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SMEs in Automotive Supply Chains: A Survey on Six Sigma Performance Perceptions of Czech Supply Chain Members

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Abstract: Six sigma is understood as a technique for the continuous improvement in process quality; however, it has been rarely scientifically analysed in small- and medium-sized enterprises (SMEs). SMEs represent the vast majority of enterprises throughout economies and contribute to automotive supply chains in various tier ranks. As SMEs are known to lack resources and skills while focusing on short-term benefits rather than on long-term gradual improvements, the aim of this paper is to analyse the perception of six sigma process capabilities in automotive supply chains assuming differences in company size, supply chain rank and six sigma duration. This was tested with Fisher's exact test. Companies with less than 1000 employees, subsuppliers and companies with a six sigma implementation in the last 3 years struggled to meet six sigma principles, suggesting that mainly small companies inhibit a risk for the supply chain. These findings contribute to the existing theoretical body of knowledge by identifying a three-to-five-year period for six sigma implementations until six sigma maturity. Practically, the findings contribute to the research by explaining the need for a continuous supplier development over a three-to-five-year period until the company meets its performance requirements, with a supply chain risk incorporated in lower-tier ranks and with small companies.

Keywords: SME; six sigma; automotive; supply chain; six sigma performance; supplier development



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1. Introduction

Six sigma is understood as a technique to facilitate continuous quality improvement [1]. Belonging to the quality and risk management strategy of supply chains, it has been applied in industries with tight supply chain relations, such as the automotive industry, the pharma industry [2] and the food industry [3]. In order to enhance quality and productivity, the big players transfer their competitive pressure to their suppliers. These suppliers then pass the pressure on to their subsuppliers [4]. Due to limited supply chain visibility, downstream companies are not able to monitor the companies upstream [5].

Supply chains integrate various enterprises of all sizes. Being known for having constraints in human resources, finances and technology [6], SMEs have been identified to have a higher degree of risk and lower performances due to lacking resources [7]. Risks mitigated to SMEs by downstream companies may therefore backfire if not managed properly [8]. The whole supply chain's resilience depends on each individual company's resilience towards unexpected events [9]. SMEs face the challenge of dealing with inherited risks mitigated to them. Due to their constraints, they are further challenged by limited technical support and finances, limited access to international markets, increased vulnerability to financial shortages and project risks, limited continuous learning abilities, limited innovative and improvement skills and a lack of competitiveness [10]. As such, SMEs are a likely single point of failure (SPOF) that may destabilise the whole supply chain [11,12]. However, based on expert interviews with researchers, six sigma frameworks are expected to work for small- and medium-sized enterprises (SMEs) and large enterprises (LEs) as well [13]. Practical approaches have been rarely scientifically documented, as far as research

focused on large enterprises as far as six sigma and quality management models were concerned [14–16]. Despite increasing numbers of publications and approaches concerning SMEs and six sigma in recent years, previous research found that there are still many research gaps existing in the literature for six sigma and lean six sigma for SMEs and their six sigma performances [15].

The capability and performance of six sigma in the automotive industry was subject to various studies. Literature reviews also found the automotive industry to be a big area for paper publishing concerning six sigma, e.g., [17–20]. Gerger and Firuzan focused on the Taguchi capability index [21], and [22] employed the process capability index and the process performance capability index to continuously improve process quality in an automotive manufacturing company as a practical approach. According to [23], the capability and performance has to be re-assessed periodically as those deteriorate over time. Furthermore, six sigma came into focus as a means of supply chain risk management (SCRM) aiming to assure quality throughout the whole automotive supply chains [24], including LEs and SMEs. Due to the differences arising from the size of the company studies also suggest specific six sigma models for SMEs with the aim to raise six sigma and lean six sigma capabilities and performances [25,26]. This led to a research agenda for SMEs, as company size was also understood to matter in terms of critical success factors of six sigma. Stankalla et al. also claim that research on six sigma implementation in SMEs in the automotive industry is also just beginning [13].

Therefore, this research paper aims to contribute to existing literature by giving an insight on implemented six sigma environments in SMEs, answering the question whether there are differences in the perceptions of capabilities of six sigma with regard to the company size, the length of introduction of six sigma and with regard to the supply chain hierarchy. It is assumed that SMEs contribute mostly in the lower tiers of supply chains. Thus, this research aims to diminish the research gap on SMEs' six sigma performances by studying the member companies of automotive supply chains. This leads to the following research question of the paper:

Research question: How do SMEs differ in their six sigma performance measures from LEs in the automotive industry?

