers. The survey highlighted three main disadvantages (Tab. 5): the increase in the bureaucratisation of company activities (3.29); an increase in the complexity of procedures in the company (3.04), and an increase in business costs (2.92). These results are in line with extant literature underlining an increase in maintenance costs and in the bureaucratic management of the standard (Santos and Barbosa, 2006; Boiral, 2011; Ilkay and Aslan, 2012).

Only a small number of Small and Micro companies have found, after the certification process, a reduction in profits.

Table 5 – Barriers Perceived from the Implementation of ISO 9001 Standard

	N	Mean (μ)	St. Deviation (σ)	Coefficient of variation (σ/μ)
Increase in business costs	493	2.92	1.13	0.4
Increase in the complexity of procedures	493	3.04	1.12	0.4
Increase in bureaucratization	493	3.29	1.14	0.3
Reduction in profits	493	1.87	0.97	0.5
Reduction in customer satisfaction	493	1.47	0.78	0.5

Subsequently, considering the perception of the cost of the certification (Tab. 6) in relation to the financial indicators of the company, such as the Return on Investment (ROI), return on Net Capital (CN) and turnover, a relevant number of respondents (161, or 32.7%) considered the costs for the implementation of a Quality Management System acceptable, only a small percentage considered them to be high (15.8%), and unacceptable (5.7%). Investigating the size of companies, it emerged that among those companies that believe that the cost for the certification is high there is the 18% of Large companies, 14.4% of Medium-sized companies, 15.2% of Small businesses and 17.4% of Micro companies. On the contrary, no company considers the costs unacceptable; in fact, the value found for this item, on average, is below 2.

Table 6 – Perceived Costs for the Implementation of ISO 9001 Standard

	N	**Mean (μ)**	**St. Deviation (σ)**	**Coefficient of variation (σ/μ)**
Irrelevant	493	2.46	1.26	0.5
Moderate	493	2.58	1.10	0.4
Acceptable	493	3.00	1.18	0.4
High	493	2.33	1.11	0.5
Unacceptable	493	1.77	1.05	0.6

Later, companies were asked whether they had other certifications, in addition to the ISO 9001, and 45.8% answered positively. Considering the size of the companies, it is mainly the Large (81.8%) and Medium-sized ones (63.3%) that adopt further standards. Among the other certifications held, it appears that 52.2% also has the ISO 14001 (Environmental Management System) standard, 35.3% also has the OHSAS 18001 (Management Systems for Safety and Health of workers) standard, 7.1% has the SA 8000 (Management Systems for Social Responsibility) standard and finally only 3.1% has also EMAS III (European Environmental Management System) standard. Furthermore, it appears that 16% of companies are certified to both ISO 14001 and OHSAS 18001 and they manage this standard in an integrated manner, just like in other countries (Ribeiro et al., 2017; Santos, Rebelo and Santos, 2017; Carvalho, Santos and Gonçalves, 2018). The purpose of integration and implementation of management systems by integrating standards and documents is in the achievement of their synergistic action in the Organization. This can promote the appearance of new businesses (Doiro et al., 2017; Bravi, Santos and Murmura, 2018; Santos et al., 2018) even when consumers are more demanding (Bravi, Murmura and Santos, 2017; Santos, Murmura and Bravi, 2019).

In continuing the investigation, it has been verified how many companies were aware of the ISO 9004:2009 standard, that is the ISO 9001 guidelines which help companies to implement a QMS oriented to excellence. Only 11.2% said they were aware of the ISO 9004:2009 standard, while 17.2% said they knew it only partially and 71.6% did not know it at all. More than half of large companies do not know it or know it only in part, however considering the total number of Large, Medium, Small and Microenterprises that make up the sample, the percentage of large companies (59%) is the more significant percentage than claims to know it more. Once the companies that were aware of the ISO 9004 guidelines had been identified, it has been tried to understand whether these were based on its principles in business management.

It appears that only 11.8% follow its principles, while 37.7% follow them, but in part, and 50.4% do not refer to its principles at all. Subsequently, respondents who are aware of the ISO 9004 standard, but do not refer to its principles, were taken into consideration their motivations.

A relevant number (68) claims that it already requires much commitment to be ISO 9001 certified, others (51) believe that referring to the principles of ISO 9004 requires excessive time and that excessive training of personnel is necessary (51). These three main obstacles are perceived to a greater extent by Small and Microenterprises. No large company believes that the procedures are too complex and only a small number (3) find that also following the guidelines provided by ISO 9004 requires an excessive commitment.

5 CONCLUSION

The respondent companies that participated in this study are mostly Small and Micro-sized ones, and this reflects the Italian entrepreneurial reality. The majority of them work in the service sector, and mainly in Italy, although a relevant percentage also operates in European markets, and it is the Medium-sized companies, more than the Large ones, that operate internationally.

In Italy, most companies are concentrated in the northern regions, and these seem to be also the most economically developed, and among them, it seems that the Large and Medium-sized ones are mainly located in the North.

A large number of companies, located between North and Center, have been certified for over seven years, overcoming the various revisions of ISO 9001 that have occurred over time. Among these, there are mostly Medium-sized companies.

Considering these first results, it is possible to affirm that the “culture of quality” is by now rooted in Italy for years and mainly in the North, which represents the most economically advanced area.

With regard to the evolution of the standard from ISO 9001:2008 to 2015, companies seem to have perceived the main changes introduced with the latest revision, in fact they believe that ISO 9001:2015 gives greater importance to the concept of Risk management; favours integration with standards related to other issues such as environmental, ethical and health and safety issues (Ribeiro et al., 2017; Santos, Rebelo and Santos, 2017; Carvalho, Santos and Gonçalves, 2018); presents a greater propensity to the aspect of "continuous improvement"; enables the implementation of a quality-oriented management system; and it adapts more easily to the organizational structure (Marques et al., 2018; Araújo et al., 2019). This is in line with what is highlighted in the literature (Tsiouras, 2015; Gigante and Ziantoni, 2015).

As far as the motivations that led Italian companies to get certified are concerned, these are in line with what was mentioned in the literature (Torre, Adenso-Diaz and González, 2001; Douglas, Coleman and Oddy, 2003; Magd and Curry, 2003; Poksinska, Eklund and Dahlgaard, 2006; Heras-Saizarbitoria, 2011; Prates and Caraschi, 2014), in fact among the internal motivations there is the interest in achieving an internal organizational improvement, and to improve corporate image, while among the external ones there is, mainly, the opportunity to use the standard as a marketing tool. In contrast with the results of different studies, pressures from customers, the possibility of improving relations with the communities and the possibility of avoiding obstacles to export do not seem to be such important reasons as to encourage companies to adopt certification.

Paying attention to the benefits obtained by the companies after having gained the certification, a correspondence can be noticed between the perceived motivations and benefits.

Therefore there is a link between the benefits of ISO 9001 and the reasons why the organisation achieves the standard, confirming the results found by Santos and Milán (2013).

Finally, it was noted that, for the companies in the sample, the improvement in delivery times and the increase in sales and profits are not among the major benefits. This fact may be because, as stated by Psomas, Pantouvakis and Kafetzopoulos (2013), the impact of the efficiency and quality of the product/service on financial performance is indirect.

Certification, however, also involves disadvantages, including: greater bureaucratisation of company activities, an increase in the complexity of procedures in the company and an increase in costs, perceived above all by Small and Micro Businesses. These are easily conceivable disadvantages, given the Small and Micro dimensions of Italian companies, and in line with the literature considered (Torre, Adenso-Diaz and González, 2001; Magd, 2008; Santos and Milán, 2013).

A positive aspect to highlight is that only a small number of Small and Microenterprises have found, following the certification, a reduction in profits and customer satisfaction, something which, on the contrary, has not been manifested at all in larger companies.

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ABOUT AUTHORS

Laura Bravi – has a Ph.D. degree in “Economics and Business Management” (Summa cum Laude) at the University of Urbino Carlo Bo, Italy, where she is now Teaching Assistant in Total Quality Management. She also collaborates with an Italian Accredited Laboratory for quality tests for the wood furniture sector. E-mail: laura.bravi@uniurb.it, Author’s ORCID: http://orcid.org/0000-0002-1733-7043.

Federica Murmura – is Professor in Total Quality Management at the University of Urbino Carlo Bo, Italy. She participates as a speaker in national and international conferences and is currently the author of several publications and reviewer for International Journals. E-mail: federica.murmura@uniurb.it, Author’s ORCID: https://orcid.org/0000-0001-8443-8680.

Gilberto Santos – is Professor at the Polytechnic Institute Cávado Ave (IPCA), Barcelos, Portugal, where he founded a master’s course on “Integrated Management Systems QES (Quality, Environment and Safety) andnwas the director of it for 7th editions. He holds an Aggregation (D.Sc.) title in Industrial

Engineering from de New University of Lisbon and a PhD degree in Mechanical Engineering from the Minho University, Portugal. He participates as a Speaker in several national and international conferences and is the author of several publications, reviewer for International Journals. E-mail: gsantos@ipca.pt, Author's ORCID: https://orcid.org/0000-0001-9268-3272.

Six Sigma: Main Metrics and R Based Software for Training Purposes and Practical Industrial Quality Control

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Ana Rita Costa, Carla Barbosa, Gilberto Santos, M. Rui Alves

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ABSTRACT

Purpose: To clarify the different types of data likely to occur in any service or industrial process, the main applicable statistics for each type of data and the Six Sigma metrics that allow characterising and benchmarking organisational processes.

Methodology/Approach: A short reference to the statistical process control is carried out, from Shewhart's works to Motorola's achievements, followed by a short discussion of the use of Six Sigma tools as a part of today's total quality approaches, and by a discussion of the continuous, attribute and counting data worlds and their main applications in process analysis. Because many quality professionals may have difficulties dealing with engineering perspectives, a review of main classic and Six Sigma process metrics is done with examples. Complementing discussions, four functions written in the R language are presented, which can deal with real organisational data, or can be used for training purposes.

