Continuous quality improvement based on Lean Six Sigma in manufacturing small and medium sized enterprises

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Contents

1. Introduction and problem statement

In this chapter the topic of the thesis is introduced. After briefly discussing the background of Lean Six Sigma from a historical and scientific perspective, the particular context of small and medium sized manufacturing enterprises, relevant for the implementation of Lean Six Sigma, is described. Subsequently, the research topic is described in more detail, concluding with the research objective and an overarching research question. This chapter ends with a brief synopsis of the main issues addressed in the chapters of this thesis.

1.1 **Continuous Improvement in industry**

Product quality is generally accepted as being crucial in today's industrial business. The traditional aspects of product quality are connected to product design (translating customer demands into attractive features and technical specifications) and to the design and specification of high performance production processes with low defect rates. Quality management is the general expression for all actions leading to quality. According to Juran (1989, ch.2) quality management consists of three processes: *quality planning*, *quality control* and *quality improvement.* Quality planning encompasses the determination of customer needs and the development of products and processes required to comply with these needs. Quality control focuses on the reaction to irregularities in the production process, and Quality improvement is defined as organised change to create a breakthrough in the quality level. Juran (1989, ch.3) states that achievements of especially the third process, Quality improvement, are best reached by working on projects.

The Six Sigma approach to quality improvement that emerged in the 1980s can be regarded as an operationalization of this vision. Six Sigma appeared initially within Motorola, followed by many large industrial organizations in the US and later on in Europe. Improving quality in the Six Sigma way is done by projects after a strategic project selection process, carried out in a structured way and supported by improvement specialists and engaged leaders using an extensive set of tools including advanced statistical tools (Schroeder et al., 2008). Recent studies of Shafer and Moeller (2012) and Swink and Jacobs (2012) confirm the impact of Six Sigma on performance, expressed in improved employee productivity and financial performance.

Already a few decades earlier a new approach emerged in Japan focussing on the improvement of process performance, The Toyota Production System (Ohno, 1988), which has evolved to what is now known as lean manufacturing. The continuous improvement approach emphasizes efforts to eliminate waste and to reduce variability (Shah and Ward, 2007) optimizing the so-called ‘value added time’ as part of the total lead time. In lean manufacturing participation of employees on the shop floor is needed and strongly stimulated. Short improvement projects are carried out on the shop floor and improvements reached in this way are visible and tangible for all employees. Since about 2001 suggestions came up to merge lean manufacturing and Six Sigma into Lean Six Sigma (George, 2002). The reasons for this merger are not completely logical: the Six Sigma approach is clearly top-down and is experienced by many adopters as less applicable on the shop-floor (Timans et al., 2012), whilst the lean manufacturing approach is more bottom up. Many lean manufacturing tools are very well applicable on the shop floor, thus offering chances for shop-floor employees to be intensively involved.

Snee and Hoerl (2007) state that the main focus of the lean approach is on improving the flow between processes, and Six Sigma mainly concentrates on improving the processes themselves. The two are not independent, poor flow between processes may deteriorate process performance and, on the other hand, low process performance may cause problems in the flow between processes. In their vision an integrated Lean Six Sigma approach should encompass both “quick hit” projects and Kaizen projects on the one hand and Six Sigma projects taking a number of months on the other.

Although the DMAIC project structure (Define-Measure-Analyse-Improve-Control) originated in Six Sigma, it can be associated and generalised as an overall framework for process improvement. This structure enables to apply the tools that are appropriate to tackle a particular problem at the appropriate point in the sequenced approach of DMAIC. Snee and Hoerl (2007) point out that there are no such things as Six Sigma tools or lean tools because neither method invented tools. The two approaches have often been implemented in isolation, creating chances for lean and Six Sigma subcultures to emerge within an organization, which can cause a conflict of interest and a drain on resources (Bendell, 2006).

We support the arguments for the integration of lean manufacturing and Six Sigma as described previously and choose to focus our research on the development and deployment of a continuous improvement infrastructure in manufacturing SMEs based on Lean Six Sigma

(LSS). In the next section the specific characteristics of SMEs relevant for quality management practices will be described thereby substantiating the need for a specific SME-focussed approach of LSS. In this dissertation, we aim to advance our understanding of such an SME-focussed approach of LSS.

1.2 Manufacturing SMEs: characteristics relevant for the deployment of LSS-based continuous improvement

In the study 'Small and medium enterprises across the globe' (Ayyagari et al., 2007), SMEs have a maximum of 250 full-time employees. According to the definition adopted by the EU Commission, SME organizations are enterprises with fewer than 250 employees, and with additional conditions, for example, on maximal annual turnover and balance sheet total. The Ayyagari study reports that in the countries of the European Union more than 50% of the employees in manufacturing companies are working in SMEs. The share of SMEs with respect to Gross Domestic Product (GDP) is lowest in Sweden (39%) and highest in Portugal (67%). The GDP data are not limited to manufacturing, but at least the data indicate that SMEs of all the economic sectors contribute strongly to the national GDP.

With respect to performance measurement in SMEs little has been published on the European scale. In their study on performance measures in Portuguese SMEs, Sousa et al. (2013) report that *on-time delivery* and *in process quality* are the highest ranked performance measures according to their importance for company strategy, and that *training of employees* was the highest ranked obstacle to adoption of new performance measures. Lack of resources is a great concern for Portuguese SMEs, just as has been reported in other studies carried out in other countries (Kumar et al., 2012). Many manufacturing SMEs have quality management systems in place and are ISO-9001 certified, but the general picture is that ISO-9001 only sets a baseline and that additional efforts are needed with respect to reaching higher levels of ability to improve continuously (Conti, 2004, Yeh et al., 2013).

The literature points out that SMEs differ significantly from large organizations, SMEs having relatively informal structures and culture (Mintzberg, 1979), small management teams with a high degree of cross-functional exchanges. In table 1.1 the main SME-characteristics are presented, based on selected literature sources (Burns & Stalker, 1961, Mintzberg, 1979, Snider et al., 2009, Gélinas and Bigras, 2004, Ates and Bititci, 2011). The first two sources are groundbreaking textbooks. The studies of Snider et al., Gélinas and Bigras, and Ates and Bititci all have the focus on implementation in an SME-context, but they do not focus specifically on the implementation of quality improvement practices. Snider et al. (2009) study the implementation of ERP, Gélinas and Bigras (2004) study the integration of logistics, and Ates and Bititci(2011) study the development of change capabilities to improve resilience. The SME-characteristics presented in table 1.1 are believed to be relevant for the management of change processes. Implementing a continuous improvement programme can be regarded as a change process.

SME-characteristics relevant for.implementing change
• There is a lack of human and financial resources (Ates, Snider). SMEs cannot afford extensive training (Snider) • A firefighting approach is used to solve day-to day problems (Ates) • The culture of the organization is characterized as a command and control culture (Ates) • The owner-manager has a need for independence, autonomy and power, combined with a low propensity to delegate and consult (Gélinas, Mintzberg) • Strategies are intuitive and opportunistic and the process of strategic planning is incremental combined with a relatively short planning horizon (Gélinas, Ates, Snider) • The prime coordinating mechanism is direct supervision (Mintzberg) • Owner-manager is in direct contact with operations (Gélinas) • The structure and culture are informal; a small management team operates with an efficient decision making process (Gélinas, Ates, Snider) • The organization is flexible (Gélinas) and organic (Burns & Stalker, Mintzberg)

Table 1.1 SME-characteristics relevant for implementing change

The first characteristic of table 1.1 is obviously unfavourable for the deployment of continuous improvement based on LSS. For many SMEs it will for instance be practically infeasible to invest in education and training for employees to become full time Black Belts, and also large investments in assistance from external agents will be difficult to realise. Also the firefighting approach to solve problems has a negative connotation, when it is a dominant cultural characteristic. A characteristic as “command and control culture” is the strongest characterization of a culture that may be unfavourable for the implementation of an LSS programme, mainly because it does not stimulate the employee’s intrinsic motivation and does not encourage employees to cooperate voluntarily. Less stronger expressed is the characterization of the owner-manager with a strong need for independence, autonomy and power. Such a manager may be interested in change itself, but will probably not be inclined to trustfully listen with an open mind to project proposals from lower managers and employees. The intuitive and opportunistic strategy and short planning horizon of SMEs are not favourable for the implementation an LSS programme that will take several years and that needs an extensive preparation. When it is poorly launched it will be difficult to regain momentum.

Favourable characteristics for the implementation of change are those which are connected to the informal structure and culture, and to the organization's properties as being flexible and organic. The direct supervision as prime coordinating mechanism can be favourable when the top-management is convinced of the need for change and the culture has organic features, and may have some risks when it is expressed in a very directive style impeding the stimulation of the intrinsic motivation of lower managers and employees. The owner-manager being in direct contact with operation similarly can work in two ways, favourable or unfavourable, depending on the vision, attitude and behaviour of the owner-manager.

Thus overlooking the complete picture it may be concluded that a specific approach is needed to deploy LSS in SMEs. Just copying and downsizing implementation programmes from large organizations to apply in SMEs is likely to be infeasible.

1.3 Objective of the thesis and research approach, research questions

On the advancement of continuous improvement many books and articles have been published in the course of recent decades. Many large companies have made tremendous progress in deploying continuous improvement programmes based on Lean Six Sigma, leading to sustainable change in their abilities to meet increasing customer demands (Snee, 2004). For SMEs, however, the current situation is quite different. In literature on the deployment of continuous improvement based on Lean Six Sigma the difficulties of implementing it in SMEs are specifically addressed (see for instance Antony et al., 2005, 2008, Kumar et al., 2011, Gnanaraj et al., 2010, Timans et al., 2012).

The research objective of this thesis is therefore to understand how continuous improvement in manufacturing SMEs can benefit from the basic principles underlying Lean Six Sigma. This is expressed in the following overarching research question:

How can continuous improvement based on the basic principles underlying Lean Six Sigma be stimulated effectively in manufacturing SMEs?

At the start of our research we first wanted to grasp the real practice of Six Sigma projects. Which are the tools that are used, how relevant are these tools in the different project stages, how does the expert's consensus reflect the theoretical base of Six Sigma project execution as described in literature. For this theoretical base we used the rational reconstruction of the Six Sigma project stages of De Koning and De Mast (2006) as a reference. We chose to focus on Six Sigma rather than on LSS because we wanted to focus on projects carried out following the DMAIC structure, which originated in Six Sigma, expecting that within these projects also often lean manufacturing tools would be applied. We did not constrain ourselves to the manufacturing SME-context in this study, because of the paucity of the literature on projects carried out in SMEs. In the second and in the third project our focus on the manufacturing SME context is prevalent and these projects are directly connected to the research objective. The aim of the second study is to find out what are the critical success factors and impeding factors for deployment of Lean Six Sigma in manufacturing SMEs, how do managers perceive their relative importance and deal with them in practice and what are the underlying mechanisms of these factors. In the third project we focus on the main properties of a framework for the deployment of an LSS-based continuous improvement program, and propose a design of such a framework. The most logical next project would have been the testing of the proposed framework in practice. However the time needed for such a longitudinal study would not fit in the timeframe available for this research, and we therefore looked for an alternative. In the second study one of the salient outcomes was about the application of DoE techniques (Design of Experiments), which are included in the LSS toolbox. The results showed a large difference between the perceived usefulness of DoE and the real use in practice, in the sense that the expectations with respect to the use of DoE were high whilst DoE was hardly used in practice. We found a manufacturing SME in the plastic injection moulding industry willing to cooperate and carried out a project using DoE in this SME. In this field research the application of DoE to optimize an injection moulding process was the main objective. Injection moulding processes are influenced by a number of process parameters. We were interested in the application of DoE in this context, because we expected that it could improve the optimization process in an effective way by delivering better and robust machine set-points. Through carrying out such a project in an injection moulding company, starting from the problem-statement, we could experience all the practical project-stages including the unforeseen problems that could come up.

1.4 **An overview of this thesis**

The first study in this research, reported in Chapter 2, focusses on the tools and techniques for different phases of Six Sigma improvement projects in manufacturing and engineering organizations. A literature review has been conducted to identify tools and techniques applied in practice. Therefore case studies reporting projects carried out in industry have been selected from the literature. In a Delphi study, a group of experts discuss and prioritize statements on tools and techniques and group them into the DMAIC phases, resulting in a description of tools and techniques to be used in DMAIC structured projects.

In Chapter 3 the research objective is to provide an analysis of Lean Six Sigma implementation in manufacturing/engineering SMEs, predominantly based in The Netherlands. Exploratory empirical evidence about Lean Six Sigma implementation was collected from a survey study in SMEs. Critical success factors (CSFs) and impeding factors are identified and analysed. A similar study had been carried out in the UK (Antony, Kumar, and Madu, 2005). However, the UK study was based on survey-data from 60 companies, only 16 of them actually being involved in a Six Sigma programme. Therefore we considered the collection of new data to be useful, also to extend the data over new international regions. We also extended the focus from Six Sigma to Lean Six Sigma. To deepen insight into how organizations translate CSFs into practice and cope with impeding factors, additional in-depth qualitative information has been gathered from five case studies carried out in The Netherlands and from one carried out in the Dutch speaking part of Belgium.

In section 1.2 the need for an SME-tailored approach for the deployment of LSS-based continuous improvement has been emphasized referring to the particular characteristics of

manufacturing SMES. The focus of chapter 4 is the design of a framework for LSS-based continuous improvement tailored to the needs of SMEs in general. An existing framework for Six Sigma implementation for SMEs (Kumar et al., 2011) has been reviewed critically using focus group research together with a literature review and retrospective research into two Dutch companies with long-term experience in the deployment of Lean Six Sigma. The results of this study are presented as a collection of confirmations and revision proposals for the framework, as well as overall recommendations for deploying Lean Six Sigma in the context of SMEs. Finally a revised framework is proposed.
In Chapter 5 a case study is presented on the optimization of an injection moulding process applying DoE-methods included in the Lean Six Sigma toolbox. We wanted to experience the execution of a project ourselves in the real practice of an SME, following the DMAIC phases.
In chapter 6 the results presented in the previous chapters are discussed, leading to conclusions on the main results in light of the research objective, and placed in a theoretical perspective on the development of learning abilities. Chapter 6 ends with suggestions for further research.

1.5 **Included publications**

In chapters 2-5 the following publications are included:

1. Timans, W., Ahaus, K., van Solingen, R. A Delphi study on Six Sigma tools and techniques, *International Journal of Six Sigma and Competitive Advantage*, 5(3), 205–220.
2. Timans, W., Antony, J., Ahaus, K., van Solingen, R. Implementation of Lean Six Sigma in small- and medium-sized manufacturing enterprises in the Netherlands, *Journal of the Operational Research Society*, 63(3), 339–353.
3. Timans, W., Ahaus, K., van Solingen, R., Antony J. Implementation of a Continuous Improvement programme based on Lean Six Sigma in small and medium sized manufacturing enterprises, under review at *Total Quality Management & Business Excellence*.
4. Timans, W. Ahaus, K., Antony, J. Six Sigma methods applied in an Injection Moulding company, *International Journal of Lean Six Sigma,* 5(2), 149-167.

2. A Delphi study on Six Sigma tools and techniques

The purpose of this chapter is to present a set of tools and techniques for the different phases of Six Sigma improvement projects in manufacturing and engineering organizations, based on a literature study and expert judgment. A literature study was conducted to identify tools and techniques applied within case studies. The findings with respect to the tools and techniques used in the industrial settings studied were listed as a set of so-called statements. In a Delphi study a group of experts commented on and prioritised 95 statements during three rounds, providing us with a final list of 46 statements. These statements were grouped into the DMAIC-phases of Six Sigma projects, resulting in a description of tools and techniques to be used in DMAIC structured projects within a manufacturing/engineering context.

2.1 **Introduction**

Since the 1980s Six Sigma has developed into a standard approach to quality improvement. Advocates of the Six Sigma approach regard it as the current state of TQM-evolution, different from earlier TQM-programmes by its focus on managing and realising quality improvement by selecting and running projects that support the core value drivers (Breyfogle, 1999; Pande, Neuman & Cavanagh, 2000; Eckes, 2001). These projects are closely connected to business aims, while the project objectives are formulated using financial indicators. Moreover, the projects are carried out in a clearly structured way; within every project step conclusions are made on the basis of reliable data only. Therefore Six Sigma is regarded as a profit centre rather than as a cost centre (Wessel & Burcher, 2004), which has a major impact on the general management attitude towards quality management based on the Six Sigma principles.

As a quality improvement approach Six Sigma is not entirely new. It is partly an accumulation of a large number of principles, tools and techniques that have been developed during several decades, existing long before Six Sigma became well-known.

This chapter is based on: Timans, W., Ahaus, K., van Solingen, R., 2009. A Delphi study on Six Sigma tools and techniques, *International Journal of Six Sigma and Competitive Advantage*, 5(3), 205-211.

Six Sigma is different from other quality improvement concepts in that its framework is comprised of many principles, tools and techniques, which, together with experience, are all integrated and translated into best practices.
In recent years a new trend has emerged: the integration of lean principles into Six Sigma (George, 2002; De Koning, 2007). Historically, lean manufacturing and Six Sigma were developed separately. Six Sigma was initially developed by Motorola in the 1980s, and later on adopted by General Electric in the 1990s, which gave Six Sigma an enormous boost towards general recognition. The development of lean manufacturing started in Japan (the Toyota production system; Shingo,1989) and focussed on flexible manufacturing systems aimed at increasing production efficiency. Within Lean Manufacturing, tools and techniques are used such as kanban, 5S, quick change-overs, SMED, and VSM. Lean Manufacturing also involved the building up of partnerships with suppliers in order to create integrated supply and production chains by extending lean concepts across company borders.

In the highly competitive environment of today Six Sigma is becoming increasingly important for Small and Medium business Enterprises (SME organizations, according to the definition adopted by the EU Commission for SMEs with less than 250 employees). However, the development of Six Sigma has started within large companies, and transferring the experiences from large Six Sigma organizations to SME is not simple.

In this study our research objectives are to grasp the real practice of Six Sigma projects and to compare this practice with the theoretical base of Six Sigma project execution. For this theoretical base we used the rational reconstruction of the Six Sigma project stages of De Koning and De Mast (2006) as a reference. The research objectives are worked out into the following research questions:

1. Which Six Sigma tools and techniques are used in case study publications on projects carried out within manufacturing or engineering organizations?
2. How do experts assess the relevancy of best practice based tools and techniques and how do they group these into a Six Sigma project structure with DMAIC-project phases?
3. To which extent is the arrangement of tools and techniques in DMAIC-project phases in accordance with the rational reconstruction of DMAIC-project phases as published by De Koning and De Mast (2006)?

Based on a number of literature sources, De Koning and De Mast have executed a rational reconstruction of knowledge of the phases of Six Sigma projects and the steps specifying the actions to be taken within these phases. Rational reconstruction is a type of descriptive research aimed at redefining knowledge, which is vaguely and imprecisely formulated, in a more accurate and consistent way. De Koning and De Mast's DMAIC-classification can be regarded as theory-based. Based on this rational reconstruction they define the following generic descriptions of DMAIC-phases: Define (problem selection and benefit analysis), Measure (translation of the problem into a measurable form, and measurement of the current situation), Analyse (identification of influence factors and causes that determine the CTQ's behaviour), Improve (design and implementation of adjustments to the process to improve the performance of the CTQ), Control (adjustment of the process management and the control system to make the improvements sustainable). In their study the 'CTQ' (critical to quality characteristic) and 'influence factor' concepts are used. These concepts often appear in Six Sigma literature, but are not always defined clearly. De Koning and De Mast define these concepts as follows: "CTQs are those quality dimensions on which a Six Sigma project focuses to achieve improvement". Quality may be related to product quality or process quality. Influence factors are factors that causally affect the CTQ.

By starting with research questions 1 and 2 we chose a different approach. Our starting point was a collection of practice-based case study publications and the practice-based perspective of experts. Research question 3 reflects our interest in comparing our results to those of De Koning and De Mast.

2.2 **Method**

Figure 2.1 shows the different stages of our study.

1. Literature study: case study search and selection.
2. Extraction of statements from case studies (202 statements). Screening the list of statements. Refined by the researchers to a list of 95 statements. Preparing a first questionnaire.
3. Delphi round 1, assessing the 95 statements by giving a priority score and reformulation of the statements by the experts.
4. Evaluation of the experts' reactions, preparing a new list of statements for Delphi-round 2.
5. Delphi round 2, refining the list of statements, preparing a new list of statements for Delphi-round 3.
6. Delphi-round 3, refining the list of 95 statements to a final list of 46 statements.
7. Grouping of statements in DMAIC-project phases.

Figure 2.1. Stages in our Delphi study

2.2.1 Literature study (February-August 2007)

In our search for case studies several conditions for inclusion were applied. The articles had to be published in a selected series of academic journals. The case studies had to be reports on projects carried out within manufacturing organizations. Within these project reports the DMAIC (Define, Measure, Analyse, Improve, Control) or equivalent (Lean) Six Sigma project structure (such as for instance DMADV; Define, Measure, Analyse, Design, Verify) had to be clearly visible. The project results had to be reported clearly on the basis of six sigma metrics and financial indicators. The articles had to be published within the time period from January 1997 until June 2007. To find relevant case studies we used tracks like Emerald, EBSCOhost, Thomson Scientific, Ingenta, Springerlink, and Google Scholar. We searched by using advanced searching facilities. We first executed a wide search for articles with ‘six sigma’ in their title or in their abstract or as key words. After that we refined our search with ‘case study’ and ‘manufacturing’, ‘engineering’ or ‘design’. We also searched with ‘six sigma’ combined with specific tools and techniques, such as ‘DoE’, ‘Taguchi’ or ‘Gage R&R’. When looking for papers about lean manufacturing case studies within a Six Sigma framework we searched with ‘lean manufacturing’ and ‘six sigma’ or ‘lean six sigma’. We tracked a total number of 98 papers that were Six-Sigma- or Lean-Six-Sigma-oriented. Many of these papers did not comply with our conditions for inclusion as stated at the beginning of this paragraph, and therefore they were excluded. Some papers dealt with strategic issues around the implementation of a Six Sigma programme, and some reported laboratory case studies set up for educational purposes. An example of the latter is an application of the Six Sigma DMAIC model to G.E.P. Box’s “paper helicopter” experiment (Johnson, Widener, Gitlow and Popovich, 2006). A number of papers presented case studies in which the DMAIC model was not fully applied, sometimes only mentioning that the research conducted was part of a Six Sigma project. Most of these case studies focussed on process improvement by using dedicated tools. Some papers presented practice-based case studies, but these were excluded because they were conducted within service organizations (including hospitals). We finally selected 24 Six Sigma case studies executed in a context of manufacturing or engineering organizations. Because of the focus of our research programme, case studies from SME-type companies received special attention. In many papers, however, no clear information was given about the size of the organization.

We selected case studies published in the following magazines: Quality & Reliability Engineering, International Journal of Advanced Manufacturing Engineering, Quality Engineering, Total Quality Management, TQM Magazine, Assembly Automation, International Journal of Six Sigma and Competitive Advantage, Journal of Engineering Manufacture, IEE Manufacturing Engineer, Production Planning & Control, Supply Chain Management, Journal of Industrial Textiles, Management of Environmental Quality, Quality Progress, and the Journal of Construction Engineering and Management. In addition we included case studies from Antony, Banuelas and Kumar’s book (2006).
We started our search for case studies with a selection of these journals and through the search process other sources were added.

The case studies we selected were the following: Antony, Kumar and Tiwari (2005), Banuelas, Antony and Brace (2005), Chen and Tsou (2003), Das (2005), Das, Roy and Antony (2007), Deshpande, Halder, Biswas, Raychauduri, Choudary, Kumar (2006), Duncan (2005), Escalante Vasquez and Díaz Pérez (2006), Foster and Maguire (2005), Hagemeyer and Gershenson (2006), Hu, Bruce and Sears (2005), Knowles, Johnson and Warwood (2004), Kumar, Antony, Singh, Tiwari and Perry (2006), Mahesh, Wong, Fuh and Loh (2006), Mortimer (2006), Mukhopadhyay and Ray (2006), Peng (2004), Pickrell, Lyons and Shaver (2005), Sekhar and Mahanti (2006), Smith (2005), Shubotham, Banuelas and Antony (2006), Tong, Tsung and Yen (2004), Tsou and Chen (2005), and Yang, Choi, Park, Suh and Chae (2007).

Decisions about including or excluding case studies were taken after a thorough process of reading the papers, making abstracts of them using a format on which the researchers mutually agreed, and finally determining which papers to in- or exclude. It was agreed that the abstracts should contain the title of the paper, the application area of the case study, organizational aspects, tools and techniques and the project results. Thereupon all case studies were reviewed in the first round by one researcher, while the other researchers each reviewed half of the collection. In this way, each case-study was analysed by two reviewers.

Based on the abstracts the tools and techniques were formulated into statements by describing each activity by means of a verb and making a short description of its aim. From the 24 abstracts we first formulated up to 202 statements. These statements, however, showed much overlap. Extensive discussions about this issue led to a refinement of the formulated statements by combining those with a similar content. After the discussions the list of statements was reduced to 95.

2.2.2 Delphi study (August-October 2007)

Next, a Delphi study was carried out to further narrow down the list and improve the statement formulations. The Delphi method is an exercise in group communication among the members of a panel of experts (Adler & Ziglio, 1996; Linstone & Turoff, 2002). The technique allows the experts to deal systematically with a complex problem. The essence of the technique is fairly straightforward. It consists of a series of questionnaires presented to a pre-selected group of experts. These questionnaires are designed to elicit individual responses to the problems posed and to enable the experts to refine their views as the group's work progresses in accordance with the assigned task. Delphi methods are used in a variety of areas, including medical, environmental and social studies, as well as in business and industrial research. In all subject domains, Delphi has been primarily employed for purposes of forecasting, planning, issue identification/prioritisation, or framework/strategy development (Okoli & Pawlowski, 2004).

The expert group members were selected according to the following criteria: Six Sigma experience at least at the Black Belt level, familiarity with a wide range of six sigma tools and techniques, professional experience in a manufacturing/engineering environment, scientific experience in quality management subjects, including Six Sigma.

We were aware that it would be almost impossible for an individual member to meet all these requirements. So we composed a group consisting of a well-balanced mix of experts coming from manufacturing companies, consultancy organizations and universities.

After the initial contacts 10 experts were willing to participate in our study. Table 2.1 gives an overview of the 10 experts participating in the first Delphi round. The study continued with a meeting in which seven group members participated. A few group members did not participate in this meeting because of job-related obligations.

The small number of experts willing to participate could be cause for some concern about the significance of the findings of the study. According to Okoli and Pawlowski (2004), however, the size of the Delphi group is not related to statistical power, but rather to the extent of group dynamics resulting in consensus among the experts. Referring to a number of literature sources, Okoli and Pawlowski recommend 10-18 experts for a Delphi panel. In addition, Day and Bobeva (2005) refer to Adler and Ziglio (1996) and Linstone (2002), asserting that seven is a suitable minimum panel size.

Name	Professional background (at the time of the study)
Brombacher, A.C.	Professor Quality and Reliability Management, Eindhoven University of Technology, Eindhoven, the Netherlands
Draisma, A.	Six Sigma Black Belt, Dyka BV, Steenwijk, the Netherlands
Ovinge, A.F.	Plant QESH manager (Quality Environment Safety and Health), SCA Personal Care, Hoogezand, the Netherlands
Horstink, P.	Vice President Maintenance and Engineering, Martinair, Schiphol, the Netherlands
Oosterhoorn, A.	Managing Director Oosterhoorn Advies BV (Lean Six Sigma consultancy), Epe, the Netherlands
Mulder, A.	General Manager UNC Slim BV, Amsterdam, the Netherlands
Van den Hoogen, Y.	Master Black Belt, Avebe BV, Foxhol, the Netherlands
van Loon, C.J.	R&D Engineer, TNO Science and Industry, Precision Manufacturing, Eindhoven, the Netherlands
Slomp, J.	Associate Professor, University of Groningen, Faculty of Economics and Business, Groningen, the Netherlands
Berenschot, H.	Sr. Engineer Moulding, Philips Domestic Appliances and Personal care, Drachten, the Netherlands

Table 2.1. Members of the group of experts

In our Delphi study we used 3 rounds to reach consensus. In the first remote access round the members of the group delivered responses to the questionnaire. The statements were listed in a randomised order. A question was added to each statement to give an assessment of the relevance of the statement on a 1-4 Likert scale, 1 meaning not relevant, 2 moderately relevant, 3 relevant and 4 very relevant. With each statement some space was left to comment on it or to reformulate it.

The resulting list served as a questionnaire to be used in the first round of the Delphi study. The second and third round were executed in a half-day meeting. During this meeting groupware (Meeting Works) was used to distribute new questionnaires to the group members, to collect the answers, to evaluate the scores and to prepare the information for the following Delphi-round. In this approach group dynamics could play a significant role. The approach can be considered as a normal Delphi procedure with collecting elements from literature and rating these on appropriateness (inappropriate means ‘lack of consensus’). A similar methodology is described in the RAND/UCLA appropriateness method user's manual (2001).

After each round elements were included if more than 80% of the experts judged these elements as relevant or very relevant to be used in industrial DMAIC structured projects. They were excluded if more than 50% judged them as not relevant or moderately relevant. In the next round new elements and elements that were neither included nor excluded were presented. After each round some statements were slightly reformulated on the basis of comments of the group members, merely to clarify them.
For an outline of the processing of Delphi rounds see Table 2.2. After finishing the Delphi rounds the final list contained 46 statements.

Response	Round 1	Round 2	Round 3	Total excluded	Total included
Number of statements at the start	95	43	20		
Included (scores >= 80%)	28	11	7		46
Excluded	24 (scores < 50%)	12 (scores < 50%)	13 (scores < 80%)	49	
Number of participants	10	7	7		

Table 2.2. Results of the Delphi panel

After the Delphi rounds an additional step was planned. The group members were asked to divide the statements of the final list among the DMAIC Six Sigma project phases. Using the Meeting Works groupware system the participants gave an individual judgment about the phase that an individual statement should be assigned to, while they were also given the opportunity to clarify the assignments. For 40 of the 46 statements the majority of the members agreed upon their assignment to the different phases. For six statements the members' choices were too diverse to reach a majority agreement.

2.3 **Results**

The resulting final set of 46 statements was extracted from publications that describe Six Sigma projects and assessed and modified by experts. The statements can therefore be regarded as being expert-based.

Table 2.3 shows the results of our Delphi study together with the assignment of the statements to the phases and a comparison with the assignment according to De Koning and De Mast.