2. Literature Review

Six sigma was first introduced in the company Motorola in 1987 in order to remove defects throughout their corporation, including manufacturing. Based on approaches such as total quality management (TQM), statistical process control (SPC) and Deming's theory of management [20], it strives to make use of the SPC control to decrease the ratio of defects to 3.4 parts per million (ppm) [27]. Being understood as a tool to diminish supply chain risks, it has been found to be able to assist the SCRM. Other researchers propose six sigma, precisely lean six sigma, to be implemented into general supply chain management (SCM) [28]. Lean six sigma combines the ability of manufacturing with a stable process according to six sigma and the elimination of waste through lean [29]. A Singaporean study showed that lean six sigma brought benefits for large logistic companies while the six sigma principles without lean were usually found in companies with a higher service standard [30]. The research of [31], however, suggests that six sigma approaches bring only small, gradual improvements, as well as small financial benefits.

While the six sigma principles were initially used in manufacturing to enhance process quality, a single-number evaluation of the six sigma level is expressed through process capability indices (PCI), such as C_p (also known as potential process capability index [32,33]) and C_{pk} , and the Taguchi capability index C_{pm} [34]. However, making use of univariate indices and making use of insufficient characteristics forces companies into a persistent trial-and-error mode [35]. Further development includes the six sigma fuzzy quality index [36] and Penthagorean fuzzy sets [37] and multivariate PCIs [38] that are able to monitor all

product characteristics at the same time [39]. The measurement of these indices may be used for production monitoring and might also be the trigger for further analysis [40].

According to [41], the relations between the potential process capability index, the process capability index and the Taguchi capability index may be characterised by the following equations:

$$C_p = \frac{1}{3} \frac{d}{\sigma} = \frac{1}{6} \frac{USL - LSL}{\sigma}, \quad (1)$$

$$C_{pk} = C_p \left(1 - \frac{|\mu - m|}{d}\right), \quad (2)$$

$$C_{pm} = C_p \left(1 + 9C_p^2 \left(\frac{|\mu - m|}{d}\right)^2\right)^{-\frac{1}{2}}, \quad (3)$$

with

$$m = \frac{1}{2}(USL + LSL), \quad (4)$$

$$d = \frac{1}{2}(USL - LSL), \quad (5)$$

where

μ : mean value of all samples in the population;

m : midpoint of the specification interval;

LSL : lower specification limit;

USL : upper specification limit;

d : half range of the specification interval.

These indices assume a normal distribution of the sample values [42]. Even though [43] suggested that tests for a normal distribution of values, these tests (Kolmogorov–Smirnov test, Shapiro–Wilk test) showed ambiguous results in a case study [43]. Already in 2002, reference [44] understood C_p and C_{pk} to be the main PCI used by practitioners. Practical case studies on six sigma, such as, e.g., [45], also focus on C_p and C_{pk} as the main indicators for continuous improvement through increased process stability. The sigma level represents the $A C_p$ value of 2.00 (six sigma level), which represents 3.4 defects per one million parts produced, corresponding to 99.99966% of good parts [46]. A C_p value of 1.00 (three sigma level) corresponds to 66807 defects and only 93.3193% of good parts [47]. A 0.33 higher C_p value represents an additional sigma level for the process and is thus a measure for process stability.

According to the research terminology used by Gartner, medium-sized companies are companies with up to 999 employees, while SMEs have at least 100 employees and more than USD 50 million in revenue [48]. The group of SMEs contributes to more than 90% of all companies in economies, as is the case in the Czech Republic [49], being assumed to be flexible and short-term oriented [50]. While the supply chain allows all participants to benefit [51], it was found that SMEs represent a potential threat for LEs [52]. SMEs lack the finances to conquer technological investments [53], and companies with less than 50 employees have been found to show weakest performances [54]. Differing in the availability of resources, SMEs and LEs do not differ in their objectives and in their task within the supply chain [53].

By applying lean six sigma methods to automated manufacturing processes, SMEs may also benefit from decreasing scrap rates [55] while continuously increasing quality [56]. However, research suggested that this required a prior innovation potential of the company [57] and training and learning phase [58], assuming managers play a crucial role in making lean six sigma approaches successful by overcoming lean six sigma barriers for the production quality [59]. Case studies in SMEs showed that the management support to promote six sigma already in early stages has a crucial effect on the later six sigma performance [60,61]. Lean six sigma and six sigma have been found to have an impact on the company culture itself [62]. Lean six sigma facilitates the company's risk management

culture by adding customers and further companies. The concept may also enhance the culture of the SCRM [63].

