Tomas Bata University in Zlín
Faculty of Management and Economics

Doctoral Thesis

Conception of an effective Six Sigma belt deployment structure for manufacturing small and medium-sized enterprises

Koncepce efektivního rozvoje struktury Six Sigma belt v malých a středních výrobních podnicích

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Zlín, May 2021

Published by **Tomas Bata University in Zlín** in the Edition **Doctoral Thesis.**

The publication was issued in the year 2021

Key words in English: *process, manufacturing, Six Sigma, concept, organization, management, Belt system, small and medium-sized enterprises*

Key words in Czech: *proces, výroba, Six Sigma, koncepce, organizace, management, Belt systém, malé a střední podniky*

Full text of the doctoral thesis is available in the Library of TBU in Zlín.

ACKNOWLEDGEMENT

This year has been unique for me since I have been adding the finishing touches to my dissertation thesis. For this reason, I would like to thank all those people who supported me throughout my doctoral studies from the beginning until the end.

First and foremost, I would like to voice my deep gratitude to my supervisor prof. Ing. Felicita Chromjakova, PhD. for giving me the opportunity to take on this dissertation research as well as for her excellent guidance and great assistance in the course of my doctoral studies.

Further, I would like to acknowledge the support of Ing. Lubor Homolka, Ph.D. who had been giving me advice as well as useful suggestions that helped me to carry out the statistical part of my research work.

Special word of thanks goes to all respondents of the survey conducted for this doctoral study who took their time to contribute, thereby providing me with valuable input. This work would not be possible without you.

I also would like to thank my colleague Ing. Oksana Koval, Ph.D. for all the insightful conversations that we shared throughout this time and for the successful colloboration in the creation of research publications.

Moreover, I would like to thank Ms. Martina Drabkova and Ms. Pavla Bartosova for providing me with all the answers to organisational questions that I had during the academic process.

It also is my pleasure to thank Saskia Grünhagen for the linguistic and grammar revision of this disseration work as well as the scientific publications associated with this thesis.

Last but not least, I would like to express my grateful appreciation to my parents, Heinrich and Christine Stankalla, as well as my sister Karin Schaller who believed and supported me throughout my childhood and still do to this day. For their patience, understanding and encouragement as well as their support throughout this thesis that allowed me to reach my goal – I dedicate this work to my family.

ABSTRACT

The Six Sigma methodology creates many possibilities for radically improving process and product quality resulting in enhanced financial performances, customer satisfaction and bottom-line results. While Six Sigma was initially applied within large organizations, the interest of small and medium-sized enterprises in using this continuous improvement initiative is increasing. Due to the fact that a wide variety of small and medium-sized enterprises act as suppliers to larger enterprises and therefore taking over a substantial part in global supply chains, small and medium-sized enterprises are demanded to have robust quality processes in place as well as offer products and services of the highest quality.

One of the most important critical success factors for the implementation of Six Sigma is the strong organizational infrastructure of process improvement specialists, also known as "Belt Hierarchy" or "Belt System" which originally consists of four core types of Six Sigma professionals: Master Black Belt, Black Belt, Green Belt and Yellow Belt. Since the traditional Six Sigma belt approach is not applicable in small and medium-sized enterprises due to a lack of human and financial resources as well as other organizational differences to larger enterprises, amendments are required when it is applied in small and medium-sized enterprises.

For this reason, the research focus of this dissertation is to investigate on an empirical basis how the Six Sigma belt deployment structure in manufacturing small and medium-sized enterprises differs from the traditional SS belt deployment structure used in large manufacturing enterprises. This research question will be supported by six research goals. In particular, the research shall identify the key Six Sigma belts for manufacturing small and medium-sized enterprises, their roles, responsibilities and required skills, their proportion in relation to the total workforce and invested working time towards Six Sigma, their possible number of Six Sigma projects that can be executed and the related cost savings compared to large manufacturing organizations as well as the differences between the current and target state of the Six Sigma belts deployment in manufacturing small and medium-sized enterprises.

The research work is established as combination of a descriptive and explanatory quantitative-based research design. Based on the findings and conclusions derived from the theoretical fundamentals and systematic literature review, research hypotheses are developed that are linked to several statistical hypotheses for their evaluation. As research instrument for testing the statistical hypotheses a questionnaire was developed and an internet survey conducted to collect primary data directly from Six Sigma experts.

The results show that Six Sigma is only implemented in a small portion of those small and medium-sized enterprises that employ the survey respondents but the Six Sigma belt deployment status in these small and medium-sized enterprises is in accordance with the developed guidelines of the study. It can be concluded that

an extensive organizational infrastructure with Master Black Belts and full-time Black Belts as applied in large manufacturing enterprises is not needed in manufacturing small and medium-sized enterprises. In comparison, Green Belts should be the driving force of the Six Sigma initiative and Black Belts shall take on the coaching and trainer role in manufacturing small and medium-sized enterprises. Master Black Belts are not required in small and medium-sized enterprises. As a result of this research a conception of an effective Six Sigma belt deployment structure for manufacturing small and medium-sized enterprises is put together as best practice model which should aid manufacturing small and medium-sized enterprises in establishing an effective and robust Six Sigma belt deployment structure in their organization.

ABSTRAKT

Metodika Six Sigma nabízí mnoho možností k radikálnímu zlepšení kvality procesů a produktů, což vede k lepší finanční výkonnosti, spokojenosti zákazníků a výsledkům. Zatímco se Six Sigma původně používala ve velkých organizacích, zvyšuje se zájem malých a středních podniků o využití této iniciativy neustálého zlepšování. Vzhledem k tomu, že široká škála malých a středních podniků působí jako dodavatel pro větší podniky, a proto přebírá podstatnou část globálních dodavatelských řetězců, je od malých a středních podniků vyžadováno, aby také měly zavedeny robustní procesy kvality a nabízeli produkty a služby nejvyšší kvality.

Jedním z nejdůležitějších faktorů kritického úspěchu při implementaci Six Sigma je silná organizační infrastruktura specialistů na zlepšování procesů, známá také jako „Belt hierarchie“ nebo „Belt systém“, která původně sestával ze čtyř základních typů profesionálů Six Sigma: Master Black, Black Belt, Green Belt a Yellow Belt. Vzhledem k tomu, že tradiční přístup založený Beltech Six Sigma není použitelný v malých a středních podnicích kvůli nedostatku lidských a finančních zdrojů a kvůli jiným organizačním rozdílům ve větších podnicích, je nutné provést změny, pokud se použije v malých a středních podnicích.

Z uvedeného důvodu je cílem disertační práce na empirickém základě zkoumat, jak se struktura nasazení Six Sigma ve výrobě malých a středních podniků liší od tradiční struktury nasazení Six Sigma používané ve velkých výrobních podnicích. Tuto výzkumnou otázku podpoří šest výzkumných cílů. Výzkum zejména identifikuje klíčové Belty Six Sigma pro výrobu malých a středních podniků, jejich role, odpovědnosti a požadované dovednosti, jejich poměr ve vztahu k celkové pracovní síle a požadovanou pracovní dobu k Six Sigma, jejich možný počet Six Sigma projektů, které lze provést a související úspory nákladů ve srovnání s velkými výrobními organizacemi, jakož i rozdíly mezi současným a cílovým stavem nasazení Beltů Six Sigma ve výrobě malých a středních podniků.

Výzkumná práce je založena na kombinaci popisného a vysvětlujícího kvantitativního výzkumu. Na základě zjištění a závěrů odvozených z teoretických základů a systematického přehledu literatury jsou vypracovány výzkumné hypotézy, které jsou spojeny s několika statistickými hypotézami pro jejich vyhodnocení. Jako výzkumný nástroj pro testování statistických hypotéz byl vyvinut dotazník a proveden internetový průzkum s cílem sbírat primární data přímo od odborníků Six Sigma.

Výsledky ukazují, že Six Sigma je implementovatelná pouze u malé části těch malých a středních podniků, které zaměstnávají respondenty průzkumu, ale stav nasazení Beltů Six Sigma v těchto malých a středních podnicích je v souladu s vyvinutými pokyny studie. Lze vyvodit závěr, že rozsáhlá organizační infrastruktura s Master Black Belty a Black Belty na plný úvazek, jak se používají ve velkých výrobních podnicích, není při výrobě malých a středních podniků potřeba. Ve srovnání s tím by Green Belti měly být hybnou silou iniciativy Six

Sigma a Black Belti by měly převzít roli koučování a školitele při výrobě malých a středních podniků. Master Black Belti nejsou v malých a středních podnicích požadovány. Výsledkem tohoto výzkumu je koncepce efektivní struktury nasazení Beltů Six Sigma pro výrobu malých a středních podniků jako modelu nejlepší praxe, který by měl pomoci výrobě malých a středních podniků při vytváření efektivní a robustní Six Sigma struktury Beltů a jejich nasazení ve společnosti.

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LIST OF ABBREVIATIONS

Six Sigma	SS
Lean Six Sigma	LSS
Small and medium-sized enterprise	SME
Master Black Belt	MBB
Black Belt	BB
Green Belt	GB
Yellow Belt	YB
White Belt	WB
Total Quality Management	TQM
Define, Measure, Analyse, Improve, Control	DMAIC
Define, Measure, Analyse, Design, Verify	DMADV
Null hypothesis	H_0
Alternative hypothesis	H_A
Research hypothesis	RH
Research goal	RG
Statistical hypothesis	SH
Survey question	SQ
Probability value	p-value
British Standards Institute	BSI
Gross Domestic Product	GDP
Institut für Mittelstandsforschung Bonn	IfM Bonn

1. INTRODUCTION

In the following, a comprehensive introduction to the research topic of the dissertation is provided. Specifically, the research background and research problem are being addressed as well as the required research question and related research goals are being defined. The introduction is concluded with an outline of the dissertation structure and research method.

1.1 Research background and research problem

Small and medium-sized enterprises (SMEs) are considered the lifeblood of a modern economy. The growing importance of supply chain management issues in a global market environment make large firms heavily dependent on SMEs when it comes to the provision of high-quality products or services at low costs. To ensure cost effectiveness, robust quality processes and the fulfilment of customer requirements, SMEs cannot avoid to consider the introduction of quality strategies like Six Sigma (SS) or Lean Six Sigma (LSS) (Wessel and Burcher, 2004; Antony et al. 2005 and 2008; Deshmukh and Chavan, 2012; Patel and Desai, 2018; Soundararajan and Janardhan, 2019).

In comparison to larger companies with more resources at their disposal, the implementation of SS or LSS is much more challenging in SMEs due to the lack of requisite human resources with sufficient SS knowledge as well as the lack of financial resources required to train and educate their employees (Wessel and Burcher, 2004; Antony et al. 2005 and 2008). Various researchers stated that SS or LSS can be applied anywhere where quality or process issues occur, irrespective of the size of the company (Snee and Hoerl, 2003; Brue, 2006; Antony et al. 2005 and 2008; Kumar and Antony, 2008 and 2009). There is no evidence that the implementation of LSS or SS in SMEs is not plausible (Reddy and Reddy, 2010; Kumar et al. 2011; Kaushik et al. 2012). For this reason, many practitioners and academics strongly advocated research regarding the application of SS in SMEs from the beginning of the millennium (Hill and Wright, 2001; Antony et al. 2005 and 2008; Kumar and Antony, 2008 and 2009; Kumar et al. 2008). In that time period, SS have been already implemented extensively and successfully in the larger industrial units such as General Electric, Honeywell, Motorola, Seagate Technology, Caterpillar, Raytheon, ABB, Bombardier, and Sony. This also means that most research studies have documented the use of SS in large companies while far less studies have been carried out with regard to SMEs (Antony et al. 2005 and 2008; Llorens-Montes and Molina, 2006; Kumar et al. 2008; Kumar and Antony, 2008 and 2009; Deshmukh and Chavan, 2012). One of the first research papers with focus on SMEs written by Antony et al. (2005 and 2008) showed a lack of SS awareness and knowledge among UK manufacturing SMEs. This finding was afterwards confirmed by Antony and

Desai (2009) among Indian manufacturing SMEs, by Taner (2012) among Turkish textile SMEs and by Enoch (2013) among Nigerian manufacturing SMEs.

The current literature demonstrates that more and more research papers about the implementation of this quality strategy in smaller organizations were published during the last decade. Alexander et al. (2019) analysed the growth of LSS publications for manufacturing SMEs in academic journals from 2008 to 2016. In total, 31 papers were published with a relatively high number of publications in the years 2011, 2013 and 2016. Upon analysing the distribution of these publications, it was found that they were printed in eleven countries. With eight papers the largest number of journal papers was published in the UK, followed by India with seven papers. All other countries did not register more than three papers (See details in table 1.1).

Table 1.1. Lean Six Sigma publications with focus on manufacturing SMEs. Source: Alexander et al. 2019.

Year	Number of publications	Country	Number of publications
2008	1	UK	8
2009	2	India	7
2010	1	Netherlands	3
2011	5	Australia	3
2012	3	Malaysia	3
2013	7	Sweden	2
2014	4	Belgium	1
2015	3	China	1
2016	5	US	1
/	/	Brazil	1
/	/	Turkey	1

During this time, many case studies were conducted in a wide range of industries (e.g. automotive, mechanical, paper and printing, electrical, bicycle, plastic, food, electronics, textile, milling, etc.) in order to enhance the quality of products and production processes, increase customer satisfaction and improve financial results by using the SS methodology (see for example, Kumar et al. 2006; Kumar and Antony, 2008; Nabhani and Shokri, 2009; McAdam et al. 2011; Kaushik et al. 2012; Timans et al. 2014; Vinodh et al. 2014; Dora and Gellynck, 2015; Shokri et al. 2016; Adikorley et al. 2017; Garrido-Vega et al. 2016; Kaushik and Kumar, 2017). In these publications, it was found that small enterprises often display several limitations which hinder a successful implementation of SS and LSS in their organization. Against this background, several researchers studied critical success factors and barriers for the successful SS or LSS implementation in manufacturing SMEs of different countries (e.g. Italy, Netherlands, UK, India, Malaysia, East Africa etc.) which are represented in table 1.2.

Table 1.2. Critical success factors and barriers for the successful Six Sigma or Lean Six Sigma implementation. Source: Based on Kumar and Antony, 2008; Antony et al. 2005 and 2008; Jeyaraman and Teo, 2010; Brun, 2011; Desai et al. 2012; Raghunath and Jayathirtha, 2013; Albliwi et al. 2014; Douglas et al. 2015; Stankalla et al. 2018.

Critical success factors	**Barriers**
• Visible management commitment and support	• Insufficient human and financial resources
• Strong organizational infrastructure and culture	• Lack of leadership
• Use of best people to drive the initiative	• Limited talent pool and poor selection for SS belt training and education
• Training and education of employees	• Internal resistance from employees
• Clear definition of customer requirements	• Lack of knowledge and awareness about SS and LSS methodology
• Strong project management skills	• Unclear prioritization and selection of SS and LSS projects
• Focusing on critical processes	• Poor communication

Prasanna and Vinodh (2013) suggested that SMEs should take essential steps to overcome these deficiencies prior to the implementation of SS or LSS. Wurtzel (2008), Chakravorty (2009) and Fursule et al. (2012) addressed another problem complicating the implementation process. They reported a lack of approaches or models to guide SMEs through an effective implementation of SS. To overcome this problem, several research contributions were published including guidelines and frameworks to improve and simplify the implementation of SS in SMEs by using the ideas, findings and results of the previous mentioned case studies and reviews about the critical success factors and barriers regarding the successful SS or LSS implementation (see for example, Kumar et al. 2006; Thomas et al. 2009; Alsmadi and Khan, 2010; Kumar et al. 2011; Gnanaraj et al. 2010a; Gnanaraj et al. 2010b; Prasanna and Vinodh, 2013; Sharma and Sharma, 2014; Timans et al. 2016; Jie et al. 2014; Thomas et al. 2016; Ben Romdhane et al. 2017 etc.).

Around the year 2015, various researchers were still of the opinion that the published SS or LSS articles with focus on manufacturing SMEs are too low in comparison with the number of articles that focused on large manufacturing enterprises (Timans et al. 2016; Albliwi et al. 2014 and 2015; Adikorley et al. 2017; Iyede et al. 2018). Consequently, the number of research papers continued to increase after the year 2016. Ghaleb et al. (2017), Abbes et al. (2018) as well as Soundararajan and Janardhan (2019) conducted SS case studies in a Tunisian SME in the clothing industry, in an Egypt SME in the cement bags industry and in an Indian guide wheel manufacturing SME. Moreover, Mukherjee (2017) and Singh et al. (2017 and 2019) studied challenges and barriers of LSS in Indian manufacturing SMEs while Fonseca (2017) investigated the reasons for the low implementation level of SS within Portuguese SMEs. Furthermore, Patel and Desai (2018) reviewed the current state of LSS applications in Indian manufacturing SMEs, Iyede et al. (2018) explored the extent of LSS implementation within manufacturing SMEs in West of Ireland and Deeb et al. (2018) as well as Moya et al. (2019) developed new frameworks to support the SS deployment in SMEs.

Nonetheless, many SS research fields with focus on SMEs still remain unexplored and thus key questions unanswered (Albliwi et al. 2015; Antony et al. 2019; Alexander et al. 2019; Stankalla et al. 2019). The traditional SS approach with a hierarchy of improvement specialists for instance, also known as "Belt System", which clearly defines and aligns the organizational roles and responsibilities that lead, deploy and implement SS or LSS to produce the expected results in larger companies (Schroeder et al. 2008; Zu et al. 2008; Gutierrez et al. 2012; Arumugam et al. 2013) is not desirable in the case of SMEs according to the following researchers: Davis (2003), Snee and Hoerl (2003), Rowlands (2004), Wessel and Burcher (2004), Kumar et al. (2006 and 2008), Antony et al. (2008), Deshmukh and Chavan (2012), Ben Romdhane et al. (2017), Antony et al. (2019), Alexander et al. (2019). They advised amendments to the SS belt approach when applied in SMEs, as it cannot be used like in large organizations due to various differences in the characteristics of SMEs and large organizations. Rowlands (2004) stated that the SS deployment needs to be considered based on the company´s available resources and the skills of its employees. Kumar et al. (2006) as well as Antony et al. (2008) argued that SMEs do not require an extensive SS belt system as it is applied to large organizations due to lower problem complexity and resource limitations. Kumar et al. (2008) noted that the SS deployment in SMEs should be effectively scaled based on the number of employees, the company culture and the organizational structure within the individual SME to guarantee that the requirements for each business segment of that SME are adequately met. For these reasons, it is vital to know the SME characteristics and to take the key differences between SMEs and large enterprises into account to ensure the successful deployment of the SS belts in SMEs.

In their literature reviews, Antony et al. (2019) and Alexander et al. (2019) pointed out that LSS in SMEs is an as of yet unexplored area of research that ought to be subject to detailed investigations in the future and identified the following research gaps:

- Lacking knowledge about the required personal traits, necessary skills, responsibilities and roles of the various SS belts
- Lacking knowledge about the required number of SS belts
- Lacking knowledge about the need of Master Black Belts and full-time Black Belts

They argued that this information must be known and understood by the SME management to develop a proper, balanced and sustainable LSS deployment infrastructure for an effective execution of LSS projects in the SME environment.

1.2 Research question and research goals

While taking the aforementioned research problem with the traditional SS belt approach into consideration, which is an essential success factor for the implementation of SS but cannot be fully adopted in SMEs, the objective of the thesis is to answer the following research question and meet the related research goals (see table 1.3).

Table 1.3. Research question and the related research goals. Source: Author.

Research question	
How does the Six Sigma belt deployment structure in manufacturing SMEs differ from the traditional Six Sigma belt deployment structure used in large manufacturing enterprises?	
Research goal 1	*To identify the key Six Sigma belts, their roles, responsibilities and their required skills in manufacturing SMEs compared to large manufacturing enterprises*
Research goal 2	*To identify the Six Sigma belt proportions in relation to the total workforce in manufacturing SMEs compared to large manufacturing enterprises*
Research goal 3	*To identify the required invested working time of the individual Six Sigma belts towards Six Sigma projects in manufacturing SMEs compared to large manufacturing enterprises*
Research goal 4	*To identify the possible number of projects that can be executed by the various Six Sigma belts in manufacturing SMEs compared to large manufacturing enterprises*
Research goal 5	*To identify the possible cost savings by the various Six Sigma belts in manufacturing SMEs compared to large manufacturing enterprises*
Research goal 6	*To identify the differences between the current and target status of the deployment of Six Sigma belts in manufacturing SMEs*

The outcome of this research should serve as input for the conception of guidelines for an effective SS belt deployment structure in manufacturing SMEs.

It should consist of the following elements:

- *Hierarchical structure and availability of the Six Sigma belts*
- *Roles and responsibilities of the individual Six Sigma belts*
- *Required skills of the individual Six Sigma belts*
- *Proportion of the individual Six Sigma belts in relation to the total workforce*
- *Working time of the individual Six Sigma belts towards Six Sigma*
- *Number of possible projects executed by the individual Six Sigma belts*
- *Possible costs saved by the individual Six Sigma belts per project*

On the basis of this comprehensive collection of information and data a best practice model should be put together which should aid small manufacturing enterprises in establishing an effective and robust SS belt deployment structure in their organizations.

1.3 Dissertation structure and research method

The following PhD thesis is divided into six chapters.

The introduction part outlines the research background, the description of the research problem and research gaps. Moreover, it establishes the required research question and corresponding research goals of the thesis. It concludes with a description of the dissertation structure and research method.

To answer the research question and achieve the corresponding research goals, an adequate research approach has to be followed. There are two predominant research approaches in the scientific world which are known as deductive and inductive approach. While the inductive approach is used to conclude general inclusions for new theories emerging from single instances, the deductive method is exactly the opposite and applies general ideas or theories to a specific situation. It usually begins with a statement or hypothesis which has to be tested to reach a logically certain conclusion (Engel and Schutt, 2005; Glaser, 2014; Tjora, 2018).

The research work starts with an outline of the theoretical basics. Therefore, in chapter 2 of this thesis, a historical overview about SS, the traditional SS belt deployment structure as used in large manufacturing enterprises, the definition and relevance of SMEs as well as their strengths, weaknesses and challenges regarding the deployment of an effective SS belt structure in manufacturing SMEs are provided.

As next step, a systematic literature review will be conducted to examine to what extent conclusions can be made regarding the research question and the corresponding research goals. Chapter 3, on the one hand, focuses on the analysis of the differences in the SS belt deployment structure between manufacturing SMEs and large manufacturing enterprises. This analysis is mainly based on the researchers' personal opinions and recommendations of the current literature. On the other hand, empirical studies will also be taken into consideration to analyse and highlight the differences in the presence of SS belts in manufacturing SMEs and large manufacturing enterprises. Finally, the findings of the analysis are being discussed and research gaps are being emphasized. Based on plausibility considerations and derived conclusions from the existing published research literature and theoretical fundamentals, research hypotheses will be developed that have to be examined further in the upcoming doctoral thesis. Hay (1981) described research hypotheses as assumptions of predicted results concerning relationships or differences between two or more variables that are formulated based on theory or existing knowledge in a certain research field. Investigating the research hypotheses shall aid in establishing meaningful conclusions regarding the research question and related research goals. On the basis of this initial analysis, it can be concluded that this research work ought to follow the deductive approach. Secondary data are gathered from previous research contributions for which appropriate research hypotheses are being formulated.

The empirical part of the dissertation is covered in chapter 4. It is divided into four subchapters. Chapter 4.1 explains the methodological approach used for the investigation of the research hypotheses. It starts with the development of statistical hypotheses to evaluate the research hypotheses and the definition of appropriate statistical tests designed to confirm or reject the statistical hypotheses. The required sample sizes needed to test the various statistical hypotheses will be calculated using the power analysis approach. In order to test these statistical hypotheses, primary data will be collected directly by surveyed SS experts. As research instrument a questionnaire will be developed and applied. For this reason, this subchapter concludes with a presentation of the survey design which includes, among other things, the target group, respondents profile, data collection method and planned timeline for data gathering. Chapter 4.2 and 4.3 present the responses to the survey, the SS implementation status and statistical hypotheses test results using descriptive and inferential statistics. While inferential statistics include procedures to test statistical hypotheses, the aim of descriptive statistics is to present larger empirical data material conveniently and clearly by using tables, diagrams, performance indicators, parameters, graphs etc. (for more details about descriptive and inferential statistics, refer to Lee et al. 2000; Taylor, 2005; Lacort, 2014). Chapter 4 ends with an evaluation of the research hypotheses based on the statistical hypotheses test results.

In short summary, this research study mainly aims to answer the research question and to meet the corresponding research goals by describing characteristics as well as using validated or rejected formulated research and statistical hypotheses derived from the current literature. This should be done by collecting primary data through a survey of SS experts over a sustained period of time. The research conclusions are presented based on facts, numerical values, variables and mathematical processes. Against this background, it can be asserted that a positivism research paradigm (for more explanations about research paradigm, see Killam, 2013; Ling and Ling, 2017; Ling and Ling, 2020; Tracy, 2019) fits to the overall scope of the present study and a combination of a descriptive and explanatory quantitative-based research design is applied (for more explanation about research designs, see Tashakkori and Teddlie, 2010; McNaab, 2004; Evans and Rooney, 2008; Babbie and Rubin, 2010).

After discussing the research findings in chapter 5, they will be considered with the aim to design a conception of guidelines for an effective SS belt deployment structure in manufacturing SMEs which shall then serve as best practice approach. In the end of chapter 5, the achievement of the research goals will be verified.

Last but not least, in chapter 6, the dissertation concludes with contributions to science and practice, limitations of the study, an outlook on future research as well as a summary of the dissertation.

The planned rough body of the dissertation is illustrated in a structured way in the following table 1.4.

Table 1.4. Dissertation structure. Source: Author.

Structure	**Description**
Chapter 1: Introduction part	To present the research background, research problem, research question, research goals, and research structure etc.
Chapter 2 and 3: Theoretical part	To outline theoretical fundamentals
	To conduct a systematic literature review
	To formulate research hypotheses
Chapter 4: Empirical part	To develop statistical hypotheses
	To define appropriate statistical hypotheses tests
	To determine the required sample sizes for the various statistical hypotheses tests by using the power analysis approach
	To design and conduct the survey
	To collect the survey data
	To conduct the statistical hypotheses tests
	To interpret the statistical test results and evaluate the research hypotheses
Chapter 5: Results part	To discuss the research findings
	To design a conception of guidelines for an effective SS belt deployment structure in manufacturing SMEs
	To verify the achievement of the research goals and answering the research question
Chapter 6: Conclusion part	To present the research works contributions to science and practice, the limitations of the study, an outlook on future research and a summary

2. THEORETICAL FUNDAMENTALS

Chapter 2 outlines the origin and development of LSS, presents the SS belt system with its various improvement specialists as well as emphasizes the definition and relevance of SMEs. In addition, strengths, weaknesses and challenges of SMEs will be highlighted to emphasize where particular attention must be paid in order to deploy SS belts successfully in an organization of this size.

2.1 A historical overview: From Six Sigma to Lean Six Sigma

In the year 2000, LSS was established as part of the evolution of SS (Snee, 2010; Timans et al. 2012; Albliwi et al. 2014). It is the combination and integration of Lean Management and SS into a comprehensive management system, which is the most popular business strategy for enabling continuous improvement in manufacturing and other fields (Delgado et al. 2010; Prasanna and Vinodh, 2013; Albliwi et al. 2015; Timans et al. 2016). The objective is to merge the tools and principles of both methodologies, thereby overcoming the weaknesses and bringing out the advantages of both programs. Lean focuses on removing all types of waste from the process while SS concentrates on controlling the process statistically and reducing variation from the process (Arnheiter and Maleyeff, 2005; Schroeder et al. 2008; Salah et al. 2010; Corbett, 2011; Cudney and Elrod, 2011; Maleyeff et al. 2012; Bhamu and Sangwan, 2014). Applying both methodologies, Lean and SS, separately one after another will not achieve the most benefits. Therefore, it was suggested using SS and lean simultaneously in order to achieve the maximum output (Salah et al. 2010).

The term "Lean" appeared in the beginning of the 1990s (Womack et al. 1990) while the development of this approach had already begun shortly after the Second World War. Taiichi Ohno from Toyota created a new manufacturing paradigm for large manufacturing operations in high-volume and low-variety facilities, known as Toyota Production System (TPS) (White and Prybutok, 2001; Womack and Jones, 1994; Pepper and Spedding, 2010; Bhamu and Sangwan, 2014). Womack and Jones (1994) defined Lean as the systematic removal of waste by all members of the organization with the goal to make the production flow as value added as possible. The seven typical types of waste are: overproduction, waiting, unnecessary transportation, inappropriate processes, excess inventory, unnecessary motion, and defects (Endsley et al. 2006; Bhasin and Burcher, 2006; Bhuiyan et al. 2006; Lee and Wei, 2010; Chakravorty and Shah, 2012). Some prominent tools for process improvements in the context of the Lean terminology are value stream mapping, Kaizen or 5S (Rother and Shook, 1999; Worley and Doolen, 2006; Chen and Lyu, 2009; Thomas et al. 2009; Drohomeretski et al. 2014). Value stream mapping is used to first identify non-value-added processes (waste) and then to develop lean improvement strategies to create the desired future state of the production system (Pepper and Spedding, 2010). Kaizen strives to improve performance and sustain a culture in line with the continuous improvement theory within an organization (Shirouzu and Moffett, 2004) while 5S is a method that describes how to organize the workplace to improve efficiency within an organization (Liker and Yu, 2000).

In the 1980s, Bill Smith from Motorola developed SS (Brady and Allen, 2006; Schroeder et al. 2008; Montgomery and Woodall, 2008; Snee, 2010) which is a disciplined and data-driven business improvement methodology that was developed to enhance the quality of processes with the objective of establishing a zero-defect quality strategy, thereby increasing customer satisfaction as well as improving financial results (Arnheiter and Maleyeff, 2005; Desai et al. 2012; Lazur et al. 2013; Gitlow et al. 2015). This can be achieved by the use of powerful and analytical statistical tools such as Statistical Process Control (SPC), Design of Experiments (DOE), Analysis of Variance (ANOVA) etc. (Bhuiyan et al. 2006). Based on the ideas of SPC, Motorola defined “Six Sigma” as 3.4 defects per million opportunities in a given production process. Sigma (σ) is the Greek letter used to represent the variation of a process mean (standard deviation). “Six” means that the distance between the mean and the critical tolerance limits shall be six standard deviations constantly (McAdam and Lafferty, 2004; Brady and Allen, 2006; Montgomery and Woodall, 2008; Pyzdek and Keller, 2014). It was initially applied in the manufacturing sector, but its use has later been extended over service, financial, healthcare and public sectors (Coronado and Antony, 2002; Aghili, 2009; He and Ngee Goh, 2015; Wei et al. 2010; van den Heuvel et al. 2005; Furterer and Elshennawy, 2005; Patel and Zu, 2009). Depending on the purpose, there are two principal approaches how SS can be applied: DMAIC (Define-Measure-Analyse-Improve-Control) and DMADV (Define-Measure-Analyse-Design-Verify). While DMAIC is a problem-solving method which is generally used for process improvement, DMADV is used to develop and design new products and services (Tjahjono et al. 2010; Watson and deYong, 2010; Edgeman and Dugan, 2008).

Over time, many papers were published about SS and its significant changes (Hahn et al. 2000; Antony, 2007; Schroeder et al. 2008; Montgomery and Woodall, 2008). Antony (2007) and Montgomery and Woodall (2008) described three SS generations. The focus of the first generation (1987-1994) was placed on statistical tools adopted to construct a framework for process improvement and defect reduction, primarily in manufacturing. Motorola is a typical example of the first SS generation (Goh and Xie, 2004; McAdam and Evans, 2004). The second generation (1994-2000) concentrated on cost reduction and was adopted by companies such as General Electric, Du Pont and Honeywell. During this phase, the SS popularity surged, driven by the work of Jack Welch (CEO of General Electric between 1981 and 2001) who enhanced SS as an effective leadership development tool and strategy to improve business profitability (Snee, 2010; Black and Revere, 2006). The third generation (2000 onwards) is more oriented towards service and commercial business processes including transactional systems quality, which also considers delivery times, customer waiting time, inventory service levels etc. It is applied in companies such as Posco and Samsung (Montgomery and Woodall, 2008; Hahn et al. 2000).

Figure 2.1 illustrates the origin and development of LSS during the last decades.