Phase	Statement	Average and stdev of score on acceptance	Accepted in round nr.	Phase-Consensus	No. of case studies found in	Phase according to De Koning and De Mast
D	1. Giving a clear definition of customers, customer demands, CTQs	3,8 ; 0,4	1	7	12	D
D	2. Giving a clear definition of a defect, including a metric	3,5 ; 0,9	1	5	4	M
D	3. Relating customer demands, CTQs, to process outputs	3,8 ; 0,4	1	6	1	D
D	4. Describing the VOC (Voice of the Customer) or VOB (Voice of the Business) for every group of stakeholders	3,3 ; 1,0	1	6	3	D
D	5. Setting up a project charter including CTQ-definition, problem statement, project goals, strategic interest, business case, financial benefits, current sigma level, target sigma level, project scope, team members, member-roles, timeframe and milestones, project deliverables, tollgates sponsor/champion, communication plan	3,6 ; 0,7	1	7	8	D
D	6. Documenting process flow descriptions using a SIPOC and/ or process flowcharts, including an outline of measurement points on inputs and outputs	3,4 ; 0,8	2	6	9	D
D	7. Studying existing process flowcharts with a team of involved experts, to mark relevant process steps to be further investigated	3,7 ; 0,5	3	5	1	D
D	8. Redefining the problem when new knowledge about causes leads to renewed problem understanding	3,2 ; 0,6	1	5	1	D
D	9. Benchmarking processes to similar processes within other organizations to compare performances and to discover improvement opportunities	3,1 ; 0,7	1	5	1	M, I
D	10. Composing a gap analysis to select (sub)projects and setting targets to (sub)projects	3,3 ; 0,8	3	6	1	D
D	11. Using a controller validated costing model to sustain decisions. A costing model could be a model comprising production costs, costs of storage, set-up costs, cost of poor quality estimated using a Taguchi loss function	3,0 ; 1,0	2	4	1	D
D	12. Applying Value Stream Mapping to separate value adding activities from non value adding activities, to minimise process time	3,0 ; 0,9	1	5	1	A
D	13. Setting up a current state map, splitting up the process into sub-processes, with time-information for each sub-process (for instance sub-process execution time, machine uptime, number of shifts, change over time, store time of components between sub-processes)	3,0 ; 0,8	1	4	1	D
D(*)	14. Identifying an internal quality characteristic, directly related to a CTQ (eventually after iterative searching)	2,9 ; 1,1	2		1	M

Table 2.3-1: Overview of results

Phase	Statement	Average and stdev of score on acceptance	Accepted in round nr.	Phase-Consensus	No. of case studies found in	Phase according to De Koning and De Mast
M	1. Setting up a data collection plan to prepare data collection to determine current process performance (including procedures for collection of data from processes)	3,2 ; 0,6	1	4	4	M
M	2. Reviewing the data collection plan and procedures together with operators and instruction of the operators who collect the data	3,3 ; 0,8	1	6	1	M
M	3. Applying Gage R&R methods to validate measurement systems and separate measurement variation into repeatability and reproducibility variance components	3,4 ; 1,1	2	7	9	M
M	4. Establishing current process capability, if necessary refined to sub-processes, through measurements on relevant process parameters (Cp, Cpk, Ppk, DPU, Yield, sigma level, other KPIs)	3,0 ; 0,6	3	7	20	M
A	1. Setting up a Cause & Effect diagram to map sources of variation	3,6 ; 0,6	1	5	9	A
A	2. Setting up a Reverse Cause & Effect diagram to map the effects of variation in a quality characteristic	3,1 ; 0,6	1	6	1	A
A	3. Plotting numbers of defects against possible causes followed by prioritising causes using Pareto analysis (if appropriate from different angles)	3,6 ; 0,5	2	5	7	A
A	4. Prioritising causes of variation (for instance sources, machines, positions within production lines) using Pareto analysis	3,2 ; 1,2	1	5	2	A
A	5. Analysing returned products associated with warranty claims to identify process-related causes	3,2 ; 0,8	1	6	1	A
A	6. Analysing tolerances using statistical methods to relate tolerance specifications to variation in user-defined properties of products	3,1 ; 0,7	1	4	1	I
A	7. Using Design Failure Mode & Effect Analysis (D-FMEA) to identify, describe and prioritise potential causes of not realising the predicted product functions	3,0 ; 0,7	1	4	1	A
A	8. Setting up a correlation matrix to discover correlations between process parameters	2,9 ; 0,9	1	6	1	A,I
A	9. Using Multivari-charts to visualise variation related for instance to shifts, measurement positions, operators, seasons	3,1 ; 0,8	1	5	3	A
A	10. Using main effect and interaction plots to find out which are the most significant effects of process parameters on quality characteristics	3,1 ; 0,4	2	6	6	A

Table 2.3-2: Overview of results

Phase	Statement	Average and stdev of score on acceptance	Accepted in round nr.	Phase-Consensus	No. of case studies found in	Phase according to De Koning and De Mast
A	11. Identifying the sub-process from which most likely problem causes arise, using brainstorming and multi-voting techniques	3,3 ; 0,8	2	4	1	A
A	12. Analysing and clarifying different components of variation through the appliance of rational sub-grouping (short- and long-term, within and between batches)	3,0 ; 0	3	5	1	A
A	13. Applying ANOVA-techniques (analysis of variance) to test significance of variation sources and to quantify their contribution	3,0 ; 0,6	3	7	3	A
A(*)	14. Documenting process runs using run charts, control charts (for instance I-MR charts)	3,3 ; 0,5	3		10	A
I	1. Documenting agreed improvement measures for all root-causes (Vital X's)	3,0 ; 0,7	1	5	3	I
I	2. Executing confirmation runs to verify that the predicted set of optimal process parameter settings ensures the predicted process improvements	3,0 ; 0,9	1	5	12	I
I	3. Applying mistake proofing/automated control to improve process robustness	3,2 ; 0,8	1	4	1	I,C
I	4. Applying 5S methods when appropriate	3,1 ; 1,1	2	5	1	I,C
I(*)	5. Executing test runs and using statistical testing techniques to prove significance of expected improvements	3.3 ; 0,5	2		3	I
I(*)	6. Executing (series of) DoEs (classical or Taguchi with or without Signal to Noise analysis) on relevant process parameters to find optimal settings	3,1 ; 1,0	1		9	I
I(*)	7. Composing tables and charts with key-metrics to compare actual situation before and after improvement (using Defect rate, First Time Yield, process capability, Mean, Stdev, OEE)	3,6 ; 0,8	3		3	I,C
C	1. Developing a control plan to sustain the quality improvements realised, including Out of Control Action plan	3,1 ; 0,7	1	6	6	C
C	2. Making a survey to compare existing and improved performance using data and performance indicators (for instance histogram, z-levels, Cpk-within/overall, Ppk, proportion outside specs in ppm, OEE)	3,3 ; 0,8	1	4	3	C
C	3. Testing effects of improvement measures during a sufficiently long period of time	3,4 ; 0,8	1	5	2	C
C	4. Documenting ideas for new improvement projects identified within current execution of improvement projects	3,2 ; 0,6	1	5	1	C

Table 2.3-3: Overview of results

Phase	Statement	Average and stdev of score on acceptance	Accepted in round nr.	Phase-Consensus	No. of case studies found in	Phase according to De Koning and De Mast
C	5. Determining whether improvements aimed at were really realised through measurements and process capability indicators (such as Cp, Cpk, Ppk, DPU, Yield, sigma level, etc.), using statistical testing methods (such as t-testing)	3,7 ; 0,8	2	5	4	I,C
C	6. Documenting project results and learning lessons	3,4 ; 0,8	2	6	1	C
C(*)	7. Updating performance charts, to visualise trends in performance	3,9 ; 0,3	1		5	C

Table 2.3-4: Overview of results

The average score column lists the average Likert scale relevance scores and standard deviations on acceptance. The next column indicates after which Delphi round the statement was accepted. The phase consensus column shows how many experts agreed on the choice of the DMAIC-phase to which a statement should be assigned. The first column depicts six statements marked by an (*). On these statements no majority agreement could be reached and therefore the assignment was done by the researchers, keeping in mind the distribution of the scores given by the experts.

The next column gives an indication of the number of times a statement was found in a case study (the total number of selected case studies was 24). This gives an impression of how frequently a tool or technique was applied. The application of tools and techniques is often strongly related to the context of the case study, which may explain why a considerable number of statements were related to only one single case study.

A complication in this analysis was that one statement could have an overlap with another. For instance, the use of DoE-techniques (Design of Experiments, see statement I6) was often combined with the application of ANOVA-techniques (statement A13). When counting the case studies in which ANOVA-techniques were applied, we did not include the case studies in which DoE was used.

2.4 **Discussion**

After the three Delphi-rounds, 49 of the original 95 statements were excluded. Some were excluded because they were considered as descriptions that had only a minor impact; some were excluded because they originated from a very specific context, and some because they showed overlap with other statements. Further, two surprising decisions were made: a statement about the use of Design FMEA (Failure Mode and Effect Analysis, statement A7) was included after round one and a statement about the use of Process FMEA was excluded. In rounds two and three the statement on the application of P-FMEA was judged as very relevant by four experts and as relevant by one expert. So five of the seven experts regarded P-FMEA as relevant and yet this statement was excluded after round three because our threshold for inclusion was 80%. Design FMEA was used in one single case study, as indicated in the column “no. of case studies found in”. Process FMEA was used in seven case studies. It therefore seemed a fair conclusion to consider it wise to drop the distinction between Design- en Process-FMEA.

Next, we will discuss the differences between the assignment of the statements to the DMAIC-phases by the Delphi panel and the assignment according to De Koning and De Mast. According to De Koning and De Mast, statement D2 (’Giving a clear definition of a defect, including a metric’) should be assigned to the M-phase. The Delphi panel, however, judged a process-related defect to be directly associated with a CTQ.

In statement D9 (‘Benchmarking processes to similar processes within other organizations to compare performances and to discover improvement opportunities’) the context of benchmarking differs from the context in which it is meant to be applied in the paper of De Koning and De Mast. According to De Koning and De Mast benchmarking should be assigned either to the Measure phase or to the Improve phase, the Measure phase being the appropriate choice when benchmarking refers to adjusting the online quality control system, and the Improve phase being the best option when benchmarking is applied in order to design improvement actions.

In the case study of Yang et al. (2007) benchmarking is applied within the Analyse phase. The majority of the members of the Delphi panel regarded benchmarking as a tool to identify improvement opportunities at a higher level and therefore saw it as a tool to select projects.

Statement D13 (‘Setting up a current state map, splitting up the process into sub-processes, with time information for each sub-process’) could be regarded as a part of statement D12 (‘Applying Value Stream Mapping to separate value adding activities from non value adding activities, to minimize process time’). Statement D12 concerns the full application of VSM, including mapping the current state as well as the future state. Setting up a current state map forms part of Value Stream Mapping, where setting up such a map is followed by actions that lead to a future state map in which the time spent on non-value-adding-activities is diminished as much as possible. According to De Koning and De Mast, VSM should be assigned to the Analyse phase. According to the Delphi panel, however, setting up a current state map as a first step in the application of VSM could be part of the Define phase to define the problem. This view is supported by Snee and Hoerl (2007), who promote VSM to be used as an instrument for the project selection process. VSM has process mapping features and can be used at different levels. Kubiak and Benbow (2009, p. 85) allocate VSM to the Measure phase, as a method to describe the current state of a process

under study. Using VSM in the context of the Analyse phase does also make sense to find the root causes of a problem, and thus providing options for process improvement.
Statements D12, D13, I4 (‘Applying 5S methods when appropriate’) have a Lean Manufacturing background. Historically, Lean Manufacturing developed separately from Six Sigma; see for instance Shingo (1989). In Lean Six Sigma the toolboxes of lean manufacturing and Six Sigma are combined. Lean Six Sigma incorporates the organization structure and the method of Six Sigma (see De Koning (2007), p. 38-41). In some of the case studies (Pickrell et al., 2005; Kumar et al., 2006), lean and Six Sigma are merged.
Statement A6 concerns analysing tolerances to relate tolerance specifications to user-defined properties of products. This should be done to calculate an allowable bandwidth around the optimal parameter set points after having established these set points. The Delphi panel assigned this technique to the Analyse phase, which makes sense if analysing tolerances is applied in the context of an existing process with fixed target process settings. Tolerance analysis can also be applied as a last step in designing adjustments to the process to improve the performance, for instance after having applied DoE to find optimal process settings for the relevant process parameters. Using tolerance analysis techniques to establish process windows for the process parameters around the optimal set-points would then be the final step. In such a case the Improve phase would be the appropriate allocation for this technique, supporting the allocation given by De Koning and De Mast.
Statement A8 deals with the correlations between the different process parameters. Process parameters can be regarded as Xs (influence factors), and this statement thus refers to different Xs that cannot be varied independently. If the correlation between two process parameters is very strong it could be wise to exclude one of the two. In that case this statement should be assigned to the Analyse phase, which would be an example of selecting the vital few influence factors. If the process parameters are moderately correlated, they could be both selected as vital few Xs. Assigning it to the Improve phase would be more appropriate, as then the correlation study would form part of the design of adjustments to the process that improves the performance of the CTQs.
According to De Koning and De Mast, statements I3 and I4 should be assigned to the Improve phase or the Control phase. The tools described in these statements (mistake proofing and 5S methods) could be used in a pilot during the Improve phase and could also be applied to assure the improvements reached within the Control phase.

This study has resulted in 46 statements extracted from a number of case study publications that were assessed by a Delphi panel as relevant in Six Sigma projects. When comparing the statements with the rational reconstruction of the Six Sigma's toolbox (De Koning & De Mast, 2006), it becomes clear that these statements largely match the elements of the toolbox. The rational reconstruction of De Koning and De Mast uses a wide range of literature sources. The particular value of our study is that it is founded on practice- and expert-based experience.

The literature sources do not entirely agree on the distribution of the tools over the DMAIC-phases (De Koning & De Mast, 2006). This uncertainty of the DMAIC-classification is to a certain extent demonstrated in our study. For the assignment of six statements the members of our group of experts did not vote by majority. With respect to eight statements only four out of the seven experts agreed upon their assignment. With regard to the other statements there was more agreement and the classifications seem to be in line with the generic Six Sigma's reconstruction of De Koning and De Mast (2006).

The column "No. of case studies found in" of Table 2.3 gives an impression of which tools and techniques are used frequently (in at least 6 of the 24 case studies):

- In the Define stage: the definition of the CTQ, setting up a process charter and the use of SIPOC and/ or flowcharts
- In the Measure stage: Establishing the current process capability and applying Gage R&R methods to validate measurement systems
- In the Analysis stage: cause and effect diagrams, Pareto plotting techniques to prioritize defects causes, the use of main effect and interaction plots, and the application of control charting techniques
- In the Improve stage: DoE techniques (Design of Experiments)
- In the Control stage: Developing a control plan to sustain improvements

This subset contains 11 tools and techniques that often are useful in the context of manufacturing, but downsizing the complete set to this subset would be too easy, many of the less frequently used tools are really needed depending on the context of the case. Establishing the current process capability (coming up in 20 of the 24 case studies) is indeed directly connected to the goal of the Measure stage, but this needs reliable measurements and therefore it is not surprising that the application of Gage R&R methods to validate the measurement system also has a high rating.

2.5 Conclusions and Managerial Implications

In response of the first research question our study has delivered 95 statements on the use of tools and techniques, formulated as an activity with a short description of the aim of their application. The expert panel assessed the relevance of these statements which delivered a final set of 46 statements on the best-practice based tools and techniques in response to the second research question. The expert panel discussions finally led to an assignment of the tools and techniques to the DMAIC project-stages, responding to the third research question.

The research contribution of this study is that it delivers information on the application of tools and techniques based on real practice, selected through the application of Delphi methods, which to our knowledge not have not been used before in this context. All the case studies used were reports of improvement projects executed in manufacturing companies using Six Sigma methods. The study thus adds empirical evidence on the application of tools and techniques to the literature on Six Sigma. The allocation of the tools and techniques to the DMAIC project-stages largely match with the results of De Koning and De Mast (2006). Many tools can be used in more than just one single project-stage, and the project-stage in which a tool can be used at best is also connected to the context of the project.

Perhaps the best contribution of this study to managers is that it can make them aware that using the toolbox as a simple set of prescribed tools and techniques to be used in project-stages is no real option. Managers involved in selection and execution of projects can benefit from this study first of all by having a set of 46 statements available providing contextual based descriptions on tools and techniques, which can help them to make the best choices for their own projects. Of course the most obvious limitation of this study is in the selection of the members of the Delphi-panel. The size of the group is small within the acceptable range recommended in the literature on Delphi-studies. However, the decision rules for inclusion were that 80 % of the experts had to consider a statement as relevant or very relevant, which for our panel means that at least six out of the seven members should give such a judgement. This means that the group of 46 finally accepted statements, some of them after discussions and refinement of their formulation, constitutes a fairly robust group of relevant statements on LSS tools and techniques.

3. Implementation of Lean Six Sigma in small- and medium-sized manufacturing enterprises in the Netherlands

In this chapter we provide an exploration and analysis of Lean Six Sigma implementation in Dutch manufacturing/engineering Small and Medium sized Enterprises (SMEs). Critical success factors (CSFs) and impeding factors are identified. Exploratory empirical evidence about Lean Six Sigma implementation in Dutch SMEs was collected from a survey study on Dutch SMEs. Statistical testing was applied to validate the ranking of the CSFs. To deepen insight in how organizations translate CSFs into practice and cope with impeding factors additional in-depth qualitative information was gathered from six case studies. Linking to customer, vision and plan statement, communication and management involvement and participation are the highest ranked CSFs. Internal resistance, the availability of resources, changing business focus and lack of leadership are the strongest impeding factors. The case studies confirmed the importance of the CSFs and revealed three new CSFs: personal LSS-experience of Top-management, development of the project leader's soft skills and supply chain focus.

3.1 **Introduction**

Application of Lean Six Sigma for deploying continuous improvement is increasing largely in the last decade and seems to have become the de-facto approach for industry. Lean Six Sigma represents the merger of two well-known improvement-programmes that both have a long history: Lean manufacturing and Six Sigma. The origin of lean manufacturing is located in Japan, where elements of lean manufacturing were applied from around 1950 (Womack and Jones, 2003). Lean manufacturing became popular after the publication of the books The Toyota Production System (Ohno, 1988) and A Study of the Toyota Production system (Shingo, 1989).

This chapter is based on: Timans, W., Antony, J., Ahaus, K., van Solingen, R. (2012), Implementation of Lean Six Sigma in small- and medium-sized manufacturing enterprises in the Netherlands, *Journal of the Operational Research Society* 63(3), 339–353.

Six Sigma, on the other hand, started at Motorola in the USA in the 1980s. Interest in Six Sigma increased rapidly after General Electric adopted Six Sigma as their leading quality improvement programme (Eckes, 2000; Henderson and Evans, 2000). The term Lean Six Sigma has been introduced around 2000 (George, 2002). Between experts a debate has been going on during a long time on the question whether both programmes should be merged towards one improvement methodology or not.
Snee (2010) argues that discussions on which approach should be used when tend to be unproductive. Taking improvement as the main issue he argues that the bodies of knowledge of both Lean and Six Sigma are needed to solve the problems encountered by organizations, and that the question is how to use the integrated approach. Therefore we will use the term Lean Six Sigma (LSS) in this paper as the name for the improvement programme that is subject of our study.

This study is part of a larger study aimed at the development of an LSS programme specially fit for manufacturing small and medium sized enterprises (SMEs). Most well-known LSS programmes come from larger companies like Motorola, General Electric, Honeywell and many others. On the implementation of LSS-programmes in SMEs much less has been written in literature. On our journey towards our final goal we first want to make a picture of the current situation regarding LSS-implementation in manufacturing SMEs in the Netherlands. Our focus on SMEs is connected to the notion that SMEs are vital contributors to economic development. According to the definition adopted by the EU Commission, SME organizations are enterprises with fewer than 250 employees, with additional conditions e.g. on maximal annual turnover and balance sheet total[1].

The well-known examples of company-wide implementation of LSS programmes largely come from large organizations. There is (still) only limited insight into successful

[1] In the study 'Small and medium enterprises across the globe' (Ayyagari et al, 2007) the classification SME250 is used for the share of the SME sector in the total formal labour force in manufacturing when 250 employees are taken as the cut-off for the definition of an SME. For a country to be classified under the SME250 classification, the SME sector cut-off could range from 200 to 300 employees. The Ayyagari-study reports that in the countries of the European Union more than 50% of the employees in manufacturing companies are working in SMEs. In Mediterranean countries (Italy, Spain, Portugal) the share of SME employment is even close to 80%. The share of SMEs with respect to GDP (Gross Domestic Product) is lowest in Sweden (39 %) and highest in Portugal (67 %). The GDP-data are not limited to manufacturing, but at least the data indicate that SMEs of all the economic sectors contribute strongly to the national GDP.

implementations of LSS in SMEs. In this chapter we aim to present an overall picture of the implementation of LSS in Dutch manufacturing SMEs and to explore the critical success factors for implementation of LSS in a manufacturing SME context. A similar study had been carried out in the UK (Antony, Kumar, and Madu, 2005). The collection of new data was useful not only to extend the data over new international regions, but also because the number of SMEs with long-term experience in deploying Six Sigma is low. In the preceding UK-study the analysis was based on results from 60 companies, but only 16 of them were actually involved in a Lean Six Sigma programme. From the picture arising we want to point out which factors are perceived to be critical success factors and which are impeding factors for the implementation of LSS. By first focusing on the status quo in the Netherlands we aim to infer from experiences in the past what is really key and why.
To reach our objectives we address the following research questions:

- RQ1: What is the current status of implementation of Lean Six Sigma (LSS) in manufacturing/engineering SMEs in the Netherlands?
- RQ2: What factors are to be perceived as critical success factors and impeding factors in LSS implementation, from a manufacturing SME perspective? How are these critical success factors and impeding factors ranked by management?
- RQ3: How are critical success factors translated into practice and how do SME organizations cope with the impeding factors in day to day practice?

According to Rockart (1979), CSFs are those factors that are critical to the success of any organization, in the sense that if the objectives associated with the factors are not achieved, the organization will fail. Following this definition of CSFs in the context of LSS implementation, this means that if the conditions associated with the factors are not met, durable LSS implementation has little chance of becoming reality.
Data were collected in two ways. First, questionnaires were distributed to 1500 Dutch manufacturing/engineering SMEs, with questions on relevant aspects of LSS implementation. To gather additional in-depth information on critical success factors and impeding factors, exploratory case studies were carried out in six companies that have implemented LSS methods with different levels of experience and that work in different manufacturing areas. As far as we know an empirical study focussing on CSFs and impeding

factors connected to LSS implementation in SMEs combining a survey with case studies has not been carried out before.

This paper proceeds in four sections. The second section contains a review of the literature relevant to our research. The third section presents our research design, describing the research methodology and data collection methods. In the fourth section our questionnaire-based research and our case study research are discussed. The fifth section is dedicated to a discussion and conclusions, ending with an outline to further study.

3.2 **Literature review**

Given our intention to describe the current overall picture of the implementation of Lean Six Sigma in manufacturing SMEs in the Netherlands and to identify the important critical success factors (CSFs), our literature study focuses on implementation studies regarding Lean Six Sigma. In our search for SME deployment of LSS we decided to include implementation studies on (just) Six Sigma as well, because we know from our experience that in these studies often lean manufacturing methods are included in the tools that are presented as Six Sigma tools. This again illustrates that industry does not make the same strong distinctions between Lean manufacturing, Six Sigma and Lean Six Sigma that often occur in the more theoretical debates. To illustrate the current state of this debate on the integration of lean manufacturing and Six Sigma we also added a few recent studies that focus on the integration of both programmes.

Achanga et al. (2005) carried out research on critical success factors for lean implementation. Case study research was carried out within 10 UK manufacturing SMEs. The results were analysed and validated through workshops, case studies and Delphi techniques. Strong leadership, excellent project management, financial capabilities, organizational culture, and skills and expertise are classified as the most pertinent issues critical to the successful adoption of lean manufacturing within SMEs.

Earlier studies on the implementation of Six Sigma (including lean aspects) in manufacturing SMEs were carried out in the UK (Kumar, 2007; Antony et al., 2005, 2008). The studies of Antony et al. (2005, 2008) present a literature review based on the experiences of academics and practitioners, followed by the results of a survey in UK manufacturing SMEs, based on data collected using questionnaires. The findings show that Six Sigma was not generally popular among SMEs. Management involvement and participation, linking the programme to customers and linking to the business strategy are the highest ranked critical factors for the successful deployment of LSS in SMEs. The study of Kumar (2007) on critical success factors and hurdles to implementation was carried out in a single UK SME company in the electronic industry. Qualitative data were collected using questionnaires and semi-structured interviews. The findings revealed that management involvement and commitment are critical to successful implementation. Poor training and resource availability were identified as the two highest ranked impeding factors encountered during the deployment of the programme.

In Taiwan an empirical study on the implementation status of Six Sigma was carried out by Yang et al. (2008). In this study 52 companies participated, 44 of them were large enterprises. Findings show a mixed appreciation by the respondents of the performance of their organizations concerning the success levels of their company's Six Sigma implementation. Conclusions of this study are that to reach dramatic benefits from the implementation organizations must enhance the implementation of CSFs and utilise more advanced statistical tools.

In Thailand Nonthaleerak and Hendry (2008) carried out exploratory case study research in nine companies including manufacturing, sales and service companies. This study aimed at exploring critical success factors and areas of weakness in Six Sigma implementation and at examining implementation differences between manufacturing and services. The case study evidence confirmed and gave further details on some of the CSFs previously identified by other authors (Antony et al. 2005; Kumar, 2007), in particular on the effectiveness of six sigma training programmes and on the nature of management involvement. The involvement of managers in setting targets in both financial and non-financial terms and tying managers performance to the success of projects were reported as examples of management involvement. A pattern of full-time or part-time Black Belts reporting structure to Project Champion and the inclusion of a dedicated team of technical support were identified as new CSFs. The study revealed two areas of weakness in Six Sigma implementation related to the use of the DMAIC methodology (define, measure, analyse, improve and control), especially with respect to the define and control phases. Firstly, project-targets tend to be focussed mainly on solving existing problems, and less focussed on strategic opportunities (for instance in projects focusing on new product development). Secondly, it is hard to organize effective control and assurance of the realized improvements. The authors conclude that part-time Black Belts are the best option for smaller companies and that the nature of the reporting structure is seen to be key, with best practice involving direct reporting to the project champion.

On aspects of the combination of lean and Six Sigma we selected a few studies to illustrate the current situation regarding the debate on the question of whether integration of both programmes would be wise. Shah et al. (2008) carried out research on the implementation of lean and Six Sigma in the USA. Their results indicate that the lean manufacturing performance levels of organizations that also implemented Six Sigma exceed the performance levels of organizations that have implemented lean manufacturing alone.

A literature study on the integration of lean and Six Sigma has been carried out by Pepper and Spedding (2010). They conclude that there are a number of encouraging articles discussing the use of an amalgamated approach, but a closer integration towards a unified methodology must be achieved, with scientific underpinning to provide a sound theoretical foundation. The study of De Koning (2007) is specifically focussing on the scientific grounding of Lean Six Sigma as an integrated programme, merging the Six Sigma and lean toolboxes, and clarifying concepts and classifications. Schroeder et al. (2008) used the grounded theory approach and literature study to propose an initial definition and theory of Six Sigma. The authors argue that Six Sigma is different from prior approaches to quality management in providing an organizational structure not previously seen. Although this study is focussed on Six Sigma, the conclusions could be valuable for the theoretical grounding of Lean Six Sigma as well.

Snee (2010) discusses the advances of LSS in the last ten to fifteen years and trends that suggest how the methodology needs to evolve. Lean Six Sigma is regarded as a holistic improvement methodology addressing the flow of information and materials through processes as well as the enhancement of value-adding process-steps to create the product for the customer. In his view this will naturally lead to making improvement a business process similar to any other important business process.

There seems to be a fair agreement on CSFs presented in the implementation studies. In our study we start using the thirteen formulated CSFs of Kumar (2007) and Antony (2005, 2008) as a starting point. With regard to the debate on the merger of lean and Six Sigma we feel strengthened by the literature, in particular by Snee (2010), that the combined approach of Lean Six Sigma is to be preferred to keeping both approaches tied to separate programmes.

3.3 **Research design**

The stages of our study are presented in figure 3.1.

First, a short questionnaire was used to collect data on LSS implementation issues from Dutch manufacturing SMEs. This one-page questionnaire was merely used to select the SMEs familiar with lean manufacturing or Six Sigma (or both). The questions concerned the products manufactured, number of employees, quality management programmes applied and since when (lean manufacturing, Six Sigma, ISO 9000, EFQM or other) and which tools and techniques are applied. The questionnaire was sent in October 2008 to about 1500 manufacturing SMEs in the Netherlands, selected from a database of the Dutch Chamber of Commerce. From the responses to the first questionnaire (198 responses were received) we selected candidates who were invited to fill in a more comprehensive web-based second questionnaire (see Appendix A). The criteria for selecting candidates to invite to respond to the second questionnaire were twofold. The first criterion was that the respondents to the first questionnaire should have stated that they had implemented Six Sigma and/or lean manufacturing. The number and complexity of tools and techniques selected in the selection table of the first questionnaire served as a second selection criterion, to gain a first impression of the level of maturity of the LSS deployment.

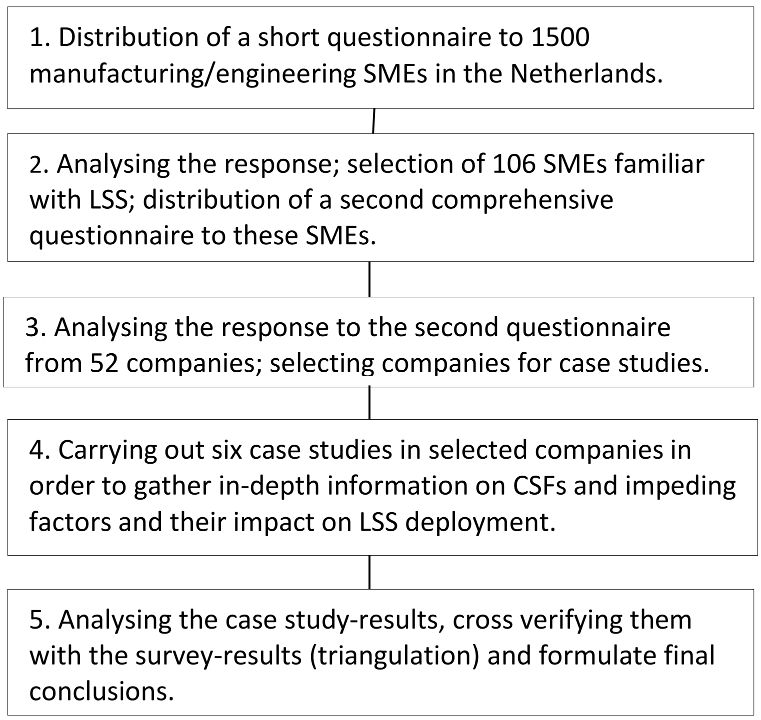

Figure 3.1 Stages of our study

The second questionnaire consisted of four parts. In the first part the respondents were asked to give information on their company's strategic objectives and main drivers to achieve orders from customers. In the second part questions were asked on the knowledge and application of quality improvement methods and tools and techniques to be used in Lean Six Sigma projects. The third part focussed on CSFs (critical success factors) critical to the implementation of Lean Six Sigma and the fourth part on impeding factors and results achieved related to Lean Six Sigma implementation. For this we used a Dutch version of the questionnaire that has been used for research on the implementation of Six Sigma in manufacturing SMEs in the UK (Kumar, 2007; Antony et al. 2005, 2008).

After the selection of candidates 106 companies were invited to respond. Questionnaires were completed by companies with different manufacturing/engineering backgrounds and with different levels of experience in Lean Six Sigma. The differences in results obtained from questionnaire responses may be related to different backgrounds and different levels of experience.

Given the need to gather in-depth, rich data on CSFs and impeding factors and their impact on the deployment of Lean Six Sigma, case study research was carried out to supply additional information. Yin (2003) distinguishes three different types of case studies used for research purposes: exploratory, descriptive and explanatory. In our study the case studies should deliver additional information useful for further exploration. Candidates for case studies were selected from the companies that had responded to the second questionnaire. Special attention was given to differences in manufacturing areas and levels of experience with Lean Six Sigma. Multiple cases enable broader exploration of research questions and theoretical elaboration (Yin, 2003; Eisenhardt and Graebner, 2007). We selected six companies that complied with the inclusion criteria. The size of these companies varies from about 50 to 250 employees. The companies are active in different industrial sectors and their LSS experience varies from one to six years. The data were collected through semi-structured interviews, using an open-ended interview protocol (see Appendix B), with managers (plant manager, quality manager, production manager) and with Lean Six Sigma experts (Belt functions).

The interview topics were:

- Reasons why the organization became interested in and started with LSS.

- The scale and scope of the current LSS efforts, the number of employees involved, examples of projects carried out, which processes are involved and project results, lean-oriented versus Six Sigma-oriented approach.
- Organizational aspects of the parallel LSS organization (as described by Schroeder et al., 2008).
- Critical success factors and impeding factors.
- Long-term vision of LSS, areas to develop and long-term goals.

All the interviews were recorded and transcriptions of the interviews were made to facilitate the analysis. Two of the researchers (WT and KA) analysed the materials and coded the interviews according to the approach of Strauss and Corbin (1998). A within-case analysis was followed by a cross-case analysis (low versus high progress) to understand the differences, to give additional meaning to the critical success factors and impeding factors and possibly to find new factors. The analysis is presented in section 4.2.

3.4 **Results and analysis**

3.4.1 **Response to the questionnaires**

Survey of respondents and company objectives

A total of 198 companies responded to the first questionnaire, 106 of which were invited to fill in the second web-based questionnaire. Within this group of 106 companies 63 stated they had implemented just Lean, 1 company just Six Sigma, and 42 companies stated they implemented both Lean and Six Sigma.

The second web-based questionnaire was completed by 52 companies (response rate 49%). Figure 3.2 shows the distribution of the size of these companies by numbers of employees.

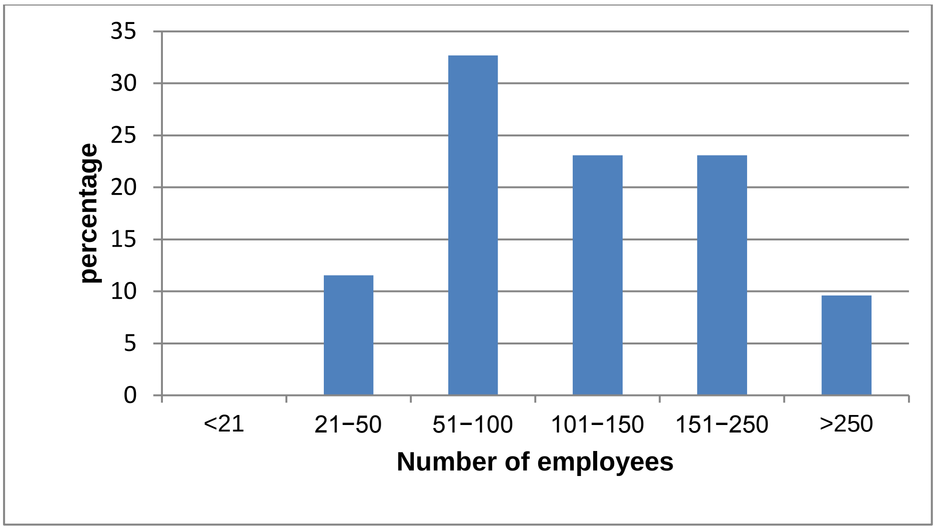

Figure 3.2: Distribution of numbers of employees of respondents to the second questionnaire

The distribution includes 5 companies with more than 250 employees. Our first selection was based on a range of 25–300 employees[2].

Position of the respondents within the company

The respondents' position within their company is depicted in table 3.1. The other category includes people from various departments, for instance from logistics, finance and operations, procurement, lean and Six Sigma programme management. It was decided by the management who would respond to the questionnaire. This may be the reason why no shop-floor employees were included.

Respondents position	%
Director	24
Quality manager	22
Operational manager	13
Belt functions	14
Other	27

Table 3.1: Respondents' position

Areas of industry

Companies from a wide variety of industries have contributed to this study. The areas of industry are depicted in table 3.2.

[2] The reason for choosing an upper limit of 300 employees was that we expected that the real number of employees would in general be somewhat lower, because of the rather pessimistic economic situation at the time of the study. As a consequence a small number of companies might not comply completely with the formal criteria for SMEs.

