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The implementation of Lean Six Sigma for operational excellence in digital emerging technology companies

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Abstract

Purpose – The purpose of this research is to develop a better understanding of the hurdles in implementing Lean Six Sigma (LSS) for operational excellence in digital emerging technology companies.

Design/methodology/approach – We have conducted case studies of LSS implementations in six US-based companies in the digital emerging technology industry.

Findings – Critical success factors (CSF) for LSS implementations in digital emerging technology companies are: (1) organizational leadership that is engaged to the implementation, (2) LSS methodology that is rebranded to fit existing shared values in the organization, (3) restructuring of the traditional LSS training program to include a more incremental, prioritized, on-the-job training approach and (4) a modified LSS project execution methodology that includes (a) condensing the phases and tools applied in LSS projects and (b) adopting more iterative project management methods compared to the standard phased LSS project approach.

Research limitations/implications – The qualitative nature of our analysis and the geographic coverage of our sample limit the generalizability of our findings.

Practical implications – Implications comprise the awareness and knowledge of critical success factors and LSS methodology modifications specifically relevant for digital emerging technology companies or companies that share similarities in terms of focus on product development, innovation and growth, such as R&D departments in high-tech manufacturing companies.

Originality/value – Research on industry-specific enablers for successful LSS implementation in the digital emerging technology industry is virtually absent. Our research informs practitioners on how to implement LSS in this and alike industries, and points to aspects of such implementations that are worthy of further attention from the academic community.

Keywords Six Sigma, Lean management, Digital technology, Implementation

Paper type Research paper

1. Introduction

In recent years, companies in digital technology industries have experienced rapid growth, due to among other reasons, the fast penetration of worldwide Internet availability. Digital technology companies are traditionally defined as "*businesses that provide a digital technical*

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service/ product/ platform/ hardware, or heavily rely on it, as its primary revenue source" (Tech Nation, 2016). The digital technology industry however comprises several categories, such as the development of software (12%), devices and infrastructure (23%), IT and business services (21%), telecom services (26%) and finally emerging technologies (19%) (CompTIA, 2020). Companies categorized under "emerging technologies" are, or for long have been, involved in technologies that span multiple categories, as is the case for most emerging as-a-service solutions that include elements of hardware, software and services, which currently comprises amongst others Internet of Things applications, experimentation with the use drones and many other recent automation technologies.

The consequence of the rapid growth in this industry is an entrepreneurial focus on product development, human resource attraction and retainment and financing needs to support further growth. When companies transcend the initial start- and scale-up phases and become established, public scrutiny will increase. Stakeholders from capital markets, governments and society will impose demands on profitability and internal efficiency, regulatory compliance and legitimate corporate conduct. Hence, the control and optimization of processes become more important. Strategies used by companies to adequately respond to such demands comprise a focus on operational excellence and by the implementation of well-known operational excellence methodologies such as Lean management and/or Six Sigma companies aim to eliminate operational inefficiencies and enhance operational control (Delgado *et al.*, 2010).

In recent years the Lean and Six Sigma methodologies are applied and studied as one (Shah *et al.*, 2008). Nevertheless, Lean Six Sigma (LSS) has a long history of development and was popularized in the production sector by companies such as Toyota, Motorola and General Electrics in the mid and late twentieth century (Shah *et al.*, 2008). Ever since, the methodology has been widely implemented in sectors such as finance, healthcare and public administration. Research on such implementations revealed that industry idiosyncrasies call for modifications of the methodology for effective implementation (Antony *et al.*, 2020; Sreedharan and Raju, 2016).

The digital emerging technology (DE-TECH) industry is rapidly growing both in size and importance for everyday societal lives. Broader information technology industry trends reveal that the portion of economic activity resulting from this sector is outgrowing traditional sectors such as retail, construction and transportation (CompTIA, 2020). In recent years, an increasing appetite for LSS implementation in DE-TECH companies is observed (PEX, 2019; McKinsey, 2014). However, the research on LSS implementation in this industry is virtually absent. In this research, we aim to develop a better understanding of the hurdles in implementing LSS for operational excellence in DE-TECH companies. We do so by (1) identifying the idiosyncrasies relevant for the implementation of LSS; (2) observing modifications of the LSS methodology in effective implementations and; (3) exploring the complementarities of data analytical capabilities that naturally exist in DE-TECH companies, with analytical techniques used in LSS implementations.

This paper presents the results from multiple case studies of companies in the DE-TECH industry that have commenced LSS implementation. Within- and cross-case analysis is performed based on in-depth semi-structured interviews with LSS implementation leaders and practitioners. First, this study explores critical success factors. We find prevalent critical success factors that have previously been identified in the literature, such as leadership that is engaged to the implementation, LSS methodology that is rebranded to fit existing shared values in the organization and finally a restructuring of the LSS training approach whereby a more incremental, prioritized, on-the-job training approach is applied. Other findings are newly identified, such as often seen modifications of the structured LSS project method by consolidation of specific phases or tools in LSS projects and the application of more iterative project management methods. We find limited complementarities and amendments to LSS's existing statistical toolbox and finally, implications for practice and future research are presented.

This paper is structured as follows. Section 2 reviews the literature and in Section 3 the research methods are described. In Section 4 the case study results are presented, the key topics that emerged from this research are discussed. Finally, in Section 5 concluding remarks, future research opportunities, implications for practice and limitations are articulated.

2. Literature review

To assure efficient, effective and consistent operations companies need to continuously invest in process improvement. A popular and widely applied methodology adopted by many organizations for process improvement is LSS, a combination of both the Lean management and Six Sigma methodologies (Shah *et al.*, 2008). Lean management originated from what was originally developed as the Toyota Production System by Toyota mid-twentieth century and was codified by authors such as Womack *et al.* (1990) and Spear and Bowen (1999) who tried to articulate its principles. In more recent literature, Lean management is defined as a coherent system of practices focused on the elimination of waste, and the practices of Lean management pertain to just-in-time production, quality management, preventive maintenance and human resources management (Shah and Ward, 2003). Six Sigma has been widely embraced since its origination at Motorola corporation mid-1980 and many books have been devoted to describing the methodology. Six Sigma methodology is strongly focused on defects and variability reduction in business processes and is an organized and systematic method for process improvement that relies on statistical methods and the scientific method to make significant improvements (Linderman *et al.*, 2003). The systematic method is the project structure that is managed according to the five-phased define, measure, analyze, improve and control (DMAIC) cycle (Zu *et al.*, 2008).

Scholarly attention has focused on explaining the critical success factors (CSFs) for successfully implementing such LSS projects. Known success factors for LSS projects are for instance the application of structured methods (Schroeder *et al.*, 2008), perceived psychological safety (Choo *et al.*, 2007a), challenging objectives to drive knowledge creation and innovation (Linderman *et al.* 2006) and project team member coaching (Hagen, 2010). Subsequently research emerged that investigated success factors in the context of LSS projects (e.g. Hilton and Sohal, 2012). Prior research has provided extensive reviews of the CSFs for LSS and alike improvement programs (e.g. see Netland, 2016; Raval *et al.*, 2018). For LSS, Sreedharan *et al.* (2018) have recently reviewed the body of research and concluded that the ten CSFs for implementing Lean, Six Sigma or Lean Six Sigma mostly named are: top management commitment and support for projects; training and education; organization wide communication; customer focus in project objectives; a focus on organizational culture transformation; the involvement of employees, improvement specialists and suppliers in projects; structured approaches to project execution and the usage of statistical tools and techniques; and finally an organizational infrastructure that allows for a clear link of LSS projects to business strategy.