While supply chain integration is assumed to provide better supply chain visibility, the integration may also provide risks [64]. The insufficient quality in production expressed by the process capability is part of the operational risks in the SCRM [65]. In addition, the financial side is assumed to have a crucial impact on the performance (a) directly on the company and (b) on the whole supply chain [66]. The supply risk and the product quality are still estimated to be the major risks for manufacturing supply chains [67]. Proactive risk mitigation strategies are becoming of rising importance [68] as downstream companies in supply chains try to mitigate their risks upwards, making it possible to reveal the risks occurring in earlier stages [69]. This allows one to assume that many risks occur in earlier stages with upstream companies. Despite the various approaches to introduce further metrics, production companies usually make use of univariate single-number PCI and of SPC.

Focusing on SMEs, authors tried to develop tailored approaches on six sigma and lean six sigma [26]. Such frameworks were developed due to the existing gap in research by not covering manufacturing SMEs and their heterogeneity [70]. Deeb et al. developed a framework for SMEs lacking skilled human resources based on the DMAIC methodology [71]. As SMEs are known to lack human resources and specialists in fields such as six sigma [72], these approaches should meet their reality better than other general approaches. Research found that SMEs suffer from various constraints in financial, technical, and human resource perspective [6], as well as lacking skills in IT and in IT security [73].

Downsizing general approaches did not meet SME realities [74], as SMEs cannot be understood as being of the same nature as large enterprises just on a smaller scale [70]. The approaches developed for six sigma in LEs were perceived as being risky from a financial perspective [60]. Researchers highlighted a lack of suitable approaches due to the heterogeneity of SMEs [75]. Other than the practical lags, research also seems to lag in crucial six sigma areas for SMEs, paired with missing empirical evidence [76]. Thus, it remains a question whether the differentiation into SMEs and LEs may be even more extended with regard to the six sigma performance. This performance may be expressed through the univariate single-number PCIs. Therefore, the research in this manuscript is formed by the perception of the PCI C_p from a downstream perspective and from an upstream perspective.

From the above-mentioned, the following hypothesis are stated:

Hypothesis 1 (H1). *All SMEs will show a lower six sigma process capability C_p than LEs.*

Hypothesis 2 (H2). *The increasing duration of the six sigma approach will lead to a higher six sigma process capability (C_p).*

Hypothesis 3 (H3). *Lower-tier ranks will lead to higher six sigma process capability (C_p).*

Hypothesis 4 (H4). *All companies throughout the supply chain will show the same ability to honor their six sigma process capability (C_p) requirements.*

3. Materials and Methods

Methodology

The Czech Republic may be considered a country with a strong tradition in production and manufacturing. As such, the concepts of six sigma and lean six sigma are known. Global cooperates are putting pressure on their supply chains to honor the principles of these concepts. The research survey on six sigma was sent to production companies in the Czech Republic, asking how the six-sigma-responsible quality managers of the companies evaluate the adherence of the required six sigma values. This research paper wants to map the perception of six-sigma-dedicated staff in production companies in the Czech Republic.

Being conducted as a pilot study, the main goal of this research is to analyse the question of whether six sigma strategies and the trust in the production chain is honored in reality. The research was conducted as a quantitative study. Quantitative research methods may be used as stand-alone methods or may be also combined with qualitative methods. Quantitative research has its strength when analysing large groups, allowing for generalising the results from the analysed sample to a broader group or population with given projection limitations [77]. This, in general, requires a design that allows measurable variables being assessed and compared with a given standard [78].

A literature review from 2017 found surveys to be used in 15.0% of all papers dealing with sustainable supply chain management, with an additional 2.1% of papers using a combined methodology of survey and interviews [79]. For empirical research, surveys were used in 32.0% of all papers concerning SCM, as [80] found in 2012. For empirical research in green supply chains, 66.7% of the papers worked with surveys as research methodology as a review found in 2021 [81]. For lean six sigma, 7.9% of the articles were found to have a survey methodology [18], while [82] found 9.1% of the articles used surveys in (lean) six sigma papers in healthcare. In six sigma research, 12.2% of the papers' methodologies were surveys contributing vastly to the 15.1% of the papers showing a quantitative empirical approach [83]. In general, the highest frequencies of papers in the field of SCM and (lean) six sigma were found in manufacturing, with the segment of the automotive industry being in the top ranks [18,79–81,83]. Hence, the methodology in this article also makes use of a survey as the research methodology. The online questionnaire was made available to the approached companies in a limited time interval between early October 2020 and April 2021.