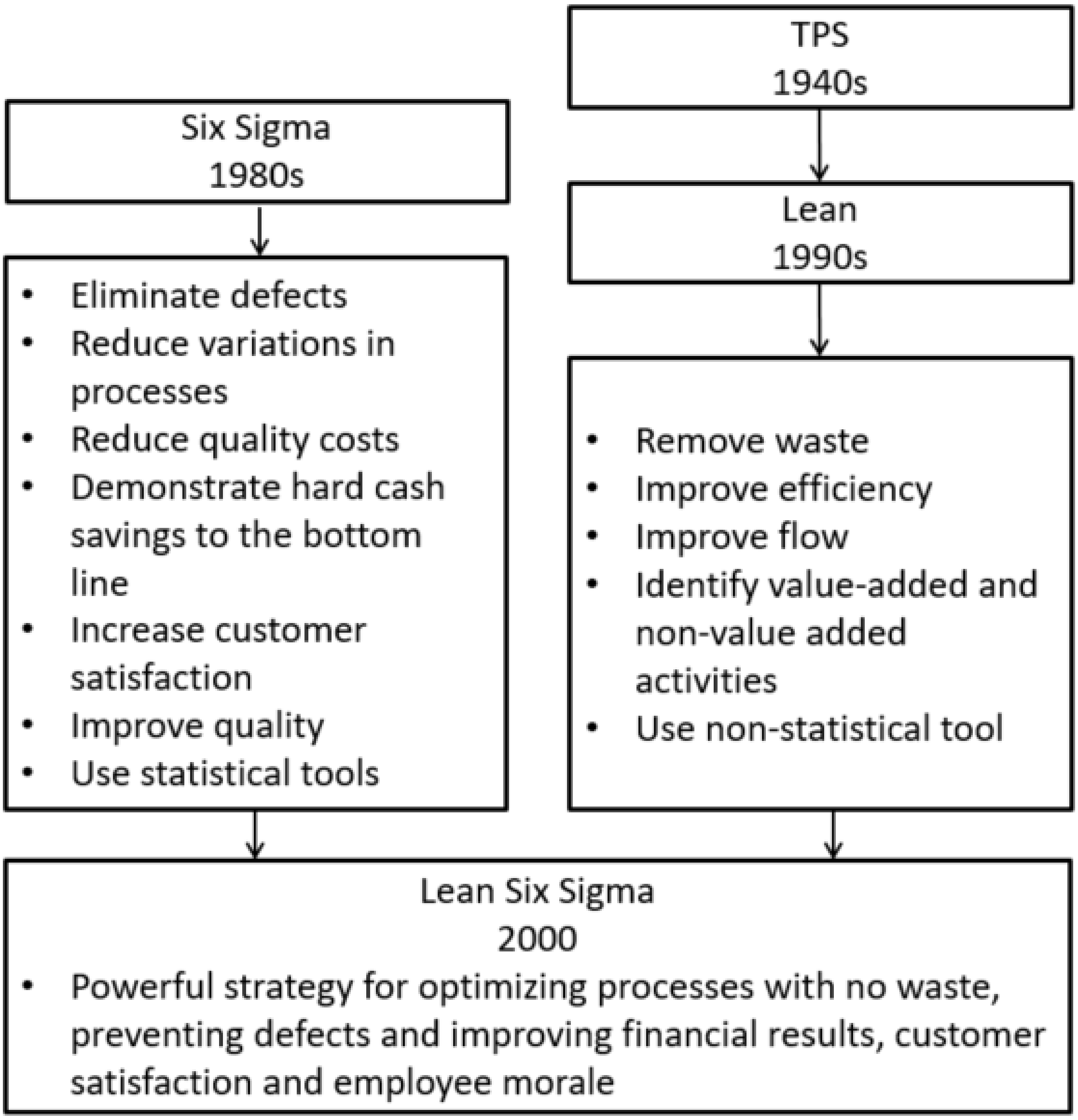

Figure 2.1. Lean and Six Sigma integration. Source: Based on Shahin and Alinavaz, 2008; Albliwi et al. 2015; Schroeder et al. 2008; Snee, 2010; Womack et al. 1990; Maleyeff et al. 2012.

2.2 Six Sigma belt system

Various authors have criticized SS as "nothing but an old wine in a new bottle" since its method originality seems to be under the umbrella of Total Quality Management (TQM) (Kumar et al. 2008; Schroeder et al. 2008; Antony and Karaminas, 2016). However, there are some key aspects differentiating SS significantly from TQM and other quality initiatives (Snee, 2004; Andersson et al. 2006; Schroeder et al. 2008; Zu et al. 2008). One of these key aspects is the creation of an infrastructure of process improvement specialists within the organization that lead the way in the data-driven quality improvement efforts. This is also known as “Belt Hierarchy” or “Belt System” (Antony et al. 2005; Arumugam et al. 2013; Antony and Karaminas, 2016).

To define the hierarchy and career paths of these improvement specialists, SS borrows its belt terminology from the world of martial arts which means that professionals trained in SS are distinguished by the colour of their belts. Within this belt system, ranks are determined based on their level of skills and responsibilities similar to karate students (Snee, 2004; Richardson, 2007). The requirements increase with each level. Each level has specifically designed intensive and differentiated trainings that impart knowledge and skills in statistical methods, project management, process design, problem-solving techniques, leadership skills and other managerial skills (Adams et al. 2003; Linderman et al. 2003; Snee and Hoerl, 2003).

The core of the SS organizational infrastructure consists of four trained and certified SS professionals: Master Black Belt, Black Belt, Green Belt and Yellow Belt (Henderson and Evans, 2000; Linderman et al. 2003; Haikonen et al. 2004; Jesus et al. 2016).

Black Belts (BBs) fall in the middle of the “Belt Hierarchy” and are the linkage between Green Belts and Master Black Belts. Consequently, BBs are the driving force of the program and play a critical operational role within their organization (Black and McGlashan, 2006; Feng and Manuel, 2008). They typically work on implementing and leading large, high-impact process improvement projects, usually focused on cost saving or quality, by using the DMAIC methodology and a specific set of statistical tools to drive up the customer satisfaction level and business productivity (Hoerl, 2001; Coronado and Antony, 2002; Antony, 2007). Candidates for BBs typically undergo 160 to 200 hours of classroom instruction (for instance, one week per month over a four-month period of time) in combination with the completion of a project that is aligned with strategic objectives of the business (Pyzdek, 2000; Snee and Hoerl, 2003; Montgomery and Woodall, 2008; Laureani and Antony, 2011; Pyzdek and Kellner, 2014).

Compared to BBs, Green Belts (GBs) are not required to have the same level of experience and knowledge in the use of statistics and leadership skills since they either assist BBs on major projects or lead teams engaged in smaller projects (Ingle and Roe, 2001; Montgomery and Woodall, 2008; McCarty et al. 2004). For this reason, they undergo one or two weeks of training in addition to their project to understand the philosophy and quality tools (Lee-Mortimer, 2006; Haikonen et al. 2004; Snee, 2004; Laureani and Antony, 2011).

Individuals of the highest expertise level carry the title “Master Black Belt” (MBB). They have completed a number of SS projects and are working full-time in the SS program as strategic leaders. They drive the companies’ performance and bring the broad organization up to the required SS competency level. Furthermore, they define and select suitable projects and develop training material. Coaching, teaching as well as mentoring the lower-level SS belts is also part of their responsibilities (Ingle and Roe, 2001; Haikonen et al. 2004; Snee, 2004; Nakhai and Neves, 2009). This requires excellent communication and teaching skills for which MBB candidates receive specialised courses in additional to their BB education. These courses focus, for instance, on topics such as communication and teaching skills, training delivery, advanced statistics, and team building (McCarty et al. 2004; Pyzdek and Keller, 2014).

Particularly MBBs and BBs are trained to obtain specialized knowledge about statistical methods and other quality tools allowing them to function as team leaders as well as technical problem solvers (Montgomery and Woodall, 2008). Over time, as SS became more successful, it was found that, additionally, it is equally important to have a large group of employees trained in basic SS tools (Henderson and Evans, 2000; Chakrabarty and Chuan, 2009; Kumar and Antony, 2009; Hilton and Sohal, 2012). The SS specialists that acquire this basic training level are named “Yellow Belts” (YBs) (Marzagao and Carvalho, 2016). They work as team members within the SS culture and help the SS project teams with tasks such as collecting data (Breyfogle et al. 2000; Laureani and Antony, 2011; Sharma et al. 2011). Hoerl (1998) argued that a YB should attend a four-day SS course while, according to the British Standards Institute (BSI) (2011), even as little as a one-day training session would be sufficient.

Table 2.1 presents the minimum requirements of the various SS belt roles according to BSI (2011).

Table 2.1. Minimum requirements for Six Sigma practitioners. Source: BSI, 2011.

Skills / Competency	Master Black Belt	Black Belt	Green Belt	Yellow Belt
Practical problem-solving skills	Highest level of ability	Highest level of ability	Highest level of ability	Basic competence
Six Sigma tools knowledge	Highest level of ability	Highest level of ability	Proficient user	Proficient user
Statistical skills	Highest level of ability	Proficient user	Basic competence	Skill not needed

Many organizations offer SS belt certifications. Laureani and Antony (2011) suggested that consultancy and training companies should use the SS belt body of knowledge provided by the American Society for Quality (ASQ) (see for more information https://asq.org/cert/catalog) which is already widely adopted and known on the market. Furthermore, Hoerl´s (2001) BB curriculum can also be recommended. It was developed specifically for manufacturing applications focused on explaining the use of SS tools within each DMAIC phase. In his article, the developed BB curriculum was also compared with the GE curriculum model which is mainly applicable to processes within financial organizations, general business operations and e-commerce processes. Ingle and Roe (2001) also compared the different implementation strategies of BB programs used in Motorola and General Electric. The authors concluded that the General Electric program has a more structured and intensive approach to train BBs in a shorter period of time which leads to a greater number of accredited BBs compared to the Motorola approach. Johnson et al. (2006 a and b) published two papers focused on demonstrating the application of the DMAIC process at BB level with the intention to provide the reader with an approach on how to structure a BB project. The SS BB projects in these two papers can be used as an excellent practice example for other similar SS belt projects in future. Along the same lines, Rasis et al. (2002 a and b) published two papers presenting an application of the DMAIC process at GB level in order to provide the readers with a profitable learning experience.

However, the SS belt certification does not signify the end of the study. Ingle and Roe (2001) warned explicitly about the danger that some employees become BBs solely to benefit from promotion opportunities. As SS evolves over time, recertification for BBs should take place at least every three years and for GBs at least every five years (Laureani and Antony, 2011). Pyzdek and Keller (2014) stated that in order for GBs to maintain their certification, a successful completion of at least one SS project every twelve months would be necessary. The company in the case study conducted by Green et al. (2006) also set this requirement for all their certified GBs. Certification requirements for MBBs vary from organization to organization. The process is less formal than that for BBs and GBs. In most cases, they are recruited from the ranks of BBs by the SS leadership (Pyzdek and Keller, 2014). In Motorola, for instance, a MBB has to gain practical experience as BB for at least five years, mentor five other successful BB candidates and obtain a recommendation from their own business unit as well as one other business unit (Ingle and Roe, 2001 and 2002).

Beside improvement specialists, SS roles at higher management level are also required. Sponsors are representatives of the senior management and responsible for the company's overall strategy as well as promoting and defining the program directives while Champions create the organization´s strategic improvement plans, ensure the availability of resources for trainings and projects and remove roadblocks for teams (Haikonen et al. 2004; McCarty et al. 2004; Pyzdek and Keller, 2014). Depending on the organization, Sponsor and Champion can be one and the same person, as the requirements and roles are applied interchangeably (McCarty et al. 2004). Sponsor and Champion should participate in SS leadership and SS basic training for two to five days in order to obtain an overview about the philosophy and methodology. This will ensure that they are able to develop a company-specific SS deployment strategy and lead the campaign (Snee, 2004; Pandey, 2007).

According to Pyzdek and Keller (2014) the "Belt Hierarchy" shall rather be considered a direct reporting structure between the different SS belt levels and thus a centralized approach. This is preferable as experience shows that it is difficult to disengage SS belts from their routine work when a decentralized approach is being following where SS belts report to their department line managers and only cooperate in SS projects together (Pyzdek and Keller, 2014). However, in contrast, the results of the exploratory case study conducted by Nonthaleerak and Hendry (2008) in nine companies from Japan, Thailand, the US and Europe showed that the SS belts of the more successful companies report to the champions that have the direct responsibility for the project and are the process owners of the area where the improvement is needed.

Figure 2.2 presents an example of an organizational structure of a SS initiative and a SS project execution.

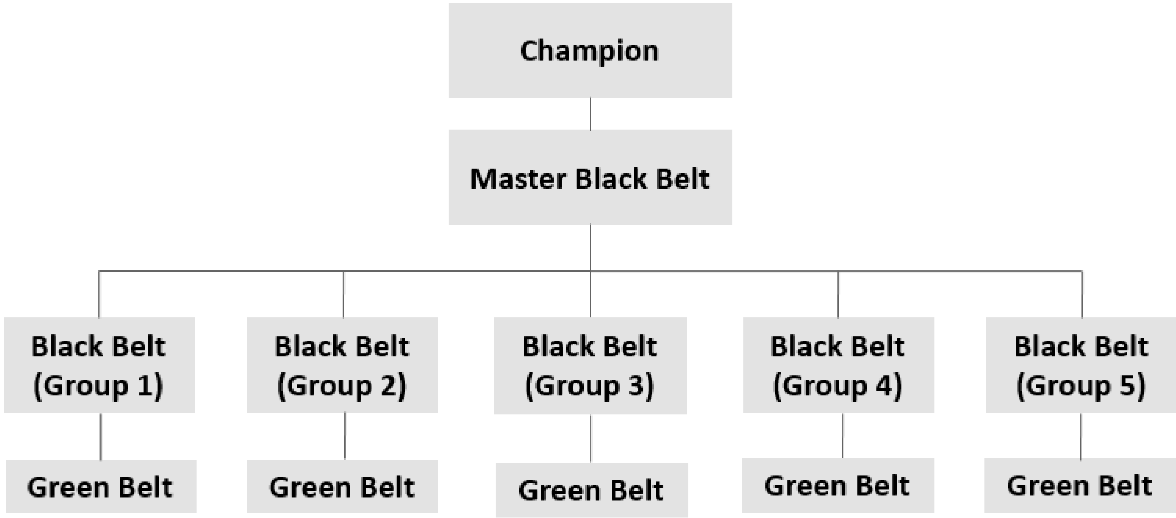

Figure 2.2. Organizational structure of a Six Sigma initiative. Source: Mahanti and Antony, 2005.

2.3 Definition of small and medium-sized enterprises

SMEs are companies that are defined by certain limits regarding the employment size, annual turnover as well as balance sheet total which must not be exceeded. Table 2.2 presents various definitions from different governments of what constitutes a SME, however, these definitions were mainly established on the basis of the manufacturing sector.

Table 2.2. The definition of what constitutes a SME as provided by various countries with focus on the manufacturing industry. Source: Based on*.

SME definitions			
Country	**Number of employees**	**Financial factors[1]**	**Sources***
Lybia	≤ 250 and	≤ 2 million € turnover ≤ 1.5 million € balance sheet	Shehab, 2008; Antony et al. 2016
South Africa	< 200 or	< 3.5 million € turnover or < 550.000 € capital assets	Antony et al. 2016
Malaysia	≤ 200 and	≤ 10 million € turnover	SME Corporation Malaysia, 2013
Singapore	< 200 or	≤ 60 million € turnover	Skills Connect, 2014
Europe	< 250 and	≤ 50 million turnover or ≤ 43 million total balance sheet	European Commission, 2005
Germany	< 500 and	≤ 50 million turnover	IFM Bonn, 2016
Japan	≤ 300 or	≤ 2.5 million capital funds	Small and medium enterprise Agency, 2019
India	/	≤ 6 million € investment in plant and machinery ≤ 30 million € turnover	Ministry of micro, small and medium enterprises, 2020
China	≤ 2000 and	≤ 40 million € turnover ≤ 50 million € total asset	He, 2016
US	≤ 1500	/	U.S. Small Business Administration, 2019a
Canada	< 500	/	Government of Canada, 2019
Australia	< 200	/	Australian Bureau of Statistics, 2002

In Europe, a company with less than 250 employees, an annual turnover of up to 50 million € or an annual balance sheet that does not exceed 43 million € is considered a SME (European Commission, 2005). In Germany, however, an enterprise is considered a SME, if the workforce does not exceed 499 employees. Besides the quantitative criteria, the "Institut für Mittelstandsforschung Bonn" (IfM Bonn) also considers qualitative characteristics in their definition of SMEs. A company in which up to two natural persons or their family members hold at

[1] Currency translation in € and rounded up on 29.04.2021

least 50% of the company shares and are members of the management of the enterprise is also recognised as SME (IfM Bonn, 2016). Thus, enterprises with 500 employees, or more, or an annual turnover of 50 million €, or more, can also be considered SMEs.

Similar to Germany, Canada defines SMEs as enterprises with less than 500 employees (Government of Canada, 2019) while South Africa, Australia, Singapore and Malaysia define SMEs as having less than or up to 200 employees (Australian Bureau of Statistics, 2002; SME Corporation Malaysia, 2013; Skills Connect, 2014; Antony et al. 2016). In Libya, according to Shehab (2008), organisations are recognised as SMEs when they employ up to 250 employees and have an annual turnover of up to 12 million LYD (approx. 2 million €) as well as an annual balance sheet total of up to 8 million LYD (approx. 1.5 million €).

Unlike the SME definitions of these above-mentioned countries that are applicable to all sectors, countries such as China, Japan and the US have chosen to set size standards for individual sectors while India even bases its classification on investments in plants and machinery. Thus, the investment in plant and machinery should not exceed Rs 50 crore (approx. 6 million €) and the annual turnover should not be more than Rs 250 crore (approx. 30 million €) to be considered as medium-sized enterprise (Ministry of micro, small and medium enterprises, 2020). A Chinese manufacturing SME is specified as an enterprise with up to 2000 employees, an annual revenue of up to 300 million RMB (approx. 40 million €) and total assets of up to 400 million RMB (approx. 50 million €) (He, 2016). In Japan, industrial SMEs are defined as companies with up to 300 employees or up to 300 million JPY capital funds (approx. 2.5 million €) (Small and medium enterprise Agency, 2019). Businesses in the US manufacturing industry can even have up to 1500 employees and still be accepted as SME (U.S. Small Business Administration, 2019a).

Based on the different SME definitions presented, it can be concluded that there is a vast degree of inconsistency on a global level and no universally agreement. Deshmukh and Chavan (2012) argued that the definition of SMEs is heavily influenced by the development stage of a country as well as its economic and political interests.

2.4 Relevance of small and medium-sized enterprises

During the past three decades, SMEs played a vital role all over the globe and are considered the backbone and lifeblood of the world economy by various researchers (Altman and Sabato, 2007; Müller et al. 2007; Antony et al. 2008; Ayyagari et al. 2011; Lande et al. 2016; Antony et al. 2016; Cherrafi et al. 2016; Paul et al. 2017; Patel and Desai, 2018; Muñoz-Pascual et al. 2019; Soundararajan and Janardhan, 2019). From the 1990s onwards, against the background of the globalization of the world market, a continuous trend toward downsizing large firms and outsourcing business to smaller firms emerged (Kumar et al. 2009;

Lande et al. 2016). At the beginning of the 21st century the productivity demonstrated by small enterprises led to a continued economic surge (Kuratko et al. 2001). They are of strategic importance for economic growth due to their considerable contributions in terms of production, innovation, sales and employment (Ardic et al. 2012; Walczak and Voss, 2013; Paul et al. 2017; Kandil and Abd El Aziz, 2018; Alexander et al. 2019).

SMEs represent 95% or more of the total number of company's worldwide, account for more than 50% of jobs and contribute with more than 35% to the Gross Domestic Product (GDP) (Ayyagari et al. 2011; WTO, 2016; Alibhai et al. 2017; Muñoz-Pascual et al. 2019). With 50 million SMEs, China has the highest number of SMEs in the world, followed by India with 48 million SMEs (Malini, 2013; He, 2016; Antony et al. 2016). While Indian SMEs contribute with about 40% of India's total employment and 17% of the country's GDP, Chinese SMEs are responsible for more than three-quarters of the country's total labour force and make up one third of its GDP (Malini, 2013; He, 2016). Nearly 30% of the Chinese SMEs are represented in the manufacturing industry (He, 2016). The US has around 30 million small businesses that employ almost 60 million people (50% of its total workforce) (U.S. Small Business Administration, 2019b) and contribute with around 45% to the country's GDP (Kobe and Schwinn, 2018). In Germany, there are nearly 3.5 million SMEs which account for around 55% of its GDP and provide more than half of all jobs (Federal Ministry for Economic Affairs and Energy, 2017; European commission, 2018; IFM Bonn, 2019). In Europe slightly more than 25 million SMEs can be found overall with displaying similar numbers as in Germany with regard to the GDP and total employment (Muller et al. 2019). Manufacturing SMEs in the EU represent around 10% of the total number of enterprises and almost 15% of total employment (Gagliardi et al. 2013).

It can be assumed that the importance of SMEs for the world economy is the decisive reason why they have moved increasingly into the focus of scientific researchers in the past decade (see mentioned research contributions in chapter 1.1). Since SMEs achieved a remarkable impact on larger enterprises as suppliers of specialized products (Kumar et al. 2014; Deshmukh and Chavan, 2012), any weaknesses in quality by SMEs could endanger the whole supply chain which would result in rising costs. Robust quality management processes have therefore become a major role in SMEs (Aoki, 2008; Dora et al. 2013). For this reason, the next chapter highlights the characteristics of SMEs which are broken down into strengths, weaknesses and challenges with regard to the implementation of SS.

2.5 Characteristics of small and medium-sized enterprises

Various authors mentioned that SMEs might easily run into problems by replicating the strategy of large enterprises with regard to implementing continuous improvement initiatives without realizing that following the same strategy might not be the best approach. Making this mistake might lead to difficulties when implementing a continuous improvement program and as a result, the idea of implementing such system is often abandoned (Alavi, 2003; Ross and Francis, 2003; Rymaszewska, 2014). To establish an effective SS belt deployment structure in SMEs, it is therefore vital to know the characteristics and environment of SMEs.

Typical strengths of SMEs are the smaller management, the flat management hierarchy with fewer layers and departmental interfaces, the limited number of business locations, the faster and effective internal communication as well as the stronger and more intimate relationships with customers (Antony et al. 2005 and 2008; Freiesleben, 2006; Thevnin, 2004; Deshmukh and Chavan, 2012; Rymaszewska, 2014). Antony et al. (2005) argued that it will be much easier to buy-in management support and commitment as it is the case in large enterprises. Moreover, the flat management hierarchy with fewer layers and departmental interfaces ensures a quick decision-making process and also higher visibility of the top management (Antony et al. 2005 and 2008; Rymaszewska, 2014).

However, Kumar et al. (2006) emphasized potential existing resistance from employees and the management when new business strategies are discussed. If the owner of the small firm is convinced of the benefits that come with such a continuous improvement initiative, its implementation will be greatly facilitated (Adams et al. 2003; Antony et al. 2005 and 2008; Kumar et al. 2009).

Furthermore, the education and training component is considerably more challenging for SMEs, because they do not have the capacity to provide trainings or free up employees to engage in trainings and SS projects (Antony et al. 2005 and 2008; Thomas and Barton, 2006; Snider et al. 2009; Deshmukh and Chavan, 2012; Prasanna and Vinodh, 2013). In SMEs, employees are crucial to the day-to-day operations and solving issues within the company (Antony et al. 2005). Others argued that every employee has usually several other roles on top of their key roles which means that they have overall fewer spare resources available (Isenberg, 2000; McAdam, 2000; Wessel and Burcher, 2004). Ates and Bititci (2011) stated that such a firefighting approach has a negative effect on SMEs because it can definitely create risks to implement any continuous improvement initiative.

Beside limited human resources, SMEs also face financial constraints (Antony et al. 2005; Thomas and Barton, 2006; Snider et al. 2009; Deshmukh and Chavan, 2012; Timans, 2014) which make it difficult to offer training opportunities, educate in-house specialists or engage external agents (Rymaszewska, 2014).

Another serious weakness is that the SME staff may not have the same overall educational level, especially when it comes to knowledge related to statistics (Thomas and Webb, 2003; Deleryd et al. 1999; Deshmukh and Chavan, 2012; Rymaszewska, 2014). This may lead to a lower application of statistical tools for problem-solving activities. Isenberg (2000) also spoke of a limited talent pool in smaller companies. For this reason, it can be a bit problematic to find and select sufficient suitable employees with good leadership skills for the SS initiative of a company as mentioned in the Kumar et al. (2011) article.

Table 2.3 summarizes the SME characteristics that have been broken down into strengths, weaknesses and challenges regarding the implementation of SS compared to large organizations. It is indispensable for SMEs to work on overcoming these deficiencies before implementing any continuous improvement initiative.

Table 2.3. Strengths, weaknesses and challenges of SMEs. Source: Based on Deleryd et al. 1999; Isenberg, 2000; McAdam, 2000; Thomas and Webb, 2003; Wessel and Burcher, 2004; Thevnin, 2004; Antony et al. 2005 and 2008; Thomas and Barton, 2006; Freiesleben, 2006; Massa and Testa, 2008; Snider et al. 2009; Kumar et al. 2009 and 2011; Ates and Bititci, 2011; Deshmukh and Chavan, 2012; Prasanna and Vinodh, 2013; Klewitz and Hansen, 2014; Rymaszewska, 2014; Prajogo and McDermott, 2014; Timans, 2014; Alexander et al. 2019; Stankalla and Chromjakova, 2018; Stankalla et al. 2019.

Strengths	Weaknesses	Challenges
• High support regarding change initiatives and lower resistance to changes. Therefore, changes can be introduced fairly quickly • Strong owner influence • Great flexibility • Management is people oriented • Smaller management with flat hierarchy layers and fewer departmental interfaces • Efficient and quick decision-making process • Absence of bureaucracy in management teams • More authority and power are given to employees by the management • Top management highly visible • Easier to buy-in management support	• Low degree of standardization and formalization • Focus is on operational matters rather than planning and strategy • Command and control culture • Intuitive rather than analytical decision making • Responsible for many facets of the business and many decisions • Decisions are generally made for short-term profitability • No training budget to offer training • Every employee usually has several roles beside their key roles, thus less spare resources • Lack of time and resources to attend in trainings • No or less resources to provide training to the staff	• State of the economy • High insurance costs can present SMEs with huge difficulties • Management commitment have to be increased • The lack of lending from banks can affect the operations of SMEs greatly and can disrupt their supply • Higher possibility of layoffs when work business is fluctuating. This makes SMEs work harder to retain a high-calibre staff • Continuous improvement strategies are not at the top of the priority list when survival of the company is a concern • To align the continuous improvement strategy with the business objectives of the organization

• High employee loyalty • Trainings are likely to be specialized • Loose and informal working relationships and structures as well as absence of standardization, thus less obstacles must be overcome • Faster communication • Managers and operatives are more likely to be directly involved with the customers • Quick responses to customers' needs • Implementing decisions and improvements quickly, thereby experiencing benefits rapidly • Application for small grants from the government for the development of skills and expertise • Higher adaptability to market needs	• Limited talent pool • Inadequate education and training are offered to employees • Lack of specialists • In-depth training and staff development are limited and informal • Formation of strategy process is intuitive rather than analytical • Lacking educational level and skills of employees and management (statistics-related knowledge) • Firefighting approach • Employees do not know the company's strategy due to poor communication • Poor process infrastructure and management • Lack of strategic planning and inspiring vision (short-term orientation) • No incentives and reward programs in many cases due to budget and resource constraints • Insufficient new initiatives and technologies • Low innovation degree	• To educate in-house specialists or engage external agents • To free up people to engage in training as they are crucial to day-to-day operations • To attract and select top talents • To apply statistical tools • To focus on long-term instead of short-term orientation • To engage technological resources • To invest in IT systems • Customer satisfaction • Higher focus on process improvement • Without any incentives or reward schemes in place, there is little motivation for continuous improvement • To increase global competitive power • To develop a learning and knowledge-sharing capability as well as an appropriate R&D infrastructure • High cost and complexity of implementing quality models

3. SYSTEMATIC LITERATURE REVIEW

According to Okoli and Schabram (2010), it is necessary to become aware about the breadth and depth of the current research to understand the level of research and identify areas that need more research in the specific field. Therefore, the objective of this chapter is to examine to what extent conclusions can be made regarding the research question and their related research goals by using the existing literature. For this, a systematic literature review will be conducted. After describing the structure of the research process, a comparison analysis of the SS belt deployment structure between manufacturing SMEs and large manufacturing enterprises will be carried out. The analysis shall focus on the availability of the various SS belt types, their roles, responsibilities and skills, their proportions in relation to the total workforce, their working times towards SS, and their number of possible projects executed as well as related cost savings. After the notes, empirical studies including the SS belt presences in manufacturing SMEs and large manufacturing enterprises will be highlighted to verify if the recommendations of the various SS experts are being followed. The final part of this chapter comprises a discussion of the findings, specifies areas for further research and formulates corresponding research hypotheses that are intended to be investigated in the further research activities in order to answer the research question and meet their related research goals as accurately and completely as possible.

3.1 Research process structure

The research process structure of the systematic literature review is adapted from other academic sources such as Okoli and Schabram (2010), Tranfield et al. (2003) and Thomas et al. (2004).

Thomas et al. (2004) described a systematic literature review as methodology to systematically research work in a given field and to clearly evaluate and synthesize the findings in a reproducible way while Tranfield et al. (2003) depicted the execution of a systematic literature as fundamental scientific activity to ensure a structured, logical and clear approach to researching a subject. Okoli and Schabram (2010) referred to a systematic, explicit, comprehensive and reproducible method for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners.

The applied approach to this systematic literature review ensures an appropriate standard consisting of seven fundamental processes which are grouped into three phases (see table 3.1).

Table 3.1. Description of the research process structure. Source: Adapted from Okoli and Schabram, 2010; Tranfield et al. 2003; Thomas et al. 2004.

Phase	**Process**	**Description**
Planning the review	To define the research purpose	The purpose and objective must be clearly defined.
	To establish research criteria and search strings	Research criteria, key words and search strings ensure that only papers that are relevant will be included into this review.
Conducting the review	To search the literature	An electronic search for relevant sources within academic databases will be conducted.
	To select sources	The selection is dependent on the research criteria, title, abstract, and introduction and conclusion part.
	To assess the quality of relevant sources	Every source should be assessed based on the quality of the content.
	To extract and synthesize the findings	The relevant findings and data from every source shall be extracted, analysed and combined.
Documenting the review	To report the research findings	The systematic literature review, the results, research gaps and formulated research hypotheses will be reported.

The vast number of published sources can make research very difficult. Therefore, as proposed by Okoli and Schabram (2010), inclusion and exclusion criteria are set to eliminate studies that do not fit to the specific research criteria of interest. For this review, refereed journal papers from high-quality research databases such as Emerald, Science Direct (Elsevier), ProQuest, Inderscience, Taylor & Francis, Springer, IEEE-Xplore, Scopus, Web of Science etc. will be taken into consideration since academics mainly use articles of the highest level of research findings to obtain information in width and depth and to disseminate their own research findings (Aboelmaged, 2010). These databases provide online access to complete research texts and abstracts that cover a wide range of multiple peer-reviewed articles with focus on SS belts. Also, information and data that originate from editorials in magazines and news reports, textbooks, conference papers and dissertations can be included in this study if they provide valuable and useful findings that were not considered in journal papers until now. The conducted review shall be based on sources concerning the SS belt deployment structure and presences in SMEs and large enterprises of the manufacturing sector without the definition of a specific industrial sector. This means that the target group consists of all possible industries such as automotive, electronic, chemical, paper, food, plastic, metal, textiles and machinery etc. Sources that include findings concerning the SS belt deployment structure and presences from other sectors such as service, higher education etc. will not be considered. Finally, the year 1998 is selected as closing date to avoid a never-ending revision of the systematic literature review.

Table 3.2 summarizes the research criteria in order to select appropriate sources for the systematic literature review.

Table 3.2. Research criteria for the source selection process. Source: Author.

Inclusion criteria	**Exclusion criteria**
Sources published after 1998	Sources published before 1998
Journal papers in academic databases but also editorials, news reports, textbooks, conference papers and dissertations with valuable as well as useful information and data that are not included in any journal papers	Editorials, news reports, textbooks, conference papers and dissertations if their findings are already represented in journal papers and include no valuable as well as useful information and data
Findings that concern the SS belt deployment structure with focus on manufacturing SMEs and large manufacturing enterprises	Findings that concern the SS belt deployment structure with focus on non-manufacturing SMEs and large non-manufacturing enterprises (service, higher education etc.)
Findings that concern the presence of SS belts in manufacturing SMEs and large manufacturing enterprises	Findings that concern the presence of SS belts in non-manufacturing SMEs and large non-manufacturing enterprises (service, higher education etc.)
Findings that concern general aspects about SS belts in manufacturing SMEs as well as in large manufacturing enterprises	Findings that concern general aspects about SS belts in non-manufacturing SMEs as well as in large non-manufacturing enterprises (service, higher education etc.)

As support when searching for applicable sources, Tranfield et al. (2003) emphasized the importance of the correct selection of search strings. For this reason, the following search strings are used to identify the sources of interest: [(SME) OR (Large enterprises) AND (Belt system) OR (Belt hierarchy) AND (Black Belt) OR (Green Belt) OR (Yellow Belt)]. Moreover, Okoli and Schabram (2010) argued that it is essential to simplify research by reviewing the title and abstract because this would help researchers to save time and effort. Beside the adoption of this approach, the introduction and conclusion parts of the sources will also be reviewed. These criteria and planned procedure ensure a comprehensive bibliography as well as a set of high-quality sources and mark the end of the planning phase.

As a result of the conducted search, 76 sources that were published between the year 1998 and the year 2019 were selected for the comparative analysis. The largest portion of the selected sources consists of 50 journal papers which were released in 27 top academic journals of well-known scientific publishers.

With six articles, the *TQM Journal* published the largest number of articles per journal while the *Journal of Six Sigma and Competitive Advantage* has with five published articles the second largest portion and the *Journal of Quality & Reliability Management* with four published articles the third largest portion. Three journals including the *Journal of Production Research*, the *Journal of Lean Six Sigma* and the *Journal of Productivity and Performance Management* share the fourth position with three published articles each. The fifth position is shared by the *Journal of Operations Management*, the *Journal of Operational Research Society*, the *Journal of Production Economics*, the *Quality Management Journal* and the *Journal of Total Quality Management & Business Excellence* (two articles each). Out of the 27 journals, 16 journals published one article. These are as follows: *International Statistical Review*, *International Review of Business Research Papers*, *Leadership in Health Services*, *Measuring Business Excellence*, *Air Transport Management*, *European Industrial Training*, *High Technology Management Research*, *Health Care Quality Assurance*, *Technology, Management, and Applied Engineering*, *Benchmarking: An international Journal*, *Strategic Direction*, *Leadership & Organization Development*, *Production Planning & Control*, *Operations & Production Management*, *Quality Technology and Manufacturing Technology Management.*

Almost half of the journals can be found in the Emerald database while the Taylor & Francis as well as Elsevier databases contain 20% of the journals each. Beside articles from journals, eleven sources are from editorials of professional magazines, eight sources are from textbooks, four sources are from the internet, two sources are from conference papers and one source originates from a dissertation (see table 3.3).

Table 3.3. Distribution of the number of various source types. Source: Author

Type of sources	**Number of various source type**
Academic journals	27
Editorials in magazines and news reports	11
Textbooks	8
Internet sources	4
Conference papers	2
Dissertation	1

The bibliography includes authors from 20 different countries (UK, US, New Zealand, Kenya, Ireland, Canada, India, Brazil, Italy, Germany, Czech Republic, Australia, Thailand, Netherlands, Pakistan, Tunisia, United Arab Emirates, Spain, China and Saudi Arabia) which are separated in table 3.4 concerning sources related to SS belts in SMEs and SS belts in large enterprises or general SS belts input.

