Critical success factors for six sigma design and deployment to complement Lean operational strategy towards capability maturity

Albert J. Viljoen (Student #: 909 703 915)

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Declaration

Declaration I, Albert J. Viljoen, hereby declare that this thesis for the Doctor of Philosophy in Engineering Management Degree, submitted to the Faculty of Engineering and the Built Environment at the University of Johannesburg has not been submitted previously for any degree at this or another university. It is original in design and in implementation, and all reference material contained therein has been duly acknowledged.

Signature:

Date: 04.12.2017

Albert J. Viljoen

Student number: 909 703 915

Supervisor

Prof. Jan-Harm C. Pretorius

Co-Supervisor

Dr Andre Vermeulen

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Abstract

Primary research will seek to evaluate by means of thorough literature review the role and application of both the Critical Success Factors for Six Sigma and Design for Six Sigma towards the achievement of Capability Maturity and Operational Excellence complementing Lean Operational Strategy maximising ROI with the impact presented but also disruptive changes presented by Industry 4.0 technologies. The Continuous Improvement methodologies are misunderstood including the Factors which are Critical in successful deployment. Six Sigma and Design for Six Sigma on the other hand, is somewhat different in origin, philosophy, range of applicability, technical content and implementation approach. While it can be tempting to capitalise on combining Six Sigma, Design for Six Sigma and Lean approaches, this merger makes for significant debate in order to achieve Capability Maturity.

Secondary Research will seek to investigate, from both survey results and interview responses, what additional methodologies can be included in an integrated Capability Maturity Model. This research will consist of analysing reported root causes in CI project failures with Critical Success Factor determination to propose a framework where Lean, Six Sigma and Design for Six Sigma can be deployed effectively to complement an operational strategy towards Capability Maturity.

Tertiary Research will seek to design and propose an integrated Capability Maturity framework consisting of a multi-model Continuous Improvement framework. This proposed integrated Capability Maturity Model will explore the contribution of Continuous Improvement methodologies such as TOC, Lean Six Sigma (LSS), Design for Six Sigma (DFSS) and Industry 4.0 technological advances presented through increasing convergence of both hard and software products. The advances made in Information and Communication Technology industries in CMMI, Agile and Scrum methodologies will also be explored for potential inclusion in an integrated Capability Maturity Model.

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Above all, I owe it all to Almighty God for granting me the wisdom, health and strength to undertake and complete this research.

"A wise son makes a father glad, but a foolish son is a grief to his mother" (Proverbs 10:1).

Contents

Glossary of terms and acronyms

1	5 S – It is the name of a workplace organisation method that uses a list of five Japanese words: Sort (Seiri), Straighten (Seiton), Shine (Seiso), Standardize (Seiketsu), Sustain (Shitsuke). It describes how to organise a work space for efficiency and effectiveness by identifying and storing the items used, maintaining the area and items, and sustaining the new order https://en.wikipedia.org/wiki/5S_(methodology) - cite_note-creativesafetysupply.com-2. The decision-making process usually comes from a dialogue about standardisation, which builds understanding among employees of how they should do the work. In some quarters, 5S has become 6S, the sixth element being safety. In TPS it is referred to as 4S+1S with the 5^{th} S being the S for Sustain (Shitsuke)
2	5 Why Analysis – It is an iterative interrogative technique used to explore the cause-and-effect relationships underlying a particular problem. The primary goal of the technique is to determine the root cause of a defect or problem by repeating the question "Why?"
3	Affinity diagram - To gather and organise ideas from a brainstorming session. Ideas are grouped into themes by the team. Is most easily done using sticky notes.
4	Agile - refers to an iterative, incremental method of managing the “design and build” activities of engineering, information technology and other business areas that aim to provide new product or service development in a highly flexible and interactive manner.
5	ANOVA (Analysis of Variance) is a statistical technique that assesses potential differences in a scale-level dependent variable by a nominal-level variable having 2 or more categories.
6	AI (Artificial Intelligence) is the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings. The term is frequently applied to the project of developing systems endowed with the intellectual processes characteristic of humans, such as the ability to reason, discover meaning, generalise, or learn from past

	experience. For purposes of this research document this term is used specifically in Industry 4.0 research.
7	AQL (Acceptable Quality Level) - A statistical measurement of the maximum number of defective goods considered acceptable in a particular sample size. If the acceptable quality level (AQL) is not reached for a particular sampling of goods, manufacturers will review the various parameters in the production process to determine the areas causing the defects. The AQL is an important statistic to companies seeking a Six Sigma level of quality control.
8	ASQ (American Society for Quality)
9	AR (Augmented Reality) - Augmented reality is the integration of digital information with the user's environment in real time. Unlike virtual reality, which creates a totally artificial environment, augmented reality uses the existing environment and overlays new information on top of it. Boeing researcher Thomas Caudell coined the term augmented reality in 1990, to describe how the head-mounted displays that electricians used when assembling complicated wiring harnesses worked.
10	BSC (Balanced Scorecard) - A balanced scorecard is a performance metric used in strategic management http://www.investopedia.com/terms/s/strategic-management.asp to identify and improve various internal functions of a business and their resulting external outcomes. It is used to measure and provide feedback to organisations. Data collection is crucial to providing quantitative results, as the information gathered is interpreted by managers and executives, and used to make better decisions for the organisation.
11	BCG (Boston Consulting Group) Is a global management consulting firm with 82 offices in 46 countries. The firm advises clients in the private, public, and not-for-profit sectors around the world, including more than two-thirds of the Fortune 500. Considered one of the most prestigious management consulting firms, BCG was ranked second in Fortune's "100 Best Companies to Work For" in 2015.

12	BB (Black Belt) – Leaders of team responsible for measuring, analysing, improving and controlling key processes that influence customer satisfaction and/or productivity growth. Black Belts often hold full-time positions whilst leading Six Sigma projects.
13	BPMM – (Business Process Maturity Model) Process maturity is an indication of how close a developing process is to being complete and capable of continual improvement through qualitative measures and feedback. Thus, for a process to be mature, it has to be complete in its usefulness, automated, reliable in information and continuously improving. The maturity of a process or activity can be defined to be at one of five levels; from Level 1 (the least mature) to level 5 (the most mature). The processes at higher levels also address the features of the lower levels. The ground level is Level 0 where no process exists for the activity.
14	Business Process Improvement (BPI): BPI is a systematic methodology assisting organisations to make significant advances in how business processes should operate in the organisation.
15	BPR – Business Process Re-engineering - aims at cutting down enterprise costs and process redundancies, but unlike other process management techniques, it does so on a much broader scale. Business Process Reengineering (BPR) is also known as process innovation and core process redesign, attempts to restructure or obliterate unproductive management layers, wipe out redundancies, and remodel processes differently.
16	CA (Capability Analysis) - Measure of the capability of a production process to produce parts within given upper and lower variability limits (tolerances). In a process that is in statistical control (has only common causes of variation), as the Cp (Process Capability Indice) increases so does the difference between what the process is capable of producing and what it is required to produce.
17	Capacity Planning: - Systematic determination of resource requirements for the projected output, over a specific period.

18	Catch ball Process - A particularly difficult phase of Hoshin Kanri (policy deployment) is in the implementation of a process known as “catch ball”, which is used to gain consensus on the deployment of Hoshin targets and measures, in a team environment known as “cross-functional management”.
19	CED (Cause and Effect Diagram) Ishikawa diagrams (also called fishbone diagrams, herringbone diagrams, cause-and-effect diagrams, or Fishikawa) are causal diagrams created by Ishikawa, K. (1968) that show the causes of a specific event.
20	CI – (Continuous Improvement), in regard to organisational quality and performance, focuses on improving customer satisfaction through continuous and incremental improvements to processes, including by removing unnecessary activities and variations.
21	CLT (Central Limit Theorem) Is a statistical theory that states that given a sufficiently large sample size from a population with a finite level of variance, the mean of all samples from the same population will be approximately equal to the mean of the population. Furthermore, all of the samples will follow an approximate normal distribution pattern, with all variances being approximately equal to the variance of the population divided by each sample's size.
22	CMM (Capability Maturity Model) The Capability Maturity Model was originally developed as a tool for objectively assessing the ability of government contractors' *processes* to implement a contracted software project. The model is based on the process maturity framework first described in the book *Managing the Software Process* by Humphrey, W.S. (1989). The model comes from the field of software development. It is also used as a model to aid in business processes generally, and has also been used extensively worldwide in government offices, commerce, and industry
23	CMMI (Capability Maturity Model Integration) Analysis of an organisation's structure and resources, aimed at identifying its inherent abilities and potential.

24	CAPP (Computer Aided Process Planning) - Software that tracks availability of equipment, costs, lead times, production volumes, etc., to help in creating a process plan.
25	CRD (Conflict Resolution Diagram) Similar to Evaporating Cloud (EC) / Evaporating Cloud Tree (ECT) or simply 'Cloud', is a necessity-logic based tool from Theory of Constraints Thinking Processes. The ECT / EC / CRD is used to surface and resolve conflicts.
26	CFM (Continuous Flow Manufacturing) - A manufacturing process that aims at optimisation of throughput using minimum inventory. This involves implementing just-in-time techniques while doing away with the batch and queue costs.
27	COPQ (Cost Of Poor Quality) - The costs associated with providing poor quality products or services. There are four categories: internal failure costs (costs associated with defects found before the customer receives the product or service), external failure costs (costs associated with defects found after the customer receives the product or service), appraisal costs (costs incurred to determine the degree of conformance to quality requirements) and prevention costs (costs incurred to keep failure and appraisal costs to a minimum).
28	CPS (Cyber Physical Systems) within which information from all related perspectives is closely monitored and synchronized between the physical factory floor and the cyber computational space. Moreover, by utilizing advanced information analytics, networked machines will be able to perform more efficiently, collaboratively and resiliently
29	CRM (Customer Relationship Management)
30	Cryptocurrency - Is a digital or virtual currency that uses cryptography for security. A cryptocurrency is difficult to counterfeit because of this security feature. A defining feature of a cryptocurrency, and arguably its most endearing allure, is its organic nature; it is not issued by any central authority, rendering it theoretically immune to government interference or manipulation.

31	CRT – (Current Reality Tree) - A method for determining the root problems that affect the quality of the output of a business process. A current reality tree is constructed by listing specific observed problems in or connected to a process, and developing a chain of causes and effects that link the problems to potential sources. The current reality tree technique is often used by practitioners of the Theory of Constraints business management methodology.
32	CSF (Critical Success Factor) - Limited number (characterised by between a number of 3 to 8) of characteristics, conditions, or variables that have a direct and serious impact on the effectiveness, efficiency, and viability of an organisation, program, or project. Activities associated with CSF must be performed at the highest possible level of excellence to achieve the intended overall objectives. Also called key success factors (KSF) or key result areas (KRA).
33	CTQ (Critical To Quality) A process characteristic or component that has a direct effect on whether the overall process or product is perceived by the customer to be of acceptable quality. Identification of specific, measurable CTQ characteristics are essential for meaningful and measurable business process improvement.
34	DOE (Design Of Experiment) is a systematic method to determine the relationship between factors affecting a process and the output of that process. In other words, it is used to find cause-and-effect relationships. This information is needed to manage process inputs in order to optimize the output.
35	DFM (Design For Manufacture) is a methodology to consider the constraints of the manufacturing processes and supply chain and optimise the design.
36	DFR (Design For Reliability) is a systematic, streamlined, concurrent engineering program in which reliability engineering is woven into the total development cycle. It relies on an array of reliability engineering tools along with a proper understanding of when and how and to use these tools throughout the design cycle.

37	DFX (X denotes a design approach) examples where X are substituted are: Assembly; Environment; Quality; Reusability or Service / Sustainability.
38	DMADV (Define, Measure, Analyse, Design, Verify) Defining the customer's needs Measuring the customer's needs Analysing and finding process options that will meet the customer's needs Designing a business model that helps meet the customer's needs Verifying that the new model meets the customer's needs
39	DMAIC (Define, Measure, Analyse, Improve, Control) Defining business processes Measuring the current performance of a business process Analysing and finding the root cause of a problem Implementing controls to alert leadership when the process is no longer in control Controlling and sustaining the desired process parameters
40	DFSS (Design for Six Sigma) a systematic methodology utilizing tools, training and measurements to enable us to design products and processes that meet customer expectations and can be produced at Six Sigma quality levels. Popular approaches are: DMADV; PIDOV; IDOV and IDDOV explained under separate headings.
41	DPMO (Defect Parts Per Million Opportunities) is the number of defects in a sample divided by the total number of defect opportunities multiplied by 1 million. DPMO standardizes the number of defects at the opportunity level and is useful because you can compare processes with different complexities. Also see PPM (Part Per Million).

42	DPU (Defect Per Unit) Defects per unit (DPU) is the number of defects in a sample divided by the number of units sampled.
43	EC (Evaporating Cloud) – Similar to CRD (Conflict Resolution Diagram) The Conflict Resolution Diagram (CRD), also known as Evaporating Cloud (EC) or simply 'Cloud', is a necessity-logic based tool from Theory of Constraints Thinking Processes. The EC / CRD is used to surface and resolve conflicts.
44	ECT (Evaporating Cloud Tree) – Similar to CRD (Conflict Resolution Diagram) The Conflict Resolution Diagram (CRD), also known as Evaporating Cloud (EC) or simply 'Cloud', is a necessity-logic based tool from Theory of Constraints Thinking Processes. The EC / CRD is used to surface and resolve conflicts.
45	EI (Economic Intelligence) also referred to as Business Intelligence.
46	Enterprise: A complex system of human-, process-, and technological components that interact to accomplish strategic goals; under the ownership or control of a directing body; and which ultimately strives to create wealth for its stakeholders.
47	ERP (Enterprise Resource Planning): provides one user-interface for the entire organisation to manage product planning, materials and parts purchasing, inventory control, distribution and logistics, production scheduling, capacity utilization, order tracking, as well as planning for finance and human resources. It is an extension of the manufacturing resource planning (MRP-II). Also called enterprise requirement planning.
48	FA (Functional Analysis) It is also known as a decision making approach in which a problem is broken down into its component functions (accounting, marketing, manufacturing, etc.). These functions are further divided into sub-functions and sub-sub-functions until the function level suitable for solving the problem is reached.

49	FAST (Functional Analysis System Technique) A technique to develop a graphical representation showing the logical relationships between the functions of a project, product, process or service based on the questions "How" and "Why".
50	FASE (Functional Analysis System Engineering) Where functional analysis is the next step in the Systems Engineering process after setting goal and requirements. Functional analysis divides a system into smaller parts, called functional elements, which describe what each part is designed to do in the system.
51	FEA (Finite Element Analysis) Is a computerised method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow, and other physical effects. The purpose of FEA is to manage risk and determine whether a product will break, wear out, or work the way it was designed before actual manufacture or physical use is done.
52	FMEA (Failure Mode and Effect Analysis) It is a qualitative and systematic tool, usually created within a spreadsheet, to help practitioners anticipate what might go wrong with a product or process. In addition to identifying how a product or process might fail and the effects of that failure, FMEA also helps find the possible causes of failures and the likelihood of failures being detected before occurrence.
53	FAIR (Focus-Alignment-Integration-Review) – It is an annual cycle, which begins when management 'acts' to review the previous year's performances and formulates the strategic focus for the coming year, which is expressed as the 'vital few objectives'. Then the cycle turns to the 'plan' phase and the vital few objectives are aligned with annual plans and deployed by the Catch-ball process through the business units. The 'do' phase is the integration of the vital few objectives into daily management, in other words the plans are executed where the PDCA cycle is used continuously for taking corrective actions, process improvement and standardization. The 'control' phase is a review of the annual performance.
54	FRT (Future Reality Tree) – It is one of the thinking processes or thinking process tools. A FRT usually follows an analysis with a Current Reality Tree (CRT) and an Evaporating

	Cloud (EC), also known as Conflict Resolution Diagram (CRD). The latter, CRD, is not systematic.
55	GEMBA - A Gemba (and sometimes genba) walk is the term used to describe personal observation of work – where the work is happening. The original Japanese term comes from *gembutsu*, which means "real thing." It also sometimes refers to the "real place." This concept stresses these ideas through: Observation: In-person observation, the core principle of the tool; Value-add location: Observing where the work is being done (as opposed to discussing a warehouse problem in a conference room and Teaming: Interacting with the people and process in a spirit of Kaizen ("change for the better").
56	GB (Green Belt) similar to a Black Belt but less skilled and often leaders of teams responsible for measuring, analysing, improving and controlling key processes that influence customer satisfaction and/or productivity growth. Green Belts are not full-time positions in Six Sigma projects.
57	HAWTHORN EFFECT - is a phenomenon that occurs when people are being observed in an experimental situation. These people exhibit behavioural changes that can be directly correlated to the times during which they were observed. When measurement is happening, most people try harder to do their best. This has been of interest to Six Sigma project managers. Six Sigma professionals must decide whether they can develop their projects with the Hawthorne Effect in play, or whether they need to do their evaluation in secret.
58	Hoshin Kanri – Policy Deployment is also known as a Japanese strategic planning process designed to ensure that the mission, vision, goals, and annual objectives are communicated throughout an organisation, and implemented by everyone from top management to the shop floor (frontline) level. In this process, the organisation develops multiple (typically four) vision statements to encourage breakthrough thinking about its future direction. Then goals and work plans are developed, based on the collectively chosen vision statement; and progress towards them is periodically monitored through performance audits. Called also Hoshin planning or policy deployment.

59	IATF 16949: 2016 - This standard, coupled with the applicable customer-specific requirements, defines the quality management system requirements for automotive production, service and/or accessory parts. IATF 16949:2016 is an autonomous QMS standard that is fully aligned with the structure and requirements of ISO9001:2015. However, it is not a stand-alone document, but is implemented as a supplement to, and in conjunction with, ISO9001:2015, which must be purchased separately. This revised standard cancels and replaces ISO/TS16949:2009.
60	IBM SPSS Statistics: IBM SPSS Statistics is an integrated computer program used for addressing the entire analytical process, from planning to data collection to analysis, reporting and deployment. Statistics included in the software: SPSS (IBM SPSS Data Collection), data mining (IBM SPSS Modeler), text analytics, statistical analysis, and collaboration and deployment (batch and automated scoring services. It includes: 1. Descriptive statistics: Cross tabulation, Frequencies, Descriptive, Explore, Descriptive Ratio Statistics; 2. Bivariate statistics: Means, t-test, ANOVA, Correlation (bivariate, partial, distances), Nonparametric tests; 3. Prediction for numerical outcomes: Linear regression; 4. Prediction for identifying groups: Factor analysis, cluster analysis (two-step, K-means, hierarchical).
61	ICT – Information and Communication Technology
62	I4.0 (Industry 4.0) Refers to the 4^{th} Industrial revolution within CPS (Cyber Physical Systems) with transforming manufacturing industry to the next generation. The term Industry 4.0 encompasses a revolution, one that marries advanced manufacturing techniques with the Internet of Things to create a digital manufacturing enterprise that is not only interconnected, but communicates, analyses, and uses information to drive further intelligent action back in the physical world.
63	IDOV – Identify, Design, Optimise and Validate is used as a DFSS approach

64	IDDOV – Identify, Design, Develop, Optimise and Validate – is used as a DFSS approach
65	Innovation Capability: The organisational means by which innovative outputs may be facilitated
66	Integrative Improvement - An Integrative Improvement System requires three key structural components to effectively drive the transformation process: 1.Maturity-based transformation; 2.Functional integration and 3.Sustainability through a three-tiered system.
67	ISO 13053-1 – Part 1: *DMAIC methodology,* describes a methodology for the business improvement methodology known as Six Sigma. The methodology typically comprises five phases: **d**efine, **m**easure, **a**nalyse, **i**mprove and **c**ontrol (DMAIC). ISO 13053-1:2011 recommends the preferred or best practice for each of the phases of the DMAIC methodology used during the execution of a Six Sigma project. It also recommends how Six Sigma projects should be managed and describes the roles, expertise and training of the personnel involved in such projects. It is applicable to organisations using manufacturing processes as well as service and transactional processes.
68	ISO 13053- 2 - Part 2: *Tools and techniques,* describes tools and techniques, illustrated by factsheets, to be used at each phase of the DMAIC approach. The methodology set out in ISO 13053-1 is generic and remains independent of any individual industrial or economic sector. This makes the tools and techniques described in ISO 13053-2:2011 applicable to any sector of activity and any size business seeking to gain a competitive advantage.
69	ISO 17258 – Statistical Methods – Six Sigma Basic criteria underlying benchmarking for Six Sigma organisations. ISO 17258:2015 describes a methodology for establishing the level of quality, performance, and productivity of processes, products, and services according to Six Sigma principles. It is applicable to all sectors (industries, services, administration, etc.) and to all types of organisations, whether it is already involved in an improvement programme such as Six Sigma, Lean, or not. In particular, it can be used to

	initiate a Six Sigma programme by providing a selection of improvement projects. NOTE. The focus of this methodology is on criteria, measures, measurement process, and comparison process. The results can then be used to identify good practices of benchmarking.
70	ISO 18404:2015 – Quantitative methods in process improvement – Six Sigma competencies for key personnel in relation to Lean Six Sigma implementation. Quantitative methods in process improvement -- Six Sigma -- Competencies for key personnel and their organisations in relation to Six Sigma and Lean implementation.
71	ISO 9000: is an internationally recognised standard of quality, and includes guidelines to accomplish the ISO9000 quality standard a set of standards related to quality management systems and designed to help organisations to ensure that they meet the needs of customers and other stakeholders while meeting statutory and regulatory requirements related to the product. The standards are published by ISO, the International Organisation for Standardisation.
72	ISO 9001:2015 - specifies requirements for a quality management system when an organisation: a) needs to demonstrate its ability to consistently provide products and services that meet customer and applicable statutory and regulatory requirements, and b) aims to enhance customer satisfaction through the effective application of the system, including processes for improvement of the system and the assurance of conformity to customer and applicable statutory and regulatory requirements. All the requirements of ISO 9001:2015 are generic and are intended to be applicable to any organisation, regardless of its type or size, or the products and services it provides.
73	ISO/CD 20575-1 Is a standard under development for Statistical and Probabilistic methods in the development of products, processes and services - Design for Six Sigma -- Part 1: DFSS Framework

74	ISO/TR 16705:2016 Statistical methods for implementation of Six Sigma -- Selected illustrations of contingency Table analysis. ISO/TR 16705:2016 describes the necessary steps for contingency Table analysis and the method to analyse the relation between categorical variables (including nominal variables and ordinal variables). It provides examples of contingency Table analysis. Several illustrations from different fields with different emphasis suggest the procedures of contingency Table analysis using different software applications. In ISO/TR 16705:2016, only two-dimensional contingency Tables are considered.
75	JIDOKA - Is one of the two pillars of the Toyota Production System along with just-in-time. Jidoka highlights the causes of problems because work stops immediately when a problem first occurs. This leads to improvements in the processes that build in quality by eliminating the root causes of defects.
76	JIT (Just In Time) Inventory: a system in which goods are made or purchased just before they are needed, so as to avoid carrying high levels of stock.
77	KAIKAKU - (Japanese for "radical change") is a business concept concerned with making fundamental and radical changes to a production system, unlike Kaizen which is focused on incremental minor changes.
78	KAIZEN is the Japanese word for "continual improvement ". In business, Kaizen refers to activities that continuously improve all functions and involve all employees from the CEO to the assembly line workers.
78	KAIZEN BURST / BLITZ – Are focussed Kaizen projects often only a week in length of time.
79	KANBAN - Is an inventory-control system to control the supply chain. Taiichi Ohno, an industrial engineer at Toyota, developed Kanban to improve manufacturing efficiency. Kanban is one method to achieve JIT.

80	KANO MODEL - The Model is an insightful way of understanding and categorizing 5 types of Customer Requirements (or potential features) for new products and services.
81	KRA (Key Result Area) – refer to general areas of outputs or outcomes for which the department's role is responsible. Key Performance Areas are the areas within the business unit, for which an individual or group is logically responsible.
82	KSA (Key Success Factor) - The combination of important facts that is required in order to accomplish one or more desirable business goals.
83	KM (Knowledge Management)
84	LEAN - Lean manufacturing or Lean production, often simply "Lean", is a systematic method for waste minimization ("MUDA") within a manufacturing system without sacrificing productivity. Lean also takes into account waste created through overburden ("MURI") and waste created through unevenness in work-loads ("MURA"). Working from the perspective of the client who consumes a product or service, "value" is any action or process that a customer would be willing to pay for.
85	LSS (Lean Six Sigma) Lean Six Sigma is a combination of two powerful process improvement methods: Lean and Six Sigma. Lean and Six Sigma complement each other. Lean accelerates Six Sigma, delivering greater results than what would typically be achieved by Lean or Six Sigma individually. Lean Six Sigma refers to the eight types of waste it strives to eliminate as "DOWNTIME," which is an abbreviation of "defects, overproduction, waiting, non-utilized talent, transportation, inventory, motion and extra-processing." Simply put, any use of resources that doesn't create value for the end customer is considered a waste and should be eliminated. Lean Six Sigma training uses "Belt" levels similar to Six Sigma.
86	MANOVA (Multivariate Analysis of Variance) is simply an ANOVA with several dependent variables. Furthermore this means ANOVA tests for the difference in means between two or more groups, while MANOVA tests for the difference in two or more vectors of means.