The minimum sample size required was stated as 140. According to the Orbis database [84], there are 772 active companies belonging to the industry of manufacturing motor vehicles, trailers and semi-trailers (NACE Rev. 2. primary code 29), while the margin of error was set to 7.5%. For this, a questionnaire was sent to 600 production companies of all sizes in the automotive industry. The companies may be found in any place among the supply chain, being directly or only indirectly in touch with the core features of the end product.

The research was conducted with industrial professionals. These professionals were responsible for the six sigma realization in production processes. A total of 600 companies were addressed in from early autumn 2020 until April-2021. Responses were obtained between October-2020 and April-2021. The request was sent to production companies with relation to the automotive industry. These production companies had a production or manufacturing plant in the Czech Republic and belonged to at least one automotive supply chain in different positions.

The survey was conducted as an online survey. 145 companies returned their survey. As all questions were mandatory, answers were needed for all questions. By default, it was not possible to submit only partly-filled surveys. The survey contained organizational multiple-choice questions, questions on the actual and required C_p values to be inserted as a two-digit number and questions on the perception of six sigma reality in the supply chain that were answered with a Likert scale.

The questionnaire consisted of three parts. The first part of the questionnaire contained questions regarding basic information on the company. With this information, the companies were classified by (a) company's rank in supply chain, (b) size of the company and (c) duration of how long six sigma has been realized in the company. For the size of the company, Gartner's definition of SMEs and LEs was used [48].

The second part of the questionnaire focused on the process capability. It contained questions on the actual C_p value of suppliers, customers and of the company itself in a supply chain. The questions targeted the values that are contractually agreed.

The third part of the questionnaire contained questions on the individual perception of the process capability. The individual perception of six sigma responsible persons was taken on a Likert scale with minimum values of 1 and maximum values of 5.

All answers of part two and part three of the survey were tested on a $p < 0.05$ value using Fisher's exact test in IBM SPSS 25 for independent samples, assuming a normal distribution of all variables. With regard to the small numbers in some segments of the sample, Fisher's exact test substituted the initially preferred Pearson's χ^2 test [85]. While Fisher's exact test is assumed to have its strengths mostly for samples with small frequencies (less than 20) in several segments, it can be used for all sample sizes [86]. As a normal distribution of the sample was assumed for sections two and three, a Kolmogorov–Smirnov test was conducted on these variables to confirm this assumption.

Fisher's exact test used the following coding of the dependent variables:

- y_1 for actual six sigma process capability value (actual C_p) of the company;
- y_2 for the direct customer-required six sigma process capability value (required C_p) of the company;
- y_3 for the supplier six sigma process capability value (supplier C_p) required by the given company;
- y_4 for the confidence that the given company meets the customer-required six sigma process capability value (customer-required C_p);
- y_5 for perception of the given company's long-term six sigma process capability value (long-term C_p);
- y_6 the perception of the whole supply chain's six sigma process capability value (supply-chain C_p).

4. Results

In total, 145 companies filled the survey. This aggregates to an overall response rate of 24.2% of all companies approached. With the survey being conducted online, no incomplete surveys were concerned. Thus, the returned 145 surveys were filled completely.

The ratio of subsuppliers:tier:OEM was 1:1.70:0.04. The return rate from OEMs (original equipment manufacturers) and the number of representations in the Czech Republic allowed only for a class with two samples. Therefore, the OEM and the Tier were taken as one group during the Fisher's exact test, as a frequency of two OEMs does not fulfill the minimum requirements for the test.

For the initial sample, the classification into three different classes was maintained. The study sample was divided into two different categories of observation: supply chain position and six sigma application years (Table 1).

Table 1. Basic information on study sample.

Criterion	OEM	
	Number	Percentage
Overall N	145	100.0%
Supply chain position		
	OEM	2
	Tier 1/Tier 2	90
	Subsuppliers	53
Six Sigma application years		
	>10 years	17
	3 to 10 years	72
	1 to 3 years	48
	<1 year	8

The second part of the study had a look at the actual process capability values in the direct network of the company. The C_p values were taken for the direct supplier, for the direct customer and also for the responding company. The results showed a mean of 2.62 and 2.41 with a standard deviation of ± 1.08 and ± 1.11 for Tier and subsuppliers, respectively, for the score of respecting the six sigma rules in the own company. The

perception on the compliance in the whole supply chain has means of 2.36 and 2.27 and a standard deviation of ± 1.07 and ± 0.75 for tiers and subsuppliers, respectively.