2.1 Industry contingent critical success factors for Lean Six Sigma project implementation

Later research revealed that success factors for the implementation of LSS projects are contingent on the context or industry in which such LSS projects are implemented (Sousa and Voss, 2008). Apart from manufacturing, LSS is increasingly applied and researched in other industries such as finance, higher education, public administration, healthcare and IT services. Sreedharan and Raju (2016) present an overview of the research on LSS implementation and conclude that most of the research stems from the manufacturing (40%) and service sector (35%), in which healthcare services (15%), IT services (10%) and financial services (7%) are the most researched industries.

When looking at the research on service-industry-specific idiosyncratic factors we find that in healthcare factors such as the incentives stemming from laws and regulations, the predominant non-monetary nature of LSS project objectives and the aversion of medical staff to statistical problem-solving techniques should be accounted for when implementing LSS (Chiarini and Bracci, 2013). Other healthcare specific difficulties are the ability to measure and the availability of data (Taner *et al.*, 2007), the suitability of specific statistical techniques (Van den Heuvel *et al.*, 2006) and the specific need for buy-in and support from physicians (Langabeer *et al.*, 2009). For the financial sector the need to actively facilitate an entrepreneurial culture for LSS to succeed (Delgado *et al.*, 2010) or at least a company culture that is compatible with the LSS mindset (Heckl *et al.*, 2010), and the intangibility of most processes, the invisibility of production flows and high involvement of customers in value delivery processes (De Koning *et al.*, 2008) are reported. Research on LSS implementation from the digital technology sector does not specifically report on idiosyncrasies for LSS implementation, but predominantly addresses approaches for software development using Lean management (Wang *et al.*, 2012; Ghane, 2014).

Looking at the digital technology industry reveals a growing economic importance. The total economic activity in the global digital technology industry is estimated at $5.2 trillion annually, and the portion of gross domestic product resulting from this industry in respectively the US (32%), the EU (20%) and China (14%) already exceeds that of other industries such as retail, construction and transportation (CompTIA, 2020). The industry comprises several categories and most of the industries' growth in the past years originated from the emerging technologies category (CompTIA, 2020) and therefore, the focus of this research is on companies in this category. Looking at the DE-TECH industry reveals a dynamic nature. Companies in this industry are confronted with continuous business model innovation and ever-expanding competitive landscapes, intensive merger- and acquisitions activity and a relatively young and mobile workforce (CompTIA, 2020). CompTIA (2020) observed in their 2021 industry outlook that "digital technology and the business of selling it has grown exponentially more complex in recent years." Taken together we argue companies in this sector are confronted with many management challenges. That raises questions about idiosyncrasies of the DE-TECH sector, that are specifically relevant for successfully implementing LSS projects in such dynamic business environments.

RQ1. What are industry contingent critical success factors for LSS implementation in digital emerging technology companies?

Identification of industry contingent success factors allows for an analysis of what makes LSS implementation in the DE-TECH industry unique. To understand what consequent amendments are needed a detailed definition of LSS implementation is required. Prior research on LSS implementation by Schroeder *et al.* (2008) distilled three unique elements that discriminate LSS from other quality management disciplines. First, the parallel meso-structure that entails the creation of separate teams led by senior project leaders and supported by organizational champions who focus on improving the organization. In this parallel organization, formal mechanisms to select projects with strategic impact are developed and organizational leadership involvement is assured. Second is the training and deployment of dedicated improvement specialists that have a full-time dedication to LSS projects. Third is the use of a structured project method, the DMAIC cycle. This structured project method is aimed at using specific customer-oriented and financial performance metrics and is one of the well-known manifestations of the scientific method applied to problem solving. Predecessors of this structured approach are W. Edward Deming's Plan-

Do-Study–Act cycle, based on Walter A. Shewhart's Shewhart Cycle (Moen and Norman, 2009). Core in these structured approaches to quality improvement is the element of learning by inspecting, or checking, whether solutions that intended to solve the problem indeed did so. Additionally the DMAIC structure is sometimes extended to DMAICL, where the latter addition stands for "learn", i.e. making sure that lessons learned from the project are captured and shared for subsequent improvement projects (Hayler and Nichols, 2005). De Koning and De Mast (2006) and De Mast and Lokkerbol (2012) further rationalized and detailed the subsequent steps of the DMAIC project structure (Table 1).

Our hypothesis is that industry specific contingency factors will affect how to effectively implement LSS projects in the DE-TECH industry. This holds that amendments to the structured LSS project method are expected, leading to the following research question.

RQ2. What modifications of the structured LSS project methodology are needed for effective implementation in digital emerging technology companies?

2.2 Lean Six Sigma analytical methodology

The purpose of LSS projects is to understand and solve complex and unstructured problems by collecting and analyzing data (De Mast and Lokkerbol, 2012). The act of LSS project execution is centered around statistical techniques, specifically applied to the problem at

Phase	Deliverables
Define: problem selection and benefit analysis	
	D1. Identify and map relevant processes
	D2. Identify stakeholders
	D3. Determine and prioritize customer needs and requirements (e.g. problem statement, project scope, goals and objectives, project performance measurements)
	D4. Make a business case for the project
Measure: translation of the problem into a measurable form, and measurement of the current situation; refined definition of objectives	
	M1. Select one or more critical to quality metrics (CTQ's or dependent variables)
	M2. Determine operational definitions for CTQ's and requirements (sampling, data collection plan)
	M3. Validate measurement systems of the CTQ's (metrology)
	M4. Assess the current process capability (descriptive statistics, graphical methods, distribution identification, process capability analysis, transformation techniques)
	M5. Define objectives
Analyze: identification of influence factors and causes that determine the CTQs' behavior	
	A1. Identify potential influence factors
	A2. Select the vital few influence factors (hypothesis testing, failure mode and affect analysis, circumstantial analysis methods)
Improve: design and implementation of adjustments to the process to improve performance of the CTQ's	
	I1. Quantify relationships between influence factors and CTQ's (correlations, linear regression, multivariate tools)
	I2. Design actions to modify the process or settings of influence factors in such a way that the CTQ's are optimized (design of experiments)
	I3. Conduct pilot test of improvement actions
Control: empirical verification of the project's results and adjustment of the process management and control system in order that improvements are sustainable	
	C1. Determine the new process capability
	C2. Implement control plans (statistical process control, total productive maintenance, visual controls, activities to sustain improvements)