87	MRP (Material Requirements Planning) is a production planning, scheduling, and inventory control system used to manage manufacturing processes. Most MRP systems are software-based, but it is possible to conduct MRP by hand as well. Plan manufacturing activities, delivery schedules and purchasing activities.
88	MRP II (Manufacturing Resource Planning 2 / MRP II) is an integrated information system used by businesses. The system is designed to centralize, integrate and process information for effective decision making in scheduling, design engineering, inventory management and cost control in manufacturing.
89	Maturity level: a well-defined evolutionary plateau or domain of practice capability maturity.
90	MBNQA (Malcolm Baldridge National Quality Award) is an annual award for the US organisations which have "excelled in quality management and quality achievement." Two awards may be given in each of three categories of manufacturing company, service company, and small business. Each award is based on seven criteria: (1) leadership, (2) information and analysis, (3) strategic planning, (4) human resource development and management, (5) business results, (6) customer focus, and (7) customer satisfaction. Established in 1987, the award is named after the quality-management champion Malcolm Baldridge (1922-87).
91	MBB (Master Black Belt) First and foremost teachers. They also review and mentor Black Belts deployed within Six Sigma projects. Selection criteria for Master Black Belts are quantitative skills and the ability to teach and mentor. Master Black Belts are often full-time positions on Six Sigma and CI / OPEX teams.
92	MIFD – Manufacturing Information Flow Diagram – similar to Visual Stream Mapping used within Toyota in TPS to analyse Jidoka to enable JIT.
93	McKinsey and Company - is a worldwide management consulting firm. It conducts qualitative and quantitative analysis in order to evaluate management decisions across the public and private sectors. According to *The New York Times*, it is considered the most

	prestigious management consultancy in the world. They have offices in 120 cities in 60 countries in the world.
94	MUDA - Any activity that consumes resources without creating value for the customer. Within this general category it is useful to distinguish between a *type one MUDA*, consisting of activities that cannot be eliminated immediately and a *type two MUDA*, consisting of activities that can be eliminated quickly through KAIZEN.
95	MURA - Unevenness in an operation; for example, a gyrating schedule not caused by end-consumer demand but rather by the production system, or an uneven work pace in an operation causing operators to hurry and then wait. Unevenness often can be eliminated by managers through level scheduling and careful attention to the pace of work.
96	MURI - Overburdening equipment or operators by requiring them to run at a higher or harder pace with more force and effort for a longer period of time than equipment designs and appropriate workforce management allow.
97	Nemawashi - in Japanese means an informal process of quietly laying the foundation for some proposed change or project, by talking to the people concerned, gathering support and feedback
98	NPD – New Product Development
99	NPI – New Product Introduction
100	OPEX (Operation Excellence) A philosophy of the workplace where problem-solving, teamwork, and leadership results in the ongoing improvement in an organisation. The process involves focusing on the customer's needs, keeping the employees positive and empowered, and continually improving the current activities in the workplace
101	OEE (Overall Equipment Effectiveness) is observed as the standard for measuring manufacturing productivity. It identifies the percentage of manufacturing time that is truly productive. An OEE score of 100% means you are manufacturing only Good Parts, as fast

	as possible, with no Stop Time. In the language of OEE that means 100% Quality (only Good Parts), 100% Performance (as fast as possible), and 100% Availability (no Stop Time). Measuring OEE is a manufacturing best practice. By measuring OEE and the underlying losses, you will gain important insights on how to systematically improve your manufacturing process. OEE is the single best metric for identifying losses, benchmarking progress, and improving the productivity of manufacturing equipment (i.e., eliminating waste).
102	OEM (Original Equipment Manufacturer)
103	OR (Operations Research)
104	Pareto - The Pareto principle (also known as the 80/20 rule, the law of the vital few or the principle of factor sparsity states that, for many events, roughly 80% of the effects come from 20% of the causes. Management consultant Joseph M. Juran suggested the principle and named it after Italian economist Vilfredo Pareto, who noted the 80/20 connection.
105	Poke Yoke - Is any mechanism in a Lean manufacturing process that helps an equipment operator avoid (yokeru) mistakes (poka). Its purpose is to eliminate product defects by preventing, correcting, or drawing attention to, human errors as they occur.
106	PPM (Parts Per Million) the number of defective units in one million units. (PPM is typically used when the number of defective products produced is small so that a more accurate measure of the defective rate can be obtained than with the percent defective.)
107	PIDOV (Plan, Identify, Design, Optimise and Validate – used as a DFSS approach
108	PCF (Process Classification Framework) serves as a high-level, generic enterprise model encouraging organisations to view their activities from a total-industry process perspective instead of a narrow functional viewpoint.
109	Process: Sequence of interdependent and linked procedures which, at every stage, consume one or more resources (employee time, energy, machines, money) to convert

	inputs (data, material, parts, etc.) into outputs. These outputs then serve as inputs for the next stage until a known goal or end result is reached.
110	POOGI (Process of Ongoing Improvement) - The five focusing steps aim to ensure ongoing improvement efforts are centered on the organisation's constraint(s). In the TOC literature, this is referred to as the *process of ongoing improvement* (POOGI).
111	Process Mapping: Structural analysis of a process flow (such as an order-to-delivery cycle), by distinguishing how work is actually done from how it should be done, and what functions a system should perform distinguished from how the system is built to perform those functions.
112	Process Re-engineering (BPR): Documenting, analysing, and comparing a process to benchmarks (such as best-in-class practices), implementing the required changes, or installing a different process.
113	Production Management: The job of co-ordinating and controlling the activities required to make a product, typically involving effective control of scheduling, cost, performance, quality, and waste requirements
114	Production System: Manufacturing subsystem that includes all functions required to design, produce, distribute, and service a manufactured product
115	ROI (Return On Investment): A performance measure used to evaluate the efficiency of an investment or to compare the efficiency of a number of different investments.
116	RTY (Roll Throughput Yield) It is also known as the First Pass Yield – the probability (or percentage of time) that a manufacturing or service process will complete all required steps without any failures. Reliability principles are the basis for calculating the rolled throughput yield. The reliability formula for a system in series with n process steps is: Rs = (R1) (R2) (R3) (R4) … (Rn)

117	Scrum - Is an agile way to manage a project, usually software development. Agile software development with Scrum is often perceived as a methodology; but rather than viewing Scrum as methodology, it is also referred to as a framework or model for managing a process.
118	Seven wastes – are: 1 - overproduction ahead of demand; 2 - waiting for the next process, worker, material, or equipment; 3 - unnecessary transport of materials (for example, between functional areas of facilities, or to or from a stockroom or warehouse); 4 - over-processing of parts due to poor tool and product design; 5 - inventories more than the absolute minimum; 6 - unnecessary movement by employees during the course of their work (such as to look for parts, tools, prints or help); and 7 - production of defective parts. Eight wastes are also used with the seven wastes being the same with the addition of Skills (TIMWOOD/S).
119	Sigma Level – It is a Lean Six Sigma metric that measures the error rate of a process, based on the DPMO estimate.
120	SIPOC (Supplier, Input, Product, Output, Customer product map) is a visual tool for documenting a business process from beginning to end. SIPOC (pronounced sigh-pock) diagrams are also referred to as high level process maps because they do not contain much detail. SIPOC diagrams are useful for focusing a discussion and helping team members agree upon a common language and understanding of a process for CI (Continuous Improvement). In Six Sigma, SIPOC is often used during the "define" phase of the DMAIC improvement steps.
121	SMART (Specific, Measurable, Attainable, Relevant and Time-Based) is an effective process for setting and achieving your project or business objectives.
122	SMED (Single Minute Exchange of Dies) - is a system for dramatically reducing the time it takes to complete equipment changeovers. The essence of the SMED system is to convert

	as many changeover steps as possible to "external" (performed while the equipment is running), and to simplify and streamline the remaining steps.
123	SS (Six Sigma / 6-Sigm / 6σ) Used to improve manufacturing processes it is also applied to optimise service processes and lends itself for improvement and performance available to all industries. It is centred on the DMAIC (Define, Measure, Analyse, Improve and Control) principles with skilled professionals trained in similar grading to martial arts Karate using MBB (Master Black Belt), BB (Black Belt), GB (Green Belt) and YB (Yellow Belts) to facilitate and improve both service and manufacturing processes. It is also applied to optimise service processes and lends itself for improvement and performance available to all industries through extensive use of statistical tools to both measure and analyse data and trends. Six-Sigma can be applied with Capability Maturity Models.
124	SQC (Statistical Quality Control) - Use of statistical methods to measure and improve the quality of manufacturing processes and products. The term "statistical process control" is often used interchangeably.
125	SPC (Statistical Process Control) - Application of statistical methods and procedures (such as control charts) to analyse the inherent variability of a process or its outputs to achieve and maintain a state of statistical control, and to improve the process capability. Also called statistical quality control.
126	STT (Strategy and Tactics Tree) - the overall project plan and metrics that will lead to a successful implementation and the ongoing loop through POOGI. Goldratt adapted three operating level performance measures throughput, inventory and operating expense and adopted three strategic performance measures: net income, return on investment and cash flow to maintain the change.
127	SWOT (Strengths, Weaknesses, Opportunities and Threats) is a structured planning method that evaluates those four elements of an organisation, project or business venture.

128	TAKT Time - Adjustable time unit used in Lean production to synchronise the rate of production with the rate of demand. Historically popularised by the Japanese, TAKT time is a German term which refers to rhythm or beat of music. Computed by dividing available production by the number of items to be produced, TAKT time provides a precise rhythm to run an entire process sequence that maximises efficiency and minimises wastes.
129	TIMWOOD(S) - The Seven wastes are also abbreviated as- TIMWOOD(S):A collection of the key Muda terms which are the following wastes: 1. Transportation 2. Inventory 3. Movement 4. Waiting 5. Over-production 6. Over-Processing 7. Defects 8. Skills (Adapted in ISixSigma)
130	TOC (Theory Of Constraints) is a methodology for identifying the most important limiting factor (i.e. constraint) that stands in the way of achieving a goal and then systematically improving that constraint until it is no longer the limiting factor. In manufacturing, the constraint is often referred to as a bottleneck.
131	TLS (Theory of Constraints + Lean + Six Sigma) A combination of these three Continuous Improvement methodologies in a framework integrating all three improvement approaches and a selection of the respective tools as appropriate to achieve Jidoka and JIT and remove any form of MUDA.
132	TPM (Total Productive Maintenance) is a methodology designed to ensure that every machine in a production process always performs its required task and its output rate is never disrupted. Pioneered by the Japanese firm Nippondenso, a manufacturer of automotive components and a member of the Toyota group.

133	TPS (Toyota Production System) A production system which is steeped in the philosophy of "the complete elimination of all waste" imbuing all aspects of production in pursuit of the most efficient methods. Toyota Motor Corporation's vehicle production system is a way of "making things" that is sometimes referred to as a "Lean manufacturing system" or a "Just-in-Time (JIT) system," and has come to be well known and studied worldwide. The Toyota Production System (TPS) was established based on two concepts: The first is called "Jidoka" (which can be loosely translated as "automation with a human touch") which means that when a problem occurs, the equipment stops immediately, preventing defective products from being produced; The second is the concept of "Just-in-Time," in which each process produces only what is needed by the next process in a continuous flow.
134	TQM (Total Quality Management) is a set of management practices throughout the organisation, geared to ensure the organisation consistently meets or exceeds customer requirements. TQM places strong focus on process measurement and controls as means of continuous improvement.
135	TRACC – Integrative Improvement framework developed by Competitive Capabilities International
136	TRACC IIS – Maturity Assessment tool developed by Competitive Capabilities International
137	TRIZ (Theory of Inventive Problem Solving) Derived from Russian acronym: *Theoria Resheneyva Isobretatelskehuh Zadach*, TRIZ is a problem solving method based on logic and data, not intuition, which accelerates the project team's ability to solve these problems creatively. TRIZ also provides repeatability, predictability and reliability due to its structure and algorithmic approach.
138	VA (Value Analysis) – A process whereby the sub processes are empirically analysed and their value to the value creation cycle is determined for relevance.
139	VAP (Value Adding Process) is a set of quality control activities which transform an input into an output that is valuable to internal and/or external customers of an organisation.

140	VSM (Visual Stream Mapping) is a Lean-management method for analysing the current state and designing a future state for the series of events that take a product or service from its beginning through to the customer. At Toyota, it is known as "material and information flow mapping".
141	WB (White Belt) Is an employee assigned to work on local problem-solving teams that support overall projects, but may not be part of a Six Sigma project team. Understands basic Six Sigma concepts from an awareness perspective.
142	WIP (Work In Progress) Is referred to as work in process, is the sum of all costs put into the production process to manufacture products that are partially completed. WIP refers to raw materials, labour and overhead costs incurred for products that are at various stages of the production process. WIP is a component of the inventory asset account on the balance sheet, and these costs are transferred to the finished goods account and eventually to cost of sales.
143	WCM (World Class Manufacturing) is the recognition of an organisation as a benchmark by its industry sector and, for some aspects, by other industry sectors. World Class organisations consistently deliver exceptional performance, frequently in excess of expectations. The final essential characteristic of a World Class organisation is that it is continuously improving its performance. There are 3 principles behind World Class Manufacturing: The 1st principle is what is known as Just in Time or Lean Manufacturing, the step by step elimination of waste. The 2nd principle is total quality, a culture of intolerance to defects (both in the processes and also information such as bills of material and stock records). The 3rd principle is the principle of total preventative maintenance where, whenever practical, a preventative maintenance programme means that unplanned stoppages due to equipment failure are minimised.

144	YB (Yellow Belt) Is an employee who participates as a Six Sigma project team member and reviews process improvements that support the Six Sigma project.

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Chapter 1

1.1 Introduction

Lean Six Sigma (LSS) and Design for Six Sigma (DFSS) are operational strategic tools oriented toward achieving the shortest possible cycle time by eliminating waste and reducing variation. According to Bozdogan, K. (2010) the Lean Six Sigma (LSS), Total Quality Management (TQM), Design For Six Sigma (DFSS), Theory of constraints (TOC), Agile manufacturing and Business Process Reengineering (BPR) have been introduced as universally applicable best methods to improve the performance of enterprise operations through continuous process improvement and systemic planned enterprise change focusing on Lean. Womack, J. P. and Jones, D. T. (1996) stated that Lean represents practice-based, rather than theory-grounded, methods with common roots in manufacturing.

Despite certain differences, Hallam, C. (2003) suggests that the methodologies potentially complement each other and established the foundation of the maturity capability model. The methodologies are closely interconnected as highly complementary approaches and can be brought together to define a first-approximation “core” integrated management system, with a Lean enterprise system serving as the central organising framework. Specific elements of the other approaches can be selectively incorporated into the “core” enterprise system to enrich its effectiveness.

To achieve the above, Nayab, N. (2011) observed that Capability Maturity Model Integration (CMMI) and LSS are two of the best proven improvement-oriented initiatives, with many overlaps. When comparing CMMI to LSS, CMMI is domain specific, whilst LSS is not. It is noted that here the basic difference between CMMI and LSS pertains to the scope of application. CMMI therefore aims at process improvement in specific disciplines or process areas whilst LSS, on the other hand aims at solving specific product or process related issues within the context of overall organisational process improvement. Thus, while CMMI is a domain specific improvement engine, LSS has a much wider application, serving as both an enterprise governance model and a tactical improvement engine cutting across domains.

In terms of CMMI and Six Sigma, - CMMI provides a framework for continual benchmarking and an improvement strategy whereas performance is directly linked with the application Six Sigma.

CMMI delivers structure to organisational processes where these are often non-existent or poorly designed.

To integrate CMMI and DFSS in Beardsley, G. (2005) one can include different strategies whereas for such implementation CMMI, Six Sigma and LSS are key choices in implementing internal processes. The implementation of the “model” as such is best illustrated in Figure 1 where CMMI and LSS “mature over time” and can therefore not provide a quick fix solution.

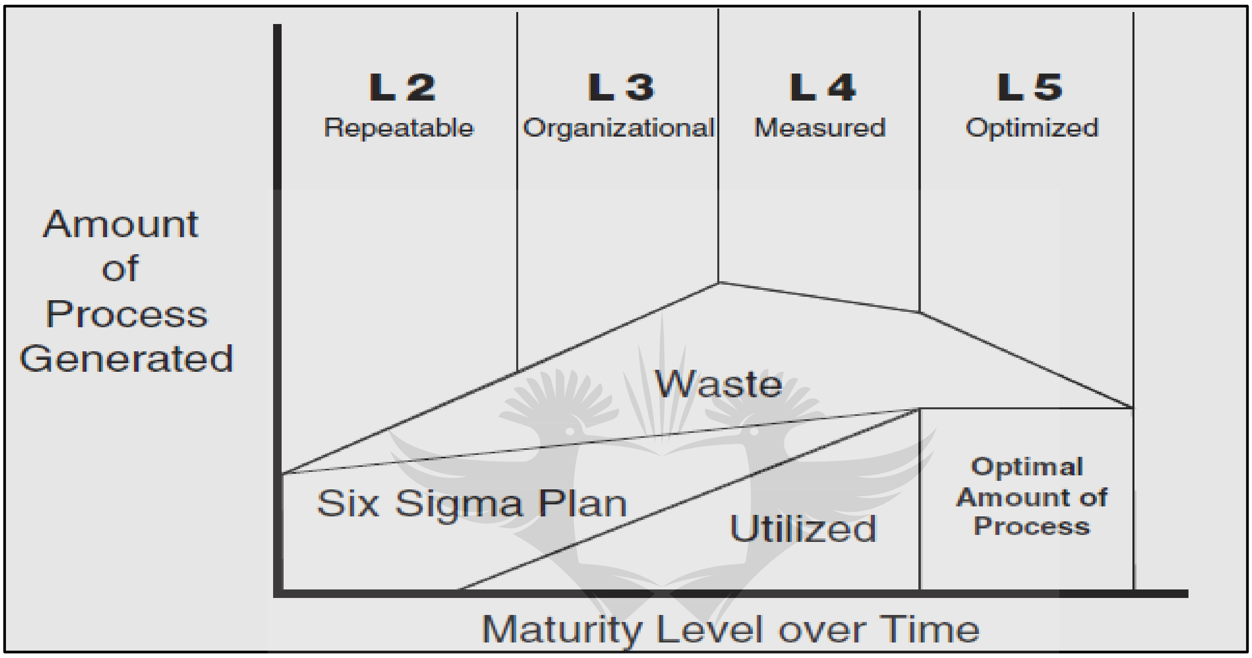

Figure 1: Implement CMMI-based processes as Six Sigma projects. Source: Beardsley, G. (2005).

CMMI and LSS / DFSS should not be in competition and it is clear that simultaneous implementation of these “concepts” in an organisation produces a synergy that helps in the successful accomplishment of company goals in a faster, better, and cost-effective way.

It is noted by Herbig, P.A. and O′Hara, B.S. (1994) that European, Japanese and American Automotive Original Equipment Manufacturer (OEM) has been developing a strategy to fundamentally disseminate the core concepts and opportunities within Lean, Six Sigma and DFSS to fundamentally drive Operational Excellence throughout the product and process life cycles.

Numerous examples of strategies exist stretching over a period of the past two decades in the automotive manufacturing industry seen in Epply, T. and Nagengast, J. (2006) who observed in the design phase of products and processes that the CSF's of DFSS research seek the opportunity to unlock tremendous profitability inclusive of Voice of the Customer (VOC) metrics.

Cook, R., Fang, N. and Hauser, K. (2006) state that the maturity level dictates Lean tool selection and deployment.

Of utmost importance in view of the above, is that a more comprehensive integrated business system approach towards DFSS application should be implemented. This should enable organisations to change from the "traditional" framework of progression towards capability, excellence and continuous performance.

DFSS is traditionally reserved for projects **after** all the "low hanging fruit" has been plucked with the aid of LSS and these processes have been optimised to levels of process entitlement or in terms of sigma maturity processes that are reaching 5 to 5.5 sigma quality. It is observed in Bozdogan, K. (2010) and Brook, Q. (2014) that various industries do not require a sigma quality of higher than 3 or 4 sigma, which is the natural quality for most industries without manifest designed or managed intervention. Process improvement in itself yields Sigma levels up to 4 but require DFSS in addition to break the 3 and 4 sigma wall. It is noted that General Electric (GE) as illustrated in Figure 2, propose the breaking 3 and 4 sigma level wall through the deployment of DFSS techniques in order to maximise return on investment (ROI).

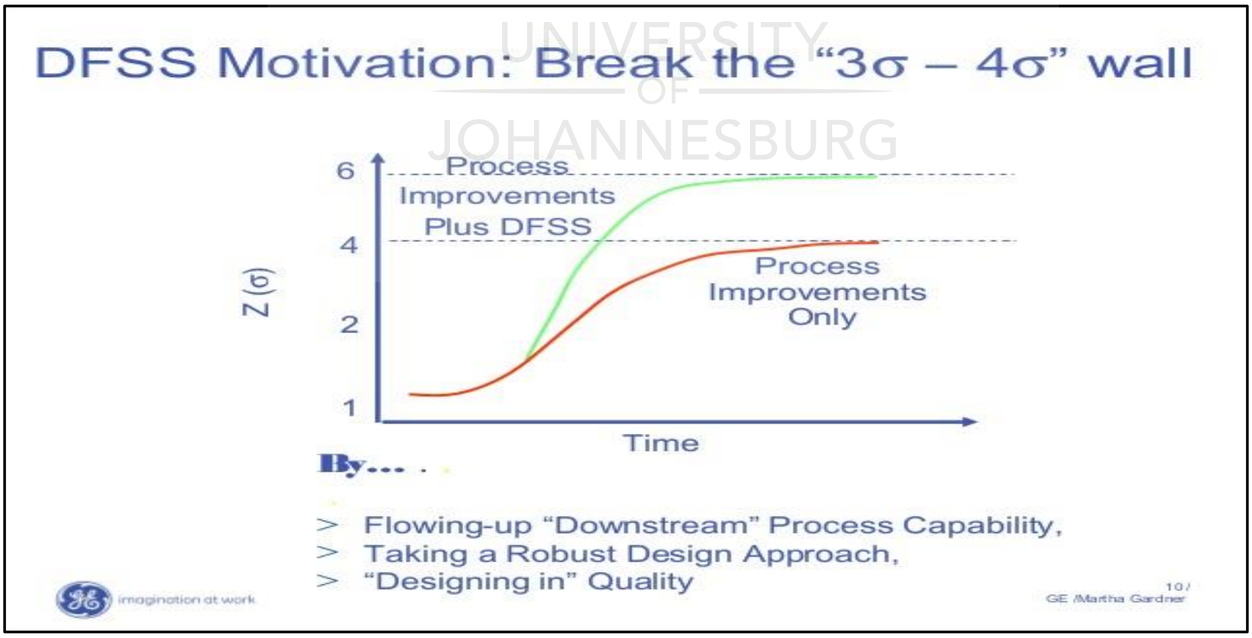

Figure 2: DFSS Motivation, Source GE 2017 www.ge.com

Based on annual reports General Electric enters their 30th year in 2017 with LSS and they depict DFSS motivation as illustrated in Figure 3 whereby through the Cost of Poor Quality (COPQ) and Cost of Poor Reliability (COPR) the prevention of these unwanted process and operational circumstances can be achieved.

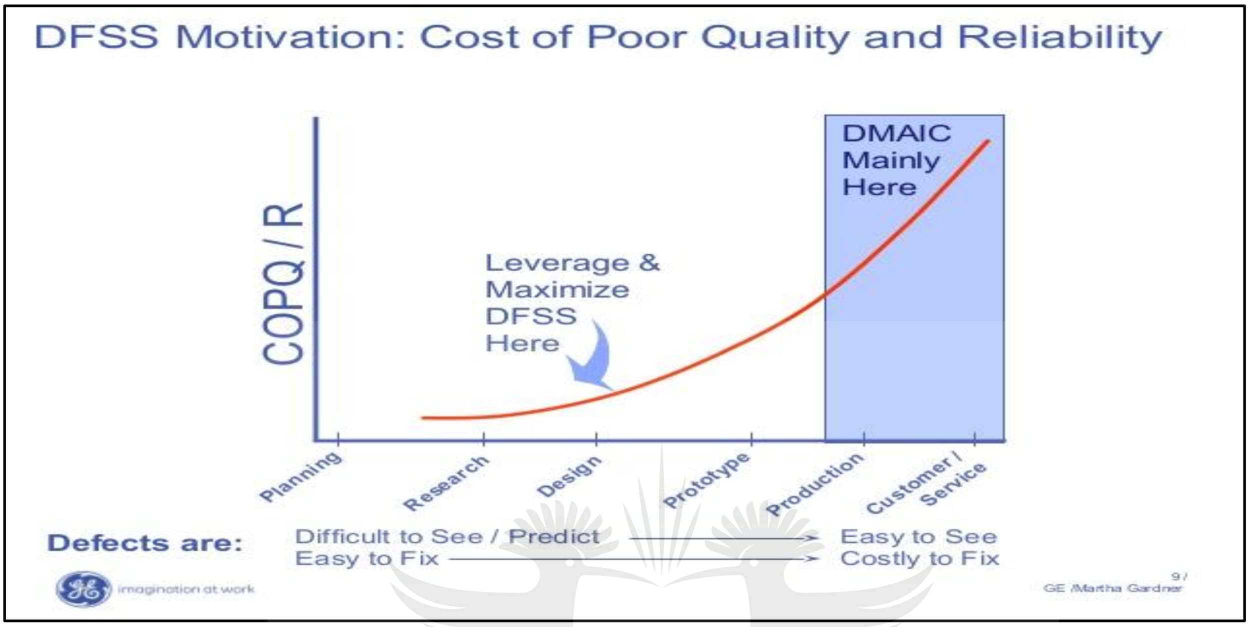

Figure 3: DFSS Motivation: Cost of Poor Quality and Reliability Source: GE website www.ge.com

It is puzzling why some organisations (that are exceptionally profitable) choose not to utilise proven LSS and DFSS methodologies whereas others do utilise these methodologies but at varying scales of integration in their organisational strategies.

DFSS is also seen as a subset of LSS tools with a primary focus of preventing errors as opposed to fixing them or optimising process capability at a later stage. However, DFSS goes further upstream to recognise and mitigate decisions made during the design phases which profoundly affect quality and operating costs of subsequent activities to build and deliver the product. Initial and early investments in achievement of good process capability has proven to deliver exceptional yields in ROI compared to the traditional approach of LSS (DMAIC) and process and product designs.

The question remains: Why do organisations in measuring productivity, optimisation and performance struggle to claim process capability and process capability maturity? Surely, if processes are in control, then the measure of processes and sub-processes performance will result in determining "optimal total process capability" leading towards excellence and performance. Manufacturing and service organisations should therefore strive towards process capability maturity.

One of the objectives of this research is to propose linking together "synergistically" key components impacting on successful implementation of LSS, DFSS and CMMI in terms of a business strategy towards continuous improvement. This involves innovative and pragmatic analysis of an organisation's capability to achieve sustainable competitiveness, growth and capability maturity and should focus on the essential application of DFSS as the starting capability within an organisation.

In order to understand the strategic importance of improvement tool selection such as DFSS, requires the development and execution of a good strategy augmented by a framework geared towards capability maturity. It requires a new thinking paradigm to meet the organisation's objectives in an ever-changing, challenging, high product quality economic environment. Such a paradigm can result in organisations being able to understand and apply maturity capability models.

1.2 Research problem and its significance

1.2.1 The importance of Maturity Models

Significant benefits for process improvement are reported in Röglinger, M., Pöppelbuß, J. and Becker, J. (2012) and also in Crosby, B. (1979) who aver that original research findings in the Quality Management Maturity Grid (QMMG) have been proven. Gaining a competitive advantage [in Porter, M.E. (1985)] over competitors has been the focus of the organisations since a long time because only a competitive advantage can assure the long term existence of the organisation. Organisations that have captured competitive advantage in our contemporary world of knowledge explosion are attempting to maintain their competitiveness by increasing knowledge and managing that knowledge. In a competitive environment organisations need flexibility to meet customers' demands by offering customised and high-quality products and services. So managing projects, organising people and the way they work (in an appropriate way) is a key success factor. LSS and DFSS are industry-proven effective Continuous Improvement methodologies.

Vermeulen, A. (2011) observed that there are two significant contributions offered by maturity models: (i) determining the capability of an organisation in its industry and (ii) determining a strategy based on best practices for the particular industry to ensure a continuous improvement program. A further observation reflects that maturity is best described as typical behaviour exhibited by an organisation against a stated number of maturity levels determined by industry as best practice for each level.

The functional organisation, with a distinct hierarchy is being left behind in the modern business world while other organisational structures enabling higher flexibility are becoming more and more dominant. For organisations to succeed in the global business competition of today, it is imperative that they produce a high standard of performance in Vermeulen, A. (2011).

1.2.1.1 Benefits of adopting a Maturity Model:

In the process of managing projects, organising people and work in an appropriate way is a key success factor. Lean, Six Sigma and Design for Six Sigma are proven Continuous Improvement tools used separately and also in various combinations.

A maturity model defines the interrelationships and identifies the “GAP” and needs of the required improvements against the standards set by internal processes and benchmark metrics enabling the following:

1. A formal structure and communication medium of performance.
2. The maintenance of lessons learned in maturity of organisational processes.
3. The focus necessary to extract and maximise continual improvements across functional areas.
4. The speed of problem resolution which can be accelerated through standard escalation in a modus operandi.

It is of utmost importance that the purpose of the maturity model is to provide a framework for improving an organisation’s business result by assessing the organisation’s strengths and weaknesses, enabling comparisons with similar organisations and achieving a measure of the correlation between organisations Vermeulen, A. (2011).

There are many reasons why organisations might choose to use the maturity model to assess their current performance, such as: justifying investment in portfolio, programme or project management improvements, gaining recognition of service quality in order to support proposals or gaining a better understanding of their strengths and weakness in order to enable improvement to happen. Maturity model is an essential element of strategic planning as it provides a methodology, a road map to determine and compress the gaps on resources and quality.

Working with diverse types of projects within an organisation requires standard models in order to deliver successful future projects repeatedly, to improve both the quality of future projects and to gain knowledge and learn from past mistakes. In Anderson, E. S. and Jessen, S. A. (2003), measuring maturity in organisations is regarded as a subjective instead of objective measurement since most significant research is primarily focusing on what people are doing operationally. Skulmoski, G. (2001) recommends a view where competence and maturity should be linked together for project success and not focusing only on action. This means a view where competence should be regarded as a combination of knowledge, skills and attitudes that supports performance. The assessment procedures help an organisation to understand where they have been, where they are, and what processes they need to implement, to continue their implementation of management methodologies. As organisations mature in business and project management processes and their use of information technology, they implement centralised solutions to facilitate these processes.