Findings: The functions developed provide useful graphical displays and calculate all necessary metrics, having the ability to let the user provide theoretical values for training activities. Real and simulated case studies help understanding data worlds and respective Six Sigma metrics.

Research Limitation/implication: This paper reports an intentionally simple theoretical perspective of Six Sigma metrics and friendly software which is available to all interested professionals on request to the authors.

Originality/Value of paper: The paper presents clear definitions of main data types and metrics and is supported by a set of four new functions that can be used by any researcher with a minimum knowledge of the R software.

Category: Technical paper

Keywords: six-sigma; data worlds; process capability; sigma level; Six Sigma software

1 INTRODUCTION

Six Sigma is essentially a methodology developed by Motorola, to address manufacturing or service problems. It is related to improvement projects following the define, measure, analyse, improve and control methodology (known as DMAIC), a well-defined project approach, utilisation of selected quality tools, and, in many circumstances, applying lean methodologies and many other specific quality tools. Theory, applications and developments can be found in many references, like Aboelmaged (2010), Antony and Banuelas (2002), Firat et al. (2017), Ward, Poling and Clipp (2008), Thomas, Barton and Chuke-Okafor (2009), Tjahjono et al. (2010).

However, it started to be a well-defined methodology to reduce variability, whose origins can be traced back to the beginning of the twentieth century after the works of Walter Shewhart (Mitra, 2016; Wadsworth, Stephens and Godfrey, 2007) dealing with the control of the variability of high yield machines. He proposed the use of statistics to control high throughput processes, and the quality control charts devised by Shewhart, which can be faced as the beginning of "statistical process control" (SPC) were the main tool to follow and control processes' performances and are still referred to as one of the seven basic quality tools (Mitra, 2016; Pyzdek and Keller, 2018).

The works of Shewhart are still valid, but the advent of computers and efficient software enabled the production of high yield machines and high throughput processes, forcing professionals to be increasingly concerned with precision and control, maintaining process parameters within very narrow specification limits, to avoid production of defectives (waste) and re-work (Antony and Banuelas, 2002; Marques et al., 2018; Pyzdek and Keller, 2018; Santos et al., 2006; Tjahjono et al., 2010).

In present times, companies without quality do not survive (Araújo et al., 2019; Santos and Milán, 2013; Santos, Murmura and Bravi, 2019). There are many companies where process control is integrated in Management Systems (quality, environmental, safety and others), seeking to optimize human and material resources (Carvalho, Santos and Gonçalves, 2018; Zgodavová et al., 2019; Santos, Rebelo and Santos, 2017; Ribeiro et al., 2017) promoting the emergence of new businesses (Bravi, Murmura and Santos, 2017; Santos et al., 2018; Doiro et al., 2017; Santos, Bravi and Murmura, 2018). In this context, tools like Six Sigma and lean are becoming more and more popular.

Six Sigma, as it is now formulated, tries to address all problems referred above, but uses procedures and metrics that are sometimes difficult to understand. Also, possibly because too many people with very different backgrounds are working in the field, a lot of confusion in critical aspects of this methodology is evident.

For example, there is unanimity in the definition and calculation of the traditional "process capability" metric (*Cp*), but in what concerns metrics defined within Six Sigma, definitions are not unanimous. The acronym *Pp* is used to refer "overall capability" or "process performance", and some authors do not provide clear definitions. The same happens with acronyms *DPMO* and *PPM*, crucial Six Sigma metrics, that can represent "defects per million opportunities", "defectives per million", or both (Antony and Banuelas, 2002; Barsalou, 2015; Brook, 2006; Moosa and Sajid, 2010). The same is true for the definition of data types, where virtually all authors agree in what concerns the "continuous data world", but with different opinions arising in relation to the "discrete data world" and the meaning of "counting", leading to difficulties in the establishment of a clear difference between "defectives" and "defects", and respective metrics.

It is essential to realise that Six Sigma is very important and is a popular quality tool, highly accepted in all types of organisations, hence the interest by the research community, the considerable amount of published papers and textbooks, and the significant number of software packages dedicated or including routines, for six-sigma. For those interested in this subject, the books of Pyzdek and Keller (2018) and Stamatis (2003) are highly recommended. But to understand that there are objections to the validity of Six Sigma as a quality tool/model by itself, reading the interview of Dr. Juran conducted by Paton (2002) is also highly recommended.

The purposes of this paper are three:

1. To try to clarify some crucial aspects of the Six Sigma methodology in what concerns important metrics, following closely the terminology used by the American Society for Quality (ASQ) (Barsalou, 2015);

2. To address three types of data worlds (continuous, attribute and counting data worlds) following the initial (not actual) Minitab terminology (Brook, 2006);

3. To present a set of useful functions, written by the authors using the R language (Alves, 2011; R Core Team, 2019) specially designed for Six Sigma lecturers and for Six Sigma practitioners, enabling the users to analyse several types of process data, producing useful graphs and automatically calculating the most important metrics.

It is must be highlighted that some functions were written in R by Cano, Moguerza and Redchuk (2012) and Cano et al. (2018) to deal with Six Sigma. However, although very comprehensive and freely accessible to the community, they require a good knowledge of the R language. Consequently, there is still an opportunity to produce simple, easy to handle functions, helpful for young practitioners and for people from backgrounds other than engineering, with low computational competencies.

2 METHODOLOGY

Four functions were written by the authors using the freely available R project software (R Core Team, 2019). The first purpose of these functions is to provide two main possibilities: (i) "simulate" and analyse data using argument "simulate=TRUE": the user supplies specification and process parameters and the functions simulate data and analyse it, so that they become quite friendly for teaching/learning purposes; (ii) "read" and analyse real examples supplied in simple text files (e.g., Notepad running in MS Windows environment), using argument "read=TRUE": the user supplies specification parameters and a data file, which is then automatically analysed.

In both "simulating" and "reading" modes, these functions produce two frames: (i) a frame with information on data, Six Sigma metrics and statistical tests; (ii) a frame with graphical aspects, including histograms or barplots and time plots.

All functions were designed in order to be confined to specific data worlds, requiring minimum knowledge of computation and Six Sigma. These functions are available to all interested readers on request.

3 RESULTS

In this section, the definition of data worlds follows that used in previous Minitab approaches (Brook, 2006), and metrics follow the definitions of the ASQ (Barsalou, 2015) closely.

3.1 The Continuous Data World

Many processes can be described by "key process indicators" (*KPI*) that are continuous variables following normal distributions, or that can be transformed in variables following that important probability distribution. This implies that a *KPI* can be characterized by a mean value (μ) and an uncertainty (3σ), i.e., in the form $\mu \pm 3\sigma$, where σ is the process standard deviation and value ± 3, which multiplies σ, is a z value from the standard normal distribution inducing a 99.74% confidence interval. Then, the "lower process limit" (*LPL*) is given by $LPL = \mu - 3\sigma$ and the "upper process limit" (*UPL*) is $UPL = \mu + 3\sigma$, with the "process range" (*PR*), also called precision, given by $PR = UPL - LPL = 6\sigma$.

To analyse these processes, they must be compared with specifications. Any specification (required by customers, laws or imposed internally) can be written in a way similar to a process, i.e., considering a "target value" (*TV*) and an "allowable error" (*AE*), and be written in the form $TV \pm AE$. Than the "lower specification limit" (*LSL*) is $LSL = TV - AE$ and the "upper specification limit" (*USL*) is $USL = TV + AE$, and the "specification range" (*SR*), also called tolerance, is $SR = USL - LSL$.

3.1.1 Capability Metrics

Taking these definitions into consideration, the main metrics for process evaluation are the "process capability" (*Cp*) and the "process capability index" *(*Cp_K) (Brook, 2006; Bartalou, 2015) given by the following equations where σ_w represents an estimate of the process σ based on several samples collected from production over time:

$$Cp = \frac{SR}{PR} = \frac{tolerance}{precision} = \frac{specification\,range}{process\,range} = \frac{USL\ -\ LSL}{6 \times\ \sigma_w} \tag{1}$$

$$Cp_L = \frac{LSL\ -\ \mu}{3\ \times\ \sigma_w} \qquad Cp_U = \frac{\mu\ -\ USL}{3 \times\ \sigma_w} \qquad Cp_K = \begin{cases} Cp_L & if\ |Cp_L| < |Cp_U| \\ Cp_U & if\ |Cp_L| \geq |Cp_U| \end{cases}$$

It is also important to evaluate the number of items falling out of the specification limits, expressed in "parts per million" (*PPM*): the PPM_L or *PPM* < *LSL*, PPM_U or *PPM* > *USL* and $PPM_T = PPM_L + PPM_U$. These *PPM* metrics refer to the process "defective yield". The "sigma level" (Z_σ or Z_{bench}) is the value of the standard normal variable corresponding to PPM_T, imagining all defective items as exceeding the *UPL*. *PPM* is calculated as areas under the normal curve exceeding the specification limits and are therefore the "expected" or "probable" fraction of defective units that will be produced, multiplied by 10^6.

Because there is confusion on several references, it must be emphasised that the total area under any normal curve always equals 1, so that tables of the normal distribution (or appropriate software) will give results (probabilities) as fractions of 1 and not as percentages. Consequently, percentages (%) are fractions of 1 multiplied by 10^2 and parts per million (*PPM*) are fractions multiplied by 10^6.

Dispersion (*D*) is a new metric, herein introduced, calculated as $D = AE/\sigma = 3\times Cp$, and is used to make a distinction between the sigma level and the common sense of 3σ. If a process mean is centred in the specification target value, *D* is the number of standard deviations between the process mean and the specification limits.

For the estimation of the process σ, referred to as σ_{within} or just σ_w, processed units can be collected in three different ways: (i) samples collected one at a time, therefore collecting *N* samples of size n=1 and estimating σ_w based on moving ranges; (ii) groups of units always with the same number of units, i.e., *N* samples of size *n*, with $n > 1$, and estimating σ_w based on samples' variances; (iii) groups of units with different numbers of units per group, i.e., *N* samples of different sizes, and estimating σ_w based on samples' sums of squares. These estimates of the process σ based on σ_w reflect the common causes of variation, inherent to the process, and therefore represent the best that the process can do, and are used for the calculation of capability metrics.