Table 3.4. Overview of selected sources. Source: Author.

Sources related to Six Sigma belts in SMEs	**Sources related to Six Sigma belts in large enterprises or general Six Sigma belts input**
Hoerl, 2001; Davis, 2003; Gnibus and Krull, 2003; Snee and Hoerl, 2003; Snee, 2004; Burton, 2004; Wessel and Burcher, 2004; Harry and Crawford, 2004 and 2005; Antony et al. 2005; Green et al. 2006; Kumar et al. 2008; Nonthaleerak and Hendry, 2008; Schroeder et al. 2008; Antony et al. 2008; Antony, 2008; Brun, 2011; Kumar et al. 2011; Timans et al. 2012; Deshmukh and Chavan, 2012; Antony, 2012; Barone et al. 2014; Timans, 2014; Douglas et al. 2015; Ben Romdhane et al. 2017; Stankalla and Chromjakova, 2017; Stankalla et al. 2019	Harry, 1998; Maguire, 1999; Wood, 1999; Chase, 1999; Breyfogle et al. 2000; Ingle and Roe, 2001 and 2002; Porter, 2002; Measuring Business Excellence, 2002; Pyzdek, 2000; Linderman et al. 2003; Motwani et al. 2004; Davis, 2004; Keller, 2003; Gowen and Tallon, 2005; Harry and Schroeder, 2005; Gupta, 2005; Antony et al. 2006; Brue and Howes, 2006; Bendell, 2006; Green, 2006; Black and McGlashan, 2006; Buch and Tolentino, 2006; Pandey, 2007; Feng and Manuel, 2008; Antony, 2007; Antony et al. 2007; Montgomery and Woodall, 2008; Ho et al. 2008; Miguel and Andrietta, 2009; Pulakanam and Voges, 2010; Snee, 2010; Moosa and Sajid, 2010; Aboelmaged, 2010; Setter, 2010; Hagen, 2010; Leyendecker et al. 2011; Gutierrez et al. 2012; Alsmadi et al. 2012; Voehl et al. 2013; Arumugam et al. 2013; Krueger et al. 2014; Pyzdek and Keller, 2014; Monteiro de Carvalho et al. 2014; Laux et al. 2015 a and b; Jesus et al. 2016; Antony and Karaminas, 2016; Stankalla and Chromjakova, 2019

In around half of the sources researchers from the US (36 sources) are involved, followed by UK authors who added their input in 19 research papers. Jiju Antony of the Hariot-Watt University in Edinburgh published most articles in this research field. Overall, he contributed to 15 research papers. He is lead author of five papers, single author of three papers and co-author of seven more papers.

27 sources cover findings about SS belts in manufacturing SMEs that can be used to outline the current state of the SS belt research in SMEs with focus on the manufacturing industry. Hoerl (2001) was the first to include his view about SS belts in SMEs in an article while the last inclusions were made by Ben Romdhane et al. (2017) and the author of this dissertation (Stankalla and Chromjakova, 2017 and 2019; Stankalla et al. 2019). Green et al. (2006), Barone et al. (2014) and Ben Romdhane et al. (2017) specifically focused their research on the SS belt system in manufacturing SMEs while the other authors mainly provided recommendations regarding the SS belt deployment structure or included empirical data about the presence of the individual SS belts in their articles. With a total of eleven publications, the highest number of sources is published between the years 2001 and 2006, followed by ten sources between the years 2007 and 2012. The year 2008 marks the highest number of publications with a total of five released articles. There are only six sources published after the year 2013 so far (see table 3.5).

Table 3.5. Distribution of the number of sources concerning Six Sigma belts in manufacturing SMEs per time period. Source: Author.

Period of time	**Number of sources**
Between the years 2001 and 2006	11
Between the years 2007 and 2012	10
After the year 2013	6

In the next two chapters (3.2 and 3.3), the comparative review will be documented by reporting the observations and findings of the mentioned sources in table 3.4.

3.2 Six Sigma belt deployment structure

The number of the key SS players (MBBs, BBs and GBs) in the companies make up a relatively small percentage of the total work force (Harry and Schroeder, 2005; Pulakanam and Voges, 2010; Jesus et al. 2016) but they are able to make significant contributions to the bottom-line results (Measuring Business Excellence, 2002). For this, SMEs must be aware about the SS belts exact roles, responsibilities and required skills as well as the personal characteristics the SS belt candidates must fulfil to be attractive for SS trainings and to get certified so that they can lead and execute SS projects successfully (Antony, 2007). In the past, some academic research has been carried out to discuss roles, responsibilities and required skills that BBs shall hold in larger enterprises (see for example Harry, 1998; Hoerl, 2001; Ingle and Roe, 2001; Snee and Hoerl, 2003; Brue and Howes, 2006 etc.) but there exist hardly any empirical studies. Black and McGlashan (2006) surveyed companies in a wide variety of industries in the US while Antony (2007) conducted his survey with UK manufacturing organizations. Antony and Karaminas (2016) recently conducted a survey with 105 SS practitioners from 14 different countries whereby the majority was from India and the UK. The conclusion of this study was that several roles and responsibilities as well as required skills are more essential than others (see details in table 3.6).

Table 3.6. Roles, responsibilities and skills of Black Belts in large enterprises. Source: Antony and Karaminas, 2016.

Ranking	Roles and responsibilities	Required skills
1	Change agent	Analytical skills
2	Six Sigma expert	Expertise in Six Sigma methods and tools
3	Coach	Data/fact driven
4	Critical problem solver	Coaching skills
5	Analyst of root causes	Problem-solving skills
6	Mentor	Leadership skills
7	Leader of strategic projects	Presentation skills
8	Demonstrating bottom-line results into hard cash savings	Customer advocacy
9	Member of improvement projects	Project management skills
10	Project manager/leader	Result-oriented leadership

It was found that the most important BB tasks should be to act as change agent, followed by serving as SS expert. Analytical skills are the most important skills that BBs must have. The second most important skill is to provide expertise in the SS method along with all related tools and techniques (Antony and Karaminas, 2016).

Kumar et al. (2011), who proposed a SS implementation framework customized to the needs of SMEs, stated that the BB role in SMEs is a little differently than in large enterprises. They were of the opinion that BBs in SMEs should primarily take on the role of the trainer on different SS expertise levels and instruct the rest of the employees. This approach was already applied in one of the six Dutch manufacturing SMEs from Timans et al. (2012) case study analysis. The staff of an aerospace SME was planned to be trained on the job by the BB team leader. Another example for this can be seen in the Green et al. (2006) case study where GBs in a small company were mentored one-on-one by BBs. Apart from that, the results of an empirical study carried out by Hagen (2010) that was based on the data of 140 BBs and 176 team members from six organizations in the US showed that the greater the level of BB coaching expertise, the greater is the learning performance of the team members and the more positive are the project outcomes. For these reasons, Kumar et al. (2011) suggestion that MBBs would not be required in SMEs at all also appears to be plausible. However, this stands in contrast to Pulakanam and Voges (2010), Miguel and Andrietta (2009), Ingle and Roe (2001), Keller (2003) and Jesus et al. (2016) that claimed that 0.1% MBBs should be present in large enterprises. Against this background, the study of Nonthaleerak and Hendry (2008), where a direct reporting structure from BBs to Champions was identified as new critical success factor for the LSS implementation in SMEs, should also be considered. According to Harry and Schroeder (2005) one champion per business group or manufacturing site shall usually be available.

However, BBs shall receive less attention in SMEs than in larger enterprises while the presence of GBs and YBs shall be increased in SMEs (Davis, 2003; Gnibus and Krull, 2003; Burton, 2004; Green et al. 2006; Pyzdek and Harrison, cited in Antony, 2008). The SME of Gnibus and Krull (2003) case study, for instance, discovered during its continual improvement program that limiting SS training to the GB training level program provided sufficient resources required to address their business problems. Davis (2003) and Burton (2004) developed in their studies step-by-step guidelines and process overviews on how SMEs shall deploy SS. Both stated that a GB and YB approach would allow SMEs to implement SS at a less costly, more manageable pace. They observed that the majority of the benefits in SMEs are rather generated from GBs instead of BBs which, in turn, means that the GB approach addresses many of the constraints SMEs face. Another finding from Burton (2004) was that GBs and BBs could be interchangeable at SMEs in about 80% of the organization´s SS opportunities. Green et al. (2006) presented in their study an approach of an effective quality improvement program in a small manufacturing company that involved specifically widespread training of GBs. Also, Pyzdek and Harrison, cited in Antony (2008), added that very small businesses should primarily rely on GBs and can collect quick improvements by applying the SS way of thinking at the basic GB level.

A few years ago, Ben Romdhane et al. (2017) even proposed a new model with the objective to facilitate the integration of SS in SMEs by avoiding the use of BBs, applying appropriate tools and simplifying the DMAIC concept. As not all problems in SMEs require the kind of complex statistical approach for which BBs are usually needed, it is more important for SME employees to gain knowledge in applying the right tools for the right opportunities. Therefore, the focus of training and education shall still be on SS but also includes and integrates Kaizen as well as Lean (Burton, 2004). Wessel and Burcher (2004) studied how SS has to be adapted to be applicable in SMEs based on German companies. They recommended a significantly shorter training program for SMEs than in large corporations but stated that it should be based on the well-proven quality management methods and tools adjusted to the specific SME needs. Green et al. (2006) had a similar opinion and proposed to design GB projects with shorter duration toward more lean-oriented SS projects through the adoption of lean tools. The SMEs of Timans et al. (2012) case study analysis should also be mentioned in this context. In this case study analysis, the application of lean tools dominated the SS projects in the various SMEs.

In their study about critical success and failure factors for implementing SS in organisations, Moosa and Sajid (2010) claimed that the use of BBs will not lead to effective results without appropriate trainings. In that context, it should be mentioned once more that the above-mentioned SME disadvantages from chapter 2.5 regarding a lack of human and financial resources may result in an inadequate amount of trainings provided to employees and this, in turn, can lead to an unskilled workforce concerning SS (e.g. Antony et al. 2005 and 2008; Deshmukh and Chavan, 2012; Timans, 2014). LSS trainings are very expensive. Douglas et al. (2015) reported during their pilot study on the LSS implementation in East African organisations that training someone to be a BB in the UK costs between 6.000 € and 11.500 €. Chase (1999) even estimated the whole training costs to amount up to 27.000 € per employee. Although SS projects are expected to reflect an improvement in the performance metrics of a company of around 70% (Gowen and Tallon, 2005), investing such a high amount in training makes SMEs hesitant to develop their staff member to SS belts (Douglas et al. 2015). In this respect, Davis (2004) emphasized that organizations always have to view training as an investment and not as costs. He believed that the payback of a BB project is around 2.5 times higher than the investment made in training. Antony et al. (2006) also stated that the benefits resulting from SS projects outweigh the investments costs. Snee (2010) was of the opinion that a LSS deployment typically passes the breakeven point in six to twelve months. Consequently, the companies will most likely see a direct impact on the bottom-line results very soon after investing in SS belt trainings. In 1997, General Electric invested around $250 million in the training of almost 4000 BBs and 60000 GBs out of a workforce of 220000 employees (Harry and Schroeder, 2005). However, they managed to complete over 500000 projects within six years and saved more than $2.5 billion in that time (Gowen and Tallon, 2005). Wood (1999) highlighted that minimum direct cost savings per BB are around 900.000 €. As yet another alternative to start SS training activities, Snee and Hoerl (2003) suggested that smaller organizations enter into a collaboration with local universities. They reported the Centre for Research in Six Sigma and Process Improvement (CRISSPI) at the Glasgow Caledonian University as an example, as it provided SS belt training to SMEs through rigorous research and case studies at a competitive price. As another example the Arizona State University that provided SS training in both live classroom and internet class formats was mentioned. The case study of Barone et al. (2004) has to be mentioned as a best practice example of a BB education. The study concerned a BB project that focused on improvements in the warehouse activities of a SME company from the Swedish steel industry and was successfully executed in cooperation with the Chalmers University of Technology in Gothenburg. Beside expensive SS training costs, Hoerl (2001) concluded in his research about required technical skills of SS BBs that SMEs will have problems to hire BBs due to their high salaries. As a reference, the reported annual salary for a BB amounts to around 92.000 € according to Voehl et al. (2013).

The high training costs and salaries for BBs as well as the inclusion of lean tools adjusted to specific SME needs instead of complex statistical techniques in SS projects provide thought-provoking impulses as to why a higher focus on GBs instead of BBs seems to be the right option for SMEs. This also means that the percentages of BBs and GBs in relation to the total workforce would differ in small and large enterprises. To get a sense of the size of such SS activities, the rule of thumb for most researchers is to deploy 1% of the workforce as BBs (Harry and Schroeder, 2005; Pulakanam and Voges, 2010; Miguel and Andrietta, 2009; Keller, 2003; Pyzdek and Keller, 2014; Jesus et al. 2016) while Snee (2004) suggested 2% of the workforce as BBs and Aboelmaged (2010) as well as Buch and Tolentino (2006) even suggested about 5% of the workforce as BBs in large enterprises. Hence, averaged across these proposals, the BB proportion in relation to the total workforce amounts to 2%[2] in large enterprises. Moreover, BBs are mostly expected to be full-time agents dedicated towards SS (Ingle and Roe, 2001; Pandey, 2007; Feng and Manuel, 2008; Gutierrez et al. 2012; Pyzdek and Keller, 2014 etc.) or shall spend at least 80% of their time towards their SS projects (Antony et al. 2007). The deployment of SS BB professionals in this manner would not be applicable in SMEs that have a turnover of few million euros (Antony, 2012). Kumar et al. (2011) indicated the need of one or two BBs for a company with 250 employees. This would be less than 1% of the total workforce and thus less than in large enterprises. Beside this, Nonthaleerak and Hendry (2008) as well as Schroeder et al. (2008), who explored the SS implementation in organizations using multiple case studies, experienced that the use of part-time BBs appears to be a more realistic option for SMEs. Existing case studies showed that the BB working time for SS projects varies from SME to SME. While BBs of the automotive SME in Timans et al. (2012) case study analysis spend at least 60% of their working time towards SS, BBs in Italian SMEs investigated in Brun’s (2011) study about critical success factors for SS implementation only dedicate between 20% to 30% of their time on SS projects.

As far as GBs are concerned, the literature recommends GBs to make up 5% of the total workforce as guideline for larger enterprises (Miguel and Andrietta, 2009; Jesus et al. 2016). Against the background of the above-mentioned recommendations, namely that the SS implementation strategy in SMEs should

[2] (6*1%+1*2%+2*5%)/9 = 2% BBs in relation to the total workforce

be rather focused on GBs, it is assumed that the proportion of GBs in SMEs should be greater compared to the GB percentage in larger enterprises. While GBs are mostly part-time improvement specialists or spend at least 30% of their time to complete their SS projects in large enterprises besides their regular full-time work (Linderman et al. 2003; Bendell, 2006; Antony et al. 2007; Schroeder et al. 2008; Aboelmaged, 2010), they should be able to spend at least 20% of their working time on their SS projects in SMEs (Antony et al. 2005 and 2008). The thermoplastic SME in Timans et al. (2012) case study analysis only includes part-time GBs for managing projects since no BBs are available there. According to Pyzdek and Keller (2014), however, GBs spend only around 5% of the working time towards SS in most cases. In this context, the case study of Green et al. (2006) in which the time employees dedicated to the GB projects remained only at around 2% to 3% must be taken into consideration. In another research of Green (2006), in which the actual GBs performance in five companies was researched by using structured in-depth interviews of 14 GBs, the respondents stated that they did not have time to focus on their projects because they had to complete their regular working duties.

In addition to training only BBs and GBs in the companies, Gupta (2005) suggested that the other employees should also attend awareness sessions and preferably obtain a YB certification to contribute to the change in the organisational culture. Correspondingly, Harry and Schroeder (2005) recommended that SS training should be provided for at least 50% of the organisation's staff in order to drive change in the business and increase profits.

Cost savings achieved by SS belts can be significant. In Snee's (2004) experience, companies that use SS effectively get following returns: large companies return 1% to 2% of the sales per year and SMEs return 3% to 4% of the sales per year. As example see Motorola ($1 billion in three years) and General Electric ($3 billion in two years) (Ingle and Roe, 2002). Researchers have different views concerning the expected cost savings by BBs per project in large enterprises. Around the year 2000, it was believed that BBs are able to deliver cost savings to the bottom-line results of approx. 120.000 € to 230.000 € per project (Harry, 1998; Maguire, 1999; Pyzdek, 2000; Porter, 2002; Snee, 2004). In comparison, GBs should only be able to save around 45.000 € per project (Harry, 1998). At a later time – around the year 2010 and after that – the expectations in regard to cost savings were decreased by other researchers. Kumar et al. (2011) estimated cost savings by BBs of around 85.000 € per project while Krueger et al. (2014) believed that BBs are only able to save around 45.000 € per project. Hence, averaged across these proposals, the BB cost savings per project amount to 100.000 €[3] in large enterprises. BBs in SMEs, on the other hand, were said to save no more than 40.000 € per project (Kumar et al. 2011).

[3] Around the year 2000: 120.000 € to 230.000 € per project/ Mean value is 175.000 €
(175.000 € + 85.000 € + 45.000 €)/3 = Around 100.000 € cost savings per project by one BB

The number of completed projects per year depends on the project scope and its complexity. Krueger et al. (2014) were of the opinion that a BB should be able to complete up to four projects each year while Snee (2004) and Leyendecker et al. (2011) estimated that a BB could complete up to five projects each year. Others, as for instance Brue and Howes (2006) or Pyzdek and Keller (2014), expected the successful completion of up to six or up to seven projects by one BB per year. Hence, averaged across these proposals, the number of projects that can be executed per year by a BB is about four projects[4]. There are also different opinions about the potential number of SS projects completed by GBs. While Snee (2004), Leyendecker et al. (2011), Krueger et al. (2014) and Pyzdek and Keller (2014) believed that a GB should be capable to execute an average of around one or two projects per year, Antony et al. (2007) trusted GBs to complete up to three projects annually. However, this data is primarily related to large enterprises.

The completion of one project shall normally not exceed more than six months, according to various experts (Breyfogle et al. 2000; Snee, 2004; Montgomery and Woodall, 2008; Arumugam et al. 2013). In this context, one particular result of Miguel and Andrietta (2009) study which identified the best practices in the use of the SS methodology by 78 surveyed Brazil companies should be mentioned. It was found that the most frequent SS project timeframe was between six and twelve months and thus longer than recommended. Also, Green (2006) reported that the GB project duration in the five companies of his study varied considerably from three months to two years with an average of nine months. Unclear goals, an improper scope, the lack of data and especially less time due to regular working duties were mentioned as barriers (Green, 2006). A similar study was conducted by Laux et al. (2015a) who researched the timeliness of completed GB projects by reviewing data of 18 GB projects from a single global US manufacturing enterprise. The results of this study revealed that the actual duration of the DMAIC phases of the various projects differed significantly from the planned duration. Nearly 50 % of the projects took 56 days longer than planned. A higher focus on project management with a classified project portfolio management and initial project planning ought to improve the timeliness of GB projects (Laux et al. 2015a). In addition to this study, Laux et al. (2015b) identified barriers for GB project completions based on a survey conducted with active GBs in the same company that was mentioned above. The significant factors contributing to an insufficient GB project completion were identified as wrong project selection, poor project management and leadership skills, priority conflicts between SS and

[4] Krueger et al. (2014): 2 to 4 projects/ Mean value is 3

Snee (2004): 3 to 5 projects/ Mean value is 4

Leyendecker et al. (2011): 4 to 5 projects/ Mean value is 4.5

Brue and Howes (2006): 4 to 6 projects/ Mean value is 5

Pyzdek and Keller (2014): 3 to 7 projects/ Mean value is 5

(3+4+4.5+5+5)/5 = Around 4 projects can be executed by one BB per year functional duties, time constraints and a lack of applying SS tools (Laux et al. 2015b). Another empirical study with a similar research objective was carried out by Ho et al. (2008). This study explored key success factors that increase the number of completed GB projects by using a survey of certified GBs within a single Asian aircraft service maintenance company. The importance of the following success factors critical to GB projects became apparent: top management commitment and participation, business strategy tied to customer's demands, use of data that is easily obtainable, investment in essential resources made in form of time for project completion and a reward system for employees (Ho et al. 2008).

The more effective the individual SS belt is and the more time schedules are being met, the more projects are being carried out and the higher the financial result for the company in the end (Ingle and Roe, 2001). Therefore, it can be concluded that a BB, for example, could possibly save approx. 450.000 € to 900.000 € per year (Chase, 1999; Pyzdek, 2000; Snee, 2004; Harry and Schroeder, 2005). Empirical investigations with regard to the number of projects executed and the related costs saved by SS belts were only carried out by few researchers. The results of Antony et al. (2008) analysis, who conducted a survey with 16 UK manufacturing SMEs, revealed that 62% of the companies experienced financial benefits of up to 280.000 € per annum and a total of 13% of the companies experienced financial benefits of between 280.000 € and 560.000 € per annum. The remaining firms did not quantify financial savings made through successful SS projects. 69% of the companies completed between one and five SS projects per year and 25% of the companies completed between five and ten SS projects per year. There was one company that even completed more than 20 projects per year. Douglas et al. (2015) studied 23 East African service and manufacturing enterprises, the majority of which were large enterprises. Around 17% of the companies saved costs between 4.500 € and 9.000 € per year, around 30% of the companies saved costs between 9.000 € and 90.000 € per year, around 22% of the companies saved costs between 90.000 € and 450.000 € per year and 4% of the companies saved costs greater than 900.000 € per year. With respect to the number of projects executed, it was reported that about 72% of the respondents carried out between one and five SS projects per year, about 14% carried out between five and ten SS projects per year, about 5% carried out between 10 and 20 SS projects per year and about 9% carried out more than 20 SS projects per year. In comparison to the studies of Antony et al. (2008) and Douglas et al. (2015), the cost savings through SS in the study conducted by Miguel and Andrietta (2009), who surveyed 78 large Brazilian companies, were not evaluated per annum but project specific. While around 30% of the respondents achieved cost savings of only 23.000 € to 46.000 € per SS project, around 22% of the respondents achieved cost savings of almost 100.000 € per SS project. Moreover, around 23% of the respondents only completed between one and five SS projects per year, whereas 17% of the respondents completed over 50 SS projects per year. Although

Douglas et al. (2015) and Miguel and Andrietta (2009) focused their studies rather on larger enterprises, regarding the amount of costs saved and number of projects executed, there was no considerable difference in results compared to the study conducted by Antony et al. (2008). In contrary to the UK, which is a developed country with better educational institutions and financial returns, Brazil and countries from East Africa are emerging countries or rather developing countries. This could be a factor contributing to the fact that these countries are generally lagging behind the UK regarding the implementation of such cost intensive quality initiatives, irrespective of the organisation size.

Besides the regular SS belts, Harry and Crawford (2004 and 2005) introduced White Belts (WBs) as part of a new belt system generation in the SS infrastructure. WBs shall be an alternative for SMEs that requires less training than the BB program. Instead of heavily investing in the BB system, using WBs is therefore highly advisable. This also addresses the problem that SMEs have a limited capacity to send their employees to BB or GB trainings. WBs shall typically be deployed for tasks such as the improvement of processes within work cells in the production lines which would not justify or require the use of BBs (Harry and Crawford, 2004 and 2005). According to Harry and Crawford (2004 and 2005) a WB should offer a much quicker return on investment by completing of up to twelve projects per year with potential savings of 22.000 € per project. This would result in total cost savings of up to 264.000 € per year by one WB. Antony et al. (2008) as well as Kumar et al. (2008) stated that the WB definition provided by Harry and Crawford (2004 and 2005) is neither realistic nor achievable. Twelve projects per year for a WB are too ambitious. For this reason, it was suggested in both articles that WBs shall aim to carry out between six and eight projects per year. Kumar et al. (2011) even recommended that WBs shall only carry out four or five projects. Estimated cost savings by WBs vary between 5.500 € per project (Kumar et al. 2008 and 2011) and 11.000 € per project (Antony et al. 2008). By taking their suggestions into account and engaging about 10 to 15 WBs per 100 employees as proposed by Kumar et al. (2008 and 2011), financial savings between 500.000 € and 1.000.000 €[5] per year could be made in a SME with 250 employees.

Craig Setter (2010), CEO of one of the leading providers of SS training and certification worldwide, raised some doubts regarding the WB level. The WB does not seem to be created because the YB training is deemed to be a too rigorous basic education. It appears that the recent development of the WB is an attempt of many training providers to expand their product line. Many providers that are on the market provide 45-minute online courses for free which was not the Harry and Crawford´s (2004 and 2005) intention when they came up with this concept

[5] Example calculation:

5500 € * 5 projects * 37 WBs = 1.017.500 € cost savings per year

5500 € * 4 projects * 25 WBs = 550.000 € cost savings per year

(Setter, 2010). It was meant to be a 40 hour long instructive training on useful problem-solving methods (Harry and Crawford, 2004 and 2005). Setter (2010) concluded that the WB training is a waste of time since the YB training already represents a recognized preschool and basic overview introduction of SS.

Table 3.7 sums up the main differences of the SS belt hierarchy (availability, roles, responsibilities and skills, proportion of total workforce, working time, number of projects that can be executed and cost savings) between manufacturing SMEs and large manufacturing enterprises.

Table 3.7. Differences of the Six Sigma belt system structure in manufacturing SMEs and large manufacturing enterprises based on the results of the systematic literature review. Source: Based on[6].

LARGE ENTERPRISE	**SMALL ENTERPRISE**
Master Black Belt 0.1% MBBs in relation to the total workforce Full-time role	**Black Belt** MBBs are not required
Black Belt 2% BBs in relation to the total workforce Full-time role 100.000 € cost savings per project Between four and seven project executions per year Main roles and responsibilities: 1. Change agent 2. SS expert 3. Coach Main skills: 1. Analytical skills 2. Expertise in SS methods and tools 3. Data/fact driven	<1% BBs in relation to the total workforce Part-time role Between 35.000 € and 40.000 € cost savings per project Main roles and responsibilities: 1. Mentor/Coach
Green Belt 5% GBs in relation to the total workforce Part-time role or at least 30% of the working time towards SS projects 45.000 € cost savings per project Up to three project executions per year	**Green Belt** >5% GBs in relation to the total workforce 20% of the working time towards SS projects
Yellow Belt Support of GBs WBs are not required	**Yellow Belt** Support of GBs
	White Belt Between 10% and 15% WBs in relation to the total workforce 5.500 € cost savings per project Four to five project executions per year

[6] Harry, 1998; Maguire, 1999; Pyzdek, 2000; Ingle and Roe, 2001; Porter, 2002; Davis, 2003; Keller, 2003; Gnibus and Krull, 2003; Linderman et al. 2003; Burton, 2004; Snee, 2004; Harry and Crawford, 2004 and 2005; Antony et al. 2005; Harry and Schroeder, 2005; Bendell, 2006; Buch and Tolentino, 2006; Brue and Howes, 2006; Green et al. 2006; Pandey, 2007; Antony et al. 2007 and 2008; Pyzdek and Harrison, cited in Antony, 2008; Feng and Manuel, 2008; Schroeder et al. 2008; Nonthaleerak and Hendry, 2008; Kumar et al. 2008 and 2011; Miguel and Andrietta, 2009; Pulakanam and Voges, 2010; Aboelmaged, 2010; Leyendecker et al. 2011; Gutierrez et al. 2012; Pyzdek and Keller, 2014; Krueger et al. 2014; Jesus et al. 2016; Antony and Karaminas, 2016; Stankalla and Chromjakova, 2017; Stankalla et al. 2019.

3.3 Six Sigma belts presence

In the existing literature, two studies outlining the presence of the SS professionals in manufacturing SMEs are found. These are the studies of Antony et al. (2008) and Timans et al. (2012). In addition, 35% of the respondent enterprises in Douglas et al. (2015) study have the size of a SME. To conduct a comparison analysis of the SS belt presences in large and small enterprises, four additional articles including surveys with large enterprises (Miguel and Andrietta, 2009; Alsmadi et al. 2012; Monteiro de Carvalho et al. 2014; Jesus et al. 2016) as well as one case study of Motwani et al. (2004) where SS belts are deployed in a large manufacturing company (Dow Chemical) are taken into consideration. While Motwani et al. (2004), Antony et al. (2008), Miguel and Andrietta (2009), Timans et al. (2012), Monteiro de Carvalho et al. (2014) and Jesus et al. (2016) focused their studies on manufacturing enterprises, Alsmadi et al. (2012) and Douglas et al. (2015) included a mixture of service and manufacturing companies in their studies.

With respect to the number of SS professionals working as MBBs, different results are found. In the studies conducted by Miguel and Andrietta (2009), Alsmadi et al. (2012) and Monteiro de Carvalho et al. (2014) the proportion of the companies that deploy MBBs is considerably greater than in the studies of Antony et al. (2008) and Douglas et al. (2015). More precisely, around half of the 46 Brazil companies responding to the survey of Monteiro de Carvalho et al. (2014), 40% of the 78 Brazil companies responding to the survey of Miguel and Andrietta (2009) and 45% of the 15 Saudi Arabia companies responding to the survey of Alsmadi et al. (2012) deploy MBBs. In comparison, only one company out of the surveyed 16 UK SMEs in Antony et al. (2008) study and one company out of the 23 East African enterprises in Douglas et al. (2015) study have one MBB. These results confirm the view of Kumar et al. (2011) who pointed out that MBBs are usually not needed in a SME environment.

Similar differences in results are found in terms of the presence of BBs. Miguel and Andrietta (2009) identified BBs in almost 80% of the surveyed companies, Alsmadi et al. (2012) identified BBs in about 60% of the surveyed companies and Monteiro de Carvalho et al. (2014) identified BBs in 86% of the surveyed companies while in Antony et al. (2008) study only 45% of the surveyed companies have BBs. The proportion of companies with GBs in Antony et al. (2008) study (80%), on the other hand, is greater than in Monteiro de Carvalho et al. (2014) study (75%) as well as Miguel and Andrietta (2009) study (50%). Only the proportion of companies with GBs in Alsmadi et al. (2012) study is identical to Antony et al. (2008) study. These both findings support the opinion of numerous authors in this field (listed in chapter 3.2) who recommended that the focus of SMEs should be on GBs instead of on BBs.

Douglas et al. (2015) provided no information regarding the proportion of companies with BBs, GBs and YBs but only reported that the number of YBs within the organizations ranges from 1 to 80 and the number of GBs ranges from 1 to 30 while the maximum number of BBs reported in one of the organizations is seven.

Although, according to Harry and Crawford (2004 and 2005), WBs are an alternative particularly suitable for SMEs, this SS belt category was only evaluated in the study conducted by Monteiro de Carvalho et al. (2014) which focused on large enterprises. The WB category was found in around 11% of the companies. Moreover, YBs are available in less than 10% of the companies in the studies conducted by Monteiro de Carvalho et al. (2014) and Antony et al. (2008). Regarding SS project champions, it was observed that more than 60% of the surveyed companies in Antony et al. (2008) study and almost 50% of the surveyed companies in Douglas et al. (2015) study have a SS project champion.

However, except for the study of Alsmadi et al. (2012), these research contributions did not show the proportion of the various SS belts to the company's total employees. In order to investigate if the in the literature recommended percentages of the SS professionals as mentioned in chapter 3.2 are met in practice, the studies of Motwani et al. (2004), Alsmadi et al. (2012), Jesus et al. (2016) as well as Timans et al. (2012) are considered. Jesus et al. (2016) investigated 29 companies, mainly from Brazil, and came to the result that an average of 0.02% MBBs, 0.2% BBs and 1.9% GBs are present in these companies. In Alsmadi et al. (2012) study, the percentage of BBs in the companies ranges between 0.2% and 0.6% of the total workforce. This survey data reveal that the number of SS professionals within the respondent companies is smaller than the standards indicated by the authors from chapter 3.2, namely that a minimum of 0.1% MBBs, 2% BBs and 5% GBs shall be available in large companies. By comparison, these recommendations are met and even exceeded by the company "Dow Chemical" of Motwani et al. (2004) case study analysis. During their corporate-wide SS implementation initiative, 150 MBBs, 1400 BBs and 2500 GBs of the around 50000 employees were trained and certified. These are 0.3% MBBs, 2.8% BBs and 5% GBs of the total workforce.

As far as SMEs are concerned, Timans et al. (2012) gathered data from six Dutch SMEs. The aerospace company with about 200 employees deploys two BBs while two other SMEs, a manufacturer of custom-made machinery with about 50 employees as well as a specialist in thermoplastic with about 100 employees, deploy one GB and three GBs respectively. A more structured LSS organization was realized within the following three companies: a supplier of plastic products with about 250 employees that deploys two BBs and has GB experience in all the primary process departments, an automotive fuel tank system manufacturer with about 200 employees deploying four BBs and 30 GBs and a chemical company with about 110 employees deploying two BBs and 17 GBs. A trained SS champion is only present in the plastic SME. Other SS professionals, as for instance YBs or WBs, are not formally deployed in these case study companies.

Looking at the results in percentage, it can be said that the two SMEs from the automotive and chemical sector exceed the proposed GB proportion of 5% in large enterprises by a considerable amount. Each company has about 15% of the total workforce as GBs. A higher percentage of GBs in SMEs is also predicted based on the findings from the current literature discussed in chapter 3.2. The GB proportions of 2% in the machinery SME and 3% in the thermoplastic SME, on the contrary, are smaller than the expected GB proportion of 5% in large enterprises. Moreover, both SMEs do not apply BBs. The aerospace company even includes no GBs but 1% BBs in relation to the total workforce. The BB proportion of less than 1% of the total workforce in SMEs as proposed by Kumar et al. (2011) is met by the plastic company. In contrast, the automotive SME and chemical SME deploy, against all expectations, with about 2% of the total workforce a higher proportion of BBs than suggested by Kumar et al. (2011).

Table 3.8 presents the results of the eight studies from the current literature with respect to the active SS belt professionals.

Table 3.8. Studies included the Six Sigma belt presence. Source: Based on*.