These models are usually divided into progressive maturity levels, allowing the organisation to plan how to reach higher maturity levels and to evaluate their outcomes on achieving that level. According to arguments in Brookes, N., Butler, M., Dey, P. and Clark, R. (2014); Levin, G. and Skulmoski, G. (2000) and in Gomes, J. and Romao, M. (2014) it is the maturity models that provide a framework to help enable organisations to increase their capability to deliver projects on schedule, within budget and according to the desired technical performance.

1.2.2 Statement of purpose

Through research in this doctoral the researcher seeks thesis to both design and develop a practical Capability Maturity Model for use as a sustainable Continuous Improvement solution for multiple industries. Such a model will consider the enabling advances provided by Industry 4.0 and a combination of Critical Success Factor analysis as well as the inclusion of various Continuous Improvement methodologies.

Significant research has been undertaken in the determining factors for effective deployment of Continuous Improvement methodologies, where few, however, have included the technological advances presented in consideration of the evolving technologies presented in the nine pillar constituents in Industry 4.0 technologies. The ever increasing levels of hard and software integration and increased levels of real-time connectivity of Human Machine Interfaces (HMI) also warrant a review in their prominent contribution to Continuous Improvement practices.

The recipe for an effective Continuous Improvement strategy is a relative one and also herein presents opportunities for additional research, outside of Lean, Six Sigma, Theory of Constraints, Design for Six Sigma, Waterfall, Agile and Scrum, ISO 9001, ITIL, etc. and also Capability Maturity Frameworks. The developments in both hard and software industries present opportunities for Continuous Improvement methodologies to be integrated and selectively deployed based on organisational maturity and capability through the support of a maturity framework.

European, Japanese and also American OEM's have started to fundamentally disseminate the core concepts and opportunities within Lean, Six Sigma and Design for Six Sigma to drive Continuous Improvement throughout the product and process life cycle. Numerous examples exist stretching over a period of the past two decades in the automotive manufacturing industry. Such examples can be seen in Epply, T. and Nagengast, J. (2006) who observed in the design phase of products and Processes that the Critical Success factors for DFSS deployment seek the opportunity to unlock tremendous profitability and incorporate the Voice of the Customer (VOC); Critical to Quality (CTQ); Kano Analysis and Quality Function Deployment (QFD) metrics. According to Cook, R., Fang, N. and Hauser, K. (2006) the maturity level of an organisation also dictates the appropriateness of Continuous Improvement tool selection and deployment. This selection and deployment of improvement tools highlights the evolutionary maturity of the organisation.

In Gitlow, H.S., Melnyck, R.J. and Levine, D.M. (2015) we find the reasons (and motivation) for some organisations that are profitable why they do not utilise proven Lean, Six Sigma and Design for Six Sigma methodologies. Other significant industry leaders, however, do so as a matter of course. Furthermore, research undertaken seeks to investigate and establish what the Critical Success Factors are for Lean Six Sigma and Design for Six Sigma deployments.

It is noted in industry experience sometimes that a Lean Six Sigma is initiated due to a process not delivering the required process capability, quality and Return on Investment. The traditional approach when introducing new products or services does not always consider the inherent reliability and process risks which may result in poor process capability and undesired levels of customer satisfaction and the Critical Success Factors (CSF's) for a successful Lean Six Sigma and Design for Six Sigma program.

It is therefore clear that the contribution of organisational capability and maturity in CI program deployment using Lean Six Sigma and Design for Six Sigma is not fully understood and this lack of understanding appears to be prevalent in both manufacturing and service industries. The research will therefore also seek to determine the relationship of CMM and CI as sub-objectives for research.

To confirm the Research Objectives: the research results obtained should assist in the design and testing of a maturity capability model. Inclusive to in this objective is the determination of the interrelationship between Lean Six Sigma and Design for Six Sigma and associated Critical Success Factors to facilitate a Continuous Improvement methodology. The research, design and development of a new and integrated framework should assist organisations to optimise processes' performance transcending into successful capability maturity outcomes.

In this thesis the researcher seeks to design and develop a practical Capability Maturity Model for use as a sustainable Continuous Improvement solution applicable in a variety of industries. Such a solution considers enabling advances presented in Industry 4.0 technologies and Critical Success Factor Analysis in LSS and DFFS as well as the selective inclusion of other prominent Continuous Improvement methodologies.

Significant research has been undertaken in effective deployment of Continuous Improvement methodologies, where few, however, have included the technological advances presented in evolving technologies as contained and elucidated in the nine pillars of Industry 4.0 and the ever increasing convergence in hard and software connectivity. The recipe for an effective Continuous Improvement framework is relative. It also presents opportunities for additional research outside of Lean, Six Sigma, Theory of Constraints, Design for Six Sigma, Waterfall, Agile and Scrum, ISO 9001, AS 9100, IATF 16949 and also Capability Maturity Frameworks.

The developments in both hard and software domains present opportunities to explore the potential for the integration of selective Continuous Improvement methodologies based on organisational Capability Maturity with the support of a Maturity Framework.

1.3 Research Methodology

1.3.1. Research techniques

The nature of this research will be primarily exploratory and descriptive. The main element of the research will be formed by thorough literature reviews, survey questionnaires and interviews with industry specialists. The objective is to document relevant and essential current scientific literature. The most important literature findings will be presented in the form of a discussion which shows different views and approaches within the existing knowledge in Sekaran, U. and Bougie, R. (2013). These views are key for clarifying the problem statement and answering the research questions. Therefore the literature review and the data (knowledge) collection will include studying and analysing existing articles, papers and journals from scientific journals and from various databases such as: ABI/Inform, ProQuest, JSTOR, ScienceDirect focusing on Six Sigma, Lean or LSS, DFSS and Capability Maturity Model (CMM) or a combination of these databases.

A structured questionnaire will be developed and distributed to a total target of 200 LSS and DFSS industry participants across industries and internationally, including academics who have conducted research to further examine the CSF's for LSS and DFSS methodologies and the relationship within Maturity Capability Model evolution. The structure of both the survey and interview questionnaires will seek to determine:

1. background of the respondent and organisation.
2. requirements for successful deployment of LSS and DFSS.
3. critical Success Factors (CSF's) for LSS and DFSS implementation.
4. respondent organisational Maturity Capability status.
5. the relationships for Capability Maturity Model in relation to LSS and DFSS implementation.

The research targets those organisations, institutions, consultancies and academics, (irrespective of industry sector) which have already implemented LSS and DFSS. The list of targeted respondents is inclusive but not limited to organisations that are public organisations, academic institutions, consultancies and industry practitioners. Also this research targets a sample of organisations with significant Continuous Improvement Programs (CIP) in both services and manufacturing industries and associations supporting, training and development including institutions such as Universities and others offering CMM, LSS and DFSS program certification or development. Not for profit government departments are also targeted where such departments have been reported to have implemented LSS and/or DFSS methodologies.

1.3.2 Hypothesis and Research Objectives

The hypothesis of this research is to establish and propose a maturity framework that is universally applicable across industries for organisations that need to manage their own Continuous Improvement Operational strategy taking cognisance of their maturity and associated capability whilst an ever evolving merging of technologies presented in Industry 4.0 necessitates the review of how tangible and intangible consumer products integrate for both hard and software. The research seeks to answer the following questions as Research Objectives to propose the intended sustainable and Integrated Capability Maturity framework. The Research Objectives identified for the determination of the hypothesis are:

i. **Research Objective 1:** What are the most significant CSF's for LSS successful deployment in an organisation?
ii. **Research Objective 2:** What are the most significant CSF's for successful DFSS deployment in an organisation?
iii. **Research Objective 3:** What is the contribution of CMM to LSS and DFSS implementation where such models have been explored?
iv. **Research Objective 4:** What impact does leadership specifically have in achieving capability maturity?
v. **Research Objective 5:** How will an integrated framework assist organisations to achieve capability maturity?

A combination of Quantitative and Qualitative results will be analysed. Quantitative analysis of Survey results will be reviewed followed by Qualitative interviews, which will be held with industry specialists and CI program leaders, including executive management, to establish correlation and support for the survey questions and literature review.

1.4 Importance of the research

Both the failure and low ROI of numerous LSS and DFSS programs throughout industry prompted this research. The avoidance by many industry leaders to adopt a structure of Continuous Improvement methodologies such as LSS and DFSS further places doubt on the industries' lack of acceptances of structured LSS and DFSS integrated Continuous Improvement programs. For example Fortune 500 organisations have already saved $427 billion in the period measured between 1987 and 2007 over just 20 years reported in Marx, M. (2007) and also Pulakanam, V. (2012) who summarised that (in the 28 organisations surveyed) savings were 1.7% of turnover and $2 for every $1 dollar invested in LSS and DFSS programs.

Worker productivity growth has been declining globally (see Figure 4) highlighting the need for a new approach for breakthrough productivity. Traditional models are delivering productivity growth but at lower levels than what is possible with the 4th Industrial revolution.

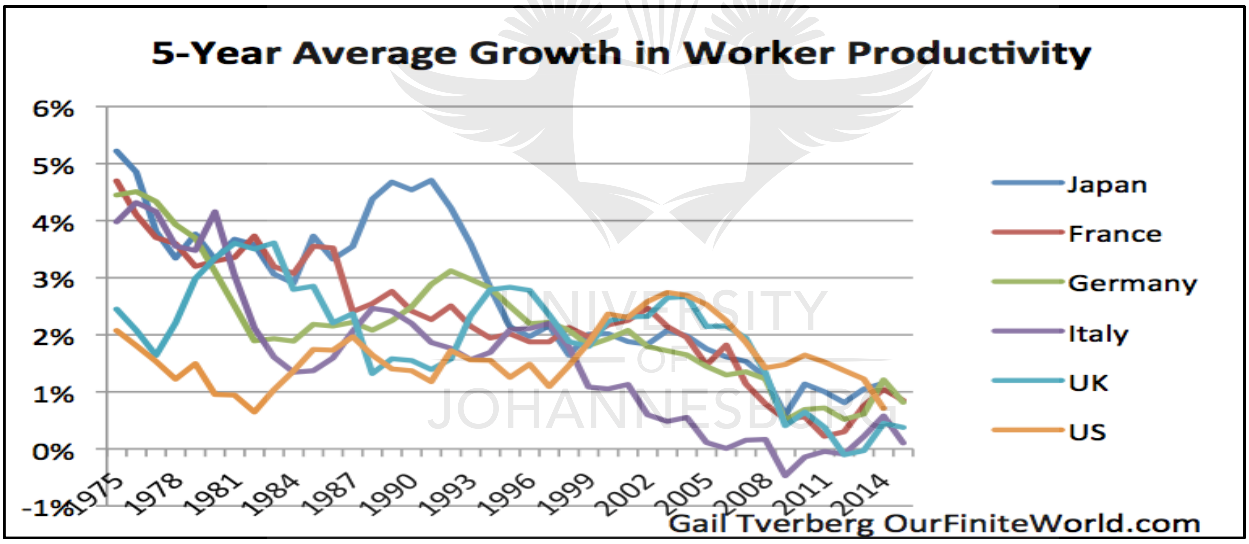

Figure 4: Five Year Average productivity growth in worker productivity, Source https://ourfiniteworld.com/2016/09/20/why-really-causes-falling-productivity-growth-an-energy-based-explanation/

Due to advances within the Internet of Things (IoT's) the need for a revised maturity model is inevitable and also involves a natural evolution with increased infusion of hard and software technologies. The contribution to the effective deployment of these tools advances the organisation's competitive advantage where organisations, in fact, manage to deploy successfully an operational excellence program. The model for true LSS and DFSS organisation cannot ignore the Maturity Capability of the organisation. The relationships need to be explored between the Maturity Levels contribution and the success of maximising ROI. To determine the broad views of integrating LSS and DFSS as highlighted in literature, it is important to note that all techniques need to complement each other.

Therefore, the researcher will investigate organisational infrastructures and Critical Success Factors when using different tools and techniques and management/employee involvement in improvement processes. The research is aligned to the recommendations of Zu, X., Fredendall, L. and Douglas, T.J. (2008) and Shah, R., Chandrasekaran, A. and Linderman, K. (2008) because these recommendations encourage researchers to explore the integration of LSS and DFSS methodologies into a unique approach to achieve operational excellence and maximise ROI.

Businesses always seek new techniques to alleviate human and organisational problems. Naslund, D. (2008) contends that businesses are more than likely to switch from one technique to another, if one improvement technique is proved to be more promising. The purpose of any change methodology is to improve efficiency and effectiveness. Naslund, D. (2008) claims that the justification of older management techniques was deficient due to lack of performance improvement. In addition, Montgomery, D.C. (2010) contends that properly constructed and validated simulation models are often good predictors of the performance of a new system. As a natural consequence, organisations can benefit immensely by using simulation models to study the performance of their own processes. Therefore, it can be deduced that integrating LSS and DFSS into a conceptual framework would provide a business improvement technique with minimum shortcomings.

This research also identifies possible shortcomings of existing continuous improvement (CI) techniques used by manufacturers and provides a view of Critical Success Factors by using LSS and DFSS to assist them in exceeding overall business excellence. It is anticipated that the result of the research will serve as a detailed, customised implementation "framework" for both manufacturing and service industries to become more competitive.

1.5 Validity and Reliability

The validity and reliability of the data collected and the response rate achieved depends on the design of the questions in both the survey and interview questionnaires by means of the structured questionnaires and the rigour of the pilot testing. Valid questions will enable accurate data to be collected. Reliable data will be meaningful when such information is collected consistently. This approach is used as a strategy to arrive at the correct conclusions according to the research questions asked and to maintain high construct validity. Since the covering letter of the questionnaire explained the benefits of the research, it was anticipated that the participants would answer the questions honestly. The external validity verification entailed working closely with other similar studies identified in literature to generalise and compare the findings as in Psychogios et al. (2012); Karthi et al. (2011); Snee, (2010); Chen and Lyu, (2009); Thomas et al., (2009); De Koning et al. (2008). Apart from the internal and external threats to validity, there are tests such as content validity, criterion-related validity and construct validity tests that are performed by researchers to ensure that the questionnaire design is valid for its intended purpose (Cooper and Schindler, (2006); Blumberg et al., (2005)).

1.6 Limitations of the Study

LSS and DFSS are known to be more than a philosophy, or continuous improvement methodology and not attainable without a significant investment in time and organisational resources which is not limited to capital and senior staff time but also with regard to projects and regular reviews and ongoing training of staff in terms of Yellow, Green, Black Belt and Master Black Belt certifications. The research review of the Critical Success Factors (CSF's) is initially qualitative and it then evolves into a quantitative review when correlation and inverse correlation of the known CSF's are compared in the development of a Capability Maturity Model. The CMMI framework is used as the point of reference for the development of a maturity model with a review of the applicability of DFSS as a significant tool in preventing LSS failures but also seeking to error-proof design parameters and systems engineering through risk mitigation modus operandi in delivering a framework to achieve quality beyond Six Sigma.

The contribution to the body of knowledge of LSS combined with DFSS and CMMI can only be evaluated through further research where a larger sample from different industry groups has been included in the research. Continuous Improvement is directly linked to strategy and resource allocation in support of the designed strategy. CMMI has proven itself as a significant framework to be considered in conjunction with LSS and DFSS.

1.7 Chapter layout of research

The research approach in the thesis design is to consider and include literature reviews of similar research hypotheses in both CSF determination for LSS, DFSS and Maturity Capability.

Chapter 1 explores and details an introduction into the problem statement, an overview of the research hypothesis and the respective Research Objectives and research scope. The research hypothesis defines the necessity of the success factors contributing the successful Lean operational strategy during Six Sigma design and deployment. Organisations do not have access to a recipe designed around a maturity model which contributes to the effectiveness of implementation across industries.

Chapter 2 incorporates extensive literature reviews of the most used Lean tools detailing their history, construction and applicability in identifying and removing waste streams with proven tested methodologies. The Chapter further includes literature reviews of the value, origins and contribution of Six Sigma, Design for Six Sigma and Critical Success factors for successful program implementation. This Chapter explores the various maturity models available and the contribution these models have on determining and improving Maturity Capability affected by dynamic changes in Industry 4.0 evolution and the integration of disciplines such as Agile, Scrum and TOC.

Chapter 3 details industry application methodology to determine the CSF's for LSS, DFSS, TOC and Agile deployment to complement a Lean operational strategy towards Capability Maturity. Industry applicability and methodology is also reviewed in this Chapter concluding a review of the relevance of the results obtained.

Chapter 4 details research methodology and the analysis of the results through descriptive statistical analysis, content relevancy evaluation, validity and reliability with proposed solutions and testing of the hypothesis.

This Chapter consists of:

1. Introduction and overview;
2. Methodological paradigm, research process and rationale for methodology used;
3. Research strategy and design and Methodology;
4. Exploratory study to discover capability maturity dilemma;
5. Populations, sampling and data collection;
6. Questionnaire design and layout for survey and interviews;
7. Steps of the research process;
8. Statistical tools, analysis and editing of data;
9. Conclusion.

Chapter 5 is an analysis of research inputs and results in both survey and interview sources along with the biographical data of participants through the Research Objectives of the hypothesis.

Chapter 6 concludes the research findings made in terms of Lean, Six Sigma, Design for Six Sigma, Agile, TOC and CMMI.

Chapter 7 proposes recommendations and a newly developed "framework" enabling organisations to adopt an integrated approach to implement CMMI, Lean Six Sigma and Design for Six Sigma and concludes with future research considerations as a result of Industry 4.0 technologies.

1.8 Conclusion

This first chapter defines the introduction and the focus of the research hypothesis in terms of LSS and DFSS supporting a Lean Operation strategy towards Capability Maturity. It stated the research problem, objectives and questions as defined in the research methodology.

Chapter 2 will expand on literature reviewed by the author reviewing the CSF's for both LSS and DFSS and the evolution and contribution of the various Lean tools towards developing Capability Maturity.

Chapter 2

2.0 Literature Study

2.1 Introduction

This chapter incorporates extensive literature reviews of Lean tools that are applicable in identifying and removing waste in manufacturing and services industries. The focus of Lean tools is to increase manufacturing and service success and commitments to high quality, low cost, as well as fulfilling customer requirements in a timely manner. The Chapter further includes literature reviews and contribution technologies in terms of LSS, DFSS and CSF's for effective and mature CI program deployment. Furthermore, the Chapter explores various maturity models available and the contribution thereof in determining and improving Maturity Capability affected by dynamic changes as applied in Industry 4.0 besides the integration of disciplines such as TOC, Agile and Scrum.

2.2 The history of applied Improvement Methodologies

Productivity and Continuous Improvement is a phrase used to describe the activity in a process to improve any aspect of a process or product when either more is done with less, or more is done with the same inputs. The actual product or service design yields improved functionality and greater levels recorded in customer delight reported in McClellan, J.E. and Dorn, H. (2015). Organisational performance-mapping and gap-analysis methodologies have been evolving in intent and design to constantly absorb best practices and new technologies which may aid in establishing a platform for Continuous Improvement initiatives and sustained improvement in a competitive global economy. In Stefaniak, J.E. (2015) continuous improvement methodologies can change the following; capability of staff; performance metrics; organisational competency as a whole and the organisation's maturity in totality across functional areas. Corsi, P. and Neau, E. (2015) postulate that in developing and sustaining capability maturity approaches it is imperative that:

1. Inno-toxic factors and common innovation diseases are identified

2. Mitigated instantly to avoid a decline in both Capability Maturity
3. Innovation Capability Maturity Model maintenance.

2.3 History of Lean

According to Hunt, B. (2009) the earliest historically recorded evidence of Lean can be found in 221 BC where standardisation was used to manufacture crossbows for warfare. This has been followed by similar Lean and Mass production techniques such as assembly line layouts which contributed to the earliest process thinking giving rise to Theory of Constraints (TOC) used in modern day process optimisation. TOC along with Six Sigma and Lean (as a methodology) have similarities and differences as can be seen in Table 1.

Table 1: Lean, TOC and Six Sigma methodologies comparison, in Nave, D. (2002): Quality Progress Magazine.

Program	Six Sigma	Lean	TOC
Theory	Reduce variation	Remove waste	Improve constraints organisation
Application guidelines	1. Define 2. Measure 3. Analyse 4. Improve 5. Control	1. Identify value 2. ID value stream 3. Row 4. Pull 5. Perfection	1. ID constraint 2. Exploit constraint 3.Subordinate processes 4. Elevate constraint 5. Repeat cycle
Focus	Problem focussed	Row focussed	System constraints

Henry Ford shared his vision with the world to build a car “for the great multitude” which resulted in the attraction of talented mechanics and the birth of the moving assembly line. The Ford vice-president at the time, Charlie Sorenson, developed the Ford production system further, increasing the production rate for the World War Two (WWII) producer of B24 Liberator bombers. Ford’s approach was influenced by Taylor, F.W. (1911) whose original work (also referred to as Taylorism) stated a foundation that job tasks and job assignments are designed, instructed and orchestrated by a managerial person. This approach received strong criticism by Matsushita, K. (2015) the founder of Panasonic, stating that business is so complex and competitive necessitating that the organisation's survival is dependent on mobilising every ounce of intellect.

Ford's approach also influenced Taiichi Ohno, the founder of the Toyota Production System (TPS), where the TPS approach organises Lean through standardisation and workplace layout in 5S with the emphasis to create flow and manage exceptions with Andon. Reducing all types of wastes (Muda) is the design of Lean by achieving low levels of inventory and JIT. TPS has seen a host of followers and copy-cats, i.e. PPS (Porsche Production System), FPS (Ford Production System), LPS (Lemforder Production System), etc.

Command and control as a result of top down management in the typical organisational hierarchy in the Western World was observed as limiting in maximising Kaizen (continual incremental improvement) activities and ROI. This development of Ford's production system increased the Japanese market share of the US automotive market where Japanese competitors were cost leaders as highlighted by the work of Deming, W.E. (1986) who was renowned as a strong thought leader for rebuilding Japan after the war driving the TQM approach in the 1980's leading into Six Sigma's popularity. It is seen as "elitist" and echoes Taylorism. Skilled Black, Green and Yellow Belts do not always have the knowledge of the process owners. These process owners often don't have a voice and are also a major reason that Six Sigma programs often fail.

The Capability Maturity Model the author is sculpting in Chapter 6 and 7 within this research document will explore also causes of failures along with the CSF's when deploying LSS and DFSS programs. Lean and Six Sigma along with DFSS is often implemented with elitism. A too narrow focus and excessive jargon such as tool usage instead of solving problems will also fail. The imperative for the organisation seeking to deploy a sustainable WCM program is to comprehend the tools that are available and to select appropriate matching tools to the ability, capability and maturity of the organisation. Further support is provided in the review of the CSF's for such an improvement program.

2.4 The historical evolution of Six Sigma (6σ)

2.4.1 Introduction

Six Sigma roots evolved over a period of three centuries from the early 1800's to the current 21st century with major industry acceptance and globalisation driving the necessity of a uniform standard used to design and maintain processes which are either tangible, non-tangible or both. The author will review major events over this evolutionary period that have sculpted Six Sigma into its modern day industry format.

2.4.2 Eli Whitney Mass Production and Interchangeable parts (1798)

Mass production and "interchangeable parts" sees Eli's company awarded a government contract to produce 10,000 muskets and in the execution of this contract, production flow and layout was achieved in assembling standardised parts for guns assembled where quality standards were implemented in the decades to follow against a known design (best possible) and to match the original design. Figure 5 illustrates the Gaussian limitations of both upper and lower tolerances of an inside hole diameter, which is an example of standardisation and tolerance control.

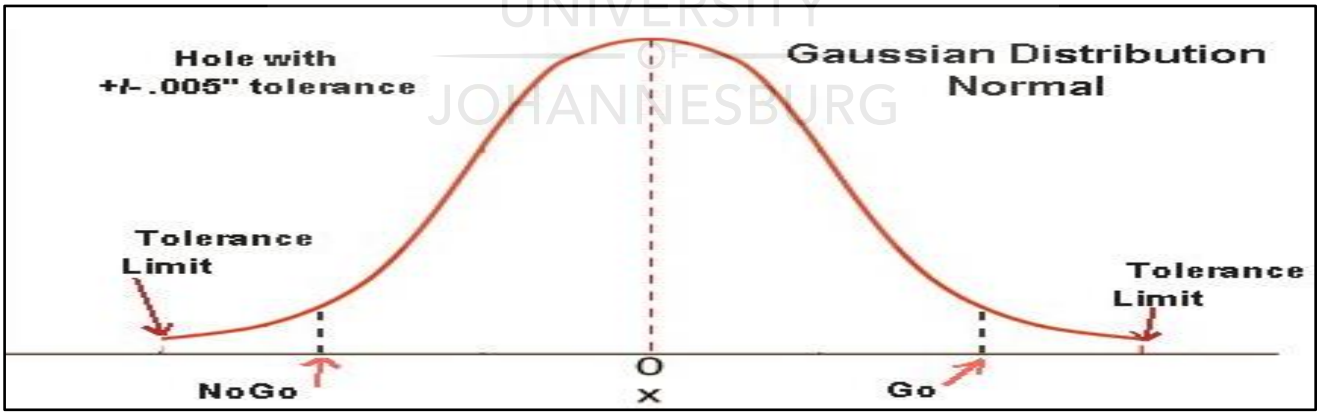

Figure 5: Gaussian distribution for upper and lower level of Go/no Go gauge tolerance.

Attribute gauges used in production measuring maximum and minimum tolerances assisted in production repeatability achievement in 1828. These measures evolved into specifications which can be seen further in this chapter in Table 2 for a list of Six Sigma eras.

2.4.3 Gaussian distribution (1825)

The origins of SS is found by one of the world's most gifted and prodigious mathematicians in history Gauss, C.F. (1825) who made major contributions to the fields of geometry, algebra, statistics, probability theory, differential equations, electromagnetics and astronomy. Gaussian distribution was named after him and is also known as Normal Distribution used extensively in quality control such as Six Sigma. The original research recorded by Gauss was translated into English by Stewart, G.W. (1987). The Gaussian (Normal) distribution is a common continuous probability distribution. Normal distribution is significant in Six Sigma data analysis because of the Central Limit Theorem (CLT) applicability (predicting probability of occurrences evaluated). Typically defect rates derived from process conformance percentage based on sampling can be evaluated as seen in Figure 6.

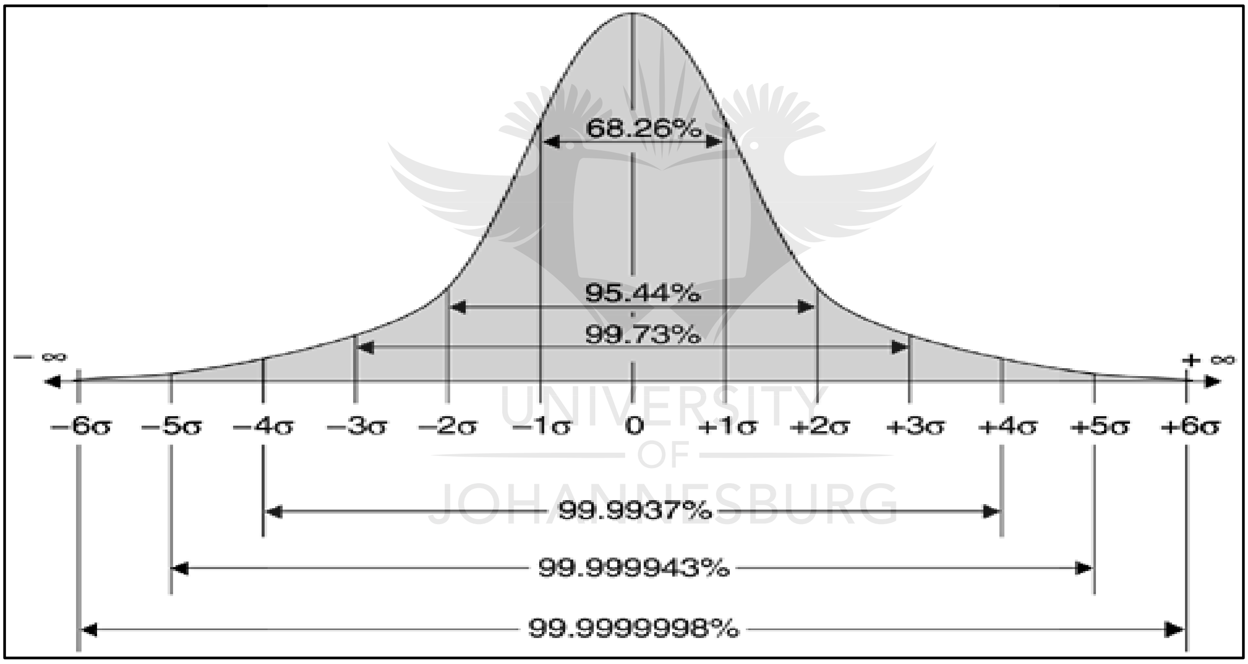

Figure 6: Typical defect rates and acceptance percentages at different sigma levels of quality conformance. Source: American Society for Quality (2015) www.asq.org

Paret, M. (2009) sites the importance of CLT where the distribution of the histogram determines the process capability index and a narrow data distribution represents a very high level of process capability and wide data distribution a lower level of process capability.