3.1.2 Function *SS.Cp*

In order to understand these definitions, function *SS.Cp* was built (mainly for teachers and students). The user supplies the values for a specification (*TV* and *AE*) and the process parameters (μ and σ). The function draws the specification and the normal curve corresponding to the process parameters and calculates all metrics referred above.

Fig. 1 was produced with function *SS.Cp* with arguments *TV* = μ = 500, *AE* = 15 and σ = *AE*/3 = 5. In this situation, the process is fully adjusted to the specification. In Figure 1, the specification values, process characteristics and the yield metrics just discussed are calculated and shown on the left-hand side, and on the right-hand side, the specification is plotted together with the normal curve corresponding to the process. Because the process is centred in the specification, *Cp* and Cp_K are equal, and because the process limits and specification limits are also equal, *Cp* = 1 and *D* = 3. Nevertheless, some defective units are produced and $Z_{bench} \approx 2.8$: hence the difference between “dispersion” and “sigma level”.

Fig. 2 was produced with function *SS.Cp* with the same arguments for the specification, *TV* = 500 and *AE* = 15, but with σ = *AE*/4 = 3.75 and μ = 500 – 1.5 × σ = 494.375, reflecting a 1.5 sigma-shift. In this situation, although the process is capable, as seen by *Cp* = 1.33 and *D* = 4, the sigma-shift displaced the process to the left, resulting in a Cp_K which is negative and smaller than *Cp* in absolute value. Consequently, more defectives are produced exceeding the *LSL*. The sigma level is now only $Z_{bench} = 2.5$.

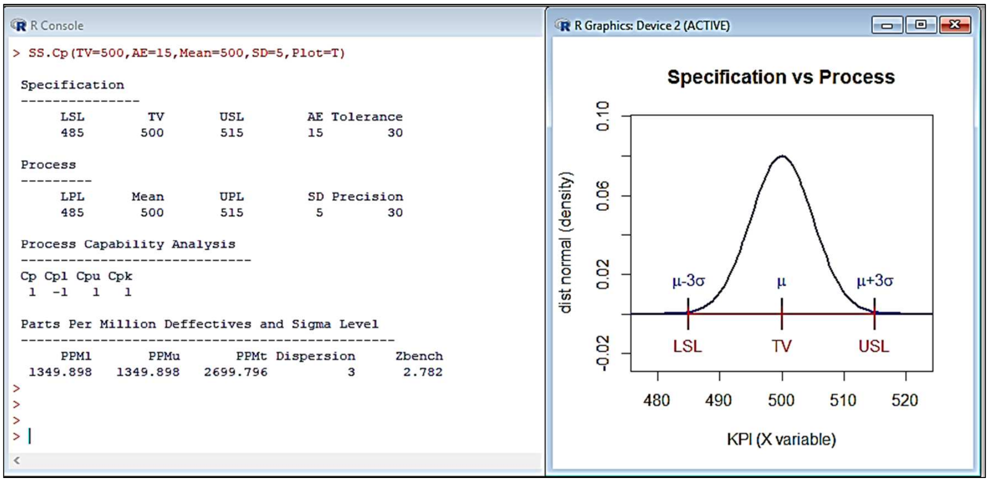

Figure 1 – Output of Function SS.Cp, Comparing a Process with μ Adjusted to TV, and with σ = AE/3. The Dispersion is 3, Cp = CpK = 1 and 2700 PPM are Produced, Corresponding to a Z_{bench} = 2.78. The Process Parameters μ and σ are not Calculated, but Stipulated by the User

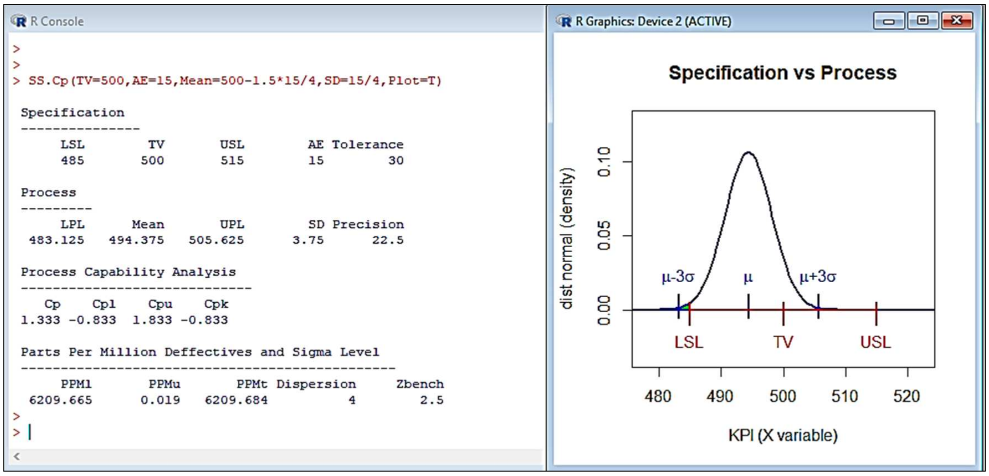

Figure 2 – Output of Function SS.Cp, Showing a Process with a 1.5σ Shift to the Left of the TV, with σ = AE/4. The Dispersion is 4, Cp = 1.33, Cp_K = −0.833 and 6200 PPM are Produced, leading to a Z_{bench} = 2.5

3.1.3 Performance Metrics

In Six Sigma projects, besides capability metrics, performance metrics are also important (Barsalou, 2015): these are the "process performance" (*Pp*), and the "process performance index" (Pp_K). The difference between capability and performance metrics resides in the estimate of the process standard deviation:

$$Pp = \frac{SR}{PR} = \frac{tolerance}{precision} = \frac{specification\ range}{process\ range} = \frac{USL - LSL}{6 \times \sigma_o} \tag{2}$$

$$Pp_L = \frac{LSL - \mu}{3 \times \sigma_o} \qquad Pp_U = \frac{\mu - USL}{3 \times \sigma_o} \qquad Pp_K = \begin{cases} Pp_L \ \ if\ |Pp_L| < |Pp_U| \\ Pp_U \ \ if\ |Pp_L| \geq |Pp_U| \end{cases}$$

As it can be seen comparing equations (1) and (2), the performance metrics are equal to capability metrics, but use a different estimate of the process σ, referred as $\sigma_{overall}$ or just σ_o. The calculation of σ_o uses all units collected, irrespectively of time or samples, i.e., as if it was just one big sample. Such an estimate is called the "overall sigma" and incorporates all common causes of variation as well as the special causes of variation arising along time.

Following the definitions for capability and performance metrics, it can be concluded that these metrics will be different if: (i) the process is affected by special causes of variation; (ii) if the process variability increases with time; (iii) if there is a sigma shift, a term that is used in Six Sigma (Pyzdek and Keller, 2018) to refer to a displacement of the project mean in relation to the specification target value, measured in standard deviation units. In all these three cases, σ_o will be higher than σ_w, and all performance metrics will be significantly higher than the corresponding capability metrics.

3.1.4 Function *SS.Norm*

Once capability, performance and defective yield metrics are understood, processes can be analysed in business practice with function *SS.Norm*. This function needs to be supplied with the specification values (*TV* and *AE*), a file name with practical data, and argument "samples". The latter argument is just the number of samples actually analysed, as described in section 3.1.1. Based on these arguments, function *SS.Norm* will automatically calculate estimates for σ_o and σ_w and all metrics just discussed.

Fig.3 presents a real industrial example: the analysis of daily losses expressed as the fraction of wasted fruit mass per day in a fruit juice processing plant. On the left-hand side of the function output, all metrics are presented: observed data and the estimates of capability, performance and yield, together with some statistical tests. On the right-hand side, the specification, a histogram of observed data and the estimates of process behaviour as two normal curves (the narrower, blue curve representing the process with only common causes of variation, and the wider, yellow curve representing the process in the long term including the observed special causes of variation), and shaded areas under the normal curves showing the fraction of defective units. Also, on the same side, a plot of data values over time enables the visual observation of the special causes of variation.

Fig. 3 is an example of a very bad process: *Cp* is lower than 1, meaning that the process range is higher than the specification range; the positive and small values of Cp_K and Pp_K demonstrate that the process mean is displaced towards the right, producing higher daily losses; the sigma level is very low and even if all special causes of variation were removed, Z_{bench} would only be slightly higher than 1.2, which is a very low value.

Fig. 4 shows the analysis of a real industrial example relative to coffee packaging. The specification limits were derived from Portuguese legal aspects related to the metrological control of pre-packaged foods (Portaria 1198/91) and internal specifications. As it can be seen on the left-hand side of Fig. 4, the short-term sigma level is extremely high ($Z_{bench(ST)} = 8.5$), reflecting a process with very high precision. The long-term sigma level is also high, and curiously reflects a sigma-shift of 1.5 ($Z_{bench(LT)} = 7.0$), as predicted in the Six Sigma theory (Pyzdek and Keller, 2018). This shift shows that the process is very accurate, but there is a margin for improvement just by the removal of the special causes of variation. It is worth noting the short-term metrics $Cp \approx 3$ and a dispersion $D \approx 9$.