Sources*	Study information	Presence of Six Sigma belts
Motwani et al. (2004), US	Case study based on the manufacturing company "Dow Chemicals" that included SS belts (employee size around 50.000)	0.3% MBBs in the company
		2.8% BBs in the company
		5% GBs in the company
Antony et al. (2008), UK	Empirical study included SS belts in 16 manufacturing SMEs	Champions in 60-65% of the companies
		MBBs in 6% of the companies
		BBs in 45% of the companies
		GBs in 80% of the companies
		YBs in <10% of the companies
Miguel and Andrietta (2009), Brazil	Empirical study included SS belts in 78 large manufacturing companies	MBBs in 40% of the companies
		BBs in 80% of the companies
		GBs in 50% of the companies
Alsmadi et al. (2012), Saudi Arabia	Empirical study included SS belts in 15 large enterprises from the service and manufacturing industry	MBBs in 45% of the companies
		BBs in 60% of the companies
		0.2% to 0.6% BBs in the companies
		GBs in 80% of the companies
Timans et al. (2012), Netherland	Case study based on six manufacturing SMEs that included SS belts	1% BBs in aerospace company
		2% GBs in machinery company
		3% GBs in thermoplastic company
		2% BBs and 15% GBs in automotive company
		2% BBs and 15% GBs in chemical company
		0.4% Champions, 0.8% BBs and many GBs in plastic company
Monteiro de Carvalho et al. (2014), Brazil	Empirical study included SS belts in 46 large manufacturing companies	MBBs in 50% of the companies
		BBs in 86% of the companies
		GBs in 75% of the companies
		YBs in 6% of the companies
		WBs in 11% of the companies

Douglas et al. (2015), East Africa	Empirical study included SS belts in 23 companies from the service and manufacturing industry (35% of these companies are SMEs)	Champions in around 50% of the companies
		Only one MBB in one company
		Seven BBs are the max. in a company
		1 to 30 GBs in the companies
		1 to 80 YBs in the companies
Jesus et al. (2016), Brazil	Empirical study included SS belts in 29 large companies from the manufacturing industry	0.02% MBBs on average in the companies
		0.2% BBs on average in the companies
		1.9% GBs on average in the companies

3.4 Discussion, research gaps and research hypotheses

Based on the 27 articles in the SS belts research field with focus on manufacturing SMEs that mainly expressed personal views from researchers, practitioners and consultants and included almost no empirical studies, it is difficult to derive meaningful conclusions. However, it can be concluded that this topic is a so far unexplored area of research that requires further attention from both, academics as well as the industry. Albliwi et al. (2015) and Alexander et al. (2019) already emphasized that very little research has been carried out that clarifies what kind of infrastructure would be required in order to successfully deploy LSS in SMEs. The aim of the last subchapter is to critically discuss to what extent the findings of the comparison analysis are providing conclusions with regard to the research question and the related research goals. Moreover, it aims to point out research gaps for further research. Based on the conclusions and findings derived from the systematic literature review, respective research hypotheses will be formulated that will be investigated in the course of this research study.

RESEARCH GOAL 1: To identify the key Six Sigma belts, their roles, responsibilities and their required skills in manufacturing SMEs compared to large manufacturing enterprises

Antony and Karaminas (2016) are the last researchers that conducted a global empirical study in which the roles, responsibilities and skills of BBs were prioritized. However, their focus was mainly placed on large enterprises. Until now, there are no research studies about the exact roles, responsibilities and required skills of the various SS belts in manufacturing SMEs. Alexander et al. (2019) already highlighted this lack of research regarding the required skills and attributes of SS belts in a SME environment. It is an unexplored area of research that as of yet has not been investigated properly. There is only the notion introduced by Kumar et al. (2011) that BBs shall take on the role of a trainer instead of MBBs, thereby leaving the MBB obsolete in a SME environment. Although a setup without MBBs has already been successfully adopted in the SMEs of the case studies conducted by Green et al. (2006), Nonthaleerak and Hendry (2008) and Timans et al. (2012) and was empirically proven by the surveys of Antony et al. (2008) and Douglas et al. (2015), it must be considered that most sources are already a few years old. Therefore, at this point, it is especially important to further analyse in the upcoming research whether the BB roles, responsibilities, and skills should be identical or different in small and large enterprises as well as whether MBBs can be replaced by BBs in a SME environment. Therefore, research hypothesis 1 is formulated accordingly and shall support the examination of this research topic.

Research hypothesis 1 (RH1): *The role of the Black Belt in manufacturing SMEs is synonymous with the role of the Master Black Belt*

In five research contributions (Davis, 2003; Gnibus and Krull, 2003; Burton, 2004; Green et al. 2006; Pyzdek and Harrison, cited in Antony, 2008) was the view expressed that it is more effective to focus on implementing and training GBs instead of BBs in small enterprises. As reasons for this, the high training costs and salaries of BBs as mentioned by Hoerl (2001) and Douglas et al. (2015) on the one hand and the lack of human and financial resources as stated in chapter 2.5 on the other hand must be emphasized. In this context, the research paper from Ben Romdhane et al. (2017) must also be mentioned as they developed a model to integrate SS in SMEs without the use of BBs. Moreover, the findings of the comparative analysis of the SS belt presences in manufacturing SMEs and large manufacturing enterprises from chapter 3.3 strengthen the opinion of the various researchers that a higher focus must be placed on GBs in SMEs. Overall, it can be concluded that the current literature may provide a direction regarding what kind of SS belts could play a vital role in manufacturing SMEs, but there is too little evidence for definite conclusions. Furthermore, most of these sources have already been published a few years ago. For these reasons, it has to be verified in the upcoming research activity whether a GB approach shall be prioritized in a SME environment and this shall be supported by the investigation of the established research hypothesis 2.

Research hypothesis 2 (RH2): *There shall be a greater presence of Green Belts and a minor presence of Black Belts in relation to the total workforce in manufacturing SMEs than in large manufacturing enterprises*

Furthermore, Harry and Crawford (2004 and 2005) introduced the idea to focus on the deployment of WBs in SMEs which was subsequently cited in journal papers of Antony et al. (2008) as well as Kumar et al. (2008 and 2011). However, their presence was, so far, only proven in the empirical study of Monteiro de Carvalho et al. (2014). Since the YB training already represents a recognized preschool and provides a basic overview introduction of SS according to Setter (2010), he raised some doubts in regard to the WB level. According to Kumar et al. (2011), considering the WB as another training alternative for SMEs is a grey area of research that needs further exploration and testing. In closing, research hypothesis 3 is formulated and its investigation shall aid to meet the research goal 1.

Research hypothesis 3 (RH3): *The role of the White Belt is synonymous with the role of the Yellow Belt*

RESEARCH GOAL 2: To identify the Six Sigma belt proportions in relation to the total workforce in manufacturing SMEs compared to large manufacturing enterprises

Until now, one case study was conducted by Timans et al. (2012) that examined the GB and BB proportions in relation to the total workforce in six SMEs. Two of the SMEs within this study deploy a lower percentage of BBs than is usual for large enterprises (around 2%), while two other SMEs exceed the proposed GB proportion of 5% in large enterprises (see chapter 3.3). This means that only a small share of the examined companies actually follows the recommended approach and guidelines from the researchers of the current literature mentioned in chapter 3.2 concerning BB and GB proportions in SMEs. However, this data only originates from one case study analysis. Apart from that, the proposed higher focus on GBs in SMEs is based on some personal views (see Davis, 2003; Gnibus and Krull, 2003; Burton, 2004; Green et al. 2006; Pyzdek and Harrison, cited in Antony, 2008) and the suggestion to deploy one to two BBs in a company with 250 employees was only mentioned in the article of Kumar et al. (2011). All of these were published several years ago and thus those opinions cannot yet be considered general rules. Some personal views and one case study are not hard evidence. For this reason, further research has to be conducted to analyse whether or not BBs and GBs are needed in SMEs in the same capacity as in large organizations. The guidelines derived from the current literature have to be confirmed or disproved and in order to do so the investigation results of the *RH2* have to be taken into consideration to meet the research goal 2.

RESEARCH GOAL 3: To identify the required invested working time of the individual Six Sigma belts towards Six Sigma projects in manufacturing SMEs compared to large manufacturing enterprises

Unlike in large enterprises where BBs shall work full-time or at least 80% of their working time towards SS projects (see chapter 3.2), Nonthaleerak and Hendry (2008) and Schroeder et al. (2008) suggested in their articles that BBs in SMEs shall work on a part-time basis beside their regular working duties. Currently, there are two studies available that gathered information about the BB working time in SMEs. While the one case company of Timans et al. (2012) study reported that their BBs spend 60% of their working time towards SS, the BBs in Brun (2011) study only spend 30% of their working time towards SS. Beside this, two research papers proposed that GBs in SMEs should spend 20% of their working time towards SS projects (Antony et al. 2005 and 2008) which is less than the suggested GB working time of 30% to 50% towards SS in large enterprises as cited in chapter 3.2. It would not be reasonable to assume the validity of the proposed working time for BBs and GBs in SMEs, which is based on some proposals in articles published several years ago, without clear empirical evidence. Therefore, further research also has to be conducted in this case in order to develop standards defining the required working time of the various SS belts towards SS in manufacturing SMEs. As support, research hypothesis 4 is formulated.

Research hypothesis 4 (RH4): *The working time of the Six Sigma belts towards Six Sigma projects in manufacturing SMEs shall be lower than in large manufacturing enterprises*

RESEARCH GOAL 4: To identify the possible number of projects that can be executed by the various Six Sigma belts in manufacturing SMEs compared to large manufacturing enterprises

Chapter 3.2 included several personal estimations with regard to the possible number of SS projects that can be executed by BBs and GBs per year in large enterprises but there are no indications concerning SMEs so far. During their study, Antony et al. (2008) gathered the number of executed SS projects per year within 16 UK manufacturing SMEs but did not break them down in order to look at which of the various SS belt categories was responsible for their execution. Therefore, this research field has to be researched completely from the beginning. According to chapter 2.5, lack of human resources and time constraints are an issue in SMEs and for this reason, research hypothesis 5 is formulated that shall bring more clarity and transparency in this matter.

Research hypothesis 5 (RH5): *The possible number of projects that can be executed by Six Sigma belts in manufacturing SMEs shall be lower than in large manufacturing enterprises*

RESEARCH GOAL 5: To identify the possible cost savings by the various Six Sigma belts in manufacturing SMEs compared to large manufacturing enterprises

The situation appears to be rather similar with regard to the possible costs that can be saved by the individual SS belts per SS project. Several personal views from authors concerning large enterprises are known (see chapter 3.2) but only one estimation in regard to SMEs was made by Kumar et al. (2011) who trusted BBs to save up to around 40.000 € per SS project. Antony et al. (2008) reported cost savings by SS projects within the 16 UK manufacturing SMEs but did not mention the SS belt types that were responsible for these savings. This research field also has to be researched completely from the beginning. For this reason and due to the lack of human resources and time constraints in SMEs (see chapter 2.5), the following research hypothesis 6 is formulated accordingly.

Research hypothesis 6 (RH6): *The possible cost savings by Six Sigma belts in manufacturing SMEs shall be lower than in large manufacturing enterprises*

RESEARCH GOAL 6: To identify the differences between the current and target status of the deployment of Six Sigma belts in manufacturing SMEs

At present, there are three studies available in the existing literature that included data about the presence of SS belts in manufacturing SMEs (see chapter 3.3). This data is too little to be considered a basis upon which conclusions can be drawn and it leaves many questions unanswered. Furthermore, there are no empirical or case studies regarding the required working time towards SS of the various SS belts in manufacturing SMEs so far. For this reason, a large number of SMEs have to be studied to evaluate if the recommended guidelines from the literature mentioned in chapter 3.2 or the guidelines that will be newly developed in the upcoming study regarding the working time of the individual SS belts towards SS and their proportion in relation to the total workforce are being followed in practice. Due to the reported low SS awareness and knowledge as well as the unexplored LSS infrastructure in SMEs (see chapter 1.1), the following research hypothesis 7 is set and shall support the investigation of this research topic.

Research hypothesis 7 (RH7): *The deployment of the Six Sigma belts in manufacturing SMEs is not implemented as required*

4. EMPIRICAL STUDY

After an extensive review of the literature, an empirical study will be conducted in the next step and it is organized based on four process steps. The applied methodology will be described in detail at first, followed by collecting the data of the survey respondents and the analysis of the survey results and statistical hypotheses test results as well as its presentation based on descriptive and inferential statistics. It concludes with an evaluation of the research hypotheses.

Throughout the complete empirical study, the process structure in table 4.1 will be followed rigorously.

Table 4.1. Process structure of the empirical study. Source: Author.

Process step	**Description**
To describe the methodological approach	To explain mathematical-statistical fundamentals
	To derive statistical hypotheses from the research hypotheses
	To define appropriate statistical hypotheses tests
	To present the power analysis approach
	To compute the optimum sample sizes to receive statistical hypotheses test results that are representative
	To design a survey questionnaire
To conduct the survey and collect the survey data	To send the survey questionnaire to respective candidates via mail or social professional networks
	To assess all replies based on the quality of the content
	To present the response rate and respondents distribution according to various categories (job title, SS belt certification, work experience, SME location, manufacturing type and industrial sector, implementation time etc.)
To analyse the data and present the results	To present the SS implementation status in manufacturing SMEs based on the surveys data
	To compute the detectable effect sizes in the various statistical hypotheses based on the surveys obtained sample sizes
	To test the statistical hypotheses
	To analyse the data and present the results based on descriptive and inferential statistics
	To compute the power of the statistical hypotheses tests that show no significant results
To evaluate the research hypotheses	To discuss the contribution of the statistical hypotheses test results with respect to the evaluation of the research hypotheses

4.1 Methodological approach

To evaluate the formulated research hypotheses from chapter 3.4, numerous statistical hypotheses will be derived from the research hypotheses as proposed by Cho and Abe (2005) and appropriate statistical tests will be defined for it. In the run-up, mathematical-statistical fundamentals will be explained for this purpose, followed by the presentation of a specifically adapted power analysis approach for the upcoming study. A priori power analysis that calculates the sample sizes (*N*) needed in order to conduct representative statistical hypotheses tests and a detailed description of the survey design which provides the required data for the conduct of the statistical hypotheses tests, finalize the chapter 4.1.

4.1.1 Mathematical-statistical fundamentals

While a research hypothesis is a statement about an expected or predicted relationship between two or more variables, a statistical hypothesis is mathematically precise and an expression of a parameter that characterizes the population distribution of interest. To decide about the research hypothesis validity or invalidity, it makes therefore sense to link statistical hypotheses with clear relationships to this substantive research hypothesis (Hay, 1981; Navarro, 2015). For testing a statistical hypothesis, a contrasting pair of a null hypothesis (H_0) and alternative hypothesis (H_A) have to be defined. While H_0 presents the basic situation that no effect is available, H_A is the reasonable assumption on the basis of observations. For this reason, a burden of proof for H_A is required to reject H_0 (Bortz and Schuster, 2010; Eid et al. 2017).

A distinction is made between one-sided and two-sided hypotheses tests, whereas one-sided tests can be distinguished again between a left-sided and right-sided test. If the probability of H_A towards H_0 decreases ($H_A < H_0$), a left-sided test must be applied. If not ($H_A > H_0$), a right-sided test is used. In these cases, the rejection rate of H_0 is only located on the side of the assumed direction of the probabilities event (H_A). In contrast, a two-sided test is applied to test if H_A differs from H_0 ($H_A \neq H_0$) without knowing the corresponding direction. In this case, both sides include rejection rates for H_0. Nevertheless, this kind of test is rather unusual because it is generally assumed in what direction H_A differs from H_0 (Bortz and Schuster, 2010; Eid et al. 2017; Sedlmeier and Renkewitz, 2018).

Since the data is drawn from a random sample, it cannot be ensured that H_0 or H_A is true. The attempt is therefore to express a statement of probability. For this, the probability value (p-value) must be calculated and a significance level must be defined as error probability. If the p-value is smaller than the established significance level, an effect is available, and the result of the test can be described as statistically significant. In other words, H_0 can be rejected in favour of H_A (Devore, 2015; Fahrmeir et al. 2016). The significance level is typically set to 5%, denoted by the Greek letter α and also known as type I error. It means that the probability to reject *H0* mistakenly in favour of *HA* is 5%. Accordingly, the probability of not rejecting *H0*, given that it is true, is 95% and designated as confidence level ($1–\alpha$) (Devore, 2015; Fahrmeir et al. 2016; Leonhart, 2017).

Unlike the type I error (α), *H0* also cannot be rejected given that it is in reality false. Such a scenario is known as type II error, denoted by the Greek letter β and typically set with a probability of 20%. In contrast, the probability to reject *H0* in favour of *HA*, given that *H0* is false, would then be 80%. This case equals $1–\beta$ and is referred to as power of the test. Its objective is to avoid the occurrence of or decrease the type II error (β) (Fahrmeir et al. 2016).

In table 4.2 the four cases that can happen during a statistical hypothesis test are illustrated.

Table 4.2. Overview of error types. Source: Devore, 2015; Fahrmeir et al. 2016; Leonhart, 2017.

	Retain *H0*	**Reject *H0***
***H0* true**	Confidence level ($1–\alpha$) = 95%	Type I error (α) = 5%
***H0* false**	Type II error (β) = 20%	Power of the test ($1–\beta$) = 80%

According to Cohen (1988), a minimum power of the test ($1–\beta$) of 80% and a significance level (α) of 5% are required so that the ratio of type II error (β) to type I error (α) is 20/5. A higher power of the test ($1–\beta$) would actually be more desirable, however, for this a much higher participation of test persons would be needed. It can be concluded that the smaller the type I error (α), the higher the type II error (β), meaning that the power of the test ($1–\beta$) also decreases provided that the sample size (N) remains the same (Cohen, 1988; Fahrmeir et al. 2016; Döring and Bortz, 2016).

Furthermore, the power of a test ($1–\beta$) also points to conclusions about the probability to find an effect of a specific size (d) (Rasch et al. 2014). The effect size (d) is a quantitative measure for the magnitude of a statistical effect and shall be reported along with the p-value because it is not only interesting to know whether a statistically significant result is available but also how strong it is. Depending on the statistical hypothesis test, various effect size metrics are available. Besides Cohen's *d*, other important metrics are, for instance, Pearson's *r*, Cohen's *h*, Cohen's *g*, Cohen's f^2, Hedge's *g*, Eta-squared or Omega squared. The effect size value can be determined based on reference values of previous similar research studies or the conduct of a pilot study. The use of defined standardised values for small, moderate and high effect sizes (d) based on the practical relevance shall simplify the determination of an effect size value and is recommended if the both options above-mentioned are not applicable (Cohen, 1988). The effect size (d) specifies the relationship between *H0* and *HA* in more detail. The more *H0* and *HA* vary from each other, the greater would be the effect size (d) which requires a smaller sample size (N) to achieve a sufficient power of the test ($1–\beta$). This in turn means that the lesser H_0 and H_A vary from each other, resulting also in a smaller effect size (d), the lower the power of the test ($1–\beta$) or, in other words, the probability to find this small effect size (d) unless the sample size (N) would be increased accordingly (Rasch et al. 2014; Döring and Bortz, 2016; Rey, 2017). It can be summed up that the type I error (α), the power of the test ($1–\beta$) or type II error (β), the effect size (d) as well as the sample size (N) are depending on one another (Rey, 2017).

4.1.2 Development of statistical hypotheses

Since the mathematical-statistical fundamentals were explained in the previous chapter, in the next step statistical hypotheses can be derived from the formulated research hypotheses in chapter 3.4.

The examination of *RH1*, which assumes that the role of a BB in manufacturing SMEs is synonymous with the role of a MBB, shall be evaluated based on the following statistical hypotheses listed in table 4.3.

Although MBBs are usually the leaders of the SS initiative as well as responsible for teaching, coaching and mentoring the lower-level SS belts (see chapter 2.2), in SMEs they can be replaced by BBs according to Kumar et al. (2011).

For this reason, five statistical hypotheses (*SH1.1* to *SH1.5*) are set to investigate if the BB roles and responsibilities “Coach”, “Mentor” and “Leader of strategic projects” as well as the required “Coaching and training” skills and “Leadership” skills in manufacturing SMEs have a significantly higher prioritization statistically than in large manufacturing enterprises.

In addition, *SH1.6* is established which states that the majority of SS experts have the opinion that MBBs are not needed in a SME environment since the BB can take on the role of the trainer on different SS expertise levels and instruct the rest of the employees.

Table 4.3. Statistical hypotheses assigned to research hypothesis 1. Source: Author.

Statistical hypotheses	**References**
SH1.1**:** The coaching role of the Black Belt in manufacturing SMEs has a higher prioritization than in large manufacturing enterprises	Ingle and Roe, 2001; Haikonen et al. 2004; Snee, 2004; Green et al. 2006; Nakhai and Neves, 2009; Antony et al. 2008; Nonthaleerak and Hendry, 2008; Kumar et al. 2011; Timans et al. 2012; Douglas et al. 2015; Antony and Karaminas, 2016
SH1.2**:** The mentoring role of the Black Belt in manufacturing SMEs has a higher prioritization than in large manufacturing enterprises	
SH1.3**:** The role of the Black Belt as leader of strategic projects in manufacturing SMEs has a higher prioritization than in large manufacturing enterprises	
SH1.4**:** The coaching and training skills of Black Belts in manufacturing SMEs have a higher prioritization than in large manufacturing enterprises	
SH1.5**:** The leadership skills of Black Belts in manufacturing SMEs have a higher prioritization than in large manufacturing enterprises	
SH1.6**:** The majority of Six Sigma experts are of the opinion that Master Black Belts are not needed in a SME environment since the Black Belt can take on the role of the trainer on different Six Sigma expertise levels and instruct the rest of the employees	

Concerning *RH2*, which assumes that in manufacturing SMEs a greater presence of GBs and a smaller presence of BBs shall be available than in large manufacturing enterprises, three statistical hypotheses are set (see table 4.4). Based on chapter 3.2, SMEs with 250 employees shall deploy one to two BBs and thus less BBs on a percentage basis than in large enterprises (around 2% of the total workforce), while the GB proportion in SMEs shall be higher than the proposed share of 5% of the total workforce in large enterprises. *SH2.1* and *SH2.2* refer to this data. Furthermore, *SH2.3* is formulated and states that the majority of SS experts would prefer a greater presence of GBs and a smaller presence of BBs in manufacturing SMEs.

Table 4.4. Statistical hypotheses assigned to research hypothesis 2. Source: Author.

<table>
<tr><th>Statistical hypotheses</th><th>References</th></tr>
<tr><td>SH2.1: The Black Belt proportion in manufacturing SMEs shall be smaller than in large manufacturing enterprises where it is proposed to be around 2% of the total workforce</td><td rowspan="3">Davis, 2003; Gnibus and Krull, 2003; Keller, 2003; Burton, 2004; Snee, 2004; Harry and Schroeder, 2005; Buch and Tolentino, 2006; Green et al. 2006; Antony, 2008; Miguel and Andrietta, 2009; Pulakanam and Voges, 2010; Aboelmaged, 2010; Kumar et al. 2011; Pyzdek and Keller, 2014; Jesus et al. 2016</td></tr>
<tr><td>SH2.2: The Green Belt proportion in manufacturing SMEs shall be greater than in large manufacturing enterprises where it is proposed to be around 5% of the total workforce</td></tr>
<tr><td>SH2.3: The majority of Six Sigma experts would prefer a greater presence of Green Belts and a smaller presence of Black Belts in manufacturing SMEs</td></tr>
</table>

With regard to *RH3*, which supposes – based on Setters (2010) view – that there is no difference between the YB and WB category, *SH3* is set (see table 4.5).

Table 4.5. Statistical hypothesis assigned to research hypothesis 3. Source: Author.

Statistical hypothesis	**References**
***SH3*:** The majority of Six Sigma experts consider a White Belt training to be a waste of time since the Yellow Belt training already represents a recognized preschool that provides a basic overview introduction of Six Sigma	Setter, 2010; Harry and Crawford, 2004 and 2005; Antony et al. 2008; Kumar et al. 2008 and 2011

RH4 states that the working time of the SS belts towards SS projects in manufacturing SMEs shall be lower than in large manufacturing enterprises. Compared to BBs in large enterprises, who work full-time or at least 80% towards SS, BBs in SMEs shall work on a part-time basis towards SS projects besides their other work duties. Also, GBs in SMEs shall only spend 20% of their working time towards SS which is less than the suggested GB working time of 30% to 50% towards SS in large enterprises. Based on this data, which was represented in chapter 3.2, *SH4.1* and *SH4.2* are formulated (see table 4.6).

Table 4.6. Statistical hypotheses assigned to research hypothesis 4. Source: Author.

Statistical hypotheses	References
***SH4.1*: The working time of Black Belts towards Six Sigma in manufacturing SMEs shall be lower than in large manufacturing enterprises where it is proposed to be at least 80%	Ingle and Roe, 2001; Linderman et al. 2003; Antony et al. 2005, 2007 and 2008; Bendell, 2006; Pandey, 2007; Feng and Manuel, 2008; Nonthaleerak and Hendry, 2008; Schroeder et al. 2008; Aboelmaged, 2010; Brun, 2011; Gutierrez et al. 2012; Timans et al. 2012; Pyzdek and Keller, 2014
***SH4.2*: The working time of Green Belts towards Six Sigma in manufacturing SMEs shall be lower than in large manufacturing enterprises where it is proposed to be at least 30%	

RH5 refers to the possible number of projects that can be executed by SS belts in manufacturing SMEs compared to large manufacturing enterprises. Since there are several expectations in the current literature regarding the number of BB projects that can be executed in large enterprises, an average value of approximately four projects as calculated in chapter 3.2 is determined for *SH5.1*. Moreover, according to Antony et al. (2007), GBs are able to complete up to three SS projects per year in large enterprises. However, the deployment of SS belts in SMEs cannot be realized in the same way as it is in large enterprises (detailed explanations of reasons for this are cited in chapter 2.5). Accordingly, *SH5.1* and *SH5.2* are established (see table 4.7).

Table 4.7. Statistical hypotheses assigned to research hypothesis 5. Source: Author.

Statistical hypotheses	References
***SH5.1*: The possible number of projects that can be executed per year by a Black Belt shall be lower in manufacturing SMEs than in large manufacturing enterprises where it is proposed to be four Six Sigma projects	Snee, 2004; Brue and Howes, 2006; Antony et al. 2005, 2007 and 2008; Leyendecker et al. 2011; Deshmukh and Chavan, 2012; Krueger et al. 2014; Timans, 2014; Pyzdek and Keller, 2014
***SH5.2*: The possible number of projects that can be executed per year by a Green Belt shall be lower in manufacturing SMEs than in large manufacturing enterprises where it is proposed to be three Six Sigma projects	

RH6 relates to cost savings per SS project achieved by the individual SS belt types in manufacturing SMEs compared to large manufacturing enterprises. Two statistical hypotheses are established for this case as well. They suppose that BBs and GBs save less costs in manufacturing SMEs than in large manufacturing enterprises (see table 4.8). This is due to the fact that the deployment of the SS belt professionals cannot be applied in a similar manner in SMEs as it can in large organizations (detailed explanations of reasons for this are cited in chapter 2.5). Since there are several cost saving estimations in the current literature regarding BB projects in large enterprises, an average value of approximately 100.000 € as calculated in chapter 3.2 is determined for *SH6.1*. Besides, *SH6.2* concerns Harry´s (1998) estimation of around 45.000 € cost savings per SS project by a GB in a large enterprise.

Table 4.8. Statistical hypotheses assigned to research hypothesis 6. Source: Author.

Statistical hypotheses	**References**
SH6.1**:** The possible cost savings by Black Belts shall be lower in manufacturing SMEs than in large manufacturing enterprises where they are estimated to be at around 100.000 €	Harry, 1998; Maguire, 1999; Pyzdek, 2000; Porter, 2002; Snee, 2004; Antony et al. 2005 and 2008; Kumar et al. 2011; Deshmukh and Chavan, 2012; Krueger et al. 2014; Timans, 2014
SH6.2**:** The possible cost savings by Green Belts shall be lower in manufacturing SMEs than in large manufacturing enterprises where they are estimated to be at around 45.000 €	

The reported lack in SS awareness and knowledge and the unexplored yet required LSS infrastructure among SMEs discussed in chapter 1.1 are typical reasons why the deployment of the SS belts in manufacturing SMEs according to the recommended guidelines from the literature mentioned in chapter 3.2 or the surveyed SS experts from the upcoming research activity is probably not feasible. For this reason, *RH7* was formulated in chapter 3.4 whose examination shall be supported by eight statistical hypotheses. The following recommendations from the current literature represented in chapter 3.2 provide the foundation for the established statistical hypotheses (see table 4.9):

- 0.4% to 0.8% BBs in relation to the total workforce in manufacturing SMEs
- 5% GBs in relation to the total workforce in large manufacturing enterprises
- 50% BB working time towards SS projects in manufacturing SMEs
- 20% GB working time towards SS projects in manufacturing SMEs

Table 4.9. Statistical hypotheses assigned to research hypothesis 7. Source: Author.

Statistical hypotheses	**References**
***SH7.1*: The Black Belt proportion in manufacturing SMEs is smaller than the proportion suggested by the current literature (0.4%)**	Antony et al. 2005 and 2008; Green et al. 2006; Nonthaleerak and Hendry, 2008; Schroeder et al. 2008; Miguel and Andrietta, 2009; Kumar et al. 2011; Deshmukh and Chavan, 2012; Prasanna and Vinodh, 2013; Timans, 2014; Pyzdek and Keller, 2014; Jesus et al. 2016
SH7.2: The Black Belt proportion in manufacturing SMEs is smaller than the proportion suggested by the Six Sigma experts of the upcoming research activity	
SH7.3**:** The Green Belt proportion in manufacturing SMEs is smaller than the proportion suggested by the current literature for large manufacturing enterprises (5%)	
SH7.4**:** The Green Belt proportion in manufacturing SMEs is smaller than the proportion suggested by the Six Sigma experts of the upcoming research activity	
SH7.5**:** The working time of Black Belts towards Six Sigma in manufacturing SMEs is lower than that suggested by the current literature (50%)	
SH7.6**:** The working time of Black Belts towards Six Sigma in manufacturing SMEs is lower than that suggested by the Six Sigma experts of the upcoming research activity	
SH7.7**:** The working time of Green Belts towards Six Sigma in manufacturing SMEs is lower than that suggested by the current literature (20%)	
SH7.8**:** The working time of Green Belts towards Six Sigma in manufacturing SMEs is lower than that suggested by the Six Sigma experts of the upcoming research activity	

In total, 24 statistical hypotheses are formulated for the evaluation of the research hypotheses. In the next chapter 4.1.3, appropriate statistical test approaches will be selected and presented.

4.1.3 Definition of statistical hypotheses tests

Two-sample proportion tests will be applied for *SH1* to *SH5* to examine if the proportions of two independent populations (*P1* and *P2*) have an effect (LeBlanc, 2004; Martin, 2007; Holmes et al. 2018). In this respect, twice two rankings will be compared with each other. This includes, on the one hand, the comparison of BB roles in SMEs against their roles in large enterprises, with their key roles mentoring, coaching and leading strategic projects at the centre of this comparison. On the other hand, their required key skills coaching, training and leadership are being compared in a SMEs environment against a larger enterprise setting. Two rankings concerning the BB roles and BB skills will be prepared on the basis of the survey during the upcoming research activity and are focused on manufacturing SMEs (*P1*), while the other two rankings concerning the BB roles and BB skills were created by the survey of Antony and Karaminas (2016) (see table 3.6) and are focused on large manufacturing enterprises (*P2*). The required parameter for these statistical hypotheses tests is the number of votes for the respective BB roles and BB skills in relation to the total number of respondents.

Table 4.10 presents formulas and measurement data of these statistical hypotheses for which the two-sample proportion test is used.

Table 4.10. Statistical hypotheses including formulas and measurement data for which the two-sample proportion test is used. Source: Author.

SH	Formula	Measurement data
1.1	$H_0: P_1=P_2$ $H_A: P_1>P_2$	P_1 = Number of votes for the BB coaching role in manufacturing SMEs in relation to the total number of respondents
		P_2 = Number of votes for the BB coaching role in large manufacturing enterprises in relation to the total number of respondents
1.2	$H_0: P_1=P_2$ $H_A: P_1>P_2$	P_1 = Number of votes for the BB mentoring role in manufacturing SMEs in relation to the total number of respondents
		P_2 = Number of votes for the BB mentoring role in large manufacturing enterprises in relation to the total number of respondents
1.3	$H_0: P_1=P_2$ $H_A: P_1>P_2$	P_1 = Number of votes for the BB role as leader of strategic projects in manufacturing SMEs in relation to the total number of respondents
		P_2 = Number of votes for the BB role as leader of strategic projects in large manufacturing enterprises in relation to the total number of respondents
1.4	$H_0: P_1=P_2$ $H_A: P_1>P_2$	P_1 = Number of votes for the BB coaching and mentoring skills in manufacturing SMEs in relation to the total number of respondents
		P_2 = Number of votes for the BB coaching and mentoring skills in large manufacturing enterprises in relation to the total number of respondents
1.5	$H_0: P_1=P_2$ $H_A: P_1>P_2$	P_1 = Number of votes for the BB leadership skills in manufacturing SMEs in relation to the total number of respondents
		P_2 = Number of votes for the BB leadership skills in large manufacturing enterprises in relation to the total number of respondents

SH1.6, *SH2.3* and *SH3* shall be verified by one-sample proportion tests that are used to assess whether a proportion of responses from a sample of data (P_1) is statistically significant higher or lower than a defined hypothesized value (P_0) (LeBlanc, 2004; Martin, 2007; Holmes et al. 2018). The proportions (P_1) of these statistical hypotheses are based on the agreed outcomes of the surveyed SS experts regarding the respective statements about the consideration of WBs, the lower BB and higher GB presence as well as the uselessness of MBBs in manufacturing

SMEs. Since it is believed that the majority of SS experts agree to the related statements, the hypothesized value (P_0) is set to 50%.

Table 4.11 presents formulas and measurement data of these statistical hypotheses for which the one-sample proportion test is used.

Table 4.11. Statistical hypotheses including formulas and measurement data for which the one-sample proportion test is used. Source: Author.