Areas of industry	%
Automotive	11
Electronic instruments	13
Chemical	7
Packaging	8
Food	8
Polymer products	8
Metal components	8
Building components	6
Industrial equipment	6
Other	25

Table 3.2: Areas of industry

Status of Lean Six Sigma and other quality initiatives

The majority of the respondents completed the questionnaire in such a way that all four parts of the questionnaire were covered, indicating that these companies were involved in Lean Six Sigma improvement programmes. Some respondents with more experience with lean manufacturing than with Six Sigma had some difficulties in responding to specific questions on Six Sigma and therefore did not answer a number of questions.

Lean Six Sigma tools and techniques

Integrating various tools and techniques of various origins within a well-defined framework (DMAIC) is typical of Lean Six Sigma. Table3.3 shows a survey of commonly used tools and techniques. The table was developed to show information in two areas, usage and usefulness of tools and techniques. The table also shows the percentage of respondents who indicated that they were unfamiliar with certain tools and techniques. The number of respondents differs a little from one tool to another, but with a small range, from 49 to 52 respondents. The respondents were asked to rate the application (i.e. usage) on a Likert scale of 1 to 5. In this scale '1' indicates 'never been used', '2' 'used only once', '3' 'used rarely', '4' 'used frequently' and '5' 'used continuously'. The respondents were also asked to rate the usefulness of tools and techniques. In the usefulness scale '1' means 'not useful', '2' 'slightly useful', '3' 'more useful', '4' 'very useful' and '5' 'extremely useful'. In table 3 the average Likert ratings of usage and usefulness are listed. The most frequently responded ratings have been added to give a better impression of the distribution of the ratings.

Tools and techniques	Usage mean rating	Most frequent rating	Usefulness mean rating	Most frequent rating	Unfamiliar (%)
5S methods	3.96	5	4.18	5	8
Brainstorming	3.72	4	4.02	4	0
PDCA (plan, do, check, act)	3.70	4	4.04	4	6
Histogram	3.56	4	3.70	4	15
VSM (value stream mapping)	3.53	4	3.84	5	23
Pareto diagram	3.49	4	3.96	4 and 5	8
Process flowchart/mapping	3.47	4	3.83	4	6
SIPOC (suppliers, inputs, process, outputs, customers)	3.45	4	3.59	4	54
Cause and effect analysis	3.40	4	3.69	4	19
Process mapping	3.36	4	3.57	4	15
Project charter	3.36	4	3.59	4	40
Failure mode and effect analysis	3.31	4	3.53	4 and 5	27
Quality costing analysis	3.21	4	3.65	4	15
Cause and effect diagram	3.15	3	3.70	4	23
Run charts	3.13	3	3.41	4	52
Kanban	3.11	5	3.42	4	12
SPC control charts (statistical process control)	3.03	1 and 5	3.70	5	46
Quick changeover, SMED (single minute exchange of die)	3.00	3	4.06	4	27
Poka-yoke	2.95	3	3.71	4	23
Kaizen events	2.88	2	3.48	4	17
Tally charts	2.83	4	3.26	4	10
Benchmarking	2.83	2	3.07	4	8
ANOVA	2.79	4	3.27	4	56
Balanced scorecard	2.79	2	3.28	3	21
Measurement system analysis	2.76	4	3.13	3	44
Scatter diagram	2.53	2	2.97	2	33
Regression analysis	2.48	3	3.03	3 and 4	46
DoE (Design of Experiments)	2.44	1	3.03	4	46
Matrix diagram	2.43	3	2.79	3	42
Relations diagrams	2.29	2	2.65	3	56
Quality function deployment	2.29	1	2.59	4	56
Hypothesis testing	2.28	1	2.67	2	46
Affinity diagrams	2.21	1 and 2	2.80	2	69
Taguchi methods	2.09	1 and 2	2.50	1	60
Process capability analysis	2.07	4	3.21	4	31
PERT chart (programme evaluation and review technique)	2.00	1	2.29	1	71
Force field analysis	1.69	2	2.33	3	65

Table 3.3: Tools and techniques (ranked on usage mean)

Familiarity with tools and techniques shows much diversity. Within the group of statistical tools and techniques the familiarity is very diverse. Unfamiliarity (%) in general shows larger percentages for more sophisticated statistical tools and techniques. Some of the non-statistical tools and techniques are very unfamiliar (affinity diagram, PERT chart, force field analysis). Lean manufacturing tools (5S methods, VSM, quick changeover and Kanban) are rather familiar, with 5S methods being the most familiar.

Usage and *usefulness* show rather modest mean ratings. Looking at mean ratings alone might give the impression that most tools and techniques might not be used frequently (below 4 on the Likert scale), but 19 out of the 37 tools and techniques have 4 or 5 as the most frequently scored rating. The majority of the distributions of the scores are skewed to the left. Regarding *usefulness* these observations are even more pronounced with 27 out of the 37 items having 4 or 5 as their most frequently scored ratings.

Some salient effects should be mentioned. 'SPC control charts' shows a very peculiar distribution with 1 and 5 as the most frequent scores. This effect could be caused by the differences in types of manufacturing SMEs, some of them being process industries or manufacturers of products in large series and some of them delivering unique custom-built products. Regarding *usefulness* a salient aspect is that DoE is regarded as useful (mean rating 3.21 and 4 as the most frequently scored rating). The most frequent *usage* rating is 1, so DoE methods are hardly used now but are nevertheless judged to be important.

Critical success factors for implementation

In the questionnaire questions were asked on thirteen CSFs. These CSFs were identified from existing literature (Antony 2005, Kumar, 2007). Every factor was divided by a number of subfactors (items). The respondents were asked to rate the importance of each item of the CSFs, with 1 corresponding to 'not important at all', 2 to 'slightly important', 3 to 'important', 4 to 'quite important' and 5 to 'very important'. Next to this question the respondents were asked to rate the actual practice within their company on a similar scale with 1 corresponding to 'very low', 2 to 'low', 3 to 'moderate', 4 to 'high' and 5 to 'very high'.

The items should all contribute to the rating of the CSF as a whole and therefore their ratings should be correlated with one another. A useful coefficient for assessing internal consistency is Cronbach's alpha (Nunnally and Bernstein, 1994). George and Mallery (2003) provide the following rules of thumb for Cronbach's alpha values: >0.9 excellent, >0.8 good, >0.7 acceptable, >0.6 questionable, >0.5 poor and <0.5 unacceptable. Out of the 13 Cronbach's alpha values of the importance rating 11 were larger than 0.7, with 8 values of at least 0.9. The CSF *cultural change* had an alpha value of 0.6 and the CSF *linking to employees* had an alpha value of 0.4. Removing sub-items from the set of sub-items did not improve the alpha coefficient. Therefore we excluded *linking to employees* from our list of CSFs. Linking Lean Six Sigma to employees nevertheless may yet be an important CSF. It is merely due to the lack of consistency of the items applied in the questionnaire that we were not able to prove the validity of this CSF. See table 3.4 for the 12 remaining CSFs and their ratings and the Cronbach's alpha values on importance.

Critical success factor	Importance		Practice
	Mean rating	Cronbach's alpha	Mean rating
1. Linking to customer	4.1	0.98	3.6
2. Vision and plan statement	3.9	0.96	3.2
3. Communication	3.8	0.97	3.0
4. Management involvement and participation	3.8	0.94	3.0
5. Linking to business strategy	3.8	0.75	3.0
6. Understanding of Lean Six Sigma	3.7	0.93	2.9
7. Project management skills	3.7	0.90	2.8
8. Organizational infrastructure	3.6	0.70	2.9
9. Project prioritization and selection	3.5	0.88	2.9
10. Cultural change	3.3	0.61	2.7
11. Education and training	3.3	0.70	2.6
12. Linking to suppliers	3.3	0.88	2.3

Table 3.4: CSFs and mean ratings of importance and practice (ranked on importance)

All the CSFs are considered to be important, since all the importance estimates are above 3. The significance of the differences between ratings was tested statistically. Because of the discrete and non-normal character of the score distributions the non-parametric Mann-Whitney test-method was applied for testing. The test results show that differences in ratings of ≥0,3 are significant at the 95% level. A few of the differences of 0,2 are significant at the 90% level, which is for instance a valid conclusion for the significance of the difference between the mean importance ratings of *linking to customer* and *vision and plan statement*.

Most of the practice averages are below 3, which means that for most practices the levels are below moderate. The *linking to customer* average is between moderate and high. *Linking the programme to suppliers* and *education and training* show the lowest rankings.

Barriers to the deployment of Lean Six Sigma

Impeding factors in implementation

The respondents were asked to identify the top three factors impeding the implementation of the programme. The results are shown in figure 3.3. *Internal resistance*, *availability of resources*, *changing business focus* and *lack of leadership* were the most frequently mentioned impeding factors. Other factors showed lower but nevertheless substantial frequencies.

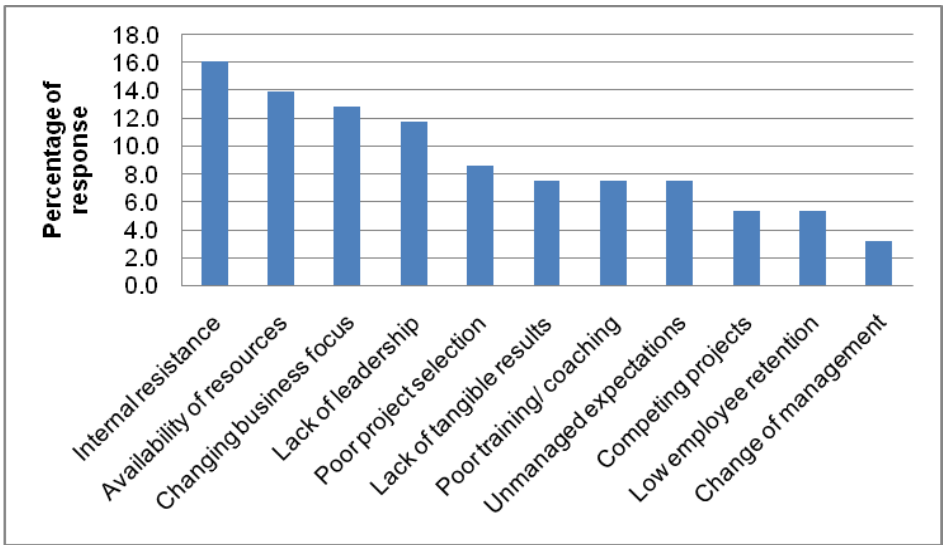

Figure 3.3: Factors impeding implementation

We recall that every respondent could identify up to 3 impeding factors. Analysis of the data made clear that internal resistance was mentioned by 54% of the respondents, availability of resources by 46%, changing business focus by 43% and lack of leadership by 39%.

Performance

Organizational performance measures

To measure performance we used performance measures based on the literature and the evaluation criteria of major international quality awards: the Malcolm Baldrige National Quality Award, the Australian Quality Award and the European Quality Award (Garvin, 1991;

Australian Manufacturing Council, 1994; Terziovski et al, 1997). To assess the benefits of the implementation of Lean Six Sigma two types of measures of organizational performance were used. The first group of measures consists of performance indicators that can be assessed by making use of the available business data. These hard performance measures concerning the benefits of the programme were assessed by the respondents using a scale of 1 to 5. The meaning of the scale was explained for every item separately. For instance for Productivity '1' is connected to 'decreasing', '3' to 'moderate improvement' and '5' to 'major significant progress'. For Delivery on time '1' is connected to <50% of the deliveries', '3' to 81-90%, and '5' to >96%. Figure 3.4 provides a survey of the mean ratings and standard deviations.

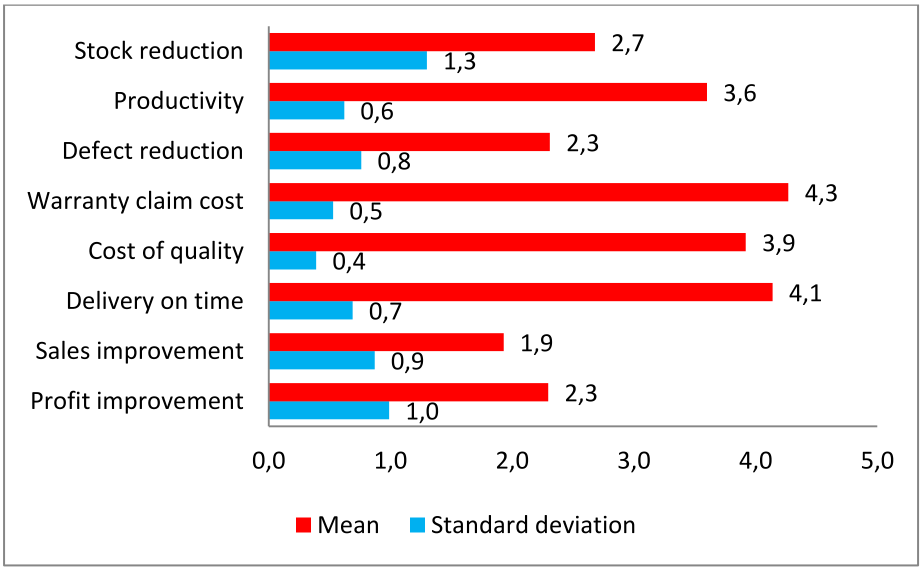

Figure 3.4: Mean scores and standard deviations of hard measures of organizational performance

Implementation of Lean Six Sigma was regarded as having a positive effect on the reduction of warranty claim costs, time delivery, the reduction of quality costs, and productivity. Their mean scores are clearly above 3 with relatively low standard deviations. The differences between the ratings were tested using the non-parametric Mann-Whitney test-method. Differences ≥ 0,3 are significant at the 95% level.

The second group of indicators is a group of organizational soft performance measures for which it is less possible to assess them by using reliable business data. Six performance measures were applied, which are presented in figure 3.5. To assess each of these performance measures the respondents had to assess a number of sub-items on a Likert scale from 1 to 5 , with '1' corresponding to 'strongly disagree', '3' to 'neutral' and '5' to 'strongly agree'. The average of the mean ratings of the items provides the mean rating of the effect of the programme on each of the performance measures. The standard deviation reflects the spread in the item mean ratings. To test the internal consistency Cronbach's alpha values were calculated for each performance measure. All the Cronbach's alpha values showed satisfactory levels (above 0.7). Mann-Whitney tests on the differences of the mean scores revealed that differences ≥0,4 are significant at the 95% level.

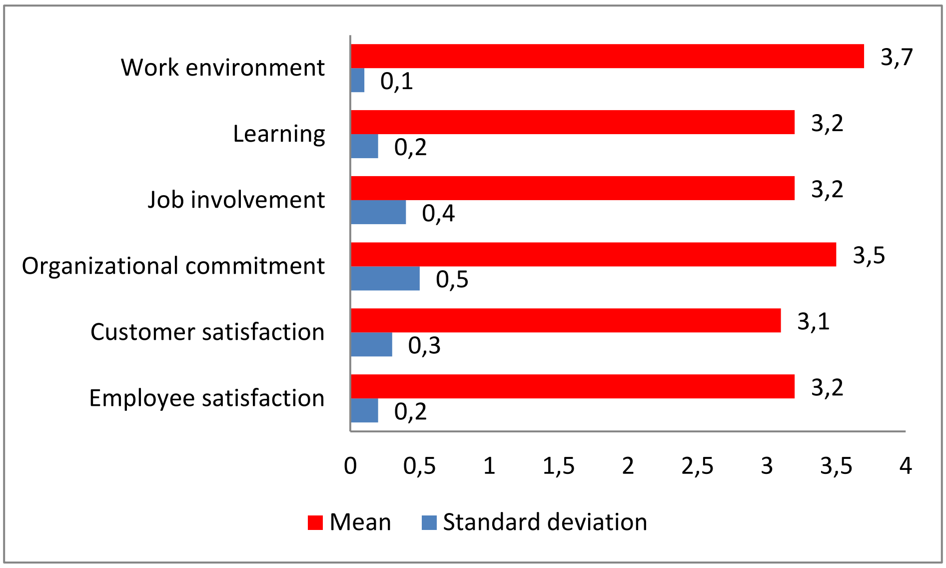

Figure 3.5: Mean scores and standard deviations of soft measures of organizational performance

All the mean ratings are above 3, which means that the majority of the respondents rate the effect of the programme on all the soft performance measures as above average, with work environment showing the highest rating with the smallest standard deviation. The sub-items of work environment do not refer to the physical work environment but to the well-being of employees, by asking questions about for instance the feeling of being valued and supported. The fact that the work environment is rated at the top level in this set of soft performance measures provides support for the notion that LSS programmes affect the organizational culture, next to the well-known cost-related operational performance issues.

3.4.2 **Case study research**

With our case study research we wanted to gain insight into CSFs and impeding factors. Therefore, we decided to compare the case study organizations with different levels of LSS implementation on different aspects of LSS implementation. In this section we will first describe the six case study organizations and then go deeper into how LSS is implemented, zooming in on CSFs and impeding factors.

The case study companies

The response to the second questionnaire served as a basis for selection of companies for case studies. The original list of candidates consisted of 10 companies, but unfortunately some companies were reluctant to cooperate, mainly because of the difficult economic situation within the time frame planned for carrying out the case studies. Table 3.5 presents a description of the six manufacturing case study companies, giving an impression of the company profile, the reasons why the company entered and the way they went along with LSS (strategic link) and elements of the organizational structure with regard to LSS. Each company was labelled using an imaginary name to assure anonymity. All companies are active as suppliers to other industrial companies, and they all have an important role in the development of their products. All the companies are registered as companies within the range of SMEs, but all but one of the companies are part of a larger organization. All of these companies are managed as separate units with their own specific markets and financial targets. Five companies are settled in the Netherlands; one is settled in Flanders (Belgium).

Company	Company profile	Strategic link	Structure
Imould	Supplier of plastic products, mainly automotive; about 250 employees. Specialist in injection moulding, both engineering and production. The company has been a family-owned company for a long time and is now part of an international organization. Primary technical and logistical processes are involved in the LSS programme. Sometimes also external partners are involved in LSS projects. No distinction is made between lean and Six Sigma projects.	Invited to take part in LSS projects by an important automotive customer and by a material supplier. The company entered LSS in 2004. Management is convinced of its competitive advantage. Based on experience in first projects the company has decided to set up its own LSS programme, adjusted to the size of the company.	The steering group is leading the development with full participation of the management team. Two BBs (Black Belts) have been trained; the quality manager has been trained as a champion. In all the primary process departments GB experience (Green Belt) is available. Top management is responsible, but the quality manager is the informal leader.
Chemic	Chemical process industry, production of emulsions in 34 grades, mainly binders for paints and several kinds of adhesives; about 110 employees. Yearly 20-30 projects are running, about 50% lean and 50% Six Sigma. Involvement of primary technical processes, mainly internal, sometimes with the involvement of other companies belonging to the same international organization.	The company entered LSS in 2005 with a new multinational owner. Projects are selected on the base of saving costs and creating revenue by raising productivity or creating new business. Management is convinced of its competitive advantage.	Project selection and review are performed two to four times per year. Selection of projects is well organized, following a stage gate process. This site has 2 certified Black Belts and 17 Green Belts have been trained; 7 of them are certified. Operators are trained on the job by taking part in projects; a training and certification system exists. The project runtime varies from 1 day to several months.
Compmat	Specialist in thermoplastic reinforced composite materials; about 100 employees; supplier to the aircraft and defence industry. Research and development is very important; the company focuses on improving production control and organization. One Six Sigma project is running in cooperation with an important customer and several lean-oriented projects with various time frames are carried out. Involvement of technical, logistical and purchasing processes.	An existing quality problem was tackled in cooperation with a customer with LSS experience, starting in 2008. Low experience, pilot projects are carried out. Management regards LSS implementation as crucial to retaining competitive advantage. Six Sigma is regarded as suitable for tackling complex problems, influenced by multiple process parameters, needing specialists' expertise for problem solving.	A steering group, consisting of the production manager, controller, GBs, is responsible for project selection. Three Green Belts have been educated in cooperation with an external customer. GBs are available part-time to manage projects. Operators learn through participating in projects. No formal champions/sponsors. LSS organization is in a pilot phase.

Table 3.5-1: Description of the case study companies

Company	Company profile	Strategic link	Structure
Aerosys	Aerospace industry, the main products being subsystems of space launching vehicles and solar array systems; about 200 employees. Production is carried out in cooperation with a number of qualified subcontractors. First pilot projects focussed on streamlining and optimizing logistics and information interchange. Lean and Six Sigma are expected to integrate in a natural way. Lean tools are very important in the first pilot projects.	In 2006 the company became part of a large European organization. From then on LSS development accelerated. Projects are selected to realize savings by streamlining processes and eliminating waste. Production and quality management are convinced that the LSS programme provides the best way to retain competitive advantage.	Pilot LSS organization. The quality department is planned to be the centre for management of improvement projects. Project selection has to be authorized by top management. One certified Black Belt is available; another Black Belt is trained. Corporate policy is to formalize only the BB-level function. Other belt levels are to be trained on the job by the Black Belt team leader. No formal GB level. No strong visible top management LSS leadership.
Machcomp	Independent specialist in the development, manufacturing and assembly of custom-made machinery and build-to-print components. The number of employees is about 50. The markets are the international aerospace, aircraft and defence industry and other high-end mechanical engineering industries. Involvement of technical and logistical processes, internal and external. Lean-oriented projects are dominant.	Realizing the cost savings necessary to stay in competition needed a new approach. LSS was believed to offer promising opportunities. The company entered LSS in 2005 with the help of an important customer.	LSS implementation is delegated to the quality department. The department manager is a GB, certified by a large manufacturer of commercial jetliners and defence aircraft systems. Projects are carried out with various time frames from one week to several months. All projects follow DMAIC project phases.
Blowmould	Manufacturer of automotive fuel tank systems with about 200 employees. The main technology is plastic blow moulding. Reducing variability and waste elimination have received the upmost attention until now; grow and innovation is regarded as having huge potential for improvement in the future. Implementation of TPM (total productive maintenance) has received special attention through a development programme with a time frame of a few years. Involvement of primary technical and logistical processes in the LSS programme; the participation of office processes is at a beginning stage.	Long history of quality improvement in an automotive context. LSS organization development accelerated after becoming part of a major USA-based industrial organization in 2003. Within this organization Blowmould is the only company working in the automotive market. LSS projects are selected on site. Yearly plans are reviewed by the European headquarters.	Leading role of plant management, special LSS coordinating function, clear procedures for project selection and reviewing, supported by a management system on the corporate level. In this plant 30 Green Belts and 4 Black Belts (variation- or lean-oriented) are available. All managing functions are GB trained. No other formal belt functions have been established. A BB and GB training and certification system is available, stimulated by a bonus system. Projects vary in time frame from one-day improvement projects to large projects running over several months.

Table 3.5-2: Description of the case study companies

How the organizations apply LSS, zooming in on CSFs and impeding factors

As explained earlier our case study research was carried out to gather more detailed information, additional to the information available from the questionnaire. This additional information is predominantly relevant for answering RQ3 on the translation of CSFs into practice and on how organizations cope with impeding factors. To find relevant information two authors individually went through the transcripts of all the case study interviews and searched for typical quotes and comments, which could be linked to the 12 CSFs summarized in table 3.4 and to the impeding factors of figure 3.3. Afterwards agreement on a final list of text phrases about CSFs and impeding factors was achieved in a consensus meeting. We present the results of this process in the next part of this section, restricting ourselves to the really salient quotes and comments recorded in the interviews.

Quotes and comments related to CSFs

On *linking the programme to the customer*.

One of the companies (Compmat) deliberately involved engineers of the customer in the project team to help solve one of their structural recurring problems concerning materials delivered to the customer. Two organizations (Aerosys and its subcontractor Machcomp) realized together that they needed a joint project to streamline the complete supply chain instead of focusing only on their own contribution.

Imould has an own policy but the initiative to embark on LSS was influenced by an important automotive customer, who offered assistance in the first Black Belt training.

On *vision plan statement*.

The plant manager of one of the organizations (Blowmould) had a compelling vision. His picture begins with DMAIC projects; later on the focus also includes lean manufacturing and in the future the focus will shift to DfSS projects to drive innovation. In this way Six Sigma is linked to innovation.

On *linking to business strategy*.

In our questionnaire sub-questions under *linking to business strategy* concerned the financial judgement of project results, a project focus on improvements and the application of both financial and non-financial indicators to measure improvement. Links to these sub-items came up in the interviews. In all the case study companies financial indicators are applied. Using non-financial performance indicators additional to financial targets came up very explicitly in our interviews with two companies (Blowmould, Aerosys).

On *understanding of Lean Six Sigma*.

One manager (from Compmat) stated: ‘for complex quality problems with many parameters having influence on the process Lean does not work, then you need a big gun like Six Sigma. Therefore the combination of Lean and Six Sigma is a very powerful one’, indicating that Six Sigma is regarded as the best way to tackle complex quality problems. The same manager is fascinated by the application of VSM combined with financial information. ‘Visualizing a sequence of processes through VSM makes clear what can be done to improve things and it also facilitates communication with management’.

Blowmould is the most experienced case study company with regard to LSS. Blowmould already had a very solid continuous improvement programme, which was integrated into LSS. A wide range of tools is applied in multiple project types with different application areas and project durations. Project types range from very short ‘on the job’ projects to large Six Sigma Black Belt projects taking several months. In short quality-related projects team members follow eight steps to complete the project. This routine of problem statement, describing the current status, looking for root causes, validating root causes, searching for solutions, validating them, implementation and follow-up is implemented in all project formats from small to very large. Of course the range and complexity of tools and techniques applied in projects differ from one project type to another.

On *project management skills*.

Dedicated software-supported systems are applied (Chemic, and even more in Blowmould) to document projects. For each project information is available about the standard project contract, project review and DMAIC structure.

On *organizational infrastructure*.

In three companies LSS deployment is at a beginning stage. A management steering group has been installed (Imould, Compmat), but there is no strong leadership on LSS-deployment. In Aerosys the quality department takes initiatives; within the quality department a new function has been instituted for the management of improvement projects and for the coordination of new project proposals coming up. Only the BB level is recognized in Aerosys. More mature LSS organization structures are present in Chemic and in Blowmould, the most visible being in Blowmould. The LSS-organization has a clearly visible own position in Bowmould, a special LSS coordinating function has been instituted. High degree of standardization has been achieved with four types of projects (A4, A3, Kaizen, Six Sigma), from very short A4-projects to Six Sigma projects that take several months. Black Belts work on projects for at least 60% of their working time. Green Belts work on projects as part of their normal job. No formal Yellow Belt level has been instituted, but management is very eager to involve operators in LSS projects.

On *project prioritization and selection*.

In four companies project prioritization and selection are the task of a management steering group. This steering group prioritizes improvement projects and selects projects that can be started, assigns members to project teams and monitors project progress without applying clear formal tollgates between the phases of the running project (Imould, Compmat, Aerosys, Machcomp). In Chemic project prioritization and selection are more sophisticated and projects are carried out in stages. The managing director states ‘the stakeholders fill the pipeline by brainstorming. First they come up with ideas, these ideas are developed to a certain degree to get an impression of the cost-benefit relations, then the projects are prioritized using a Cause & Effect matrix. Then we proceed with the most valuable ones to the next stage, in which concepts are developed for them. Focus is laid upon costs, benefits and feasibility of success. Then in a next round of prioritization we concentrate on the projects that add the most value, since the resources lack to do all of them’.

Approved projects have direct consequences for the next year’s budget (Blowmould). The predicted financial benefits are translated into budget reductions for the next budget year after project closure. This is performed to emphasize the importance of predicting feasible project targets.

An increasing interest in projects focusing on lean manufacturing issues was observed in all the companies. In a few companies a current state map as part of VSM is used to select projects (Compmat, Machcomp).

On *cultural change*.

Signs of cultural change should be visible and tangible in the company. Especially 5S projects are supposed to have a positive cultural impact, as one manager stated: ‘5S should be fixed in their genes’ (Compmat). One of the interviewees in Blowmould refers to classifications of levels of development of LSS: ad hoc, tool-driven, system-driven and cultural-embedded. His modest appreciation of the level of LSS development in Blowmould is on the ‘system-driven’ level, with perhaps some elements that could be associated with the ‘cultural-embedded’ level.

On *education and training*.

In table 3.5 information is presented about the numbers of Green and Black Belt functions in the different case study companies. In Chemic Green Belt training takes two weeks and Black Belt training takes two additional weeks. The training is very intense: ten to twelve hours daily. The expected financial benefits (in Chemic) generated by a Black Belt amount to one million dollars per year. The training in Aerosys consists of four blocks of one week each, and candidates must be assigned to a project that has to go through an approval procedure before the training starts. Training is combined with coaching during the time the candidate is leading the project. In Blowmould Green Belts are trained and certified within the local site. The Black Belt training takes five weeks and the Black Belt exam consists of one hundred questions in different categories that must be answered within four hours. Next to passing this exam candidates have to carry out two projects and train GB candidates before certification is granted. For reaching certification within a limited time frame of twelve to fifteen months a bonus is granted. Other Belt-levels, for instance Yellow Belts, have not been formally implemented in the case study companies, but the management of one of them (Blowmould) would welcome implementation.

On linking to suppliers

Blowmould has linked her computer-system to that of an important supplier. The supplier has access to the inventory database of Blowmould and is allowed to schedule new deliveries without needing a previous permission from Blowmould.

Machcomp has executed a project together with Aerosys to optimize the supply chain. Machcomp proposed this project, targeting 75% reduction of lead time and 30% reduction of transport between the participating companies.

Quotes and comments related to impeding factors

On *internal resistance*.

There is a certain resistance with regard to the use of the internal software-supported system for project documentation that must be used by project teams. 'What people don't like is the administrative part of Six Sigma. The project structure needs administration in all parts of the projects, something that engineers and hands-on people don't like to do' (Chemic).

Operators are sometimes reluctant to cooperate with lean manufacturing efforts. Operators who have worked in the company for many years are stimulated to change their working routines, which is sometimes experienced as threatening (Compmat).

On *availability of resources*.

Having enough time available to participate in projects is felt to be a problem (Compmat), which is recognized by management: 'a Black Belt of the customer was involved and we had to join the team with a few engineers of our company. We learned from that project that we really must detach these engineers for at least two days per week from their normal work'. The first trained Black Belt of Aerosys, the leader of the first large-scale Black Belt project, also refers to the time available for carrying out projects: 'BBs should have a significant part of working time available for projects, more than 50%, it should be their main task'.

On *lack of leadership.*

A manager of Imould stated: 'management is said to be convinced of working in the right direction, but there is some difference between commitment being in their genes and just being supportive'. A GB-trained engineer (from Compmat) is worried about LSS leadership: 'there certainly is management focus on LSS deployment, but it is rather weak. Middle management is doing well, but up to top management you feel focus fading'. One of the interviewees of Aerosys puts it this way: 'We are not yet an organization that really tries to develop itself to an organization with a clear continuous improvement driven focus, real commitment is poor. You don't feel a firm steering effort from the management team'.

On *competing projects*.
From Aerosys: 'other running projects, direct related to customer-orders, always get priority'.

We also traced a salient quote that is not directly related to the impeding factors of figure 3.3, but certainly refers to a disturbing effect on LSS implementation: 'It is too much the project leader's party' was heard from management (of Compmat), referring to a project leader who is very enthusiastic about LSS himself, but who's steering effort felt by team members could even be too strong.
Some of the CSFs and impeding factors of table 3.4 and figure 3.3 did not come up explicitly in our interviews. Explicit quotes on CSF *management involvement and participation* did not

come up in our interviews, yet the case studies show much diversity in the involvement of management in LSS deployment. At Blowmould the local management is very much involved by taking major initiatives with regard to policy deployment and organizational deployment measures. In other companies top management is very positive about LSS deployment, but does not show strong leadership in deployment.
Changing business focus was an impeding factor that did not spontaneously come up in our interviews. It simply was not an impeding factor felt by any of the six case study companies.
Comparing our survey study results on CSFs and impeding factors with our case study results we conclude that the survey study and the case studies did not provide contradictory information. Our case study research was carried out to deepen insight in what is really important to make LSS-implementation successful. New CSFs and impeding factors could emerge. Analysing the interview transcriptions we found arguments to identify three new CSFs. The first new CSF we call *personal LSS-experience of Top-management.* In Blowmould the plant manager was previously the company's quality manager. The plant manager's experience in the field of quality management, including LSS experience, was recognized by the interviewed managers as very favourable for LSS deployment. Another new CSF we derive from weaknesses in project leader attitude. Especially in Compmat one project leader

was said to be ‘making it his party’, reflecting a certain impatience to accelerate projects. This attitude could impede LSS deployment, and motivates us to introduce *development of project leader’s soft skills* as a second new CSF. A third new critical success factor, called *supply chain focus*, is related to projects directly connected to the world outside the company, with involvement of cooperating organizations in a supply chain. Saving costs on a certain sub-process may jeopardize the performance of other processes in the supply chain. Improving processes involving more companies needs coordination on a higher level of project- and production-management.

Finally we want to point out that in all case study companies lean oriented projects as well as projects focussed on improvement of process steps are carried out. Except for one company (Aerosys) under the umbrella of LSS different project-structures are applied for projects with a wide variety in project-length.

3.5 **Discussion**

For the discussion of the results of our study we return to the three Research Questions. RQ1 and RQ2 will be discussed mainly based on the result of our questionnaire, in the discussion of RQ3 the case study results will play an important role.

On RQ1: What is the current status of implementation of Lean Six Sigma (LSS) in manufacturing/engineering SMEs in the Netherlands.