The scores of both OEM companies showed much higher numbers, having means of 4.50 and 4.37 and standard deviations of ± 0.71 and ± 0.18 . The perceptions of both variables seemed to be much higher, but have to be taken carefully, as there were only two answers returned. The means and standard deviations are shown in Table 2.

Table 2. Answers and means and percentage or standard deviation.

Criterion	Mean	Standard Deviation
OEM		
Own C _p	2.00	± 0.00
Customer requirement of C _p	1.83	± 0.24
Supplier-required C _p	2.00	± 0.00
Suppliers respecting C _p	4.50	± 0.71
Perception on supply chain six sigma compliance	4.37	± 0.18
Tier 1 & Tier 2		
Own C _p	1.57	± 0.30
Customer requirement of C _p	1.52	± 0.25
Supplier-required C _p	1.33	± 0.28
Suppliers respecting C _p	2.62	± 1.08
Perception on own C _p score	2.52	± 1.05
Perception on supply chain six sigma compliance	2.36	± 1.07
Subsupplier		
Own C _p	1.34	± 0.26
Customer requirement of C _p	1.32	± 0.27
Supplier-required C _p	1.21	± 0.27
Suppliers respecting C _p	2.41	± 1.11
Perception on own C _p score	2.43	± 0.72
Perception on supply chain six sigma compliance	2.27	± 0.75

With Fisher's exact test, the research aims to find a pattern in the answers suggesting the dependence of some variables. The Fisher's exact test suggests a dependence for the variables from the three independent variables: supply chain rank, company size and the duration of six sigma realization in the company.

The independence of the variables was confirmed with an additional t-test. For the significance level $p < 0.05$, the long-term C_p compliance and the perception of respecting six sigma rules in the supply chain show a significant dependence on the company's size (see Table 3).

Table 3. Fisher's exact test values depending on company size, data for whole sample.

Dependent Variable	df	Chi-Square Crit.	Fisher's Exact Test (χ^2 -Asymptotic Test)	Sig.
y1	9	16.92	—(48.544)	0.000 ***
y2	6	12.59	15.974	0.012 *
y3	6	12.59	11.897	0.061
y4	9	16.92	—(76.319)	0.000 ***
y5	9	16.92	—(40.221)	0.000 ***
y6	9	16.92	14.265	0.106

Notes: Stars indicate significance level for p -value < 0.05 (*) and p -value < 0.001 (***). In case SPSS was not able to compute the Fisher's exact test statistics, the χ^2 -asymptotic test value is given in brackets.

Fisher's exact test analysis show that the long-term C_p and the perception of the supply chain's C_p depended on the size of the company. The sample showed a difference between companies up to 999 employees and companies above 999 employees. Smaller companies were less confident that supply chain requirements were met and that in the long-term the six sigma rules were followed consistently. Variable y_2 suggested that bigger companies in general have a higher actual requirements on C_p values from their customers. The requirements on the process capabilities of suppliers did not vary significantly with the company size.

The same tests were conducted with the second class of the research sample. The sample was checked with Fisher's exact test for the independence of the variables. The independence was checked towards the classified variable of the six sigma duration resembling how long six sigma was already realized in the given company. Table 4 shows the results for the whole sample. When running the tests only with SME data, there is a hint that the perception on the supply chain C_p also depended on six sigma duration and changed with the company size (Appendix A, Table A1).

Table 4. Fisher's exact test values depending on the six sigma duration, data for whole sample.

Dependent Variable	df	Chi-Square Crit.	Fisher's Exact Test	Sig.
y1	9	16.92	12.944	0.131
y2	6	12.59	3.738	0.724
y3	6	12.59	9.051	0.159
y4	9	16.92	27.499	0.000 ***
y5	9	16.92	15.197	0.063
y6	9	16.92	12.721	0.148

Notes: Stars indicate significance level for p -value < 0.001 (***).

For the six sigma duration in companies, it may be suggested that various other variables are not independent from it. The six sigma duration has an impact on the actual C_p and on the perception of suppliers respecting the C_p , as well as on the long-term C_p respecting in the company and on the perception whether the supply chain respects the six sigma rules.