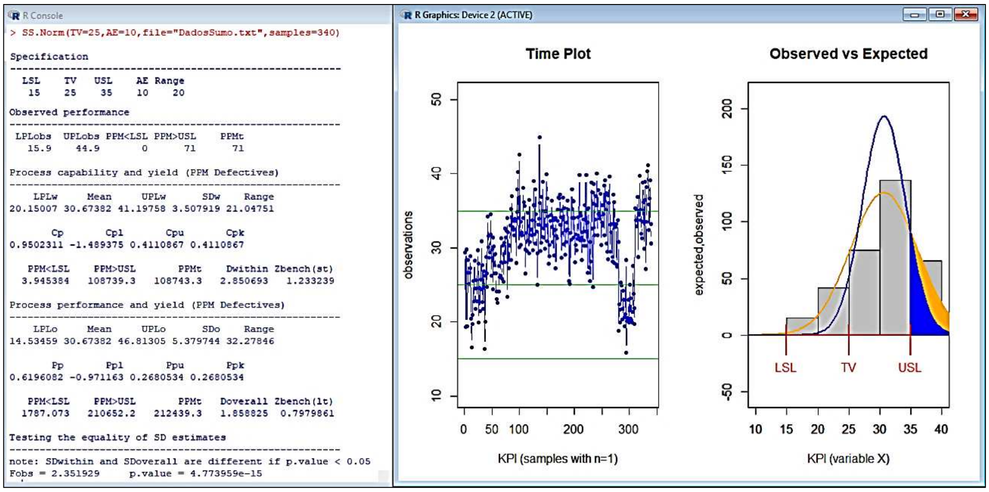

Figure 3 – Output of Function SS.Norm, Showing a Real Industrial process dealing with Daily Losses in Juice Production. The Process has Very Low Performance (Pp = 0.62) and is Displaced towards the Right (Pp_K = 0.268), Producing 108743 PPM Corresponding to a Long Term Sigma Level of 0.798. There are Evident Special Causes of Variation (p = 4.773959×10^{-15}), and a Cp = 0.95 Shows a Need for Improvement

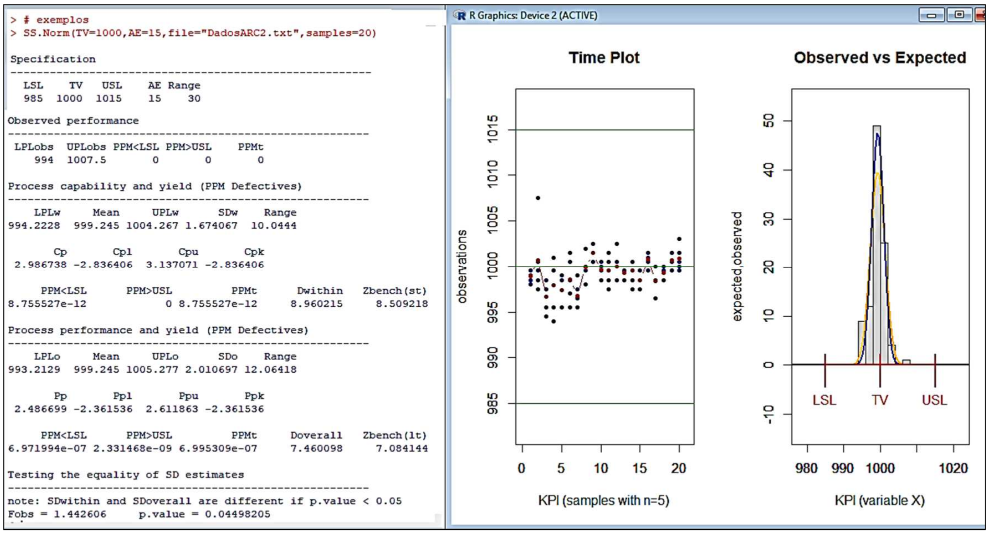

Figure 4 – Output of Function SS.Norm, Showing a Real Industrial Process of Coffee Packaging. The Process has a Very High Capability Expressed as a Short-Term Sigma Level Equal to 8.5. Metrics Show that with Time this Level Will Be Reduced to 7, Reflecting a True 1.5σ Shift.

3.2 The Attribute Data World

Some processes can be described by *KPI*s that classify units as "defective" or "non-defective", i.e., as "1" or "0". In this situation, data follows a binomial distribution, and the critical process parameter is the fraction of defective items produced, denoted by π. These *KPI*s that correspond to counting defective units are expressed as only two possible quality outcomes and are referred to as "attributes" (Brook, 2006).

3.2.1 Main Metrics for Attributes

In the case of attributes, one has to collect and inspect *N* production units, classifying each unit as a "1" (defective) or a "0" (non-defective). Units can be collected and inspected in different ways, leading to different aspects.

One can collect and inspect *N* units, one at a time, leading to a series of *N* "zeros" and "ones". In this case, two data displays are useful: (i) a barplot with two bars, one for the number of defective units, the other for the amount of non-defective units; (ii) a plot of results (of "zeros" and "ones") over time, to try to investigate possible special causes of variation.

If one collects *N* samples of equal size *n*, this leads to a series of natural values ranging between "0" and "*n*" representing the number of defective units observed in each sample. Therefore, a barplot with *n* columns, with the height of each column representing the number of samples with 0, 1, …, *n* defectives will be informative. Also, a plot of the evolution of the number of defective units per sample along time will be necessary.

Finally, one may have a series of *N* samples of different sizes. In this situation it is essential to convert the number of defective units per sample to the fraction of defective units per sample, producing a plot of the fraction of defective units observed over time and a histogram showing the distribution of the fraction of defectives per sample.

Whatever the procedure applied, all data is used to estimate the process defective fraction, π. Such an estimate is calculated as the sum of all values (the sum of all defective units) divided by the total number of inspected units (*M*), which is referred by *P*.

In mathematical notation, one collects a series of *M* values, which can be represented as $x_1, x_2, x_3, \ldots, x_i, \ldots, x_M$, and *P*, the estimate of π, is:

$$\pi \sim P = \frac{1}{M}\sum_{i=1}^{M} x_i \qquad PPM_T = P \times 10^6 \tag{3}$$

It is worth noting that it is irrelevant if one is talking about samples of size 1, or equal or unequal sizes since the average of sample's defective fractions are always equal to the overall defective fraction.

As shown in equations (3), an estimate of the long-term defective production yield is just the part per million defectives, calculated as $PPM_T = P \times 10^6$. Consequently, a sigma level, $Z_{bench(LT)}$, can be calculated using P as the extreme right-hand side area under the standard normal distribution and determining the value of the corresponding z variable.

However, with this type of data, unless one is talking about very high numbers of inspected units, it is virtually impossible to distinguish between short- and long-term defective fractions, as well as special causes of variation. Hence, all data is faced as long-term, and if a short-term sigma-level, $Z_{bench(ST)}$, is desired, it can be approximated by $Z_{bench(ST)} = Z_{bench(LT)} + 1.5$.

3.2.2 Function *SS.Defectives*

In order to deal with attribute data, function *SS.Defectives* was built. This function has two possibilities: (i) using argument “Simulate = TRUE”, intended for teaching and studying purposes, leading to the simulation of production outputs based on values supplied by the user for π (the true production defective fraction), N (number of samples) and n (sample size); (ii) indicating a data file, which overrides all other arguments, leading to the automatic analysis of real data.

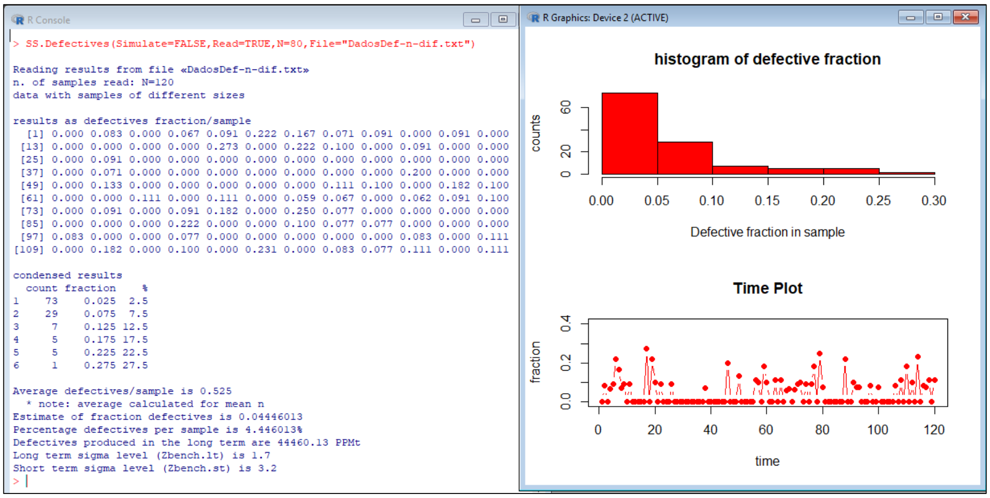

Figure 5 – Output of Function SS.Defectives, Showing a Real Industrial Process, Analysing Samples of Different Sizes of Pre-Packaged Coffee Beans. Units with Contents Lower than the Legal AE or Higher than the Internal AE, Are Defective. $Z_{bench\ (LT)}$ *Shows Possibilities for Improvement*

Fig. 5 shows an example of the use of function *SS.Defectives* applied to real data consisting of N=120 samples of different sizes. All raw values in the file are converted to sample defective fractions, which are shown on the left-hand figure frame, together with a division in classes for analysis of dispersion and as the basis for the histogram. Several metrics are also presented, mainly the estimate of the defective production fraction, total *PPM*, and the sigma-levels $Z_{bench(LT)}$ and $Z_{bench(ST)}$. In this example, 4.45% of defective units are estimated to be produced over time, which corresponds to a long-term sigma-level of 1.7.

3.3 Counting Data World

The last type of *KPI*s of interest belongs to the "counting data world". To work with this type of data, each production unit is faced as an "area", or "quantity", where some "types of defects" are possible. Each type of defect is called an "opportunity", and the total number of opportunities is referred to as "*NO*". The number of units inspected is *N* (Barsalou, 2015; Brook, 2006).

The purpose of this quality control practice is to count the number of defects observed for each opportunity and for each unit, for all units, and calculate an estimate of the population parameter of interest: the average number of defects per opportunity in the long-term, λ, expressed in parts per million, usually referred to as "defects per million opportunities" (*DMPO*) (Moosa and Sajid, 2010).