Table 1. Rational reconstruction of the DMAIC procedure, after De Koning and De Mast (2006)

hand. The domain of data analytics however is broader and hence needs definition. The use of data analytics emerged in the 1950s and started with limited data sources from internal systems, with data being stored in a repository or data warehouse (Davenport, 2014). Most applications of data analytics were descriptive and were aimed at reporting and decision support, known as business analytics or business intelligence (Bartlett, 2013). Early 2000 the concept of Big Data (defined by Megahed and Jones-Farmer (2015) as data that is high in velocity, volume and variety) emerged when digital technology companies started using Big Data for internal- and customer-behavioral analytics. The velocity of Big Data required data to be stored and processed more quickly. Predictive and prescriptive analytics emerged and specific algorithms were developed to discover patterns in data, also known as data mining (Fayyad *et al.*, 1996). Nevertheless, visual analytics of descriptive data remained prevalent (Davenport, 2014). With the emergence of Big Data, the domain of data analytics evolved: data had to be turned into information fast for analysis, more focus on prescriptive and predictive analysis that utilizes machine learning techniques emerged and "fast analytics" through visualization became more important (Jarr, 2015). For the implementation of data analytics projects industry standards emerged, such as the Cross Industry Standard Process for Data Mining (CRISP-DM) (Azevedo and Santos, 2008). Unique to this framework is that iteration between phases exist and earlier research has investigated cases whereby LSS project methodology is complemented by existing data analytics methodology in the financial services sector (Zwetsloot *et al.*, 2018).

DE-TECH companies heavily rely on capturing, managing and analyzing data, and the capabilities needed for this are fundamental to the dominant business models in this industry. To identify where specific data analytics methodology complements LSS methodology a more specific understanding of the statistical techniques natural to LSS is needed. The American Society for Quality (ASQ) provides a thorough industry standard overview of statistical techniques that LSS practitioners need to master, known as the body of knowledge (ASQ, 2019) (Table 2). One of the objectives of this research is to determine what and how existing data analytics applications are applied in LSS projects, and how these complement or replace LSS statistical techniques.

RQ3. What, and how can, data analytics applications complement traditional LSS analytical methodology for digital emerging technology companies?

3. Research methodology

The topic of LSS implementation is not novel and would not justify exploratory research methods. The implementation in an under-researched industry and exploration of synergies between adjacent improvement methodologies especially present in that industry however does justify exploratory research, as we are seeking to "uncover areas for further research and theory development" (Voss *et al.*, 2002). The implementation of LSS in DE-TECH industries is recent and at an early stage. The benefit of case study research for our research questions is that more "exploratory depth" is enabled, allowing for more elaborate and in-depth investigation of the relations between LSS and the implementation of it in our industry of study (Yin, 2017). The multi case study approach allows for comparison of differences and similarities between the companies that operate in the same industry. As unit of analysis we have adopted the level of individual LSS programs (cases) that are being deployed in the companies of study. Via a process of within- and cross-case analysis a distinction is made between organization-specific and generic findings (Eisenhardt and Graebner, 2007).

Despite the benefits of case study research, we do acknowledge its flaws especially in providing objectivity and accuracy due to the central role of the researcher's interpretation of

Table 2.
Overview of LSS statistical analytical techniques (ASQ, 2019)

Phase	Statistical techniques
Define	(1) Data collection methods (surveys, focus groups, interviews, observations)
	(2) Analytical tools (affinity diagrams, tree diagrams, matrix diagrams, prioritization matrices, activity network diagrams)
Measure	(3) Process analysis methods (value stream maps, process maps, work instructions, flowcharts, spaghetti diagrams, circle diagrams, Gemba studies)
	(4) Data collection methods (sampling, data collection methods)
	(5) Measurement system analysis (gauge repeatability and reproducibility studies and other MSA tools)
	(6) Probability analysis methods (distribution identification)
	(7) Process capability analysis methods (for normal and non-normal data)
Analyze	(8) Measuring and modeling relationships (correlation, linear regression, multivariate regression)
	(9) Hypothesis testing (errors, power, significance, confidence and prediction intervals, test for means and variances, analysis of variance, goodness of fit tests, nonparametric tests)
Improve	(10) Design of experiments (design principles, one-factor, two-level fractional factorial, full factorial)
Control	(11) Statistical process control (control chart analysis)

the data. Qualitatively obtaining data from multiple cases poses an inherent vulnerability as data collection methods are subject to researcher biases (Patton and Appelbaum, 2003). The strategy to mitigate these vulnerabilities is for one the design of a systematic approach to collection and documentation of data, and secondly the application of triangulation methods. The procedure for triangulation comprised the collection of data from several sources and assessment as to whether this supported conclusions (Miles and Huberman, 1994). For an overview of the research protocol development and consecutive data analysis see Figure 1.

3.1 Data collection method

The data was collected by semi-structured interviews using open question interview protocols. The interviews were held with senior LSS implementation leaders and senior LSS practitioners who are involved in the implementations. The open question interview protocols comprised two parts and are available as Appendix:

(1) Factual protocol for obtaining general company data and information about the implementation (e.g. duration, reasons, scale, number of projects, areas or functions where projects were carried out, perceived benefits)

(2) Protocol for the research questions covering several topics including the process of implementing LSS, the challenges encountered in this process and the mitigation strategies applied, key learnings on LSS methodology implementation and finally key learnings on data gathering, handling and analysis in LSS implementation processes.

The interview protocols were piloted by interviews with three people from one organization holding both practitioner and managerial roles, which led to revision and improvement of the protocol. Next to the interviews existing archival data was requested and reviewed. Examples include formal status reports, newsletters and executive meeting documentation. Observations related to questions in the interview protocols were documented in the database and labeled as an additional source. A total of 11 LSS implementation leaders (Master Black Belts) and practitioners (Black Belts) with extensive experience in LSS implementation in the DE-TECH industry were interviewed. The interviewers took elaborate notes and subsequently transcribed and coded the interview data in a three step fashion as proposed by Strauss and Corbin (1990) and Voss *et al.* (2002):

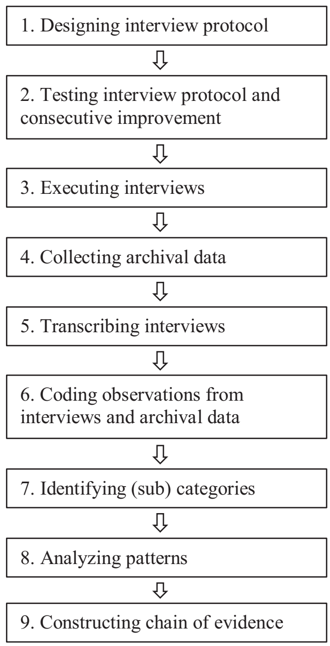

Figure 1. Research protocol development and data analysis process

(1) Open coding: individual observations were labeled and grouped in sub-categories.

(2) Axial coding: these subcategories were then rationally linked to higher level categories.

(3) Selective coding: the categories were linked to other (sub) categories to identify relations.