These results were generated with a delimiter of 3 years. This implies that companies with a longer time of a six sigma implementation had more confidence in the system. Companies that were in their first three years of six sigma implementation showed a lower confidence that the supply chain and the company respect the six sigma rules.

The third class that was checked for independence with the outcome variables was the rank in the supply chain. Companies had the possibility of answering this classifying question by classifying the company as OEM, Tier 1/Tier 2 or any other subsupplier. Due to the answers and possibilities of the sample, the OEM and the Tiers were taken as one class together. Hence, the class had the two characteristics OEM+Tier 1/Tier 2 or any other subsupplier down the supply chain.

The independence of this class was analogously checked with Fisher's exact test. The confidence interval was again set to $p < 0.05$. The outcome variables were checked for their independence on the class of the rank, representing the position of the company in the supply chain. Table 5 shows the results of Fisher's exact test for the whole sample. Different results have been obtained when focusing only on SMEs that may be found in Appendix A, Table A2.

Table 5. Fisher’s exact test values depending on the supply chain rank, data for the whole sample.

Dependent Variable	df	Chi-Square Crit.	Fisher’s Exact Test	Sig.
y ₁	3	7.81	23.039	0.000 ***
y ₂	2	5.99	17.627	0.000 ***
y ₃	2	5.99	7.089	0.029 *
y ₄	3	7.81	19.112	0.000 ***
y ₅	3	7.81	8.436	0.037
y ₆	3	7.81	9.988	0.012 *

Notes: Stars indicate significance level for p -value < 0.05 (*) and p -value < 0.001 (***).

The long-term C_p and the perception of the supply chain C_p seemed to depend on the rank of the company in the supply chain. As such, OEM+Tier 1/Tier 2 had a higher confidence in the process capabilities throughout the supply chain and over time. While it seemed that suppliers respected the contractual C_p , subsupplier companies were not confident that long-term C_p and supply chain principles were followed throughout the whole supply chain. OEM+Tier 1/Tier 2 companies had a higher confidence in trusting their suppliers to respect the supply chain rules.

The test results suggested for companies in lower tiers to provide significantly different understanding on the working and risk management in supply chains. Significant differences have been found suggesting lower process capabilities the further upstream a company was. While companies downstream seemed to trust the work of their partners upstream, those partners were not sharing the same level of confidence. Companies in lower tiers therefore seem to weaken the performance of the whole supply chain without the knowledge of OEM+Tier 1/Tier 2 companies

Concerning the working hypothesis of this paper, the hypothesis H1 may be accepted. Due to the heterogeneity of the SME fraction, there seems to be a difference between small companies and medium-sized companies. Hypothesis H2 assumes rising process capabilities with longer six sigma durations. However, there seems to be a turning point after three to five years of six sigma implementation. In addition, hypothesis H3 was confirmed by the analysis. However, while higher-tier ranks show a higher commitment to meet their six sigma process capability requirements, hypothesis H4 has to be rejected, as lower six sigma requirements seem to lead to even lower performances to meet these requirements. A summary may be found in Table 6.

Table 6. Hypotheses’ summary and outcome.

Hypothesis	Description	Outcome
Hypothesis 1 (H1)	All SMEs will show a lower six sigma process capability C_p than LEs.	Accepted. The population of SMEs suggests small companies to have lower C_p values.
Hypothesis 2 (H2)	The increasing duration of the six sigma approach will lead to a higher six sigma process capability (C_p).	Accepted for an interval of 3–5 years after implementation as turning point.
Hypothesis 3 (H3)	Lower-tier ranks will lead to higher six sigma process capability (C_p).	Accepted.
Hypothesis 4 (H4)	All companies throughout the supply chain will show the same ability to honor their six sigma process capability (C_p) requirements.	Rejected.

5. Discussion

In this paper, a questionnaire was handed out to six sigma experts in Czech companies belonging to automotive supply chains. Statistical analysis identified several patterns that should be highlighted. Companies with a maximum of 999 employees showed a lower six sigma process capability C_p . The differences in six sigma performances found in the sample was statistically related to the company size; however, differences were found mainly within the group of SMEs. Furthermore, it was found that it is the supply chain tier rank that has an impact on the latter of the six sigma performances. This also sheds a light on the actual ongoing processes in automotive supply chains that do not fully comply to the six sigma performance specifications throughout all tier ranks. While downstream

companies trust the six sigma measures introduced, upstream companies do not have the same trust in their own work.