With respect to the current status of LSS in the Netherlands we experienced that out of the 106 companies invited to respond to the second questionnaire, 63 of them were predominantly lean-oriented, 42 focussed on lean and Six Sigma and 1 on Six Sigma alone. This means that 59% of the respondents was predominantly lean-oriented. The second questionnaire was completed by 52 companies, 42% of them applying both lean and Six Sigma to a certain extent. From the analysis of tools and techniques applied (see table 3.3) we infer that the typical lean tools (from 5S to Kaizen events) are on average more familiar than the more sophisticated statistical tools (like DoE, MSA, ANOVA, hypothesis testing, regression analysis). However, the usage and usefulness ratings of more advanced tools show salient differences, which is for instance the case for DoE. There seems to be a high potential in the application of more sophisticated tools and a need for education in the backgrounds and application-fields of these tools.

With regard to the management of LSS-implementation it is clear that most Dutch companies are in a beginning stage of deployment. Many companies are more or less in a pilot phase, trying to gain experience from pilot-projects, often stimulated by large companies to which they supply products. Typical the responsibility for LSS-deployment is delegated to an enthusiastic manager and only moderate leadership is shown by Top-management. However, the general feeling about LSS is positive. The majority of the survey respondents (85%) appreciate of the achievements with regard to the implementation of LSS from 'reasonable' to 'high'. On the final question of the questionnaire on future expectations 77% of the respondents answered that the importance of LSS-implementation is expected to increase in the future.

On RQ2: What are the CSFs and impeding factors in LSS implementation, especially for manufacturing SMEs? How are these CSFs and impeding factors ranked by management?
From both our survey study and our case study research practically all 12 CSFs seem to be important. In table 3.4 all the importance ratings are above 3, and in the results of our case study research the importance of the CSFs is underlined. *Linking to customer*, *vision and plan statement*, *communication* and *management involvement and participation* are the highest ranked CSFs. In addition to the 12 CSFs a few new CSFs have been identified, *personal LSS-experience of Top-management*, *development of the project leader's soft skills* and *supply chain focus.* The differences between the importance- and practice-ratings show that on all CSFs there is room for improvement, but the highest ranked CSFs all have practice ratings of at least 3, which indicates a moderate level.
The ranking of impeding factors from our questionnaire-based results is represented in figure 3.3. The most important impeding factors are *Internal resistance*, *Availability of resources*, *Changing Business focus*, and *Lack of Leadership*. In our case study research the impeding factors *availability of resources, internal resistance,* and *lack of leadership* came up too, but *changing business focus* did not.

On RQ3: How are these CSFs translated into practice and how do organizations cope with the impeding factors?
From our case study research we highlight the most salient results with regard to translating CSFs into practical LSS deployment measures in the manufacturing SME context. Blowmould

is the most experienced company of the six companies that have been selected for case study research. This company embarked on Six Sigma in 2003 and during the implementation Six Sigma evolved to Lean Six Sigma. Blowmould has reached a high level, with standardized approaches for project-generation, -prioritizing and –selection, supported by systems. The plant-managing director is a convinced advocate of the LSS approach. The CSFs *management involvement and participation* and *understanding of Lean Six Sigma* are clearly recognizable in the top management. The LSS-organization has a visible place in the company's organization. The company has about 200 employees, so it is a large company within the SME-range according to the EU-definitions (<250 employees). The somewhat smaller Chemic, which has embarked in 2005 on LSS, and has a fairly stable LSS-organization with organized project selection rounds 2-4 times each year and a standardized procedure for project-generation, -prioritizing and – selection. The other companies have made less progress. Common to these companies is that the initiatives started at lower management levels. The top management is interested and cooperating, but the involvement and understanding is modest. These companies have no standardized systems for project selection in place. Compmat used VSM at management level to generate options for improvement projects, and this VSM has been used for communication to engineers and shop-floor. This way of working however has not been standardized and there is no plan to use this method on a regular basis. In the four companies Compmat, Machcomp, Aerosys, and Imould the LSS-deployment is developing slowly with stimulation from outside (customers, parent organisation), and not as a result of inspiring steering actions from the local top-management. The CSFs *vision and plan statement* and *management involvement and participation* make the difference, Blowmould and Chemic perform better with respect to these CSFs.

In our case study research the impeding factors a*vailability of resources*, *internal resistance*, and *lack of leadership* came up as the most important issues. *Changing business focus* did not come up in the case studies, and it was among the strongest impeding factors derived from the survey study. This impeding factor is connected to the management's poor ability to comply to the deployment plan, which can be understood by realising that to build a long-term strategy is difficult for SMEs. *Lack of leadership* is directly opposing the important CSFs *management involvement and participation* and *vision and plan statemen*t. Lack of understanding and experience with respect to LSS was perceived to be an important cause and therefore a new CSF *personal LSS experience* was proposed as a new CSF. The *internal resistance* is mainly referring to the shop-floor. For instance the introduction of lean oriented projects was reported by Compmat to cause changes in working routines on the shop-floor. Acceptance of these changes appeared to be difficult because employees were reluctant to changes in working routines that they were accustomed to for many years, and also because some fear existed that that they could lose their job through these changes. The new CSF *development of project leader's soft skills* was proposed to mitigate the negative effects of internal resistance.

Common to all the six companies is the tendency that lean methods have grown in importance, mainly because of its expected impact on the shop-floor. Six Sigma tools stay important but seem to be perceived as appropriate mainly to solve more complex problems which need the application of advanced methods to solve them.

3.6 Conclusions and outline to future research

This study started from repeating a survey study that has been carried out earlier in the UK (Antony, Kumar, and Madu, 2005). The survey results are based on the response from 52 companies that are deploying lean or LSS, until now the largest number of companies contributing to a similar survey study.

Linking to customer, *vision and plan statement*, *communication* and *management involvement and participation* are the highest ranked CSFs. The most important impeding factors are *Internal resistance*, *availability of resources*, c*hanging business focus*, and l*ack of leadership.*

The case studies show that the two most successful companies are supported by their larger parent organizations, and that the local management has LSS experience and is showing leadership, accepting their role in the deployment. In the other companies the deployment initiatives started at lower management levels, and coping with impeding factors is mainly done by cooperating with customers in projects and in education and training, including training in soft skills.

Both the survey results and the case studies support the observation that lean manufacturing and Six Sigma tend to be merged, but Six Sigma projects are regarded overall as more appropriate for tackling more complex quality problems, which need to be solved

by teams using more sophisticated tools and techniques. In general there is a belief among the management of SMEs that LSS offers opportunities for the development of their organization to reach higher levels of sustainable continuous improvement. The challenge is in finding feasible ways to implement LSS in SMEs, especially for those SMEs that cannot rely on the support of larger organizations (e.g. parent companies, large customers).
Based on this study and on studies on Lean/ Six Sigma implementation in the USA, Europe and Australia (Van Iwaarden et al., 2008, Kumar et al, 2012) it seems fair to conclude that national and cultural factors in these regions are not dominant in the application of Lean Six Sigma.
We want to elaborate further on how to be successful in increasing the power to improve continuously in the SME context. Our final goal is to build a framework for the implementation of LSS-based continuous improvement, tailored to the needs of manufacturing SMEs.

4. A framework for the implementation of Continuous Improvement based on Lean Six Sigma in small and medium sized enterprises

The success of LSS implementation in SMEs is highly dependent on the extent to which an LSS deployment programme addresses the specific properties of SMEs. In this chapter an existing framework for Six Sigma implementation for SMEs (Kumar et al. 2011) is evaluated using a multi-method triangulation approach. The objectives of this study are firstly to strengthen the foundations of the existing framework by uncovering evidence for some of its elements and, secondly, to identify proposed revisions to the framework, especially focussed on its application in manufacturing SMEs. The results of this study are expressed as confirmations and revision proposals for the framework, leading to a revised conceptual framework.

4.1 Introduction

Only a limited number of studies have been published on the implementation of Lean Six Sigma (LSS) in small- and medium-sized enterprises (SMEs). Some of these have focussed on critical success factors and barriers in the implementation of Six Sigma, Lean or Lean Six Sigma approaches (Achanga 2006; Antony et al. 2005; Timans et al. 2012). Only a few studies have focussed primarily on roadmaps for implementing LSS as a change programme for SMEs (Hansson and Klefsjö 2003; Chakravorty 2009; Kumar, Antony and Tiwari 2011).
The study by Kumar et al. (2011) clearly focuses on the implementation of a Six Sigma programme in SMEs. In this study, a framework for the implementation of Six Sigma is introduced (Figure 4.1) that includes instruments reflecting a lean manufacturing background. Because of this, the introduced framework supports the merger of lean manufacturing and Six Sigma, as inspired by George (2002) and Snee and Hoerl (2007). LSS combines two improvement approaches that originated from different parts of the world, as described by Dahlgaard-Park (2011).

A version of this chapter is under review at *Total Quality Management & Business Excellence* for publication: Implementation of continuous improvement based on Lean Six Sigma in small- and medium-sized enterprises

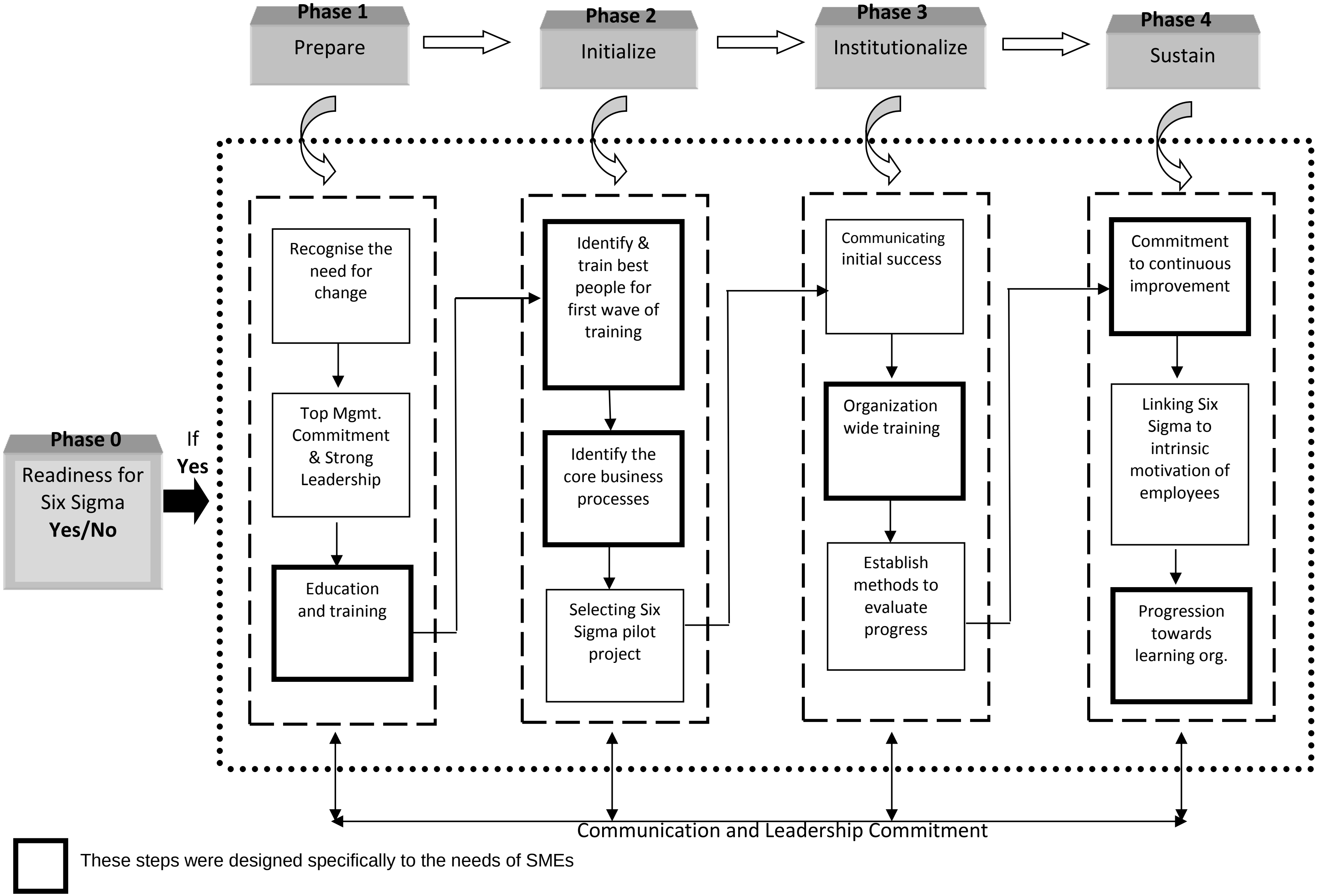

Figure 4.1. The framework of Kumar et al. (2011)

The main focus of the lean approach is on improving the flow between processes and on reducing waste and variability, while Six Sigma mainly concentrates on improving the processes themselves by closely examining causal relations through collection and analysis of real data. The two are not independent: Poor flow between processes and the existence of waste and variability may deteriorate process performance; while on the other hand, low process performance may cause problems in the flow between processes and may cause waste and variability. Because of this, it makes sense to draw on Lean and Six Sigma simultaneously in an integrated way to address all the root causes of poor performance.

The framework proposed by Kumar et al. (2011) is comprised of five phases, including a preliminary 'Phase 0' that is focussed on testing the SME's readiness for Six Sigma. The authors themselves indicated that their framework (Figure 4.1) had only been tested in three SMEs, and stated that "its robustness needs to be checked and refined based on suggestions and comments from industry, practitioners and academics." The objective of our research is to respond to this call by contributing to the further validation and improvement of the Kumar et al. framework, keeping in mind the SME-characteristics that have been listed in table 1.1. Our research intentions can be summarized in the following research questions:

1. What supporting, confirmatory evidence can be found on the phases and steps of the framework proposed by Kumar et al. (2011)?
2. What evidence can be found that the framework needs improvement? What revision proposals can be formulated based on this evidence?
3. What are the building blocks of a revised and validated framework that will meet the formulated proposals for revision while keeping the confirmed elements in place?

In the following sections of this paper, we first start by explaining our research approach and methods, which are comprised of a literature study, an expert focus group study, and retrospective interviews in two companies with long-term experience in the deployment of LSS methods. In the next section, we will present the results of our research as components of evidence that support the existing framework and add proposals for revisions. In the discussion and conclusion sections, we summarize and discuss our main results, and from there, come to a revised conceptual framework.

4.2 Research approach and methodology

In order to strengthen the basis of a framework with only limited validation, a focus group study makes sense. Bringing expertise from both consultants and practitioners together in a focus group that is balanced with respect to academic backgrounds and experience offers the opportunity to achieve good results within a short time frame. Relying on the results of one focus group alone, however, is precarious. We, therefore, strived for triangulation by firstly starting with a structured literature study to connect to contributions from other studies, and then by following up on the focus group with retrospective interviews to learn from practical experience from SME companies that have implemented LSS. The results from the three research methods will be discussed and will be converted into a revised framework.

The research approach is depicted in Figure 4.2. The discussions will lead to confirmatory evidence from, in this order, the literature, the focus-group research, and the retrospective interviews, and to proposals for revision.

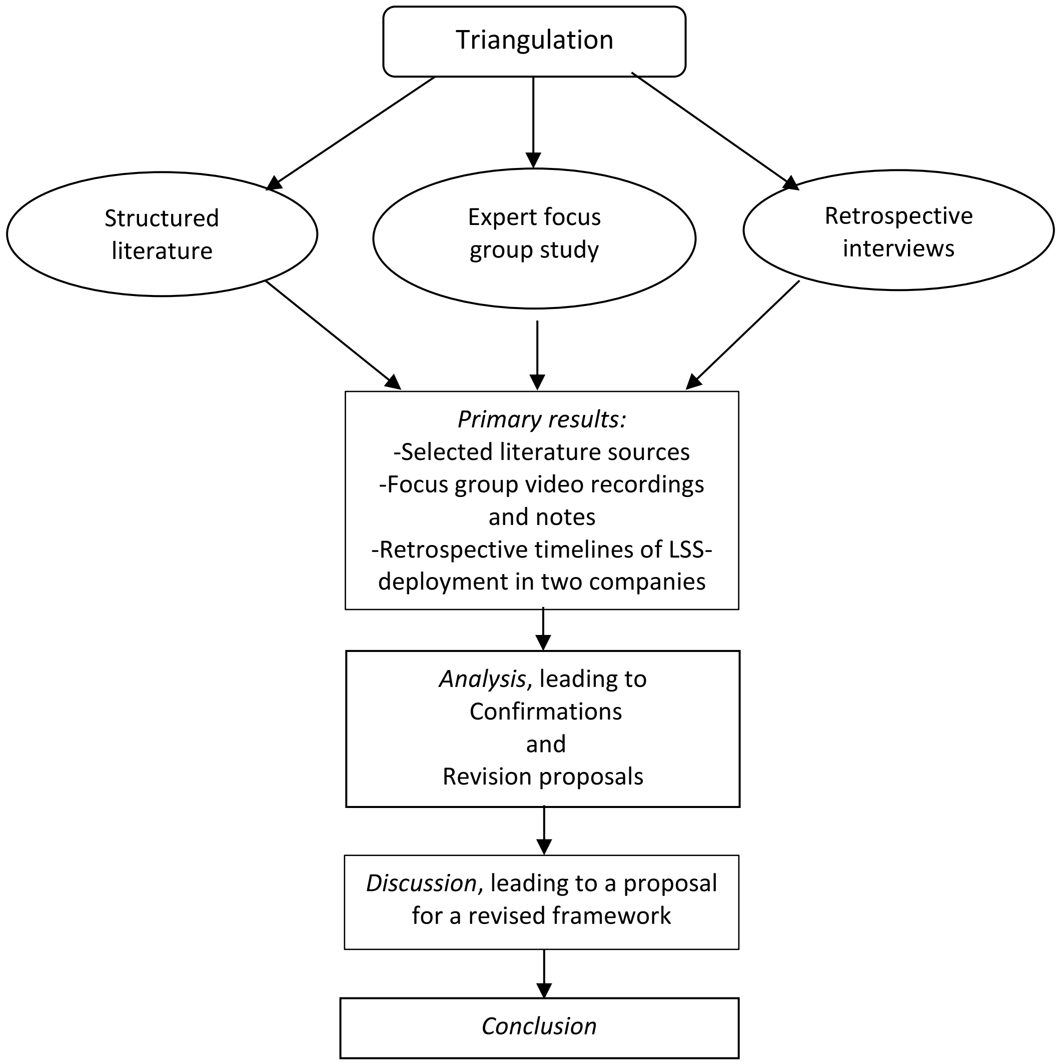

Figure 4.2. Research approach and methodology

Structured literature search

In our literature study, we searched for articles on issues relevant to implementation in a manufacturing context. Advanced search facilities were used in Science Direct, Emerald, Taylor & Francis, EBSCOhost and Springer databases, using the following keyword formulation: <“Six Sigma” OR “Lean” OR “Lean Six Sigma”> AND <“Implementation”> AND <“Learning” OR “Knowledge”>. The search was not restricted to articles that specifically focussed on SMEs because we wanted to first gain a broad picture of implementation issues. A list of 78 papers remained after limiting the search to peer-reviewed academic journals with references, restricting the timeframe to publications after 2003, and adding the additional condition that Six Sigma, Lean or Lean Six Sigma be explicitly mentioned in the abstract. We then excluded papers that were far outside the manufacturing context and added one additional article identified from the papers’ references, which qualifications resulted in a final list of 19 articles.

Focus group research methodology

The Kumar et al. framework displayed in Figure 4.1 can be regarded as a theoretical model for change. Focus group research that aims to discuss existing theory is related to the experiential type of focus-group task, according to Fern (2001, 6) in his book, *Advanced Focus Group Research*. For experiential tasks, a focus group should ideally have around 10 to 12 participants with some degree of homogeneity so the participants can share, exchange, and discuss ideas based on having comparable relevant knowledge in the field being studied (Fern, 2001, 180). We, therefore, invited experts in the field of LSS with backgrounds in practice and consulting. The group would thus be homogeneous with respect to LSS knowledge and experience but would differ with regard to the context of the members’ experiences. Table 4.1 presents a summary of the backgrounds of the participating consultants and practitioners.

Background	Education level	LSS level	LSS Experience (years)
Consultant	Master	MBB	12
	Master	MBB	12
	PhD	MBB	8
	Master	MBB	>12
Practitioner	PhD	Champion, MBB	>12
	Master	Champion, BB	4
	Master	Champion	5
	Master	Champion, BB	6
	Bachelor	Champion, BB	>12
	Bachelor	BB	7

Table 4.1. Background and experience of the focus-group participants

The programme set for the focus group meeting followed a three stage programme, an individual round, a second round in subgroups, and a third plenary round. In the third plenary round (video- and audio-recorded) final conclusions were formulated. Focus group research is not focussed on reaching complete unanimity (Krueger and Casey, 2009, 19-20). However, the ideas of our focus group through the three rounds converged to final results with a high degree of consensus.

Retrospective research in the industry

We used additional retrospective interviews to add experiences from managers who have led the actual deployment of LSS in an SME company. We selected seven companies that were interested in our study. We visited them all to explain our research goals and to receive information about their deployment efforts. Only two companies appeared to have long-term experience in the deployment of a continuous improvement programme. Long-term experience was needed because experienced organizations would presumably have passed through different phases of deployment. These two companies were visited again for interviewing managers who were involved in the deployment process from an early stage. Company A produces components for plastic pipe systems for water supply and sewage. Company B produces high-tech products for medical, pharmaceutical, and food industries. The first LSS experience dates back to 2003 for company A and to 2007 for company B.

The interviews were focussed on the LSS deployment steps in retrospect. Key to the process of collecting retrospective data is the need to reduce recall bias (Berney and Blane, 2003). We decided to use the lifegrid interview as our methodology for improving the validity and reliability of the results. These strategies have been seen as improving the accuracy of recalled data, particularly with reference to the time at which events happened.

4.3 Results and analysis

Results from literature

The complete list of selected articles is displayed in Table 4.2. Although some of the papers would fit in more than just one single category, we used the research focus to categorize the articles into four groups: Implementation frameworks, Strategic implementation issues, Culture development, and Learning and knowledge development.

Literature in categories		Research method	Main Results
Implemen-tation frameworks	1. Chakravorty (2009)	Single case study in a large organization	A six-step Six Sigma implementation model.
	2. Hansson and Klefsjö (2003)	Multiple case study research	A three phase roadmap for implementing TQM in small organizations.
	3. Kumar et al. (2011)	Multiple case study research, expert interviews, literature study	The roadmap presented in Figure 1, Six Sigma implementation in SMEs.
Strategic implementation issues	4. Linderman et al. (2006)	Survey study, data collected from Six Sigma projects in a large organization	Goals can be effective when project-teams adhere to the Six Sigma method and tools. However, when the tools and methods are not used rigorously setting challenging goals can be counterproductive.
	5. Hilton and Sohal (2012)	Interviews with Master Black Belts, literature study	Technical (for instance statistical, financial) and interpersonal attributes of Black Belts and Master Black Belts are identified as well as factors for success in deploying an LSS-programme.
	6. De Mast (2006)	Literature study	Competencies for disciplined and effective problem solving and decision-making behaviour can be developed by a strategic use of Six Sigma.
	7. Shah et al. (2008)	Literature study, survey study	Using lean methods improves the likelihood of implementing Six Sigma methods too. Performance levels are raised when lean methods are extended with Six Sigma methods.
	8. Timans et al. (2012)	Survey study and additional case study research	Ranking of critical success factors and barriers for LSS implementation in SMEs. Data on use and usefulness of LSS-tools.
Culture develop-ment	9. Done et al. (2011)	Multiple case study research	Best Practice Interventions carried out in SMEs are unlikely to develop sufficient capability for long-term change. For sustainable improvement an implementation programme is needed.
	10. Jones (2005)	Single longitudinal case study	Entrepreneurship within project teams appeals to the development of a natural attitude to take initiatives, which is only feasible when social relations are optimised.
	11. Zu and Fredendall (2009)	Survey study, regression analysis	Employee-involvement, -training, -performance and -recognition significantly affect the use of Six Sigma methodology. The Six Sigma role structure can be integrated in quality-oriented HRM practices.
Learning and knowledge development	12. Arumugam et al. (2013)	Survey study on projects in one single company, regression analysis	Six Sigma technical support to the project team and team psychological safety promote learning behaviour and knowledge creation in project teams and enhance the impact of Six Sigma projects.
	13. Choo et al. (2007)	Conceptualising study, formulation of propositions	A conceptual framework consisting of methodological and contextual elements for learning and knowledge creation.
	14. Gutierrez Gutierrez et al. (2012)	Survey study, structured equation modelling	Six Sigma teamwork and process management positively affect the development of Absorptive Capacity (AC). AC and organizational learning orientation are significantly and positively related.
	15. Hagen (2010a)	Literature review	Champions and Black Belts are examples of roles for which coaching capabilities are extremely important.
	16. Hagen (2010b)	Survey study, principal component analysis, regression analysis	Results indicate that ‘coaching expertise’ explained most of the variance in project management performance for both Black Belts and team members.
	17. McAdam et al. (2011)	Multiple case study research	A model demonstrating the underlying routines for knowledge absorption processes. Propositions are defined relating the characteristics of SMEs to LSS implementation.
	18. Mukherjee et al. (1998)	Survey study on projects in one single company, factor- and regression analysis	Recommends conceptual learning alongside operational learning, especially when the applied technology is poorly understood.
	19. Tu et al. (2006)	Literature study, survey study, structural equation modelling	Dimensions of the AC concept, and an instrument for measuring AC.

Table 4.2. Selected Articles

Results from our focus group study

In the focus group session, the group first reflected on the framework of Kumar et al. (2011) as a whole and argued that the separation between Phases 2 and 3 was somewhat artificial and that these phases could be merged into one single phase. Phase 0, "Readiness for Six Sigma," was regarded as very important, but the focus group argued that it should come later, as a management concern in the steps after the step "Recognise the need for change," which was regarded as a logical first step in Phase 1.

The steps of the first phase were confirmed to be relevant, but the focus group proposed to incorporate the "Identify core business" step of Phase 2 into the steps "Top Management Commitment & Strong Leadership" and "Education and training" (for management) of Phase 1. The focus group proposed to start the second phase ("Initialise and Institutionalise") with the selection and execution of a pilot project, and to organise the education of the project leader and team members within that project. The involvement of process owners was emphasized as very important, as process owners have a direct interest in the project outcomes.

The focus group missed a step regarding the organization of the selection and support of next projects, coming after the successful completion of the first pilot project. "Communicating initial success" and "Establishing methods to evaluate progress" were confirmed to be important as separate steps. The focus group argued that the Sustain phase is very important. Embedding of changes realised in the previous phase in the existing management system, widening the scope towards suppliers and customers, and "learning faster" were regarded as main issues for the Sustain phase. The focus group pleaded for special steps at the end of the first two phases for reflection on the progress of the implementation until then, to reconsider scope and ambitions.

Results from our retrospective interviews

The deployment of the programme as it has run in Company A is depicted in the time line of Figure 4.3. In 2003 a consultant was invited by Company A's management to introduce Six Sigma. After this presentation, the management decided to start with the education and training of two Black Belts (BBs). The BBs and the consultant would then, afterwards, together train the members of the management team at the Green Belt (GB) level. From then, new GB-training sessions were led by the BBs without further assistance. The GB training took about 5 months, having two days of training planned each month, and in between, participants worked on a project. In 2003 the deployment was exclusively focussed on Six Sigma, but lean aspects came in in an evolutionary way.

In 2005 basic operator training started. This training was introduced because shop-floor employees were only poorly involved prior to this step and occasionally showed some reluctance to cooperate. In the first version, this training took two days, which was shortened, afterwards, to one day, with an emphasis on lean.

Major problems in the deployment arose in 2007 and in 2011. In 2007 a gap was felt between the GB level and the Basic Operator level, and a new Orange Belt (OB) level was introduced to bridge this gap. The training of OBs contained tools to be used in teams like brainstorming techniques, root cause analysis using cause and effect diagrams, and on simple statistical measures. OB projects have a planning timeframe of 2 to 3 months. GB projects are more complex and have a planning timeframe of 3 to 6 months. In 2010 management decided to integrate Lean and Six Sigma completely. In 2011 management experienced a serious dip in performance at the GB level. Measures were taken with respect to the project-selection and -approval process by strengthening the roles of the champion, the BB, and the process owner. One of the measures was to introduce the obligation for certified GBs to carry out at least one project each year as a condition to keep the certification valid. From 2005 the intranet-based supporting system has developed continuously and is accessible for management and project team members.

Company B’s first lean-oriented deployment efforts date from 2007 when a bottom-up approach at the local level started, with the help of a British consultancy company, invited by the then owning holding company. In Figure 4.4 the time line for Company B is depicted. Between 2007 and 2012, the ownership of the company changed a few times, which caused changes in the management and in management priorities. In 2009 the local production manager took the initiative to revitalise the programme as a Continuous Improvement (CI) programme. A selection was made of problems that had to be tackled within the next year, from a 40-points list. Project subjects were predominantly on waste reduction, 5S, OEE (Overall Equipment Effectiveness). For instance the commonly-called 5S-“Red Tag” sessions were organised around production machines (Marria et al., 2012). By the end of 2010 decisions were made to reinforce the programme under the Lean Six Sigma banner at division level. At the beginning of 2011, BB- and GB-training started for one BB- and two GB-candidates and were organised around projects.

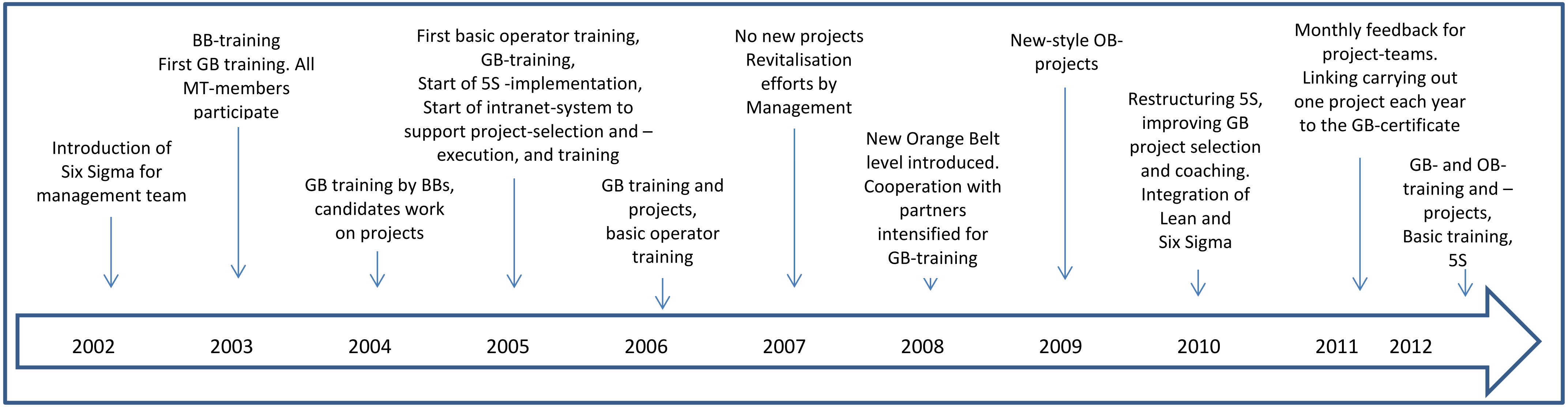

Figure 4.3. timeline of company A

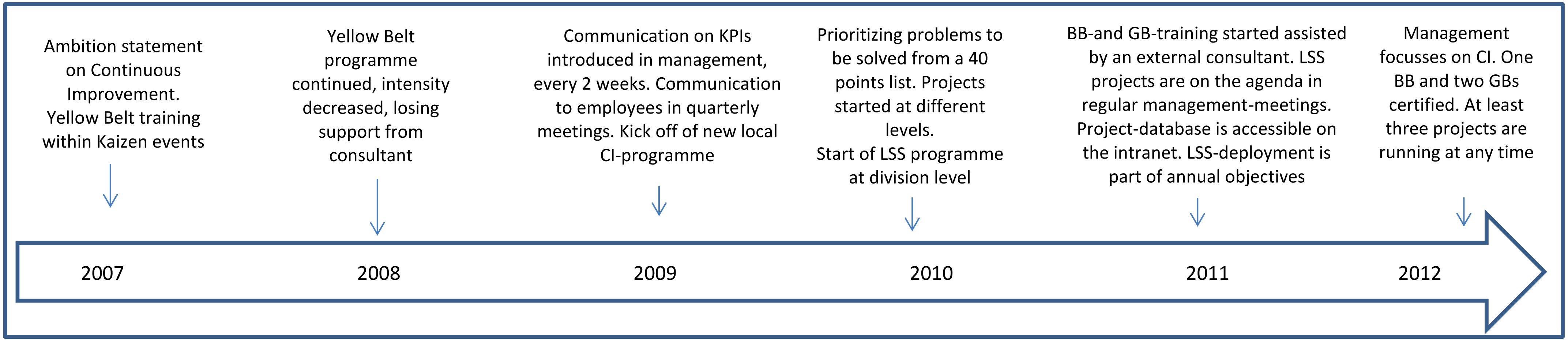

Figure 4.4. timeline of company B

Confirmatory evidence and revision proposals

Confirmatory evidence

From the results of the three research methods, elements of confirmatory evidence for the existing framework were inferred. From our literature review, we first of all identified two elements of confirmatory evidence that did not confirm parts of the framework itself, but referred to the usefulness of a framework and the need for external expertise. The first element of confirmatory evidence was on the need for a roadmap towards continuous improvement. Just setting up pilot projects is not enough to realize long-term change. Achieving sustainable improvement requires a comprehensive implementation programme (Shah et al., 2008; Done at al., 2011—Sources 7 and 9 in Table 4.2). The second element was about the need for the temporary assistance of external experts. The assistance of external experts is advised for successful implementation (Done et al., 2011). The need for such a roadmap is also illustrated in the results of our retrospective interviews. The deployment in Company A was more top-down than it was in Company B, and the course of the implementation efforts was better structured than it was in Company B. Neither company's approach followed a framework for implementation exactly, but Company A's more disciplined top-down approach came close.