The coded information was stored in a spreadsheet database to allow for accurate and imitable data analysis (Yin, 2017). This process of data analysis led to the identification of core- and subcategories within the interview data related to each of the research questions. Subsequent content analysis lead to the identification of patterns related to our research questions. Thereby a chain of evidence was constructed for the analysis as presented in this paper. Data triangulation was performed by comparing and validating observations from at least two interviews or from interviewees in different organizational roles (level of LSS practitioner – experience and responsibility) where possible.

3.2 Case presentation

Data collection was performed from October 2019 to March 2020, in the United States San Francisco bay area. Table 3 presents a summary of the six involved companies from the DE-TECH industry that implemented LSS programs. The companies are all involved in Internet-based digital emerging technologies, aimed at consumers and businesses.

The average age of the companies in our sample is 22.5 years. Company sizes vary from \$1.3 billion to \$136.3 billion in annual revenues and from 2,300 to 145,000 employees. The duration of the LSS implementations in the studied companies ranges from less than a year to 17 years for program E1. For company A and D their LSS programs were studied separately as these were concurrently executed but managed separately (i.e. differed in

Table 3.
Presentation of the case study companies

Company	A	B	C	D	E	F
Company characteristics						
Age[a]	20 years	36 years	13 years	21 years	35 years	10 years
Revenue[b]	$18	$78	$1.5	$136.3	$49.3	$1.3
Employees[c]	35,000	145,000	2,300	99,700	77,700	19,000
Main industry focus	IT software	IT hardware	IT software	IT soft- and hardware	IT soft- and hardware	IT software
LSS programs and durations[d]	(1) A1 (4 years) (2) A2 (2 years)	(1) B1 (10 years)	(1) C1 (<1 year)	(1) D1 (<1 year) (2) D2 (<1 year) (3) D3 (9 years)	(1) E1 (17 years)	(1) F1 (4 years)
LSS trained practitioners associated to LSS programs[e]	(1) 65 GB's (2) 1 BB's (3) 3 MBB's	(1) 1000 YB's	(1) 5 GB's (2) 1 BB (3) 1 MBB	(1) 80 GB's (2) 3 BB's	(1) 3 BB's	(1) 300 YB (2) 92 GB (3) 4 BB (4) 3 MBB
Interviewee characteristics						
Respondent roles and LSS experience[d]	(1) 1 BB (8 years) (2) 1 BB (15 years) (3) 2 MBB (12–18 years[f])	(1) 1 MBB (18 years[f])	(1) 1 BB (13 years)	(1) 1 BB (15 years) (2) 1 BB (19 years[g]) (3) 1 MBB (22 years)	(1) 1 BB (19 years) (2) 1 BB (19 years[g])	(1) 1 BB (7 years) (2) 1 MBB (20 years)
Respondent prior industry experience	(1) Digital technology (2) Manufacturing (3) Finance (4) Healthcare (5) Professional Services (6) Oil and gas	(1) Manufacturing	(1) Digital technology (2) Healthcare	(1) Digital technology (2) Manufacturing (3) Finance	(1) Digital technology	(1) Digital technology (2) Manufacturing (3) Finance (4) Wholesale

(*continued*)

Table 3.

Company	A	B	C	D	E	F
LSS implementation characteristics						
Rationale for LSS implementation	(1) Cost reduction (2) Improved process management (3) Process automation	(1) Employee development	(1) Cost reduction (2) Employee development	(1) Cost reduction (2) Improved process management (3) Improved customer satisfaction	(1) Cost reduction (2) Improved process management	(1) Cost reduction (2) Improved customer satisfaction (3) Process automation
Perceived results of LSS implementation	(1) Cost reduction (2) Results unclear (3) Several process related improvement	(1) Results not tracked	(1) No aggregate insight in results yet	(1) No aggregate insight in results yet for programs D1 and D2 (2) Increased customer satisfaction and efficiency for program D3	(1) Cost reduction (2) Quality improvement (3) Employee development	(1) Cost reduction (2) Variation reduction (3) No aggregate insight in results yet

Note(s): [a]In years, [b]In billion $ over 2018, [c]Reported in the 2018 annual reports, [d]In years per January 1, 2020, [e]Reported by corresponding program management leaders, [f,g]These practitioners held experience in multiple companies and were therefore interviewed twice, each time for a different company leadership, rationale, scope, format and staffing). For each company and their separate programs, practitioners who were involved have participated in the research. From these companies, a total of 11 LSS practitioners with an average experience of 15.3 years were interviewed. Four hold LSS Master Black Belt (MBB) and seven hold LSS Black Belt (BB) certifications. Also, the average duration of the LSS implementation programs in our sample (5.5 years) means that most participants have gained their experience in other industries, predominantly being Digital Technology, Manufacturing, Finance and Healthcare before becoming involved in the DE-TECH industry.

Strategic rationales for implementing LSS in the companies of study varies, with cost reduction as the prevalent reason (mentioned by interviewees in five of the six case-companies). Cost reduction is a commonly found rationale for LSS implementation (Vashishth *et al.*, 2019), and here cost reduction was often related to the need to scale operations efficiently as the company continued to grow. Secondly the improvement of process management as organizational function was mentioned most, followed by customer satisfaction improvement. Apart from cost reduction, different categories of perceived results are reported. In two out of the six companies results are not tracked or there is no aggregate insight in the benefits that the LSS implementations have yielded so far.

4. Results and discussion

Per research question the empirical findings and results are presented and discussed. In each section future research directions are discussed when appropriate.

4.1 Industry contingent critical success factors for Lean Six Sigma implementation

Prevalent CSF's for LSS projects in DE-TECH companies are organizational leadership that is engaged to the implementation, LSS methodology that is rebranded to fit existing shared values in the organization and finally a restructuring of the traditional LSS training program whereby the amount time spent on physical training is reduced and replaced by on-the-job training. An overview of research findings for the first research question, being industry-specific challenges to LSS implementation, the solutions that have been applied by the interviewees and finally the acknowledged underlying critical success factors that were considered to be pivotal in adequately responding to the challenges are presented in Table 4.

4.1.1 The need for engaged leadership. The most acknowledged CSF is engaged leadership (A1, A2, B1, D3, E1, F1), manifested by among others a mandate for implementation from senior management, active participation of senior management in steering committees and the appointment of dedicated resources for the implementation. The CSFs importance is rooted in several industry-specific challenges.