Six Sigma roots evolved over a period of three centuries from the early 1800's to the current 21st century with major industry acceptance and globalisation driving the necessity of a uniform standard to design and maintain processes which are either tangible, non–tangible or both.

Normal distribution is critical to LSS as it addresses any process analysis by segmenting the total data distribution into six equal distribution zones, each equal to one sigma (1σ), also known as "standard deviation," and two groups of three sigma (3σ) each bisected by the mean, with the total sum equal to, and thus the designation, Six Sigma. In Figure 7 the shift in 1.5 Sigma can be observed.

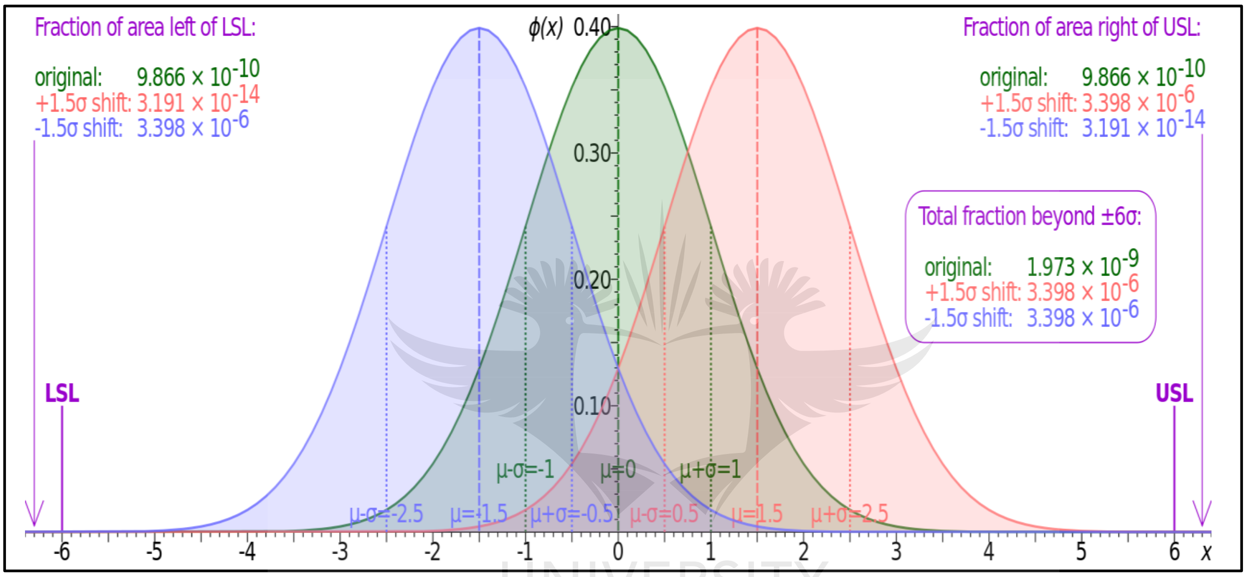

Figure 7: Shift in plus or minus 1.5 sigma with the Gaussian curve satisfying ± 4.5 Sigma quality and calculated 3.4 DPMO, 2009 Source: www.isixsigma.com

Six Sigma's origins in Gauss, C.F. (1825) pioneered the application of the bell curve in the 18th century. Sigma (σ) is the unit scale that identifies the difference between the inflection point and the mean identified as µ. The distance determines the spread of data points for the sample group measured where a narrow distribution represents a capable (Cp/Pp) process but not necessarily in control (Cpk/Ppk) between Upper Specification Limit (USL) and Lower Specification Limit (LSL), which is where the 1.5 sigma shifts comes into play. The assumption is that if a process is Six Sigma capable it satisfies ± 4.5 Sigma process distribution seen in the blue and pink bell shape curves in Figure 7. The values for the green bell curve represents Sigma of 1 and µ at zero in the centre of the specification level. LSS DMAIC attempts to frequently measure and control process variation within ± 4.5 Sigma limits economically or to that of the process entitlement sigma Level according to Markoulides, D. (2016). Where such a process does not yield the Sigma quality, which is often desired but not designed during product and process development it suggests intervention such as a DFSS project to achieve the higher desired sigma level.

In a research paper published by ASQ, the review of LSS future trends, Folaron, J. (2003) arrived at several conclusions which will be reviewed by the author starting with a comparison drawn by Patton, G.S. (2007) a military general and a student of history. He stated (through his readings and research) that CI and lessons learned in a learning organisation determine an organisation's ability to mitigate recurring failures and faults.

2.4.4 Henry Ford Moving assembly line (1913)

Henry Ford introduced the *Moving production space and work area,* which highlighted quality repeatability where a nonconforming part would result in line stoppage or slow down whilst remedy or good product was sorted or acquired. The maturing industrial revolution required innovative methods to assure product consistency and testing parts with attribute Go No Go gauges was slow, laborious and expensive. Methods needed to be found for sampling accurately moving away from 100% inspection.

2.4.5 Walter Shewhart 1924

At Western Electric Manufacturing Walter Shewhart (in 1924) was part of the breeding ground for many published and recognised quality leaders and also the development of Statistical Control Chart (SQC) Control limits were computed as a derivative data collection and used to pre-control a process and alert the process controllers to changes in the process before it was out of control. The typical detection role has changed to monitoring stability. The use of statistics grew into the US government adopted military standard MIL-STD-105A (1951) defining contractual product requirements and sampling to assure compliance to process population. In later versions MIL-STD-105C and MIL-STD-105D (1963) are part of the evolution of statistical sampling made more prominent and according to Squeglia, N.L. (1994) and (2008) and the Acceptance Quality Level (AQL) has changed from accepted levels of rejections to zero defects.

2.4.6 Japanese move on the US market (1973 and mimics Japan 1980)

The Japanese were more effective at constantly improving quality and manufacturing efficiencies than the competing US industries during this period in Shainin, D. (1963). The focus by the Japanese was centred in defect elimination and cycle time reduction. The oil embargo of 1973 forced the US industry to recognise the value of quality and this continued after the embargo subsided when the Japanese developed and delivered vehicles that were of a higher quality, more affordable and more efficient than US-produced vehicles resulting in US market share losses to foreign vehicles. In a NBC (1980) documentary initiated by US industry leaders visiting Japan they had to observe how the Japanese were achieving stellar process efficiencies compared to their US counterparts. Deming, W.E. (1993) assisted US managers to understand the concept of process and product variation and also the application of statistical tools in their respective industries. Significant quality contributions are observed in Feigenbaum, A. (1945), Ishikawa, K. (1981), Akao, Y. (1990), Taguchi, G. (2005), Shingo, S. (1986) and Crosby, P. (1979).

2.4.7 Total Quality Control (TQC) (1983)

TQC (in Stone, K.B. (2012) and in Feigenbaum, A. (1951)) defines this approach as the staged control of quality. In TQC every station for production becomes an inspection and quality gate in the process flow which is visualised with Andon and visual display boards of key metrics in production, inventory and quality. Japanese quality designers historically sought 100% inspection and not merely sample inspection deployed by the West even with the advent of SPC and SQC.

2.4.8 International Standardisation for Organisation (ISO) (1987)

The establishment of ISO 9000 management systems for quality was a direct creation of a global need for the development of industrial standardisation organisations dating back to Great Britain in 1901. Most industrialised nations had similar organisations. In 1987 the first publication was printed by ISO derived from BS-5750 which gave input into the establishment of the quality management system ISO9000 series specifying standard expectations for an organisation. Promoting uniformity by its design between nations which had their own set of specifications these global standards set the platform for customers sourcing from different nations.

Table 2 is a summary of evolutionary events across the globe that have resulted in LSS and DFSS as we know it in 2017, including major historical intervention points as reviewed in the literature.

Table 2: Time Line of Six Sigma development and preceding eras. Source: Six Sigma Forum Magazine www.asq.org (2011) and adapted with inclusion of ISO 13053 part1 and 2 standard.

1798	E. Whitney – Standardise parts and standardised volume production • Production, design repeatability and non-conformance classifications
1825	Gaussian distribution (Six Sigma distribution)
1913	Henry Ford Moving production line
1924	W. Shewhart • Process orientated thinking • Control charts (assignable and common cause)
1945	Japan standardisation • SPC and SQC • CI and PDCA deployment • Reversal of pyramid organisation into inverted bottom up employee approach • RCA and CA, Ishikawa
1973	Japan evolution • Fast response to VOC and CQT needs

1980	P. Crosby • Systemic approach to QC and QA design • CI for business in all functional areas • Lean approach and zero defect
1987	ISO • Minimum requirements for organisations through standard practices • Empirical CI structure
1987	MBNQA (US) • Maturity framework with VOC emphasis
1987	LSS • VOC and DMAIC interlinkage • Set approach for CI and problem solving using statistical tools
1960-1995	Alternate approaches • CI and CA methods without structure
2011	Establishment of further focussed ISO 13503-1/2 series for Six Sigma performance improvement Methodology

In addition ISO 9000 requires suppliers to conform to 3rd party business and quality systems audits and confirmation of adherence to a set of standard rules within one management system. This approach does not guarantee but provides reasonable assurances of good maintenance of integrity and also management of deviations within a controlled environment. ISO 9000 series therefore assisted in the definition of sound quality practices but did not guarantee product fitness for use by addressing mostly process consistency. In many supply agreements 3rd party certification became a minimum standard condition of supply.

2.4.9 Malcolm Baldridge National Quality Award (MBNQA) (1987)

It was evident that throughout the 1980's US organisations lost market share to constantly improving foreign competition and in particular to Japanese organisations who would constantly share and implement best practices within their respective operations. MBNQA was introduced in the USA and is also seen as a Maturity framework with VOC emphasis driven by improving VOC metrics and predecessors.

2.4.10 Six Sigma (1987)

Quality improvement flourished under Bob Galvin's leadership and support and it was also impacted externally by market improvements of foreign products. Motorola internally ran the bandit program, which was similar to MBNQA inclusive of VOC and industry best practices. Process capability and defect reduction through process variation reduction [in Pyzdek, T. (2003)] allowed for lower rejection rates measured in Parts per Million (ppm). The message was clear to ensure adoption in the industry was pivoting on the comprehension of the significant opportunities identified using the DPMO formula and that customers' ever changing expectations must remain a product design and delivery consideration. The significance often misunderstood is not the achievement of a low LSS defect rate such as 3.4ppm but rather the structure which the DMAIC approach offers in LSS.

2.4.11 Post Motorola (1988)

MBNQA recipients and recognised quality leadership created a best practice sharing expectation and the CI platform provided by LSS and in particular DMAIC which also saw Allied Signal being another early adopter of the Six Sigma methodology led by the CEO at the time, Larry Bossidy, who turned the loss making organisation around between 1991 and 1999 before he retired. In 1995 Larry introduced Six Sigma to his former colleague, CEO Jack Welch, at General electric who, in turn, turned it into a corporate requirement with tremendous successes.

2.4.12 Other Initiatives (1960-1995)

The big three US auto manufacturers led by Ford, GM and Chrysler devised a Quality Management system consolidating the US automotive industry standard titled QS 9000 introduced in 1994. Third party certification to the standard was a requirement for vendors supplying to any of these three manufacturers or Original Equipment Manufacturers (OEM's). The standard is based upon ISO 9000 and includes additional requirements as agreed by the big three what should be seen as a standard for their respective supply base to ensure the necessary controls (not covered for manufacturers) in the basic ISO 9000 quality management system. In particular tools that are mandated within the vendors subscribing to QS 9000 automotive quality management system are statistical process control, sub-supplier management and sub-supplier quality management quality system certifications, PFMEA/DFMEA, strategy and evidence of focussed and documented continuous improvement system within the business. Other quality initiatives from the 1960's through to the 1990's made significant contributions in product or service quality and business redesign, but because these were not comprehensive and all-inclusive systemic approaches most failed the much needed sustained industry acceptance over and above consultant jargon.

2.4.13 International Standard for Organisations and Six Sigma ISO 13053-1/2, ISO 17258 and ISO 18404

ISO 13053-1/2 – In 2011 due to both manufacturing and non-manufacturing industry's rapid industry need and adoption of Six Sigma saw ISO publishing ISO 13053-1, which describes the DMAIC approach and ISO 13053-2 which describes the tools and techniques. According to Boulanger, M. (2011) process variation is reduced when using DMAIC to improve QTC and VOC metrics.

Industry acceptance and use has necessitated the development of a series of ISO Standards for LSS deployment to address both the needs of mature but also immature LSS organisations.

ISO 17258 – Describes a set methodology to achieve organisational maturity when performing internal and external benchmarking using statistical methods described in the standard which is also a component of MBNQA and EFQM.

ISO 18404 – It is the 3rd party certification process whereby an external party establishes either the Lean or the Six Sigma (or both) methodologies' conformance to the standard requirements. In effect it is an attempt to confirm organisational maturity to Lean, Six Sigma or LSS combined. The establishment of the standard was as a result of poor Lean and/or Six Sigma deployments in the industry.

2.5 Lean manufacturing Tools and Techniques

2.5.1 Introduction

Production and operations management (POM) is the discipline from which Lean originated in the Toyota Management System (TMS) known in the manufacturing word as TPS or the Toyota Production System (in Ohno, T. (1988a), Monden, Y. (1993), Womack, J., Jones, D. and Roos, D. (1990) and Emiliani, M.L., Stec, D., Grasso, L. and Stodder, J. (2003)).

The Lean Management System (LMS) in (Kimoto, S. (1991); Togo, Y. and Wartman, W. (1993); Reingold, E. (1999); Wada, K. and Yui, T. (2002)) has a singular focus on improving worker productivity through waste removal classified as the three big wastes in Muda, Mura and Muri which are described as follows:

Muda – Waste in general, which is what Lean seeks to mitigate and remove economically and herein there are seven classifications of wastes described in the industry abbreviation TIMWOOD which relates to, Transport; Inventory; Motion; Waiting; Over Processing; Over Production and Defects.

Mura – signifies unevenness requiring balance which is possible when JIT is achieved through Heijunka (line balance) in one piece flow and minimal WIP.

Muri – means unreasonableness requiring a standard approach mitigated through a key Lean tool being standardisation.

Lean is a journey and as such requires maturity to manifest itself in the DNA of an organisation and or functional area [Sayer, N.J. and Williams, B. (2012) and Emiliani et al., (2003)]. Bottom lines in terms of EBITDA and ROI are realised at a fraction of the cost for implementing and sustaining a Lean approach.

The following five primary elements emerge [Feld, W.M. (2001) supported in Hall, P. et al. (2001) and Sayer, N.J. and Williams, B. (2012)]:

1. **Manufacturing flow** –Takt-time, line balance and standardised work enables one piece flow and minimal WIP.
2. **Metrics** – Visualisation of actual metrics and Andon for escalation in OEE data signifying the major loss contributors.

3. **Process Control** – SPC, SQC, TPM in AM and PM activities and for risks mitigation Poka Yoke and SMED to reduce change over losses within a 5S environment.
4. **Organisation** – Hoshin Kanri and inverted delta hierarchical management structure with significant employee empowerment
5. **Logistics** – Kanban and JIT in the entire organisation and supply chain reducing WIP and cost associated with stock holding.

The most prominent industry used Lean tools according to Sayer, N.J. and Williams, B. (2012). These tools will now be discussed individually for both origin and intended use.

2.5.2 Five S (5S)

The manufacturing industry has accepted that 5S is the starting point and the foundation for any Lean program to maximise efficiency in the workplace. 5S is derived from 4S where the 5th S is for sustain or Seiketsu. Table 3 details the translation and significance between the various 5S methodologies.

Table 3: 5S translated adapted from www.qualitydigest.com

S	Japanese word	English word	Actions	Effect
1S	SEIRI	Sort, Clearing, Classify	Identify and eliminate all unnecessary items	Action
2S	SEITON	Straighten, Simplify and Set work place in order	Work place organisation and ease of access to tools and materials	
3S	SEISO	Sweep, shine, Scrub, Clean and Check	Clean work place thoroughly as found when new	

4S	SEIKETSU	Standardise, stabilize, Conformity	Maintain very high standards of housekeeping	Culture
5S	SHITSUKE	Sustain, self-discipline, custom and practice	Create a culture where all employees practice 1-4s	Habit

Hirano H. (1990) and Ohno, T. (1988a) were regarded as the designers of the 5S methodology. Figure 8 below describes the complementary nature of 5S methodology.

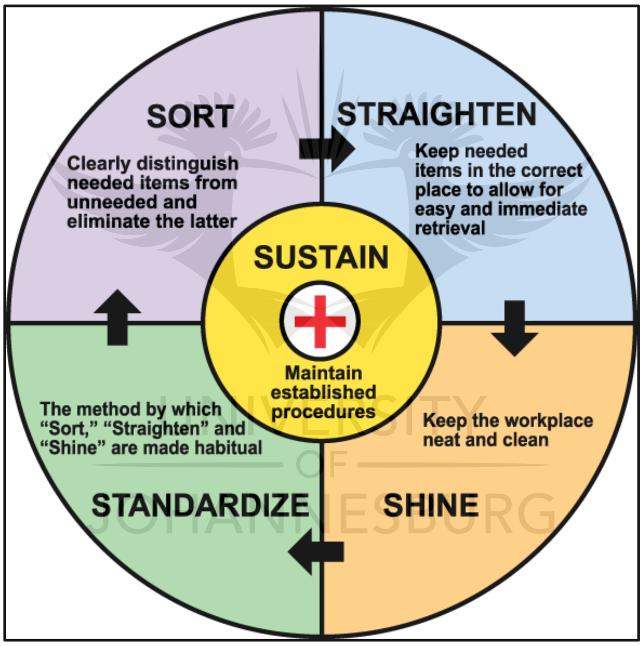

Figure 8: 5S Methodology Source: www.Leanaccount.com

Bicheno, J. (2009) diluted 5S into 4S in Hirano, H. (1995) which is an original approach combining 2nd and 3rd S which did not see significant industry followers and the default 5S for workplace organisation remains. In Figure 9 below it shows the practical shadow board often created out of the necessity to have the standard tools ready at hand and uses a visual shadow to identify the return position of any tools used and also the signal that a tool is missing to complete the set of assets.

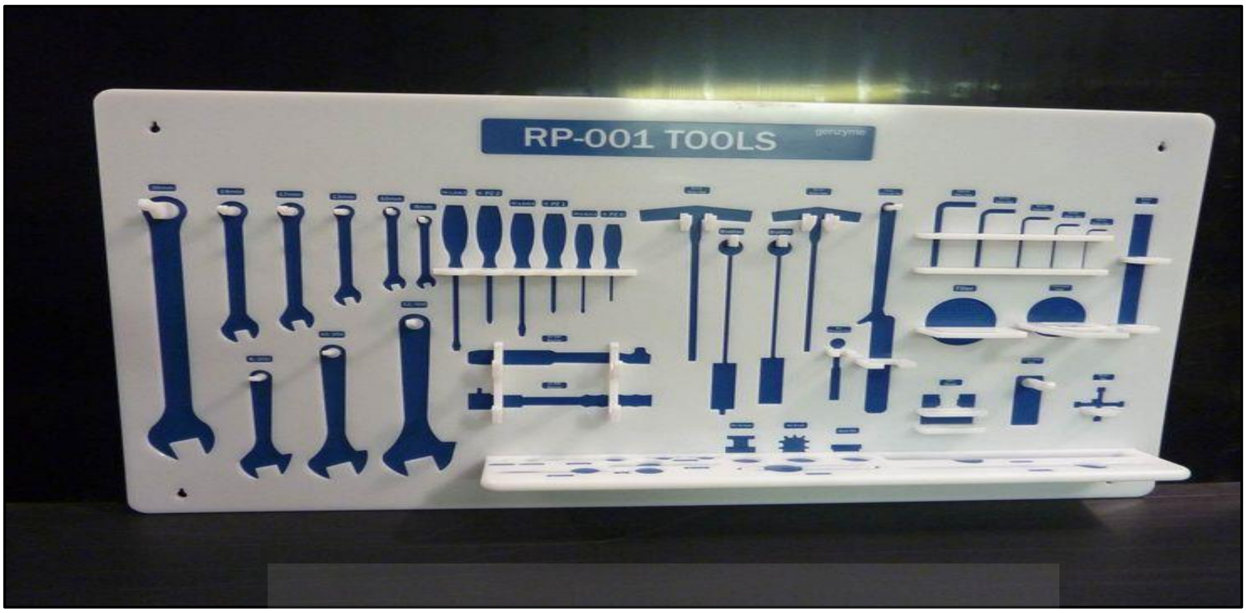

Figure 9: Shadow tool board, source: http://davebarryplastics.com

The Hawthorne effect is a reality in Lean failure that many practitioners and implementers struggle with where the change in Lean is maintained whilst management drives the process and in turn it also is not sustained after management focus has left such a change initiative and will be explored in Chapters 5 and 6 in the survey analysis and Research Objectives relating to management and leadership's contribution in CI programs including Lean and LSS deployments.

2.5.3 Andon

Liker, J. (2004) observes that Andon is mostly used on the shop floor as visual feedback tool relating to production status, quality alerts and it empowers operators to be process owners that have the authority to stop a nonconforming production process. Andon has a primary function of improving throughput by strengthening the weakest link in the supply chain manufacturing process. The Ford Production System (FPS) makes extensive use of Andon and confirmed by Berry, O. (2017) to both enable escalation to be done and to respond timeously as a result of significant process or standard conditions during normal working processes. Figure 10 below illustrates a modern day Andon OEE display used inside a manufacturing operation visualising real-time operating metrics.

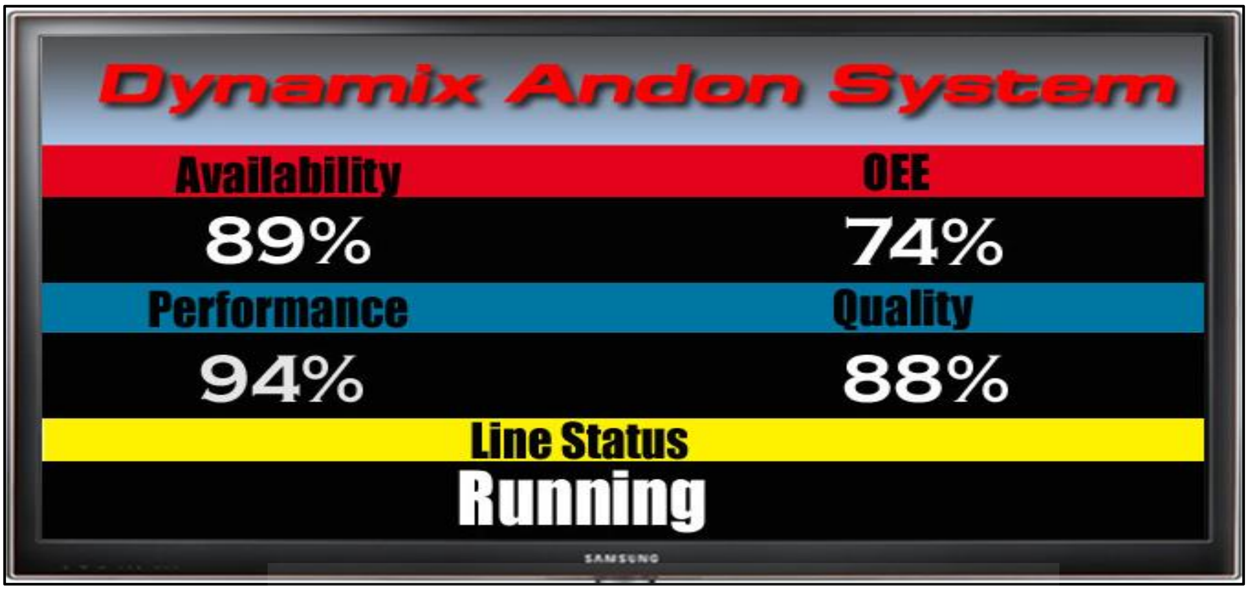

Figure 10: Andon OEE display, source: www.dynamixautomation.com

Andon visualises key metrics and alerts process owners to react. Modern Andon requires Industry 4.0 technology to automatically detect and react to events such as machine or process stoppage controls to prevent adverse machine or process conditions causing significant value and/or time losses. This type of automation is especially a direct result of human fatigue and variation in responses and processes that require zero part per million (ppm) rejection quality.

2.5.4 Theory of Constraints (TOC)

Bottlenecks are often the term used in any process constraint. TOC aims to identify these bottleneck constraints and ultimately to mitigate them to achieve economic cycle times. TOC (Cox, J. Goldratt, E. M. (2014)) seeks to reduce cost and maximise investments made through the application of the 5 steps of focus (Identify, Exploit, Subordinate, Elevate and Repeat) for constraint reduction and elimination which can be seen in Table 4. TOC also allows for processes similar to DMAIC and RCA for analysis and problem resolution and importantly Throughput Accounting (TA) (Hohmann, C. (2016)) which allows for distinct three KPI's which are Throughput, Operation Expense and Investments with two ratios ROI and Net Profit (NP) metrics and subsequent mitigation.

TOC features a set of FIVE focus steps and reality **tools** to examine the entire system for continuous improvement. Table 4 identifies the five focus steps and their respective objectives. These five steps are also referred to as POOGI (Process of Ongoing Improvement).

Table 4: Five focus steps in TOC process, Source: http://www.Leanproduction.com

n	Focus
Step 1 – Identify	ID process constraint or process bottleneck
Step 2 – Exploit	Utilising minimal additional inputs seek to implement rapid improvements (Lean philosophy)
Step 3 – Subordinate	Consider the entire process chain and also actions that impact on the constraint
Step 4 – Elevate	Measure the result and establish if additional actions are required to reduce the constraint
Step 5 – Repeat	Continuously seeking to eliminate constraints maximising NP and ROI

TOC also consists of three thinking processes which are:

- Identify the details of what requires a change
- Determine: "what should the transformed process look like or change to?"
- Establish: "what are the physical activities which will result in the desired change?"

One of these tools, the current reality tree (CRT), seen in Table 5 below compares cause and effect diagrams (CEDs), a total quality management (TQM) tool, to help identify what needs to change. Each tool is applied to an actual business problem to illustrate advantages and disadvantages. Because the use of CEDs is so well understood, the focus here is on the use of a CRT to solve the problem. TOC tools that have been formalised are discussed in Bakke, E. and Shoulder, S. (2017).

Table 5: Primary Thinking Processes in TOC, Source: TOC Institute (2017).