3.3.1 Main Metrics for Counts

In what concerns the actual work that has to be carried out to calculate main metrics, the following aspects are important: (i) a template is prepared with a matrix-like structure, with columns representing opportunities (types of defects) and rows representing sample units (see left hand-side frame of Fig. 6); (ii) a unit is collected and inspected, counting the number of defects of each type, filling a matrix row; (iii) this practice is repeated for all *N* units, filling all *N* matrix rows; (iv) the last matrix column is the automatic row sum, i.e., the total "number of defects per unit" (*NDU*); (v) the last matrix row is the automatic column sum, i.e., the total "number of defects per opportunity" (*NDO*).

Based on these initial metrics (*NDU* and *NDO*), two crucial intermediate metrics are derived: (i) the average "number of defects per unit" (*DPU*); (ii) the average "number of defects per opportunity" (*DPO*):

$$DPU = \frac{1}{N}\sum_{i=1}^{N} NDU_i \quad DPO = \frac{1}{N \times NO}\sum_{i=1}^{N}\sum_{j=i}^{NO} NDO_{ij} = \frac{DPU}{NO} \qquad (4)$$

Because any unit with one or more defects is faced as a defective unit, *DPU* is an estimate of the process parameter λ, the long-term number of defects per unit. Because this parameter follows a *Poisson* distribution, the probability of "0" defects per unit, i.e., the probability of *NDU*=0, can be calculated and the process yield, in terms of fraction defective units, in the long-term, is expected to be the quantity $1–e^{-DPU}$ (Brook, 2006):

$$P(NDU = 0) = \frac{DPU^0 \times e^{-DPU}}{0!} = e^{-DPU} \qquad (5)$$

$$P = fraction_{(defectives)} = 1 - e^{-DPU} \quad PPM_t = 10^6 \times P \tag{6}$$

The long-term sigma-level, $Z_{bench(LT)}$, is the z value corresponding to the extreme right-hand side area under the standard normal curve equivalent to P (fraction defective), and the short-term sigma-level, $Z_{bench(ST)}$, is:

$$Z_{bench(ST)} = Z_{bench(LT)} + 1.5 \tag{7}$$

Finally, if instead of PPM_T the interest is in the study of "defects per million opportunities", referred as *DPMO*, instead of defective units per million (PPM_T), then metric *DPMO* is the important metric, calculated as (see Fig. 6):

$$DPMO = 10^6 \times \frac{DPU}{NO} \tag{8}$$

This metric, although famous in the area of Six Sigma projects, should always be avoided, unless one can be sure that all opportunities for defects are unambiguously defined and that no new opportunities will arise in the course of a practical industrial work (Brook, 2006).

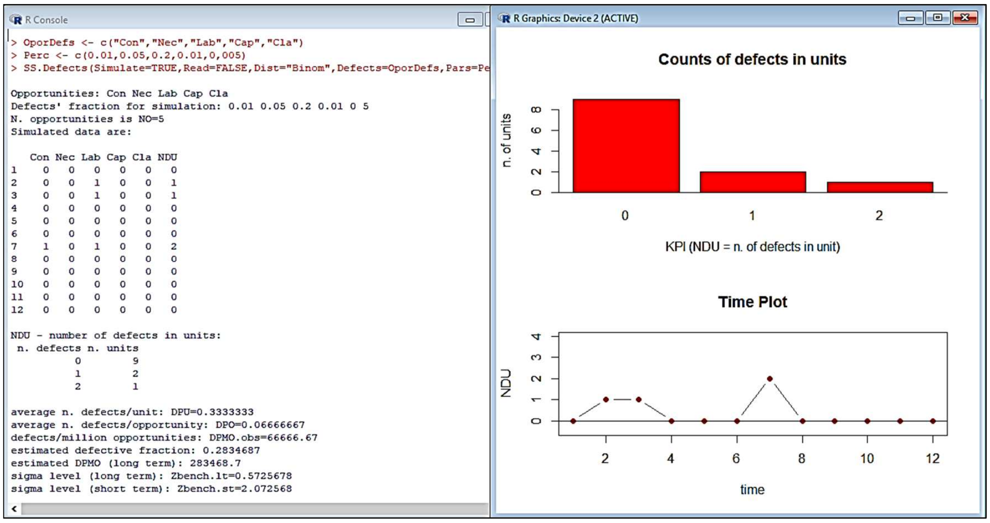

Figure 6 – Output of Function SS.Defects, in the Simulation Mode. Simulated Data is Presented on the Left-Hand Side, Together with the Main Metrics: DPU, DPO, DPMO and Sigma-Levels. On the Right-Hand Side, Barplot with Main Observed Counts of Samples per Number of Defects, and Evolution with Time. $Z_{bench(LT)}$ *is Very Small and* $Z_{bench\,(ST)}$ *Must be Seen with Caution Since Its Meaning is Doubtful*

3.3.2 Function *SS.Defects*

Function *SS.Defects* was built to address counting data problems as described in section 3.3.1, and is similar to function *SS.Defectives*, enabling simulations for teaching/studying purposes, but also the treatment of practical organizational problems.

Figure 6 provides an example of the use of this function in the simulation mode. The user supplies the function with a list of opportunities (a list of names of defects that can occur in bottles of mineral water) and a list of defective fractions for each opportunity (a list of π values). In this simulation, the opportunities were "content" (*Con*), "bottleneck" (*Nec*), "label" (*Lab*), "capsule" (*Cap*) and "clamping" (*Cla*), with π values equal to 0.01, 0.05, 0.2, 0.01, 0.5, respectively. The user also tells the function how many units are to be generated (N). Then, using the binomial distribution, the *SS.Defects* function, generates random data for each opportunity and, afterwards, provides two frames: a frame with reports and metrics (left-hand side), and a frame with graphical aspects (right-hand side).

4 CONCLUSION

Although Six Sigma is a very comprehensive methodology, involving a lot of quality tools and ways to address projects, Six Sigma metrics may be a key question in the methodology.

In this paper, the main metrics and the main graphical displays were presented, and discussions were followed with practical cases treated with functions *SS.Cp*, *SS.Norm*, *SS.Defectives* and *SS.Defects*, which were designed using the R language, to work within the "continuous", "attribute" and "counting" data worlds. These functions are very versatile because they can be used in the "simulation mode" for teaching/learning purposes, and on the "reading mode" for the analysis of real data, enabling users to quickly carry out any process analysis with the correct Six Sigma metrics.

The examples show that with very little knowledge of computing or statistics, any interested professional can analyse real cases, producing illustrative graphs and all relevant Six Sigma metrics. Furthermore, these functions can be used to simulate data, treating simulated data as real and produce the same graphs and metrics, being very useful for teaching Six Sigma metrics and for students to compare specifications with process parameters and understand the meaning of Six Sigma metrics. These functions are available to any interested reader.

All functions presented in this paper accept only one *KPI* and single stage processes. In order to make them more versatile, work is being carried out in order to treat data arising from multistage processes and it is envisaged to extend them to deal with more than one KPI.

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ABOUT AUTHORS

Ana Rita Costa – is a BSc in Food Engineering and is now a student carrying out a one-year training period in industry as a partial fulfilment of the Master Degree in Food Engineering. She is applying statistical process control technics included in lean/Six Sigma projects. E-mail: anaritarcosta@hotmail.com, Author's ORCID: https://orcid.org/0000-0002-1756-7789.

Carla Barbosa – is Prof. at Polytechnic Institute of Viana do Castelo (IPVC), Viana do Castelo, Portugal. She is a member of LAQV/REQUIMTE and CISAS (investigation centres accredited by FCT – the Portuguese Foundation for

Science and Technology), holds a MSc (Food Engineering), and a PhD (Nutrition and Food Chemistry). Her current research interests include Quality Management and Quality Tools, Statistical Process Control and Product Development. Special focus on physical properties and their relationships to Consumer Acceptabilities and Preferences. E-mail: cbarbosa@estg.ipvc.pt, Author's ORCID: https://orcid.org/0000-0002-8042-8642.

Gilberto Santos – is Prof. at Polytechnic Institute Cávado Ave (IPCA) Barcelos, Portugal. He holds a PhD degree in Mechanical Engineering from Minho University, Portugal. His current research interests include industrial and mechanical engineering, namely, innovation, quality systems and integrated management systems. Gilberto participates as a speaker in several national and international conferences, and he is currently author of several publications in integrated management systems (IMS) – QES (quality, environment and safety) (books, papers in international and national journals). He is member of the research team of several IMS – QES research projects and supervises Master and PhD thesis, as well as reviewer of international journals. He founded a master's course on "Integrated Management Systems QES" at the College of Technology of Polytechnic Institute Cávado, where he was Director of the MSc during the first six editions. E-mail: gsantos@ipca.pt, Author's ORCID: https://orcid.org/0000-0001-9268-3272.

M. Rui Alves – is this paper's corresponding author. He is Full Prof. at Polytechnic Institute of Viana do Castelo (IPVC), Viana do Castelo, Portugal. He is a member of LAQV/REQUIMTE and CISAS (investigation centres accredited by FCT – the Portuguese Foundation for Science and Technology), holds an MPhil (Food Science & Technology), a PhD (Nutrition and Food Chemistry) and a Post-Graduation (Six-Sigma Black Belt). His current research interests include Quality Management and Quality Tools, Statistical Process Control, Product Development and Consumer Studies. Special focus on R based friendly algorithms for non-statisticians. E-mail: mruialves@estg.ipvc.pt, Author's ORCID: http://orcid.org/0000-0003-1844-485X.

Downtime in the Automotive Industry Production Process – Cause Analysis

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Radosław Wolniak

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ABSTRACT

Purpose: The article presents an analysis of the application of selected quality management methods and tools in order to identify factors affecting downtimes in the production line, illustrated with an example of the automotive industry.

Methodology/Approach: The paper contains an analysis of downtimes in the production process using selected methods and tools of quality management. The authors used a combination of tools and methods to carry out the analysis. In this concept, first, the 5WHY method and the Ishikawa diagram were used.

Findings: The research results presented in the paper suggest that better results can be achieved by using a set of quality tools instead of one particular tool. The authors found that using a wide range of quality tools can be useful to reduce downtimes on the production line.