First, many LSS programs (A1, A2, C1, D2) acknowledged that the sector's fast paced nature makes that business priorities quickly change (e.g. quarterly). Completing a medium to high impact project just as quickly, i.e. before business needs change, was considered challenging. For example (A1) "*. . .*in Silicon Valley, efficient operations is not a priority but an afterthought; culturally, the focus is on product innovation and on growth. In addition, digital technology trained employees typically lack the knowledge and understanding of Operational Excellence methods, and are typically working in silos, thereby limiting their understanding of the end-to-end processes they are part of". Second, central core-teams that oversee and coordinate the LSS implementation had difficulty with delegating the ownership of process improvement projects to process owners (A2, F1). In similar fashion little appetite from process owners to request core-teams to support or lead process improvement efforts was observed. As stated (A2, E1, F1): "asking help from the LSS core-teams" was perceived as

LSS program	Industry-specific challenges to LSS implementation	Solutions for challenges to LSS implementation	Critical success factors for LSS implementation
A1	(1) Fast paced environment (2) Low operational excellence awareness and maturity (3) Poor reputation of LSS (outdated) (4) Little industry-specific challenges exist	(1) Adapting to organizational needs (flexibility) (2) Selecting LSS trainees carefully (3) Providing LSS career paths (4) Reframing the LSS approach (5) Rebranding the LSS approach	(1) Engaged leadership (2) Rebranded LSS methodology (3) Reduction in training days (4) Dedicated central core-team
A2	(1) Fast paced environment (2) Push for project execution by central organizations	(1) Adapting to organizational needs (flexibility) (2) Partnering with proponent leaders (3) Focusing on quick-win projects (4) Creating broad awareness (5) Reframing the LSS approach (6) Deploying experienced LSS practitioners	(1) Engaged leadership (2) Committed subject matter expertise (3) Dedicated coaching
B1	(1) Little industry-specific challenges exist	(1) Rebranding the LSS approach (2) Selecting LSS trainees carefully	(1) Engaged leadership (2) Reduction in training days
C1	(1) Fast paced environment	(1) Reframing the LSS approach (2) Creating broad awareness (3) Selecting LSS trainees carefully	
D1	(1) Low operational excellence awareness and maturity	(1) Reframing the LSS approach (2) Deliberated project selection	
D2	(1) Fast paced environment	(1) Creating broad awareness	(1) Rebranded LSS methodology (2) Dedicated coaching
D3	(1) Low operational excellence awareness and maturity	(1) Reframing the LSS approach (2) Deliberated project selection	(1) Engaged leadership (2) Motivated trainees

(*continued*)

Table 4.
Industry-specific challenges, solutions and critical success factors

LSS program	Industry-specific challenges to LSS implementation	Solutions for challenges to LSS implementation	Critical success factors for LSS implementation
E1	(1) Low operational excellence awareness and maturity (2) Bias towards technological solutions	(1) Reframing the LSS approach (2) Deliberated project selection (3) Identifying process owners	(1) Engaged leadership
F1	(1) Poor reputation of LSS (outdated) (2) Push for project execution by central organizations	(1) Reframing the LSS approach (2) Creating broad awareness (3) Rebranding the LSS approach	(1) Engaged leadership (2) Dedicated coaching (3) Motivated trainees (4) Aligned LSS project objectives with organization

Table 4.

introducing "paralysis by analysis", "DMAIC feels like red-tape". Premier causes for these challenges are a strong company-wide external and innovation-driven focus. Development of new products and achieving company growth consistently trumped improvement of processes and maintaining efficient operations. To overcome these challenges dedicated and prolonged leadership support proved to be pivotal, or as several respondents argued: "having had results-oriented and dedicated project sponsors proved to be pivotal in securing motivated and knowledgeable project team members, which lead to ultimate project success" (F1) and "having had managers that were supportive was a major success factor, as they allowed resources the time to work on their improvement projects" (D3).

In case of insufficient leadership engagement, deliberated project selection was mentioned by several programs (A2, D1, D2, D3) as an adequate solution: these programs decided to only train and coach LSS trainees with projects earmarked as high priority for their teams (i.e. directly related to team annual or quarterly objectives). For example, programs A2 and D2 asked project leads and champions to clearly show how the business impact of the project ties back to the team's yearly and quarterly goals. Thereby, availability of project support resources and leadership engagement could be secured. An additional strategy to mitigate the risk of insufficient engagement is to partner first with leaders who see value in LSS implementation and together create success stories. For example: "by making sure that the LSS projects are directly linked to quarterly business objectives, managers were able to commit to the implementation" (F1). Thereby the interest of unconvinced leaders elsewhere in the organization was obtained. Finally, to mitigate the risk of obsolescence due to fast changing business priorities several programs (A2 and D2) scoped projects using Agile Scrum's minimum viable product (MVP) concept (Schwaber and Sutherland, 2017). The MVP approach applied to LSS projects helps teams to spilt LSS projects in multiple phases to progressively solve the highest priority process problems. For example F1 and A2 respondents mentioned "the identification of quick wins (solutions) in a project while continue working on the meaty root causes that will lead to long-term solutions proved to be helpful in securing buy in from managers" and "leaders do not want to commit their resources on long training programs with untested benefits".

4.1.2 Discussion of the need for engaged leadership. In conclusion, engaged leadership appeared to be of utmost importance for LSS implementation, thereby corroborating prior researches on the topic (Kwak and Anbari, 2006; Saad *et al.*, 2006; Panizzolo *et al.*, 2012; Laureani and Antony, 2012). For the DE-TECH industry specifically, management commitment is needed to (1) make and keep LSS implementation priority in the dynamic business environment and (2) keep emphasizing the importance of internal process improvement over external business development. The underlying challenge that committed management ought to address is to maintain focus on exploitation (by means of effective and efficient operations), over exploration (new business development), also known as ambidexterity (O'Reilly and Tushman, 2013). An important concept related to this challenge is that of motivation to engage in LSS application (Anand *et al.*, 2009), especially in an environment where process optimization is important but is not perceived as such by the majority of the workforce. The scope of future research should include questions of motivation for LSS application and adoption, especially for companies that are in fast growing and in dynamic business environments. Prior research on entrepreneurial start-up processes synthesized how entrepreneurial values and convictions are important and dominant in early phases of company growth (Estay *et al.*, 2013). At a certain moment a more professional approach to managing the internal organization is demanded by various forces. A better understanding when and how this balance needs to be achieved has important implications for practice.

4.1.3 Altering Lean Six Sigma's name and training approach. Rebranding of LSS and offering an incremental, prioritized, on-the-job training approach are the second most recognized CSFs (A1, B1, D2). Programs A1 and D2 changed the name of the methodology and its phased approach. Instead of LSS and the "DMAIC" phases, these programs adopted a name that was better aligned to their corporate identity (i.e. Process Innovation Program, Process Design Program, Define-Understand-Solve). The methodology was renamed, phases were merged and/or renamed (i.e. Measure and Analyze were executed as one phase (C1), or (F1) while the Define phase was mandatory, the Measure, Analyze and Improve phase were organized in an iterative fashion), and the traditional (i.e. Green–or Black Belt) certification was replaced by one Green Belt equivalent certification. Programs A1 and B1 credited success of their LSS implementation to reducing the number of days for entry-level (i.e. Green Belt equivalent) LSS training from 10 to 3 days. Lowering the number of training days from 10 to 3 made the Green Belt classroom training more accessible. What were considered to be the most useful skills and tools for that moment was taught (also referred to as a "light-shade of Green Belt"). Several tools such as Gage Repeatability and Reproducibility, 5S, Value Stream Map, Failure Mode and Effect Analysis, Hypothesis Testing, Regression Analysis and Statistical Process Control were excluded from the curriculum. The core of the 3 days curriculum focused on the tools of the Define phase: project charter, Voice of the Customer, SIPOC, Process Maps. For the Measure phase the focus was on measuring Process Capability and graphical analyses such as pareto-charts. For the Analyze phase, the emphasis was on Root Cause Analysis, 5-Why and for the Improve phase the emphasis was in brainstorming techniques, solution prioritization tools such as the Pugh Matrix. Programs (A2 and D2) compensated the shorter training period with dedicated weekly one-on-one coaching during project execution by an experienced LSS MBB practitioner, wherein the yet uncovered tools and techniques were discussed when relevant.