The confirmatory evidence for the framework of Kumar et al. (2011) is summarized in Table 4.3. The first column of Table 4.3 contains the steps within the phases of the framework proposed by Kumar et al. (2011). The table shows which steps are confirmed as completely or partly relevant indicated by our research and makes clear which sources deliver the confirmatory evidence.

	Phases and steps in the framework of Kumar et al. (2011)	Confirmed	Source of confirmatory evidence L: Literature (numbers refer to literature sources of Table 2), F: Focus group, R: Retrospective interviews
Phase 1	Recognise the need for change	Yes	L: 1 and 2. F: Start with a statement of urgency for change. Is there a *burning issue* directly threatening the company's future, or is it just because many problems are *recurring problems*. R: The need for better performance to meet customer expectations was the drive to embark on LSS. As such the need for change was recognised.
	Top Mgmt. Commitment & Strong Leadership	Yes	L: 6, 8 and 13. F: Emphasize the Top-Mgmt.'s role with respect to defining purpose and scope of the programme and linking this to the organization's mission and vision. R: The approach of Company A was more top-down, showing less periods of falling back compared to company B. Company B followed a more bottom up approach in the beginning.
	Education and Training	Yes	F: Management should be educated at LSS awareness level. The responsibility for the implementation programme has to be assigned to a member of the management team. The formation of a temporary steering team is proposed. R: Company A started with management education. All members of the management team were trained at Green Belt level. All educated members of the management team are prepared for a role as Champion.
Phase 2	Identify & train best people for first wave of training	Yes, but not as a separate step	L: 5, 8, 13, 15, 16. Subjects covered are Project-management, LSS methods, Coaching skills. F: The focus group regards this as important, but not as a separate step, prefers to connect training to projects. R: Both companies have selected candidates for training at Green Belt level, but training is always connected to the execution of a project.
	Identify the core business processes	Yes, but not as a separate step	L: 1, connected to strategic analysis and process mapping (not in a specific SME-context). F: This is recognised as to be important, but the identification of core business processes should come earlier. R: This has been part of the initial management discussions, internal and with consultants. Later on it has been a management concern, in particular when falling back was observed.
	Selecting Six Sigma pilot project	Yes	L: 4, 10, 12 on goal setting and Six Sigma projects, on social safety within project teams. F: Criteria for the first pilot project are chance for success and the general recognition of the project's relevance and impact.
Phase 3	Communicating initial success	Yes	F: Strongly supported, together with celebrating initial success.
	Organization wide training	No	F, R: Training on different levels is important, but is not a separate step in deployment. Training has to be connected to projects. R: Company A introduced a basic training (one day) for shop-floor employees to gain commitment on the shop-floor. This does not justify *Organization wide training* as a separate step.
	Establish methods to evaluate progress	Yes	F: Recognised as management responsibility. Regular reviews of on-going projects, taking measures for improvement. Seeking for spin-off projects. R: In both companies project results are presented to the management team and discussed with the management. In both companies the management has taken measures to revitalise the programme.
Phase 4.	Commitment to continuous improvement	No	F: Commitment to continuous improvement is important, but the development of dedicated managers cannot be connected to one single step.
	Linking Six Sigma to intrinsic motivation of employees	Yes, but not as a separate step	L: 10, 11, 12, 13, 18. Subjects covered are Rewarding and recognition, Social environment, Team-work, Knowledge development. F: The focus group argued that this is important, but it cannot be covered by a step in an implementation framework.
	Progression towards learning org.	Yes, but not as a separate step	L: 10, 12, 13, 14, 18. Subjects covered are learning, active attitude towards taking initiatives, measurement of progress in learning abilities. F: Supported as reflecting cultural change in which *striving for the best* and *learning faster* are main characteristics.

Table 4.3. Confirmatory evidence

Proposals for revision

From our primary research results, 11 revision proposals (Rps) were inferred. The Rps and the motivation for these Rps are displayed in Table 4.4. How the Rps lead to a proposal for a revised framework will be explained in the discussion (Section 4.4). The focus group strongly recommended first educating a project leader and then the team members, after selecting the first pilot project. Our retrospective interviews delivered a slightly more moderate view, but coupling education with projects was commonly agreed upon.

Revision proposals		Motives and explanation L: Literature (numbers refer to literature sources of Table 2), F: Focus group, R: Retrospective interviews
Rp 1	Reduce the number of phases, into Phase A (Recognise and Prepare), Phase B (Initialize and Institutionalise) and Phase C (Sustain). Incorporate a Readiness test in Phase A	L: Hansson and Klefsjö (2) and George (2002) also propose a three phase model. George (2002) discerns three phases: (1) Initiation, (2) Resource and Project selection plus Implementation, and (3) Sustainability and Evolution. F: In practice the first step would always be *recognise the need for change* and therefore proposes to incorporate the Readiness test in Phase A. The focus group did not see a reason to separate the phases *Initialize* and *Institutionalise*.
Rp 2	Incorporate *Identifying core business processes* in Phase A	F: The focus group argued that *Identifying core business processes* (part of Phase 2 in Figure 1) could better be transferred to the first phase. In mobilising commitment of management the identification of core business processes is an important issue.
Rp 3	Let Phase B start with a pilot project	F: The focus group believed that in Phase B the selection of a first pilot project should come first. The project leader must be selected with a focus on the skills needed to lead a team.
Rp 4	Connect the education of a project leader to a project. Let educated project leaders educate new project leaders. Educate team members within a project.	F, R: The focus group pleaded to first select a project and to organise education within that project. The managers interviewed in our retrospective research did not fully support that view, but acknowledged that carrying out a project should be part of the education. F, R: The focus group and the managers interviewed in our retrospective research emphasized that educated project leaders should be able to educate new project leaders (train the trainer approach).
Rp 5	Identify process owners. Involve the process-owners in the project-definition. Communicate to process-owners frequently in the course of the project	L: Hilton and Sohal (5). F: Management must be keen to involve process owners – process owners have the most direct interest in project results. R: This is confirmed by the managers interviewed in our retrospective research.
Rp 6	Involve shop-floor employees from the earliest stage through communication and training within projects	R: The interviewees emphasized that involving shop-floor employees from the beginning of deployment is crucial. In company A the involvement of shop-floor employees was postponed to a later stage, giving internal resistance an opportunity to rise.
Rp 7	Start developing a system for project-selection, -planning, -administration and –support, as soon as the first selected project starts.	F: The focus group missed this issue in the framework of Figure 1. R: Both companies A and B of our retrospective research have such a supporting system in place, accessible for teams and supervisors.
Rp 8	Discuss the progress of the deployment in regular management meetings.	F: The focus group proposed that at the end of the phases A and B the management should specifically reflect on the scale and ambition of the programme. R: Overviewing the history of the deployment in both companies, a few periods of severe falling back are visible. In the course of the deployment efforts periods of falling back seem to occur almost naturally. Evaluation of the deployment and reconsidering plans regularly is necessary.
Rp 9	In Phase C integrate LSS procedures in the existing management system	L: Zu and Fredendall (11) emphasize this with respect to HRM-practices on employee-involvement, -training and –performance and recognition. F: The focus group argued that in Phase C (Sustain) embedding of new LSS procedures into normal operations is the first priority, including arrangements for educational programmes and rewarding.
Rp 10	In Phase C widen scope towards customers and suppliers	F: In the Sustain phase widening the scope towards external relations is due, in the first place to customers and suppliers.
Rp 11	Develop and implement an instrument for the evaluation of progress with respect to learning abilities.	L: Based on our literature study we propose to adopt the concept of Absorptive Capacity (14, 17 and 19). The instrument to measure Absorptive Capacity as developed by Tu et al.(19) could be used in practice F: The focus group argued that one of the characteristics of sustaining would be the improvement of abilities to learn.

Table4.4. Revision proposals

4.4 Discussion, proposal for a revised framework

This study has strengthened the justification for the framework of Kumar et al. (2011) and has thus contributed to the validation of the framework. Up to this point, our first two research questions have been answered, on supporting confirmatory evidence for the framework of Kumar et al. (2011) and on what revision proposals can be formulated. The third research question was "What are the building blocks of a revised framework, meeting the formulated proposals for revision while keeping the confirmed elements in place". Based on the results of our study, we propose a revised framework as depicted in Figure 4.5. The revised framework is the answer to the first part of this research question

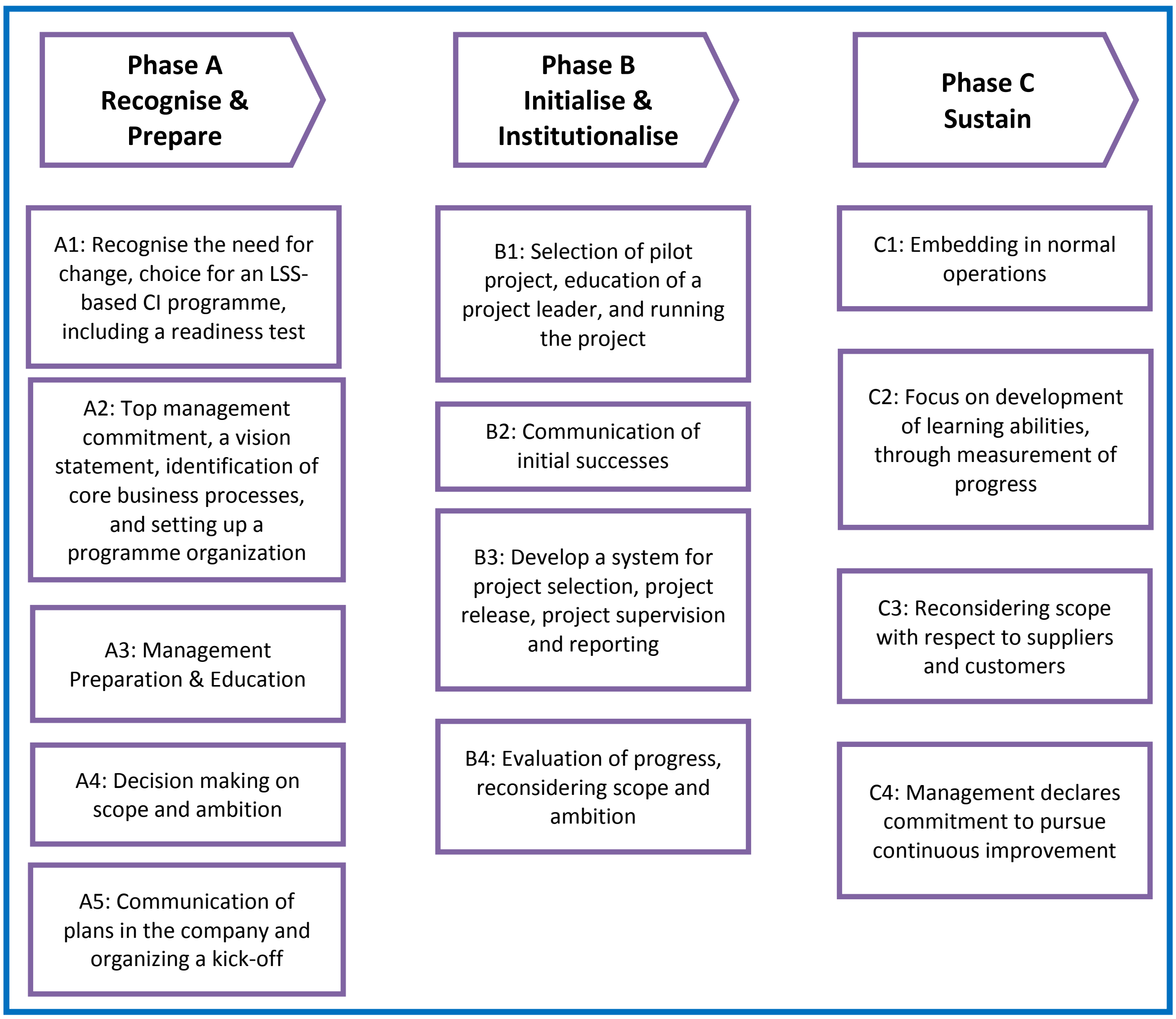

Figure 4.5. Phases and steps of the revised framework

To answer the second part, we will briefly explain how the confirmatory evidence and the revision proposals lead to the revised framework depicted in Figure 4.5. The phases A and B of the revised framework depicted in Figure 4.5 contain practically all elements of the phases 0, 1, 2, and 3 of the original framework of Figure 4.1. Table 4.3 shows that except from *Organization wide training* all steps of the phases 0, 1, 2, and 3 of the original framework are fully or partly confirmed. The major modifications (see also table 4.4) are in the reduction of the number of phases, the embedding of *Identify core business processes* in the steps of phase A, in removing the separation between training and project execution, and in the new step B3 *Develop a system for project selection, project release, project supervision and reporting*. Figure 4.5 suggests that step B3 is a closed step, but in fact the system building can already begin during the pilot project, and the system will develop evolutionarily over time, far beyond step B3.

Progression towards a learning organization is the common focus of the Sustain phases of both the original and the revised frameworks. The major differences are in the step C1 of the revised framework, emphasizing the need to embed what has been developed in the programme into normal operations, and in the focus to measure the progress in the development of learning abilities (step C2). Measurement of progress is a fundamental issue in quality management. The steps B3 and C2 both focus on the evaluation of progress, step C2 specifically on the measurement of progress in learning abilities, which is according to Bessant et al. (2001) and De Mast (2006) connected to the enhancement of innovative power.
Of course, sustaining is never ending, but Phase C comes to an end when the embedding of all measures for change have reached a level from which the organization will be able to develop further in an evolutionary way. The last step, Step C4 is to emphasize that pursuing further continuous improvement is a key responsibility for the management.

4.5 Conclusions

We expanded the theory on the deployment of LSS in SMEs with a stronger foundation for the framework of Kumar et al. and expanded upon this framework with a revised version that requires confirmations and (probably) revisions as well. The key contribution of this study is the development of this framework, keeping in consideration the needs and characteristics of SMEs. The need for a framework has been discussed in previous sections, referring to Shah et al. (2008) and Done et al. (2011), and is also supported by our retrospective research in the two companies A and B. The framework as illustrated in figure 4.5 looks generic and the specific features which makes it suitable for SMEs are not explicitly visible. An important element for SMEs to make the use of the framework a success is the connectedness of project selection and the education of the project leader and team members. Another important element in the framework is the decision making by management about the scope and ambition (steps A4 and B4). SMEs are not strong in long-term strategic planning (Gélinas and Bigras, 2004, Snider et al.,2009) which means that the timeframe for implementation must be relatively short, for instance to two years for the first two phases. In the framework the steps A4 and B4 may help SMEs to reflect on their plan’s feasibility which may prevent the deployment’s timeframe to elongate. Complete implementation could then be reached within three years, keeping in mind that afterwards the development to higher levels of continuous improvement should proceed in an evolutionary way.

We realise that our research has certain limitations, despite the use of three research methods in triangulation. The availability of highly qualified literature focussing on continuous improvement based on LSS in SMEs is limited, and we cannot deny the fact that our focus group results are based on a single focus group session in a Dutch context. Also, we only found two companies with sufficient experience in the deployment of continuous improvement (CI) with whom to organise our retrospective interviews. Nevertheless we believe that the revised framework is applicable to a wide range of sizes and types of industry. For SMEs, especially for the very small ones, facing the constraint of the resource barrier will be the main challenge. For the management, important challenges will be to carefully consider the scope and ambitions of the programme linked to the company’s strategic objectives, and to seek cooperation with similar companies and knowledge institutions in regional networks.

5. Six Sigma methods applied in an Injection Moulding company

This chapter presents a field research study that demonstrates the application of techniques for robust optimization for the improvement of injection moulding processes in an injection moulding SME.
A critical to quality characteristic (CtQ) which is connected to assembly problems is the subject of investigation. The CtQ is not directly measurable. The variation in a dimension of a product which is correlated to the CtQ, is studied using DoE (Design of Experiments) and Taguchi methods. A two-cavity mould is used in the injection moulding process. The initial results showed that finding optimal process parameter settings commonly valid for both cavities was impossible. After a modification of the mould the experiments were rerun and optimal settings could be found. Applying DoE techniques in small and medium sized injection moulding companies is far from common practice. This study demonstrates a method to apply DoE with five process parameters which can serve as a standard method to prepare production when a new mould is used for the first time.

5.1 **Introduction**

Injection moulding is a cost-effective production process for producing complex plastic parts in large quantities. A hot melt of thermoplastic polymer is forced into a mould-cavity at a lower temperature, where the hot melt solidifies. After solidification, the mould is opened and the product removed from the mould cavity. The process is regulated by a number of process parameters. The process looks rather simple at first sight, but predicting the quality of the final part is very complex, especially when the demands with respect to specified dimensional, shape, and surface properties are high. Shrinking of the product after ejection from the mould is a very well-known source of quality problems, especially for complex products with low wall thicknesses and asymmetric shapes.

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In The Netherlands practically all injection moulding companies are SMEs, only 4% of them having a workforce of more than 100 employees (ING Economics Department, 2005). Practically all companies are active in “business to business” markets, buying materials from material suppliers and delivering products to other industries, which are partly OEMs (Original Equipment Manufacturers) and partly again suppliers to OEMs. According to the ING study there is little cooperation between similar companies, and strong cooperation between companies and customers, material suppliers and mould manufacturers. The ING study also indicates that lowering costs of production is the main focus of injection moulding companies, improvement of quality of products and processes following at a close distance.

In general, these companies are familiar with state-of-the-art technology with regard to mould design, including CAD, melt-flow and FE simulation methods. When a new mould has been mounted for the first time on the injection moulding machine experienced engineers and shop floor employees determine initial machine set-points, using information from simulation studies, material specifications, and machine signals. Customers express demands not only with regard to the quality of the final products but increasingly also to the level of control of the related process parameters. To meet these demands the application of tools available in the LSS toolbox becomes increasingly important.

Implementation of LSS methods in manufacturing SMEs has been the subject of earlier studies (Antony et al., 2005 and 2008, Timans et al., 2012). Case studies in which tools are applied which are included in the LSS toolbox are available (see, for instance Dodd K. et al., 2002, Liu et al., 2002, Lin and Chananda, 2003-04, Lee et al., 2006, Oktem et al., 2007, Tang et al., 2007, Lo et al., 2009). In these case studies, both Taguchi and classical DoE methods have been applied, but none of the case studies addresses SME-implementation issues as a main topic of study. These case studies all are all advanced studies carried out in cooperation with research centres or universities. Such studies could hardly have been executed in injection moulding SMEs without external support. The SME-context makes it very important to lay emphasis on clarifying methods and tools and on the need for standardization of the application, to make it easier to repeat in new projects. In this study we focus on the optimization of the injection moulding process once a new mould has been mounted on the injection moulding machine for the first time. The determination of set-points for critical process parameters is mainly based on the experience of engineers and shop-floor employees. Therefore we propose to implement a standard routine project focussed on improving the level of control of actions to be taken to prepare for normal production. The effect of this routine should lead to shortening the time between first mount of the mould on the machine and production release. The Lean Six Sigma DMAIC-cycle (Define, Measure, Analyse, Improve, and Control) can be used to structure the project. Many researchers have described DMAIC project stages and appropriate tools for use in the different DMAIC phases; see for instance Timans et al. (2009). In this study, we refer to DMAIC project stages in a generic form as described by De Koning and De Mast (2006), and outlined in Figure 5.1. SMEs active in polymer injection moulding are in general familiar at a basic level with the application of tools from the LSS toolbox, especially with basic control charting techniques and process capability indicators, like Cp and Cpk. Supporting software is often provided by manufacturers of injection moulding equipment. Measurement system analysis is recognized as very important, but standardized methods to evaluate measurement systems have not been widely implemented. Advanced statistical methods such as Design of Experiments (DoE) are seldom applied within injection moulding SMEs. A study on the implementation of Lean Six Sigma (Timans et al., 2012) revealed that manufacturing SMEs in The Netherlands recognised the importance of DoE, but also that DoE-techniques were seldom used in practice. For injection moulding companies in particular the application of DoE techniques can be effective in searching for optimal process settings when a new mould is mounted on an injection moulding machine for the first time.

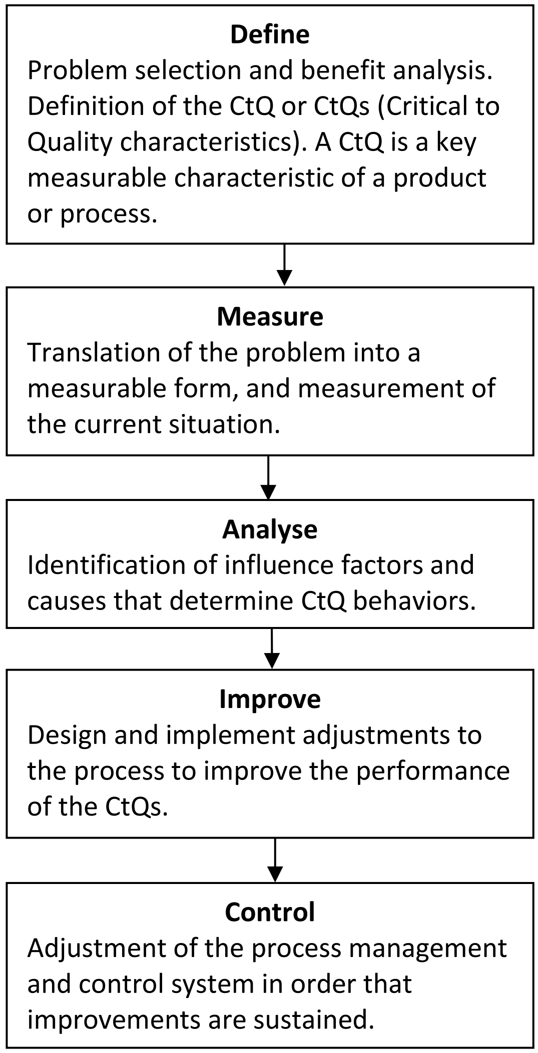

Figure 5.1. Flowchart of the DMAIC steps

The product under study is to be produced in a company with about 20 employees, so the SME-context is evident. For the injection moulding company, it is a pilot study for gaining experience in the application of methods which it intends to apply as standard methods in preparing production runs in the future. The engineers should be able to understand the rationale of the method, and the experiments should be completed in a brief timeframe.

In the following sections, first the field research study will be presented. Initially, the approach was rather straightforward, but during the investigations some unexpected problems arose making it necessary to return to a previous stage and take some unanticipated measures to solve the problems. As such, this study illustrates the iterative nature of the DMAIC project stages, as has been described earlier (see, for example, Pande 2000, p. 239). The subsequent discussion section focuses on issues connected with carrying out such projects within the injection moulding industry, paying attention to the specific technological aspects of this industry and the awareness that many injection moulding companies are SMEs. Recommendations will be proposed for research to improve the methods described in this study further.

5.2 **Field research study**

The product studied, illustrated in Figure 5.2, is a plastic housing for a pressure measuring device. This is produced by a company in Emmen, the Netherlands. The material specified is a 35% glass reinforced, heat stabilized, lubricated high performance polyamide. The customer delivered fully specified CAD drawings of the product and responsibility for the mould design was transferred to the company. The mould design was carried out in cooperation with an external company that is specialized in mould- design and -manufacturing. The mould has two cavities such that every cycle of the injection moulding process delivers two products. A flow study was carried out by an external specialist to analyse the moulding process regarding filling behaviour and warping risks. This analysis delivered recommendations on gate position and gate dimensions, wall thicknesses at critical spots, venting of the mould to prevent air-traps, and cooling and ejection system. Production would be carried out on an Arburg injection moulding machine.

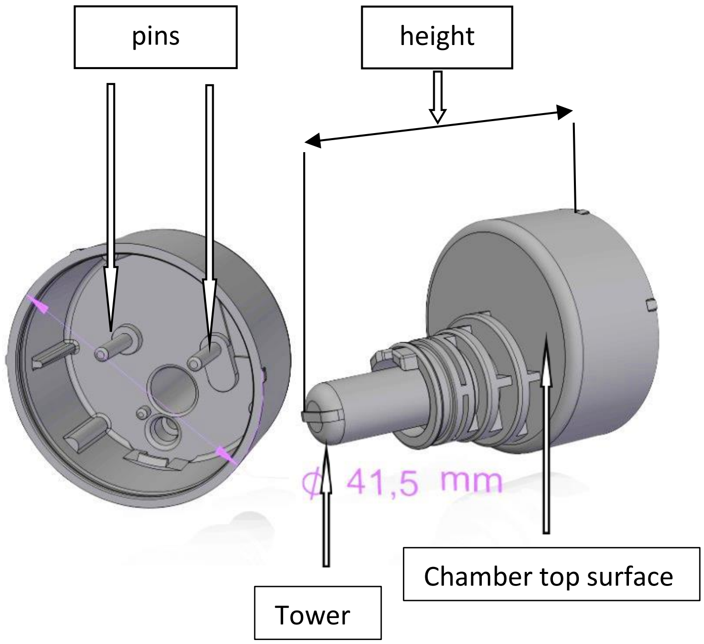

Figure 5.2. The product

The DMAIC Steps

Define

The Critical to Quality (CTQ) characteristic in this study is the parallelism of the two pins which are visible in figure 5.2. For the customer the parallelism of the pins is very important, because on these pins the measuring device is mounted in the assembly process. The parallelism of the pins therefore is regarded as critical by the customer. Significant deviations from the ideal parallelism of the pins will cause problems in the assembly process. Measuring this parallelism directly is very hard and would need specialist equipment and skills unavailable within the company. Therefore a product dimension which in this paper is referred to as "height" (see figure 5.2) was selected as a measurable characteristic which is correlated to the parallelism of the pins. Antony (2003) highlights this particular aspect in his book stating that experimenters should seek correlated characteristics if some CTQ characteristics are difficult to measure. Due to the asymmetric structure of the product some warp is evoked when the product shrinks after ejection from the mould. This warp causes variation in both the parallelism of the pins and in the height. During shrinking the top surface of the chamber (see figure 5.2) will be distorted and will get a slightly hollow shape and the tower will

bend inwards. The stronger the tower is bended, the stronger the chamber's top surface will be deformed into a hollow shape. The deformation of the top surface of the chamber causes deviations in the parallelism of the pins. By controlling the injection moulding process in such a way that the height is stabilized the parallelism of the pins is stabilized too.
Given the final mould design and material specifications, the following project goals were specified in the Define phase:

- to quantify the contributions of the process parameters to variations in the height;
- to divide these parameters into those which mainly affect product to product variation of the height and those which mainly affect the mean level, followed by the determination of optimal set points for the process parameters.

Four team members were directly involved: two experienced operators, the company's technical managing director, and an external expert. In this pilot study, no financial targets were set: the main goal of this project was to ensure a stable and robust production process, easily controllable through the important process control parameters.

Measure

The mould was designed for a completely new product. The new mould was tested by an experienced operator, who tried to operate the process with initial set-points for the process parameters based on experience. During the initial tests it was not possible to find acceptable set-points, in particular because trapped air caused burn-spots in the polymer material at a specific location on the product. The mould manufacturer therefore modified the mould, especially by widening the channels through which air could escape during injection of the polymer. After this minor modification, a first series of products was made. During this production run, the operator was able to produce a series of products that appeared acceptable regarding visible surface properties.
To validate the measurements of the height the measurement system was analysed. Fifteen products were measured three times to quantify the contribution to variance caused by the

measurement process as compared to the total variance. The total variance can be split up as follows:

$\sigma^2_{total} = \sigma^2_{process} + \sigma^2_{meas}$

The variance component due to the measurement system was estimated to be 1.27% of the total variance. The σ_{meas} was therefore estimated to be 11.3% ofσ_{total}. General industrial guidelines for measurement system analysis are prescribing that the σ_{meas} should preferably be less than 10% of σ_{total}, and that contributions up to 30% could be acceptable depending on the application (AIAG, MSA Manual, 2010). In this case the contribution of the measurement system is close to 10%. Based on these data we qualified the performance of the measurement system to be acceptable.

Analyse

The members of the team discussed which factors should be included in the research. Based on material specifications, flow-analysis, and experience, the team selected five process parameters which should be included in the experiments:

- injection velocity (Vinj)
- holding pressure (Phold)
- melt temperature (Tmelt)
- mould temperature (Tmold)
- cooling time (t-cool)

The team was aware that, next to controllable factors, noise factors could also influence the process performance. These noise factors could be environmental (for instance the temperature of the environment), could be related to small variations in machine-settings (small variations in controlled set-points over successive machine cycles), or to variations in material properties. The team considered specifically the risk of variations due to inconsistencies in the material properties, and judged these risks to be very small with the material being used. A larger risk was expected due to differences related to the two cavities in the mould, and therefore it was decided to pay specific attention to these differences in the study. In the brainstorming session, risks were also discussed related to the perceived influences of interaction effects. These discussions did not deliver clear arguments on which interactions should be included or excluded in the research. Therefore the team decided that a design set up should be selected in such a way that all two-factor interaction effects could be estimated separately.

Preliminary trials were carried out to explore the experimentation window. The limits of the process parameter settings should be such that all the products would come out of the machine completely filled and also could easily be ejected from the mould. The team also discussed the nature of the relationships between the measurement-data and the process control parameters within the process window, and argued that these relationships would be at least monotonous and probably close to linear, and therefore decided to vary the control parameters at two levels within the process window. Based on the preliminary trials, the team set limits for the variation of the five control parameters (see Table 5.1):

Control parameter	Low level	High level
Vinj	40%	60%
Phold	500 bar	700 bar
Tmelt	320 ^{o}C	330 ^{o}C
Tmold	140 ^{o}C	160 ^{o}C
t-cool	13 s	17 s

Table 5.1. Process window for performance tests

The injection velocity is not expressed in physical units, but as a percentage of its maximum value. In the injection moulding machine employed, this is controlled by a regulating valve in the injection system.

Improve

The safest design for the experiments would be a full factorial design with five control parameters. A full factorial design with five factors, with all factors being set to two levels, would need 2^5 = 32 experiments. Using this design, and assuming linearity, all main factor effects, all two-factor interaction effects, and all higher order interaction effects could be estimated. However, it seemed fair to assume that, in our study, higher order interaction effects would be small compared to main effects and two-factor interaction effects, and therefore we concluded that a fractional factorial design would be adequate (see for instance Montgomery, 2005). Given that it was not possible to exclude any two-factor interactions based on technical arguments, the decision was taken to use a 2^{5-1} design, in which all main effects and two-factor interaction effects could be estimated from 16 experiments at corner points. To be able to test for curvature it was decided to add some centre-point runs. These centre-point runs were planned at the start, midway and at the end of the experiments. Table 5.2 summarizes the overall test design.

The design was not randomized because of practical considerations. Injection moulding processes running with fixed process parameters are very stable. The time needed to carry out all of the 19 experiments would only take about three hours and trends in the measurement results due to slowly changing uncontrolled influences were not expected to occur within a timeframe of three hours. Changing Tmold settings would take some time because, after a change in Tmold, the injection moulding machine needs some time to stabilize. Tmold is controlled by an external temperature regulating unit and, after a change in the Tmold set-point, it takes some time to reach a new thermal equilibrium. Hence, the test schedule was organized to minimize the number of times Tmold would have to be altered. Using the centre-point settings for the first experiment, at the halfway stage, and at the end enabled us to test our assumption that randomization was unnecessary.

Vinj	Phold	Tmelt	Tmold	t-cool
0	0	0	0	0
-1	-1	-1	-1	1
1	-1	-1	-1	-1
-1	1	-1	-1	-1

Vinj	Phold	Tmelt	Tmold	t-cool
1	1	-1	-1	1
-1	-1	1	-1	-1
1	-1	1	-1	1
-1	1	1	-1	1
1	1	1	-1	-1
0	0	0	0	0
-1	-1	-1	1	-1
1	-1	-1	1	1
-1	1	-1	1	1
1	1	-1	1	-1
-1	-1	1	1	1
1	-1	1	1	-1
-1	1	1	1	-1
1	1	1	1	1
0	0	0	0	0

Table 5.2. Design array for the experiments

Each trial was carried out by allowing the machine to run for five cycles and so produce ten products, five from each cavity. After the runs, the products were stored for twenty-four hours to allow them to cool to room temperature and to shrink to their final dimensions. The products were then measured and the measurement values were stored in a Minitab spread-sheet.

Analysis of data from Cavity1 and Cavity2:

In the analysis, we first concentrated on the main effects. Figures 5.3 and 5.5 present Pareto charts of the main effects. The residuals are approximately normally distributed, and Figure 5.4 illustrates this for Cavity 1.