Research limitation/implication: The major limitation of the paper is that it is based on one case of an organisation from the automotive industry. In the future, it will be necessary to conduct studies in more organisations so as to find out if the same result can be achieved.

Originality/Value of paper: The article is concerned with the use of quality management methods and tools to analyse production line breakdowns. Until present, in subject literature, the causes of downtimes have been analysed without differentiating between planned and unplanned downitmes of the production line.

Category: Research paper

Keywords: quality tools; production line; downtime; quality management; quality improvement; quality methods

1 INTRODUCTION

The problems connected with using quality management methods and tools in the automotive industry are described in many papers in international literature. Many authors suggest that a tool is simple, stand-alone application, whereas a technique tends to be a more comprehensively integrated approach to problem solving (Dale and McQuarter, 1998).

One of the main assumptions underlying a quality management system is improving the ability to define nonconformities, as well as to plan and carry out corrective and preventive actions. ISO/TS 16949 is a standard for QMS. This standard outlines the specific requirements for the application of ISO 9001:2015 in automotive production and relevant service part organizations (Lin et al., 2004). This standard recognizes the uniqueness of every automotive supplier's process, while providing critical tools to help your company better meet customer specific requirements (Bakhtiar, Mohammad and Kazemzadeh, 2010; Wolniak, 2014; Skotnicka-Zasadzień, Wolniak and Zasadzień, 2017; Thia et al., 2005).

The findings of other authors (Bunney and Dale, 1997) suggest that the use of tools and techniques is a vital component of any successful improvement of. production processes. By using quality management tools, an organization can investigate problems, identify solutions and implement them in its work practice. Quality management tools are classified generally into two groups: soft and hard (Evans and Lindsay, 1999; Wilkinson and Wilmott, 1995). In this paper we concentrate on production organizations and their use of hard tools. The technical system consists of a set of tools, while the hard part includes production and work process control techniques which ensure the correct functioning of such processes, including among others quality control tools (Silombela and Mutingi, 2018).

A significant number of those methods are called systems, because they constitute an integral and necessary element of cooperation between organisations in the customer-supplier relations, (Liker and Hoseus 2009; Bandyopadhyay, 2007; Delbridge and Barton, 2007; Liker and Meier, 2008; Sila, Ebrahimpour and Birkholz, 2006; Żuchowski and Łagowski, 2004; Imai, 2007; Nazrul, Kumar and Datta, 2012; Łuczak and Wolniak, 2015; Wolniak and Skotnicka-Zasadzień, 2014; Skotnicka-Zasadzień, 2013).

When we try to solve a particular problem in the industry, it is not enough to use one particular tool, as it cannot provide a sufficient amount of data to cope with the problem. Quality tools such as for example, seven quality tools are usually perceived as too simplistic and not suitable to solve problems in the automotive industry (Dale, 2003). The best way is to establish a set of tools which can be applied together, using a similar method. The use of a combination of quality tools and techniques provides the possibility to (Bamford and Greatbansk, 2005):

- highlight complex data in a simple, visually powerful way,

- evaluate areas that cause most problems,
- specify areas to be prioritized,
- show relationships between variables,
- establish causes of failures,
- show the distribution of data,
- establish whether the process takes place in a state of statistical control and determine the effect of specific causes.

Automotive industry organisations use many tools to analyse and improve their processes. The research done by Hys indicates that automotive organisations operating in Poland use mainly (Hys, 2014; Zasadzień, 2017):

- classical seven "old" tools of quality management (Pareto analysis, histograms, correlation charts, Ishikawa diagram, sheet counting data) – 40% of organisations,
- "new" tools of quality management (affinity diagram, interrelationship diagram, tree diagram, prioritisation matrix, matrix diagram, process decision program chart) – 12.3% of organisations,
- statistical process control – 21.5% of organisations,
- other tools – 7.69% of organisations.

The implementation of quality methods and tools is not successful in all cases. It may be a failure as well. In source literature, one can find mentions of unsuccessful implementation of quality tools. They are connected with the following problems (Putri and Yusouf, 2008):

- lack of confidence in potential benefits prevents some companies from trying to implement quality tools,
- problems in determining how to choose from a large number of existing tools in various organisations,
- problems in determining how to react to new developments in quality tools and programs,
- lack of ability to follow developments and apply tools that were applied successfully in other companies.

To achieve success in the quality tools implementation process, we should deal with those problems carefully.

The problem analysed in this paper is connected with production downtimes. Resources, as well as time in an automotive organisation, are scarce, so it is important to reduce the unwanted downtimes and interruptions in the production process. The most useful information for a production manager is related to the duration of downtime due to performance of maintenance tasks and other production problems (Knezevic, 1994; Hussan et al., 2014; Zennaro et al., 2018; Stal et al., 2012). Reducing downtimes to improve efficiency is a well-known concept used in many industries. Its effectiveness depends on a particular case and a set of methods used (Battini et al., 2015). According to TPM framework, most downtimes related to failures in industrial organisations can be controlled and reduced (Bokrantz et al., 2016). The article analyses the production line that produces semi-finished products for the manufacture of ready-made two-pipe shock absorbers for the rear of passenger cars. The production process starts with cutting the pipes that are the main element of the finished shock absorber. The cut tube is given a shaping treatment, such as widening the ends, in order to locate the shock absorber bottom in a proper way at the later stages of production, and narrowing it in order to give it a proper shape that allows the shock absorber to be finally fixed in the car.

The finished pipes are stored in the storage area located next to the body production line. The production of shock absorber bodies starts with the delivery of pipes and components from the warehouse. The finished components are stored in the area located next to the final assembly line of the shock absorber, where the components delivered from previous areas and the warehouse are stored. The finished shock absorbers go to the painting line, where they are covered with protective paint that does not allow corrosion. Painted shock absorbers go to the last line, where they are packed into cardboard boxes, and the necessary accessories needed to mount a shock absorber in the car are added.

2 METHODOLOGY

The article concerns the use of various quality management methods and tools for analysis of downtimes on the production line. In the discussed enterprise, until the present, the quality management processes have not been improved. The company documentation does not provide information on whether traditional or modern quality management tools have been used or what quality methods have been applied.

We collected data from the analysed company about the time of the production line availability. For this purpose, we used control sheets. All working days, additional work days and holidays were calculated from the data obtained. Formulas 1-3 were used for calculations. The next step was the use of quality management methods and tools. First, the 5 WHY method was applied, next analysis was performed using the Ishikawa diagram. Many quality management methods and tools can be used in the case of this type of analysis. We chose the two above mentioned ones on the basis of our pilot studies conducted in organisations from the Silesian automotive industry. We asked engineers about particular tools which were useful in this type of problems, and we chose the two most important ones.

After the analysis, improvement actions were proposed. Until present, the individual stages of analysis have not been used in the analysed enterprise. We supposed they would allow for reducing the duration of production line downtimes.

3 RESULTS

The application of quality management tools and methods in the surveyed enterprise provides opportunities and a starting point for a wider application of quality management elements to improve production processes in other organisations as well as in various industries. The analysis and evaluation of the availability time were divided into planned and unplanned stoppages of the production line, and the total time of the production line availability was calculated. Studies carried out in this way provide a broader view of the problem.

3.1 Total Time of the Production Line Availability

The time of production line availability was calculated as follows: all working days and additional working days were calculated; next, holiday days were deducted, such as holiday leaves, production stoppage time in the summer and winter season (annual leaves of employees) and the time of stocktaking. Each full working day consists of three production shifts, lasting 8 hours. In the event of needed production at the customer's request or failure to comply with the production plan over the weekend, the company management may arrange additional working hours, which are multiples of full 8-hour work shifts.

In order to calculate the total working time, the following formula (1) was used:

$$T_C - T_W = T_D \tag{1}$$

where:

T_D – Time of production line availability

T_C – Total time during the considered period

T_W – Time off days

The total time of the production line availability was calculated as follows (2):

$$1{,}054{,}080\ (min) - 337{,}440\ (min) = 716{,}640 (min) \tag{2}$$

The calculated time of 716,640 minutes consists of 1,493 production shifts, lasting 480 minutes of work. The exact distribution of the number of shifts and working days is shown in Tab. 1.

Table 1 – Time of the Production Line Availability

Production line availability (min)	Days	Sum of the production line work (min)
480	12	716,640
960	13	
1,440	485	

Next, the production line downtime was calculated. The first stage of the analysis involved identifying the main groups of downtimes in order to categorise data with similar features; the division enables focusing on the major causes of the most important problems (Tab. 2).

Table 2 – Main Groups of Production Line Downtimes

No.	Group	Description	Downtime (min)
1	Planned downtime	Breakfast break, cleaning, top-down production stoppage	71,607
2	Unplanned downtime	Unplanned production stoppage, for example, due to lack of components	14,199
3	Failure	Extended unplanned machine breakdown due to technical stoppage	11,286
4	Micro failure	Short production stoppage that does not require calling for maintenance services	1,565
5	Conversion	Replacing the machine equipment and changing the production parameters	81,019

Table 3 – Summary of Reasons for Planned Downtimes and Their Duration

The cause of the planned downtime	Downtime (min)
Breakfast break for employees	29,860
TPM production line	14,930
Cleaning the production line	14,930
Cleaning the welding machine’s burner	11,417
Staff training	280
Meeting for employees	190

In the further part, the causes of downtimes in the studied area will be analysed. They are divided into particular groups and listed in Tab. 2. All planned downtimes of the production lines were analysed. It results from the applicable law, the work organisation and the rules in force in the enterprise. The causes of planned production line downtimes and their duration are presented in Tab. 3.

Breakfast break for employees – according to the Labor Code, during each 8-hour shift, an employee is entitled to a minimum 15 minutes break. The management of the plant decided to increase the break time from 15 to 20 minutes due to the significant distance separating the production hall, the canteen and the employee locker rooms.

TPM (Total Productive Maintenance) production line – an action is resulting from the TPM philosophy. At the beginning of each shift, the machine operator must perform several necessary steps to reduce the number of failures and breakdowns in the plant.