Tool	Role	Description
Core Conflict Cloud (CCC)	Conflict clouds	Identifies the UDE's (Undesirable Effects) or GAPs within a process
Current Reality Tree (CRT)	Documents the current state.	ID and defining existing status with possible RCA resolutions
Evaporating Cloud Tree (ECT)	Evaluates potential improvements.	Similar to the **A** in DM**A**IC seeks to analyse and review potential solutions for migrating from CRT to the FRT.
Future Reality Tree (FRT)	Designs the desired and future state.	FRT simulates the condition designed or required
Negative Branch Reservations (NBR)	Identifies any negative impacts of any applied actions	NBR is to understand the causal path between the action and negative impacts so that the negative effect can be adjusted.
Prerequisite Tree (PRT)	Intermediate objectives	Identifies the influencing objectives that will have an impact on the constraint / process.
Transition Tree (TT)	Defines actions required for changes	Describes in great detail the actions and activities that leads to the changes required stemming from the PRT
Strategy and Tactics Tree (S&TT)	GAP analysis	Design that allows for the FRT to be implemented with define actions as define in the GAP analysis and supersedes the PRT.

CRT relies on cause and effect logic to identify root causes and core problems requiring change. CRT adheres to a set of rules for construction, validation, and interpretation that creates a consensus among those involved with the problem. While considered by many to be easier to use, CED doesn't picture the underlying logic of the problem nor does it identify the root cause as quickly as does CRT structure. CRT's ability to identify what to change can help focus team members on identifying the root cause of a problem.

Bottlenecks and TOC solutions – Hohmann, H. (2016) observes that (logically applied) more than one tool can be used to eliminate or improve a constraint and the following are tools included in the literature review in Chapter 2 and also provide input into the design of the integrated maturity framework in Chapters 6 and 7:

1. **Six Sigma** can help resolve quality problems, (also reported in Harver, G. (2015)) who reports the reduction of quality defects and reworks increased capacity immediately of any process.
2. **Setup reduction** is a performance loss and standardised works combined with 5S and SMED improvements increases availability and also capacity.
3. **Lean** seeks to achieve flow and JIT with Andon and Kaizen events.
4. **TPM** classifies the 6 big losses and also through visualisation of these losses may afford the teams opportunities to mitigate losses identified.
5. **Industry 4.0** and technology deployment enables improved response and reaction to defects, real time MES data where setups are completed outside of allocated time which are automatically escalated and AM pillar in TPM will require upskilling in calibration and cleaning equipment such as 3D printers providing greater Agility in manufacturing.

The inclusion of TOC within Lean and Six Sigma for Industry 4.0 can assist in an integrated framework which will be explored further in Chapters 6 and 7 and the verification of the five Research Objectives as stated in Chapter 1.

All processes have inherent constraints [Papadopoulos H. T. and Heavey C., (1996)] and cycle times may match customer demand but will be exposed as soon as demand increases sufficiently past the constraint [Akeniz, C. (2016)].

It is observed that constraints can move when similar capacities are confirmed in Goldratt, M.E. (2014) and Li J., Blumenfeld, D. E., Huang N. and Alden J. M., (2009). Criticisms observed and cited in respect of TOC are seen in Steyn, H. (2000) incorporating significant aspects from systems dynamics developed by Forrester, J. (1968) and from SPC.

2.5.5 Cellular manufacturing

Cellular manufacturing is derived from arranging assets in a closed cell configuration where the starting point often is also the exit point, in figure11 below is a depiction of a cellular layout also known as a U-Shaped manufacturing cell layout:

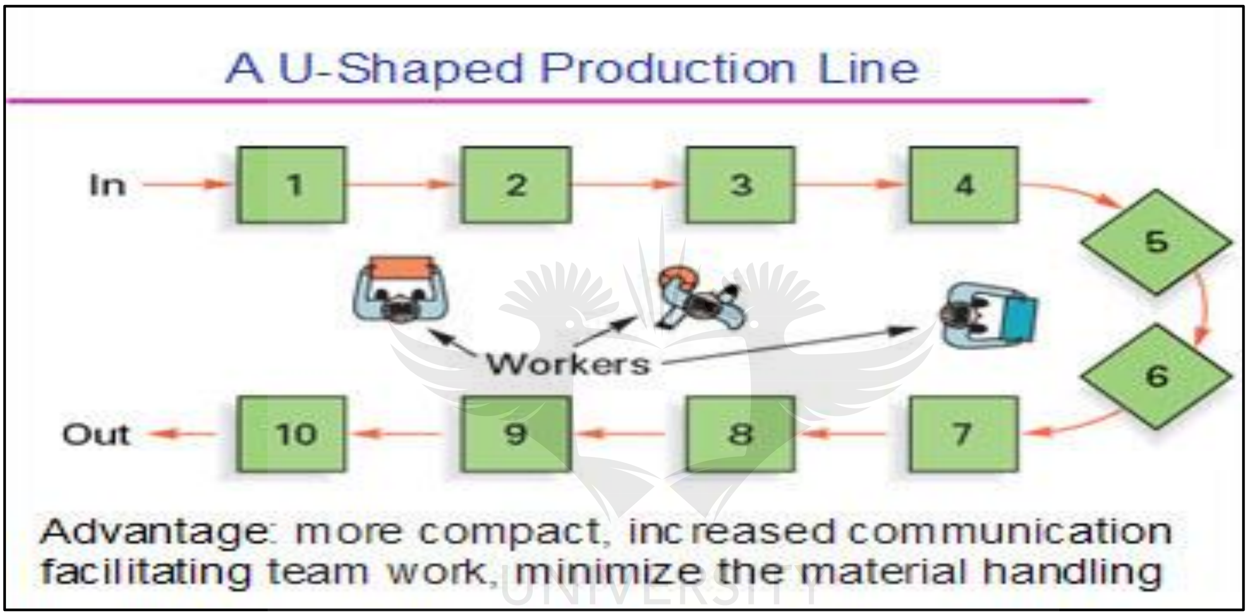

Figure 11: U-Shaped (Cellular) Production layout, source: http://www.mdcegypt.com

Cellular layouts originated as proposed by Flanders, R.E. (1925) and a derivative of group technology and later adopted and refined in Russia by Mitrofanov, S.P. (1959) in earlier work, started in 1933 and was translated into English in 1959 only. Burbidge, J.L. (1975) actively promoted group technology in the 1970's at the same time as Japanese organisations started with deployment of cellular manufacturing where its migration was seen in the US in the 1980's integrated with JIT deployment in production organisations.

Advantages of group technology are:

a. Enable cellular manufacturing
b. Reduce engineering cost
c. Accelerate product development

d. Improve costing accuracy
e. Simplify process planning
f. Reduce tooling cost
g. Reduce labour cost
h. Simplify purchasing
i. Facilitate VSM

Group technology such as Computer Aided Process Planning (CAPP) is the use of computers to assist in these activities. It benefits manufacturing further by reducing the inputs for process planning through CAPP and also provides a link between product design and manufacturing [Scallan, P. (2003)]. At the “macro” level, the sequence of operations and appropriate resources are the main concern while “micro” process planning focuses on defining parameters of each operation, determining the time it takes, and selecting tools and fixtures as needed [ElMaraghy, A. (1993)].

2.5.6 Continuous Flow

JIT has a close relation with Continuous flow and similarly know as “repetitive-flow” Manufacturing (RFM) which is a flow of material without stock or delays in-between processes. Rother, M. and Harris R. (2001) state that most manufacturing organisations work in their facilities to create flow. Unfortunately, little of it is actually achieved. For example, it seems that many organisations concentrate on making U-shaped process layouts instead of on the more important part: creating and maintaining an efficient continuous flow.

Almost any grouping of machines that performs processing steps in a sequence is called a ‘cell’, but it is rare to find real continuous flow which is what actually makes a cell a cell. Cycle time needs to be matching the pacemaker time or Takt-time. It is advisable to have a lower Takt time than your cycle time since things go wrong in manufacturing and on a three 8 hours shift allows for high machine utilisation but little if any time to recover from any production problems such as machine failure or quality problems which is part of such an operation. Leone, G. and Rahn, R.D. (2003) observe that Kanban and JIT enables flow, however, quality and break-down disruptions and associated management determines continuous flow effectivity.

2.5.7 Gemba (The real place derived from Japanese)

Gemba is where the process and production takes place; this could be an office, or factory floor or a customer's premises. A Gemba walk is a walk where the action is taking place and in Mazur, G. (2007) who cites the customer as the central driver for all activities and QFD allows for listening to what is important to the customer similar to VOC but a focus on building the quality into all activities.

Genba walks denote the action of going to see the actual process, to understand the work, ask questions, and to learn. It is also known as one fundamental part of Lean management philosophy.

In Liker, J.K. (2003): Genichi Genbutsu is a Japanese phrase that translates into English as to "go and see for yourself" is a central tenet of TPS. The idea behind Genichi Genbutsu is that business decisions need to be based on first-hand knowledge, not the understanding of another person which might be biased, outdated or incorrect.

According to Dunn, E. (2016) out of the five key principles of the Toyota Way, the one that most changed western approaches towards work and life is Genchi Genbutsu. The other four approaches being Challenge, Kaizen, Teamwork and Respect for People did not necessarily represent new ideas. However, the way that people in Toyota practice them is indeed very particular. Hinners, N.W. (2009), Peters, T. (2006) and Waterman, R. H. (2006) observes Gemba as management by walking about, looking to see where is there opportunities to assist and support Kaizen activities.

2.5.8 Heijunka (Level Scheduling)

Heijunka is a synonym for levelling in Japanese. In Todorova, D, (2013) in Deif, A. (2011) Heijunka is considered to be an enabler for organisations to meet consumer demand and simultaneously reducing wasteful activities in the processing of tasks and operations. Heijunka optimisation is possible following value streams finalisation and subjected to a Lean framework philosophy where such process and materials cycles have been optimised.

Figure 12 triangulates the relationships of agility in flexibility, control through predictability, production evenness in labelled level scheduling. Heijunka works with continuous flow, you cannot have the flow without predictability, flexibility and stability which can be achieved through good consistent planning.

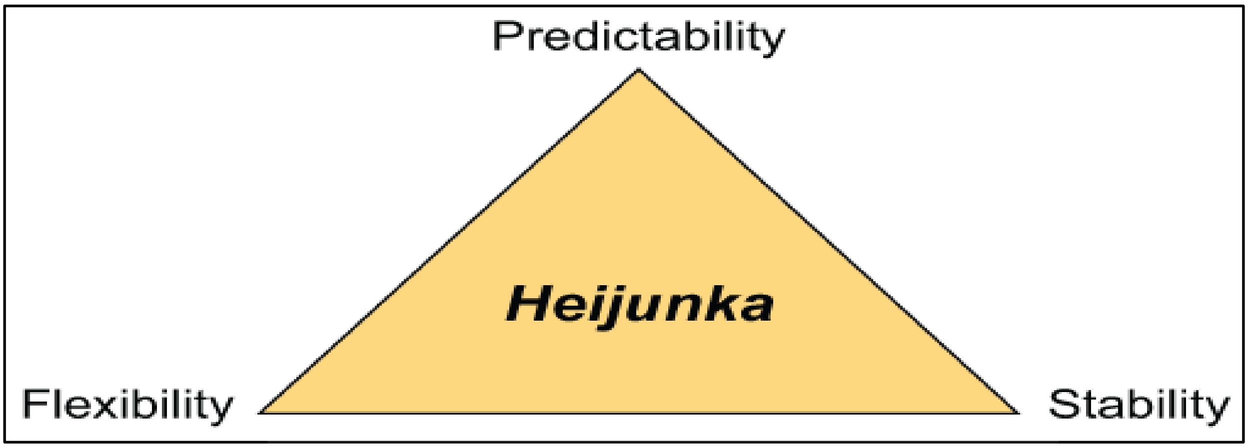

Figure 12: Heijunka is the outflow of flexibility, stability and predictability when production is balanced. Source: http://www.isixsigma.com

Heijunka in Haaster et al (2010) is observed as being a significant Lean tool that is used to stabilise a manufacturing system and confirmed in Forrester, J. (1961) one that reduces the bullwhip effect. Production levelling is a kind of cyclic scheduling that creates production regularity and coordination simplicity. The assembly line is organised according to Lean principles with Heijunka-Kanban production control. The simulation technique is applied to evaluate the performance of the manufacturing system which requires modifications to achieve two objectives, i.e. to minimise the average throughput time and to minimise the average work-in-progress.

Heijunka, also called production levelling, is a key element of TPS which levels the release of production Kanbans in order to achieve an even production flow over all possible types of products, resulting in reducing the WIP. It is also known that a supply chain that is not managed remains inherently unstable and increases demand variability and perpetuates and accentuates as product moves in the supply chain. Minor customer order fluctuations result in significant accentuated production expectations and this requires additional aggregate planning. Herlyn, W. (2014) describes the resultant Bullwhip effect that increases cost, reduces service and destroys JIT and Kanban. Sources of variability are often seen in demand variability, quality problems, strikes, electricity supply and poor schedule adherence.

The following can further contribute to the Bullwhip effect according to Bray, R.L. and Haim, M. (2012) in most supply chains through the following:

1. Overreaction to backlogs;
2. Inventory reduction ordering;
3. Poor supply chain communication;
4. Poor supply chain coordination;
5. Time delay in information flow;
6. Time delay in material flow;
7. Order batching;
8. Shortage gaming;
9. Demand forecast inaccuracies and
10. Free return policies.

Technology such as Electronic Data Interchange (EDI), Advanced Shipment Notifications (ASN's) and Computer Aided Ordering (CAO) is used to mitigate the Bullwhip effect are observed in Canella, S. and Ciancimino, E. (2010) including Supplier Level Agreements (SLA'S); Vendor Managed Inventory (VMI) and demand driven MRP and this procedure is confirmed in Bohnen, F., Maschek, T. and Deuse, J., (2011).

Lean manufacturing is an engineering paradigm that aims at helping companies increase process effectiveness, reduces costs inside products and services and consequently increases competitiveness observed in Al-Aomar, R. (2011) and with process simulation concluded that levelling a workload is a Key Success Factor (KSF) which will support improved performance. The simulation model used based on full factorial design was developed using ARENA to determine which key factors have the greatest impact on the operational conditions.

Heijunka is used to level the release of production Kanbans in order to achieve an even flow production program over all possible types of products and hence eliminating (but at the very least reducing) the bullwhip effect. The presented statistical analysis, with MANOVA, ANOVA and post-hoc analysis, confirmed that the use of Heijunka has a significant positive impact on system efficiency. So through adjusting various Heijunka characteristics it can result in performance-parameters being improved. Gains observed (in WIP and throughput time) could be as much as 10 percent in the supply chain.

2.5.9 Hoshin Kanri (Policy Deployment)

Policy is a result of strategy. Strategy is a result of needs identified by the organisation. Without policy formulation an organisation can seldom if ever survive in the constantly changing competitive business environment. Akao, Y. (1988) highlights that Hoshin Kanri's primary purpose is to synchronise strategy and tactics to achieve policy intent. Hoshin Kanri aims to ensure progress in strategy execution to achieve business objectives.

BMGI (along with other Lean Six Sigma consultancies training Policy deployment) is also labelled as Hoshin deployment as part of LSS BB development. Very little was known about Hoshin Kanri until Bridgestone won the prestigious Deming prize in 1965. Similarly aligned with Plan DO Check Act (PDCA) reported in Witcher B. J. and Butterworth R. (1999), which is presented in the Focus Alignment Integration Review (FAIR) Figure13 below.

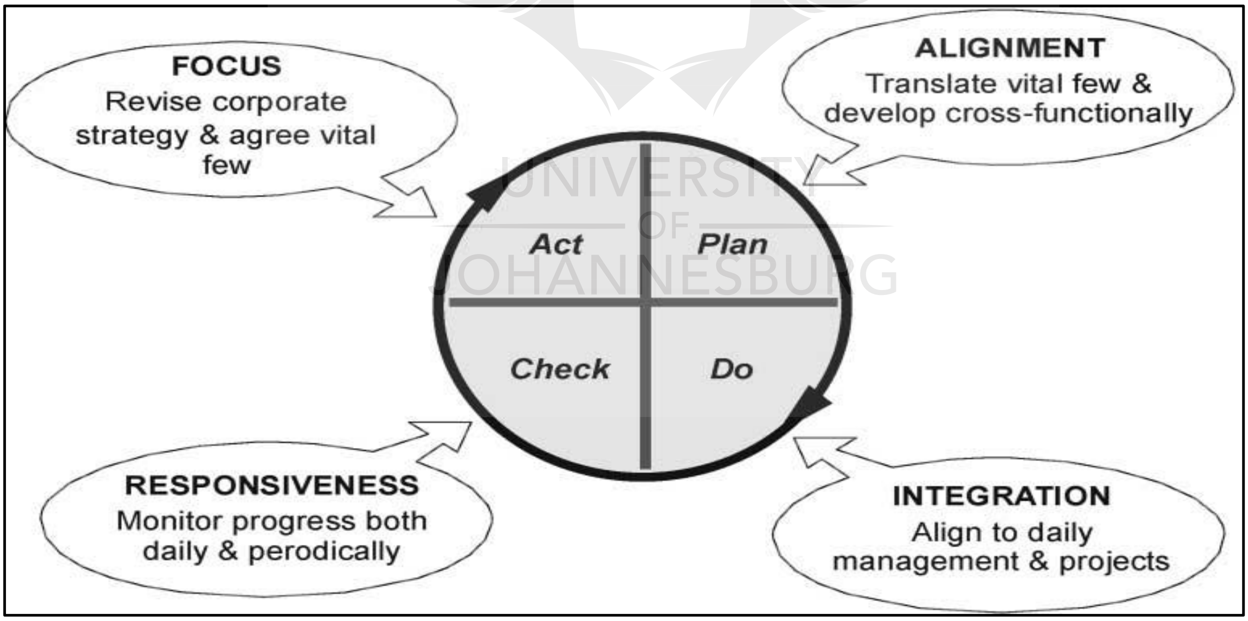

Figure 13: FAIR process of Hoshin Kanri, Source: http://www.hoshinkanripro.com

The policy deployment is a result of agreed metrics and tactics to establish organisational visions. FAIR is complemented annually by the 'catch-ball-process' which is throwing "brainstorming" business objectives around like a ball between organisational functional areas and different levels of structure until consensus is reached and organisational ownership is assured. The catch ball process is not limited to objectives and tactics but also how metrics will be measured and managed. PDCA depicted in Figure 13 allows the participants to determine targets autonomously quoted from Tennant, C. and Roberts, P.A.B. (2000).

Another approach as opposed to the FAIR approach (which Janis, I.L. (1982) cautions against) is “groupthink” which may erode the intent of policy deployment as seen in the Delphi and the Social judgment approaches which are two differing decision-making processes. A comparison is made between the two processes in Table 6.

Individual contributions are absent and consensus building is not possible due to the absence of a team approach and focus shift to logic of judgment relying on the maturity of the participants whereas the Delphi Approach uses a survey-type engagement to obtain information.

Table 6: Delphi and social judgement techniques, source: http://www.hoshinkanripro.com

Delphi Approach	Social approach
Absence of team consensus	Team consensus through group dynamics.
Primary directive is the analysis of deliverables	Primary directive is aimed at judgment
Carefully restricted exchange of information	Face to face encounters
Survey type information gathering	Group participation and engagement

Hoshin target setting calls for a model which can embrace Hoshin and business objectives according to Villalba-Diez, J. (2017) as shown in Figure 14.

The strength in Hoshin planning is in the construction by ordinary workers while they are guided by leadership in the construction.

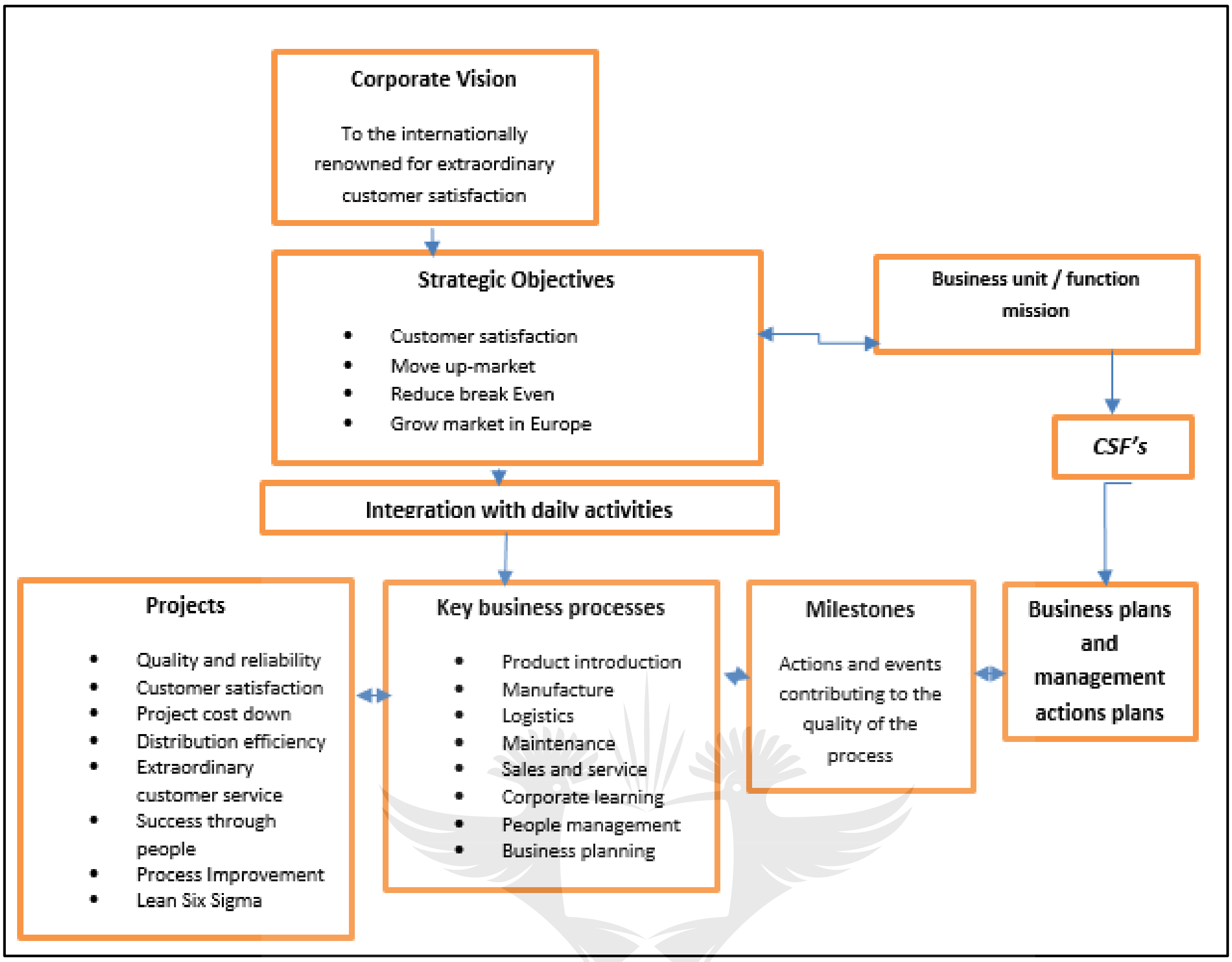

Figure 14: The extent of policy execution, Source: http://www.hoshinkanripro.com

Policy deployment will be extensively evaluated in Chapter 5 as one of the CSF's in Survey questions designed for Research Objective 1 and also in the responses obtained from Interview responses.

The extent to which any one activity must be completed in a network of soft inter-dependent milestones for the goal to be achieved depends on how far the other activities have been completed. In this case, failure to achieve any one milestone does not invalidate the plan: it simply imposes a higher level of achievement as a minimum requirement on all other milestones.

2.5.10 Jidoka (Autonomation)

Jidoka is also referred to as autonomation which is defined within Lean as automation interlinked and combined with human input. Jidoka is derived from Jido which means automation and this term evolved into Jidoka as a result of the automatic loom (a weaving loom in a factory) following the applied logic that it will stop when known process deviations and/or faults occur. Industry 4.0 would refer to HMI where human and machine interfaces are increasingly becoming interwoven.

The applied logic is that the loom stops when a known problem would arise. The loom would stop and resultant outputs would be defect free. The productivity gain was a single operator operating several looms without any risk or defects produced.

Applied logic remains where equipment will discontinue operating when faced or presented with a known process fault. Often this logic is combined with Andon discussed earlier in Chapter 2.

Autonomation according to Shingo, S. (1989) is pre automation. He identifies twenty-three stages between purely manual and fully automated work. Full automation classification requires equipment to both detect and correct integral operating problems which mostly are not cost effective. The logic applied with Jidoka deployment benefits approximately ninety percent of the benefits of full automation through Autonomation. The rationale behind Jidoka is the quality control process that uses four core criteria to render the desired control effect. These are: identify abnormality; stop process; return state of control or rectify undesired condition and determine failure mode and cause with defined remedial action. The ability of Jidoka is strengthening the quality result for internal process and client delivery experience. The additional benefits derived from Jidoka are to eliminate over-production (a waste categorised as Muda) and to focus on determination of Root-Cause coupled with elimination, so that the problem does not re-occur.

Ohno, T. (2015) describes the lessons that management can benefit from through the application of Autonomation within JIT and Lean lessons are to visualise risks, mitigate risk through complete removal and safe-guard down-stream processes and clients from defective products and process as a business imperative.

In Lean (and in particular TPM) the original equipment designed and fitted machine covers are replaced with transparent covers that facilitate visual inspection of the inside working parts visualising problems more clearly and the use of Kamishibai boards to schedule maintenance and other tasks. If cards are not turned one can see at a glance where there are problems. The daily attainment figures displayed at the workplace show what the production targets are; the current attainment, if target is being met and reasons why not.

Jidoka is one of the two pillars in the TPS house as seen in Figure 15 below.

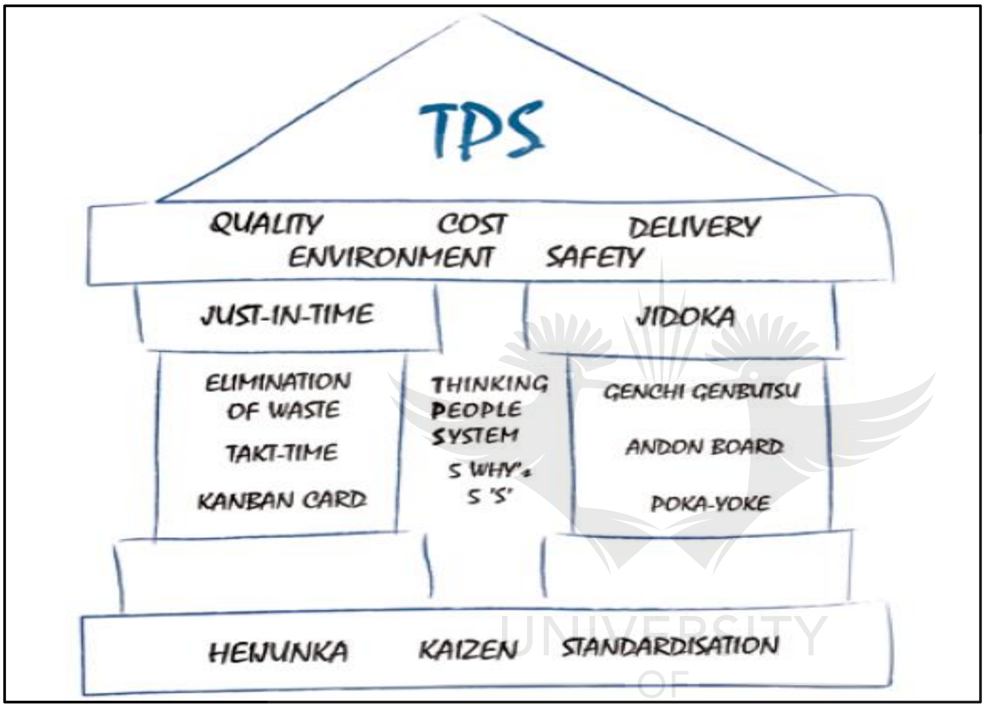

Figure 15: TPS model illustrating Jidoka Pillar. Source: https://harishsnotebook.wordpress.com

Lean relies on Jidoka principles across the various tools and gets employees to use visual management techniques to highlight whenever an abnormality occurs for management to take action. As team leaders, supervisors and managers, we need to keep a focus walking through the workplace on the look-out for these abnormalities and follow through on the Jidoka principles:

1. Discover process deviation
2. Halt operation
3. Remedy the pressing deviation
4. Perform a RCA and take appropriate corrective action.