SH	Formula	Measurement data
1.6	H_0: $P_1=P_0$ H_A: $P_1>P_0$	P_1 = Number of agreed outcomes of the surveyed SS experts about the uselessness of MBBs in manufacturing SMEs in relation to the total number of respondents
		P_0 = 50%
2.3	H_0: $P_1=P_0$ H_A: $P_1>P_0$	P_1 = Number of agreed outcomes of the surveyed SS experts about the lower BB and higher GB presence in manufacturing SMEs in relation to the total number of respondents
		P_0 = 50%
3	H_0: $P_1=P_0$ H_A: $P_1>P_0$	P_1 = Number of agreed outcomes of the surveyed SS experts about the consideration of WBs in manufacturing SMEs in relation to the total number of respondents
		P_0 = 50%

The one-sample t-test will be used for the following statistical hypotheses: *SH2.1*, *SH2.2*, *SH4.1*, *SH4.2*, *SH5.1*, *SH5.2*, *SH6.1*, *SH6.2*, *SH7.1*, *SH7.3*, *SH7.5* and *SH7.7*. This kind of test verifies if a mean value of a sample of data (μ) is statistically significant higher or lower than a defined hypothesized value (μ_0) (LeBlanc, 2004; Martin, 2007; Bortz and Schuster, 2010; Rasch et al. 2014; Holmes et al. 2018). The hypothesized values (μ_0) are based on recommendations made by researchers from the current literature about the BB and GB proportion in relation to the total workforce, their invested working times towards SS, their number of projects they can execute and the related cost savings in large enterprises or SMEs (see chapter 3.2). The mean values (μ) shall be determined on the basis of responses from surveyed SS experts. In this regard, a distinction is made between “real” data and “ideal” data. The term “real” refers to data about the actual state of the SS belt deployment structure in manufacturing SMEs and the term “ideal” refers to data about the target state of the SS belt deployment structure in manufacturing SMEs.

Table 4.12 presents formulas and measurement data of these statistical hypotheses for which the one-sample t-test is used.

Table 4.12. Statistical hypotheses including formulas and measurement data for which the one-sample t-test is used. Source: Author.

SH	Formula	Measurement data
2.1	*H0: μ=μ0* *HA: μ<μ0*	*μ* = Ideal data regarding the BB proportion in manufacturing SMEs proposed by SS experts
		μ0 = 2% BB proportion in large enterprises
2.2	*H0: μ=μ0* *HA: μ>μ0*	*μ* = Ideal data regarding the GB proportion in manufacturing SMEs proposed by SS experts
		μ0 = 5% GB proportion in large enterprises
4.1	*H0: μ=μ0* *HA: μ<μ0*	*μ* = Ideal data regarding the BB working time in manufacturing SMEs proposed by SS experts
		μ0 = 80% BB working time in large enterprises
4.2	*H0: μ=μ0* *HA: μ<μ0*	*μ* = Ideal data regarding the GB working time in manufacturing SMEs proposed by SS experts
		μ0 = 30% GB working time in large enterprises
5.1	*H0: μ=μ0* *HA: μ<μ0*	*μ* = Ideal data regarding executed BB projects in manufacturing SMEs proposed by SS experts
		μ0 = Four executed BB projects per year in large enterprises
5.2	*H0: μ=μ0* *HA: μ<μ0*	*μ* = Ideal data regarding executed GB projects in manufacturing SMEs proposed by SS experts
		μ0 = Three executed GB projects per year in large enterprises
6.1	*H0: μ=μ0* *HA: μ<μ0*	*μ* = Ideal data regarding cost savings by a BB per project in manufacturing SMEs proposed by SS experts
		μ0 = 100.000 € cost savings by a BB per project in large enterprises
6.2	*H0: μ=μ0* *HA: μ<μ0*	*μ* = Ideal data regarding cost savings by a GB per project in manufacturing SMEs proposed by SS experts
		μ0 = 45.000 € cost savings by a GB per project in large enterprises
7.1	*H0: μ=μ0* *HA: μ<μ0*	*μ* = Real data about the BB proportion available in manufacturing SMEs
		μ0 = 0.4% BB proportion in SMEs
7.3	*H0: μ=μ0* *HA: μ<μ0*	*μ* = Real data about the GB proportion available in manufacturing SMEs
		μ0 = 5% GB proportion in large enterprises
7.5	*H0: μ=μ0* *HA: μ<μ0*	*μ* = Real data about the BB working time applied in manufacturing SMEs
		μ0 = 50% BB working time in SMEs
7.7	*H0: μ=μ0* *HA: μ<μ0*	*μ* = Real data about the GB working time applied in manufacturing SMEs
		μ0 = 20% GB working time in SMEs

The Welch´s two-sample t-test is used to test *SH7.2*, *SH7.4*, *SH7.6* and *SH7.8*. Unlike the two-sample independent t-test that is used to verify if there is an effect between two mean values from independent populations (μa and μb) with equal variances, the Welch´s two-sample t-test is used when the variances are unequal (Wilcox, 1996; Bonnet and Price, 2002; Bortz, 2006; Rasch et al. 2014). While the mean values (μa) are based on the real BB and GB proportions in relation to the total workforce and their invested working times towards SS in manufacturing SMEs, the other mean values (μb) are based on the the ideal BB and GB proportions in relation to the total workforce and their invested working times towards SS in manufacturing SMEs.

Table 4.13 presents formulas and measurement data of these statistical hypotheses for which the Welch´s two-sample t-test is used.

Table 4.13. Statistical hypotheses including formulas and measurement data for which the Welch´s two-sample t-test is used. Source: Author.

SH	Formula	Measurement data
7.2	$H0: \mu a = \mu b$ $HA: \mu a < \mu b$	μa = Real data about the BB proportion available in manufacturing SMEs
		μb = Ideal data regarding the BB proportion in manufacturing SMEs proposed by SS experts
7.4	$H0: \mu a = \mu b$ $HA: \mu a < \mu b$	μa = Real data about the GB proportion available in manufacturing SMEs
		μb = Ideal data regarding the GB proportion in manufacturing SMEs proposed by SS experts
7.6	$H0: \mu a = \mu b$ $HA: \mu a < \mu b$	μa = Real data about the BB working time applied in manufacturing SMEs
		μb = Ideal data regarding the BB working time in manufacturing SMEs proposed by SS experts
7.8	$H0: \mu a = \mu b$ $HA: \mu a < \mu b$	μa = Real data about the GB working time applied in manufacturing SMEs
		μb = Ideal data regarding the GB working time in manufacturing SMEs proposed by SS experts

The statistical analysis will be done with the free statistical computing software *R* which is widely used for testing hypotheses and data analysis. It is the most common standard programming tool for statistical issues, both in economy and science (Tippmann, 2015; Weiss, 2015). However, prior to testing the statistical hypotheses, the required sample sizes (*N*) have to be defined for it. For this, the power analysis approach provides an effective method which will be explained in the next chapter 4.1.4.

4.1.4 Power analysis approach

There are five types of power analysis that can be carried out either before data collection, after data collection or after the completion of the statistical hypothesis test. For this, the type I error (α) (significance level), the type II error (β) or power of the test ($1\text{-}\beta$), the effect size (d) as well as the sample size (N) play an essential role because they are depending on one another and, if three parameters are known, the fourth parameter can be calculated (Rey, 2017). Beside this, the nature of the used statistical hypothesis test has to be known.

One type is the *priori power analysis* which shall be executed before data collection during the design stage of the study and is considered the generally preferred power analysis type (Salkind, 2010). Its aim is the calculation of the necessary sample size (N) to detect a relevant effect with a specific size (d) in accordance with an appropriate significance level (α) and power of the test ($1\text{-}\beta$) (Bredenkamp, 1969; Cohen, 1988). Apart from that, the *sensitivity power analysis* uses the final obtained sample size (N) to determine what possible effect size (d) a study is able to detect in accordance with a defined significance level (α) and power of the test ($1\text{-}\beta$) (Cohen, 1988; Erdfelder et al. 2005). By contrast, the *compromise power analysis* determines the type I error (α) and type II error (β) as function of the desired error probability ratio (β/α), sample size (N) and relevant effect size (d) (Erdfelder, 1984; Cohen, 1988). The *post hoc power analysis* makes sense after the statistical hypothesis test is completed and when the result is not statistically significant. It calculates the power of the test ($1\text{-}\beta$) based on the obtained sample size (N), the assigned significance level (α) and relevant effect size (d). Its aim is to find out if there is really no effect available. In fact, a decision that no effect exists and to reject H_A cannot be made when the power of the test ($1\text{-}\beta$) is too low (<80%) and the type II error (β) correspondingly too large (>20%). In addition, it can also be examined by a *post hoc power analysis* how much larger the sample size (N) had to be to achieve a statistically significant result with an effect of a specific size (d) (Faul et al. 2007; Rasch et al. 2014; Aberson, 2011). The *criterion power analysis* is an alternative to the *post hoc power analysis* and reasonable whenever the control of the type I error (α) is less important than the control of the type II error (β). In this case, the significance level (α) will be calculated as a function of the power of the test ($1\text{-}\beta$), the effect size (d), and the obtained sample size (N) (Cohen, 1988; Faul et al. 2007).

A specific power analysis approach that is adapted based on the explained theoretical fundamentals and similar approaches of Rasch (2015) as well as Buchwald and Thielgen (2008) will be used for the forthcoming statistical hypotheses tests. At first, a *priori power analysis* shall determine the necessary sample sizes (N) to carry out representative statistical hypotheses tests. If the sample sizes (N) are not achieved by the survey, a *sensitivity power analysis* will be conducted as next step to calculate the possible detectable effect sizes (d) in the individual statistical hypotheses tests based on the final obtained sample sizes

(N) from the survey. After the statistical hypotheses tests are completed, a *post hoc power analysis* will be carried out to calculate the power of the tests (*1-β*) for these cases where the sample sizes (N) were not achieved by the survey and the results are not statistically significant. Throughout the whole procedure a significance level (α) of 5% and power of the test (*1-β*) of 80% are kept as proposed by Cohen (1988). The *compromise power analysis* and *criterion power analysis* shall not be applied in this approach.

For the computation of the necessary parameters, the G*Power software program from the University of Düsseldorf will be applied which is commonly used in social, behavioural, and biomedical sciences and available free of charge via the Internet for both Windows and Mac OS X platforms (Faul et al. 2007). It provides power analysis options for a variety of statistical hypotheses tests for which different kinds of effect size metrics are relevant.

Figure 4.1 illustrates the procedure of the applied power analysis approach for this study.

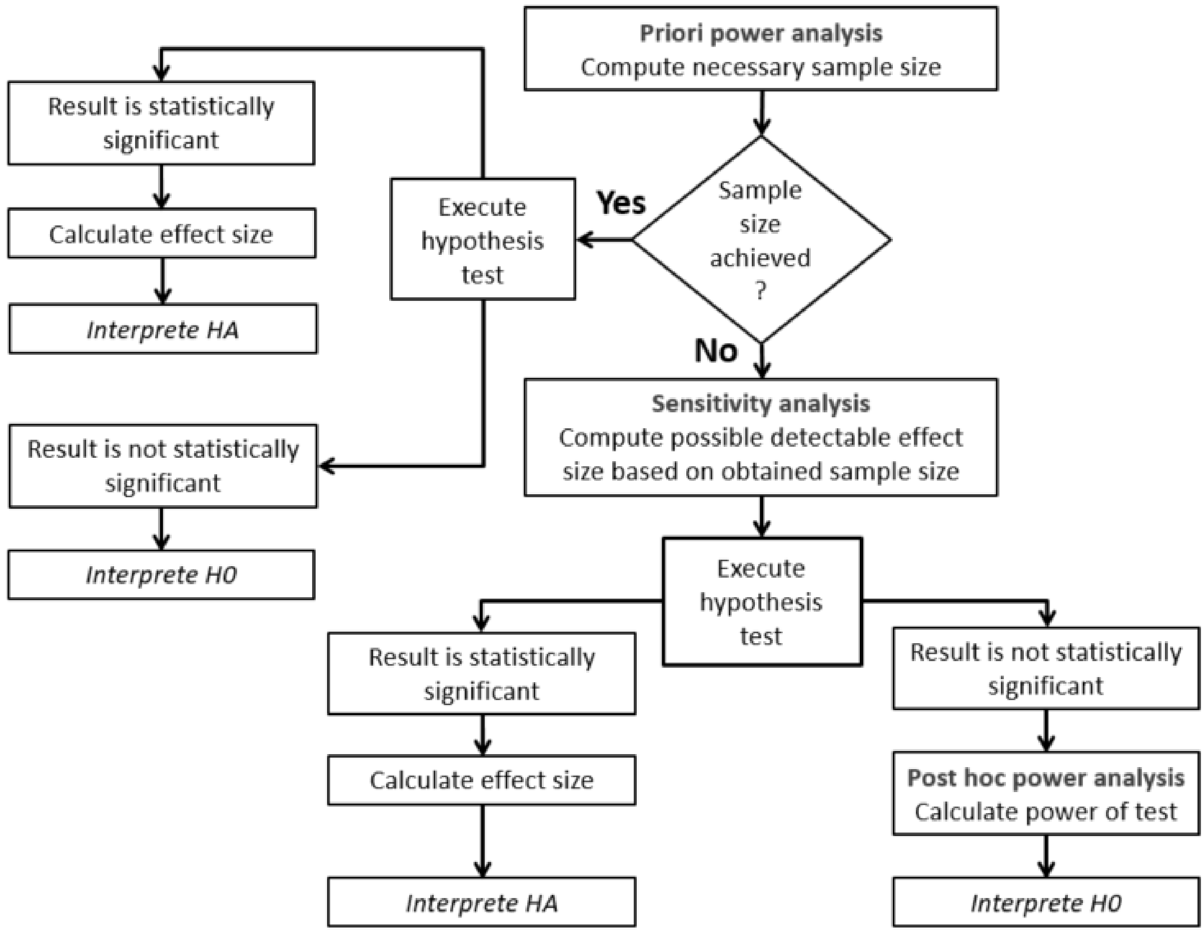

Figure 4.1. Power analysis approach. Source: Based on Rasch, 2015 and Buchwald and Thielgen, 2008.

4.1.5 Priori power analysis

Since the test approaches used to verify the various statistical hypotheses were defined in chapter 4.1.3, the relevant effect size metrics now have to be selected and their values estimated as they are required to compute the necessary sample sizes (*N*) for the statistical hypotheses tests in accordance with a significance level (α) of 5% and power of the test (*1-β*) of 80% by using the G*Power software tool.

As stated in chapter 4.1.1, reference values of previous studies should be considered as effect size values or a pilot study for their determinations has to be conducted. Due to the fact that no reference values could be found in the current literature, personal opinions from current researchers, as cited in chapter 3.2, will be considered to determine one of the proposed small, moderate or high standard effect size values by Cohen (1988) for the individual statistical hypotheses tests. Since these researchers published several SS papers in well-known peer-reviewed journals and thus proved their expertise in this research field, it is decided to favour this approach instead of relying on data of a small pilot survey consisting of perhaps less experienced SS experts. Alternatively, available data from empirical studies, as cited in chapter 3.3, can also be used to calculate the effect size values.

However, although the recommendations or empirical data are from well-known researchers and therefore of a high weighting, this research field is still a relatively unexplored area. To be on the safe side, determining a high effect size value for the calculation of the required sample sizes (*N*) will be avoided in order to carrying out representative statistical hypotheses tests. The primary aim is to conduct more ambitious tests in the upcoming research study.

In case of the two-sample proportion test, which is used for *SH1.1* to *SH1.5*, Cohen (1988) proposed the use of the effect size metric *h* which is calculated as follows:

$$h = \varphi 1 - \varphi 2$$

where

$$\varphi i = 2\ arcsine\ \sqrt{Pi}$$

In case of the proportions (P_2), the results of the survey from Antony and Karaminas (2016) concerning the importance of the coaching, mentoring and leadership role as well as of the coaching/training and leadership skills of BBs in large manufacturing enterprises will be considered. In total, 105 SS practitioners responded to their survey. 50 SS experts found the role “Coach”, 45 SS experts found the role “Mentor”, 42 SS experts found the role “Leader of strategic projects”, 56 SS experts found “Coaching/training” skills and 42 SS experts found “Leadership” skills of high importance. This results to proportions for (P_2) of 0.47, 0.43, 0.40, 0.53 and 0.40 respectively.

The proportions (P_1) shall correspond to the same roles and skills as mentioned previously but with focus on manufacturing SMEs. They have to be prepared on the basis of the results of the surveyed SS experts during the upcoming research activity. To compute the required sample sizes (*N*) for testing *SH1.1* to *SH1.5*, the expected proportions (P_1) have to be calculated for which the estimation of a relevant effect size value is necessary. Cohen (1988) suggested for two-sample proportion tests the effect size *h* values of 0.2, 0.5 and 0.8 as small, medium and large effect size respectively. The five statistical hypotheses derived from *RH1* are based on the opinion of Kumar et al. (2011) that a MBB is not needed in a SME environment and that a BB can take on his job. The results in the studies of Green et al. (2006), Antony et al. (2008), Nonthaleerak and Hendry (2008), Timans et al. (2012) and Douglas et al. (2015) strengthen this idea and therefore, it is assumed that other SS experts have a similar view. For this reason, a relevantly moderate effect size of at least h=0.5 should be detected in these statistical hypotheses tests. Consequently, this results to proportions for (P_1) of 0.71, 0.68, 0.65, 0.76 and 0.65 as well as to required sample sizes (*N*) of around 40 test persons (see table 4.14).

Table 4.14. Results of the priori power analysis concerning the statistical hypotheses 1.1 to 1.5. Source: Author.

Statistical test	**Statistical hypotheses**	**Effect size *h***	***P1***	**Computed sample size *N* for *P1***	***P2***	**Sample size *N* for *P2***
Two-sample proportion test	*SH1.1*	0.5	0.71	42	0.47	105 (Study of Antony and Karaminas, 2016)
	SH1.2		0.68	37	0.43	
	SH1.3		0.65	37	0.40	
	SH1.4		0.76	41	0.53	
	SH1.5		0.65	37	0.40	

In case of *SH1.6*, *SH2.3* and *SH3* the one-sample proportion test is applied. While the effect size metric *h* as proposed by Cohen (1988) is used for the two-sample proportion test, Cohen (1969) suggested to use the effect size metric *g* for the one-sample proportion test where the constant proportion (P_0) is 0.5 (50%). It is defined as the deviation of an event's probability (P_1) in a given population from the hypothesized probability (P_0) (Buchner et al. 2020), that is

$$g = P1 - P0.$$

Cohen (1969) proposed the following effect size conventions: small g=0.05, medium g=0.15, large g=0.25.

SH1.6 was also derived from *RH1* for which a moderate effect size *g* of 0.15 will be selected. *SH2.3,* which is based on the notion that a greater presence of GBs and minor presence of BBs in manufacturing SMEs is needed, refers to the research contributions of Gnibus and Krull (2003), Davis (2003), Burton (2004), Green et al. (2006), Pyzdek and Harrison cited in Antony (2008). Since the recommendations originate from numerous experienced researchers, it is also supposed that other SS experts have a similar view. Therefore, the detection of an at least relevantly moderate effect size *g* of 0.15 also seems to be realistic in this case and this results in a required sample size (*N*) of 69 test persons for these statistical hypotheses tests.

SH3 in contrast, which assumes that the majority of SS professionals consider WB training as waste of time since the YB training already provides a basic overview introduction of SS, relies on the view of Setter from the year 2010, who is the CEO of the Aveta Business Institute Six Sigma Online. However, this view stands in stark contrast with the notion of Harry and Crawford, researchers who belong to the pioneers of the SS method and introduced the idea of the WB in the years 2004 and 2005. They believed that this SS belt category would bring great benefits for SMEs. In addition, the WB approach of Harry and Crawford (2004 and 2005) was also cited in research papers of Antony et al. (2008) and Kumar et al. (2008 and 2011) who supported the benefits of WBs for SMEs. Due to the different opinions regarding this matter, a significantly more comprehensive test has to be conducted in this case as the availability of a small effect size (g=0.05) is likely to be relatively high. Finally, a sample size (*N*) of 620 test persons is computed for its detection.

Table 4.15 presents the estimated effect size values and computed sample sizes (*N*) required for testing *SH1.6*, *SH2.1* and *SH3*.

Table 4.15. Results of the priori power analysis concerning the statistical hypotheses 1.6, 2.1 and 3. Source: Author.

Statistical test	**Statistical hypotheses**	**Effect size *g***	**Computed sample size *N***
One-sample proportion test	*SH1.6/SH2.3*	0.15	69
	SH3	0.05	620

In case of t-tests, which shall be applied for all further statistical hypotheses, the effect size metric *d* is used. Its conventional values are similar as Cohen's *h*: small d=0.2, medium d=0.5 and large d=0.8. It is defined as the difference between two mean values divided by the standard deviation of these data (Cohen, 1988).

$$d = \frac{\mu 1 - \mu 2}{\sigma}$$

SH2.1 focuses on the target BB proportion in manufacturing SMEs which shall be lower than the proposed BB proportion of 2% in large manufacturing enterprises as cited in chapter 3.2. Although BBs shall deploy one to two BBs in a company with 250 employees according to Kumar et al. (2011), which makes up around 0.4% to 0.8% of the total workforce, two case study SMEs in Timans et al. (2012) article even include 2% BBs. One reason for this – as Antony et al. (2018) and Alexander et al. (2019) already highlighted – might be that the required number of BBs in SMEs is not researched yet and therefore not clearly defined (see chapter 1.1). Nonetheless, using these percentages result in a high effect size of *d*=0.85 for *SH2.1*[7] for which only a sample size (*N*) of eleven test persons would be needed for its detection.

The previously mentioned views from Gnibus and Krull (2003), Davis (2003), Burton (2004), Green et al. (2006), Pyzdek and Harrison cited in Antony (2008) regarding a greater GB presence indicate that for *SH2.2*, which focuses on a higher GB proportion in manufacturing SMEs as the proposed 5% in large manufacturing enterprises cited in chapter 3.2, a relevantly moderate effect size of *d*=0.5 should realistically be detected for which a required sample size (*N*) of 27 test persons is computed.

SH4.1 and *SH4.2* focus on the target BB and GB working time towards SS in manufacturing SMEs which shall be lower than the proposed BB working time of at least 80% and the proposed GB working time of at least 30% in large manufacturing enterprises as cited in chapter 3.2. In two research papers of Nonthaleerak and Hendry (2008) and Schroeder et al. (2008), it was suggested that BBs in SMEs shall work on a part-time basis besides their regular work duties. This is also partly followed in the companies of the case studies conducted by Brun (2011) (BB working time = 30%) and Timans et al. (2012) (BB working time = 60%). Considering this data results in a large effect size of *d*=0.8 for *SH4.1*[8] and for its detection a sample size (*N*) of twelve test persons is computed. In two another research papers of Antony et al. (2005 and 2008), a GB working time of 20% in SMEs was recommended but there are no empirical or case studies available, where this guideline was followed. Therefore, a lower effect size of *d*=0.5 is estimated in that case and for its detection a sample size (*N*) of 27 test persons is computed.

SH5.1 to *SH6.2* are based on the number of executed SS projects and cost savings by BBs and GBs which shall be lower in SMEs than in large enterprises. Researchers hardly made any estimations about this regarding manufacturing SMEs. However, due to the fact that the SS belts deployment structure cannot be realized in SMEs in the same way as it is in large enterprises (detailed explanations of reasons for this are cited in chapter 2.5), an at least relevantly

[7] Calculation of effect size *d* for *SH2.1*:

$\mu 1$ = 0.4 * 0.8 * 2 * 2 = 1.3; $\sigma 1$ = 0.82; $\mu 2$ = 2

d = (2 -1.3)/0.82 = Large effect size of *d*=0.85

[8] Calculation of effect size *d* for *SH4.1*:

$\mu 1$ = 0.5+0.5+0.3+0.6 = 0.475; $\sigma 1$ = 0.126; $\mu 2$ = 0.8

d = (0.8 -0.475)/0.126 = 2.57 = Large effect size of *d*=0.8

moderate effect size of d=0.5 shall be detected in these statistical hypotheses which requires a sample size (N) of 27 test persons.

SH7.1 to *SH7.8* were derived from *RH7* which states that the deployment of SS belts in manufacturing SMEs is not followed as required. As outlined in chapter 1.1, LSS and SS are only recently used increasingly in small manufacturing enterprises. For this reason, the needed number of SS belts including their invested working time towards SS is probably not known yet in most SMEs. Moreover, due to the lack in SS awareness and knowledge (as mentioned in chapter 1.1) and the lower educational level of the employees, limited talent pool as well as human and financial constraints (as mentioned in chapter 2.5), the SME management would not be able to implement the SS belts deployment structure as effectively as it should be. Therefore, the detection of an at least relevantly moderate effect size of d=0.5 can be considered as realistic for these statistical hypotheses. Since the Welch's two-sample test will be applied to test *SH7.2*, *SH7.4*, *SH7.6* and *SH7.8*, two sample size groups (N) are computed, each with 51 test persons. For *SH7.1*, *SH7.3*, *SH7.5* and *SH7.7*, the one-sample t-test will be applied for which a sample size (N) of 27 test persons is computed.

Table 4.16 summarizes the relevant effect size values and computed sample sizes (N) for all t-tests.

Table 4.16. Results of the priori power analysis concerning the statistical hypotheses 2.1, 2.2 and 4.1 to 7.8. Source: Author.

Statistical hypotheses	**Statistical test**	**Effect size *d***	**Computed sample size *N***
SH2.1	One-sample t-test	d=0.85	11
SH2.2	One-sample t-test	d=0.5	27
SH4.1	One-sample t-test	d=0.8	12
SH4.2	One-sample t-test	d=0.5	27
SH5.1	One-sample t-test	d=0.5	27
SH5.2	One-sample t-test	d=0.5	27
SH6.1	One-sample t-test	d=0.5	27
SH6.2	One-sample t-test	d=0.5	27
SH7.1	One-sample t-test	d=0.5	27
SH7.2	Welch's two-sample t-test	d=0.5	2 x 51
SH7.3	One-sample t-test	d=0.5	27
SH7.4	Welch's two-sample t-test	d=0.5	2 x 51
SH7.5	One-sample t-test	d=0.5	27
SH7.6	Welch's two-sample t-test	d=0.5	2 x 51
SH7.7	One-sample t-test	d=0.5	27
SH7.8	Welch's two-sample t-test	d=0.5	2 x 51

4.1.6 Survey design

Finally, the last subchapter of chapter 4.1 describes how the data for the statistical hypotheses tests will be collected. As already stated in chapter 1.3, the dissertation is designed as quantitative-based research. Therefore, primary data will be used that is directly collected over a sustained period of time and involves understanding of the complexity, details as well as context of the research subject (Hox and Boeije, 2005). As research instrument a survey questionnaire is selected which is the common method in a positivism paradigm (Zikmund et al. 2010; Babbie, 2011).

The survey design incorporates eight steps which are shown in figure 4.2.

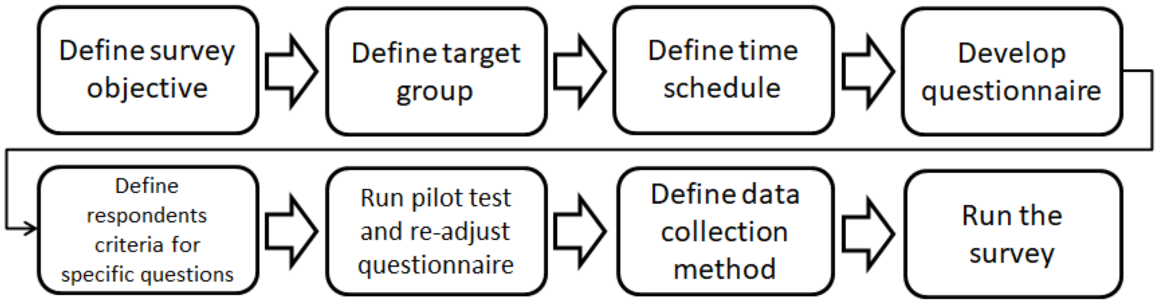

Figure 4.2. Survey design process. Source: Based on OECD, 2012.

There are various reasons for the selection of a survey questionnaire. According to Glasow (2005) or Nguyen (2010) surveys provide expeditious and reliable mean values of gathered data about the population while Visser et al. (2000) stated that surveys are suitable to identify and evaluate relationships or differences between variables. Kumar et al. (2009) argued that a survey-based approach is commonly and widely used to identify and understand continuous improvement initiatives in SMEs. For this reason, a survey questionnaire seems to be the appropriate method to collect data for testing the statistical hypotheses of the present study.

Finding out what key informants in organisations believe about the research subject is crucial, as they have access to organizational knowledge, great understanding and practical experience in the actual industrial environment on a day-to-day basis (Huber and Power, 1985; Gold et al. 2001; Wilkens et al. 2004; Habidin and Yusof, 2013). Therefore, the target group is comprised of employees working in manufacturing SMEs. These SMEs are mainly located in Germany and the selected informant profiles should be MBBs, BBs, GBs, YBs, CEOs, Directors, General Managers, Middle Managers, Quality and Production Professionals as this group is best suited to provide information with regard to the SS belt system in manufacturing SMEs. Since LSS and SS have only recently been used in manufacturing SMEs (see chapter 1.1), the survey is not planned for SMEs of a specific industrial sector but is conducted across all possible sectors as, for instance, automotive, electronic, chemical, paper, food, plastic, metal, textiles and machine industry etc. Due to the fact that the survey participants shall mainly be SS experts of German SMEs, the definition of the IfM Bonn, which classify SMEs as companies with less than 500 employees, is established as limit value for the selection of the SMEs participating in the survey.

The planned timeline for data gathering is set for about eight months. The questionnaire distribution started in January 2019 and lasted until August 2019.

As conducted by Kumar et al. (2009) and proposed by Jenn (2006), the survey questionnaire is constructed by drawing upon the reviewed literature and the previously presented discussions (please refer to chapter 3). It is prepared in English and includes close-ended questions, open-ended questions as well as a Likert scale. While open-ended questions focus on the respondent's free opinions, close-ended questions provide the respondents a list of items with one or more answer options (Jenn, 2006; Houtkoop-Steenstra, 2000). In contrast, a Likert scale consists of five to seven items and is known as bipolar method that accurately reflects the respondent's opinion by measuring either positive or negative reactions to a specific statement (Jenn, 2006; Allen and Seaman, 2007).

A pilot test before the conduct of the survey was carried out as suggested by Jenn (2006). Researchers with expertise in SS of the department of Industrial Engineering and Information Systems from the Tomas Bata University reviewed the first draft of the survey questionnaire based on weaknesses in terms of content, grammar and format. Subsequently, the survey questionnaire was readjusted according their remarks. Finally, 39 questions were developed. In appendix A, the whole and detailed questionnaire is presented.

The questionnaire comprises three parts. It starts with questions about the participating SS expert's job position and SS belt certification, their work experience in SS as well as in SMEs, the location of their SME as well as its size, age, manufacturing type and industrial sector. The second part of the questionnaire focuses on the current state of the SS belt system in their respective manufacturing SMEs (as-is state). It contains questions regarding their SS implementation status, their starting point, their available SS belts, their SS belt percentages in relation to the total workforce and their working time towards SS, their number of completed SS projects as well as related cost savings etc.

Table 4.17 presents an extract of the related survey questions (*SQ*) of the second part of the questionnaire needed for testing *SH7.1*, *SH7.3*, *SH7.5* and *SH7.7*.

Table 4.17. Relevant survey questions for the statistical hypotheses 7.1, 7.3, 7.5 and 7.7. Source: Author.

Statistical hypotheses	**Survey questions**
***SH7.1*:** The Black Belt proportion in manufacturing SMEs is smaller than the proportion suggested by the current literature (0.4%)	**SQ2.10*:*** How many Black Belts are available in your SME? (*Answer in %*)
***SH7.3*:** The Green Belt proportion in manufacturing SMEs is smaller than the proportion suggested by the current literature for large manufacturing enterprises (5%)	**SQ2.11:** How many Green Belts are available in your SME? (*Answer in %*)
***SH7.5*:** The working time of Black Belts towards Six Sigma in manufacturing SMEs is lower than that suggested by the current literature (50%)	**SQ2.12:** How much working time do Black Belts spend for Six Sigma in your SME? (*Answer in %*)
***SH7.7*:** The working time of Green Belts towards Six Sigma in manufacturing SMEs is lower than that suggested by the current literature (20%)	**SQ2.13**: How much working time do Green Belts spend for Six Sigma in your SME? (*Answer in %)*

The third part of the questionnaire contains questions on how the SS belt system in manufacturing SMEs shall be structured (target state). These are questions about the target percentages of BBs and GBs in relation to the total workforce, their invested working time towards SS, the possible number of projects they can execute and the related cost savings as well as their roles, responsibilities and required skills. Since this part is focusing on the target state of the SS belt system in manufacturing SMEs, these questions require a higher level of attention. For this reason, only answers of specific participants that fulfil one of the three mentioned criteria in table 4.18 will be accepted.

Table 4.18. Criteria for participants that are questioned on the target state of the Six Sigma belt deployment structure in manufacturing SMEs. Source: Author.

Criteria 1
• Participant must be Six Sigma Black Belt
Criteria 2
• Participant must be Six Sigma Green Belt with at least two years of work experience in Six Sigma or at least two years of work experience in manufacturing SMEs
Criteria 3
• **Option 1:** Participant must be Six Sigma Yellow Belt or Six Sigma White Belt or Six Sigma Champion with at least two years of work experience in Six Sigma and at least two years of work experience in manufacturing SMEs • **Option 2:** Participant must be Six Sigma Yellow Belt or Six Sigma White Belt or Six Sigma Champion with at least five years of work experience in Six Sigma • **Option 3:** Participant must be Six Sigma Yellow Belt or Six Sigma White Belt or Six Sigma Champion with at least five years of work experience in manufacturing SMEs

Table 4.19 presents an extract of the related survey questions of the third part of the questionnaire needed for the respective statistical hypotheses tests.

Table 4.19. Relevant survey questions for the statistical hypotheses 1.1 to 6.2 and 7.2, 7.4, 7.6, and 7.8. Source: Author.