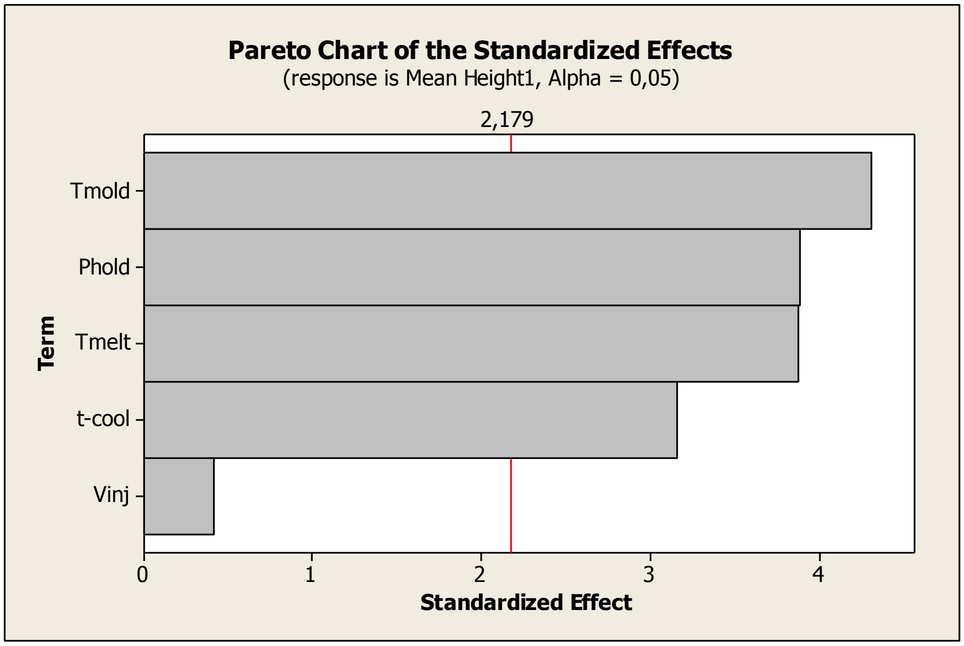

Figure 5.3. Pareto of effects based on data from Cavity1

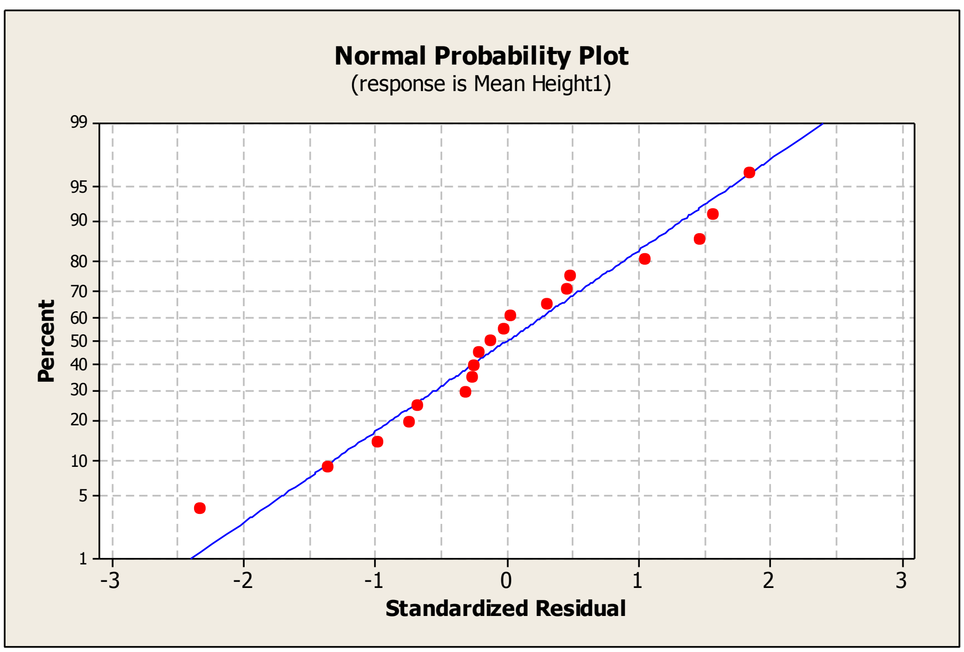

Figure 5.4. Normal plot of residuals based on data from Cavity1

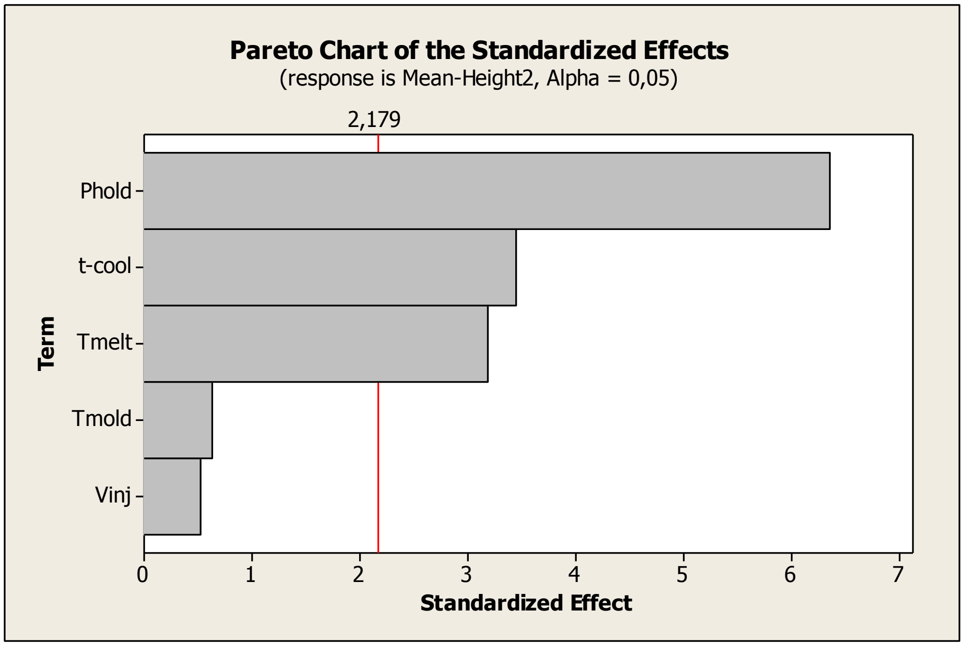

Figure 5.5. Pareto of effects based on data from Cavity2

Approximately 80% of the variation is caused by the main effects. The total variation in the data is considerably larger for Cavity2 than for Cavity1. An F-test revealed that the variances of the data from the two cavities are significantly different with a confidence level above 99%.

To compare the data means of the two cavities, a two-sample paired t-test was carried out. The paired test was appropriate because the samples were produced pairwise in a two-cavity mould, and therefore were not independent from each other. The estimate of the difference was 22.7 µm ($\mu_2 > \mu_1$). The 95% confidence interval of μ_2-μ_1 ranged from 17.0 to 28.4 µm.

Comparing the results of the two cavities, the most salient differences are visible in the Pareto charts. For both cavities, the injection velocity does not have a significant effect (α=0.05). For Cavity1, Tmold is the most important factor whereas this is not significant for Cavity2. This means that it will be impossible to optimize the process for both cavities at the same time. This conclusion had certainly not been anticipated, and greatly worried the management team. It was concluded from studying the construction of the mould that the main cause was probably the layout of the cooling channels inside the mould. The two cavities were cooled by an external temperature regulating unit. The cavities were cooled sequentially: the cooling channel first flowed around the first cavity and then on to the second cavity before returning to the external tempering unit. A consequence of this is that the temperature of the cooling fluid has increased when it reaches the second cavity, so the cooling of the second cavity will be less effective. This cooling method is not uncommon in injection moulding practice, but in our study it could very well be the main cause of the different outcomes for both cavities. It was decided to return the mould to its manufacturer to modify the layout of the cooling channels in such a way that both cavities would be directly connected to the tempering unit. In this way, in both cavities the temperature of the cooling fluid would be the same at the start of the cooling process. After the return of the modified mould the experiments would be repeated.

As the system stood, Vinj seemed to be the only parameter that was not significant for either cavity, although this could change with the modified mould. Overall, it was believed that the balance among the influences of the process parameters could change after modifying the layout of the cooling channels.

Analysis of data from Cavity1 and Cavity2 (modified mould)

Some weeks later, once the mould was modified and returned, the set of experiments listed in table 2 was repeated. The new data were collected in the same way as before. In the tables 5.3 and 5.4 analysis of variance results are presented. Figures 5.6 and 5.8 present Pareto charts for both cavities. The residuals are again approximately normally distributed for both cavities. Figure 5.7 shows a main effect plot for cavity1, based on the new data. In the ANOVA tables (based on means per experiments) all insignificant effects (α=0,05) have been pooled into the Residual Error. The Lack of Fit contains the insignificant contributions of Tmelt and of all two-factor interactions. The curvature is clearly insignificant confirming our initial expectation that within the process window (see Table5. 1) a linear model would be sufficient.

Analysis of Variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	3076,24	3076,24	769,06	47,91	0,000
Vinj	1	262,44	262,44	262,44	16,35	0,001
Phold	1	207,36	207,36	207,36	12,92	0,003
Tmold	1	1310,44	1310,44	1310,44	81,63	0,000
t-coo	1	1296,00	1296,00	1296,00	80,73	0,000
Residual Error	14	224,74	224,74	16,05		
Curvature	1	13,75	13,75	13,75	0,85	0,374
Lack of Fit	11	163,60	163,60	14,87	0,63	0,753
Pure Error	2	47,39	47,39	23,69		
Total	18	3300,98				

S = 4,00661   R-Sq = 93,19%   R-Sq(adj) = 91,25%

Table 5.3. ANOVA of Height1, based on new data from Cavity1

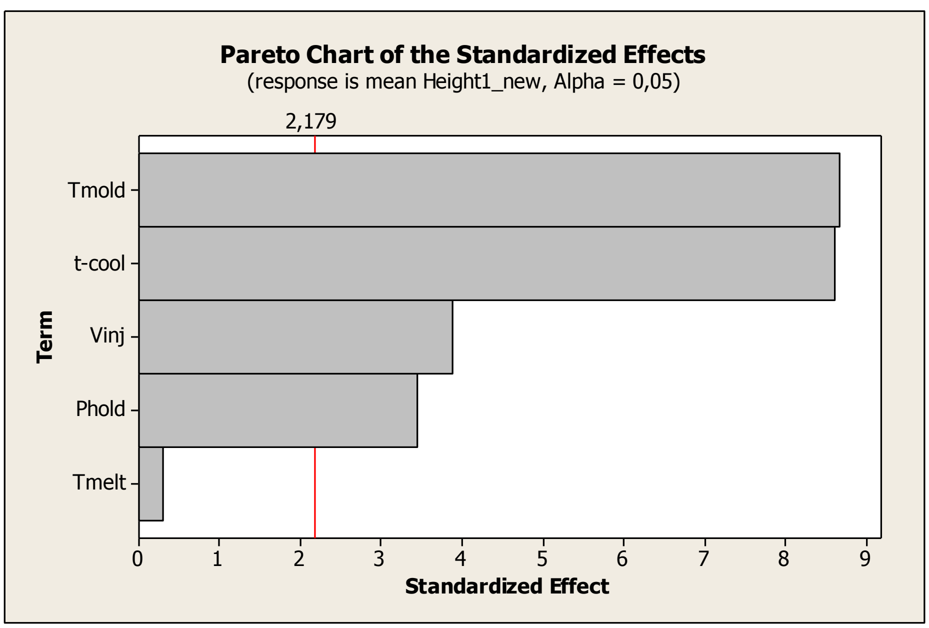

Figure 5.6. Pareto of main effects based on new data from Cavity1

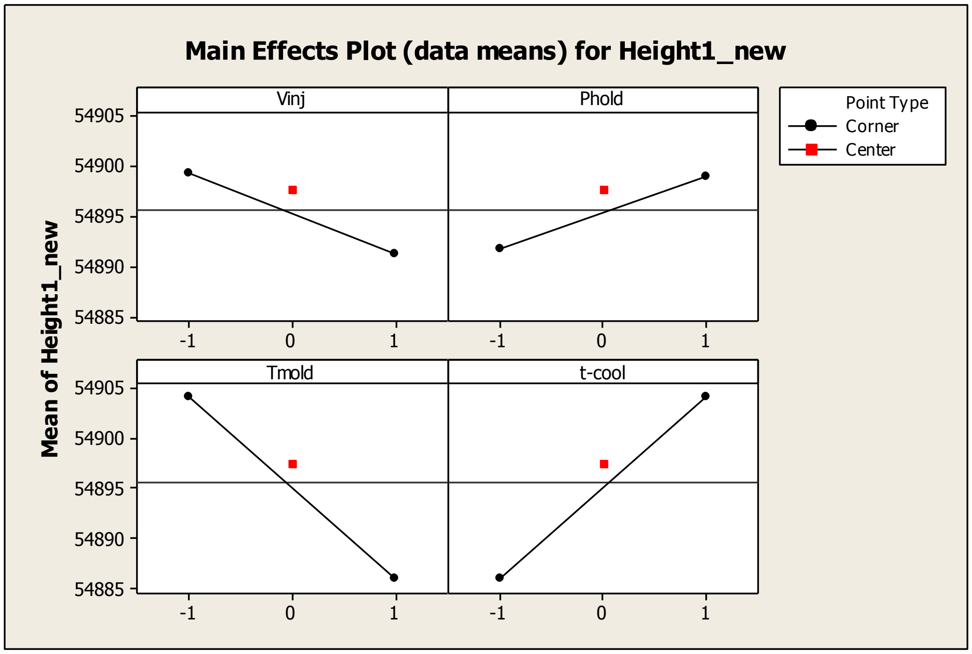

Figure 5.7. Main effect plots based on new data from Cavity1

Analysis of Variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	3516,93	3516,93	879,23	28,56	0,000
Vinj	1	174,24	174,24	174,24	5,66	0,032
Phold	1	408,04	408,04	408,04	13,25	0,003
Tmold	1	1730,56	1730,56	1730,56	56,21	0,000
t-cool	1	1204,09	1204,09	1204,09	39,11	0,000
Residual Error	14	431,01	431,01	30,79		
Curvature	1	60,66	60,66	60,66	2,13	0,168
Lack of Fit	11	335,07	335,07	30,46	1,73	0,423
Pure Error	2	35,28	35,28	17,64		
Total	18	3947,94				

S = 5,54853 R-Sq = 89,08% R-Sq(adj) = 85,96%

Table 5.4. ANOVA of Height2, based on new data from Cavity2

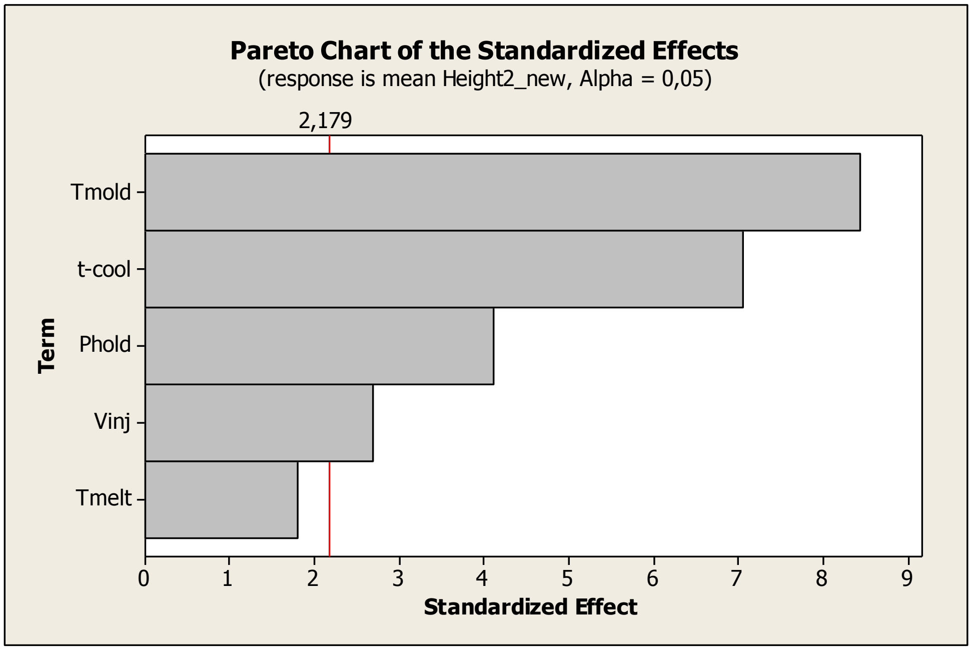

Figure 5.8. Pareto of main effects based on new data from Cavity2

Over 85% of the variation is caused by the main effects alone. The total variation of the data is still somewhat larger for Cavity2 than for Cavity1, but the difference is much smaller than with the original mould. An F-test showed that the variances of the data are not significantly different for the two cavities. The most significant control parameters, Tmold and t-cool, have comparable influences with both cavities (see Figures 5.6 and 5.8). For both cavities, these two control parameters determine about 75% of the total variation. Tmelt is insignificant for both cavities.

The data from both cavities are not independent from each other because in each process cycle two products are produced, one in each cavity. The difference between the means was again tested by applying a two-sample paired t-test. The estimate of the difference was 29.7 µm ($\mu_2 > \mu_1$). The 95% confidence interval of μ_2-μ_1 covered the range from 28.3 to 31.2 µm. The confidence interval has narrowed considerably compared to the earlier test results, primarily due to the decreased variation in the data from Cavity2. From a process-control perspective it would be appropriate to analyse all the data together. To do this correctly, the data should be corrected for any systematic differences between the data from both cavities. Therefore, 30 µm (rounded value of 29.7 µm) was subtracted from the Cavity2 data and the complete dataset (called Height-overall) was analysed. The results are presented in table 5 and illustrated in Figures 5.9 and 5.10.

Analysis of Variance for mean Height-overall

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	3278,21	3278,21	819,55	50,94	0,000
Vinj	1	216,09	216,09	216,09	13,43	0,003
Phold	1	299,29	299,29	299,29	18,60	0,001
Tmold	1	1513,21	1513,21	1513,21	94,06	0,000
t-cool	1	1249,62	1249,62	1249,62	77,67	0,000
Residual Error	14	225,24	225,24	16,09		
Curvature	1	33,04	33,04	33,04	2,24	0,159
Lack of Fit	11	189,47	189,47	17,22	12,63	0,076
Pure Error	2	2,73	2,73	1,36		
Total	18	3503,45				

S = 4,01105 R-Sq = 93,57% R-Sq(adj) = 91,73%

Table 5.5: ANOVA of combined data from both cavities (In this ANOVA the Lack of Fit contains the main factor Tmelt and two factor interactions between control factors)

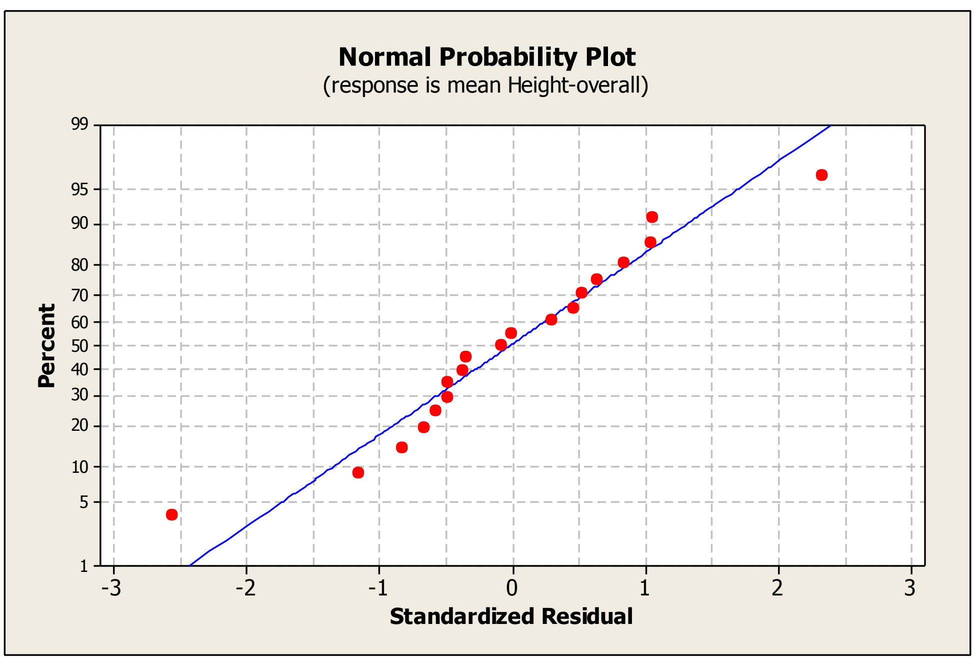

Figure 5.9. Normal probability plot based on new data from both cavities

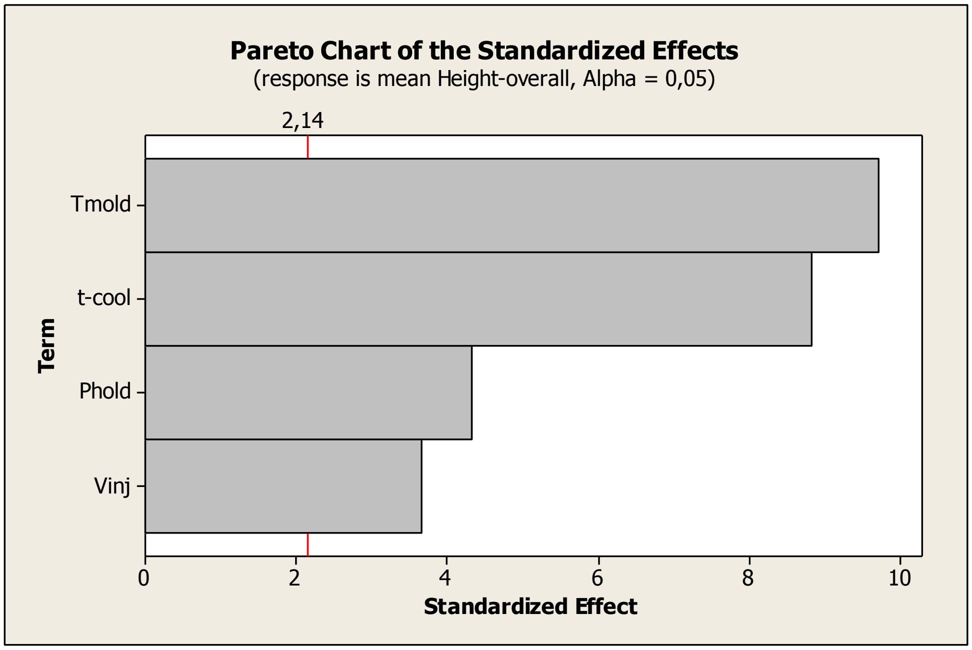

Figure 5.10. Pareto of main effects based on new data from both cavities

Figure 5.9 shows that the residuals follow an approximately normal distribution, providing confidence that the transformation of the data for Cavity2 was appropriate. The Pareto values shown in Figure 5.10 are in line with the Pareto graphs of the distinct cavities. The estimated standard deviation (S) and R-Sq values of the overall height (see table 5.5) are similar with the estimates from the data for the individual cavities (see tables 5.3 and 5.4).

The second research goal formulated in the Define phase was to divide the parameters into those which mainly affect the process stability and those which mainly affect the mean height. To achieve this, a Taguchi Signal-to-Noise analysis was carried out on the Height-overall data. Many literature sources are available on the application of Signal-to-Noise analysis in relation to robustness (see for instance Ross, 1996, Phadke, 1989) . For each experimental run, a Signal-to-Noise value was calculated using the variance-only formula for S/N nominal is best: $S/N = -10\log(\sigma^2)$. In this formula, σ is estimated from s, the sample's standard deviation calculated from the ten data points for each of the experiments. The alternative Taguchi S/N nominal is best formula – a better choice when the variance is related to the mean level – $S/N= -10\log(\sigma^2/\mu^2)$ was also tested, but a comparison showed that both transformations led to the same conclusions. From this result we infer that the influence of the mean experimental levels is very low in the S/N analysis. The analysis revealed that mould temperature, Tmold, and the holding pressure, Phold, were the factors with the strongest influences on the S/N levels. Both factors should be set to their higher levels to achieve the highest S/N value, corresponding to the lowest standard deviation (and the most consistent product). In general high S/N values correspond to good process-stability. Figure 5.11 shows that the effect of mould temperature on S/N is very high when the holding pressure is set at the higher level, but more modest when the holding pressure is set at the lower level. This means that setting both the holding pressure and the mould temperature at high levels will improve the stability of the process. An analysis of the standard deviations of the experiments leads to the same conclusions.

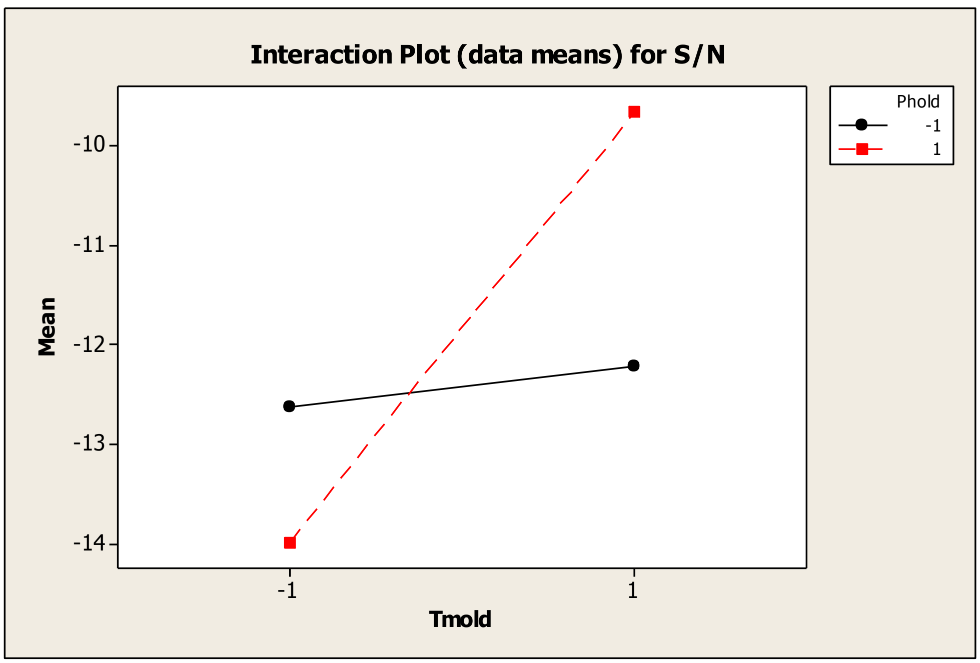

Figure 5.11. S/N interaction plot of Tmold*Phold

The cooling time, t-cool, is insignificant in the S/N analysis but was a very significant factor in the Pareto analysis shown in Figure 5.10. As such, the cooling time t-cool could be used to control the mean level.

An important concern was what was causing the difference between the means of product heights of the products coming out of the two cavities. The difference between the means was 29.7 µm

($\mu_2 > \mu_1$) with a 95% confidence interval (28.3 to 31.2μm). The question raised if the difference was caused by differences in process parameter values (pressure, temperature) inside the two mould cavities or by differences in the corresponding physical dimensions of the cavities. The difference between the two cavity depths was measured using a digital height gage instrument and appeared to be 30 μm. Therefore we conclude that the difference between the means of the product heights from the two cavities was mainly due to differences in mould cavity depths and not to differences in process parameters inside the cavities.

Control

The experiments were not carried out in a laboratory environment, but on a production machine situated in the production hall alongside other machines producing a wide range of products. Therefore additional effects of scaling up to production are not anticipated. The study was set up to prove that the company was able to produce the product on a continuous and consistent basis. The recommended process settings have been implemented and documented in the process parameter sheets which are used by employees during production.

We recall that the CtQ characteristic was the parallelism of the two pins, as depicted in Figure 5.2. Bad parallelism causes problems during production because then the assembly of the measuring device on these pins is troubled. Since the process runs with the important process settings set on their optimal values several production orders have been delivered to the customer without receiving any customer complaints.

5.3 **Discussion, conclusions, and outline of further study**

5.3.1 **The field research study**

In the Define phase, the following goals were set:

- to quantify the contributions of the process parameters to the variation in height;
- to divide these parameters into those which mainly affect product to product variation of the height and those which mainly affect the mean level, followed by the determination of optimal set points for the process parameters.

With regards to the first goal, the Pareto plot of the main effects in Figure 5.10 presents the contributions of the parameters to the variation of the height. The validity of the analysis is sufficiently justified by the ANOVA results shown in Table 5 and the normal probability plot in Figure 5.9. The second goal was addressed through a Taguchi S/N analysis, and it was concluded that high values for Phold and Tmold, shown in Figure 5.11, enhance the stability of the process.

This field research study demonstrates the iterative nature of the DMAIC project phases, especially with regard to the Analyse and Improve phases. In the Analyse phase, the focus is on determining which parameters are important, and which interactions between the process parameters could be important. The experimental results showed that it was not possible initially to find optimal settings that were equally valid for both cavities. Only after modifying the mould cooling system it was possible to optimize the process. Looking back this demonstrates that the separation between the Analyse and Improve phases is somewhat artificial. As anticipated in the introduction it is not always realistic to straightforwardly follow the DMAIC project phases. This finding offers definitely a new perspective on the use of the DMAIC project phases'. Sometimes it is necessary to step back to a previous phase, reaching the best results through an iteration of the phases. Recognizing this during this study was an important lesson.
As to the main goal of our research, providing a standardized approach to improve the optimization of the injection moulding process between first mount of the mould on the injection moulding machine and production release, this case study demonstrates the methods that we have proposed. The applied DoE-array itself is very useful as a standard to be used in similar projects, because it delivers reliable information on main effects and two-factor interaction effects when no more than five process parameters are included in the experiments, which will in general be sufficient. In this particular case curvature does not seem to be a major problem, but in new cases it would be wise to investigate curvature again, especially when a process window is used with wider ranges from the lowest to the highest parameter settings.

5.3.2 **Implementing LSS in an Injection Moulding SME**

Lean Six Sigma has been developed, since about 2000, as an effective merger of lean manufacturing and Six Sigma (George, 2002, Snee and Hoerl, 2007, Snee, 2010). The LSS toolbox provides a diversity of tools, some of which are easy to use and others that are less easy to use and need a thorough education and training programme before application is feasible. The toolbox contains tools with a lean background as well as tools with a Six Sigma background. In this case study primarily Six Sigma tools were applied.Based on the results of this study, we recommend that if small injection moulding companies aspire to grow into organizations applying LSS, at least one engineer should have sufficient knowledge on the use of relevant statistical tools, including Gage R&R and DoE. Statistical techniques are only useful when applied correctly. Attaching importance to the understanding of the technicalities of statistical methodology by management is not common practice (Sheil and Hale, 2012). Preparing for the production of newly developed products, ones that have not been produced before, is a critical issue on the way towards production-release. Production preparation involving new moulds could be carried out as best practice LSS projects, embedded in standardized routines.

5.3.3 **Further Study**

In this study, it was noted that while the value of applying DoE in an LSS programme may be evident, the question remains as to how such a tool may be introduced effectively in such a programme in an SME. The application of a two-level designs has been justified in this particular case study, but further study is needed to justify the application in new cases. New studies can be carried out using both two-level designs with centre-point measurements and three-level designs to find out which designs are the best choices in particular cases to serve as standards in the context of polymer injection moulding. Moreover, in a 2-level factorial design, we choose the best level from the two values for a process parameter. However the true optimal value could be either less than or more than the chosen value for that process parameter. The authors would therefore would like to explore the potential of utilising a Response Surface Methodology in the future to determine the optimal process window. How to educate engineers and operators in applying statistical techniques in the SME context at levels appropriate for their daily practice will be an important challenge in the near future.

6. General discussion

The objective of this research was to understand how continuous improvement based on Lean Six Sigma (LSS) can be effectively stimulated in manufacturing SMEs (small- and medium-sized enterprises). One major starting point was the notion that LSS implementation in an SME cannot be realized using just a downsized copy of an implementation programme designed for large organizations.

In this final chapter we discuss and reflect upon the main findings of the previous chapters and the implications for theory and practice. We will end with strengths and limitations and directions for future research.

6.1 **Summary of the main findings**

In this section the research questions and main findings of the four research projects are highlighted.

In Chapter 2, "A Delphi study on Six Sigma tools and techniques", our research focussed on the following three research questions:

1. Which Six Sigma tools and techniques are used in case study publications on projects carried out within manufacturing and engineering organizations?
2. How do experts assess the relevance of best practice-based tools and techniques and how do they group these into a Six Sigma project structure with DMAIC-project phases (Define-Measure-Analyse-Improve-Control)?
3. To what extent is the arrangement of tools and techniques in DMAIC-project phases in accordance with the rational reconstruction of DMAIC-project phases as published by De Koning and De Mast (2006)?

We produced, by conducting a Delphi study, a list of 46 practical tools and techniques (that were actually used in 24 real-life case studies), confirmed by experts to be useful in our target domain of manufacturing/engineering companies, and an assignment of these tools and techniques to the DMAIC phases (based on expert opinions and cross-checked to the De Koning and De Mast (2006) study). We have created a better focus on which tools and techniques will help at which point in the

DMAIC stages to successfully deploy LSS in a manufacturing/engineering context. The list of 46 tools and techniques is extensive and 21 of them were found in just one case study, indicating that the usefulness of tools and techniques is strongly dependent on the particular case-context. The most frequently used tool and techniques are:

In the Define stage: the description of the CtQ-characteristic (Critical to Quality) from the customer perspective, setting up a project charter, and using the SIPOC method (Supplier-Input-Process-Output-Customer) to clarify the project borders

In the Measurement stage: using Gage R&R techniques to validate measurement systems, and establishing the current process capability using process capability analysis and control charting techniques.

In the Analyse stage: analysing process control charts, root cause analysis using Cause and Effect diagrams, using Pareto analysis techniques to prioritize causes of defects or non-conformance, and analysing main and interaction plots.

In the Improve stage: identifying optimal process settings using Design of Experiments (DoE) and/or Taguchi techniques, and confirming optimal settings by executing test runs.

In the Control stage: confirming improvements using process capability analysis in production, and developing control plans for ongoing production.