Jidoka has an integral relationship with JIT and Kanban where JIT and Jidoka formulate two significant pillars within the TPS structure. Liker, J. and Meier, D. (2007) highlight the contribution of Jidoka which is a large part of the difference between the effectiveness when comparing Toyota with other motor car manufacturers who have attempted to "adopt" a Lean manufacturing strategy. Successful Autonomation is a key component within Lean Manufacturing operations and deployment.

JIT success is dependent on zero defects (6 and 7 sigma) processes where such failure in quality delivery will result in delivery disruptions and the orderly flow of work.

Monden, Y. (1998) mentions the contribution of Autonomation that is as significant as Industry 4.0 technology which works as a catalyst for achieving removal or reduction of Muda.

Selection of automation levels are linked to risk and ROI metrics when designing and implementing a CMM. The author will expand on the different types of models available and construct an Integrated CMM which could provide a platform for assessment of organisations' status quo and resultant deployment *modus operandi*.

2.5.11 Kaizen

The Japanese term Kaizen is widely known in the Western world and has gained much popularity in its applicability after notable successes have been recorded where the philosophy has been deployed successfully. Harriman, F. (2000) describes Kaizen as Continuous Improvement (CI) where the relentless pursuit of waste removal seeks to implement a Lean culture.

Kaizen is derived from "Kai" which relates to change and "Zen" which signifies formulating an improvement for the betterment of a process or existing status in Chen, J. C., Dugger, J. and Hammer, B. (2000) and also in Palmer, V. S. (2001). The Japanese improvement methodology is also observed in Dean, M. and Robinson, A. (1991) as a relentless CI in the organisation [Malik, S. A. and YeZhuang, T. (2006)].

Kaizen centres on employee engagement and empowerment [observed in Brunet, P. (2000) and Imai, M. (1986)] where the aim is to improve products and processes through constant re-evaluation of the way things are done. After the World War II Japan had to do more with less and this necessity drove Kaizen and Lean [reported in Ashmore, C. (2001)]. The term Kaizen encapsulates under one umbrella a host of CI tools used in the industry according to Imai, M. (1986) in Figure 16.

Figure 16: Kaizen Umbrella, Source: https://www.researchgate.net/file (2015).

The philosophy of Kaizen [in Deniels, R. C. (1996) and Reid, R. A. (2006)] holds relevance because of the quantifiable improvements in productivity also discussed in Imai, M. (1986) which explains Kaizen being a drive and methodology that harnesses the contribution of all levels in an organisation.

Plan-Do-Check-Act is also another Lean tool (discussed in this Chapter) widely used by the ISO organisation as a basis for ISO 90001 and IATF 16949 observed by Watson, M. (1986). Shewhart, W.A. (1931) was a strong believer in system design and PDCA afforded both system design and CI in Kaizen events.

Suzaki, K. (1987) states that Kaizen originated from the production environment but later found widespread adoption in service industries to improve all processes. Software industry also adopted Lean which considers that all forms of waste (Muda, Mura and Muri) and wasteful product development cycles are mitigated in Agile and Scrum approaches [confirmed in Greer, D. and Hammon, Y. (2011)]. Research explores the interactions and cross relations between agile methods and safety critical software development and the contribution to Kaizen and Lean software development.

Bassant, J. and Caffyn, S. (1994) define the CI concept as a company-wide strategy aimed at sustained innovation in iterations of improvement and reshaping at cross functional levels by all employees. Deming, W.E. (1995) believes that maturity in Kaizen creates increased innovation opportunities allowing for increased levels of stability to free teams from daily routine activities.

Capability Maturity is an indirect result of stability and processes that are naturally replicating suggesting that sustained Kaizen can assist with achieving both Lean but also organisational improvement in maturity in Kikuchi, K., Kikuchi, T. and Takai, T. (2007).

2.5.12 Overall Equipment Effectiveness (OEE)

Developed in the 1960's by Seiichi Nakajima and based on the Harrington Emmerson way of thinking OEE is relates to labour efficiency. It allows for reasonable operating performance comparisons between industries by stating results in a generic format. It is a very popular way of measuring key data in terms of efficiency across functional areas into one single measure best used to identify and scope opportunities for improvement through further analysis of the key contributors to the calculation of OEE.

OEE visualises losses in Hansen, R.C. (2001) and in Hayes, R.H. and Pisano, G.P. (1994). These losses are classified as quality, performance and availability losses in Shah, R. and Ward, P.T. (2007). Significant differences are also observed in OEE being a Lean tool or a Lean measurement [Wong, Y.C., Wong K.Y. and Ali, A. (2009)]. OEE measurement allows for the visualisation of major production losses and it is confined to processing and manufacturing industries as reported by Williamson, R.M. (2007). There is no specific value for so-called world-class OEE regardless of 85 percent OEE [Bamber, C.J., Castka, P., Sharp, J.M. and Motara, Y. (2003) and Kenis, P. (2006)].

Setup reduction achieved through Single Minute Exchange of Dies (SMED) activities and 5S work layout can reduce performance losses which are management losses [Mileham, A.R., Culley, S.J., McIntosh, R.I., Gest G.B. and Owen, G.W. (1997)]. OEE is often deployed with a combination of other Lean tools, especially the ones such as Andon which visually shares production operating metrics in Hilmola, O.P. (2005) where RCA supplies the management with tools to establish the causes of the major losses. Modern day software measures OEE in real time and also incorporates predictive analytics with Industry 4.0 technologies such as

Industrial Internet of Things (IIOT) and Augmented reality in software suppliers such as Wonderware, SAP and Oracle applications. The Major OEE losses are summarised as:

1. Availability loss (Unplanned and Planned Stoppages)
2. Performance loss (Small Stoppages, Change Overs and Slow Cycles)
3. Quality Loss (Production and Start up rejections)

Wireman, T. (2004) proposes that through a staged TPM another Lean tool is the ultimate objective to develop a loss culture of as close as possible to zero which is similar for DMAIC in LSS and the purpose of mitigating the 6 big losses. The calculation to determine process is

OEE = *Availability x Performance x Quality*

World Class OEE is described as the relationship of actual productive time compared to planned productive time and set out as follows:

Availability – 90% (Ideal) and 79% (Normal)

Performance – 95% (Ideal) and 80% (Normal)

Quality – 99.9% (Ideal) and 95% (Normal)

The six big losses are seen as integral to OEE improvement and will be discussed next.

2.5.13 Six Big Losses

OEE improvement is possible through Root-Cause-Analysis (RCA) of Six Big Losses combined with defined Corrective Actions. The three big losses are now expanded to detail the Six Big Losses which are described in Sahoo, A.K., Singh, N.K., Shankar, R. and Tiwari, M.K. (2008) who consider that Big Loss No 1: Mechanical Downtime (Availability) identifying downtime is not sufficient enough; it is critical to comprehend the causes of the loss, also what drives change and includes breaking downtime down into its constituent parts. The analysis of the downtime becomes more prevalent when the downtime was reported, the duration of downtime and maintenance to respond and return to a state of repair and running again. In Wilson, L. (2007) the implementation of the review and analysis of the Six Big Losses it is clear that without detailed measurement the analysis of the sources of losses and the significance of losses are diluted. Liker, J. (2007) further avers that the detail in information that determines the quality of the losses and ranking the losses is a logical problem-solving departure point.

Detailed comprehension of the losses is necessary to effect any possible improvements according to research conducted by Aptean (2012) and Bamber et al. (2003). It is possible to find two different classifications of losses. O'Sullivan, J., Nick, T. and Abraham, S. (2016) also describe the impact of Big Data on manufacturing and Industry 4.0 technology. Dennis, P. (2016) proposes possible countermeasures for the six big losses as follows:

1. Planned downtime (loss countered by 5S and PM management)
2. Breakdown losses (countered by TPM, PM, RCA, Asset care and Kaizen Blitz)
3. Minor Stop losses (countered by Autonomous Maintenance, Cleaning and 5S)
4. Speed losses (countered with line balance optimisations)
5. Production rejections (countered with RCA, Poke Yoke and Six Sigma)
6. Start-up rejections (countered by SOP's and 5S work organisation)

These Lean tools combined with Six Sigma can mitigate and counter Six Big Losses confirming industry application for LSS as a combined CI mechanism to resolve losses in production processes. All losses cost time, capacity and reduced customer satisfaction. In the pursuit of seeking customer delight it is necessary to not only identify losses but also to mitigate them "cost and time effectively". Dennis, P. (2016) argues that Lean is one of the world's most powerful production systems.

2.5.14 Total Productive Maintenance (TPM)

TPM is a very popular Lean tool to assist with maximising machine availability through employee empowerment and inclusiveness of routine Autonomous maintenance activities with production as described in Arunraj, K. and Maran, M. (2014). Autonomous Maintenance is also one of the 8 prominent TPM Pillars.

The 8 constituents (also referred to as the pillars) that are inherent of TPM allow for focus on the respective pillar areas which allow improvements within the 8 defined areas, namely:

1. Autonomous Maintenance
2. Planned Preventive Maintenance

3. Early Equipment Management
4. Education and Training
5. Quality Maintenance
6. Focus Improvement
7. Health, Safety and Environment
8. Office and Administration TPM

TPM is used effectively with other Lean tools such as 5S, OEE, Six Big Losses, RCA, Kaizen, Poke Yoke, Kanban, Takt-Time and TPM facilitates JIT in the supply chain through Standardised Work and Andon in [Ahuja, I.P.S. (2009) and Rhyne, D.M. (1990)]. Maximising plant utilisation and plant availability allows for the maximisation of ROI and EBITDA financial metrics. However it does not address the VOC and QFD requirements of a modern day customer [Venkatesh, J. (2007)] and requires other tools to complete the operations' role in meeting customer demands such as CTQ metrics. Hybrid TPM models are a direct development of organisational production systems seeking to find solutions for quality and performance problems and one often sees the inclusion of DOE, DMAIC and DMADV tool deployment under the Quality and also under the Focus Improvement pillar. Condition Based Maintenance (CBM) is also used with other Manufacturing Execution Software (MES) Data to predict failures through real time monitoring and predictive analytics used to compute Mean-Time-Between-Failures (MTBF) and Mean-Time-To-Repair (MTTR) results according to Madu, C.N. (1994) and Swanson, L. (1997).

TOC and TPM are complementary in B. (2000) and Waeyenbergh, G. and Pintelon, L. (2004) but require real time data to be most effective. Therefore here Industry 4.0 technology integration within TPM can improve OEE results significantly [confirmed in Farkas, S. (2010) and Arunraj, K., and Maran, M. (2014)]. It is observed that global OEE increases have been possible with sustainment of pillar focus activities seen in research undertaken in Wakjira, M.W. and Singh, A.P. (2012) and in Katkamwar et al. (2013).

South African TPM project organisations in Lubbe, R. (2016) report typical OEE increases ranging from 20 to 50% when achieving machine restoration with production back to original condition and some cases even better than original [reported by Aaditya, C. (2012); Arunraj, K. and Maran, M. (2014); Khamba, J.S. (2007) and Bohoris, G.A., Vamvalis, C., Tracey, W.

and Ignatiadou, K. (1995)]. Other researched and improved OEE results are ranging from 20 to 60% in Gupta, A.K. and Garg, R.K. (2012).

Significant global TPM program adoption in processing industries is observed in Lubbe, R. (2016) such as recycling, automotive, food and chemical plants with selection of other CI tools such as VSM, 5S, SMED, OEE and also with LSS.

2.5.15 Plan-Do-Check-Act (PDCA)

Edwards, W.E. (1986) designed the PDCA Deming wheel of CI adapted from the PDSA cycle in Shewhart, W. A. (1931) where organisations required a methodology and framework to continuously improve their processes. Holbeche, L. (2005) cites in CI strategy a review of the linkages between high performance organisations. The development of a Capability Maturity Model will be explored in greater detail in Chapters 2, 3, 5, 6 and 7.

Research in the early evolution of PDCA is made in Moen, R.D. and Norman, C.L. (2009) who explored *the science of improvement*. It continues with additional contributing authors over and above Edwards, W.E. (1986) and the contribution to early origins are also seen in Steffens, B. (2006) crediting Ibn al-Haytham in the period 965-1040 as the first scientist within this early discipline of PDCA. Juran, J.M. (1990) ascribes the origins of the science of improvement to the handicraft industries and the applied quality control in China to be 16th century [B.C. Galileo. Morgan, M. H. (2007)] findings support Steffens, B. (2006) who also cites where quality control seeks to improve any method once stability is achieved.

Galileo, G. and Bacon, F. in Tsao, J.Y. et al (2008) describes the knowledge management and development in a planned structure to be most effective when based on deductive logic. They imply that inductive reasoning should become more prevalent with the advent of knowledge management and knowledge advancement.

The research and model of Shewhart, W. (1939) research and model included three components which are: i) to review the specification, ii) followed by manufacture or production of the specification and then iii) the inspection to confirm specification has been met as intended.

The circular arrangement of the three components is described as the Shewhart cycle and formulates the basis for CI presented at the time.

Imai, M. (1997) compares constituents in both the PDSA cycle with the PDCA cycle in Table 2.11 where similarities are observed which see all work and processes with defined inputs and outputs described below:

1. Specification	**P**	(Plan)	Specification to the intended design
2. Manufacture	**D**	(Do)	Manufacture to design specification
3. Inspection and Sales	**C**	(Check)	Inspection and sales and market repeat purchases confirms market acceptance or rejection
4. Research	**A**	(Act)	Complaints / returns / rejections provides inputs for future designs

PDCA cycle inherent design seeks to prevent reoccurrence with adopting standardisation central to Lean and was also termed the Standardise-Do-Check-Action (SDCA) cycle. Ishikawa, K. (1985) suggested that if standards are not reviewed and or revised every six months no one is using such standards.

Continuous Improvement is a continual cycle of repeat incremental changes over time and also central to the KAIZEN methodology which is the modern PDCA cycle used throughout the world.

Both 2015 revisions of management systems for ISO 9001 and ISO 14001 management systems for all production and service organisations follow the PDCA approach as a result of its widespread industry acceptance as a method for Continuous Improvement. Deming revisits the adapted Shewhart cycle in 1986 along with the developments by JUSA in 1951 development of PDCA and labels the model the PDSA (Plan Do Check Study) Cycle.

The current IATF 16949:2016, ISO 9001: 2015 and ISO 14001: 2015 systems are now based on the framework as a result of increased industry maturity capability.

The maturity of ISO has evolved into an industry-wide acceptance of Leadership (ISO 9001 Element 5) as a key element and central to compliance and supported by Improvement (ISO 9001 Element 10) which will be explored in the survey and interview questionnaires towards maturity capability.

2.5.16 Poka-Yoke (Error Proofing)

Poka-Yoke means error proofing and is used on important product and process characteristics according to Besterfield D.H. (2011). Process error proofing can reduce customer and organisational risk. Zero defect process and product characteristics are grouped hereunder Poka-Yoke in Telsang, M.T. (2006). Special and common cause and Poka-Yoke is used to mitigate special cause product characteristic failures.

Norman, D.A, (1989) , Grout, J.R. and Downs, B.T. (2009) observe that special design considerations are made by design teams to “mistake proof” certain manufacturing process steps, especially relevant in Aviation, Automotive and Medical device manufacturing processes. Middleton, P. and Sutton, J. (2005) also defines Poka-Yoke as the systematic practice of eradicating errors, by locating their root cause. Plonka, F.E. (1997) considers that a Poka-yoke is a mechanism for detecting, eliminating, and correcting errors at their source, before they reach the customer. Other studies simply define a Poka-yoke by means of examples, either by simply substituting this label with others, such as sensors and jigs, or by translations such as mistake-proofing or error-proofing. Such synonyms draw on concepts that are intuitively meaningful in the sense that everyone associates something with them, so they feel they understand them. In this study, based on the above mentioned definitions, a Poka-Yoke is defined as a device that either prevents or detects abnormalities, which might be detrimental either to product quality or to customers’ Health and Safety, where 3.4 ppm failure rate is not good enough when human lives are at risk. Higher sigma quality may be necessary and the importance of a linkage between TLS and DFSS requires additional exploration and the relevance to higher than Six Sigma quality levels is required in a journey towards capability maturity framework for the safety of customers.

2.5.17 Root Cause Analysis (RCA)

Root Cause Analysis in Wilson, P.F., Dell, L.D. and Anderson, G.F. (1993) is a systematic division of probable causes through the use of tools to determine possible causes of an event that has occurred which was neither anticipated nor desired and this view is also held by Ammerman, M. (1998).

Robitaille, D. (2004) reports that the Kepner-Tregoe Analysis (KTA) was a popular predecessor to the Management Oversight Risk Tree (MORT) an assessment developed by NASA due to the complexities associated with the KTA. Similar approaches have been use in both Aviation and Automotive applications. Ford developed the 8D problem-solving-tool which consists of 8 Defining steps also known in the industry as the 8 Disciplines of problem-solving which includes the popular fishbone / Ishikawa diagram.

The identification of the root cause instead of the symptom is often a failure in investigations of a critical nature and it calls for a holistic approach reported in Andersen, B. and Fagerhaug, T. (2006) and Okes, D. (2009). They also suggest that RCA applicability is determined by the industry and the severity of an event.

Popular RCA tools are:

- 5-why analysis
- Barrier analysis
- Causal Factor Tree analysis
- Cause mapping
- Cause and Effect analysis
- Change Analysis
- Fault tree analysis
- Pareto's 80/20 analysis
- Failure mode and effect analysis (FMEA) which is also an effective DFSS tool.

Popular industry-used problem-solving-tools are found in cause-and-effect diagram (CED), the interrelationship diagram (ID) and the current reality tree (CRT) which are used in a variety of industries to determine root cause.

The CED was designed by Ishikawa, K. (1982). It later gained popularity within the quality and engineering communities and asks root causes from cross functional teams who have best process knowledge surrounding possible contributions from measurement, method, machine/equipment, material, man and environment (mother nature) in Arcaro, J.S. (1997); Moran, J. W., Talbot, R.P. and Benson, R.M. (1990) and Sproull, B. (2001).

RCA is an instrumental tool used within most systemic routine problem-solving activities and also used as a key step in the 8D Problem solving tool. It was developed by Ford Engineers and Designers for internal and also external supply recurring or undesired isolated events.

Rambaud, L. (2011) observes that the eight disciplines (8D) model is a problem-solving approach which is typically employed in the automotive industry. The purpose of the 8D methodology is to standardise on reporting and solving problems big and small, simple and complex alike. Where the root cause in the RCA step is not confirmed a possible DOE is considered to test and simulate probable root cause/s.

2.5.18 Single Minute Exchange of Dies (SMED)

SMED is proven Lean technique in optimising and reducing the time when changing from one manufacturing job and/or process to another in the fastest possible time. The origin dates back to the 1950's [Ohno, T. (1988) and Shingo, S. (1985)]. The SMED methodology enables setup reduction opportunities when applied correctly as part of CI.

In high volume manufacturing, fast equipment setups play an important part in maximising the capability of equipment. Organisations must find ways to reduce setup and changeover times through SMED activities and adopting innovative standardised quick changes.

Sustained Kaizens in SMED activities assist to find the various factors and barriers which effect the die setup time. Due to decrease in die setup time flexibility of production increases. Flexibility increases mean increase in production, sale growth increases, customer growth increase and increase in customer satisfaction level. Achievement of key measurement systems are used such as Die setup variables, ANOVA test and Regression analysis to facilitate in visualising actual measurements and time opportunity and the identification of the waste (Muda) within the value stream.

In SMED research conducted by MIT Professors Digra, M. and Sharma, A. (2014) the project work questionnaire data was analysed by one way ANOVA technique for finding which parameter is more significant towards the die setup time. Regression analysis was used to fit a predictive model to survey data and used that model in the form of regression equation to predict value of dependent variables (die setup time) and established which factors are most important. The findings were as follows:

1. The regression equation showed that die setup time will predict a decrease in value (Unstandardised Coefficients) when the respective factor went up by 1 unit and die setup time is predicted to increase constant value of unstandardised Coefficient when all factors are zero.

2. Employee participation and skills and the effect on efficiency and sales growth, are the two factors having large weightage score. This shows that these two factors are most important to affect the die setup time.

There is positive effect of implementing SMED process on performance of die but not many studies have been reported in the literature of South African (SME's). In the study by Digra, M. and Sharma, A. (2014) the factors which depend upon die setup time are classified into five groups, namely: advance planning, employee participation and skills, effect on efficiency and sales growth, motion and handling and die setup time can be reduced in future. However, the ANOVA test and effect size and regression test performed on each factor showed that factor 2 (employee participation and skills) and factor 4 (effect on efficiency and sales growth), are more significant with die setup time. *So these above factors are most appropriate to affect the overall die setup time*. This is also confirmed in Robinson, A. (1990) where there are five qualities that organisations must possess in order for training to succeed. The five qualities include alignment, anticipation, alliance, application, and accountability [Gill, S.J. (2006)]. Duggan, K. (2007) and King, P. (2009) observe that one of the key principles of operations management is determining the order variety and order size. In some cases lengthy change over activities dictate order campaigns; however, setup reduction implementations derived from basic SMED principles significantly reduce the amount of lost capacity incurred during smaller lot sizes and configuration changes.

2.5.19 Standardised work and Takt-Time

Muri is identified as major contributor to adopting and designing standardised work. Muri is also designed to reduce variability in the processes, with particular reference to process cycle times. To reduce and eliminate variation in intermodal terminal operations, we suggest the application of standard work. As was stated previously, standard work is applied in Lean both to reduce variation in processes and to encourage continuous improvement [Imai, M. (1986) and Shingo, S. (1989)]. The framework also includes the specification of a standard communication method within the standardisation construct. Visualisation (Andon) is also a key theme within Lean [Bicheno, J. and Holweg, M (2009)], and it is suggested that it should be effectively integrated with an organisation's efforts for standardisation. For example, standard work procedures should by located at the point of use in a visible manner, so that procedures are always up-to-date. Also, by making important information instantly visible, there is no time wasted in hunting for the information.

In standardised work Mintzberg, H. (2009) and Holweg, M. (2009) mention four distinct constituents: 1 – Takt-Time; 2 – Sequence of work; 3 – Flow of work and material and 4 – the agility of both man and process.

Standardised work benefits immensely from Value Stream Mapping [also another Lean tool discussed later in Chapter 2 individually] but in essence visualises flow and also lack of flow which can be resolved with tools such as TOC according to Davies, C., Greenough, R.M. (2002) and Kalsaas, B.T. et al. (2015). Takt time originated from the tool (used in orchestra) to keep time by the conductor and it is calculated based on the following formula:

Takt Time = Available time for production / required units of production

The Western world in the 1970's, after trying to uncover the secrets of the Japanese economic challenge, started with implementation of Takt time and the Lean language is therefore known as the production rate or production tempo which is expressed in units of time such as seconds or minutes.

In practice, all operations produce with a slightly higher pace than what the Takt time calculation contributes in Lean. Olofssen, O. (2011) observes when it does not consider this parameter is it not possible to have any opportunity to be able to fend for known process disturbances. Takt-time should therefore not be seen as a *tool but rather as a vision*. It is also observed that when production pace is exactly the same as the *mean customer demand*, it would require perfectly stable processes and completely balanced flows. This is a long term goal in Lean Manufacturing.

2.5.20 Value Stream Mapping (VSM)

Value Stream Mapping (VSM) and the subsequent Value Stream Analysis (VSA) seeks to establish the process and production chronology from VOC and QFD metrics to delivery as reported in Davies, C. et al. (2002). Visualising VSM enables the analysis of processes that may be non-value adding, critical to success and also risks during realisation [in Kalsaas, B.T. (2002)]. Analysis begins through a typical roadmap and visual display of process steps which represent the current state of events and are then interrogated and optimised to produce a future and desired state of the VSM according to Harrison, A. and van Hoek, R. (2005) and herein lies the CI of process once implemented. Complex processes are broken down into sub process until all opportunities with existing technology, including Industry 4.0 technologies have been explored.

The term Value Stream Management originates from Supply Chain Management (SCM) that typically refers to the entire supply activity of a firm and SCM is "emerging into value activity management, which recognises the importance of demand in addition to supply" [Krishnamurthy, R. and Yauch, C. A. (2007)]. Companies explore the potential of the concept of SCM to improve their revenue growth by developing Lean supply chains. Lower production cost and increased ROI are a direct result when new VSM is realised according to Gunasekaran, A., Lai, K-h, and Cheng, T.C.E. (2008). Lean supply chain integrates all the key processes and partners necessary to realise customer satisfaction by adjusting the activities to the constantly changing demand of customers while delivering products quickly. As a result, companies that are part of a Lean supply chain become more competitive because they have lower cost than their competitors [Srinivasan, M. (2004)]. Wood, N. (2004) stated that VSM results in the reduction of wasteful activities. Improved JIT and Kanban metrics are realised with shorter lead times which allows for increased operational agility according to Stalk, G. and Hout, T.M. (1990) and Rich, N. and Hines, P. (1997).

According to Koskela, L. (2004), the prominent five Lean principles reported in Womack and Jones, (2003) are:

- Product valuation specific
- VSM for all line items
- Create flow and limit WIP with JIT and Jidoka pillars
- Kanban relationship between supplier and customer

- Sustain through continual Kaizen

These five Lean elements provide a comprehensive foundation for transformation of productive activity from traditional to Lean production. However, there are some limitations in the application of Lean thinking. Lean thinking is fragmented and lacks an adequate conceptualisation of production and relies on experienced workers and practitioners who sustain the methodology.

One of the core principles in researching organisation maturity levels conducted by Lindemulder, M. (2015) is that management should be based on facts. The first key element is Lean management. Lean management is one of the most popular programs reported in Arnheiter, E. D., and Maleyeff, J. (2005). Process mapping often precedes one of the key techniques of Lean management, which is observed in VSM. As a tool it continuously aims to identify and eliminate waste and does so by [as seen in Hines et al. (1998)] analysing the series of activities to manufacture and process a product in a focussed manner [also in Rother, M., and Shook, J. (2003)]. Various tools are available for VSM, but all come down to mapping the various activities, identifying the wastes to be reduced, and identifying and executing improvements to reach the desired future value stream (Hines et al., 1998). In other words, it supports the key element: eliminating waste and creating flow. This level thus encompasses Lean projects to improve the processes within an organisation. Lindemulder, M. (2015) also observes that projects of this kind regularly follow the Six Sigma roadmap since it helps in eliminating unproductive steps.

2.6 The components of Six Sigma

Six Sigma is an industry tried and tested CI tool used by specialist trained and skilled belt operators following the DMAIC approach. It can be deployed in both manufacturing and in services and has seen a wide range of application within Cyber Physical Systems (CPS) and also banking, healthcare and aerospace where 0 ppm quality is required. It is not a quality tool but seeks to establish through MSA a baseline quality and to continuously improve from there. The integral DNA of Six Sigma is the use of applied statistical tools to complete the DMAIC cycle using software such as Minitab when analysing data and or designing experiments. Project management is a key component which the belts report on their Six Sigma project yields and maturity.