Statistical hypotheses	**Survey questions**
SH1.1**:** The coaching role of the Black Belt in manufacturing SMEs has a higher prioritization than in large manufacturing enterprises	**SQ3.1**: From your viewpoint, what roles and responsibilities should Black Belts in manufacturing SMEs have? Available options: *Change agent, Six Sigma expert, coach, critical problem solver, analyst of root causes, mentor, leader of strategic projects, demonstrating bottom-line results into hard cash savings, involved in improvement projects, project manager/leader.*
SH1.2**:** The mentoring role of the Black Belt in manufacturing SMEs has a higher prioritization than in large manufacturing enterprises	
SH1.3**:** The role of the Black Belt as leader of strategic projects in manufacturing SMEs has a higher prioritization than in large manufacturing enterprises	

***SH1.4*: The coaching and training skills of Black Belts in manufacturing SMEs have a higher prioritization than in large manufacturing enterprises	**SQ3.3**: From your viewpoint, what skills should Black Belts in manufacturing SMEs have? Available options: *Analytical skills, expertise in Six Sigma (e.g. DMAIC), data/fact driven, coaching/training skills, problem-solving skills, leadership skills, presentation skills, customer advocacy, project management skills, results-oriented leadership skills, technical skills, collaboration skills, organisational skills, process-oriented skills, social/interpersonal skills.*
SH1.5: The leadership skills of Black Belts in manufacturing SMEs have a higher prioritization than in large manufacturing enterprises	
SH1.6: The majority of Six Sigma experts are of the opinion that Master Black Belts are not needed in a SME environment since the Black Belt can take on the role of the trainer on different Six Sigma expertise levels and instruct the rest of the employees	**SQ3.5:** Master Black Belts are not needed in a SME environment since the Black Belt can take on the role of the trainer on different Six Sigma expertise levels and instruct the rest of the employees. Do you agree with this statement? Likert scale with five points *(1 = strongly disagree/ 5 = strongly agree*)
SH2.1: The Black Belt proportion in manufacturing SMEs shall be smaller than in large manufacturing enterprises where it is proposed to be around 2% of the total workforce	**SQ3.6:** From your viewpoint, how many Black Belts per 500 employees shall be available in a SME of your manufacturing sector and with your production process complexity on average? (*Answer in %*)
SH2.2: The Green Belt proportion in manufacturing SMEs shall be greater than in large manufacturing enterprises where it is proposed to be around 5% of the total workforce	**SQ3.7:** From your viewpoint, how many Green Belts per 100 employees shall be available in a SME of your manufacturing sector and with your production process complexity on average? (*Answer in %*)
SH2.3: The majority of Six Sigma experts would prefer a greater presence of Green Belts and a smaller presence of Black Belts in manufacturing SMEs	**SQ3.8:** Using a Green Belt approach instead of a Black Belt approach would allow SMEs to implement Six Sigma at a less costly, more manageable pace. Do you agree with this approach? Likert scale with five points *(1 = strongly disagree/5 = strongly agree*)

SH3**:** The majority of Six Sigma experts consider a White Belt training to be a waste of time since the Yellow Belt training already represents a recognized preschool that provides a basic overview introduction of Six Sigma	**SQ3.11:** The current White Belt training offered is a waste of time since the Yellow Belt training already represents a recognized preschool and provides a basic overview introduction of Six Sigma. Do you agree with the statement? Likert scale with five points *(1 = strongly disagree/ 5 = strongly agree*)
SH4.1**:** The working time of Black Belts towards Six Sigma in manufacturing SMEs shall be lower than in large manufacturing enterprises where it is proposed to be at least 80%	**SQ3.12:** From your viewpoint, how much working time shall Black Belts spend on Six Sigma in a SME of your manufacturing sector and with your production process complexity on average? (*Answer in %*)
SH4.2**:** The working time of Green Belts towards Six Sigma in manufacturing SMEs shall be lower than in large manufacturing enterprises where it is proposed to be at least 30%	**SQ3.13:** From your viewpoint, how much working time shall Green Belts spend on Six Sigma in a SME of your manufacturing sector and with your production process complexity on average? (*Answer in %*)
SH5.1**:** The possible number of projects that can be executed per year by a Black Belt shall be lower in manufacturing SMEs than in large manufacturing enterprises where it is proposed to be four Six Sigma projects	**SQ3.14:** From your viewpoint, how many Black Belt projects can be executed in a manufacturing SME on average per year? Available options: *1 project, 2 projects, 3 to 5 projects, 6 to 8 projects, more than 8 projects.*
SH5.2**:** The possible number of projects that can be executed per year by a Green Belt shall be lower in manufacturing SMEs than in large manufacturing enterprises where it is proposed to be three Six Sigma projects	**SQ3.15:** From your viewpoint, how many Green Belt projects can be executed in a manufacturing SME on average per year? Available options: *1 project, 2 projects, 3 to 5 projects, 6 to 8 projects, more than 8 projects.*

SH6.1**:** The possible cost savings by Black Belts shall be lower in manufacturing SMEs than in large manufacturing enterprises where they are estimated to be at around 100.000 €	**SQ3.16:** From your viewpoint, how many costs on average can a Black Belt save per project in a manufacturing SME? Available options: *Less than 10000 €, between 10000 € and 20000 €, between 20000 € and 30000 €, between 30000 € and 40000 €, between 40000 € and 50000 €, more than 50000 €.*
SH6.2**:** The possible cost savings by Green Belts shall be lower in manufacturing SMEs than in large manufacturing enterprises where they are estimated to be at around 45.000 €	**SQ3.17:** From your viewpoint, how many costs on average can a Green Belt save per project in a manufacturing SME? Available options: *Less than 10000 €, between 10000 € and 20000 €, between 20000 € and 30000 €, between 30000 € and 40000 €, between 40000 € and 50000 €, more than 50000 €.*
SH7.2: The Black Belt proportion in manufacturing SMEs is smaller than the proportion suggested by the Six Sigma experts of the upcoming research activity	**SQ2.10:** How many Black Belts are available in your SME? (*Answer in %*)
	SQ3.6: From your viewpoint, how many Black Belts per 500 employees shall be available in a SME of your manufacturing sector and with your production process complexity on average? (*Answer in %*)
SH7.4**:** The Green Belt proportion in manufacturing SMEs is smaller than the proportion suggested by the Six Sigma experts of the upcoming research activity	**SQ2.11:** How many Green Belts are available in your SME? (*Answer in %*)
	SQ3.7: From your viewpoint, how many Green Belts per 100 employees shall be available in a SME of your manufacturing sector and with your production process complexity on average? (*Answer in %*)

SH7.6: The working time of Black Belts towards Six Sigma in manufacturing SMEs is lower than that suggested by the Six Sigma experts of the upcoming research activity	**SQ2.12:** How much working time do Black Belts spend for Six Sigma in your SME? (*Answer in %*)
	SQ3.12: From your viewpoint, how much working time shall Black Belts spend on Six Sigma in a SME of your manufacturing sector and with your production process complexity on average? (*Answer in %*)
SH7.8: The working time of Green Belts towards Six Sigma in manufacturing SMEs is lower than that suggested by the Six Sigma experts of the upcoming research activity	**SQ2.13**: How much working time do Green Belts spend for Six Sigma in your SME? (*Answer in %*)
	SQ3.13: From your viewpoint, how much working time shall Green Belts spend on Six Sigma in a SME of your manufacturing sector and with your production process complexity on average? (*Answer in %*)

As an electronic survey is e-mailed to participants, it provides an easier access to world specialists in the related field and a quicker response time (Evans and Mathur, 2005). The survey questionnaire was transferred into an online version created by the free of charge and user friendly survey tool Google Docs (see https://docs.google.com/forms). This way, survey participants can gain access via internet link which will be sent to them per mail or via XING. XING is a social network for business and career where people can register and create their own business page (see https://www.xing.com). In order to find and contact suitable SS experts, SMEs with focus on the manufacturing sector will be searched at first. For this, the database from the homepage https://www.berufsstart.de/ was selected. It provides a comprehensive list of manufacturing SMEs from all 16 German federal states. After suitable manufacturing SMEs were found, terms such as [*name of the company*] and [*Six Sigma*] or [*Bel*t] will be entered as search strings into the XING search machine. These wordings shall ensure that highly qualified experts in the SS belt field with focus on manufacturing SMEs are found.

In total, 363 SS experts working in manufacturing SMEs could be found in XING and are asked via private message or mail to participate in this internet survey. To protect the privacy of the survey participants, the questionnaire is anonymous and the results will only be used for the purpose of this scientific research. Individual names and contact information of the participants will therefore not be mentioned in the dissertation thesis.

4.2 Data collection

After distributing the survey to SS experts, the respondent's data will be collected. In total, 108 out of the contacted 363 SS experts working in manufacturing SMEs participated in the internet survey and completed the questionnaire. This represents a response rate of 29.75%. A full copy of each answered questionnaire can be provided upon request.

The largest number of participants in this survey is made up of Quality Managers and Production Managers. Both positions make up about 21% of the overall participants, followed by Production Engineers (15%), Project Managers (12%) and Production Directors (12%). Almost half of the respondents have a GB certification and around 20% have a BB certification while 17% of the respondents have no SS belt certification. No MBBs and WBs were among the respondents (see table 4.20).

Table 4.20. Distribution of respondents per job position and Six Sigma belt certification. Source: Author.

Job position	**Quantity and %**	**Six Sigma belt certification**	**Quantity and %**
Project Manager	13 (12%)	Champion	4 (4%)
Quality Engineer	7 (7%)	Master Black Belt	0 (0%)
Quality Manager	23 (21%)	Black Belt	23 (21%)
Quality Director	4 (4%)	Green Belt	51 (47%)
Production Engineer	16 (15%)	Yellow Belt	12 (11%)
Production Manager	23 (21%)	White Belt	0 (0%)
Production Director	13 (12%)	No belt certification	18 (17%)
CEO/Senior Management	9 (8%)	/	/

While almost half of the respondents demonstrate work experience in manufacturing SMEs of up to five years, around 20% of the respondents have even more than 15 years of work experience in manufacturing SMEs. Moreover, around 60% of the respondents do not have more than five years of work experience in SS which also indicates that SS has only recently become popular in manufacturing SMEs (see table 4.21).

Table 4.21. Distribution of respondents per work experience in Six Sigma and manufacturing SMEs. Source: Author.

Work experience in Six Sigma	**Quantity and %**	**Work experience in manufacturing SMEs**	**Quantity and %**
Less than 2 years	38 (35%)	Less than 2 years	16 (15%)
Betw. 2 and 5 years	31 (29%)	Betw. 2 and 5 years	35 (32%)
Betw. 5 and 10 years	24 (22%)	Betw. 5 and 10 years	24 (22%)
Betw. 10 and 15 years	10 (9%)	Betw. 10 and 15 years	10 (10%)
More than 15 years	5 (5%)	More than 15 years	23 (21%)

Almost all SMEs in which the respondents of this survey are employed are located in Germany. With 32%, Baden Wuerttemberg accounts for the greatest portion, followed by Bavaria with 19%. Beside this, six participants working for Czech SMEs and one participant working for a Swiss SME have also been found during the internet search within the social network XING and were considered suitable participants for this survey. Table 4.22 lists all SME locations.

Table 4.22. Distribution of respondents per SME location. Source: Author.

SME location	**Quantity**	**Percentages**
Czech Republic	6	6%
Germany – Baden Wuerttemberg	35	32%
Germany – Bavaria	21	19%
Germany – Berlin	1	1%
Germany – Brandenburg	1	1%
Germany – Bremen	3	3%
Germany – Hesse	4	4%
Germany – Lower Saxony	10	9%
Germany – North Rhine-Westphalia	9	8%
Germany – Saxony	4	4%
Germany – Saxony-Anhalt	2	2%
Germany – Schleswig-Holstein	1	1%
Germany – Thuringia	7	6%
Germany – Rhineland-Palatinate	3	3%
Switzerland	1	1%

The distribution of the participating SMEs according to their size is as follows: Three companies have between 10 and 50 employees, 56 companies have between 50 and 250 employees and 49 companies have between 250 and 500 employees. Moreover, more than half of the participating SMEs are more than 40 years old (see table 4.23).

Table 4.23. Distribution of respondents according to their SME size and SME age. Source: Author.

SME size (Number of employees)	Quantity and %	SME age	Quantity and %
Betw. 10 and 50	3 (3%)	Less than 10 years	8 (7%)
Betw. 50 and 100	11 (10%)	Betw. 10 and 20 years	11 (10%)
Betw. 100 and 150	14 (13%)	Betw. 20 and 30 years	17 (16%)
Betw. 150 and 200	16 (15%)	Betw. 30 and 40 years	12 (11%)
Betw. 200 and 250	15 (14%)	More than 40 years	60 (56%)
Betw. 250 and 350	15 (14%)	/	/
Betw. 350 and 500	34 (31%)	/	/

The SMEs that are employing the respondents in this survey are from a wide variety of different sectors. Most strongly represented in this survey are SMEs that manufacture electric, machinery, metal and plastic products, each representing a share of more than 10%. Furthermore, more than half of the respondent SMEs belong primarily to the automotive and machinery sector (see table 4.24).

Table 4.24. Distribution of respondents per manufacturing type and industrial sector. Source: Author.

Manufacturing type	Quantity and %	Industrial sector	Quantity and %
Metal products	16 (15%)	Automotive	33 (31%)
Chemical products	8 (7%)	Chemical	8 (7%)
Electrical products	20 (19%)	Consumer	8 (7%)
Electronic products	9 (8%)	Energy	11 (10%)
Food, beverages and tobacco products	9 (8%)	Food	8 (7%)
Machinery products	18 (17%)	Machinery	26 (24%)
Medical products	5 (4%)	Medicine	3 (3%)
Plastic products	15 (14%)	Pharmaceutical	4 (4%)
Transport equipment	2 (2%)	Electronics	1 (1%)
Others	6 (6%)	Others	6 (6%)

As already stated in chapter 4.1.6, answers regarding questions about the target state of the SS belt deployment structure in manufacturing SMEs will only be considered from those survey participants who fulfil one of the three criteria which were already described in table 4.18. In the end, 75 respondents fulfil one of these three criteria. The distribution is illustrated in table 4.25.

Table 4.25. Distribution of respondents' criteria fulfilment. Source: Author.

	Criteria 1 fulfilment	**Criteria 2 Fulfilment**	**Criteria 3 fulfilment**	**No criteria fulfilment**
Quantity	23	46	6	33
Percentage	21%	42%	6%	31%

4.3 Analysis

Before testing the statistical hypotheses by using the statistical software *R* and presenting its results, the SS implementation status in manufacturing SMEs will be presented and a sensitivity power analysis conducted to compute the possible detectable effect sizes (*d*) in the various statistical hypotheses tests in accordance with the obtained sample sizes (*N*) from the survey. The last subchapter concludes with a post hoc power analysis, the aim of which is to compute the power of these statistical hypotheses tests ($1\text{-}\beta$) that show no significant results in order to evaluate if the formulated statistical hypotheses are really not true.

4.3.1 Six Sigma implementation status

Only 23 of the 108 manufacturing SMEs implemented SS yet (21%) while 47 of these SMEs (44%) plan to implement SS in future. It shows that SS has not yet been implemented extensively in German manufacturing SMEs, however, its application will increase within the next few years. 40% of those companies that have already implemented SS employ 50 to 250 people while 60% of those companies employ 250 to 500 people (see table 4.26).

Table 4.26. Distribution of the 23 SMEs that already implemented Six Sigma according to their SME size. Source: Author.

SME size (Number of employees)	**Quantity**	**Percentages**
Between 50 and 100	2	9%
Between 100 and 150	3	13%
Between 150 and 200	2	9%
Between 200 and 250	2	9%
Between 250 and 350	4	17%
Between 350 and 500	10	43%

Six companies manufacture electrical products (27%), four companies manufacture chemical products (17%) and three companies are responsible each for manufacturing food, beverages and tobacco products (13%), metal products (13%) as well as electronic products (13%). By far most of the SMEs employing the respondents of this study belong to the automotive industry (40%), followed by the food industry (13%) and machinery industry (13%). All other industrial sectors are represented with a share of less than 10%.

Table 4.27 presents the distribution of the 23 SMEs according to their manufacturing type and industrial sector.

Table 4.27. Distribution of the 23 SMEs that already implemented Six Sigma according to their manufacturing type and industrial sector. Source: Author.

Manufacturing type	**Quantity and %**	**Industrial sector**	**Quantity and %**
Metal products	3 (13%)	Automotive	9 (40%)
Chemical products	4 (17%)	Chemical	2 (9%)
Electrical products	6 (27%)	Consumer	1 (4%)
Electronic products	3 (13%)	Energy	2 (9%)
Food, beverages and tobacco products	3 (13%)	Food	3 (13%)
Machinery products	1 (4%)	Machinery	3 (13%)
Medical products	1 (4%)	Medicine	1 (4%)
Plastic products	2 (9%)	Pharmaceutical	1 (4%)
/	/	Aviation	1 (4%)

While the largest number of SMEs (39%) implemented SS between two and five years ago, four SMEs (17%) already implemented SS more than eight years ago (see table 4.28).

Table 4.28. Distribution of the 23 SMEs that already implemented Six Sigma according to their Six Sigma implementation time. Source: Author.

Six Sigma implementation time	**Quantity**	**Percentages**
Less than 2 years	5	22%
Between 2 and 5 years	9	39%
Betw. 6 and 8 years	5	22%
More than 8 years	4	17%

The largest number of SMEs (35%) only completed less than five SS projects so far, whereas seven SMEs (31%) are already more advanced and completed 20 SS projects or more. Five of these seven SMEs implemented SS six years or longer ago. More than half of the respondents (56%) specified that their SMEs currently start between three and five SS projects per year while almost half of the respondents (44%) reported cost savings between 50.000 € and 150.000 € per year at present.

Table 4.29 shows the distribution of the 23 SMEs according to their number of completed SS projects until now, their started SS projects per year and their related cost savings per year.

Table 4.29. Distribution of the 23 SMEs that already implemented Six Sigma according to their number of completed Six Sigma projects until now as well as started Six Sigma projects per year and cost savings per year. Source: Author.

Number of completed Six Sigma projects until now	**Quantity and %**	**Number of started Six Sigma projects per year**	**Quantity and %**	**Cost savings per year**	**Quantity and %**
Less than 5 projects	8 (35%)	**Less than or 2 projects**	5 (22%)	**Less than 50.000 €**	3 (13%)
Betw. 5 and 10 projects	4 (17%)	**Betw. 3 and 5 projects**	13 (56%)	**Betw. 50.000 € and 150.000 €**	10 (44%)
Betw. 10 and 20 projects	4 (17%)	**Betw. 6 and 8 projects**	2 (9%)	**Betw. 150.000 € and 250.000 €**	4 (17%)
Betw. 20 and 30 projects	5 (22%)	**More than 8 projects**	3 (13%)	**Betw. 250.000 € and 500.000 €**	3 (13%)
More than 30 projects	2 (9%)	/	/	**More than 500.000 €**	1 (4%)
/	/	/	/	**No response**	2 (9%)

Around half of the SMEs that already implemented SS in their organizations have SS champions and MBBs. BBs can be found in almost all of these SMEs and GBs are even present in all of these SMEs. Compared to this, the YB and WB presence is much rarer. YBs are only present in 30% of these SMEs and WBs only occur in three SMEs.

Moreover, the 47 SMEs that intend to implement SS in future already have SS belts in their company. 40% of these companies employ BBs, around 60% of these companies employ GBs and 17% of these companies employ YBs. Champions and MBBs are also available there. These figures indicate that the organizations are already well prepared to start applying SS in near future.

However, many SMEs that do not intend to implement SS in future also have SS belts. In nearly 60% of these companies GBs are available, in nearly 30% of these companies BBs are available and in nearly 20% of these companies YBs are available. Champions und MBBs are also present in some few SMEs. Although the presence of educated SS belts confirms an existing SS knowledge in these companies and would serve as a solid basis for the implementation of SS in the future, they decided against applying SS.

Until now, WBs are neither present in those SMEs that plan to implement SS in the future nor in those SMEs that do not want to implement SS in the future.

Table 4.30 shows the presence of the individual SS belts types in the surveyed 108 manufacturing SMEs.

Table 4.30. Six Sigma belt presence in the 108 surveyed manufacturing SMEs. Source: Author.

Six Sigma belt type	**SMEs that implemented Six Sigma (23 SMEs)**	**SMEs that plan to implement Six Sigma in the future (47 SMEs)**	**SMEs that do not plan to implement Six Sigma in the future (38 SMEs)**
	Quantity and %		
Champion	13 (57%)	10 (21%)	2 (5%)
Master Black Belt	10 (43%)	3 (6%)	1 (3%)
Black Belt	20 (87%)	19 (40%)	11 (29%)
Green Belt	23 (100%)	29 (62%)	22 (58%)
Yellow Belt	7 (30%)	8 (17%)	8 (21%)
White Belt	3 (13%)	0 (0%)	0 (0%)

4.3.2 Sensitivity power analysis

Based on the responses to the survey and the presented SS implementation status in manufacturing SMEs, the actual sample sizes (*N*) are now available and can be assigned to the respective statistical hypotheses tests with which the possible detectable effect sizes (*d*) in the individual statistical hypotheses tests should be calculated in accordance with a significance level (α) of 5% and a power of the test ($1-\beta$) of 80% by using the G*Power software tool.

Not all 108 respondents who answered the survey can be considered for the various statistical hypotheses tests. Since only 23 of those SMEs that employ the respondents of this survey have implemented SS, only this number will be used for the examination of the statistical hypotheses with focus on the actual state of the SS belts deployment in manufacturing SMEs. By contrast, for the statistical hypotheses tests concerning the target state of the SS belt deployment structure in manufacturing SMEs, 75 respondents can be taken into consideration as they fulfilled one of the required criteria presented in table 4.18 from chapter 4.1.6.

While the needed sample sizes (*N*) for the investigation of *SH1.1* to *SH2.3* and *SH4.1* to *SH6.2* were achieved or rather exceeded, the required sample sizes (*N*) needed for the investigation of the other statistical hypotheses could not be obtained through the survey.

Due to the fact that only 33 out of the 108 respondents know the roles and responsibilities of WBs and merely 32 respondents answered SQ3.11, only this number can be considered as sample size (*N*) for testing *SH3*, whereby an only available large effect size of g=0.24 is possible to be detected. The sample size (*N*) of 620 test persons that was initially computed for testing *SH3* during the priori power analysis as the number of test persons required for the detection of the relevant small effect size of g=0.05 could not be met.

The required sample size (*N*) of 27 test persons needed for the detection of the relevant effect size of d=0.5 in the context of *SH7.1*, *SH7.3* and *SH7.7* was only scarcely missed. Ultimately, 22 respondents provided data about the actual BB and GB proportions in relation to the total workforce as well as the actual GB working time towards SS for testing these statistical hypotheses, whereby an available moderate effect size of d=0.55 can possibly be detected. In contrast, data about the BB working time towards SS for testing *SH7.5* was only provided by 16 respondents, whereby an available medium to high effect size of d=0.65 can possibly be detected.

The sample size (*N*) of 51 test persons per group that was computed for testing *SH7.2*, *SH7.4*, *SH7.6* and *SH7.8* during the priori power analysis as the number of test persons required for the detection of the relevant effect size of d=0.5 could also not be achieved. In the end, 73 responses regarding the target BB and GB proportion in relation to the total workforce and target GB working time towards SS as well as 22 responses regarding the actual BB and GB proportion in relation to the total workforce and actual GB working time towards SS can be considered to test *SH7.2*, *SH7.4* and *SH7.8*. On the basis of these responses, it is possible to detect an available medium to high effect size of d=0.61. As far as *SH7.6* is concerned, 73 responses about the target BB working time towards SS can be considered as well, however, as already stated above, merely 16 responses regarding the actual BB working time towards SS can be taken into consideration. On the basis of these responses, it is possible to detect an available medium to high effect size of d=0.69.

Table 4.31 shows the computed detectable effect sizes for the statistical hypotheses whose required sample sizes (*N*) could not be met by the survey.

Table 4.31. Results of the sensitivity power analysis. Source: Author.

Statistical hypotheses	**Obtained sample size *N***	**Detectable effect size *g* or *d***
SH3	32	g=0.24
SH7.1	22	d=0.55
SH7.2	73 and 22	d=0.61
SH7.3	22	d=0.55
SH7.4	73 and 22	d=0.61
SH7.5	16	d=0.65
SH7.6	73 and 16	d=0.69
SH7.7	22	d=0.55
SH7.8	73 and 22	d=0.61

4.3.3 Six Sigma belts roles, responsibilities and required skills

Chapter 4.3.3 focuses on reaching research goal 1. Its aim is to identify the key SS belt types, their roles and responsibilities as well as their required skill set in manufacturing SMEs and to compare them to large manufacturing enterprises. Some findings were already recorded during the systematic literature review in chapter 3, however, as they are mainly based on recommendations and personnel opinions of some authors, they shall now be verified. For this reason, three research hypotheses, which shall be supported by ten statistical hypotheses, were formulated to achieve research goal 1.

RH1 assumes that the BB role in manufacturing SMEs is identical to the typical role of the MBB. For this, the ranking created by Antony and Karaminas (2016) regarding the BB roles and responsibilities in large manufacturing enterprises that was already presented in table 3.6 from chapter 3.2 will be compared with the ranking newly created on the basis of the survey conducted in the context of this study concerning the BB roles and responsibilities in manufacturing SMEs (see table 4.32). Special focus is placed on the roles “Coach”, “Mentor” and “Leader of strategic projects”, which usually are the main responsibilities of the MBB as reported in chapter 2.2. The goal is to determine if these roles are of higher importance for BBs in manufacturing SMEs than for BBs working in large manufacturing enterprises.

Table 4.32. Comparison analysis of Black Belt roles and responsibilities in large manufacturing enterprises and manufacturing SMEs. Source: Author.

Roles and responsibilities of Black Belts					
Large manufacturing enterprises Source: Antony and Karaminas (2016) 105 responses			Manufacturing SMEs Source: Survey 75 responses		
Rank	*Responsibility*	*Points*	*Rank*	*Responsibility*	*Points*
1	Change agent	60	1	Mentor	61
2	Six Sigma expert	53	2	Coach	60
3	Coach	50	3	Six Sigma expert	57
4	Critical problem solver	48	4	Leader of strategic projects	55
5	Analyst of root causes	46	5	Critical problem solver	44
6	Mentor	45	6	Project manager/leader	42
7	Leader of strategic projects	42	7	Analyst of root causes	38
8	Demonstrating bottom-line results into hard cash savings	38	8	Member of improvement projects	31
8	Member of improvement projects	38	9	Change agent	30
8	Project manager/leader	38	10	Demonstrating bottom-line results into hard cash savings	29

The roles “Coach” and “Mentor” are ranked in the first and second place in this study while in Antony and Karaminas (2016) study the role “Coach” was ranked in the third place and the role “Mentor” took the sixth place. Moreover, the role “Leader of strategic projects” also plays a more important role in manufacturing SMEs than in large manufacturing enterprises.

In addition to this, the ranking created by Antony and Karaminas (2016) regarding the required BB skills in large manufacturing enterprises that was already presented in table 3.6 from chapter 3.2 will be compared with the newly created ranking on the basis of the survey conducted in the context of this study concerning the required BB skills in manufacturing SMEs (see table 4.33). In this comparison, special focus is placed on the “Coaching/training skills” and “Leadership skills”, which are typical key skills for MBBs required to train employees in SS and lead the SS initiative as reported in chapter 2.2. The goal is to determine if these skills are of higher importance for BBs in manufacturing SMEs than for BBs working in large manufacturing enterprises.

Table 4.33. Comparison analysis of Black Belt skills in large manufacturing enterprises and manufacturing SMEs. Source: Author.

Required skills of Black Belts					
Large manufacturing enterprises Source: Antony and Karaminas (2016) 105 responses			Manufacturing SMEs Source: Survey 75 responses		
Rank	*Skills*	*Points*	*Rank*	*Skills*	*Points*
1	Analytical skills	84	1	Coaching/training skills	67
2	Expertise in Six Sigma methods and tools	75	2	Expertise in Six Sigma methods and tools	62
3	Data/fact driven	62	3	Analytical skills	56
4	Coaching/training skills	56	4	Leadership skills	53
4	Problem-solving skills	56	5	Problem-solving skills	48
5	Leadership skills	42	6	Project Management skills	46
6	Presentation skills	37	6	Presentation skills	46
7	Customer advocacy	36	7	Result-oriented leadership	39
7	Project management skills	36	7	Data/fact driven	39
7	Result-oriented leadership	36	8	Organizational skills	38
9	Social/interpersonal skills	/	9	Process-oriented skills	37
9	Collaboration skills	/	10	Social/interpersonal skills	36
9	Process-oriented skills	/	11	Customer advocacy	26
9	Technical skills	/	11	Collaboration skills	26
9	Organizational skills	/	12	Technical skills	21

Table 4.33 shows that for BBs in manufacturing SMEs “Coaching/training skills” are the most important skills while these skills were only ranked on the fourth place in Antony and Karaminas (2016) study. It is a similar situation with “Leadership skills” which is also ranked higher in this study than in Antony and Karaminas (2016) study.

In this context, also the two-sample proportion tests conducted for the five formulated statistical hypotheses (*SH1.1* to *SH1.5*) verify that the BB roles “Coach”, “Mentor” and “Leader of strategic projects” as well as their required “Coaching/training skills” and “Leadership skills” are prioritized statistically significantly higher in manufacturing SMEs than in large manufacturing enterprises. The results of the applied two-sample proportion tests show p-values of below 0.05 with moderate to high effect sizes *h* that are ranging between 0.64 and 0.84. Thus, H_0 is rejected in favour of H_A in these cases (see table 4.34).

Table 4.34. Results of statistical hypotheses tests 1.1 to 1.5. Source: Author.

Statistical hypotheses	**P-value**	**Result**	**Achieved effect size *h***
SH1.1	<0.001	H_0 is rejected in favour of H_A	*h*=0.68
SH1.2	<0.001	H_0 is rejected in favour of H_A	*h*=0.81
SH1.3	<0.001	H_0 is rejected in favour of H_A	*h*=0.68
SH1.4	<0.001	H_0 is rejected in favour of H_A	*h*=0.84
SH1.5	<0.001	H_0 is rejected in favour of H_A	*h*=0.64

In addition, *SH1.6* was set to support *RH1* which states that the majority of SS experts are of the opinion that MBBs are not needed in a SME environment since the BB can take on their role.

RH2 argues that, compared to large manufacturing enterprises, a greater presence of GBs and minor presence of BBs in relation to the total workforce shall be available in manufacturing SMEs. In this context, *SH2.3* was defined to verify this assertion. Precise data about the target BB and GB proportion in relation to the total workforce in manufacturing SMEs will again be provided and discussed in chapter 4.3.4.

In order to evaluate *RH3*, *SH3* was established. Its aim is to verify the notion that the WB training is a waste of time since the YB training already provides a basic SS overview.

A 5-point Likert scale will be used to measure the positive and negative responses from the surveyed SS experts regarding the various statements (please refer to table 4.35). Subsequently, one-sample proportion tests will be applied to test these three statistical hypotheses.

Table 4.35. Results of survey questions 3.5, 3.8 and 3.11. Source: Author.

Likert scale	Survey question 3.5	Survey question 3.8	Survey question 3.11
Strongly agree	17 (23%)	9 (12%)	12 (38%)
Agree	28 (37%)	37 (49%)	7 (22%)
Neither agree nor disagree	10 (13%)	17 (23%)	8 (25%)
Disagree	16 (21%)	9 (12%)	0 (0%)
Strongly disagree	4 (6%)	3 (4%)	5 (15%)

Despite the fact that the sample size (*N*) obtained through this survey is large enough to test *SH1.6* and to detect the relevant moderate effect size of *g*=0.15, an effect could not be identified in the one-sample proportion test of *SH1.6* (p-value=0.053). Therefore, *H0* is failed to be rejected. However, at least 60% of the 75 respondent SS experts agreed that no MBBs are needed in manufacturing SMEs while 27% did not agree and 13% neither agreed nor disagreed on this statement (see SQ3.5 in chapter 4.1.6 or appendix A).

The result concerning *RH2* shows that a bit more than 60% of the 75 respondent SS experts agreed on a higher focus on GBs in manufacturing SMEs while 16% did not agree and 23% neither agreed nor disagreed on this approach (see SQ3.8 in chapter 4.1.6 or appendix A). Consequently, the computed p-value of 0.032 in the one-sample proportion test of *SH2.3* shows an effect with a small to moderate size of *g*=0.11 which means that *H0* is rejected in favour of *HA*.

The computed p-value of 0.188 resulting from the one-sample proportion test of *SH3* indicates that a statistically significant result is not available and therefore *H0* is failed to be rejected. Although *SH3* cannot be confirmed, at least 60% of the 32 respondent SS experts agreed that the WB training is a waste of time, while 15% disagreed and 25% neither agreed nor disagreed with this opinion (see SQ3.11 in chapter 4.1.6 or appendix A).

The results of these statistical hypotheses tests are shown in table 4.36.

Table 4.36. Results of statistical hypotheses tests 1.6, 2.3 and 3. Source: Author.

Statistical hypotheses	P-value	Result	Achieved effect size *g*
SH1.6	0.053	*H0* is failed to be rejected	/
SH2.3	0.032	*H0* is rejected in favour of *HA*	*g*=0.11
SH3	0.188	*H0* is failed to be rejected	/

Based on the result of the statistical hypothesis *SH2.3*, it can be assumed that GB roles and responsibilities as well as their required skills may have to be redefined in manufacturing SMEs compared to large manufacturing enterprises. During the systematic literature review in chapter 3, no studies could be found so far in which the importance of GB roles, responsibilities and their required skills were evaluated, neither with focus on manufacturing SMEs nor with focus on large manufacturing enterprises. For this reason, 75 SS experts were surveyed about this topic and had to vote on the importance of various GB roles, responsibilities and required skills with focus on manufacturing SMEs (see results in table 4.37).

Table 4.37. Roles, responsibilities and required skills of Green Belts in manufacturing SMEs. Source: Author.