The uncertainty in assigning of some tools and techniques to the DMAIC phases observable in the literature sources used by De Koning and De Mast is also demonstrated in this study. The most salient uncertainty is in the determination of the Critical to Quality criteria (CtQs) in the Define phase. CtQs are supposed to express critical to quality characteristics from the viewpoint of the customer, but in practice process parameters are frequently indicated as CtQs that do not explicitly express the voice of the customer. The notion that occasionally the initial CtQ definition might be reconsidered at the end of the Measure phase, when the correlated influence factors are known, indicates the iterative nature of the Define and Measure steps in the DMAIC structure.

The focus of Chapter 3, “Implementation of Lean Six Sigma in small- and medium-sized manufacturing enterprises in the Netherlands”, is on the critical success factors (CSFs) and impeding factors in connection with LSS implementation in manufacturing/engineering SMEs, addressing the following three research questions:

1. What is the current status of implementation of LSS in manufacturing/ engineering SMEs in the Netherlands?
2. What factors are to be perceived as critical success factors and impeding factors in LSS implementation, from a manufacturing SME perspective, and how are these CSFs and impeding factors ranked by management?
3. How are CSFs translated into practice and how do SMEs cope with impeding factors in day-to-day practice?

To answer the first two research questions exploratory empirical evidence about LSS implementation in Dutch SMEs has been collected from a survey study of Dutch SMEs. The survey study delivered information about the usage and perceived importance of LSS tools and techniques, on CSFs and impeding factors and on results achieved through LSS implementation in the Netherlands. *Linking to the customer* is the highest ranked CSF, containing the following elements: identification of customer (internal/external) needs, implementation of projects with high impact on customer satisfaction, periodical evaluation of market knowledge, and effective resolution of customer complaints. Other important CSFs are *vision and plan statement* (vision of the long-term future of the company)*, communication about plans to deploy Six Sigma,* and *management involvement and participation* (with active participation in projects as one of the elements). The most important impeding factors are *internal resistance against Six Sigma deployment, availability of resources, changing business focus* and *lack of leadership*.

On the use of tools and on the perceived usefulness of them the survey results show that for the more complex tools the degree of familiarity in the Dutch SMEs is rather low. For instance, for DoE 46% of the respondents indicated being unfamiliar with this technique. DoE was hardly used in the current practice but future application of DoE was expected to be very useful. Importantly, the most frequent usage rating is 1 (very low usage), and the most frequent usefulness rating is 4 (highly perceived usefulness).

To gain deeper insight into how organizations translate CSFs into practice and cope with impeding factors, additional qualitative information was gathered from six case studies. From our case study

research three new CSFs were inferred: *personal LSS experience of top management*, *development of the project leader's soft skills* and *supply chain focus*. The case studies showed that more often companies have started initiatives to adopt Six Sigma and later on shifted more towards lean manufacturing. The case studies confirm the image that the use of lean manufacturing tools is rising. Yet the case studies also confirm that Six Sigma tools are valuable for solving problems with higher levels of complexity. All case study companies wanted to combine both approaches in an integrated way.
Therefore, in Chapter 3, we created a better view on what (Dutch) SMEs have done with LSS, what CSFs and impeding factors are present for deploying LSS, and how SMEs cope with these CSFs and impeding factors. SMEs can benefit from the findings of this chapter in applying LSS in a sustainable manner.

In Chapter 4 an existing framework for Six Sigma implementation for SMEs (Kumar et al., 2011) is evaluated, which was the first framework with implementation phases and steps addressing the particular constraints that SMEs face in implementing Six Sigma. We have done this because we regard the design of such a framework a logical next step after previous studies. As there was already a proposed framework, we wanted to find out to what extent it matches the needs of manufacturing SMEs. The objectives of this study were expressed in the following research questions:

1. What supporting evidence can be found regarding the phases and steps of the framework proposed by Kumar et al. (2011)?
2. What evidence can be found that the framework needs improvement, and what revision proposals can be formulated based on this evidence?
3. What are the building blocks of a revised and validated framework that will meet the formulated proposals for revision while keeping the confirmed elements in place?

In this study a triangulation approach was used comprising a literature review, focus group research, and retrospective interviews in two Dutch companies with long-term experience in the deployment of LSS. The results are presented as elements of confirmatory evidence and revision proposals for the framework, as well as overall recommendations for deploying LSS in SMEs. Finally, the results are translated into a proposal for a revised framework, as depicted in figure 6.1. This revised framework represents a new "piece of the puzzle", and offers a better validated phased approach to implement LSS in manufacturing SMEs.

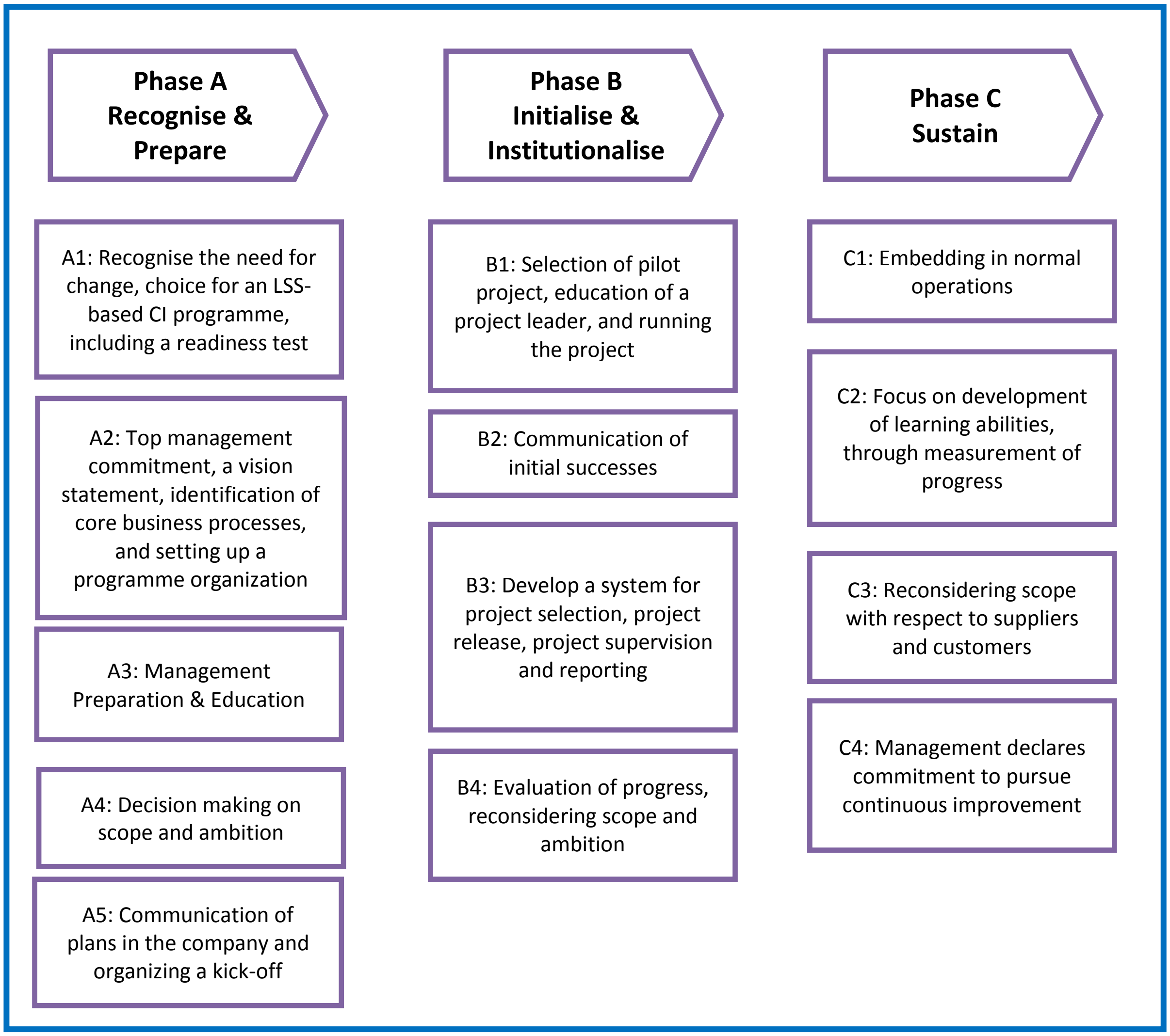

Figure 6.1. Phases and steps of the revised framework for LSS implementation in SMEs.

Chapter 5 contributes to the literature by presenting a field research study on the improvement of a production process. The goals of the project are to quantify the contributions of process parameters to the variation of the CTQ, and to determine optimal set points for these process parameters.
In this study DoE methods are used in an SME that produces products using polymer-injection moulding technology. In Chapter 3 a difference between the usage of DoE and its perceived

usefulness has been found, which challenged us to demonstrate the power of these methods. This study serves first of all as a demonstration of how DoE can be applied effectively in an injection moulding SME to optimize the machine settings for the injection moulding process. A CtQ characteristic that is connected to assembly problems is the subject of investigation. The assembly problems are caused by warp in the product, which is incurred by the shrinking of the product after ejection from the mould when it cools down to room temperature. The CtQ is defined as the parallelism of two pins on which a metal component has to be mounted in the assembly process. The variation in the product dimension is studied using DoE and Taguchi methods. Five process parameters are varied around initial set points that have been chosen by injection moulding experts. The most important process parameters were selected based on their influence on the mean level of the CtQ and on the stability of the CtQ around the CtQ's mean level. It did not become apparent that the mould needed modifications to make it possible to find optimal process settings, valid for both mould cavities at the same time, until the experiments in the Improve phase were run. Only after the mould had been modified and the experiments of the Improve phase had been repeated did it become feasible to determine optimal process settings. As a consequence of these unforeseen problems the Improve phase had to be repeated , illustrating the iterative nature of the DMAIC stages.

The project delivered optimal process settings for a robust and predictable process. As such, the example described in Chapter 5 can help injection moulding companies to learn how to apply a specific technique from the Six Sigma toolbox to optimize the injection moulding processes. Also, the approach can be valuable for other manufacturing SMEs too, when product quality is impacted by multiple process parameters and the influences of these parameters are only moderately understood.

6.2 **Theoretical implications**

In this section we will reflect upon the theoretical implications of our research. The deployment of continuous improvement using LSS methods in manufacturing SMEs is the main focus of this thesis, expressed in the overarching research question: How can continuous improvement based on the basic principles underlying Lean Six Sigma be stimulated effectively in manufacturing SMEs?

The rationale behind the first study (reported in Chapter 2) was that the available literature on Lean Six Sigma was to a major part restricted to theoretical publications and textbooks, and we felt the need to explore the real practice of DMAIC projects. The contribution made by this study to the theory of Chapter 2 is that the knowledge base about the use of tools and techniques in DMAIC projects has been improved by comparing existing theoretical knowledge on the subject (De Koning and De Mast, 2006) with data derived from empirical research from 24 case studies, with the help of a Delphi panel of experts. The case studies were not restricted to cases in SMEs, because such a restriction would have made it hard to find a satisfying number of fully DMAIC structured case studies.

In the remaining chapters the context was clearly restricted to that of manufacturing SMEs. In Chapter 3 the CSFs and impeding factors for the implementation of LSS are studied as a preparation for Chapter 4, which ends with a framework for the implementation of LSS. The survey study of Chapter 3 is partly a replication of a survey study in the UK (Antony and Kumar, 2011) and delivered new results based on data collected in manufacturing SMEs in the Netherlands. The collection of new data was useful not only to extend the data to new international regions, but also because the number of SMEs with long-term experience in deploying Six Sigma is low. In the preceding UK study the analysis was based on results from 60 companies, but only 16 of them were actually involved in a Lean Six Sigma programme. In our study we included the validation of the survey results on the consistency of the contribution of the ratings of the sub-items to the CSFs, and also tested the significance of differences between scores. We extended the survey study with case study research in six SMEs, to develop a deeper insight into the CSFs and impeding factors.

Understanding the findings on CSFs and impeding factors requires them to be considered in connection with the typical SME characteristics listed in table 1.1. The unfavourable SME characteristics are the lack of resources (human and financial), the characterization of the process of strategic planning as having a relatively short planning horizon, and some of the management-style characteristics, with the ’command and control’ style as the most unfavourable type. The first two characteristics will be valid for many SMEs, for the management-style characteristics the picture is more diverse. In contrast to the unfavourable characteristics of management style some other characteristics are favourable, such as informal culture, small management teams really connected with operations and operating with efficient decision-making processes, and flexibility. The CSFs' *vision and plan statement* and *management involvement and participation* were very important. The first CSF is again closely connected to the quality of strategic planning and the second to the management style. In one of the case studies *the personal LSS experience of management* was emphasized as being important, because otherwise the credibility of management would be poor. An important message is that embarking on LSS needs momentum, falling back is dangerous, and could ultimately lead to a complete failure. For SMEs this is a strong risk, because of their relatively short planning horizon. A thorough preparation by management is needed and could easily take more than one year.

The lack of availability of human and financial resources is one of the SME characteristics of table 1.1 and from our survey study of Chapter 3 *availability of resources* was the second main impeding factor for SMEs. The lack of resources makes it difficult to invest in the education and training of project leaders to the level of Green or Black Belt. The main impeding factor from our survey study was *internal resistance*, and in one of the case studies this impeding factor was emphasized in connection with the participation of shop-floor employees. Paying attention to the development of soft skills in the training of project- leaders was suggested to be critical to mitigate the effects of the reluctance of shop-floor employees to cooperate. Changing business focus was the third important impeding factor from our survey study and this factor again can be connected to the SME characteristics of the short-term strategic planning horizon. To prevent the deployment being disturbed by other business priorities coming up, this pleads again for thorough management preparation followed by planning the deployment over a relatively short time frame.

After having studied the CSFs and barriers for the implementation of LSS, the next logical step is to find a practical way to implement LSS in SMEs. Could implementation be realized in an evolutionary way, by carrying out pilot projects and improving steadily towards higher levels, or should a roadmap for implementation be used as a guideline? Done et al. (2011) studied the impact of BPIs (Best Practice Interventions) in a lean manufacturing context in SMEs. They concluded that in the first place the presence of a clear pre-BPI strategy for long-term change is the most important differentiating factor for long-term change. Such a strategy should encompass the outlining of objectives of best practices, the rolling out of BPIs and the communication of the strategy and objectives for change. The framework of figure 6.1 provides measures regarding these issues. It is actually a framework to support the change process to implement LSS, reflecting the classical "unfreeze, move and refreeze" phases in change processes (Lewin, 1951). "Refreeze" refers to the Sustain phase, and sustaining is never-ending. But there will be a point marked by management from which the implementation programme is regarded as losing its special status, and from then further development should continue in an evolutionary way. The framework looks generic and the specific features which make it suitable for SMEs are not explicitly visible. An important element for SMEs to make the use of the framework a success is connected to the combination of project execution and education of the project leader and team members. Another important element in the framework is the decision making by management about the scope and ambition (steps A4 and B4). To keep the development going the feasibility of goals is extremely important, not least to keep all the employees committed to cooperating.

In the third phase (Sustain) the development of learning abilities and the measurement of progress in the level of learning abilities is an important focus point. Bessant et al. (2011) connect the development of CI (continuous improvement) to the development of a learning organization and through that to improving innovative capabilities, which is regarded as vital for the organization's long-term perspective. The concept of a learning organization is rather vague. We suggest using the concept of Absorptive Capacity (AC) as a reference. In the study of Tu et al. (2012, p. 694) AC is defined as "the organizational mechanisms that help to identify, communicate, and assimilate relevant internal and external knowledge". The internal knowledge in this definition refers to existing knowledge available in the organization, including tacit knowledge that can only be communicated by direct social interaction. Social integration mechanisms that facilitate the sharing and exploitation of knowledge will have a positive influence on the development of AC (Zahra and George, 2002), and Lean Six Sigma teamwork has a positive influence on the development of AC (Guttierez, Guttierez et al., 2012). In the framework of figure 6.1 measuring the progress of learning abilities is part of the Sustain phase (step C2). Tu et al. (2012) developed a questionnaire to assess the level of AC. The questionnaire focuses on four dimensions of AC: worker knowledge, manager knowledge, communications network, communications climate and knowledge scanning. In the Sustain phase this instrument could be usable in practice to measure progress in the development of learning abilities, expressed in terms of AC-dimensions. The instrument has not been tested in the context of LSS in manufacturing SMEs and testing and improving the instruments could be part of future research.

Measuring progress in learning abilities is part of the Sustain phase, but of course the development of these abilities will start earlier. Management education is part of the first "Recognize and Prepare" phase and the education and training of team members needs to be addressed as soon as the first project is selected. The education of management should encompass LSS subjects and a reflection on the management's role in the deployment. A reflection on the management style is appropriate at this stage, emphasizing treating people as knowledge resources and encouraging participation in efforts to improve.

The case study of Chapter 5 is focussed on the application of DoE in the context of the polymer-injection moulding industry. In Chapter 5 no new theory is developed, but the value of the field research study as such is that it demonstrates that the application of existing methods cannot be done by simply following a procedure straightforwardly by the book. The project also illustrates two issues that are important in a wider sense, because they are expected to be relevant in other cases too. The first issue is that a CtQ defined from the customer's perspective can be understood very well but can be hard to measure, making it necessary to find a dimension that is strongly correlated to the CtQ and that can be measured properly. The second issue is referring to the iterative nature of the DMAIC sequence of project stages. In the case study, going through the project stages straightforwardly was not possible because of unanticipated problems that came up in the Improve stage. It was necessary to go through the Improve stage twice, before and after a modification of the mould.

An important contribution of this study is also that it provides an example of how to effectively introduce new relatively unknown methods to SMEs. The members of the team were not extensively educated in DoE methods before the case study was carried out. Because of the poor resources of SMEs the management will, in general, be reluctant to invest in the education and training in subjects that ''may be" relevant in the future. Apart from this barrier it would be unwise to separate education and training completely from application in practice. In our study the experiments were prepared, planned and carried out by the researcher together with employees who were usually involved in the preparation of new production start-ups. The team members learned during the experiments and understood that the sequence of experiments could be applied at production start-ups in general.

The framework is at the core of the results of this thesis as the most direct contribution to answering the overarching research question. It is generic and the usability is strongly dependent on the concrete activities within each of the steps.

6.3 **Practical implications**

In addition to the theoretical implications, this dissertation offers managers of SMEs and LSS specialists background information and practical clues relevant for implementation of LSS-based continuous improvement. Chapter 2 delivers background information on tools and techniques. Chapters 3 and 4 deal with LSS implementation in an SME context.

The framework of figure 6.1 can help managers who are interested in embarking on LSS. They can use the framework in the dialogue with colleagues in their management team, and use it as a guidance for deployment of LSS-based continuous improvement. The framework starts with recognizing the need for change, and articulating that need is a necessary step. Along with recognizing the need for change, the following questions arise: what are the important conditions necessary for embarking on LSS?; what are the risks and pitfalls?; and what bottlenecks can be foreseen? In considering the readiness of the organization, taking careful notice of the CSFs and impeding factors (Chapter 3) will be an important part of this assessment. Management will consider the need for external assistance to roll out the deployment programme. In the discussions with candidates for external support the framework can serve as a reference for management to understand whether the ideas of a candidate comply with the fundamental ideas underlying the framework.

LSS specialists can benefit from this thesis in assisting management in developing a more detailed plan for the implementation of LSS, tailored to the specific SME context of the company. LSS specialists may contribute to the education of management, first of the project leader and project team members, and by coaching the project team in the first pilot project. Finding a proper balance between knowledge transfer and project execution is crucial. In this thesis no detailed prescriptions for practice on education are presented, but our findings show that education and training should be closely connected to the execution of projects. Projects, however, must not be selected and defined to support educational purposes. The point of departure should be the project selection based on the company's priorities, closely linked to the company's strategy, and education and training should be adapted to the project needs.

Chapter 5 can serve as an example for managers, LSS-specialists, project leaders and team members of how projects may run following the DMAIC structure in real practice, which is sometimes quite different from following the DMAIC sequence by the book. The study shows how new methods, in this study those being DoE methods, can be introduced into an SME without advanced DoE knowledge. The key-contribution is that it presents an example of a field research study that directly helps project teams to solve an existing problem and at the same time improves their knowledge base.

The management's interest in embarking on LSS will be incurred by a sense of urgency that change is needed to stay competitive in the long term. The need for change may be articulated by the perceived necessity of better performance of existing processes, or of the development of new products, or even of the introduction of new technologies. This thesis links such needs to the improvement of learning abilities and knowledge levels, which also has an impact on the company's culture. Using the framework and taking notice of the underlying studies of this dissertation will help in finding a way to steadily improve the organization.

6.4 **Strengths and limitations**

We first highlight the strengths of the thesis as a whole, looking back at the overarching research question on how continuous improvement based on the basic principles underlying Lean Six Sigma can be stimulated effectively in manufacturing SMEs.

In the light of this research question the framework of figure 6.1 is the main result of our research. The research has underlined the need for a framework based on literature (Done et al., 2011) and found indications supporting that need related to the differences in progress of the case study companies. The framework has been composed taking into account the critical success factors and the factors that impede the process of implementation. With the exception of the first study we have continuously focussed on research objectives keeping in mind the specific characteristics of SMEs. We have used a broad range of research methods in the studies reported in the previous chapters, and as a general strength of the thesis as a whole we may also include that for each of the four studies new data were collected separately.

In Chapter 2 Delphi methods are applied starting from statements on tools and techniques extracted from case studies. Applying Delphi methods with a group of experts to assess and assign quality improvement tools and techniques that are used in practice has, to our knowledge, not been done before.

In Chapter 3 a survey instrument is used that was developed, tested and used earlier by researchers in Glasgow (UK) (Antony, Kumar and Madu, 2005). In the analysis of the data, statistical techniques are used to validate the consistency of the answers to the main survey questions inferred from the answers to sub-questions, and to test the significance of the differences between mean scores. The additional case studies delivered in-depth information on CSFs and impeding factors and their impact on LSS deployment.

In Chapter 4, three research methods were applied in a triangulation approach: focus group research (Fern, 2001; Krueger and Casey, 2009), a structured literature search and retrospective interviews. The triangulation approach was followed because this type of focus group research, aimed at testing an existing theory, needs to be combined with other research methods.

The core of the case study of Chapter 5 was based on the application of classical DoE techniques (Montgomery, 2005), explicitly paying attention to complying with preconditions connected to the safe use of these techniques. This study also demonstrates once again the iterative nature of DMAIC-project phases by showing that in practice it is not always feasible to run a project by straightforwardly following the DMAIC phases. In particular, the Improve stage has to be repeated because the results of the first round made clear that the mould had to be modified. After this modification new experiments were run and based on the new results it became feasible to optimize the process.

We also need to pay attention to the limitations connected to the studies, again starting with the limitations of the thesis as a whole in light of the overarching research question. The main limitation is that the framework has not been tested in a real intervention within an SME. Such an intervention was not feasible within the time frame available for this research.

In Chapter 2, case studies have been selected that were published between 2003 and 2007. We formulated 95 statements on the use of tools and techniques and after the Delphi study 46 statements remained and were assigned to the DMAIC-project stages. The main limitation is incurred by the composition of the group of experts that was involved in the Delphi study. Ten experts participated in the first remote round of the Delphi study; seven experts participated in the Delphi session, which is the minimum level recommended by the literature (Linstone and Turoff, 2002).

In Chapter 3 a survey study and additional case studies were carried out. The survey instrument was a Dutch version of a questionnaire that was used earlier in the UK. The response came from managers of 51 manufacturing SMEs, and although the response was collected anonymously the absence of informant bias cannot be warranted.

In Chapter 4 the strongest limitation is the fact that the results of our focus group study rely on a single focus group. Relying on one single expert focus group is, however, acceptable (Fern, 2001) when the focus group research is combined with other research methods. Another limitation is in the selection of the companies for the retrospective interviews. It was difficult to find SMEs with experience in LSS deployment. We visited seven companies before we were able to select two companies with sufficient experience in LSS implementation.

In Chapter 5 the main limitation is in the applied design array, because all factors are two-level factors, and as a consequence the modelling of the response is restricted to linear models. In the study of Chapter 5 the design appeared to be adequate, but additional field research is needed to prove that the design is appropriate to be used as a standard in the context of injection moulding.

6.5 **Directions for future research**

To test the framework empirically, carrying out an intervention study in a manufacturing SME is a logical next step. Doing this would require a longitudinal approach that monitors progress over several years. Before embarking on such an intervention we propose to carry out a preceding study on what are the essential elements for the education of manager, project leaders and team member employees who have a role in the supervision or execution of projects. A remaining question for practice is how closely education should be connected to the execution of projects. Should education take place completely within projects or should it rather be organized preceding participation in projects, or would a mixed approach be better? And how should operational learning (know-how) and conceptual learning (know-why) be balanced (Mukherjee et al., 1998)? What are effective learning methods for project leaders and team members, bearing in mind differences in starting levels and learning styles. How can project leaders be prepared on their tasks to train team members in parallel to project execution? How can the progress of learning abilities at different levels be measured using the concept of Absorptive Capacity as a reference? How does the development of learning abilities impact on the development of resilience and dynamic capabilities, as described by Ates and Bititci (2011) and Anand et al., 2009.)? Resilience refers to the ability to anticipate emerging trends and opportunities, dynamic capability is the ability to generate and adapt routines through learned and stable collective activities. Anand et al. view continuous improvement as a potential dynamic capability.

Large companies with long-term experience in LSS deployment have systems in place for education, but in SMEs such a system is not feasible because of strong restrictions with respect to the availability of resources.

We are currently seeking cooperation with the Dutch injection moulding industry to explore the feasibility of such a study. Injection moulding is one of the focus areas of the mechanical engineering department of Stenden University and provides, as such, good contacts with SMEs within this sector. Focus on this area of industry is thus a choice, carrying out such a study in a different area would be possible just as well.

Meanwhile the technological developments in the injection moulding industry are also progressing towards areas that reach beyond traditional borders. New technologies come up, such as 3D printing as an alternative for injection moulding, especially promising for producing products in small series. Another rapidly developing trend is connected to increased demand for sustainable production methods. In the industrial context, focus points are the lowering of energy consumption and harmful emissions of industrial processes, recycling and ‘upcycling’ of materials, and the application of biodegradable materials. The research on continuous improvement, to which this thesis is contributing, should not progress without any connection to technological trends. Technological trends together with continuous improvement initiatives are the driving forces for innovation.

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Samenvatting (Summary in Dutch)

Dit proefschrift richt zich op kwaliteitsverbetering op basis van Lean Six Sigma (LSS) in kleine en middelgrote industriële ondernemingen (industriële KMO's). De doelgroep voor het onderzoek is dus het deel van de maakindustrie waartoe de KMO's behoren. Industriële KMO's zijn voor een belangrijk deel bepalend voor de economische groei en werkgelegenheid. Veel grote bedrijven hebben in de laatste decennia grote vooruitgang geboekt in het tot ontwikkeling brengen en ten uitvoer leggen van programma's voor continu verbeteren op basis van LSS, maar voor KMO's is het beeld veel minder gunstig.

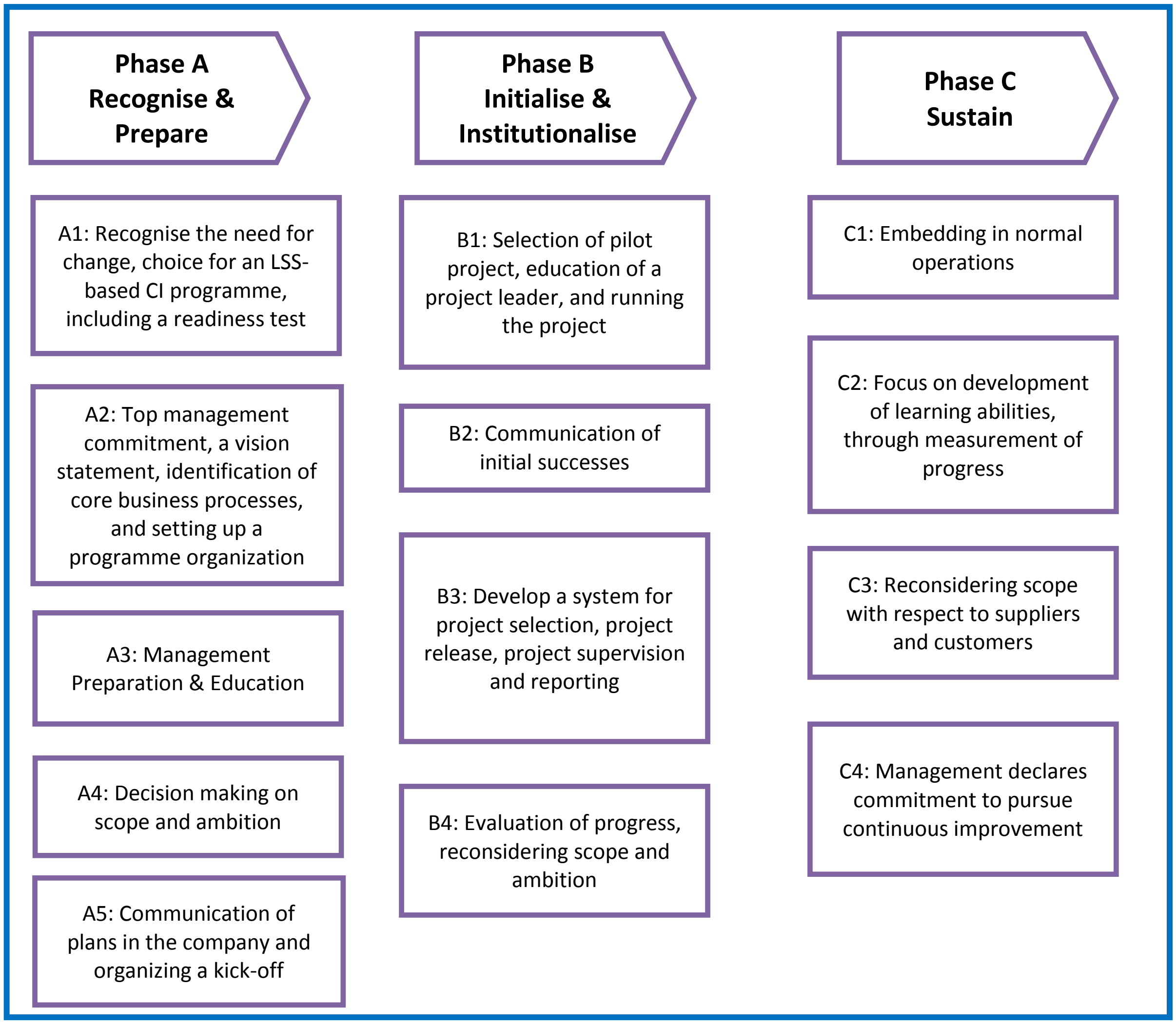
Hoofdstuk 1 gaat eerst in op de Juran's visie op kwaliteitsmanagement, waarin wordt uitgedragen dat het vermogen om continu te verbeteren ontwikkeld moet worden via projecten, en schetst in het kader van continu verbeteren de ontwikkeling van Six Sigma, lean manufacturing en de integratie naar Lean Six Sigma. Vervolgens wordt kwaliteitsmanagement gekoppeld aan de context van het deel van de maakindustrie, waartoe de KMO's behoren. Gebruik makend van literatuurbronnen over de specifieke kenmerken van kleine en middelgrote bedrijven wordt beargumenteerd waarom de implementatie van Lean Six Sigma in KMO's een op de context van KMO's toegesneden benadering vergt. Door de omvang van deze bedrijven zijn er beperkte middelen voor de ten uitvoerlegging van breed opgezette implementatietrajecten. Bovendien zijn deze bedrijven i.h.a. gericht op doelen die voor het voortbestaan op kortere termijn belangrijk zijn en is mede daardoor de planningshorizon beperkt. Managers van KMO's zijn dikwijls ook (mede-) eigenaren, hetgeen vaak leidt tot een managementstijl die gekenmerkt wordt door directe supervisie en zichtbaarheid op de werkvloer. Vooral de beperkte beschikbaarheid van mensen en financiële middelen, de weinig uitgewerkte bedrijfsstrategie en de relatief korte planningshorizon maken dat programma's opgezet voor grote organisaties niet eenvoudig naar een kleinere schaal kunnen worden omgebouwd om ze geschikt te maken voor KMO's. Het doel van dit onderzoek was dan ook allereerst om te begrijpen hoe industriële KMO's kunnen profiteren van de principes die ten grondslag liggen aan LSS, hetgeen tot uitdrukking wordt gebracht in de volgende overkoepelende onderzoeksvraag:

Hoe kan continu verbeteren op basis van de principes die ten grondslag liggen aan Lean Six Sigma effectief worden gestimuleerd in KMO's die tot de maakindustrie behoren.