Cleaning the production line - this is an action based on the philosophy of “5S”. At the end of each production shift, the operator is required to clear his workstation of waste or garbage produced, organise tools and prepare the necessary materials for the next shift.

Meeting for employees – the meeting is aimed at raising the employees’ awareness of the company’s condition, planned production, results in previous months and planned development. Meetings are held regularly, with an average frequency of every 2-4 months. Meetings must be organized for all employees, which is why they take place during the production shift.

Training for operators –training takes place each time when pieces of body or shock absorbers that would endanger the customer’s safety will be produced. The training is aimed at raising the operators’ awareness of potential defects in their areas of work, which is why the plant management agreed to stop production for up to 10 minutes for each training course.

Cleaning of welding torches – welding torches need to be cleaned to prevent the production of bodies with damper welds connecting the pipe to the shock absorbers’ ear. The cleaning of the burner has been included in the operator's manual of the machine and is performed after every 100 pieces of the manufactured product.

All reasons for planned downtimes affect the quality of products or result from the organisation of work; therefore, they are impossible to eliminate.

The changeover time is the main factor causing a long-term downtime from the time point of view and the most common factor of problems. During the period under consideration, the production line changeover occurred 4,894 times with an average number of 3.2 changeovers per day. In this paper, we used the definition according to which changeover is the time between the manufacture of the last piece and the commencement of the serial production of another batch. For each changeover of the production line, the standard time with the existing technology is 15 minutes. The entire period of the planned changeover time is qualified as an over-standard changeover time, which means additional downtime.

The total time spent on retooling in the period under consideration recorded in the production reports by the foremen during each shift was 81,019 minutes.

The standard changeover time of the production line was calculated with the following equation (3):

$$Changeover\ time\ x\ the\ number\ of\ retoolings = the\ standard\ changeover\ time \tag{3}$$

$$15\ (min)\ x\ 4{,}894\ =\ 73{,}410\ (min)$$

The standard changeover time of 73,410 minutes is the time planned to change the tools and settings for the production of subsequent products. Normative changeover time results from specific procedures – it is a factor impossible to eliminate. However, in the process of line retooling, unplanned problems may occur, called the over-standard changeover time, which is calculated with the following formula (4):

$$Total\ time - normative\ time\ over - standard\ changeover\ time \tag{4}$$

$$81{,}019\ (min) - 73{,}410\ (min) = 7{,}609\ (min)$$

The calculations show that the over-standard changeover time was 7,609 minutes. Based on data gathered during the period under consideration, three major causes of long transition time were identified:

- Incorrect description of the setting parameters in production technology
- Damaged production tool
- Incorrect description of the tool number in production technology

For each of the factors mentioned above, a “5 WHY” analysis will be carried out to determine the exact source of the problem (Fig.1).

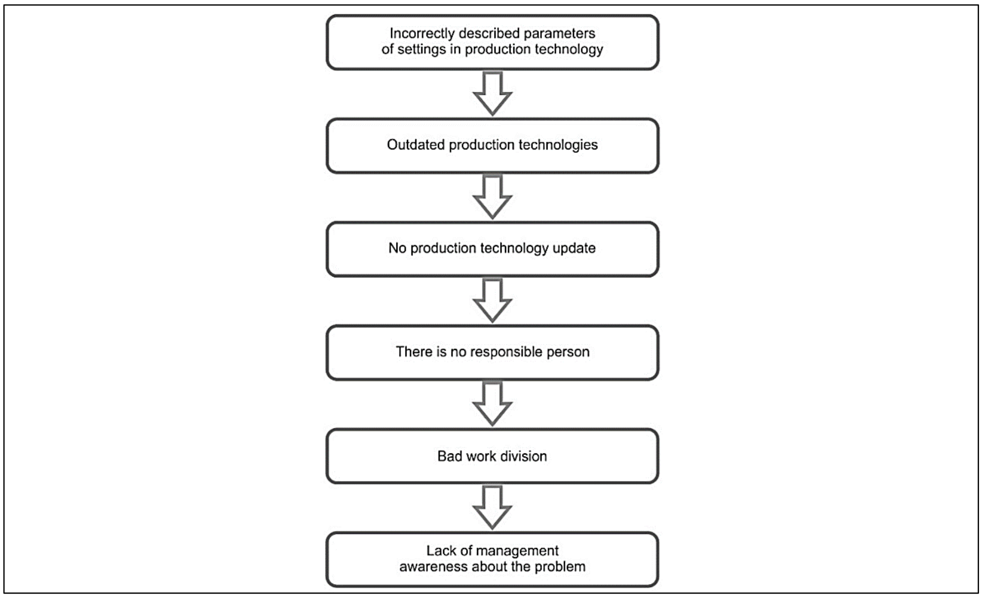

Figure 1 – 5 WHY Tools Used for Identifying the Causes of Incorrectly Described Technological Parameters of Production

We used 5 WHY tools to analyse the problem of erroneously described parameters of settings in the production technology. Based on our analysis, it was found that the major factor was lack of the management's awareness about the problem, resulting in failure to appoint a person responsible for systematic updates of the production technology.

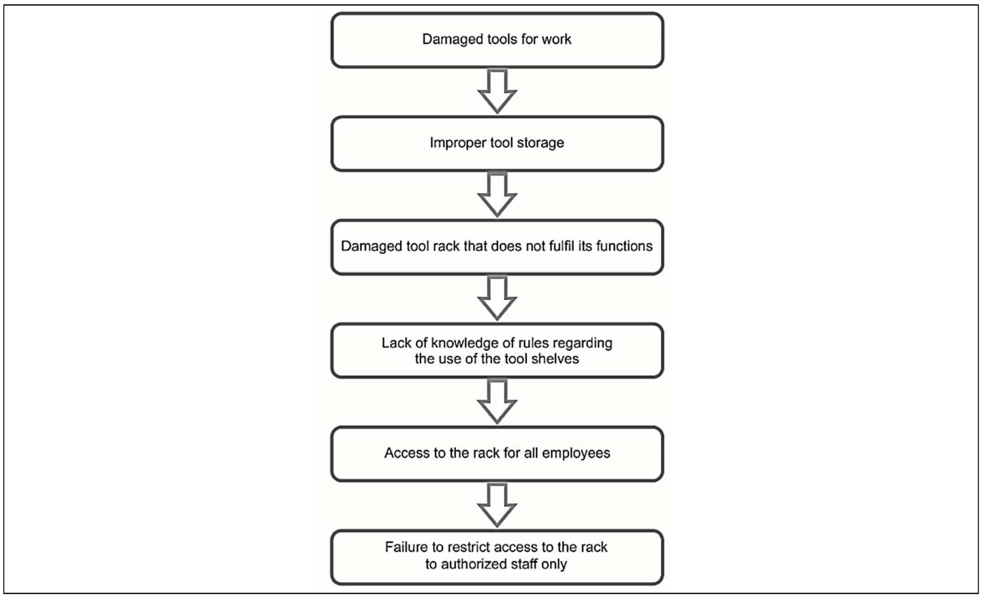

Figure 2 – 5 WHY Tools for Identifying the Cause of Damage to Production Tools

We used 5 WHY tools to analyse the problem of damaged tools for production. Our analysis revealed that it resulted from failure to restrict access to the tool shelves to authorized staff only (Fig. 2).

We used 5 WHY tools to analyse the problem of erroneously described tool numbers in the production technology. We found that the main reason for that was the lack of management's awareness about the problem (Fig. 3).

Based on the conducted analysis, it was determined that the primary factor causing the over-normative changeover time was the lack of management's awareness of the problem and failure to restrict access to the toolbox only to authorised staff.

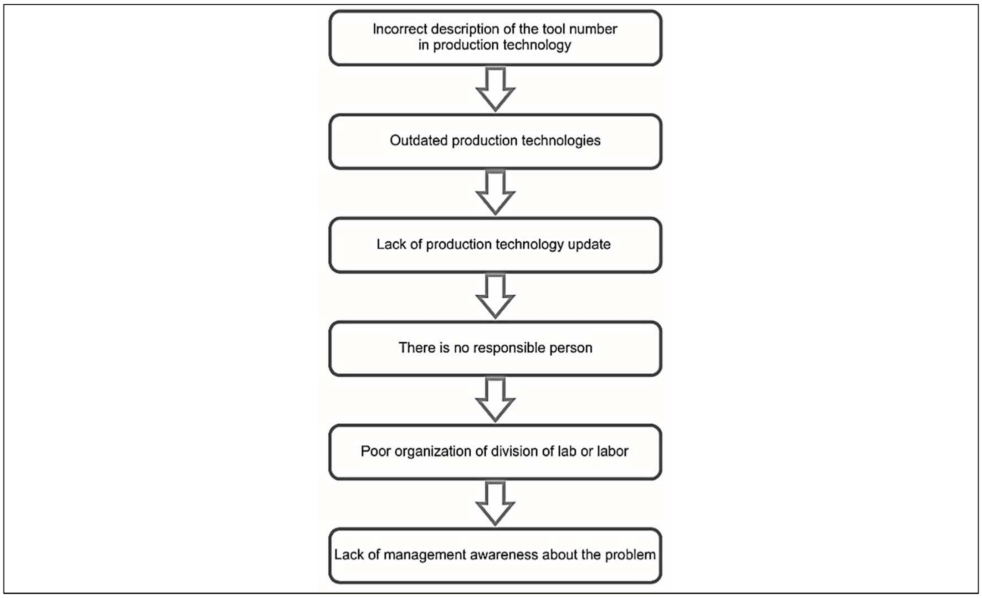

Figure 3 – 5 WHY Tools for Identifying the Cause of Incorrectly Described Tool Numbers in The Production Technology

3.2 Unplanned Downtimes of the Production Line

According to the data provided by the company, the total time of unplanned downtimes was 14,199 minutes. Particular causes of these downtimes are presented in Tab. 4.