Process variation reduction and improved quality yields allow for bottom line savings and also a key metric for ROI in belt and Six Sigma projects with the use of statistics reported in Noone, B.M., Namasivayam, K. and Tomlinson, H.S. (2010); Thomas, A., Barton, R. and Chuke-Okafor, C. (2009); Antony, J. and Desai, D.A. (2009). DMAIC affords the Six Sigma project teams with a host of statistical tools to increase visualisation of the metric or metrics being analysed, which increases visibility for continuous improvement opportunities reported in Schroeder, R.D., Linderman, K., Liedtke, C. and Choo, A.S. (2008). Where Kaizen events and Lean tools allow for incremental improvements over time Six Sigma offers rapid and significant ROI results reported in Starbird, D. and Cavanagh, R. (2011); Mehrjerdi, Y.Z. (2011); Foster, 2010:429; Noone et al., (2010); Nakhai, B. and Neves, J.S. (2009); Przekop, P. (2006) Antony, J. (2006); Keller, P. (2005). Six Sigma project results are only possible through disciplined measurement of key metrics during Six Sigma DMAIC evolutions according to Chen, M. and Lyu, J. (2009) and Chakrabarty, A. and Tan, K.C. (2007). "Define, Measure, Analyse, Improve and Control" Eckes, G. (2001) details Six Sigma methodology through DMAIC where:

Define: Scope of problem or metric that needs improvement

Measure: Measurement System Analysis is designed to confirm key metrics and key drivers to the scope of the project into sigma metrics.

Analyse: RCA with inputs from Lean tools such as *Ishikawa* and *hypothesis testing* is established using extensive statistical methods with the aid of software such as Minitab.

Improve: GAP analysis similar to CMMI Scampi report details step by step actionable activities to mitigate RCA's and facilitate improvement.

Control: Similar to the 5th S in 5S this step requires mature leadership to sustain new improved process controls and metrics designed.

DMAIC Black Belt training defines seven tools respectively for each category in quality, customer, Lean, project statistics and for design [reported in Pulakanam, V. and Voges, K.E. (2010)] with the seven quality tools remaining the most prominent in the categories described here.

Foster, Y. (2010) agrees with Pulakanam, V. and Voges, K.E. (2010) in the importance of the Pareto principle where 80 percent of the improvement actions are identified and improved with the basic quality tools and only the balance requiring advanced statistical tool deployment cementing the value of Lean and the seven quality tools reported in Karthi, S., Devadasan, S.R. and Murugeh, R. (2011) and Spedding, T.A. (2010).

A CSF that will be explored in Chapter 5 is the contribution of Leadership and Management in LSS, according to Schroeder et al. (2008), which relates to both LSS and DFSS approaches contribution to organisational improvements in Evans, J.R. and Lindsay, W.M. (2005) and will be included in research questionnaires for both survey and interviews.

In Rathilall, R. (2014) we find he reports LSS spreading to a variety of industries and also confirmed in Pepper, M.P.J. and Spedding, T.A. (2010) and Foster, T. (2010). Further literature suggests that the LSS technique has been practised for almost three decades and it has demonstrated success in delivering value where business decisions are based on facts and accurate data [McCarty, T.D. and Fisher, S.A. (2007); Gupta, P. (2005); Haikonen et al., (2004)].

Literature reviews confirm the widespread industry adoption of DMAIC and LSS which have become the default choice for CI in both manufacturing and service industries and early adopter GE in 2017 culminating to its 30th year of LSS CI strategy deployment. It is observed that De Koning et al. (2008) contend that LSS creates a platform of learning and in becoming a learning organisation in [Foster, T. (2010) and Schroeder et al. (2008)]. Mature LSS creates opportunities for increased levels of innovation in Rathilall, R. (2014).

2.7 Design for Six Sigma (DFSS)

DFSS and LSS have been used extensively in improvement initiatives around the globe and have been popularised by the Industry's adoption as stated earlier in 1986 Motorola and 1995 General Electric.

The LSS methodology evolved and in addition to several new tools, the basic improvement process received an additional step namely "define", meaning that the old MAIC was now DMAIC, a new methodology was shaped under the basic LSS and it was called DMADV in DFSS. The difference was that DFSS focused on new product and process design rather than improving the existing products and processes. DFSS also has its own process which consists of steps which define the process, measure the key metrics, analyse relevant data, design the necessary controls and verify the designed controls and metrics in DMADV observed in Hopp, and Spearman, (2008). Tennant, G. (2002).

Mesec, A. (2005) also found that in the service industry the above methodology is applicable, for Design stage can be expanded to include the Design, Optimise, and Verify loop. It is reported in Hopp and Spearman (2008) that in IT systems design and major DFSS-IT projects, should users consider the many layers to DFSS to realise the potential cost and time saving opportunities in product launches and project deployment.

DMADV is intrinsic in the Design and Optimisation stage. DFSS allows for a systematic methodology in which new products and/or processes are designed which allows for pre-emptive development cycles where the CTQ and VOC metrics are dominating the inputs seeking “customer first” and the technology available as key metrics.

2.8 Toyota Production System (TPS)

TPS consist of two pillars, Just-in-Time (JIT) and Jidoka seen and discussed in Figure 15. 5S is the foundation of TPS and these two pillars. TPS was the predecessor of Lean in the Western world, Lean and TPS is the same program; it is a selection of Lean tools used by Toyota Motor Corporation (TMC) according to Womack, et al., (1990) were the Japanese plants and also found in Dahlgaard, J.J., and Dahlgaard-Park, S.M. (2006). Lean was developed by Ohno, T. (1988) and Shingo, S. and Epley T.S. (2007) at TMC and also confirmed and researched in Arnheiter, E.D. and Maleyeff, J. (2005).

TPS encapsulates all the Lean tools discussed in this research document and reviewed by Arnheiter, E.D. and Maleyeff, J. (2005). TPS was the developed for manufacturing to assist managers and workers to eliminate the 7 wastes after the 2nd World War, with key contributions from Ohno, T. (1987). TPS was the most significant way of work and production during the 1980’s and 1990’s according to Katayama, H. and Bennett, D. (1996); Bartezzaghi, E. (1999). JIT became the key Lean driver for western organisations to also adopt and implement TPS according to Pepper, M.P.J., and Spedding, T.A (2010). At the start of the first two decades of the 21st century it has been the improvement approach of choice researched in Snee, R.D. (2010) and Pyzdek, T. and Keller, P. (2014).

Values and respect are integral to the TPS philosophy in the modern era as published by Toyota Corporate Japan in 1992 and revised in 1997. The seven guiding principles at Toyota are:

1. Integrity throughout the world in all operations with sustainable and good governance
2. Mutual respect in all the markets and nations where business is conducted.
3. Quality of life and safety first for both employees and customers
4. Use VOC and QFD metrics to establish and satisfy customer needs.
5. Nurture a corporate culture of trust and cooperation
6. Use innovation as a growth driver
7. Engage with supply chain to achieve desired business objectives.

Toyota's Production System (TPD) is derived from a set of three main principles:

- Continuous Improvement through Kaizen and Genchi Genbutsu
- Respect for people and teamwork
- Decision making on long term goals, not short term objectives.

Development of relationships and nurturing these over the long-term and the construction of corporate social responsibility are central themes in TMC business philosophy.

2.9 Business Process Maturity Models (BPMM)

The BPMM is the collection of process models describing and measuring process maturity within businesses ranging from immature to stable and improving. BPMM allows for structured review of process maturity steps that are progressive and allows for evolution into the higher stage based on capabilities met according to set standards. An improvement strategy drawn from BPMM in Curtis, B. and Alden, J. (2007) describes incremental maturity levels based on CI abilities and competencies within an organisation.

Crosby, P. (1979) as discussed previously developed the Quality Maturity Grid and maturity frameworks saw early beginnings (1989) reported by Humphreys, W.S. (1989). This lead to the creation of the Process Capability Maturity Model at the Software Engineering Institute

(SEI) derived from Capability Maturity Model (CMM) for the industries aligned with computer Software in CMM found in Paulk, et al. (1985) maturing into Capability Maturity Model Integration (CMMI) and reported in Chrissis, et al. (2002).

CMM designed for use to better or enhance the case for business steps and although their design intent is to assist organisations, the proliferation of maturity models does leave many organisations lost, having little if any analysis in frameworks and respective variances, making selection of a suitable model difficult at best. Choosing the suitable BPMM is very important according to Van Looy, A., De Backer, M., Poels, G. (2010) in a review of 69 BPMM's. Harrington, H.J. (2006) observes organisations need process stability to compete in the markets and to grow profits. The notion of *maturity* has been adopted since the assumption that existing processes may not necessarily be excellent and regular reviews of *process maturity* and capability becomes a norm. The adoption of the Balanced Scorecard (BSC) is a very popular method of measuring business performance according to Bain Company (2015); Sullivan (2001) and Ulfeder (2004).

Business Process Capability Model (BPCM) is a derivative of BPMM in QMMG as identified by Crosby, P. (1979) and Humphrey, W.S. (1989) consisting of five maturity levels where maturity competency stage assimilate a different maturity competency against a known and set criteria.

The five levels of BPMM are:

Level 1 Initial (Chaotic) characterised by processes that are erratic and not formalised and controlled in a reactive ad hoc manner by either users or events resulting in an unstable processing environment.

Level 2 Repeatable during times of stress although not ensured this level allows for increased consistency.

Level 3 Defined is characterised by Standard Operating Procedures with evidence of CI over time.

Level 4 Managed is characterised by the use of metrics with management control to adjust and influence proactively any quality losses and deviations. Process Capability is established and known at this level.

Level 5 Optimising is characterised when sustained improvements with staged and creative innovations are done simultaneously whilst maintaining the quantitative process improvement targets.

Capability Maturity Model Integration is a derivative of the original maturity model developed by Crosby's QMMG for detailed analysis in Chapters 5 and 6.

2.10 Critical Success Factors (CSF's) for Lean Six Sigma (LSS) and Design for Six Sigma (DFSS)

Analysis of literature research in Rockart, J.F. (1979) and Rungasamy, S., Antony, J. and Ghosh, S. (2002) in Laureani, A. and Antony, J. (2012) suggests that the CSF's in CI deployment of LSS illustrate the concept of CSF and the contribution to the information needs of managers. CSF's are the mission critical factors that determine success or failure. CSF include the cardinally important factors to an organisation's sustained operations according to Boynlon, A.C. and Zmud, R.W. (1984).

Lean and Six followed different evolutionary paths since the 1980's with Lean culminating into TPS in Japan and Six Sigma into the DMAIC philosophy in the US and in the global manufacturing arena integration was inevitable in the late 1990's and early 2000's noted in Snee, R.D. (2010) where LSS is recognised to be a common CI planned objective to improve VOC and QFD metrics in conjunction with improved financial and operational metrics [Snee, R.D. (2010)]. LSS therefore utilises tools from both toolboxes from the Auto and industry Giants in the East and West to achieve the best from both methodologies increasing speed through waste reduction and increasing accuracy.

DFSS is significant in operations strategy to complement LSS – Tools are required to break through the sigma quality barrier with a new approach to research and development projects. DFSS is a natural development from LSS. Very little research has been done relating to effective DFSS deployment and also no CSF's established which could be included as input for the questionnaire design for Research Objective 2.

In Laureani, A. and Antony, J. (2012) research in the overview of CSF's for LSS included 31 sources discussing CSF's for implementation which consisted of 22 articles and 9 published books from which a list of nineteen CSF's was compiled.

Anthony, J. and Banuelas, R. (2002) with Coronado and Athony, J. (2002) observed the CSF's were: management commitment and involvement; understanding of LSS methodology, tools and techniques; linking LSS to business strategy; linking LSS to customers; project selection, reviews and tracking; organisational infrastructure; cultural change; project management skills; linking LSS to suppliers and training.

Process management systemic needs during project tracking were cited by Martens, S.L. (2001) and project priority and selection in Ingle, S. and Roe, W. (2008) was reviewed as extremely critical. Antony, J. (2006) also added more CSF's including team member composition and selection, tools comprehension and linking LSS to customers and project accountability.

A structured questionnaire was developed including the following:

- Background of respondents
- LSS successful implementation criteria
- CSF's for LSS implementation
- CSF's for DFSS implementation
- CMM Contribution

The questionnaire was distributed to 200 LSS and DFSS practitioners or program leaders across industries globally with a response rate of 72 (36%) and average importance scores were summarised in a number of 5 point Likert scale type questions.

Key findings from the literature review in summary were that (i) management commitment is mission critical for LSS program success and (ii) validity confirmed in interviews planned.

Organisational LSS culture linkage to business strategy was identified as CSF's in the literature research conducted by Antony, J. and Banuelas, R. (2002), including contributions of leadership styles that were more prevalent than pure literature reviewed prior to interviews. The findings of the Literature review CSF's are seen in Figure 17.

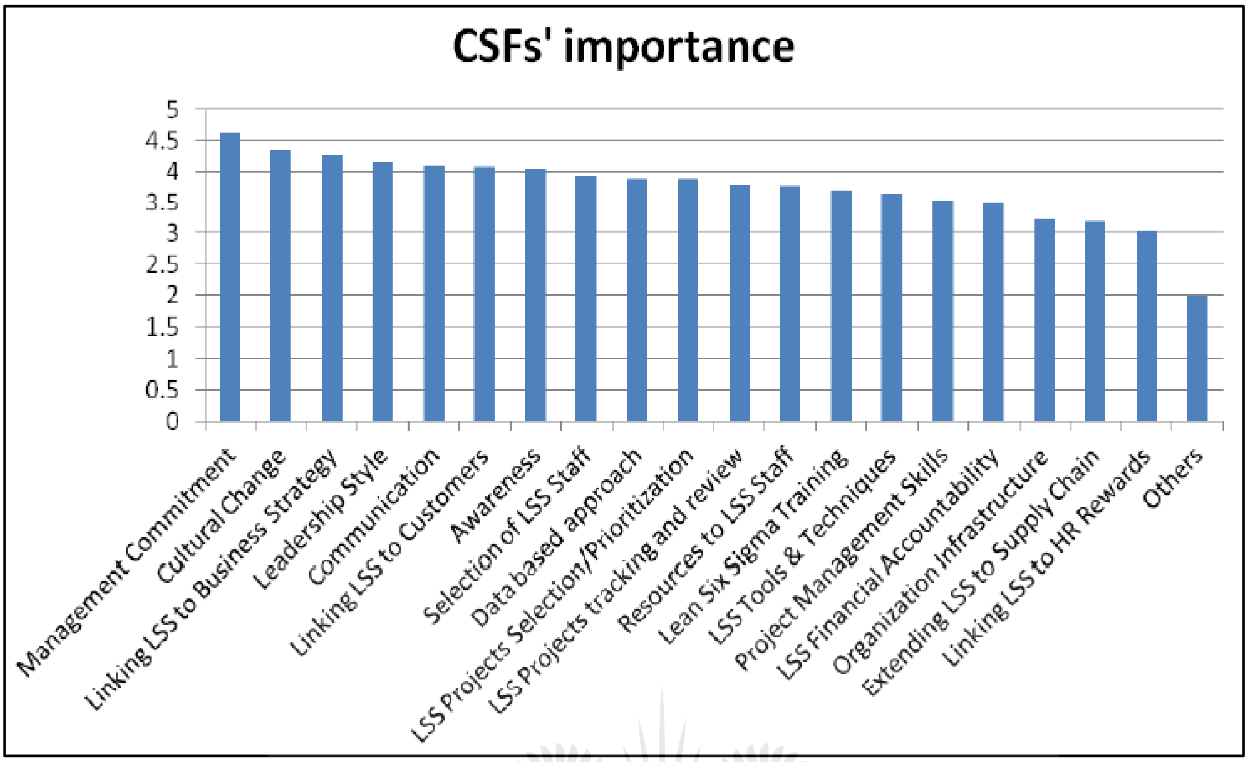

Figure 17: Average importance scores for LSS CSF's, Source: University of Glasgow, Laureani, A. and Antony, J. (2012)

It is also noted in the scoring of CSF's that before the roll out is extended to the rest of the supply chain, one must first master the LSS methodology. What was surprising in these findings was the low score achieved for Organisation Infrastructure which contradicts literature reviewed as a key differentiator of LSS when compared to previous quality initiatives observed in Snee, R.D. (2010). The most important CSF's were identified in Figure 17 with management commitment in the number 1 position.

The CSF identified for leadership style as one of the top four CSF's identified and limited coverage in LSS CSF literature suggests additional research opportunities for further research in determining which type of executive guidance in terms of leadership will assist LSS deployment.

2.11 Agile and Scrum

Agile originated in the software domain and basically describes a *set of principles* that allows self-governing cross functional software development teams to collaborate in aspects of highly flexible planning, fast response in delivery and continuous improvement with increased responsiveness to changes that may be required through the development process. In the evolution of software management since 1968 in Conway's Law defining any organisation designing a system it will ultimately result in the creation of a modus that reflects the organisation's structure by which it communicates. Agility within project teams and organisations is seen as the flexibility and ability to respond to the dynamic customer environment, which is changing all the time.

Agile Manufacturing (AM) complements Lean Manufacturing (LM) where the primary centrum is to deliver both products and/or services in optimised fashion with all wastes removed in a timely fashion [Kovach, J., Stringfellow, P., Turner, J. and Cho, R.B. (2005)]. AM as production system originated in detailing a focus on constant change. The philosophy of constant change is central to the strategy to outperform the market even when you are number one in any sector and industry through relentlessly evolving. The components are corporate partners, intelligent workers and information technology also detailed in Gunasekaran, A. (1998) and Yusef, Y.Y., and Adeleye, E.O. (2002).

Scrum can be found in software development from the late 1950's characterised in both iterative and incremental software development methodology. This was succeeded in adaptive and evolving management of software projects two decades later in the 70's.

Further evolutions two decades later in the 90's saw the emergence of "lightweight" approaches contrarian to the existing "heavyweight" approaches and marred by over regulation and limited in responsiveness and flexibility. Further evolutions followed, but noteworthy was Dynamic Systems Development Method (DSDM), Scrum, ABD, Crystal Clear and Extreme Programming (XP). Collectively these evolutions were classified as Agile software which preceded the publicised Agile Software Manifesto and concurrent progressive evolutions were taking place in Agile manufacturing and in unison similar progression similar transitions were being made in Agile and Lean aerospace and manufacturing. Twelve principles formulate the "Manifesto in Agile Software Development" which are:

- Value and continuous delivery in software development seeking ultimate customer satisfaction.
- Seeking ways to enhance the customer's competitive advantage and embrace changes in expectations even late in a project.
- Delivery of operating software frequently but weekly as opposed to lengthy monthly milestones.
- Users and developers working closely frequently and mostly daily.
- High levels of motivation in both project teams and individuals entrusted to deliver project scope.
- Communication is typical face-to-face conversations between stakeholders.
- Software that functions is the single KPI of project progression.
- Agile processes that enable sustainable software and project development in a progressive manner with observable maturity.
- Agility which is enhanced through continuous focus on continuous improvement and technical excellence and design of exemplary quality.
- Simplicity in reviews and execution of development and project delivery.
- Maturity of self-regulating and managing teams that deliver exceptional quality in projects execution.
- Internal review by project team that seeks to continuously improve and make necessary adaptions to achieve such improvements.

A significant catalyst in project speed and delivery is the iterative test phase and nature of Agile as opposed to the Waterfall test phase which is always separate after the Build phase.

Law, E. and Lárusdóttir, M.K. (2015) conclude that there is validity in establishing user experience and the relationship between fitness of Scrum and Kanban linking QFD to customer needs or rather VOC ambitions. Agile is dynamic and testing is done every step of the project and validation is done frequently. Scrum herein is characterised by iterations of less than four weeks and often only two weeks and facilitates teams' ability to maximise value delivered and is linked to Lean startup philosophy. Similar DFSS uses tools such as CTQ, QFD and VOC in parallel to Agile and Scrum in Wadhawan, K. and Sharma, T. (2014) seeking to observe and satisfy customer evolving needs from inception to completion.

2.12 Sustainability

The number of organisations that manage to not only understand but also navigate the sustainability paradigm remains small and is increasing at a steady pace. Sustainability considers the Triple Bottom Line (TBL) and institutes KPI's to physically ensure a CI strategy is deployed with DMAIC. The typical TBL model or 3BL observed in Figure 18 is an accounting framework that consists of economic, environment and social stakeholders and the associated impact that the organisation's products, services and activities have on these 3 stakeholders.

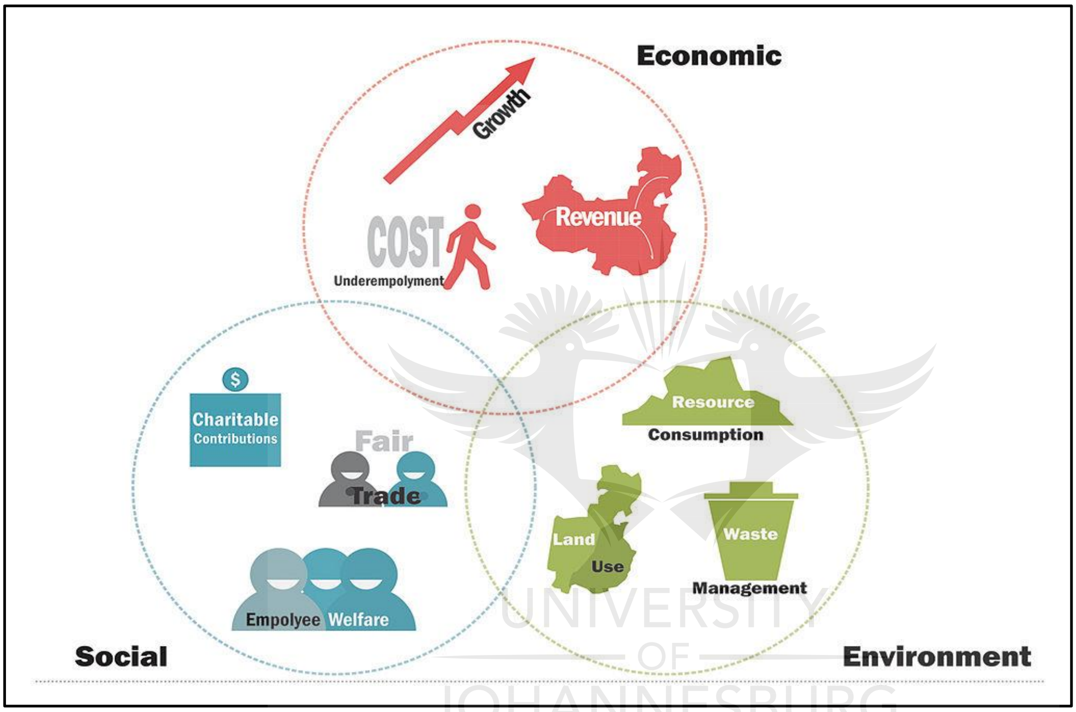

Figure 18: Incorporating visual classification and presentation TBL accounting reporting frameworks. Source: Slaper, T.F. (2011).

Incorporating the KPI's of the organisation's economic, environmental and social KPI's into its management and reporting processes, it is argued by Milne, M.J. and Gray, R. (2011), that such reporting has become synonymous with corporate sustainability. In the process concern for ecology has almost diminished. The frequent process of TBL reporting has become reinforced and institutionalised through Sustainability's biennial benchmarking reports, KPMG's triennial surveys of practice, and initiatives by the accountancy profession and, particularly, the Global Reporting Initiative (GRI)'s sustainability reporting guidelines. In Slaper, T.F. (2011) it is observed that the TBL and the GRI are insufficient conditions for organisations contributing to the sustaining of the earth's ecology and also paradoxically, such reporting coheres such organisation to increasingly achieve lower levels of sustainability

Several techniques have been developed with the "design for" which have focused on industries observed in Arnette, A.N., Brewer, B.L. and Choal, T. (2014) considering manufacturing, supply chain, environment, etc. culminating in the encompassing term Design for X (DFX) where X represents a specific function, description, activity, feature or goal which is central during the product and/or process design phase. Sustainability, which is an evolutionary and growing business dynamic most often fails to receive sufficient design attention resulting in sustainability not designed in and requiring expensive recovery phases in product life cycle. The Capability Maturity Model is used to describe the behaviours, practices and processes of an organisation that enable reliable and **sustainable** outcomes. The typical CMM in Hassner, A. Perkins, N. and Perkins, C. (2011) has 5 levels of maturity across three key organisational change categories which are:

1. Strategic Change Leadership
2. Business Change Readiness
3. Project Change Management.

These keys combined (or separately deployed) are an ideal tool to assess current capability levels and develop approaches to develop further maturity. Herein CMM depicts demeanours, corporate culture, SOP's and general modus operandi facilitating the firm in McKinsey and Co. (2010) consistently and **sustainably** reproduce predetermined and controlled results. Company readiness and engagement remains pivotal and critically important to avoid the risks associated with unsustainable, poorly designed, transitioned and integrated change which supports the importance of DFSS in facilitating high levels of organisational maturity.

2.13 Industry 4.0

In Schlaepfer, R.C. and Koch, M. (2015) summary of research conducted in 2013 and 2014 across major European manufacturers postulated that in Industry 4.0 it can be defined as further developmental state or increased maturity capability of both organisation and management of the value chain and also called the 4th Industrial Revolution. LSS and DFSS is influenced in not just defining the problem, but defining the dataset and then cleaning and manipulating it so that it can be analysed in Minitab or Excel. Positive evolution that IIoT trends are pioneering innovation in process efficiency optimisations in continuous improvement lifecycles. Industrial IoT and big data provide compelling enablers for real-time improvements as well as enhancing and dramatically speeding up LSS type improvement. It is also reported that the influence in operations are noteworthy with advanced technology allowing enhanced analytical capability by the typical data-intensive processes in LSS projects completed. Internally GE has predicted $1 trillion in opportunity annually by 2025 improving how assets are used and how operations and maintenance are performed within industrial markets.

It is reported in a Geissbauer, R., Vedso, J. and Schrauf, S. (2016) Industry 4.0 survey (done in 26 countries with over 2000 respondents) that annual digital revenue will be $493bn, annual cost and efficiency gains will be $421bn through combined digital investments of $907bn. This means cost reductions of 3.6% as a result of shorter lead times, higher asset utilisation, improved productivity and sigma quality. Products and packaging using (Radio Frequency Identity) RFID in real time updates the ERP system in the Internet of Things (IoT's).

Sastry, N. (2015) surveyed and analysed more than 150 use cases, ranging from people whose devices monitor health and wellness to manufacturers that utilize sensors to optimise the maintenance of equipment and protect the safety of workers. Bottom-up analysis for the applications estimates that the IoT will contribute from $3.9 trillion to $11.1 trillion a year by 2025 representing 11 percent of the world economy. This is extended into the Industrial Internet of Things (IIoT's).

Industry 4.0 stems from a German government initiative and high technology strategy to promote computerisation of manufacturing at the Hannover fair in 2011 and labelled in 2012 by the Working group of Industry 4.0 who designed and presented a set of recommendations for the Industry 4.0. This revolution follows the 1st, 2nd and 3rd industrial revolutions seen in Figure 19.