Hoofdstuk 1 wordt afgesloten met een motivatie van de verschillende projecten die in het kader van het onderzoek zijn uitgevoerd en een overzicht van de overige hoofdstukken van het proefschrift.
In hoofdstuk 2 wordt ingegaan op tools en technieken die in de praktijk van Six Sigma projecten worden toegepast binnen de DMAIC-fasen (Define-Measure-Analyse-Improve-Control) van een project. De praktijkervaringen zijn in kaart gebracht door een literatuuronderzoek naar case studies waarin verslag wordt gedaan van uitgevoerde projecten, waarin technieken gebruikt worden afkomstig uit de toolbox van Six Sigma. Op basis van de case studies is een lijst met gestandaardiseerde formuleringen van het gebruik van technieken gemaakt. Door een groep experts is deze lijst in een Delphi studie uitgewerkt tot een lijst met 46 gestandaardiseerde beschrijvingen van toepassingen van technieken, gegroepeerd naar de DMAIC-fasen waarin ze naar het oordeel van de experts gebruikt kunnen worden. De indeling in DMAIC-fasen is vergeleken met de indeling van De Koning en De Mast (2006), gemaakt op basis van hun theoretische generieke reconstructie van Six Sigma. Voor 40 van de 46 technieken komt de toewijzing aan DMAIC-fasen overeen met die van De Koning en De Mast. Voor de onduidelijkheden in de toewijzingen naar de verschillende DMAIC-fasen zijn verklaringen gezocht. Een deel van de onzekerheid wordt veroorzaakt door verschillen in interpretatie, o.a. van het begrip CtQ (Critical to Quality). CtQ's zouden direct gekoppeld moeten zijn aan kwaliteitskenmerken zoals die worden ervaren door de klant, maar in de praktijk worden ook vaak aan een CtQ gecorreleerde procesparameters als zodanig gebruikt. Procesparameters die een causaal verband hebben met een CtQ zouden pas in de Measure of Analyse fase moeten worden benoemd.
In hoofdstuk 3 wordt onderzoek gedaan naar de factoren die bepalend zijn voor het met succes implementeren van LSS in industriële KMO's en ook wordt onderzocht hoe organisaties omgaan met belemmerende factoren. Het onderzoek is uitgevoerd langs twee lijnen. Eerst is er een survey-studie uitgevoerd en vervolgens zijn aanvullend zes case studies uitgevoerd om inzicht te krijgen in de achtergronden van de kritische succesfactoren en de belemmerende factoren van LSS implementaties, vijf in Nederland en één in Vlaanderen. De survey heeft informatie opgeleverd over

het gebruik van de tools en technieken en over de door respondenten ingeschatte belangrijkheid ervan, over kritische succesfactoren en belemmerende factoren samenhangend met de implementatie van LSS in industriële KMO's, en over de bereikte resultaten. Een belangrijke waarneming is dat de bekendheid van de complexere technieken vrij laag is. Zo verklaarde 46 % van de respondenten niet vertrouwd te zijn met DoE (Design of Experiments). Op basis van de respons blijkt DoE op zeer bescheiden schaal gebruikt te worden, terwijl de mogelijkheden voor het gebruik van DoE-technieken juist hoog worden gewaardeerd. Het niet vertrouwd zijn met DoE staat dus in schril contrast met het verwachtingspatroon ten aanzien van de effecten van toepassing van DoE. Op basis van de survey studie zijn de belangrijkste kritische succesfactoren *het verbinden van LSS aan klanten, visie en plannen* (visie op de toekomst van het bedrijf op langere termijn en plannen voor uitwerking), *communicatie* (over de invoering van LSS), en *betrokkenheid en participatie van het management* (ook blijkend uit actieve deelname aan projecten). De belangrijkste belemmerende factoren zijn *interne weerstand* (tegen het uitrollen van LSS), *ontoereikende beschikbaarheid van middelen, veranderingen in de koers van de organisatie* en *gebrek aan leiderschap.* De zes case studies bevestigen grotendeels het beeld van de resultaten van de survey studie ten aanzien van de belangrijkste kritische succesfactoren en belemmeringen, en verdiepen het inzicht in het hoe en waarom van de achterliggende mechanismen. Zo zijn bijvoorbeeld in de meest ervaren case *de betrokkenheid en participatie van het management*, *het begrijpen van LSS* en *de prioritering en selectie van projecten* zeer goed herkenbaar. In dit bedrijf is de LSS organisatie zeer goed zichtbaar en is de betrokkenheid van het top-management bij die organisatie groot. In de LSS organisatie worden gestandaardiseerde projectvormen gebruikt van zeer korte projecten tot Black Belt projecten die over meerdere maanden verlopen. De projectvoorstellen worden systematisch gegenereerd en geprioriteerd in overleg met het management en de proceseigenaren. Drie nieuwe kritische succesfactoren zijn naar aanleiding van een analyse van de case studies benoemd: *persoonlijke ervaring met LSS van het top management*, *ontwikkeling van "soft skills" van projectleiders*, en *focus op de supply chain*. De praktijk van de zes organisaties laat een integratie van lean en Six Sigma tot LSS zien. Daarbij is een beeld ontstaan dat Six Sigma technieken wel degelijk belangrijk zijn, maar dat de complexere technieken voornamelijk worden gebruikt om problemen op te lossen waarvan de oorzaken alleen met diepgaander onderzoek te achterhalen zijn.

In hoofdstuk 4 wordt via een triangulatie benadering een raamwerk voor de implementatie van LSS in industriële KMO’s gebouwd. Het uitgangspunt was een eerder gepubliceerd conceptueel raamwerk voor de implementatie van Six Sigma (Kumar et al., 2011). Dit raamwerk is onderwerp geweest van een focus groep studie, een literatuuronderzoek en retrospectieve interviews in twee bedrijven met langdurige ervaring met de implementatie van LSS. Het onderzoek was gericht op het vinden van onderbouwend bevestigend bewijs voor het bestaande raamwerk, en waar nodig op het formuleren van onderbouwde voorstellen voor revisie. Uiteindelijk wordt het totale beeld vertaald in een voorstel voor een raamwerk dat in de volgende figuur is weergegeven in de originele Engelstalige versie.



Raamwerk voor de implementatie van LSS

De belangrijkste wijzigingen zijn:

- Het terugbrengen van het aantal fasen van het raamwerk naar drie: Recognise &Prepare, Initialise & Institutionalise and Sustain. Het verplaatsen van "Identify core business processes" naar de eerste fase, als onderdeel van de management voorbereiding.
- De integratie van opleiden en werken aan projecten.
- Het opnemen van het bouwen aan een systeem voor project-selectie, -administratie en –ondersteuning in de tweede fase na de uitvoering van een pilot project en het communiceren van de eerste successen.

- Het zorgen voor een meer concrete uitwerking van de Sustain fase, met als hoofdpunten het inbedden van de nieuw ontwikkelde werkwijzen in de normale operaties en het ontwikkelen en monitoren van de progressie van het lerend vermogen. Het meten van de progressie in lerend vermogen is in praktische zin gekoppeld aan het meten van de “Absorptive Capacity”, waarvoor wordt verwezen naar een instrument dat is ontwikkeld door Tu et al. (2006).

In hoofdstuk 5 wordt velonderzoek gepresenteerd waarin de introductie van een van de meer geavanceerde methoden uit de LSS toolbox in een klein kunststofspuitgietbedrijf centraal staat. De context is dus weer die van de industriële KMO’s, en dan met name dat deel van de maakindistrie dat de bijzondere belangstelling heeft van de onderzoeker. In de bevindingen van de survey-studie van hoofdstuk 3 werd al het saillante verschil tussen het werkelijke gebruik van DoE-technieken (Design of Experiments) en de verwachtingen ten aanzien van de gebruiksmogelijkheden ervan aangegeven. Het veldonderzoek van hoofdstuk 5 maakt duidelijk hoe DoE effectief kan worden gebruikt om een spuitgietproces te optimaliseren. De CtQ is afgeleid van assemblageproblemen die optreden als het eindproduct in een volgende processtap samengevoegd wordt met andere componenten. Deze CtQ is verbonden met vervorming van het product ten gevolge van het nakrimpen als het product afkoelt na afloop van het spuitgietproces. Die vervorming is heel moeilijk direct meetbaar, maar is zelf weer sterk gecorreleerd aan de wel goed meetbare hoogte van het product. De variatie in deze productmaat wordt bestudeerd met gebruikmaking van DoE en Taguchi technieken. De gebruikte benadering zou ingebouwd kunnen worden in een procedure voor de voorbereiding van de productie van nieuwe producten. De studie maakt ook duidelijk dat effectieve toepassing van LSS zowel kennis van LSS methoden als van de gebruikte technologie vraagt. En zelfs dan kunnen onverwachte resultaten het achtereenvolgens doorlopen van de DMAIC-fasen verstoren. In deze studie bleek in de loop van het project dat de koeling van de matrijs tussentijds aangepast moest worden. Pas na aanpassing van de matrijs en herhaling van de experimenten was het mogelijk om tot eenduidige conclusies te komen, geldig voor beide matrijsholten. Daarvoor moesten de Analyse en de Improve fasen twee keer doorlopen worden, hetgeen het in de literatuur beschreven iteratieve karakter bevestigt van de DMAIC fasen die doorlopen worden tijdens de uitvoering van een project (zie bijvoorbeeld Pande, 2000, p.239).

In hoofdstuk 6 worden allereerst de bevindingen van de voorgaande hoofdstukken samengevat, waarna er een discussie volgt van de resultaten in het licht van de oorspronkelijke overkoepelende onderzoeksvraag. Vervolgens wordt voor elk van de vier uitgevoerde studies ingegaan op de theoretische implicaties ervan. De belangrijkste daarvan zijn dat op basis van empirisch onderzoek de theoretische kennisbasis van de tools en technieken en hun toepassing in de DMAIC projectfasen is verbeterd, de onderbouwing van de kritische succesfactoren en belemmeringen voor implementatie van LSS in kleine en middelgrote bedrijven is verdiept, en een raamwerk voor de implementatie van LSS toegespitst op kleine en middelgrote bedrijven is versterkt. Het raamwerk is opgedeeld in drie fasen, conform de klassieke volgorde van veranderingsprocessen "*unfreeze*, *move, refreeze"* (Lewin, 1951). Het is eenvoudig van opzet en vrij generiek, de toespitsing op KMO's zit vooral in de invulling van de stappen van het raamwerk. Zo is de praktische uitvoering van de wijze van educatie en training voor KMO's heel relevant i.v.m. de bescheiden middelen. Verder zijn ook de reflectiestappen aan het eind van de eerste twee fasen (A4 en B4), waarbij de voortgang wordt geëvalueerd en de scope en ambities worden heroverwogen, bijzonder van belang voor KMO's. Het raamwerk zal zeker niet de laatste versie zijn, maar door het gebruik van drie onderzoeksmethoden in combinatie is de onderbouwing aanzienlijk versterkt. Vanuit de literatuur (Done et al., 2011) is ook de behoefte aan een dergelijk raamwerk als veranderstrategie voor de implementatie van best practice interventies onderbouwd. Verondersteld mag worden dat het systematisch doorlopen van de fasen in dit raamwerk leidt tot een toename van het lerend vermogen (absorptive capacity) in organisaties.

De implicaties voor de praktijk worden daarna toegelicht, met als belangrijkste implicatie het gebruik van het nieuwe raamwerk voor de implementatie van LSS met de focus op het versterken van het lerend vermogen van de organisatie. Tenslotte worden de sterke punten van de studie en de limitaties ervan toegelicht en wordt het proefschrift afgesloten met aanbevelingen voor verder onderzoek. Daarbij staat onderzoek naar de beste methoden voor opleiding van managers, projectleiders en leden van projectteams in de context van KMO's voorop, gevolgd door onderzoek naar methoden om de progressie van het lerend vermogen te meten.

Dankwoord (acknowledgements in Dutch)

Alweer lang geleden vroeg Rini van Solingen, destijds lector Quality Management & Quality Engineering van de Hogeschool Drenthe (in 2008 opgegaan in de Stenden Hogeschool) of ik nog de ambitie had om te promoveren. Ik had daarvoor een lange periode achter de rug waarin ik taken als manager van het kennistransfercentrum van de hogeschool en als hoofd van de opleiding Werktuigbouwkunde combineerde met het ontwikkelen en geven van onderwijs aan studenten en aan ingenieurs die al een baan hadden in de industrie. Ik ben al heel lang geïnteresseerd in de beheersing van kwaliteit in industriële voortbrengingsprocessen. Die belangstelling heeft zich ontwikkeld vanaf het meten van kritische kwaliteitskenmerken naar SPC (Statistical Process Control) en naar het optimaliseren van productontwerpen en productieprocessen. Later heeft zich dit vertaald in een grote belangstelling voor Lean Six Sigma. Het thema van het promotieonderzoek is dan ook gezocht in de hoek van Lean Six Sigma, en is met name gericht op de implementatie in kleinere bedrijven, met een accent op kunststofverwerkende bedrijven die spuitgiettechnologie toepassen. Toen Rini met zijn vraag kwam ben ik vrij onbevangen een promotietraject ingegaan. Rini heeft me in contact gebracht met Kees Ahaus, die zelf kort daarvoor in deeltijd hoogleraar Kwaliteitsmanagement aan de RUG geworden was. Wij hebben toen kennisgemaakt in Hoogeveen, een strategische plaats waar we Kees konden ontmoeten op zijn reis van Groningen op weg naar huis. Sindsdien hebben Kees en ikzelf elkaar vaak ontmoet in Groningen, waarbij Rini regelmatig meedeed via een Skype verbinding, en daarnaast hebben we ook regelmatig met elkaar overleg gehad op strategisch gelegen locaties in het midden van het land. Het was in het begin wel heel erg wennen. Het gewenningsproces had hoofdzakelijk te maken met twee aspecten: de aard van wetenschappelijk onderzoek en het combineren van het onderzoek met de andere taken die ik binnen de hogeschool nog had. Mijn eerste geschreven teksten hadden volgens Kees en Rini een nogal sterk normatief karakter. Met ander woorden, teveel geschreven vanuit eigen overtuigingen, veelal ontstaan door in mijn eigen beroepspraktijk ontwikkelde opvattingen. Kees en Rini hebben me hier steeds weer duidelijk op gewezen, met veel geduld en hebben ook steeds weer de goede dingen die zij zagen in mijn werk benadrukt, en alleen daarvoor alleen al ben ik hen veel dank

verschuldigd. Ik heb in dit proces geleerd om de studies zorgvuldig op te zetten, in een zoektocht naar de theoretische en praktische relevantie.
Kees heeft voorgesteld voor de eerste studie Delphi methoden te gebruiken en heeft een grote inbreng gehad in het design van de Delphi studie. Ook heeft hij de studie ter onderbouwing van een raamwerk voor de implementatie van Lean Six Sigma mede vormgegeven door retrospectief onderzoek in bestaande bedrijven met Lean Six Sigma ervaring voor te stellen, naast de literatuurstudie en de focus groep studie. Kees is ook steeds behulpzaam geweest in het zoeken naar de bijdrage die we met onze deelonderzoeken aan de literatuur konden leveren. De meermalen door hem gestelde vraag naar welke gap we met onze onderzoeken in de literatuur konden dichten was typerend voor zijn focus op het helder maken van de relevantie van het onderzoek.
Via literatuuronderzoek kwamen we op het spoor van Jiju Antony en Maneesh Kumar, die in Groot Brittannië al langer bezig waren met onderzoek naar methoden voor implementatie van Lean Six Sigma in het MKB. De samenwerking met hen is begonnen met een bezoek dat ik met Kees aan Jiju in Glasgow heb gebracht, en is daarna al gauw bijzonder vruchtbaar gebleken. Ik heb op uitnodiging van Jiju presentaties gegeven tijdens conferenties in Glasgow, Edinburg en Roanoke (Virginia, USA). Kees heeft ook deelgenomen aan een van de conferenties in Schotland en bij die gelegenheid hebben we samen met Jiju nog flink gewerkt aan een artikel. De commentaren van Jiju en Maneesh op conceptteksten, gegeven tijdens onderling overleg of via e-mail, waren bijzonder waardevol en mede richtinggevend voor het verloop van het onderzoek. Ik wil Jiju en Maneesh ook hartelijk bedanken voor de samenwerking in de afgelopen jaren.
Rini heeft ook in belangrijke mate bijgedragen aan het onderzoek als meedenker in het bedenken van ideeën voor te gebruiken onderzoeksmethoden, zoals bijvoorbeeld het uitvoeren van focus groep studies, waar ikzelf vanuit mijn eigen werk nauwelijks ervaring mee had. In mijn ogen was hij bijzonder goed in het redigeren van de uiteindelijke tekst van een artikel. Als de inhoud zo ongeveer klaar is en het concept voor een artikel de eindfase heeft bereikt kan Rini nog een flinke stap zetten door de tekst nog een keer goed te verbeteren, vooral op consistentie en leesbaarheid. Schrijven is een kunst die Rini bijzonder goed beheerst en ik wil hem hartelijk bedanken voor de moeite die hij genomen heeft om ons bij elk artikel telkens weer van zijn schrijftalenten te laten profiteren.

Ik wil Gina Gustan en Tobias van de Most ook hartelijk bedanken voor hun bijdragen aan het onderzoek. Beiden hebben zij bijgedragen aan de retrospectieve studie in bedrijven met Lean SIx Sigma ervaring, Gina via haar Master Thesis aan de RUG en Tobias in het kader van zijn afstudeeropdracht Werktuigbouwkunde aan de Stenden hogeschool. Beiden hebben zij een belangrijke bijdrage geleverd aan de analyse van de resultaten.
Tenslotte ben ik de Stenden hogeschool dank verschuldigd voor de gelegenheid die mij geboden is om in de eindfase van mijn loopbaan aan de hogeschool aan een promotieonderzoek te werken. Ik heb dat voor een groot deel als eenling moeten doen, in de laatste fase onder de vlag van Stenden-PRE. Ik hoop dat ik in de toekomst nog lang mijn kennis en kunde zal kunnen inzetten voor de ontwikkeling van Stenden-PRE en de technische opleidingen van de hogeschool.

Appendices

Questionnaire used for survey in chapter 3

Part I. Company Background

This section asks for some background details of yourself and your organisation

1. What is your current position within the company?

    1. CEO/ Director/ General Manager
    2. Quality manager
    3. Black Belt
    4. Yield manager
    5. Shop Floor Employee
    6. Other (please specify)

2. Select top three largest factors that define the company strategic objective (Tick up to 3 boxes that you consider are largest issues)

    - ☐ Profitability
    - ☐ Flexibility
    - ☐ Quality
    - ☐ Market Share
    - ☐ Innovation
    - ☐ Cost
    - ☐ Other (please specify)

3. Select top three important criteria that helped your company to win orders (Tick up to 3 boxes that you consider are largest issues)

    - ☐ Manufacturing Quality
    - ☐ Product reliability
    - ☐ Delivery lead-time
    - ☐ On-time delivery
    - ☐ Wide product range
    - ☐ Price
    - ☐ Other (please specify)

Part II: Knowledge and Usage of Quality Improvement Methods, Tools and Techniques Used Within Six Sigma Programmes

	Knowledge **Is this tool known within your company?**		**Usage** **How often is this tool used in your company?** **1 – Never been used** **2 – Used only once** **3 – Used rarely** **4 – Used frequently** **5 – Used continuously**	**Usefulness** **How do you assess the usefulness of this tool?** **1 – Not useful** **2 – Slightly useful** **3 – More useful** **4 – Very useful** **5 – Extremely useful**
Statistical	**Known**	**Unknown**	**1 2 3 4 5**	**1 2 3 4 5**
Histogram	□	□	□ □ □ □ □	□ □ □ □ □
Process Mapping	□	□	□ □ □ □ □	□ □ □ □ □
Cause & Effect Diagram	□	□	□ □ □ □ □	□ □ □ □ □
Scatter Diagram (correlation)	□	□	□ □ □ □ □	□ □ □ □ □
Tally charts (collecting data)	□	□	□ □ □ □ □	□ □ □ □ □
Run Charts	□	□	□ □ □ □ □	□ □ □ □ □
SPC Control charts	□	□	□ □ □ □ □	□ □ □ □ □
Pareto Diagram	□	□	□ □ □ □ □	□ □ □ □ □
Process Capability Analysis	□	□	□ □ □ □ □	□ □ □ □ □
Measurement System Analysis	□	□	□ □ □ □ □	□ □ □ □ □
Design of Experiments (DoE)	□	□	□ □ □ □ □	□ □ □ □ □
Taguchi Methods	□	□	□ □ □ □ □	□ □ □ □ □
ANOVA	□	□	□ □ □ □ □	□ □ □ □ □
Hypothesis testing	□	□	□ □ □ □ □	□ □ □ □ □
Regression analysis	□	□	□ □ □ □ □	□ □ □ □ □
Other: ______________	□	□	□ □ □ □ □	□ □ □ □ □
Other: ______________	□	□	□ □ □ □ □	□ □ □ □ □

	Knowledge **Is this tool known within your company?**		**Usage** **How often is this tool used in your company?** **1 – Never been used** **2 – Used only once** **3 – Used rarely** **4 – Used frequently** **5 – Used continuously**	**Usefulness** **How do you assess the usefulness of this tool?** **1 – Not useful** **2 – Slightly useful** **3 – More useful** **4 – Very useful** **5 – Extremely useful**
Team Problem Solving Tools	**Known**	**Unknown**	**1 2 3 4 5**	**1 2 3 4 5**
Process-Flowchart/Mapping	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Brainstorming	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Cause & Effect Analysis	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Affinity diagrams	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Relation diagrams	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
5S Practice	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Matrix diagram	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Matrix analysis	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
PERT Chart	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Force Field Analysis	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Balanced Scorecard	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Project Charter	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Other: _______________	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Other: _______________	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐

Other Methods and Techniques	**Known**	**Unkown**	**1 2 3 4 5**	**1 2 3 4 5**
QFD, Quality Function Deployment	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
FMEA, Failure Mode and Effect Analysis	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Kaizen	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
SIPOC (Suppliers, Inputs, Process, Outputs, Customers)	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
PDCA (Plan, Do, Check, Act)	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Poka-Yoke	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Benchmarking	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Quality Costing Analysis	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Other:_______________	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐
Other:_______________	☐	☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐

Part III. Critical Success Factors in Six Sigma Implementation This section asks for the factors that you consider to be crucial whilst implementing Six Sigma to your business process (es). Please tick the appropriate box according to the following code:

For Importance

1 Not Important at all
2 Slightly Important
3 Important
4 Quite Important
5 Very Important

Level of implementation in Practice

1 Very Low
2 Low
3 Moderate
4 High
5 Very high

Importance 1 2 3 4 5	**A. Management involvement and participation**	**Practice** 1 2 3 4 5
☐ ☐ ☐ ☐ ☐	Understanding of Six Sigma methodology by top management	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Participation of top management in Six Sigma projects	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Project review/verification by top management	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Provision of appropriate budget and resources for project by top management	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Top management discussion on Six Sigma related issues in the management meetings	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Top management focus on production process and service quality rather than yield	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Top management encouraging employee participation in Six Sigma implementation	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	A credible and effective leadership in deploying Six Sigma	☐ ☐ ☐ ☐ ☐

Importance 1 2 3 4 5	**B. Organisational infrastructure**	**Practice** 1 2 3 4 5
☐ ☐ ☐ ☐ ☐	Creation of cross-functional teams within the organisation	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	To have employees dedicated completely to Six Sigma deployment	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Facilitative leadership behaviour	☐ ☐ ☐ ☐ ☐

Importance 1 2 3 4 5	C. Cultural change	Practice 1 2 3 4 5
☐ ☐ ☐ ☐ ☐	Showing the difference between Six Sigma and other quality improvement initiatives	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Demonstrating the need for Six Sigma in terms of benefits to the employees	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Few status distinctions between managers and workers to create an open, highly empowered work environment	☐ ☐ ☐ ☐ ☐

Importance 1 2 3 4 5	D. Education and Training	Practice 1 2 3 4 5
☐ ☐ ☐ ☐ ☐	Application of the belt system throughout the company	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	To identify the key roles of the people directly involved in applying Six Sigma	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Training employees on how to use tools and techniques within Six Sigma	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Management attitude and action fully committed to educate and train people prior to Six Sigma implementation	☐ ☐ ☐ ☐ ☐

Importance 1 2 3 4 5	E. Vision and Plan statement	Practice 1 2 3 4 5
☐ ☐ ☐ ☐ ☐	Organisation has a clear long-term vision statement	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Statement communicated throughout the company and supported by employees	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Manufacturing operations effectively aligned to central business mission	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Written statement of strategic plans covering all manufacturing operations clearly articulated and agreed by senior management	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Employees at different levels involved in planning and policy making	☐ ☐ ☐ ☐ ☐

Importance 1 2 3 4 5	F. Linking Six Sigma to customers	Practice 1 2 3 4 5
☐ ☐ ☐ ☐ ☐	Identification of customer (internal/external) needs	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	To implement projects with high impact on customer satisfaction	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Understanding your market and evaluating it periodically	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	To have effective process in place to resolve external customer's complaint	☐ ☐ ☐ ☐ ☐

Importance 1 2 3 4 5	G. Linking Six Sigma to business strategy	Practice 1 2 3 4 5
☐ ☐ ☐ ☐ ☐	Financial appraisal of Six Sigma projects	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Target Six Sigma projects on improvements that have a direct impact on the financial and operational goals of the company	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Regular measurement of key financial & non-financial indicators of improvement in Six Sigma	☐ ☐ ☐ ☐ ☐

Importance 1 2 3 4 5	H. Linking Six Sigma to employees	Practice 1 2 3 4 5
☐ ☐ ☐ ☐ ☐	Employees empowered to take action whenever they encounter a problem likely to impact cost, quality, delivery, or /and input	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	To make Six Sigma training mandatory for promotion consideration	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	To award monetary bonuses to employees based on successful implementation of Six Sigma projects	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	To make every employee responsible for the detection of potential and actual problems	☐ ☐ ☐ ☐ ☐

Importance 1 2 3 4 5	I. Linking Six Sigma to suppliers	Practice 1 2 3 4 5
☐ ☐ ☐ ☐ ☐	To involve suppliers in Six Sigma projects	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	To have suppliers who have implemented Six Sigma	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	To establish effective two-way communication with suppliers	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	To have detailed information about supplier performance	☐ ☐ ☐ ☐ ☐

Importance 1 2 3 4 5	J. Communication	Practice 1 2 3 4 5
☐ ☐ ☐ ☐ ☐	Early and effective communication on the why and how of Six Sigma	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Major achievements stemming from Six Sigma implementation formally communicated and celebrated	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Information passing process such as team meetings and “state-of-the-business” regular part of work	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	To establish honest, open two-way communication between management and employees for proper functioning	☐ ☐ ☐ ☐ ☐

Importance 1 2 3 4 5	K. Understanding of Six Sigma methodology	Practice 1 2 3 4 5
☐ ☐ ☐ ☐ ☐	To understand fully all steps of the DMAIC/ DFSS/ DMEDI/ IDOV methodology	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	To adapt Six Sigma methodology to your organisation	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	To use simple tools and techniques during Six Sigma implementation	☐ ☐ ☐ ☐ ☐

Importance 1 2 3 4 5	L. Project management skills	Practice 1 2 3 4 5
☐ ☐ ☐ ☐ ☐	To develop project management skills	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	To establish a project score card	☐ ☐ ☐ ☐ ☐

Importance 1 2 3 4 5	M. Project prioritisation and selection	Practice 1 2 3 4 5
☐ ☐ ☐ ☐ ☐	Project selection based on financial returns	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Project prioritisation based on customer requirements	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Project selection focussed on poorly performing areas of the company	☐ ☐ ☐ ☐ ☐
☐ ☐ ☐ ☐ ☐	Project selection based on brainstorming session involving cross-functional team, suppliers, and customers	☐ ☐ ☐ ☐ ☐

Part IV. Results of Implementation of Six Sigma

1. **Organisational Performance**
   This section asks about the benefits that your organisation experienced following the implementation of Six Sigma in your business process(es). Please indicate (by writing a single number, ranging from one through to five, in the end column) your organisation performance level for each of the listed attributes.

Performance outcome	1	2	3	4	5	Score (1-5)
Customer Satisfaction	Sometimes meets expectations	Generally meet expectations	Consistently meets expectations	Always meet expectations	Expectation exceeded delighted customers	
Employee Morale	Very low	Low	Satisfactory	High	Very high	
Productivity	Decreasing	Static	Moderate Improvement	Consistently Improving	Major and Significant gains	
Defects reduction	< than 0.1%	0.1-10%	10.01-20%	20.01-30%	>30%	
Warranty claims cost as a % of total sales	> than 30% (Very poor)	20.01-30% (Poor)	10.01-20% (Satisfactory)	0.1-10% (Good)	< than 0.1% (Very good)	
Cost of Quality (error, scrap, rework and inspection) as a % of total sales	> than 30% (Very poor)	20.01-30% (Poor)	10.01-20% (Satisfactory)	0.1-10% (Good)	< than 0.1% (Very good)	
Delivery in full on time to our customer	< than 50%	50-80%	81-90%	91-96%	97-100%	
Inventory Reduction	< than 0.1%	0.1-10%	10.01-20%	20.01-30%	>30%	
Profit Improvement	<than 0.1%	0.1-10%	10.01-20%	20.01-30%	>30%	
Sales Improvement	< than 0.1%	0.1-10%	10.01-20%	20.01-30%	>30%	

2. Attitude

1	2	3	4	5
Strongly Disagree	Disagree	Neutral	Agree	Strongly agree

I. Employee Satisfaction	**1 2 3 4 5**
There is less absenteeism among staff	☐ ☐ ☐ ☐ ☐
There is lower staff turnover rate	☐ ☐ ☐ ☐ ☐
There is less grievances/complaints from the employee	☐ ☐ ☐ ☐ ☐
There is less request for transfer from the employee current position	☐ ☐ ☐ ☐ ☐
Employees doing the job properly because they are doing what they want to do	☐ ☐ ☐ ☐ ☐

II. Customer Satisfaction	**1 2 3 4 5**
The number of customer complaints is lesser	☐ ☐ ☐ ☐ ☐
The number of repeat customer has increased	☐ ☐ ☐ ☐ ☐

III. Organisation Commitment	**1 2 3 4 5**
Employees feel proud to tell people that they work for Company	☐ ☐ ☐ ☐ ☐
Employees feel themselves to be a part of Company	☐ ☐ ☐ ☐ ☐
Employees feel that they are making effort not only for themselves but for Company also	☐ ☐ ☐ ☐ ☐
Management empowering the employee with the necessary tools and techniques to enhance production processes	☐ ☐ ☐ ☐ ☐
Employees encourage their peers to participate in Six Sigma program	☐ ☐ ☐ ☐ ☐

IV. Job Involvement	**1 2 3 4 5**
Employees' contributions to the organisation economically acknowledged	☐ ☐ ☐ ☐ ☐
Employees identify the organisation goals as their own	☐ ☐ ☐ ☐ ☐
Employees believe that quality is their responsibility	☐ ☐ ☐ ☐ ☐
Employees proactively pursue Six Sigma	☐ ☐ ☐ ☐ ☐

V. Learning	**1 2 3 4 5**
Learning among employees encouraged by means of cross- functional team and implementing Six Sigma strategy	☐ ☐ ☐ ☐ ☐
Employees encouraged to learn the ways to enhance performance and work processes	☐ ☐ ☐ ☐ ☐
Employees encouraged to learn the ways to manage the collective objective and interests	☐ ☐ ☐ ☐ ☐
Employees' learning accelerated by company-wide training on Six Sigma	☐ ☐ ☐ ☐ ☐
Employees understand the purpose of Six Sigma implementation	☐ ☐ ☐ ☐ ☐

VI. Work Environment	**1 2 3 4 5**
Organisation have work sub-divided and established processes for the effective completion of work	☐ ☐ ☐ ☐ ☐
Employees have the feelings of a good working atmosphere	☐ ☐ ☐ ☐ ☐

Employees have the feeling of being valued members and belonging to the organization	☐ ☐ ☐ ☐ ☐
Employees being supported and helped by managers and other employees	☐ ☐ ☐ ☐ ☐
Employees understand the importance of company goals and performance standards	☐ ☐ ☐ ☐ ☐

3. What have been the three largest issues you have faced during Six Sigma implementation? (Tick up to 3 boxes that you consider are largest issues)

- ☐ Availability of resources
- ☐ Change of management
- ☐ Lack of tangible results
- ☐ Competing projects
- ☐ Changing business focus
- ☐ Poor training/coaching
- ☐ Unmanaged expectations
- ☐ Lack of leadership
- ☐ Low employee retention
- ☐ Internal resistance
- ☐ Poor project selection

4. What % of the company resources has been devoted to the implementation of Six Sigma?

- ☐ < than 1%
- ☐ 1-5 %
- ☐ 6-10%
- ☐ 11-15%
- ☐ > than 15%

5. Overall, how would you classify results of implementing Six Sigma in your Organisation?

- ☐ Poor
- ☐ Quite good
- ☐ Average
- ☐ Very good
- ☐ Excellent

6. How do you perceive the future of Six Sigma within your company?

- ☐ Growing in importance
- ☐ Becoming less important

Interview protocol for cases studies in chapter 3

Company data

- How many employees are working in this company?
- Is the company independent, or part of a larger organization?
- Can you give brief overview of the products of this company?

LSS organization

- Can you give an impression of the history of LSS in your organization? What were the reasons to embark, how did it develop?
- Can you give an overview of the kind of projects that are carried out (BB, GB, Kaizen,….)
- How are project-proposals generated, how are projects prioritised and selected, which functions have to play a role?
- Can you categorize the different projects by timeframe, financial results, ….?
- Does your company separate Six Sigma and Lean manufacturing projects, or not? What is your view on that, do you support integration or rather keep these projects separated?
- Do you recognise lean experts and Six Sigma experts in your company, or LSS experts?
- Can you give an overview about how many projects of different kinds are carried out over one year?
- What is the role of top-management in the deployment?
- What is your view on the future regarding LSS in your organization?
- What are the specific LSS-functions/ roles recognizable in your organisation?
- How is time allocation regulated for project leaders and team members?

Methods, tools and techniques

- Can you give a brief overview on the prescribed methods, tools and techniques applied in projects?
- Are there other methods, tools and techniques used occasionally? Can you give examples?
- Can you allocate the methods, tools and techniques to DMAIC project stages?

Critical Success Factors and Impeding factors

- What are the main factors critical for success, and what are the main impeding factors in your view?
- How do you deal with them, what are managerial measures connected to them?
- Have external agents played an important role in the deployment? If yes, when and how?

Results

- How are project-results measured in your organization? Financially? Or using other KPIs, please specify.
- What about the more general effects on the organization with respect to the ability to improve continuously?
- What are your expectations for the future regarding LSS?