The importance of these CSFs was recognized while responding to several industry-specific challenges. First was the perception of the LSS methodology by company staff as an old methodology that was used by traditional manufacturing companies, which implied traditional methods of doing business that do not fit the fast paced and innovative culture of the DE-TECH sector (A1, F1). For example (F1): "applying a methodology that was popularized 3 decades ago, for that you have to be creative on how to teach that so that it relates to the service processes we are working in". As a solution LSS was rebranded and reframed (A1, A2, B1, C1, D1, E1, F1). Similarly, several programs decided to reframe LSS to fit company culture (A1, A2, C1, D1, D2, D3, E1, F1). Reframing comprised being less rigid in the application of the LSS methodology (e.g. replace LSS jargon and alleviate the project structure) and incorporate concepts, methods and tools from adjacent methodologies, such as

Agile Scrum (Schwaber and Sutherland, 2017) and Design Thinking (Liedtka, 2018). For example for F1 where the DMAIC became an iterative approach: “the Define phase is on its own, but the M, A, and I phases are iteratively based on highest priority subproblems”. Another solution to the reputational problem was to encourage the application of the most relevant tools for the problem at hand (such as process mapping, root cause analysis) in isolation and not as part of the project framework, to advance the problem solving (A1, A2).

The second challenge of interest is the reported lack of operational excellence maturity and process management understanding (A1, D1, D3, E1). For example (A1): “there is a lack of alignment at the top level on who is responsible for improving what. Getting people to work cross functionally is difficult and there is little alignment of who does what and when in end-to-end processes”. To overcome this challenge, creating a broad awareness about the rebranded and reframed LSS methodology was mentioned. Pivotal in this approach was the display of implemented high-impact and low-effort solutions (quick wins) to show that LSS projects can be swift and adequate. For instance, LSS projects were scoped following the concept of the Minimum Viable Product approach used in Agile Scrum. The Minimum Viable Product approach is defined as “a version of a new product, which allows a team to collect the maximum amount of validated learning about customers with the least effort” (Ries, 2011). In the context of LSS project scoping this entailed a focus on quick win high-impact low-effort projects. By doing so, the LSS program gained credibility in the short term and created confidence needed to tackle more complex problems. Additionally, the hiring of experienced operational excellence core-teams to manage and execute the LSS program was named. These teams then took responsibility over, among others, building process management understanding by carefully selecting LSS trainees and providing career paths (promotion to more senior roles) to these newly selected operational excellence professionals. Thereby, an incentive to complete projects and gradually expand operational excellence knowledge and expertise in the companies was installed.

4.1.4 Discussion of altering Lean Six Sigma’s name and training approach. To conclude both rebranding LSS and offering incremental, prioritized, on-the-job training appeared to be highly important CSFs for ultimate acceptance and adoption, thereby corroborating the notion that outside practices and methodologies can be altered and adjusted to the companies’ idiosyncrasies in the process of diffusion (Ansari *et al.*, 2010). Earlier research examined the relation between the rhetoric and the reality of total quality management (TQM) (Zbaracki, 1998) and Lean (Langstrand and Drotz, 2016; Netland and Aspelund, 2013) implementation and revealed how these methodologies were differently diffused in different companies. Ansari *et al.* (2010) showed how practices are subject to adaptation in the process of implementation based upon how these *fit* with the existing organization. Different types of fit are acknowledged, and in our case cultural *misfit* seems to be applicable: LSS’s name, reputation and arrangement does not fit well with existing norms and values, something which if not managed is known to increase chances for failure of the LSS initiative (Bhasin, 2013; McLean *et al.*, 2017). In response, implementation leaders can choose to alter the methodology. Altering the methodology has risks on both sides. Too much alteration may result in deterioration of the methodology (and its potential benefits), too little alteration might spark active resistance or passive indifference among employees. Future research should explore this tension between rigidity and flexibility, and the associated risks, regarding LSS implementation, not necessarily only for the DE-TECH industry. Developing a better understanding of when and how to allow for amendments and preference-based disregards in LSS methodology diffusion processes has important practical implications.

4.1.5 Discussion of remaining identified CSF’s. Finally, the remaining CSFs were mentioned once and are acknowledged by existing research, being committed subject matter expertise in projects (Kappelman *et al.*, 2006; Jurburg *et al.*, 2017), dedicated central core-teams (Schroeder *et al.*, 2008; Lameijer *et al.*, 2020), motivated LSS trainees (Anand *et al.*, 2009) and LSS project objectives that are aligned with the organizational goals (Laureani and Antony, 2018).

4.2 Modifications of the structured LSS project method

An overview of the results for the second research question, being insight in the adherence to the traditional and structured LSS project method and the modifications deemed necessary for this industry by the interviewees is presented in Table 5. Often seen modifications of the structured LSS project method are consolidation of specific phases or tools in LSS projects and the application of more iterative project management methods.

4.2.1 High adherence to the LSS project method. High adherence to the traditional LSS project structure was reported most (A1, A2, C1, F1). In these cases the traditional DMAIC approach is widely adopted and applied. Even when quick results are needed, adherence to the traditional structure remains. For instance, program F1 applied the Kaizen approach; teams gather for three to five consecutive days and work on a process problem following the DMAIC structure. Programs A1 and A2 reported a high adherence with the traditional LSS DMAIC approach in their training curriculum and application in projects in between the Yellow Belt or Green Belt level. Both programs noted that the use of inferential statistics was not emphasized since these programs were intended to create awareness of LSS methods at entry level. The intended result of this approach is to identify employees who will show interest in further developing their skills at the Black Belt level where more emphasis in the LSS statistical methods will be emphasized. In the case of high adherence, other methods, such as Design Thinking, Agile Scrum and Business Architecture are integrated. For example (E1): "we merged business architecture methodology with LSS. Business architecture helps to identify all the capabilities that an organization is missing, but it does not have the improvement concepts of voice of the customer and measurement of business outcomes." In addition, after the conclusion of each phase these programs have implemented a brief lessons learned or retrospective exercise for each project (C1) in accordance with the DMAICL approach (Hayler and Nichols, 2005). Also, an iterative application of measure, analyze and improve phases, following Agile Scrum principles, was applied. For example, opportunities to improve a process are identified, prioritized, and treated independently. After root causes and solutions for the first opportunity are understood and implemented, the approach is repeated for the next opportunity. This approach is based on Agile Scrum's minimum viable product (MVP) concept (Schwaber and Sutherland, 2017), an iterative approach to gradually add and test functionality of a product, that was applied to process improvement.