Table 4 – Summary of Reasons for Unplanned Downtimes

No.	Causes of unplanned downtimes	Percentage share in all unplanned downtimes (%)	Downtime (min)
1	Lack of pipes for production	88.13	12,513
2	Pipes with defects unsuitable for production	6.23	885
3	No comps from the warehouse	5.64	801

The use of a cause and effect diagram allowed us to analyse the causes of these downtimes (Fig. 4).

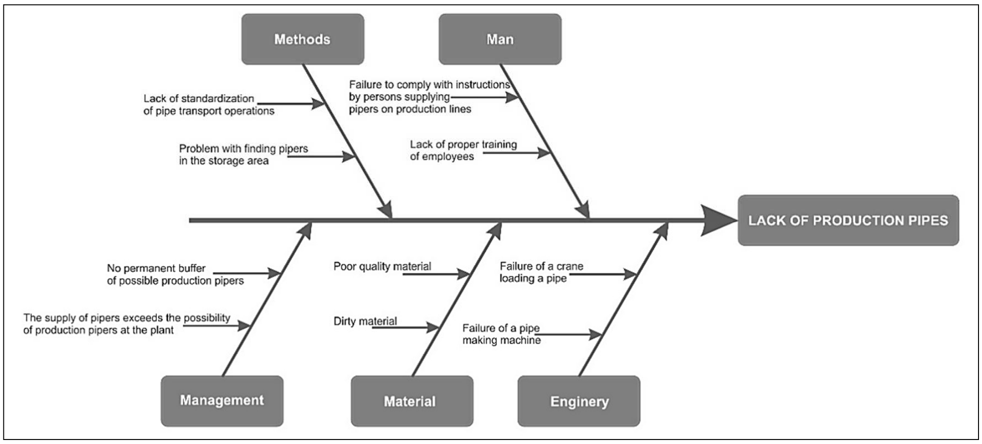

Figure 4 – Cause and Effect Analysis of Downtimes Due to Lack of Production Pipes

Failures of the production line. The production line downtime during the investigated period was 11,286 minutes. A list of all significant failures has been provided in Tab. 5.

Table 5 – Summary of Machine Failures Resulting in Downtimes

No.	Machine	The reason for the downtime	Downtime (min)
1	Welder	Failure of the welding electrode system	4,120
2	Welder	Broken shaft	1,656
3	Welder	Transformer failure	970
4	Welder	Failure of the cooling system	805
5	Welding apparatus	Failure of the welding curtain	705
6	Welder	Power failure	500
7	Welding apparatus	Tool failure	420

No.	Machine	The reason for the downtime	Downtime (min)
8	Welding apparatus	Torch burner failure	330
9	Welder	Spring pusher failure	310
10	Welder	Short circuits	290
11	Water test	Failure of seals	270
12	Welding apparatus	Power failure	200
13	Welder	Broken fastening thread	150
14	Welding apparatus	Broken pipe handle screw	115
15	Welder	Control panel failure	100
16	Welder	Start button failure	100
17	Welding apparatus	Ventilation duct replacement	95
18	Welding apparatus	Control panel failure	80
19	Water test	Water leak	70

The data contained in Tab. 6 shows that the welding machine is the one with the highest number of different types of failures.

Table 6 – List of Causes of Downtime as a Result of Machine Failures with a Cumulative Share

No.	Cause of downtime	Time (min)	Percentage share (%)	Cumulative share of failures (%)	Class
1	Failure of the welding electrode system	4,120	36.51	36.51	A
2	Broken cardan drive	1,656	14.67	51.18	A
3	Transformer failure	970	8.59	59.77	A
4	Transformer failure	805	7.13	66.91	A
5	Failure of the welding curtain	705	6.25	73.15	A
6	Power failure	500	4.43	77.58	A
7	Tool failure	420	3.72	81.30	B
8	Torch burner failure	330	2.92	84.23	B
9	Spring pusher failure	310	2.75	86.98	B
10	Short circuit	290	2.57	89.54	B
11	Failure of seals	270	2.39	91.94	B
12	Power supply	200	1.77	93.71	B

No.	Cause of downtime	Time (min)	Percentage share (%)	Cumulative share of failures (%)	Class
13	Broken fastening thread	150	1.33	95.04	C
14	Broken pipe handle screw	115	1.02	96.06	C
15	Control panel failure	100	0.89	96.94	C
16	Start button failure	100	0.89	97.83	C
17	Ventilation duct replacement	95	0.84	98.67	C
18	Control panel failure	80	0.71	99.38	C
19	Water leak	70	0.62	100.00	C

The data presented in Tab. 6 shows the division of failures causing the machine downtime. A cause and effect analysis will be carried out for three failures causing the longest downtimes, to determine their exact causes (Fig. 5).

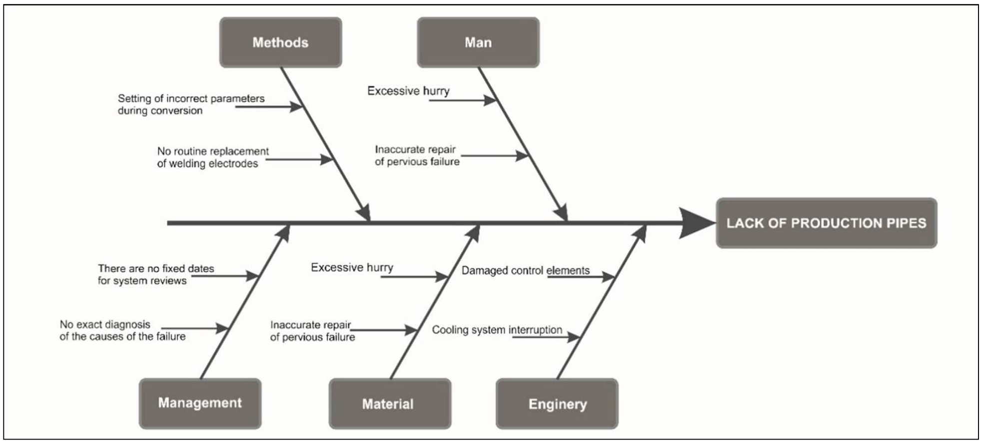

Figure 5 – Cause and Effect Analysis of Welding Electrode Failures

Micro-failures of the production line. During the period under consideration, the production line downtime due to micro-faults was 1,565 minutes. The list of all micro-faults is given in Tab. 7.

Table 7 – List of Micro-Failure Causes with the Resulting Downtimes

No.	Cause of unplanned downtime	Percentage share in all micro downtimes (%)	Downtime (min)
1	Problems with welding wire traction	90.16	1420
2	Replacement of welding wire	9.84	155

The downtime resulting from welding wire traction failures was 1,420 minutes. It accounts for 90.16% of all the failures.

4 DISCUSSION AND SUGGESTIONS FOR IMPROVEMENTS

Based on conducted analyses and research, the following actions were proposed to reduce production line downtime: the main factors causing the over-standard time of line changeover were obsolete parameters and information about the manufacture of products in technological cards. Based on the problem analysis, it was found that the main reason for this was the failure to update the technological cards and conduct routine data checks due to problems with delegating a person responsible for the cause of the problem by the plant management.

The proposed improvements which should contribute to reducing the duration of downtimes include: appointing a person responsible for the correction of data in technological cards and c periodic reviews of data in the cards in order to obtain the effect of continuous control over the production process. The time intervals between successive failures of the welding system have been calculated. Also, preventive inspections and replacement of priority parts of machines related to this system have been proposed.

The failure of welding electrodes in the tested period occurred 135 times with a total downtime of 4,185 minutes. The average downtime was calculated using the equation (5):

$$MTTR = (4185\,min) / 135 \tag{5}$$

The mean time to repair (MTTR) was 31 minutes. The next step was to calculate the time between the repair of failure and the time of its re-occurrence. The following calculations were made (6):

$$MTTF = (716{,}640\,min - 4{,}185\,min) / 136 \tag{6}$$

$$MTBF = 31\,min + 5{,}238\,min$$

The mean time between failures (MTBF) was 5,269 minutes, which translates into 87 hours and 49 minutes of machine operation.

This is the frequency with which inspections of welding electrodes should be conducted. This period ought to be adapted to the current work of an organisation. Therefore, maintenance service teams operating in the company should perform reviews during the breakfast break organised for employees of all 11 production shifts. Assuming that breakfast breaks take place during every shift, but in non-standard hours, usually between the 4th and 6th hour of work, inspections would usually take place after every 84-86 hours of machine operation. Another proposed improvement is to create instructions for correct installation of the welding wire in the welding machine and placing it in a place easily accessible to operators in order to verify their work during the replacement. The addition of welding wire position control in the welding chamber as a standard during each machine TPM inspection will depend on visual evaluation of the cleanliness inside the welding chamber.

5 CONCLUSIONS

The research results presented in the paper allow concluding that the application of a complex set of tools and quality management methods can give better results than using specific tools separately. The analysis allows concluding that: the failure of welding electrodes in the tested period occurred 135 times with a total downtime of 4,185 minutes. The average downtime (MTTR) was 31 minutes. The mean time to failure (MTTF) was 5,238 minutes, which translates into 87 hours and 18 minutes of machine operation. The mean time between failures (MTBF) was 5,269 minutes, which translates into 87 hours and 49 minutes of machine operation.

The use of individual tools may be insufficient when dealing with a complex production line or a specific type of industry, e.g. the automotive industry. Using a complex set of tools and quality management methods to solve a problem on the production line can in this situation bring more significant benefits and be more productive.

The research aimed to show that there is a great need to use specific sets of quality management tools and methods to improve production processes both in various industries and in enterprises diversified in terms of size. Both quantitative and quantitative methods should be used to analyse defects and errors in production processes.

Each company should depending on the needs and problems, establish its own set of tools and methods for quality management to improve the quality of the production processes, for example by reducing the production line downtime.

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ABOUT AUTHOR

Radosław Wolniak – Silesian Technical University, Organization and Managemnt Faculty, Poland. E-mail: radek_wol@o2.pl, Author's ORCID: http://orcid.org/0000-0003-0317-9811.