The results of this research correspond to findings of [87] assuming a continuous improvement in the performance of companies in (lean) six sigma frameworks. Moreover, [88] also suggested SMEs with an ISO (International Organization for Standardization) certification show better (lean) six sigma performances. The findings in this paper retrieved the same findings. Furthermore, this study identifies the turning point of the six sigma performance to be set between 3 and 5 years of the six sigma introduction (Table 4). Hence, the cultural change of companies for a (lean) six sigma approach as indicated by [13,89] takes its time until showing significant effect.

Several studies were conducted on (lean) six sigma performances, with ambiguous results. While [90] claim in their study of technical supply chains that there is no relation between the introduction of six sigma and the SME's operational performance, a study from the same country concluded a boost in performance for SMEs with the introduction of (lean) six sigma [91]. This goes along with findings from [92] assuming SMEs do not have the resources and skills to measure their own performances correctly. Hence, the research in this paper supports the findings of [93] from the clothing industry suggesting limitations and shortcomings in the preparation of a (lean) six sigma approach. An explanation could be presented by the findings of [94] showing financial constraints known from previous SME research and inadequately budgeted (lean) six sigma projects as a critical barrier. The authors of [59] doubt the readiness and suitability of the automotive industry for (lean) six sigma approaches identifying one of the key barriers to be the lack of understanding and the insufficient preparation for (lean) six sigma.

The second key barrier of (lean) six sigma success was identified to be the insufficient quality provided by SMEs [59]. The findings of the research conducted in this paper, however, only partly comply, as the (lean) six sigma performance is not primarily bound to company size. This finding corresponds to previous research on critical success factors of six sigma, where training and the establishment of a relationship of employees towards six sigma are top-ranked [13,89,95]. Another critical success factor found in a Dutch study is the personal experience of the management personnel with lean six sigma [96]. Taking this thought a bit further, SMEs seem to lack confidence in their abilities to receive a long-term stability in processes according to the requirements of the supply chain based on trust [97], as also found in this study.

Company size was understood by several previous studies throughout time [60,75,96,98,99] as one factor to determine the confidence of the own six sigma performances. This goes along with the findings in this study. The difference in the perception was based on the company size, where smaller companies under 1000 employees had less confidence in the supply chain than companies and corporations with more than 1000 employees.

The results showed that a longer-implemented six sigma corresponded with a higher actual C_p and a higher C_p required by the direct customer. Companies that had higher requirements on themselves seemed to be the companies that had a longer history in six sigma. This corresponds to findings from previous studies finding six sigma to be a tool of continuous improvement after the six sigma introduction [90,100,101]. The continuous improvement was also identified as a key variable for lean six sigma [102]. The statistical analysis also suggests that companies with a six sigma history of less than three years did not have the same requirements as companies that had been participating longer than three years in the supply chain.

Six sigma research showed only on paper dealing with the situation in the Czech Republic since 2018 [13] providing a gap in the literature for this country. A recent publication found companies focusing on process quality to be usually also ISO 9001 certified [103]. Information may be found for the nearby former brother state Slovakia [104], where six sigma was found to have led to significant improvements in manufacturing companies. A publication on management and quality management tools suggests that enterprises in the Czech Republic more frequently applied those tools than companies in Slovakia [105]. In-

formation on the implementation six sigma in SMEs is missing, while the research on SMEs itself brought up various results throughout scientific databases. Recent qualitative research of SMEs with regard to (lean) six sigma has been found globally, e.g., in India [106,107]. However, while assuming structural differences between SMEs and LEs, research found that downsizing LE approaches alone does not consequently lead to successful six sigma implementations [70,74]. While the research in this paper confirmed the heterogeneity of SMEs, it also gives information on the differences within this group with regard to six sigma.

As the research was conducted as a pilot study, it allowed to give an insight into the different perceptions on process capability in different companies from the automotive industry in the Czech Republic. According to the minimum sample size calculation, the sample meets the requirement for generalization with a 7.5% margin of error. However, the sample does not fully mirror the industry's distribution of company sizes and of supply chain ranks. Thus, this study is conducted as a pilot study that allows for providing the field for further and deeper research.

6. Limitations

This research survey also has to be assessed mentioning its strengths and limitations. An important strength is that the data gathered were all gathered within one month and are homogeneous data. Companies participating were solely companies with a manufacturing plant in the Czech Republic, while only the automotive industry was observed.