4.2.2 Medium adherence to the LSS project method. Programs describing their adherence to the traditional LSS project structure as medium (A1, A2, B1) stated that most of the projects focus specifically on process mapping (B1) or had little to no emphasis on inferential statistics (A1, A2, B1), no clear scope definition in the define phase (A2, D3) and had no tollgates after phase-completion (A2; implemented several informal checkpoints throughout the project). Premier reasons for medium adherence comprise the need to balance the LSS methodology with the company's fast changing business priorities and the preference to "fail fast and learn" over exhaustive and time-consuming analysis. Medium adherence seemed to be an intentional strategy by the core teams. By gradually introducing the methodology, and emphasizing the qualitative and visualization-oriented tools which can be implemented relatively quickly, teams remained able to respond to changing business priorities.

Second a lack of process management maturity seemed to contribute to deliberate medium adherence. As reported (A2) "the language of LSS can be a barrier in a company where almost

Table 5.
Reported adherence to- and deviations from LSS project structure

LSS program	Reported adherence to LSS project structure	Reported LSS project structures	Reported deviations to LSS project structure
A1	(1) High (2) Medium	(1) DMAIC problem solving cycle (2) Process analysis only	(1) Renaming of DMAIC phases
A2	(1) High (2) Medium	(1) DMAIC problem solving cycle (2) Kaizen plan-do-check-act cycle	(1) No inferential statistics (2) No scope definition (3) No per-phase tollgate meetings
B1	(1) Medium	(1) Process analysis only	(1) No inferential statistics
C1	(1) High	(1) DMAIC problem solving cycle	(1) Retrospectives after each phase
D1			
D2	(1) Low	(1) Fragmented tool application	
D3			(1) No scope definition (2) No measurements
E1	(1) Low	(1) Fragmented tool application	(1) Integration of other methods (2) No measurements (3) No control measures
F1	(1) High	(1) DMAIC problem solving cycle (2) Kaizen plan-do-check-act cycle	(1) Integration of other methods (2) Iterative application of measure-analyze-improve

	Category	Count	Category	Count	Category	Count
Totals	High	4	(1) DMAIC cycle	4	(1) Renaming DMAIC	1
					(2) Retrospectives	1
					(3) Integration other methods	1
					(4) Iterative application of measure-analyze-improve	1
	Medium	2	(1) Kaizen cycle	2	(1) No inferential statistics	2
			(2) Process analysis	1	(3) No scope definition	2
					(4) No tollgate meetings	1
	Low	3	(1) Fragmented tool application	2	(1) Integration other methods	1
			(2) Process analysis	1	(3) No measurements	2
					(4) No control measures	1

no one knows process management/ improvement terminology", referring to the fact that the use of the LSS tools is kept basic, e.g. project charter, SIPOC, and the use of process maps. For example (A2): "Define does not get enough attention", "more time in the Define phase for better understanding of the problem is needed", and "in and out scope exercises are an afterthought, creating a sense of frustration for LSS project leads, champions, and teams".

4.2.3 Low adherence to the LSS project method. Finally several programs described their adherence to the traditional structure as low (E1, D2) and their use of tools from the LSS methodology as fragmented (D2, E1). In addition, omitting the measure phase due to the inability or lack of patience to gather data (D3, E1) and omitting the control phase (E1; i.e. no control plan created and used after solution implementation) were mentioned. An important reason for low adherence is to let employees experience the benefits of using fragments of the LSS methodology without the formal structure and perceived dreaded bureaucracy. Low adherence to the traditional LSS structure is reportedly intentional: LSS implementation leaders attempted to create awareness of the benefits of using LSS methodology as a way to build credibility for the use of more complex and comprehensive tools. The programs reporting low adherence focused on the teaching and use of the most basic tools for project management (e.g. project charter), and process characterization (e.g. SIPOC, process maps) as the stepping stone to introduce the LSS project method, and reported no effort to further mature their programs. Such a strategy is however deemed prone to imminent danger: when the LSS Six Sigma project structure is never fully applied ample opportunities to showcase the value of doing so exists. Thereby, creating a need or willingness to increasingly adhere to the LSS project method might prove to be difficult.

4.2.4 Discussion of modification to the structured LSS project method. In conclusion the results indicate that DE-TECH companies favor smaller scoped improvement projects that can deliver solutions quicker, thereby corroborating findings from earlier research by Coronado and Antony (2002). We find both elimination of tools and phases in LSS projects as well as an integration with more iterative Agile Scrum based project management methods. This finding for one is opposing prior findings about the importance of applying structured problem-solving (i.e. DMAIC) approaches, in order to facilitate employee learning and knowledge creation, and thereby facilitating sustainable impact of improvement methodology (i.e. LSS) implementation (Choo *et al.*, 2007b). Hence, how the amendments made in applying the LSS DMAIC approach ultimately impacts the sustainability of the LSS implementation and its effect on business performance remains unclear and needs further research. This finding also contributes to the recent debate on the integration of the LSS framework with the Agile Scrum way of working (Correia *et al.*, 2019). Examples of such an integration include the execution of separate LSS DMAIC phases in two-week Agile Scrum sprints (time-boxed periods of activity dedicated to a DMAIC phase, i.e. unlike Kaizen events wherein complete execution of the complete structured problem-solving approach is time constrained) or the identification of causes and defects in Agile Scrum retrospective meetings. Future research opportunities lay in further exploring if and how LSS and Agile Scrum principles can be effectively combined. The scope of future research should include questions of enhancing the effectiveness of LSS application in more uncertain and dynamic business environments, where more iterative- instead of waterfall project approaches are desired.

4.3 Application of additional data analytics methodologies

An overview of the results for the third research question, being insight in the use of additional data analytics applications to complement traditional LSS methodology in DE-TECH companies is presented in Table 6. The results reveal that one program is using additional data analytics techniques to complement LSS analytical methods. Instead, most programs reported rare use of inferential statistics in LSS projects, or as stated (E1): "we used individual techniques as needed, there was less emphasis in using the complete set of LSS statistical techniques."

Good adherence to traditional LSS techniques was mostly reported (A1, A2, B1, C1, D2, D3, E1). Good adherence comprised consistent use of data collection plans, descriptive statistics- and mostly process capability analyses (mean, SD, individual value plots) and Pareto analysis. Good adherence programs reported little to no use of inferential statistics and/or statistical process control, whereas excellent adherence (D1, F1) programs did.