Rank	Roles and responsibilities	Points	Rank	Skills	Points
1	Analyst of root causes	51	1	Analytical skills	60
2	Critical problem solver	49	2	Problem-solving skills	58
3	Member of improvement projects	45	3	Expertise in Six Sigma method and tools	51
4	Change agent	44	4	Process-oriented skills	48
5	Six Sigma expert	41	5	Data/fact driven	47
6	Project manager/leader	31	6	Technical skills	44
7	Demonstrating bottom-line results into hard cash savings	30	6	Presentation skills	44
8	Six Sigma expert	20	7	Social/interpersonal skills	30
9	Coach	18	7	Project management skills	30
10	Leader of strategic projects	14	8	Organizational skills	27
11	Mentor	13	9	Collaboration skills	23
12	/		9	Results-oriented leadership	23
13	/		10	Customer advocacy	14
14	/		11	Coaching/training skills	12
15	/		12	Leadership skills	9

According to the respondents, the GB roles “Analyst of root causes” and “Critical problem solver” are considered the most important ones in manufacturing SMEs, followed by the roles “Member of improvement projects”, “Change agent” and “Six Sigma expert”. Lower in the ranking are the roles “Coach” and “Mentor” of team members within the SS belt hierarchy as well as “Leader of strategic projects” which shall typically be one of the main responsibilities of BBs in small enterprises (see table 4.32). Beside this, GBs must also acquire specific skills. The results of the survey show that “Analytical skills” and “Problem-solving skills” are by far the most important skills for GBs in manufacturing SMEs, followed by “Expertise in Six Sigma methods and tools”, “Process-oriented skills”, “Data/fact driven”, “Technical skills” and “Presentation skills”.

4.3.4 Six Sigma belts proportions and their invested working time towards Six Sigma

Beside *SH2.3*, also *SH2.1* and *SH2.2* were defined as useful for drawing conclusions regarding the evaluation of *RH2* and thus also contribute to reaching research goal 2. Their objective is to find out if the BB proportion in relation to the total workforce shall be smaller and the GB proportion, in turn, shall be greater in manufacturing SMEs than in large manufacturing enterprises. For this, 73 SS experts of the survey provided their suggestions (see results in table 4.38).

Table 4.38. Distribution of the suggestions given by 73 Six Sigma experts concerning the Black Belt and Green Belt proportion in relation to the total workforce in manufacturing SMEs. Source: Author.

Proportion in relation to the total workforce	**Number and percentage of suggestions made by Six Sigma experts regarding the Black Belt proportion**	**Number and percentage of suggestions made by Six Sigma experts regarding the Green Belt proportion**
<1%	52 (71%)	
1%	18 (25%)	4 (6%)
2%	/	14 (19%)
3%	/	11 (15%)
4%	/	1 (1%)
5%	2 (3%)	22 (30%)
6%	1 (1%)	3 (4%)
7%	/	2 (3%)
8%		2 (3%)
10%	/	9 (13%)
20%	/	3 (4%)
25%	/	1 (1%)
40%	/	1 (1%)

The majority of the surveyed SS experts (71%) recommended a BB proportion of less than 1% in manufacturing SMEs. This is in accordance with the suggestion of Kumar et al. (2011). 18 surveyed SS experts recommended a BB proportion of 1%. Overall, the suggestions of the surveyed SS experts result in a mean value of 0.8% BBs in relation to the total workforce and a p-value of <0.001 with a high effect size of d=1.23 in the one-sample t-test of *SH2.1*. Correspondingly, it can be concluded that a statistically significantly smaller proportion of BBs shall be available in manufacturing SMEs than in large manufacturing enterprises, where a BB proportion of around 2% in relation to the total workforce is assumed as reported in chapter 3.2, and thus H_0 is rejected in favour of H_A.

Considering the proposed GB percentages in table 4.38, it can be stated that around 70% of the surveyed SS experts recommended a GB proportion in relation to the total workforce of up to 5%. This contradicts with the conclusions drawn in chapter 3.2, namely that the GB proportion in SMEs shall be greater than in large enterprises, where a GB proportion of around 5% in relation to the total workforce is proposed. Although the mean value is 6% GBs in relation to the total workforce, *SH2.2* cannot be confirmed. The conducted one-sample t-test shows a p-value of 0.073 which means that the result is not statistically significant and thus *H0* is failed to be rejected.

To investigate *RH4* and meet the research goal 3, *SH4.1* and *SH4.2* were set to analyse if the working time of GBs and BBs towards SS projects in manufacturing SMEs shall be lower than in large manufacturing enterprises. 73 SS experts of the survey provided their suggestions in this context (see results in table 4.39).

Table 4.39. Distribution of the suggestions given by 73 Six Sigma experts concerning the Black Belt and Green Belt working time towards Six Sigma projects in manufacturing SMEs. Source: Author.

Working time for Six Sigma	**Number and percentage of suggestions made by Six Sigma experts regarding Black Belt working time**	**Number and percentage of suggestions made by Six Sigma experts regarding Green Belt working time**
5%	1 (1%)	2 (3%)
10%	6 (8%)	5 (7%)
15%	/	3 (4%)
20%	2 (3%)	17 (23%)
25%	5 (7%)	12 (16%)
30%	10 (14%)	15 (21%)
35%	2 (3%)	
40%	8 (11%)	7 (10%)
50%	17 (23%)	11 (15%)
60%	3 (4%)	/
65%	1 (1%)	/
70%	5 (7%)	/
75%	2 (3%)	/
80%	5 (7%)	1 (1%)
90%	2 (3%)	
100%	4 (5%)	/

Most of the surveyed SS experts (85%) believed that BBs in manufacturing SMEs shall spend less working time towards SS than the proposed working time of 80% in large manufacturing enterprises as cited in chapter 3.2. A BB working time of 50% was most commonly selected with 17 responses, followed by a BB working time of 30% with ten responses and a BB working time of 40% with eight responses. The resulted mean value is a BB working time towards SS of approx. 50%, which was also proposed by Nonthaleerak and Hendry (2008) as well as Schroeder et al. (2008). Based on the computed p-value of <0.001 and high effect size of *d*=1.33 in the one-sample t-test of *SH4.1*, it can be stated that *H0* is rejected in favour of *HA*.

Regarding the GB working time towards SS, 39 surveyed SS experts (53%) believed in a lower GB working time towards SS in manufacturing SMEs than the proposed GB working time of at least 30% in large manufacturing enterprises as cited in chapter 3.2. 15 surveyed SS experts (21%) suggested that GBs shall spend 30% of their working time towards SS while 19 surveyed SS experts (26%) were of the opinion that GBs shall spend more than 30% of their working time towards SS. Correspondingly, the resulted mean value is a GB working time towards SS of around 30% and the p-value in the one-sample t-test of *SH4.2* is 0.234. It shows that in this case no statistically significant result exists and, therefore, *H0* is failed to be rejected.

Table 4.40 summarizes the results of the four statistical hypotheses tests from this chapter.

Table 4.40. Results of statistical hypotheses tests 2.1, 2.2, 4.1 and 4.2. Source: Author.

Statistical hypotheses	**P-value**	**Result**	**Achieved effect size *d***
SH2.1	<0.001	*H0* is rejected in favour of *HA*	*d*=1.23
SH2.2	0.073	*H0* is failed to be rejected	/
SH4.1	<0.001	*H0* is rejected in favour of *HA*	*d*=1.33
SH4.2	0.234	*H0* is failed to be rejected	/

4.3.5 Six Sigma belts possible number of projects that can be executed and the related cost savings

The research goals 4 and 5 were formulated to identify the possible number of SS projects that can achievably be executed by the various SS belts as well as the related cost savings in manufacturing SMEs compared to large manufacturing enterprises. For this subject, the current literature offers almost no information (see chapter 3.2). For this, *RH5* and *RH6* with the respective statistical hypotheses *SH5.1*, *SH5.2*, *SH6.1* and *SH6.2* were defined. The goal is to examine if BBs and GBs in manufacturing SMEs execute fewer SS projects overall and thus save less costs than in large manufacturing enterprises. The results of this investigation shall strengthen this research field and entail new insights. Various suggestions were made by 75 SS experts of the survey regarding the possible number of BB and GB projects that can be executed annually. The results are shown in table 4.41.

Table 4.41. Distribution of the suggestions given by 75 Six Sigma experts concerning the number of possible Six Sigma projects that can be executed per year by a Black Belt and a Green Belt in manufacturing SMEs. Source: Author.

Number of Six Sigma projects that can be executed	**Number and percentage of suggestions made by Six Sigma experts regarding the number of possible Six Sigma projects that can be executed by a Black Belt per year**	**Number and percentage of suggestions made by Six Sigma experts regarding the number of possible Six Sigma projects that can be executed by a Green Belt per year**
1	22 (29%)	5 (7%)
2	35 (47%)	29 (39%)
3-5	17 (23%)	31 (41%)
6-8	1 (1%)	7 (9%)
More than 8	0 (0%)	3 (4%)

Most surveyed SS experts (76%) were of the opinion that BBs are able to execute one or two SS projects per year. This is clearly below the expected minimum of four SS project executions per year in large manufacturing enterprises as calculated in chapter 3.2. The resulting mean value is two BB projects per year. Consequently, a p-value of <0.001 and high effect size of $d=1.44$ are computed in the one-sample t-test of *SH5.1*. This means that a statistically significant result exists and, therefore, H_0 is rejected in favour of H_A.

In comparison, more than 50% of the surveyed SS experts believed that GBs are able to execute more than two SS projects per year. There are even seven SS experts who expected GBs to execute six to eight SS projects and three SS experts who believed GBs are able to execute more than eight SS projects. The resulted mean value is 3.5 GB projects per year. Accordingly, the one-sample t-test of *SH5.2* shows a p-value of 0.986 and, therefore, it cannot be confirmed that GBs shall execute statistically significantly less SS projects per year than in large manufacturing enterprises, where up to three SS project executions per year are suggested by Antony et al. (2007). To sum this up, H_0 is failed to be rejected.

In the next step, the various possible cost savings made by BBs and GBs per SS project, as suggested by 75 surveyed SS experts, will be presented in table 4.42.

Table 4.42. Distribution of the suggestions given by 75 Six Sigma experts concerning the possible cost savings by a Black Belt and a Green Belt per Six Sigma project in manufacturing SMEs. Source: Author.

Cost savings per Six Sigma project	**Number and percentage of suggestions made by Six Sigma experts regarding possible cost savings by a Black Belt per Six Sigma project**	**Number and percentage of suggestions made by Six Sigma experts regarding possible cost savings by a Green Belt per Six Sigma project**
Less than 10.000 €	5 (7%)	22 (29%)
Betw. 10.000 € and 20.000 €	14 (19%)	31 (41%)
Betw. 20.000 € and 30.000 €	17 (22%)	12 (16%)
Betw. 30.000 € and 40.000 €	15 (20%)	6 (8%)
Betw. 40.000 € and 50.000 €	14 (19%)	2 (3%)
More than 50.000 €	10 (13%)	2 (3%)

The fact that only ten SS experts of the survey believed that BBs can save more than 50.000 € per SS project proves that the estimated cost savings by a BB in large manufacturing enterprises of around 100.000 € per SS project, as calculated in chapter 3.2, would be far more difficult to achieve in manufacturing SMEs. This leads to a computed p-value of <0.001 in the one-sample t-test of *SH6.1*. The same result is also computed in the one-sample t-test of *SH6.2,* which reveals that GBs in manufacturing SMEs save statistically significantly less cost than the suggested 45.000 € per SS project in large manufacturing enterprises by Harry (1998). In both cases, high effect sizes (*d*) are computed and thus, H_0 is rejected in favour of H_A. On average, BBs shall be able to save around 30.000 € per SS project while GBs shall be able to save around 17.000 € per SS project.

The statistical hypotheses test results are summarized in table 4.43.

Table 4.43. Results of statistical hypotheses tests 5.1, 5.2, 6.1 and 6.2. Source: Author.

Statistical hypotheses	P-value	Result	Achieved effect size *d*
SH5.1	<0.001	H_0 is rejected in favour of H_A	d=1.44
SH5.2	0.986	H_0 is failed to be rejected	/
SH6.1	<0.001	H_0 is rejected in favour of H_A	d=4.61
SH6.2	<0.001	H_0 is rejected in favour of H_A	d=2.34

4.3.6 Differences between the current and the target state of the Six Sigma belt deployment

The research goal 6 was defined to outline the differences between the current status and the target status of the SS belts deployment in manufacturing SMEs with particular focus on whether the recommended guidelines from the literature reported in chapter 3.2 or the suggestions from the surveyed SS experts are being followed in practice. For this, *RH7* was set which assumes that the deployment of the SS belts in manufacturing SMEs is not implemented as required due to a low SS awareness and knowledge as well as an unexplored LSS infrastructure (see chapter 1.1). In total, eight statistical hypotheses tests were carried out for its evaluation.

As already mentioned, only 23 of the 108 manufacturing SMEs the respondent SS experts are working for implemented SS. Out of these 23 SMEs, 22 SS experts provided information about their current BB and GB proportion in relation to the total workforce. While four of these SMEs have a BB proportion of less than 1%, there are five SMEs that have a BB proportion of 1% and ten SMEs that have a BB proportion of more than 1%. One SME even includes 50 BBs (20% of the total workforce) and two SMEs each include 40 BBs (10% of the total workforce) and 20 BBs (5% of the total workforce) respectively. This results in a mean value of 3.2% BBs in relation to the total workforce which means that most companies exceed the BB proportion of less than 1% as suggested by Kumar et al. (2011) and the surveyed SS experts. This is also proven by the one-sample t-test of *SH7.1* and the Welch's two-sample t-test of *SH7.2* where p-values of almost 1 are computed. Hence, in both cases, H_0 is failed to be rejected.

Beside this, ten SMEs show a GB proportion of up to 5% while twelve SMEs demonstrate a GB proportion of more than 5%. Seven of these twelve SMEs have a GB proportion between 6% and 10%, one SME has a GB proportion of 15% and four SMEs even have a GB proportion of 20%. This translates to a mean value of 7.6% GBs in relation to the total workforce. The computed p-values of 0.958 in the one-sample t-test of *SH7.3* and 0.834 in the Welch's two-sample t-test of *SH7.4* show that the recommended proportion for GBs based on the conclusions drawn in chapter 3.2 and the responses of the surveyed SS experts is followed in practice. For this reason, *H0* is also failed to be rejected in both cases.

Table 4.44 presents a distribution of the respondents data per number and percentage of SMEs with a respective proportion of BBs and GBs in relation to the total workforce.

Table 4.44. Distribution of the 23 SMEs that implemented Six Sigma per number and percentage of SMEs with respective Black Belt and Green Belt proportion. Source: Author.

Proportion in relation to the total workforce	Number and percentage of SMEs with respective Black Belt proportion	Number and percentage of SMEs with respective Green Belt proportion
0	3 (13%)	/
<1%	4 (17%)	1 (4%)
1%	5 (22%)	3 (13%)
1.5%	/	1 (4%)
2%	3 (13%)	1 (4%)
3%	/	2 (9%)
4%	2 (9%)	/
5%	2 (9%)	2 (9%)
6%	/	4 (18%)
7%	/	1 (4%)
10%	2 (9%)	2 (9%)
15%	/	1 (4%)
20%	1 (4%)	4 (18%)
Available but no figures	1 (4%)	1 (4%)

Beside the individual BB and GB proportions, their invested working time towards SS also plays an essential role when it comes to using SS in SMEs effectively. As stated in chapter 4.3.2, 22 respondents provided data about the actual working time of GBs towards SS while only 16 respondents provided data about the actual working time of BBs towards SS.

Table 4.45 presents a distribution of the respondents data per number and percentage of SMEs with a respective working time of BBs and GBs towards SS.

Table 4.45. Distribution of the 23 SMEs that implemented Six Sigma per number and percentage of SMEs with respective Black Belt and Green Belt working time towards Six Sigma. Source: Author.

Working time towards Six Sigma	Number and percentage of SMEs with Black Belt working time	Number and percentage of SMEs with Green Belt working time
5%	2 (10%)	3 (13%)
10%	1 (5%)	2 (9%)
15%	1 (5%)	/
20%	3 (15%)	8 (35%)
25%	/	2 (9%)
30%	1 (5%)	4 (18%)
35%	2 (10%)	1 (4%)
40%	1 (5%)	1 (4%)
50%	2 (10%)	1 (4%)
80%	1 (5%)	/
100%	2 (10%)	/
Available but no figures	4 (20%)	1 (4%)

Except for the BBs in three SMEs, who even invest 80% or more of their working time towards SS, the BBs of the remaining 13 SMEs spend up to 50% of their working time towards SS. This results in a mean value of around 40% which is nearly the same value as proposed for SMEs by Nonthaleerak and Hendry (2008) as well as Schroeder et al. (2008) and the surveyed SS experts. Accordingly, the computed p-values of 0.077 in the one-sample t-test of *SH7.5* and 0.133 in the Welch's two-sample t-test of *SH7.6* show that no effects exist. Therefore, it cannot be confirmed that BBs spend insufficient time towards SS in manufacturing SMEs and thus, H_0 is failed to be rejected in both cases.

Moreover, GBs in eight SMEs spend 20% of their working time towards SS while in four SMEs the GBs spend 30% of their working time towards SS. GBs in three SMEs devote with 35%, 40% and 50% even more working time towards SS. The mean value is a GB working time of around 20% which is also proposed for SMEs by Antony et al. (2005 and 2008). While *SH7.7* cannot be confirmed because the one-sample t-test computes a p-value of 0.820, the Welch's two-sample t-test of *SH7.8* results in a p-value of 0.015 and moderate effect size of d=0.52. In this case, H_0 can be rejected in favour of H_A. The reason for this is that the surveyed SS experts proposed an on average higher GB working time towards SS in manufacturing SMEs than Antony et al. (2005 and 2008). As stated in chapter 4.3.4, the mean value of the GB working time towards SS as proposed by the surveyed SS experts is around 30%.

A summary of the statistical hypotheses test results is shown in table 4.46.

Table 4.46. Results of statistical hypotheses tests 7.1 to 7.8. Source: Author.

Statistical hypotheses	**P-value**	**Result**	**Achieved effect size *d***
SH7.1	0.994	H_0 is failed to be rejected	/
SH7.2	0.987	H_0 is failed to be rejected	/
SH7.3	0.958	H_0 is failed to be rejected	/
SH7.4	0.834	H_0 is failed to be rejected	/
SH7.5	0.077	H_0 is failed to be rejected	/
SH7.6	0.133	H_0 is failed to be rejected	/
SH7.7	0.820	H_0 is failed to be rejected	/
SH7.8	0.015	H_0 is rejected in favour of H_A	d=0.52

4.3.7 Post hoc power analysis

As described in chapter 4.1.4, the aim of the post hoc power analysis is to calculate the power of the test ($1-\beta$) that reveal no statistically significant result. Only if the power of the test ($1-\beta$) is large enough (≥80%) or the type II error (β) is low enough (≤20%), a decision in favour of H_0 can be made (Faul et al. 2007; Rasch et al. 2014; Aberson, 2011). Therefore, the power of the respective tests ($1-\beta$) where the sample sizes (N) were not achieved by the survey and the results are not statistically significant will be computed via the G*Power software tool by using the obtained sample sizes (N) from the survey, the relevant effect sizes (g or d) and a significance level (α) of 5%.

With regard to the statistical tests of *SH1.6*, *SH2.2*, *SH4.2* and *SH5.2*, the probability to find the relevant moderate effect sizes (g or d) is higher than the required 80% according to Cohen (1988) which means that the power of the tests ($1-\beta$) is large enough. For this reason, it is correct that H_0 is failed to be rejected in those cases.

With regard to the statistical tests of *SH7.1* to *SH7.7*, the required power of the test ($1-\beta$) of 80% according to Cohen (1988) was just scarcely missed. However, the probability to not reject H_0, given that it is false, is in those cases 27%, 35%, 40% and 44% respectively (type II error (β)) and thus higher than the limit value of 20% mentioned in chapter 4.1.1. Beside this, the probability of finding the relevant small effect size of g=0.05 in the statistical test of *SH3* is only 8%. The risk regarding the occurrence of the type II error (β) is significant in this case. Taking all these facts into consideration, a decision in favour of *H0* cannot normally be made in those cases.

Table 4.47 summarizes the results of the post hoc power analysis.

Table 4.47. Results of the post hoc power analysis. Source: Author.

Statistical hypotheses	**Obtained Sample size (*N*)**	**Relevant effect size (*g or d*)**	**Power of test ($1-\beta$)**	**Type II error (β)**
SH3	32	*g*=0.05	0.08	0.92
SH7.1	22	*d*=0.5	0.73	0.27
SH7.2	73 and 22	*d*=0.5	0.65	0.35
SH7.3	22	*d*=0.5	0.73	0.27
SH7.4	73 and 22	*d*=0.5	0.65	0.35
SH7.5	16	*d*=0.5	0.60	0.40
SH7.6	73 and 16	*d*=0.5	0.56	0.44
SH7.7	22	*d*=0.5	0.73	0.27

4.4 Evaluation of the research hypotheses

Finally, the last subchapter aims to discuss the contribution of the statistical hypotheses test results with respect to the evaluation of the research hypotheses.

The results of five (*SH1.1* to *SH1.5*) of the six statistical hypotheses tests set to evaluate *RH1*, which states that the BB role in manufacturing SMEs is identical with the typical role of the MBB, are statistically significant. In contrast, only the one-sample proportion test of *SH1.6* shows no effect but at least 60% of the 75 respondent SS experts of the survey confirmed that MBBs are not needed in manufacturing SMEs. On the basis of this information, it can be concluded that BBs should take on the role of the MBB in manufacturing SMEs. Therefore, *RH1* is accepted in the course of this study.

Three statistical hypotheses tests were carried out to draw conclusions for *RH2* which relates to a greater GB and minor BB presence in manufacturing SMEs than in large manufacturing enterprises. While the one-sample t-test of *SH2.1*, which states that a smaller BB proportion is required in manufacturing SMEs than in large manufacturing enterprises, results in a high effect size, there is no effect in the one-sample t-test of *SH2.2* found that is pointing towards a greater GB proportion in manufacturing SMEs than in large manufacturing enterprises. However, a mean value of 6% GBs in relation to the total workforce was suggested by the 73 respondent SS experts of the survey. Moreover, the positive result in the one-sample proportion test of *SH2.3* shows that the SS implementation strategy in manufacturing SMEs should be rather focused on implementing and training GBs instead of BBs. Although one of the three statistical hypotheses tests shows no effect, the identified supporting facts are strong enough to indicate an acceptance towards *RH2*.

The result in the one-sample proportion test of *SH3* that was defined to support the evaluation of *RH3,* which states that the role of the WB is identical to the role of the YB, is not statistically significant. However, since the probability to not reject *H0,* given that it is false, is around 90% in that statistical hypothesis test, the result is not reflecting a proper basis to evaluate *RH3*. At least 60% of the 32 respondent SS experts of the survey agreed with the notion that the WB training is a waste of time since the YB training already provides a basic SS overview. Moreover, nearly 15 years after the proposal of the WB category by Harry and Crawford (2004 and 2005), only 33 out of the 108 respondents from this survey know about the roles and responsibilities of the WB (see chapter 4.3.2) and only three SMEs from all those companies that employ these 108 respondents have implemented this WB type in their own organization (see chapter 4.3.1). This proves that there is a high degree of unawareness surrounding this SS belt category to the present day and indicates that the YB category is sufficient. For these reasons, an acceptance of *RH3* is favoured despite the negative test result of *SH3*.

The evaluation of *RH4*, which presumes a lower working time towards SS of the SS belts in manufacturing SMEs than in large manufacturing enterprises, is based on *SH4.1* and *SH4.2*. While the one-sample t-test of *SH4.1* that focuses on a lower BB working time towards SS in manufacturing SMEs compared to large manufacturing enterprises results in a high effect size, the one-sample t-test of *SH4.2* that focuses on a lower GB working time towards SS in manufacturing SMEs compared to large manufacturing enterprises shows no effect. However, since the mean value is calculated at about 30% which is just about the proposed minimum GB working time towards SS in large manufacturing enterprises as reported in chapter 3.2, a decision in favour of accepting *RH4* is quite realistic.

A similar result presented itself upon examining *RH5* which looks at the number of SS projects executed and presumes that a SS belt completes a smaller number in manufacturing SMEs than in large manufacturing enterprises. Here as well, only one of the two statistical hypotheses test results is statistically significant. While the result in the one-sample t-test of *SH5.1* clearly shows that BBs in manufacturing SMEs are not able to execute the same number of SS projects per year as in large manufacturing enterprises, it does not affect the number of SS projects executed by GBs per year according to the result of the one-sample t-test of *SH5.2*. Same as in large manufacturing enterprises, GBs in manufacturing SMEs shall be able to execute an average of three to four SS projects per year. From this result the rejection of *RH5* can be derived.

By comparison, the results of the one-sample t-tests of *SH6.1* and *SH6.2* can be described as statistically significant. For this reason, *RH6*, which assumes lower cost savings per SS project by SS belts in manufacturing SMEs than in large manufacturing enterprises, can be accepted.

The last formulated research hypothesis *RH7* supposes that the deployment of the SS belts in manufacturing SMEs is not implemented as required and its evaluation was supported by eight statistical hypotheses tests. Out of these eight statistical hypotheses tests only the result from the Welch two-sample t-test of *SH7.8* can be described statistically significant. Besides the GB's working time towards SS in those 23 manufacturing SMEs that is in accordance with the recommendations given by Antony et al. (2005 and 2008) but not according the suggestions of the surveyed SS experts, it also cannot be confirmed that the BB and GB proportion in relation to the total workforce as well as the BB working time towards SS suggested by researchers in the current literature (see chapter 3.2) and the surveyed SS experts are not followed in practice. Since the required power of the test ($1\text{-}\beta$) of 80% according to Cohen (1988) was just scarcely missed in the statistical tests of *SH7.1* to *SH7.7*, *RH7* will be rejected in the context of this study.

The evaluations of the individual research hypotheses are summarized in table 4.48.

Table 4.48. Evaluation of research hypotheses. Source: Author.

Research hypotheses	Supporting statistical hypotheses	Statistical hypotheses results[9]	Research hypotheses evaluation
RH1: *The role of the Black Belt in manufacturing SMEs is synonymous with the role of the Master Black Belt*	*SH1.1* to *SH1.5*	+	***Accepted***
	SH1.6	-	
RH2: *There shall be a greater presence of Green Belts and a minor presence of Black Belts in relation to the total workforce in manufacturing SMEs than in large manufacturing enterprises*	*SH2.1*	+	***Accepted***
	SH2.2	-	
	SH2.3	+	
RH3: *The role of the White Belt is synonymous with the role of the Yellow Belt*	*SH3*	-	***Accepted***
RH4: *The working time of the Six Sigma belts towards Six Sigma projects in manufacturing SMEs shall be lower than in large manufacturing enterprises*	*SH4.1*	+	***Accepted***
	SH4.2	-	
RH5: *The possible number of projects that can be executed by Six Sigma belts in manufacturing SMEs shall be lower than in large manufacturing enterprises*	*SH5.1*	+	***Rejected***
	SH5.2	-	
RH6: *The possible cost savings by Six Sigma belts in manufacturing SMEs shall be lower than in large manufacturing enterprises*	*SH6.1 and SH6.2*	+	***Accepted***
RH7: *The deployment of the Six Sigma belts in manufacturing SMEs is not implemented as required*	*SH7.1* to *SH7.7*	-	***Rejected***
	SH7.8	+	

9 (+) = *H0 is rejected in favour of HA*
(-) = *H0 is failed to be rejected*

5. RESEARCH RESULTS

On the one hand, the results of the survey and statistical hypotheses tests largely correspond with the opinions and recommendations made by the researchers of the current literature as reported in chapter 3. On the other hand, these results also provide new insights into this research field and allow for new conclusions to be drawn. This chapter starts with a discussion of the study's research results, followed by a conception of an effective SS belt deployment structure in manufacturing SMEs and concludes with a verification of the target achievement of the research goals established in the framework of the dissertation.

5.1 Discussion of research results

RESEARCH GOAL 1: To identify the key Six Sigma belts, their roles, responsibilities and their required skills in manufacturing SMEs compared to large manufacturing enterprises

Besides the case studies conducted by Green et al. (2006), Nonthaleerak and Hendry (2008) and Timans et al. (2012) as well as the empirical evidences provided by Antony et al. (2008) and Douglas et al. (2015), the results of this survey and the statistical hypotheses tests strengthen the idea of Kumar et al. (2011) that BBs in manufacturing SMEs shall take on the coaching and trainer role in manufacturing SMEs. This, in turn, also indicates that MBBs are not required in manufacturing SMEs. Compared to the survey of Antony and Karaminas (2016) which focused on large enterprises, the BB roles "Coach", "Mentor" and "Leader of strategic projects" as well as their "Coaching/training skills" and "Leadership skills" have a higher prioritization in manufacturing SMEs according the surveyed SS experts.

However, a greater focus on GBs instead of BBs was proposed for manufacturing SMEs in various older research contributions (see Davis, 2003; Gnibus and Krull, 2003; Burton, 2004; Green et al. 2006 and Pyzdek and Harrison, cited in Antony, 2008). The validity of the greater GB approach was so far only partially empirically proven by the studies of Timans et al. (2012) and Antony et al. (2008) but they could not be considered hard evidences for a topic of this nature. However, the results of the conducted survey and statistical hypotheses tests validate this approach. This can be justified due to the high training costs and the high salary of BBs as well as the higher importance of lean tools for SS projects in SMEs instead of complex statistical techniques (see chapter 3.2). Further reasons are the lack of human and financial resources in SMEs (see chapter 2.5). Comparing the identified roles, responsibilities and skills of GBs in manufacturing SMEs presented in table 4.37 to those of BBs presented in table 4.32 and table 4.33 and considering the results of the statistical hypotheses tests, it can be argued that GBs are the key SS belts in manufacturing SMEs who should be the driving force behind improvement initiatives and drive up customer satisfaction as well as business productivity.

As far as the idea of Harry and Crawford (2004 and 2005) about the introduction of WBs in SMEs is concerned, it can be stated that Setters (2010) doubts that the WB training is a waste of time since the YB training already represents a basic SS overview are valid. Therefore, the YB category currently ought to be rather recognized as a SS basic education level until more positive findings about the advantages and successes of the WB type will be become known and published.

RESEARCH GOAL 2: To identify the Six Sigma belt proportions in relation to the total workforce in manufacturing SMEs compared to large manufacturing enterprises

Regarding the investigation whether or not BBs and GBs are needed in manufacturing SMEs in the same capacity as in large manufacturing organizations the situation is similar. As there are only personal views from a few researchers regarding a greater focus on GBs as already mentioned above, the suggestion of Kumar et al. (2011) to deploy less than 1% BBs, the results of the case study conducted by Timans et al. (2012) and against the background that these sources are quite a few years old, it is hardly possible to draw meaningful conclusions about this topic.

However, the conducted investigations in the course of this study show that the vast majority of the surveyed SS experts had a similar opinion as Kumar et al. (2011) and agreed that a smaller proportion of BBs is sufficient in manufacturing SMEs compared to large manufacturing enterprises, where a BB proportion of around 2% in relation to the total workforce is assumed as reported in chapter 3.2. At the same time, it could not be confirmed statistically that a higher GB proportion in relation to the total workforce is required in manufacturing SMEs than the proposed 5% for larger enterprises as mentioned in chapter 3.2. 30% of 73 surveyed SS experts proposed a GB proportion of 5% while another 30% proposed a GB proportion of more than 5% in relation to the total workforce. The resulted mean value is 6% GBs.

In summary, the results support the view that a minor representation of BBs and stronger representation of GBs is required in manufacturing SMEs compared to large manufacturing enterprises. As recommended on the basis of the outcome of this study, a BB proportion of less than 1% and a GB proportion of at least 5% in relation to the total workforce are proposed for manufacturing SMEs.

RESEARCH GOAL 3: To identify the required invested working time of the individual Six Sigma belts towards Six Sigma projects in manufacturing SMEs compared to large manufacturing enterprises

In large enterprises, BBs shall work full-time or spend at least 80% and GBs 30% to 50% of their working time towards SS projects (see chapter 3.2). However, as stated in chapter 2.5, employees in SMEs have usually several other roles on top of their key roles. Therefore, it is quite unrealistic that the SS belts in SMEs are able to invest their working time towards SS in the same manner as in larger enterprises. There are few conclusions with almost no empirical evidences by researchers of the current literature concerning the lower invested working time of the SS belts towards SS projects in manufacturing SMEs compared to large manufacturing enterprises. For this reason, the difference in working time was further examined in the framework of this dissertation. The results of the survey and statistical hypotheses tests exhibit that the working time of BBs towards SS in manufacturing SMEs shall be lower than in large manufacturing enterprises. A BB working time of 50% was most commonly selected by the surveyed SS experts and the resulted mean value is a BB working time of approx. 50%. This was also proposed by Nonthaleerak and Hendry (2008) as well as Schroeder et al. (2008) as the optimal solution for SMEs. Statistically speaking, the GB working time in manufacturing SMEs shall not be lower than the proposed minimum working time of 30% in large manufacturing enterprises. However, a GB working time of 20%, as also proposed by Antony et al. (2005 and 2008), was most commonly selected during this survey.

RESEARCH GOAL 4: To identify the possible number of projects that can be executed by the various Six Sigma belts in manufacturing SMEs compared to large manufacturing enterprises

As there are so far no findings in the current literature regarding the possible number of SS projects that can be executed by the various SS belts per year in manufacturing SME, this subject matter had to be researched from the beginning. About three quarters of the surveyed SS experts suggested that a BB can execute one to two SS projects per year which is significantly less than the estimated four SS projects per year of BBs in large manufacturing enterprises as calculated in chapter 3.2. GBs shall execute an average of three to four SS projects per year according the surveyed SS experts which is almost similar to the proposal made by Antony et al. (2007) for large manufacturing enterprises.

In contrast to the literature that states that BBs execute more SS projects than GBs in large manufacturing enterprises (see chapter 3.2), the results of the survey and statistical hypotheses tests show the opposite in case of manufacturing SMEs. Besides the potential reasons given by the surveyed SS experts, namely that BB projects are more complex, larger and have longer project durations than GB projects, BBs also have to coach and mentor the lower-level SS belts in manufacturing SMEs and thus have less time at their disposal that they can dedicate to their own projects. This is an additional finding that advocates the approach of a greater GB presence in manufacturing SMEs.

RESEARCH GOAL 5: To identify the possible cost savings by the various Six Sigma belts in manufacturing SMEs compared to large manufacturing enterprises

The situation appears to be similar regarding the possible cost savings that can be made by the various SS belts per SS project in manufacturing SMEs. The results of the survey reveal that BBs in manufacturing SMEs shall be able to save an average of around 30.000 € per SS project which is almost identical to the cost savings of around 35.000 to 40.000 € per SS project as proposed by Kumar et al. (2011). This is also considerably less than the estimated cost savings of around 100.000 € per SS project in large manufacturing enterprises as calculated in chapter 3.2. The survey produced a similar result with regard to the cost savings of GBs per SS project, which are around 17.000 € on average, and thus less than the 45.000 € per SS project in large manufacturing enterprises as suggested by Harry (1998).