Shortcomings of the research survey that have to be mentioned were the form of conducting the survey, namely, the use of an online questionnaire. The research itself was limited, as data were only taken from the Czech Republic. A further limitation to be mentioned was the thin basis of data for the OEM companies. As there only 0.05% of the companies were OEM companies, it was not possible to derive any suggestions from the survey. This also limits the possibilities to classify the companies into three different categories for the rank characteristic. With the available data, this research focused on finding significant relations to assess associations between the characteristics.

7. Conclusions

This paper concentrated on the perception of six sigma supply chains performances in SMEs in the Czech automotive industry. It was shown that the duration period of the six sigma implementation had a higher impact on the performance of companies overall than the company size per se. While there could be no significant difference found between LEs and SMEs, it seemed that the group of SMEs itself showed an inhomogeneous and inconsistent behavior. Companies in lower-tier ranks also represent a higher risk for the supply chain in general. Research suggests that the companies were aware of this, as they rated the assumed real performance of the supply chain lower than their contractual quality requirements were.

The paper also contributes to the practical body of knowledge. The lower six sigma performances in lower-tier ranks shall be a trigger for the practical SCRM. While companies try to mitigate their risks upstream, those may backfire when being handled by companies who are not capable of managing the risk appropriately. Thus, the supplier risk might be underevaluated in the existing approaches as far as the lower-tier companies are concerned. For practitioners, this increases the requirement for an enhanced supply chain visibility. Further emphasis should also be put on the supplier development programme of companies. According to the herein-mentioned findings, it took a period of three to five years until the observed companies reached six sigma maturity. However, it seemed to be small companies that inhibited the highest risk.

As previous studies already showed, subsuppliers were neglected from research for a long time [108]. Moreover, SMEs are long-known to contribute vastly to the economy and supply chains [54], while research and empirical evidence lag far behind LE research [76]. Research on SMEs also shows a relevant gap [70] in the area of six sigma [15]. This research

provides theoretical implications by assuming a six sigma maturity level in general after three to five years of the six sigma implementation. A continuous improvement process was assumed also before; however, the duration had not yet been stated. A further finding contributing to the theoretical body of knowledge is the lack of confidence SMEs seemed to have in themselves and in the whole supply chain performance, in particular in the long-term. Hence, the research in supply chain moderation and supply chain communication is also triggered by the findings of this research.

Thus, the research contributes to the scientific body of knowledge assuming that, among SMEs, smaller enterprises also show significant inclination towards lower process capabilities. Another important contribution is that the honoring of six sigma requirements is met less by companies with lower requirements. Again, the group of SMEs is very much heterogeneous itself and smaller enterprises. Further research therefore should go deeper into the differences arising in SMEs with regard to their six sigma performances and the requirements put on them.

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Abbreviations

The following abbreviations are used in this manuscript:

C _p	Potential process capability index
C _{pk}	Process capability index
C _{pm}	Taguchi capability index
ISO	International Organization for Standardization
LE	Large enterprise
OEM	Original equipment manufacturer
PCI	Process capability index
ppm	Parts per million
SCM	Supply chain management
SCRM	Supply chain risk management
SME	Small and medium-sized enterprise
SPC	Statistic process control
SPOF	Single point of failure
TQM	Total quality management

Appendix A

Table A1. Fisher's exact test values depending on the six sigma duration, data for SMEs.

Dependent Variable	df	Chi-Square Crit.	Fisher's Exact Test	Sig.
y ₁	9	16.92	8.017	0.811
y ₂	6	12.59	7.692	0.189
y ₃	6	12.59	3.884	0.794
y ₄	9	16.92	21.918	0.001 **
y ₅	9	16.92	11.485	0.198
y ₆	9	16.92	14.342	0.049 *

Notes: Stars indicate significance level for p -value < 0.05 (*) and p -value < 0.01 (**).

Table A2. Fisher’s exact test values depending on the supply chain rank, data for SMEs.

Dependent Variable	df	Chi-Square Crit.	Fisher’s Exact Test	Sig.
y ₁	3	7.81	9.107	0.020 *
y ₂	2	5.99	0.211	0.940
y ₃	2	5.99	10.277	0.005 **
y ₄	3	7.81	7.650	0.054
y ₅	3	7.81	4.455	0.245
y ₆	3	7.81	9.770	0.016 *

Notes: Stars indicate significance level for p -value < 0.05 (*) and p -value < 0.01 (**).

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