Common explanation for the low adoption of inferential statistical analyses in LSS projects is the widespread lack of operational excellence maturity. For instance (F1): "once in a

LSS program	Reported adherence to DMAIC statistics[a]	Reported use of statistical methods	Reported deviations to DMAIC statistics	Reported use of additional methods
A1	(1) Good adherence	(1) Descriptive statistics (2) Process capability analysis	(1) No inferential statistics	(1) None
A2	(1) Good adherence	(1) Descriptive statistics (2) Process capability analysis	(1) Some to none inferential statistics	(1) None
B1	(1) Good adherence	(1) Descriptive statistics (2) Process capability analysis	(1) Statistics course offered to LSS leadership team	(1) None
C1	(1) Good adherence	(1) Descriptive statistics (2) Process capability analysis	(1) No inferential statistics	(1) None
D1	(1) Excellent adherence	(1) Descriptive statistics (2) Process capability analysis (3) Inferential statistics	(1) No deviations	(1) None
D2	(1) Good adherence	(1) Descriptive statistics (2) Process capability analysis	(1) Some to none inferential statistics	(1) None
D3	(1) Good adherence	(1) Descriptive statistics (2) Process capability analysis	(1) Some to none inferential statistics	(1) None
E1	(1) Good adherence	(1) Descriptive statistics (2) Process capability analysis	(1) Some to none inferential statistics	(1) None
F1	(1) Excellent adherence	(1) Descriptive statistics (2) Process capability analysis (3) Inferential statistics	(1) No statistical process control	(1) Process mining

Note(s): [a]Excellent adherence = Program frequently use process capability analysis, descriptive- and inferential statistic and/or statistical process control (SPC). Good adherence = Program frequently use process capability analysis and descriptive statistics but rarely use inferential statistics and/or SPC in projects. Poor adherence = Program does not consistently use traditional statistical Lean Six Sigma methods

Table 6.
Reported adherence to- and deviations from LSS statistical methodology

while someone from the business will ask you about sample size, people do not really care about techniques." Most programs reportedly are implementing simplified LSS programs, wherein teaching inferential statistical tools is perceived as an uphill task. For example (A1): "LSS specialists sometimes do the (statistical) work independently, the team validates intermediate deliverables and results, which is less than ideal." This finding corroborates research by Null *et al.* (2019), who have concluded that on average lesser quantitative (i.e. statistics based) LSS techniques have a relatively higher impact in terms of project benefits realized in service environments.

One program (F1) reported a non-traditional LSS technique, being process mining. Process mining is a data mining technique that is traditionally focused on short-term (process) performance by analyzing process data (Van der Aalst, 2011). This program consistently implemented process mining techniques to speed-up the process of collecting and visualizing process data related to cycle times, consistency of process execution and bottleneck analysis. Synergies between process mining techniques and LSS statistical analytical techniques for process improvement is a promising avenue for future research.

5. Conclusion and future research directions

This paper explored critical success factors, LSS methodology modifications and data analytics synergies relevant for LSS implementation in DE-TECH companies. By interviewing 11 practitioners from 6 companies this multiple case study revealed a number of insights that are concluded upon below.

Prevalent CSFs for LSS implementation in DE-TECH companies are organizational leadership that is engaged to the implementation, LSS methodology that is rebranded to fit the shared values in the company and finally a restructuring of the traditional LSS training program whereby a more incremental, prioritized, on-the-job training approach is applied. For the DE-TECH industry specifically, management commitment is needed to (1) make and keep LSS implementation a priority in the dynamic business environment and (2) keep emphasizing the importance of internal operational excellence improvement besides external business development. The scope of future research should include questions of motivation for LSS application and adoption, especially for companies, or business units within companies, with an entrepreneurial focus on product development, human resource retainment and development and strong financing needs to support growth, that are in fast growing and in dynamic business environments. In addition, both altering the name and the curriculum of the LSS methodology appeared to be highly important CSF's for ultimate acceptance and adoption. Future research should explore when and how to allow for amendments and preference-based disregards in LSS implementation processes.

Often seen modifications of the structured LSS project method are elimination of specific phases or tools in LSS projects and integration of other methods in more iterative project structures. We find both elimination and consolidation of tools and phases in LSS projects as well as integration with more iterative Agile Scrum based project management methods. Future research opportunities lay in further exploring if and how LSS and Agile Scrum principles can be effectively combined.

Good adherence to traditional LSS statistics was mostly reported. Common explanation for the low adoption of inferential statistical analyses in LSS projects is the widespread lack of operational excellence maturity. One program reported the application of a non-traditional LSS technique, being process mining. Synergies between broader data analytics/process mining techniques and LSS statistical analytical techniques is a promising avenue for future research.

5.1 Limitations

Several limitations to the study remain. First the research is scoped on the DE-TECH industry, thereby reducing the generalizability of the findings. Also, from each of the case companies only representatives with dedicated LSS functions were included in the sample, thereby providing a limited perspective. Moreover only companies from the United States have been included in the sample. Despite the fact that the implementation of LSS programs in these companies is global in scope, this limits the generalizability of the findings. A final important limitation is that the nature of this research is exploratory. Hence, our findings are preliminary and future research is needed to corroborate our findings.

5.2 Practical implications

Practical implications that have resulted from this study comprise the awareness and knowledge of critical success factors and LSS methodology modifications specifically relevant for DE-TECH companies or companies or business units within these companies that are similar in terms of focus on product development, innovation and growth, such as R&D departments in high-tech manufacturing companies. LSS implementation leaders are better equipped knowing specifically why the role of leadership engagement is important, how LSS methodology branding can contribute to ultimate success of the implementation and what modifications in the LSS project structure and training program are deemed necessary to facilitate adoption.

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Appendix

General information

(1) What is your name

(2) What is your current- and previous role(s) (champion, project manager (MBB), project lead (BB) or sr. manager)?

(3) How many years of experience do you have with Lean Six Sigma?

(4) In what organization(s) (including their sizes and industries) have you gained your experience with Lean Six Sigma?

(5) What is the specific methodology that is focused on in your current engagement (Lean, Six Sigma, Lean Six Sigma)?

Lean Six Sigma implementation

(6) What is the strategic rationale for implementing Lean Six Sigma in your organization?

(7) What is the duration of the Lean Six Sigma implementation (years)?

(8) What is the % (Black Belt/ Green Belt per staff) of LSS practitioners in your organization (BB and GB level)

(9) What is the firm size of the company you currently work in (number of employees or annual sales)?

(10) What results have the Lean Six Sigma implementation you were involved in mostly yielded?

RQ1: What are industry contingent critical success factors for Lean Six Sigma project implementation in digital emerging technology organizations?

(11) What were significant challenges when implementing LSS projects in the organization, and why?

(12) How did you overcome these challenges?

(13) Which of these challenges do you think are specific for the industry, and why?

(14) What known CSF's applied to your project implementation (show list of known CSF's)?

RQ2: What modifications of the structured LSS project method were needed for effective implementation in digital emerging technology organizations?

(15) How where LSS projects executed, in what order of steps, and why?

(16) To what extend has the traditional DMAIC deliverables structure been adhered to, and why?

(17) What are the largest deviations to the traditional DMAIC deliverables structure, and why?

RQ3: What, and how can, data analytics methodologies complement traditional LSS methodology for digital emerging technology organizations?

(18) What (statistical) data analysis are executed in LSS projects, in what order of steps, and why?

(19) To what extent has the traditional DMAIC statistical methodology been adhered to, and why?

(20) What are the largest deviations to the traditional DMAIC methodology structure, and why?

(21) What are the most prominent complementary data analytics methodologies being applied, and why?

Closure
Last remarks

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