Table 5.1 complements table 3.7, which shows the main differences of the SS belt system structure (availability, roles, responsibilities and skills, proportion of total workforce, working time, number of projects that can be executed and cost savings) between manufacturing SMEs and large manufacturing enterprises, on the basis of the findings obtained from the survey and statistical hypotheses tests.

Table 5.1. Differences of the Six Sigma belt system structure in manufacturing SMEs and large manufacturing enterprises based on the results of the systematic literature review, survey and statistical hypotheses tests. Source: Based on sources relevant for table 3.7 and findings of the survey and statistical hypotheses tests.

LARGE ENTERPRISE **(Based on the results of the systematic literature review)**	**SMALL ENTERPRISE** **(Based on the results of the systematic literature review)**	**SMALL ENTERPRISE** **(Based on the results of the survey and statistical hypotheses tests)**
Master Black Belt 0.1% MBBs in relation to the total workforce Full-time role	**Black Belt** MBBs are not required	**Black Belt** MBBs are not required
Black Belt 2% BBs in relation to the total workforce Full-time role 100.000 € cost savings per project Between four and seven project executions per year Main roles and responsibilities: 1. Change agent 2. SS expert 3. Coach Main skills: 1. Analytical skills 2. Expertise in SS methods and tools 3. Data/fact driven	<1% BBs in relation to the total workforce Part-time role Between 35.000 € and 40.000 € cost savings per project Main roles and responsibilities: 1. Mentor/Coach	<1% BBs in relation to the total workforce Part-time role 30.000 € cost savings per project One to two project executions per year Main roles and responsibilities: 1. Mentor/Coach 2. SS expert 3. Leader of strategic projects Main skills: 1. Coaching/training skills 2. Expertise in SS methods and tools 3. Analytical and leadership skills

Green Belt 5% GBs in relation to the total workforce Part-time role or at least 30% of the working time towards SS projects 45.000 € cost savings per project Up to three project executions per year	**Green Belt** >5% GBs in relation to the total workforce 20% of the working time towards SS projects	**Green Belt** 5% GBs in relation to the total workforce 30% of the working time towards SS projects 17000 € cost savings per project Three to four project executions per year <u>Main roles and responsibilities</u>: 1. Analyst of root causes 2. Critical problem solver 3. Member of improvement projects <u>Main skills</u>: 1. Analytical skills 2. Problem-solving skills 3. Expertise in SS method and tools
Yellow Belt Support of GBs WBs are not required	**Yellow Belt** Support of GBs **White Belt** Between 10% and 15% WBs in relation to the total workforce 5.500 € cost savings per project Four to five project executions per year	**Yellow Belt** Support of GBs WBs are not required

RESEARCH GOAL 6: To identify the differences between the current and target status of the deployment of Six Sigma belts in manufacturing SMEs

The current literature presents one article of Timans et al. (2012) that included the proportion of the various SS belts in relation to the total workforce in manufacturing SMEs. However, this is too little data to draw conclusions and evaluate if the recommended guidelines from the literature reported in chapter 3.2 and the surveyed SS experts are being followed in practice. For this reason, more SMEs had to be studied. Although the survey of this study reveals that SS is only implemented in 23 of the 108 manufacturing SMEs that employ the surveyed SS experts, the results of the survey and statistical hypotheses tests show that the SS belt deployment in these companies is largely in accordance with the recommended guidelines of the current literature reported in chapter 3.2 and the surveyed SS experts (see table 5.2).

Table 5.2. Difference between the current and target status of the Six Sigma belts deployment in manufacturing SMEs. Source: Author.

Six Sigma belt deployment elements	Current status in the 23 SMEs[10]	Proposal of current literature	Proposal of Six Sigma experts[11]
Black Belt proportion	3.2%	0.4%-0.8%	0.8%
Green Belt proportion	7.6%	>5%	6%
Black Belt working time	40%	50%	50%
Green Belt working time	20%	20%	30%

The BB proportion of less than 1% as suggested by Kumar et al. (2011) and the surveyed SS experts as well as the proposed GB proportion of 5% to 6% by the surveyed SS experts and the researchers of the current literature mentioned in chapter 3.2 are exceeded in most of the 23 manufacturing SMEs. On average, 3.2% BBs and 7.6% GBs in relation to the total workforce are deployed in the 23 manufacturing SMEs.

[10] Consideration of mean values

[11] Consideration of mean values

The BB working time towards SS is found to be at around 40% on average in those 23 manufacturing SMEs. Thus, it is fairly similar to the working time of 50% proposed by Nonthaleerak and Hendry (2008), Schroeder et al. (2008) and the surveyed SS experts. The GB working time towards SS is on average around 20% in the 23 manufacturing SMEs. These 20% are in line with the recommendation of Antony et al. (2005 and 2008) but not with the suggestion of the surveyed SS experts who proposed an average GB working time of around 30% towards SS.

5.2 Conception of an effective Six Sigma belt deployment structure

The research findings will be used as input for the conception of an effective SS belt deployment structure in manufacturing SMEs.

Since SS cannot be applied in SMEs in the same way as in larger enterprises due to the various disadvantages that SMEs face (see chapter 2.5), a minor presence of BBs than in large enterprises and at least identical presence of GBs as in large enterprises on a percentage basis are suggested. Moreover, the deployed SS belts are largely not able to invest their working time towards SS, execute SS projects and accordingly save costs in the same manner as in larger enterprises.

It was found that GBs shall be the driving force for improvement projects while the focus of BBs shall rather be placed on coaching, teaching and mentoring the lower-level SS belts, whereby the presence of MBBs can be omitted. To support GBs and BBs in their daily work, the YB educational level as basic training form is recommended for other employees in the organization.

Table 5.3 summarizes the research findings in a concept consisting of guidelines regarding the following points: main responsibilities, roles, required skills, proportion in relation to the total workforce, invested working time towards SS, possible number of SS projects that can be executed and related cost savings of GBs and BBs. Moreover, it shall serve as a best practice guide for small manufacturing enterprises aiding the establishment of an effective and robust SS belt deployment structure in their organizations.

Following these guidelines, a SME with an employee size of 500 employees that includes four BBs (0.8%) and 25 GBs (5%) could be able to save between 1.5 million € and 2 million € in total per year.[12]

[12] 4 Black Belts * 1.5 Six Sigma projects * 35.000 € cost savings = 210.000 € cost savings/year by Black Belts

25 Green Belts * 3.5 Six Sigma projects * 17.500 € cost savings = approx. 1.5 million € cost savings/year by Green Belts

Table 5.3. Conception of an effective Six Sigma belt deployment structure in manufacturing SMEs. Source: Author.

Black Belt	
Mentor and coach	
Roles and responsibilities	**Skills**
1. Mentor and coach 2. Six Sigma expert 3. Leader of strategic projects	1. Coach/training skills 2. Expertise in Six Sigma method and tools 3. Analytical and leadership skills
Proportion in relation to the total workforce	**Invested working time towards Six Sigma**
<1%	Around 50%
Potential number of Six Sigma projects that can be executed	**Potential cost savings per Six Sigma project**
1-2 per year	30.000 € - 40.000 €
Green Belt	
Driving force for improvement projects	
Roles and responsibilities	**Skills**
1. Analyst of root causes 2. Critical problem solver 3. Member of improvement projects	1. Analytical skills 2. Problem-solving skills 3. Expertise in SS methods and tools
Proportion in relation to the total workforce	**Invested working time towards Six Sigma**
Minimum 5%	20% - 30%
Potential number of Six Sigma projects that can be executed	**Potential cost savings per Six Sigma project**
3-4 per year	15000 € - 20000 €
Yellow Belt	
Basic training form for other employees in the organization Support Black Belts and Green Belts	

5.3 Verification of research goals

In view of the problem description, namely that the traditional SS belt approach cannot be fully adopted in SMEs, the main objective of this dissertation was to answer the research question in what way the Six Sigma belt deployment structure in manufacturing SMEs differs from the traditional Six Sigma belt deployment structure used in large manufacturing enterprises. In line with the research question, six research goals were established. The research findings of this study provide sufficient evidence on the basis of which the research goals could be achieved.

Table 5.4 summarizes the evaluation of the research goals, including references of the evidence discussed and obtained in the course of this research study.

Table 5.4. Verification of research goals. Source: Author.

Research goals	**References of evidence**	**Status**
RG1: *To identify the key Six Sigma belts, their roles, responsibilities and their required skills in manufacturing SMEs compared to large manufacturing enterprises*	Tables 3.7, 3.8, 4.32, 4.33, 4.34, 4.35, 4.36, 4.37, 5.1	Resolved
RG2: *To identify the Six Sigma belt proportions in relation to the total workforce in manufacturing SMEs compared to large manufacturing enterprises*	Tables 3.7, 3.8, 4.38, 4.40, 5.1	Resolved
RG3: *To identify the required invested working time of the individual Six Sigma belts towards Six Sigma projects in manufacturing SMEs compared to large manufacturing enterprises*	Tables 3.7, 4.39, 4.40, 5.1	Resolved
RG4: *To identify the possible number of projects that can be executed by the various Six Sigma belts in manufacturing SMEs compared to large manufacturing enterprises*	Tables 3.7, 4.41, 4.43, 5.1	Resolved
RG5*: To identify the possible cost savings by the various Six Sigma belts in manufacturing SMEs compared to large manufacturing enterprises*	Tables 3.7, 4.42, 4.43, 5.1	Resolved
RG6: *To identify the differences between the current and target status of the deployment of Six Sigma belts in manufacturing SMEs*	Tables 3.8, 4.38, 4.39, 4.44, 4.45, 4.46, 5.2	Resolved

6. CONCLUSIONS

Last but not least, contributions of the thesis to science and practice as well as its limitations, an outlook on future research and brief summary will be presented.

6.1 Contribution to science

There are a number of personal views from practitioners and consultants about the deployment of the various SS belts in manufacturing SMEs, however, there are so far almost no empirical studies.

As stated in chapter 1.1, many researchers request adaptions to the deployment of the SS belt approach in SMEs as it cannot be applied in the same manner as in large organizations. The conducted study is one of the first attempts to research the SS belt deployment structure in manufacturing SMEs empirically, thereby following-up the research gaps by Antony et al. (2019) and Alexander et al. (2019).

An important contribution of this research to science lies in its research methodology which is a combination of a descriptive and an explanatory quantitative-based research design. After a systematic literature review, a survey was conducted. Its data was used to test statistical hypotheses for the evaluation of respective research hypotheses. Thus, valuable mathematical findings regarding the probability value (*p-value*), effect size (d) or power of the test ($1-\beta$) could be identified.

A further novelty is the demonstration of the SS implementation and SS belt deployment status in German SMEs. Although SS is only implemented in a small portion of those SMEs that employ the 108 respondents, the SS belts deployment in these companies is largely done in accordance with the guidelines identified through the current literature and surveyed SS experts. It must also be mentioned that there is already a high proportion of certified SS belts in the remaining SMEs that did not implement SS yet. This would greatly facilitate a SS implementation in future.

In addition, the new empirical findings and the knowledge acquired through this research extends the body of knowledge in the field of SS belts. The study makes several contributions to the industrial management, quality management, operations management and SME literature that were shared in well-known peer-reviewed journals and conference proceedings (see list of author’s publications on page 166).

6.2 Contribution to practice

The dissertation helps SMEs and their management with valuable information and provides knowledge on how to develop a proper and sustainable SS belt infrastructure for an effective execution of LSS projects despite several obstacles.

Although implementing SS is challenging for manufacturing SMEs (see chapter 1.1), the study shows that the SS belt system is already effectively implemented in some of those SMEs that employ the survey respondents. The cost savings from completed SS projects per year in those SMEs that already implemented Six Sigma (see table 4.29) as well as possible cost savings from a GB or BB per SS project in SMEs (see table 4.42) prove the benefit of that continuous improvement initiative. These facts give the management of SMEs more certainty that SS can be applied successfully in any organization, irrespective of its size.

Another input is table 2.3 of chapter 2.5 that focuses on the strengths, weaknesses and challenges regarding the implementation of SS in manufacturing SMEs. This collection of information helps the SME management to gain awareness on what deficiencies they have to overcome before implementing SS.

Since standard approaches or frameworks were not specifically developed for SMEs so far (see chapter 1.1), the research study provides a solution for the unique challenge that this organization size faces. Table 5.3 of chapter 5.2 includes a concept for an effective SS belt deployment structure in manufacturing SMEs. It can be considered as best practice approach or can be adjusted slightly according to respective circumstances and situations such as manufacturing type or industrial sector, production process complexity, product and production type, R&D expenditure etc.

Furthermore, the dissertation can have an additional effect, namely to attract more researchers and practitioners from different regions of the world to this field. The research results can be used to develop study materials for lectures, seminars and summer schools as well as to prepare students for a career in operations or quality in a manufacturing SME.

6.3 Limitations of the study

Despite the attempt to minimize weaknesses in this research work, there are some limitations that stand out.

Firstly, the present study focuses on the manufacturing sector on the whole. For this reason, it is difficult to carry over and generalize the findings to a specific type of industry such as automotive, consumer, chemical, energy etc. or to a manufacturing type such as metal, electrical, electronic, plastic or machinery products etc.

Secondly, more than 90% of the survey's respondents are from Germany (see table 4.22). For this reason, other researchers and practitioners of this topic area must consider that the findings are primarily applicable to SMEs with up to 500 employees as per definition of the IfM Bonn (2016). Since there is a vast degree of inconsistency on a global level and no universal agreement concerning a SME definition (see chapter 2.3), a comparison of the results on a global level may not be possible and using the findings of this research to make further investigations could be difficult for researchers from other countries. It also means that the developed concept for an effective SS belt deployment structure in manufacturing SMEs presented in chapter 5.2 is also not applicable for all SMEs worldwide. In the case of Chinese or American manufacturing SMEs that include more than 1000 employees (see chapter 2.3), for instance, the guidelines need to be adapted.

Thirdly, since the data was collected from a survey, the approach used to answer the questions may affect the quality of the research results because each respondent has a different view and experiences and this may contain certain bias.

Last but not least, for some of the statistical hypotheses tests, the required sample size (*N*) to detect the relevant effect size (*d*) could not be met by the survey which caused an insufficient power of the test of lower than 80% (see chapter 4.3.2). In this context, it also has to be mentioned that in some of these cases where *H0* was failed to be rejected, a decision in favour of *H0* could not really be made (see chapter 4.3.7).

6.4 Outlook on future research

Finally, the following research gaps are identified by the dissertation and it is proposed to investigate these research gaps in future research contributions.

At first, it is recommended that future research studies about the SS belt deployment system in SMEs shall focus on a specific industry sector such as automotive, consumer, chemical, energy etc. or manufacturing type such as metal, electrical, electronic, plastic or machinery products etc. to receive a more precise and deeper knowledge about this research topic since this study considers the entire manufacturing sector on the whole.

Secondly, similar surveys shall be conducted in different countries of the world to investigate the SS implementation and SS belt deployment status there and compare the results with that study, since this study focuses mainly on the German industry. Also, the proposed concept including the guidelines developed in the context of this study must be verified.

Thirdly, since this research study focuses mainly on how the SS belts deployment shall be structured in manufacturing SMEs compared to large manufacturing enterprises, future research contributions shall primarily provide deeper knowledge about the reasons why the SS belt deployment structure in manufacturing SMEs differs from the traditional SS belt deployment structure used in large manufacturing enterprises.

Fourthly, a survey as research instrument was chosen in the course of this research study. For future research contributions, it is proposed to also include other research methods such as reviews, case studies, expert interviews, group discussions and conversations, observations, content analysis etc.

Fifthly, effect sizes (*d*) that present the magnitude of a statistical effect are known through this research study and can be used in future empirical studies to compute the required sample sizes (*N*) as well as be compared with other statistical hypotheses test results.

Sixthly, these statistical hypotheses tests where $H0$ was failed to be rejected and the power of the test ($1-\beta$) was large enough (≥80%) can be repeated in future research studies with an increased sample size (*N*) to find out if smaller effect sizes (*d*) might possibly exist.

Seventhly, these statistical hypotheses tests where $H0$ was failed to be rejected and the power of the test ($1-\beta$) was lower than 80% can also be repeated in future research studies with an increased sample size (*N*) so that the probability to detect the relevant effect sizes (*d*) is large enough (≥80%) and representative results can be received. These required sample sizes (*N*) were already computed during the priori power analysis (see chapter 4.1.5).

Last but not least, the described benefits of the WB type for SMEs in the current literature could not be confirmed by this study. Future research contributions must place special focus on the WB category since it is still a grey area. More SS experts of SMEs from the entire world have to be surveyed about this SS belt type and share their experiences.

6.5 Summary

LSS and SS belong to the most popular continuous improvement strategies that were developed to enhance processes with the objective of eliminating non-value-added activities and achieving error-free products, thus increasing customer satisfaction, business productivity as well as financial performance (Schroeder et al. 2008; Snee, 2010; Albliwi et al. 2014 and 2015).

Since the traditional SS organizational infrastructure is not desirable in the case of SMEs according to many researchers (see chapter 1.1), the research question of the dissertation is how the SS belt deployment structure in manufacturing SMEs differs from the traditional SS belt deployment structure used in large manufacturing enterprises. In order to answer the research question, six research goals were defined as support. In detail, the research is focusing on the key SS belts for manufacturing SMEs, their roles, responsibilities and skills, their proportion in relation to the total workforce and invested working time towards SS, their possible number of SS projects that can be executed and the related cost savings compared to large manufacturing organizations. Moreover, it focuses on identifying the differences between the current and target state of the SS belts deployment in manufacturing SMEs.

It is one of the first attempts to research the SS belt deployment structure in manufacturing SMEs on an empirical basis. A combination of a descriptive and explanatory quantitative-based research design was chosen as research methodology to answer the research question and meet the research goals. Based on conclusions from theoretical fundamentals and a systematic literature review, research hypotheses were defined that have to be evaluated by statistical hypotheses tests for which primary data were collected through a survey of SS experts such as MBBs, BBs, GBs, YBs, CEOs, Directors, General Managers, Middle Managers, Quality and Production Professionals. In total, seven research hypotheses were defined that were linked to a large number of statistical hypotheses for their evaluation. Finally, five of these seven research hypotheses could be accepted.

The results obtained in the course of the dissertation work show that SS is only implemented in a small portion of those manufacturing SMEs that employ the 108 respondents. However, the SS belts in these manufacturing SMEs are largely deployed according to the guidelines established by the researchers in the current literature and surveyed SS experts. It could be determined that manufacturing SMEs do not need such an extensive organizational infrastructure with MBBs and full-time BBs as applied in large manufacturing enterprises. By contrast, it is highly advisable to focus on GBs who should be the driving force of the initiative and be responsible to drive up business performance as well as customer satisfaction in manufacturing SMEs. BBs shall take on the coaching and trainer role in manufacturing SMEs while MBBs are not required in a SME environment at all. Concerning the WB type praised in the current literature as alternative for SMEs, it can be said that it remains a grey area and needs to be the focus of future research contributions.

The research findings were used as input for the development of a conception, including guidelines for an effective SS belt deployment structure that shall serve as best practice guide for manufacturing SMEs. It turned out that a BB proportion of less than 1% in relation to the total workforce and a BB working time of 50% would be suitable for manufacturing SMEs. As far as GBs are concerned, a proportion of 5% in relation to the total workforce and a working time between 20% and 30% was found to be suitable for manufacturing SMEs. Furthermore, BBs shall be able to execute one to two SS projects per year, thereby saving around 30.000 € to 40.000 € costs per SS project while GBs shall be able to execute three to four SS projects per year, thereby saving around 15.000 € to 20.000 € per SS project.

To sum this up, it can be said that the dissertation work provides enough findings to resolve all of the formulated research goals and answer the research question as accurately and completely as possible. The dissertation makes a valuable contribution to the literature of the SS belt system as well as provides knowledge for the industry on how to create a proper and sustainable SS belt infrastructure in manufacturing SMEs. However, there is a need to supplement the gained findings from this dissertation work in future research contributions in order to obtain more meaningful and in-depth knowledge of the topic area. In conclusion, this dissertation work implies immense potential for science and industry and, consequently, has to be considered as a starting point for further research about this topic.

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APPENDIX A. SURVEY ABOUT THE SIX SIGMA BELT SYSTEM

Dear Sir or Madam,

This is an academic study of the Tomas Bata University in Zlin, Czech Republic, and your responses are very valuable to us as researchers. I would like to know your viewpoint and experiences with regard to the individual Six Sigma belts in small manufacturing enterprises. This questionnaire is anonymous and the results will be used for the purpose of scientific research. The ultimate outcome of this research survey will be sent to you. Respondents of the survey should mostly be employees working at small manufacturing enterprises. The profile of the respondents selected for the survey should be Master Black Belts, Black Belts, Green Belts, Yellow Belts, CEOs, Directors, General Managers, Middle Managers, Quality and Production Professionals. However, also some study participants whose company has not yet implemented the Six Sigma methodology but who have excellent knowledge in Six Sigma will be included in this survey. The questionnaire takes approximately 20 minutes to complete.

Introduced information:

While Six Sigma was initially applied within large corporations, the interest of small and medium-sized enterprises (SMEs) in improvement initiatives is increasing. More than a decade ago, SMEs became aware that they can enhance their capability, improve quality and increase their profitability by using Six Sigma. One of the most important critical success factors for the implementation of Six Sigma is a strong organizational infrastructure led by different improvement specialists, also known as Six Sigma belts (Master Black Belt, Black Belt, Green Belt, Yellow Belt and White Belt). Since there are too many organizational differences between large enterprises and SMEs, the traditional Six Sigma belt approach used by large organizations cannot simply be transferred for the application in small enterprises. Therefore, the aim of this survey is to review how the Six Sigma belt deployment structure in manufacturing SMEs would differ from the Six Sigma belt deployment structure in large manufacturing enterprises. There are various expert opinions but almost no empirical evidences regarding the availability, proportion to the total workforce, working time, hierarchy, number of projects that can be executed and cost savings, skills, roles and responsibilities of the various Six Sigma belts in small enterprises. This research field is by no means sufficiently explored and requires further research from both, academics and the industry. For this, more and more practical and empirical studies as well as expert interviews must be conducted in different regions of the world so that an infrastructure for a sustainable Six Sigma belt deployment in small manufacturing enterprises can be specified.

<u>PART I:</u> **General Information**

Survey question 1.1: *What is your current work title?*

- CEO/Managing Director
- Senior Management
- Project Manager/Leader
- Quality Manager
- Quality Engineer
- Operation/Production Manager
- Operation/Production Engineer
- Consultant
- Quality Director / VP
- Operation/ Production Director / VP
- Other...

Survey question 1.2: *What kind of Six Sigma belt do you have?*

- Master Black Belt
- Champion
- Black Belt
- Green Belt
- Yellow Belt
- White Belt
- None
- Other...

Survey question 1.3: *How much work experience do you have with Six Sigma / Lean Six Sigma?*

- Less than 2 years
- Between 2 and 5 years
- Between 5 and 10 years
- Between 10 and 15 years
- More than 15 years
- None

Survey question 1.4: *How much work experience do you have in small manufacturing enterprises?*

- Less than 2 years
- Between 2 and 5 years
- Between 5 and 10 years
- Between 10 and 15 years
- More than 15 years
- None

Survey question 1.5: *What is the employee size of the manufacturing location you are working for?*

- Less than 10 employees
- Between 10 and 50 employees
- Between 50 and 100 employees
- Between 100 and 150 employees
- Between 150 and 200 employees
- Between 200 and 250 employees
- Between 250 and 350 employees
- Between 350 and 500 employees

Survey question 1.6: *What is the age of your SME?*

- Less than 10 years
- Between 10 and 20 years
- Between 20 and 30 years
- Between 30 and 40 years
- More than 40 years

Survey question 1.7: *In which country is your SME?*

- Czech Republic
- Slovakia
- Germany (Bavaria)
- Germany (Baden Württemberg)
- Germany (Rheinland Pfalz)
- Germany (Nordrhein Westfalen)
- Germany (Niedersachsen)
- Germany (Thüringen)
- Germany (Hessen)
- Germany (Bremen)
- Germany (Hamburg)
- Germany (Saarland)
- Germany (Schleswig Holstein)
- Germany (Mecklenburg-Vorpommern)
- Germany (Brandenburg)
- Germany (Sachsen-Anhalt)
- Germany (Sachsen)
- Germany (Berlin)
- Other...

Survey question 1.8: *In what kind of industrial sector is your SME operating?*

- ◯ Consumer goods industry
- ◯ Automotive industry
- ◯ Energy industry
- ◯ Chemical industry
- ◯ Pharmaceutical industry
- ◯ Food industry
- ◯ Machinery industry
- ◯ Medicine industry
- ◯ Textile industry
- ◯ Other...

Survey question 1.9: *What kind of manufacturing sector does your SME belong to?*

- ◯ Manufacture of food products, beverages and tobacco
- ◯ Manufacture of textiles, leather and corresp. products
- ◯ Manufacture of paper products, publishing and printing
- ◯ Manufacture of chemicals, chemical products, etc.
- ◯ Manufacture of rubber and plastic products
- ◯ Manufacture of basic metals and fabricated metal produ
- ◯ Manufacture of machinery and equipment n.e.c.
- ◯ Manufacture of electrical products and equipment
- ◯ Manufacture of transport equipment
- ◯ Manufacture of electronics products
- ◯ Manufacture of medical, precision and optical instrument
- ◯ Manufacture of glass products
- ◯ Other...

PART II: Current state of the Six Sigma belt system in manufacturing SMEs

Survey question 2.1: *Did your SME implement the Lean Six Sigma/Six Sigma approach?*

- ☐ Yes
- ☐ No

Survey question 2.2: *Does your SME intend to implement the Lean Six Sigma/Six Sigma methodology in the future? (Only to be answered if the previous question was answered with "No")*

- ☐ Yes
- ☐ No

Survey question 2.3: *Since when is your SME working with Six Sigma?*

- ○ Less than 2 years
- ○ Between 2 and 5 years
- ○ Between 5 and 8 years
- ○ 8 years and more
- ○ None

Survey question 2.4: *How many Six Sigma projects has your SME already completed?*

- ○ Less than 5 projects
- ○ Between 5 and 10 projects
- ○ Between 10 and 20 projects
- ○ Between 20 and 30 projects
- ○ More than 30 projects
- ○ None

Survey question 2.5: *How many Six Sigma projects does your SME start per year?*

- ○ Less than or 2 projects
- ○ Between 3 and 5 projects
- ○ Between 6 and 8 projects
- ○ More than 8 projects
- ○ None

Survey question 2.6: *What kinds of Six Sigma belts are available in your SME?*

- ☐ Master Black Belt
- ☐ Champion
- ☐ Black Belt
- ☐ Green Belt
- ☐ Yellow Belt
- ☐ White Belt
- ☐ None
- ☐ Other...

Survey question 2.7: *How many costs does your SME save through Six Sigma projects per year?*

- ○ Less than 50.000 €
- ○ Between 50000 € and 150000 €
- ○ Between 150000 € and 250000 €
- ○ Between 250000 € and 500000€
- ○ More than 500000 €
- ○ None

Survey question 2.8: *How many Champions are available in your SME? (Answer in %)*

Survey question 2.9: *How many Master Black Belts are available in your SME? (Answer in %)*

Survey question 2.10: *How many Black Belts are available in your SME? (Answer in %)*

Survey question 2.11: *How many Green Belts are available in your SME? (Answer in %)*

Survey question 2.12: *How much working time do Black Belts spend for Six Sigma in your SME? (Answer in %)*

Survey question 2.13: *How much working time do Green Belts spend for Six Sigma in your SME? (Answer in %)*

PART III: Target state of the Six Sigma belt system in manufacturing SMEs

Survey question 3.1: *From your viewpoint, what roles and responsibilities should Black Belts in manufacturing SMEs have?*

- ☐ Change agent
- ☐ Coach
- ☐ Critical problem solver
- ☐ Analyst of root causes
- ☐ Mentor
- ☐ Leader of strategic projects
- ☐ Demonstrating bottom-line results i
- ☐ Member of improvement projects
- ☐ Project manager/leader
- ☐ Six Sigma expert

Survey question 3.2: *From your viewpoint, what roles and responsibilities should Green Belts in manufacturing SMEs have?*

- ☐ Change agent
- ☐ Coach
- ☐ Critical problem solver
- ☐ Analyst of root causes
- ☐ Mentor
- ☐ Leader of strategic projects
- ☐ Demonstrating bottom-line results i
- ☐ Member of improvement projects
- ☐ Project manager/leader
- ☐ Six Sigma expert

Survey question 3.3: *From your viewpoint, what skills should Black Belts in manufacturing SMEs have?*

- ☐ Analytical skills
- ☐ Expertise in Six Sigma methods and tools
- ☐ Data/fact driven
- ☐ Coaching/training skills
- ☐ Problem solving skills
- ☐ Leadership skills
- ☐ Presentation skills
- ☐ Customer advocacy
- ☐ Project Management skills
- ☐ Result-oriented leadership
- ☐ Technical skills
- ☐ Collaboration skills
- ☐ Organisational skills
- ☐ Process-oriented skills
- ☐ Social/interpersonal skills

Survey question 3.4: *From your viewpoint, what skills should Green Belts in manufacturing SMEs have?*

- ☐ Analytical skills
- ☐ Expertise in Six Sigma methods and tools
- ☐ Data/fact driven
- ☐ Coaching/training skills
- ☐ Problem solving skills
- ☐ Leadership skills
- ☐ Presentation skills
- ☐ Customer advocacy
- ☐ Project Management skills
- ☐ Result-oriented leadership
- ☐ Technical skills
- ☐ Collaboration skills
- ☐ Organisational skills
- ☐ Process-oriented skills
- ☐ Social/interpersonal skills

Survey question 3.5: *Master Black Belts are not needed in a SME environment since the Black Belt can take on the role of the trainer on different Six Sigma expertise levels and instruct the rest of the employees. Do you agree with this statement?*

	1	2	3	4	5	
strongly disagree	○	○	○	○	○	strongly agree

Survey question 3.6: *According to personal views of some researchers, the rule of thumb for large enterprises is to deploy 10 Black Belts per 500 employees. This is not applicable for SMEs. The literature shows that in small enterprises around 1–2 Black Belts have to be available in a firm with 250 employees. From your viewpoint, how many Black Belts per 500 employees shall be available in a SME of your manufacturing sector and with your production process complexity on average? (Answer in %)*

Survey question 3.7: *As guideline for larger enterprises various researchers argue for having approximately 5 Green Belts per 100 employees in a company. The proportion of Green Belts in relation to the total workforce is assumed to be higher in SMEs than in larger enterprises. From your viewpoint, how many Green Belts per 100 employees shall be available in a SME of your manufacturing sector and with your production process complexity on average? (Answer in %)*

Survey question 3.8: *The focus in small manufacturing enterprises should rather be on the implementation and training of more Green Belts and there should be less Black Belts compared to large enterprises. The reason for this is that Black Belts and Green Belts could be interchangeable at SMEs in about 80% of the organization´s Six Sigma opportunities. Therefore, using a Green Belt approach instead of a Black Belt approach would allow SMEs to implement Six Sigma at a less costly, more manageable pace. Do you agree with this approach?*

	1	2	3	4	5	
strongly disagree	○	○	○	○	○	strongly agree

Survey question 3.9: *Are you familiar with White Belts?*

☐ Yes ☐ No

Survey question 3.10: *Do you know the roles and responsibilities of White Belts?*

☐ Yes ☐ No

Survey question 3.11: *The current White Belt training offered is a waste of time since the Yellow Belt training already represents a recognized preschool and provides a basic overview introduction of Six Sigma. Do you agree with the statement?*

	1	2	3	4	5	
strongly disagree	○	○	○	○	○	strongly agree

Survey question 3.12: *According to personal views of some researchers, the rule of thumb for large enterprises is to deploy full-time Black Belts. This is not applicable for SMEs. It is suggested that Black Belts shall spend around 50% of their working time on Six Sigma projects in SMEs. From your viewpoint, how much working time shall Black Belts spend on Six Sigma in a SME of your manufacturing sector and with your production process complexity on average? (Answer in %)*

Survey question 3.13: *Green Belts are part-time improvement specialists in large enterprises. In SMEs, Green Belts should be able to spend 20% of their working time on Six Sigma. From your viewpoint, how much working time shall Green Belts spend on Six Sigma in a SME of your manufacturing sector and with your production process complexity on average? (Answer in %)*

Survey question 3.14: *From your viewpoint, how many Black Belt projects can be executed in a manufacturing SME on average per year? Please consider that Black Belt projects are more complex and take more time to execute. Moreover, Black Belts should be responsible to support Green Belts in their Six Sigma projects.*

○ 1 project

○ 2 projects

○ 3-5 projects

○ 6-8 projects

○ More than 8 projects

Survey question 3.15: *From your viewpoint, how many Green Belt projects can be executed in a manufacturing SME on average per year?*

- 1 project
- 2 projects
- 3-5 projects
- 6-8 projects
- More than 8 projects

Survey question 3.16: *From your viewpoint, how many costs on average can a Black Belt save per project in a manufacturing SME?*

- Less than 10000 €
- Between 10000 € and 20000 €
- Between 20000 € and 30000 €
- Between 30000 € and 40000 €
- Between 40000 € and 50000 €
- More than 50000 €

Survey question 3.17: *From your viewpoint, how many costs on average can a Green Belt save per project in a manufacturing SME?*

- Less than 10000 €
- Between 10000 € and 20000 €
- Between 20000 € and 30000 €
- Between 30000 € and 40000 €
- Between 40000 € and 50000 €
- More than 50000 €

Roland Stankalla

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Koncepce efektivního rozvoje struktury Six Sigma belt v malých a středních výrobních podnicích

Doctoral Thesis

Published by: Tomas Bata University in Zlín,

nám. T. G. Masaryka 5555, 760 01 Zlín.

Edition: 5 pcs

Typesetting by: Roland Stankalla

This publication has not undergone any proofreading or editorial review.

Publication year: 2021