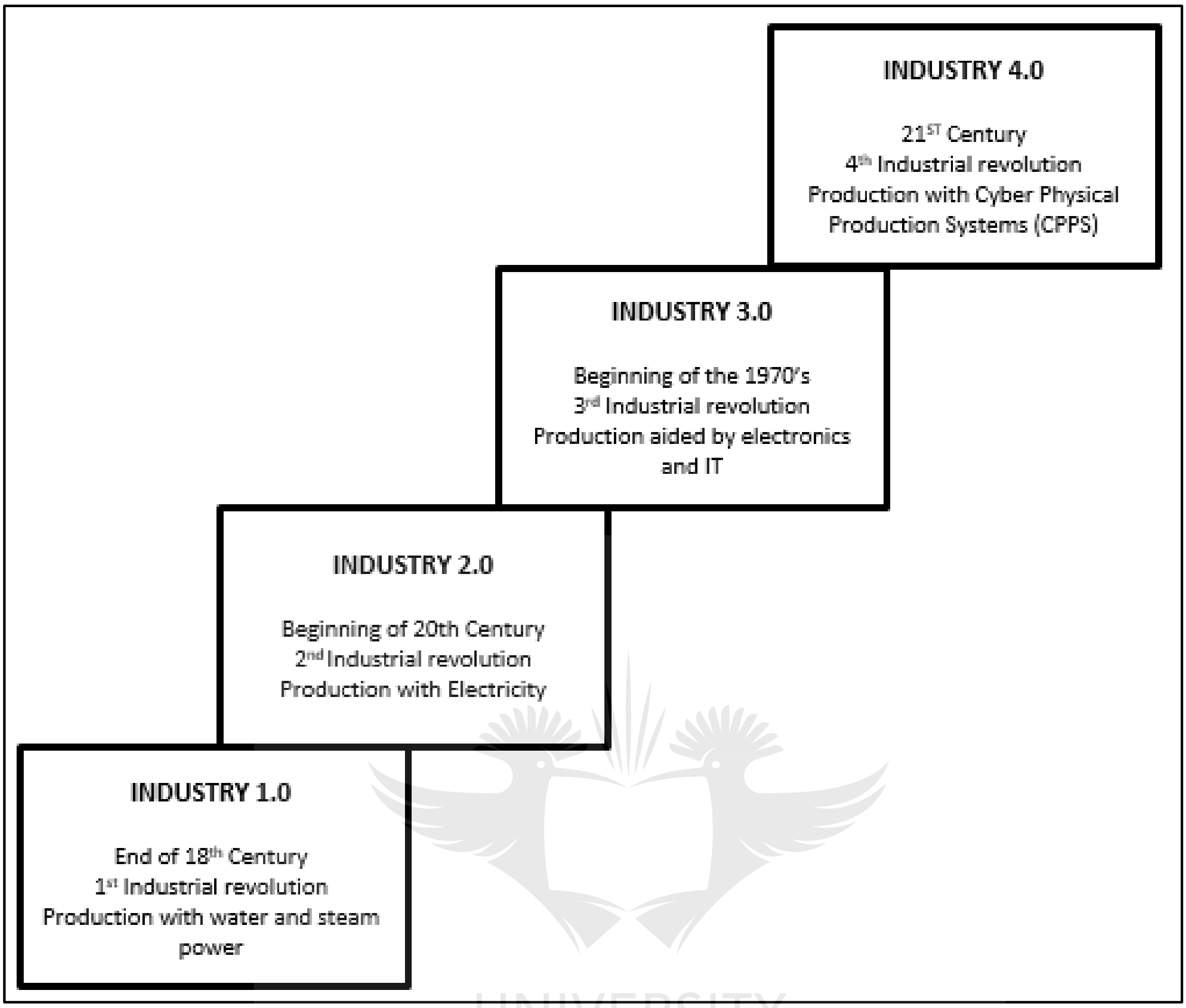

Figure 19: Definition of Industry 4.0, Source: Schlaepfer, R.C. and Koch, M. (2015).

Industry 4.0 is centred within the following characteristics which are:

- **Vertical networking of smart production systems** – This enables smart production systems using Cyber Physical Production Systems (CPPS) enabling plants to be more Agile and responsive to changes in faults and production outputs. Production and maintenance management is autonomous. Smart sensors technology is used for primary data inputs and all stages of processing and equipment condition is recorded in real time and then visualisation of any events are possible. Resource efficiency is maximised with new skills developed for CPPS.
- **Horizontal integration through global value chain network creation** – Global optimisation is nurtured through value creation networks which are optimised in real time as a result of integrated transparency which enables high levels of supply

flexibility and agility. Real time tracking is possible and both customer and supply chain partners can generate new business and cooperation models, which in turn will create legal challenges for intellectual and product liability.

- **Cross disciplinary engineering throughout product life cycle** – New synergies are unlocked between product development and production systems and data and informatics are available at all stages of product life cycle, which supports increased process flexibility derived from data modelling to prototypes and production cycles in Haberli, A. (2015) and Deloitte (2015).
- **Acceleration through exponential technologies** – Increased flexibility, cost savings and individualised customer solutions are direct results of the impact of exponential technologies. It is viewed and confirmed by Nadkarni, G. (2015) that Artificial Intelligence (AI), advanced robotics combined with sensor technology enables exceptional levels of autonomy through the analysis of big data, autonomous processes and transportation systems including saving costs in Supply Chain Management (SCM). Quality management will see exceptionally higher quality of sigma quality through complete automisation with the addition of nanomaterials and Nano sensors deployed aiding production systems and control mechanisms. Increased levels of autonomous drones and flying robots in factories and business making repairs and deliveries, minimising stock and maximising customer delight. Exponential technologies such as 3D printing (additive manufacturing) facilitates increased flexibility.

Major nine technologies which are currently transforming industrial production can be seen in Exhibit 1 in Figure 20 and work next to humans whilst learning from them.

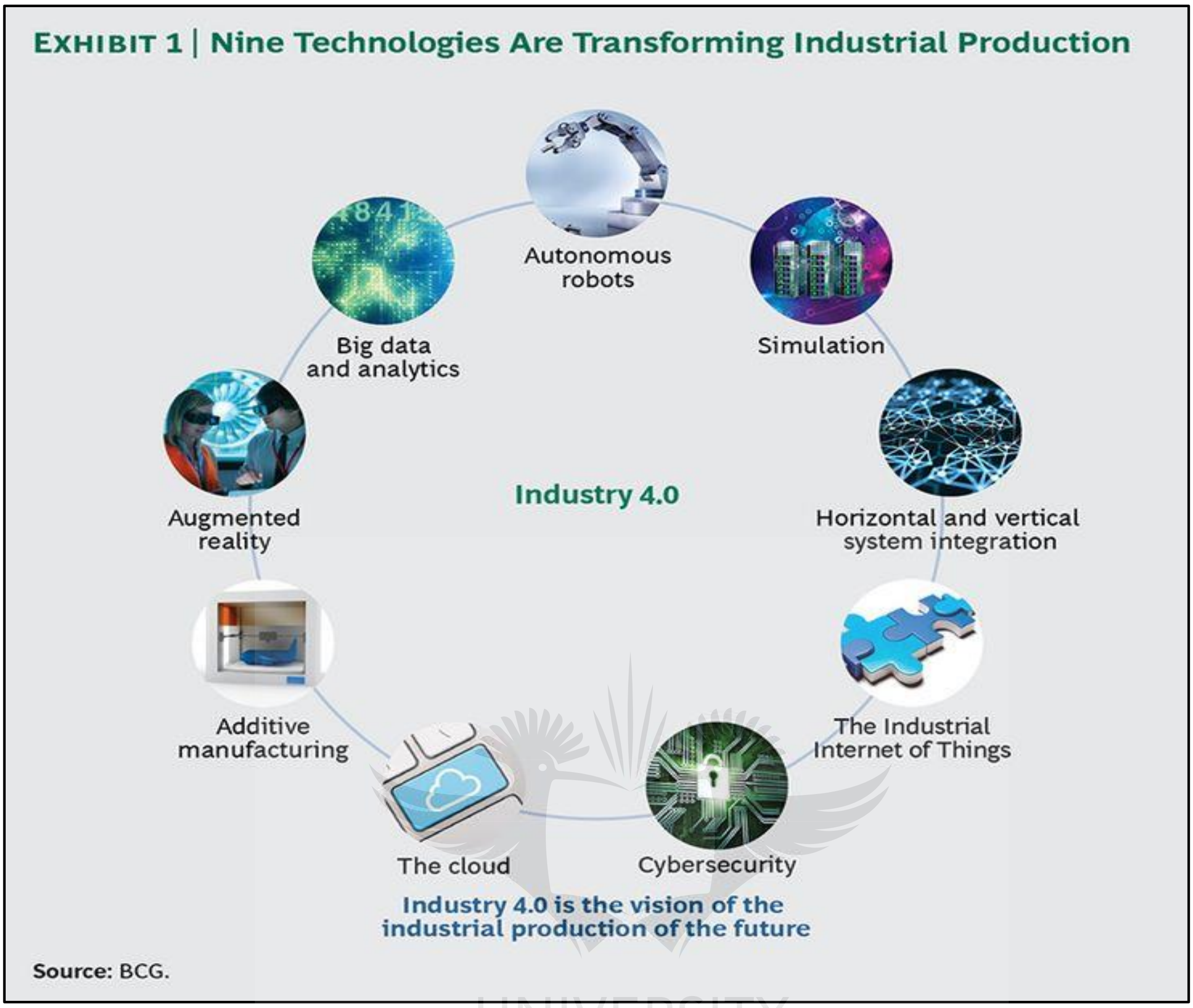

Figure 20: Nine Pillars of Industry 4.0, Source: www.bcg.com (2017).

These disruptive nine industry evolutionary technologies are:

- Big Data and Analytics
- Autonomous Robots
- Simulation
- Horizontal and vertical system integration
- The industrial internet of things
- Cybersecurity
- The Cloud
- Additive manufacturing
- Augmented reality

Columbus, L. (2014) reports notable advances in Big Data use by manufacturers taking advantage of advanced analytics that can reduce process flaws, saving time and money.

The technology available in both software and advanced analytics refers to the application of increased levels of statistics and other mathematical tools to business data in order to assess and improve practices seen in Figure 21. It is observed by Auschitzky, E., Hammer, M. and Rajagopaul, A. (2014) that within manufacturing, leadership and management is able to extract with advanced analytics and capitalise by a deep dive into historical process data central to QFD, VOC, DMAIC and CTQ inputs and identify patterns and relationships among discrete process steps and inputs which will then facilitate and optimise the factors that prove to have the greatest effect on yield. Decision making becomes increasingly driven by data used for analysis.

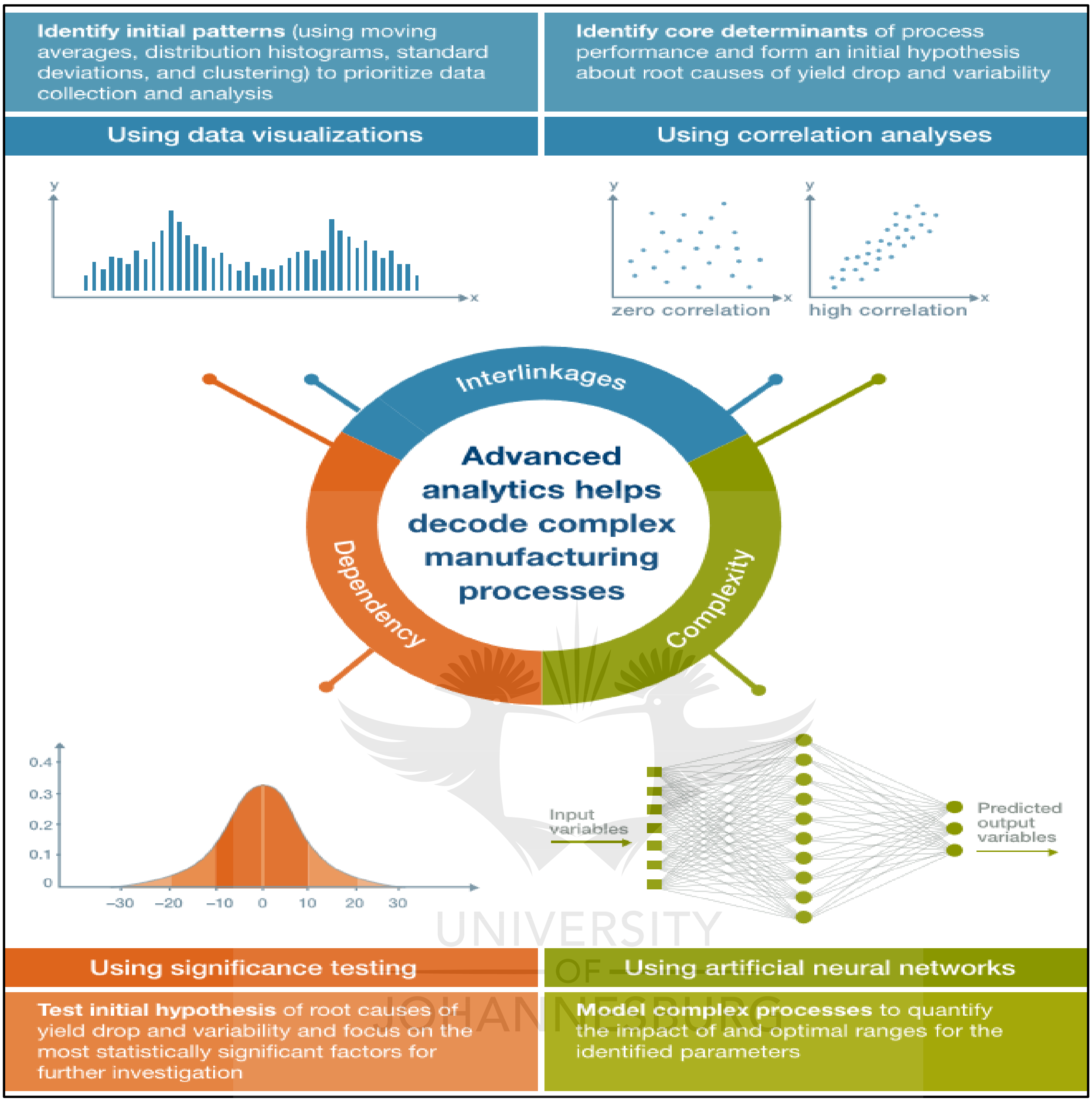

Figure 21: Big Data Analytics, Source McKinsey and Co. (2014) http://www.mckinsey.com/business-functions/operations/our-insights/how-big-data-can-improve-manufacturing.

In addition the anticipated impact of Industry 4.0 on TLS (TOC + Lean + Six Sigma) is not to be overlooked and in Hohmann, C. (2014) advanced analysis of both processes value streams and constraints to continue with aid of the new big data and Real Time Analytics is predicted.

DOE could be either complemented or compromised by Big Data computing which is confirmed in Otto, H.P. (2016) as rapid advances in computing power among the three TLS (TOC, Lean and Six Sigma) approaches, with Six Sigma requiring stable repeatability that will increasingly pave the way for automation.

Hohmann, C. (2014) also suggests that potentially Black Belt and Master Black Belts will be superseded by reliable automation. Professional LSS contribution will be restricted to LSS intelligence.

The emergence of different and innovative techniques and methods will be a reality but classic CMMI, DMAIC, PDCA, Pareto, TOC and VSM will still be seen used frequently integrated with increased streams of data.

Problem solving will still require a certain level of human intuition and the kind of reasoning that even in the face of increased use of smart devices is it reasonable that apart from data correlation human intuition machines should not have so soon. It will only be possible when AI is able to assimilate data and showcases HMI skills and people will still occupy factories but at increasingly lower staffing volumes.

2.14 Conclusion

The review of Literature for key CI improvement methodologies is inclusive of history, evolution and contribution to maximising ROI. Rapid changes in industry and consumer behaviour can be reviewed and correlated within mathematical patterns through big data analytics and incorporation of predictive mathematics in AI with quantum computer technology.

Innovation levels will increase drastically with DOE done through increased use of simulation as opposed to actual cost intensive experiment. Further this research review's purpose is to confirm the contribution and criticality of success factors as well as the different aspects posed by the research in both the origin and evolution of LSS, DFSS and the significance in the contributions a Capability Maturity Model makes to the study undertaken. This is significant because many organisations have a different approach to Continuous Improvement seeking to maximise ROI. TOC and LSS also referred to as TLS. This approach offers a holistic approach in both Lean and DMAIC approaches.

There has been much research and discussion conducted on these CI tools such as the adapted TLS methodology and opinions of the Continuous Improvement Community, including both established and emerging methods and a variety of approaches, linked to culture, strategy and maturity capability. Most of the research focusses around the manufacturing industry but the service industry was not excluded due to availability of organisations and previously researched literature. More research and testing is required to gain a better understanding of why those firms with declining labour productivity growth in Figure 4 profits or service levels choose not to capitalise on the opportunities presented but also the urgency for Industry 4.0 and rapid industry adoption. It is important to conduct more studies on the results and reasons why they decide to not pursue tried and tested CI methods and techniques adopted by global industry leaders.

Nations and industries will embrace Industry 4.0 at differing frequencies and also in associated differing strategies. Maturity capability of the organisation within industries with a high level of product variants, such as automotive, pharmaceutical, aviation, FMCG, will be best positioned to benefit from the increased degree of flexibility that can generate productivity gains, especially where high sigma quality beyond 5 and 6 sigma such as aviation, pharmaceutical, autonomous transport and semiconductors will benefit from data-analytics-driven CI that reduce error rates. Existing methodologies such as DFSS, TLS, Agile, Scrum and organisational maturity such as measured in CMMI, MBNQA and EFQM will benefit from increased data flow. Industry responsiveness of CI programs and organismal agility as a result of real time changing key metrics with key inputs in customer and supplier data will unlock increased speed, customer satisfaction levels and reduce costs in various functional areas not possible previously.

Integration of software and traditional manufacturing requires a revisit of existing maturity models to both absorb sustainability expectations from TBL and Industry 4.0 stakeholders. Maturity models can only consider all the varied metrics through an adaption which also nurtures the ever increasing need for advanced Artificial Intelligence methods and also Innovation in itself a CSF for sustainability of any industry and organisation.

Chapter 3

3.0 Research results and Industry application and methodology

3.1 Introduction

The Continuous Improvement drive, also referred to as Organisational Excellence has been an integral part of differentiating and manifesting a competitive market position. Profitability is directly linked to improving speed and accuracy in the execution of product, process and service delivery to the end user. Sustaining such competitive ambitions requires an organisation that is both Agile and Capable to their customers and markets they serve. This amplifies in DFSS tool selection and deployment such as listening to the customer in Kano Analysis and extending design inputs into quantifiable metrics in VOC, QFD and CTQ which can be continuously replicated in maturity of execution.

3.2 Common misconceptions in LSS, DFSS and CMMI

The following summary is necessary to provide an overview of the misconceptions that often manifest themselves in industry and project teams relating to LSS, DFSS and CMMI:

- It’s not just about statistics
- Limited to manufacturing industries
- Defect analysis focussed
- Limited to large organisations
- Alternatives for compliance company system standards such as ISO 9000 series
- Restricted to users with Maturity levels 4 and 5
- The only KPI

The review of these misconceptions is necessary as part of the background research that needs to be done before CSF’s for LSS and DFSS are established including building blocks for an integrated CMM.

LSS and DFSS deployments are not substitutes for management systems certifications and maturity frameworks – Regular review and assessments are necessary to confirm compliance for both frameworks and International and Industry standards such as Six Sigma in ISO 13053-1/2, ISO 17258; ISO 18404; ISO 12207; ITIL V3; EFQM, MBNQA, IEEE standards in Siviy, J. M., Lynn Penn, M. and Stoddard, R. W. (2008a). LSS and DFSS will assist in conformance with some of the standards and in turn accepting LSS and DFSS deployments. It is such framework conformance which is technically incorrect and misleading, defeating its respective design intents.

LSS and DFSS deployment is not restricted to mature organisations with maturity levels of 3, 4 or 5 – Industry perception that CMMI can only function with LSS and DFSS deployments with processes that display mature process domains, is incorrect. What is important is to be aware of the linkage which exist in LSS and DFSS deployments and the CMMI process areas applicable to all 5 maturity levels. In Beardsley G, (2005) it is observed that strategically the possibility to implement characteristics of high process areas at low level maturity domains lays a platform to increase velocity of building maturity rapidly and much earlier for higher maturity capability.

LSS and DFSS are not maturity models or in competition with CI improvement standards – CMMI acts as a catalyst, enabler and governing framework within which CI tools such as LSS, DFSS, TOC, Agile and Scrum can be implemented and Industry 4.0 technology deployments can coincide as part of an integrated improvement strategy [in Bergey, J. et al. (2004)].

3.3 Operational Metrics – Lean

In the quest to determine the CSF's for DFSS and LSS to support a Lean Strategy the author observes [Mintzberg, H. (1992)] the reflection of an organisation structure as its first dimension in achieving the organisation's objectives. It is furthermore confirmed that Standardised work is a key Lean and TPS component observed in Table 7 seen in Mintzberg's Five Organisational Structures. Of importance is the highlighted section under Prime Coordinating Mechanism columns referring to Standardisation of work processes, skills and outputs which is central to LSS and CMMI level 2 and 3 approaches.

Table 7: Mintzberg's Five Organisational Structures, Source: Lunenberg, F.C. (2012).

Structural Configuration	Prime Coordinating Mechanism	Key Part of Organisation	Type of Decentralization
Simple structure	Direct supervision	Strategic apex	Vertical and horizontal centralization
Machine bureaucracy	Standardisation of work processes	Techno structure	Limited horizontal decentralisation
Professional bureaucracy	Standardisation of skills	Operating core	Vertical and horizontal decentralisation
Divisionalised form	Standardisation of outputs	Middle line	Limited vertical decentralisation
Adhocracy	Mutual adjustment	Support staff	Selective decentralisation

The research reveals that in the unfolding of a CMM for LSS and DFSS deployment to complement a Lean strategy there is significant support for standardisation within the operation, a key Lean component and also intrinsic within TPS.

Critical Lean enablers and CSF's determination for Lean deployment in Oehmen, J. et al (2012) identifies *people maturity capability* and *organisation maturity capability* are pivotal for CI program success. The need for structure is necessary and a framework is adopted with seven enablers, which are:

1. Kaizen
2. Lost Time Analysis
3. Standard Work
4. 5 S
5. Autonomous maintenance
6. Value stream mapping
7. Visual management

3.4 Operational Metrics – Six Sigma

SS relates to varying areas of the organisation such as management where SS in Yang, K. and El-Haik, B.S. (2009) observes initiatives of management that depends on its implementation by team members. Six Sigma requires an egalitarian form of communication and delegation of authority, as opposed to a *command and control management approach* relied on which is similar to Lean and Six Sigma. Such tools require close and regular feedback to team constituents. Capability is achieved through capacity building and an ongoing process of development in the varying levels of Six Sigma Belts. All work is a process, all functions have processes and management process often requires CI.

Labour within any organisation is a major cost and here Six Sigma can be applied to maximise labour to be more effective. Applying TOC with Six Sigma can afford monitoring and visualise labour distribution across shifts and functional areas and redeploy to create increased labour balance.

JIT a Lean tool (but also a Lean *outcome* where Six Sigma is applied through DMAIC) can reduce excess inventory which increases cash flow not tied up in stock by establishing balanced stock levels based on regular review of consumption patterns.

Lead time reduction is possible where Six Sigma approach to reducing lead time would be to compare various customer needs with the time it takes to incorporate these VOC features into a product and determine how to cut lead times with minimal effect on customer needs. For example, some customers might prefer to sacrifice minor, time-consuming features of a product if lead time is reduced by 50 percent. The VOC allows only essentials to be included in product design and production.

QFD is possible in improved Quality by increasing product quality in design and manufacture and reducing failure rates, creating customer delight through improved quality, achieving process designed quality intent, often overlooked during the design phase.

3.5 Process and Product Metrics – CMMI, LSS and DFSS joint integration

Organisations are necessitated to drive process improvement for one or more of the following three reasons discussed in a multi-model lecture given by Siviy, J. M., Lynn Penn, M. and Stoddard, R. W. (2008a):

a. Performance issues – Evolution or product performance issues in the field or development phases
b. Regulatory and customer mandates – ISO standard compliance, Process capability i.e. Cp/Cpk ≥ 1.67, Sarbanes Oxley Act requiring level 3 CMMI maturity for contracting entry
c. Critical Business needs – Losing a contract/client/market share or business survival depends on it.

Another look at CMMI, LSS and DFFS is required for multi-model proliferation and the different standards and methodologies and terminologies in each approach and the risk in failing to recognise model commonality.

3.5.1 LSS and CMMI

Table 8 depicts the key differences between CMMI and LSS and it is noted that LSS focus on process variation reduction and CMMI focus on improving overall business. LSS is a methodology, similar to DFSS and CMMI in turn is a maturity framework which is designed around certifying the organisation as opposed to LSS where the individual is certified. Certification authorities are not reflecting ISO joining the foray which now also can certify organisations with ISO 18404:2015 to either Lean or Six Sigma standards, although industry uptake has been very slow since 2015.

Table 8: Comparison and overview of LSS and CMMI, Source, www.isixsigma.com

Sl No	Feature	LSS	CMMI
1	Initiation	Motorola 1986	SEI at CME in 1987
2	Objective	Focus on quality to reduces process variation and defects	Improving business processes
3	What is this	Methodology to deliver quality products and customer focus	Model that establish organisation process maturity
4	Origination	Manufacturing Industry	Software Industry
5	Certification	Yellow Belt, Green Belt, Black Belt and Master Black Belt, etc.	CMMI level 1,2,3,4 and 5
6	Certification authority	• Institute for Industrial Engineers • ASQ • BMGI • Selected Universities	SEI
7	Who will be certified	Employee	Organisation

3.5.2 DFSS and CMMI

DFSS (also known as DMADV) is used for projects aimed at creating new product or process designs (Williams *et al*., (2001); Cronemyr, (2007); EPA, (2009). Original LSS methodology evolved as stated previously and in addition to several new tools, the **basic improvement process** received an additional step "define", meaning that the old MAIC was now DMAIC, a new methodology was shaped under the basic LSS labelled DFSS. Figure 22 depicts the overlapping of Risk and CI methodologies and the interrelationship explored between Design for Reliability (DFR) and DFSS in DMADV.

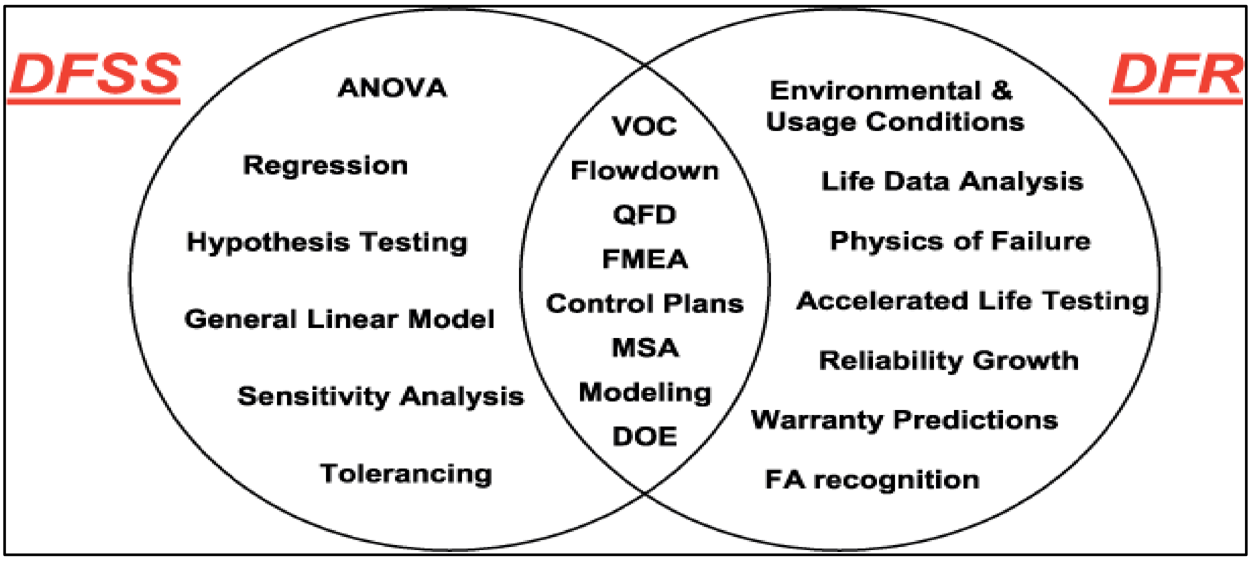

Figure 22: DFSS and DFR interrelationship explored, Source: www.isixigma.com

The overlap that occurs in key factors such as VOC, Flow down, QFD, FMEA, Control Plans, MSA, Modelling and DOE underpins the contribution DFSS makes within reducing risk and increasing reliability through Design of the quality with a very high yield process design imperative. The difference was that DFSS focused on new product and process design rather than improving the existing products and processes. DFSS also has its own process which consists of steps: define, measure, analyse, design and verify (DMADV) observed in Hopp, W.J. and Spearman, M.L. (2008) and significant opportunity exists in the Total cost curve which is intersected with a dynamic DFSS approach before 5 Sigma level as seen in Figure 23. It's only with DFSS deployment that AQL can be realised past typical 5 sigma barriers with process and/or product redesign potentially reducing significant product life cycle cost parameters.

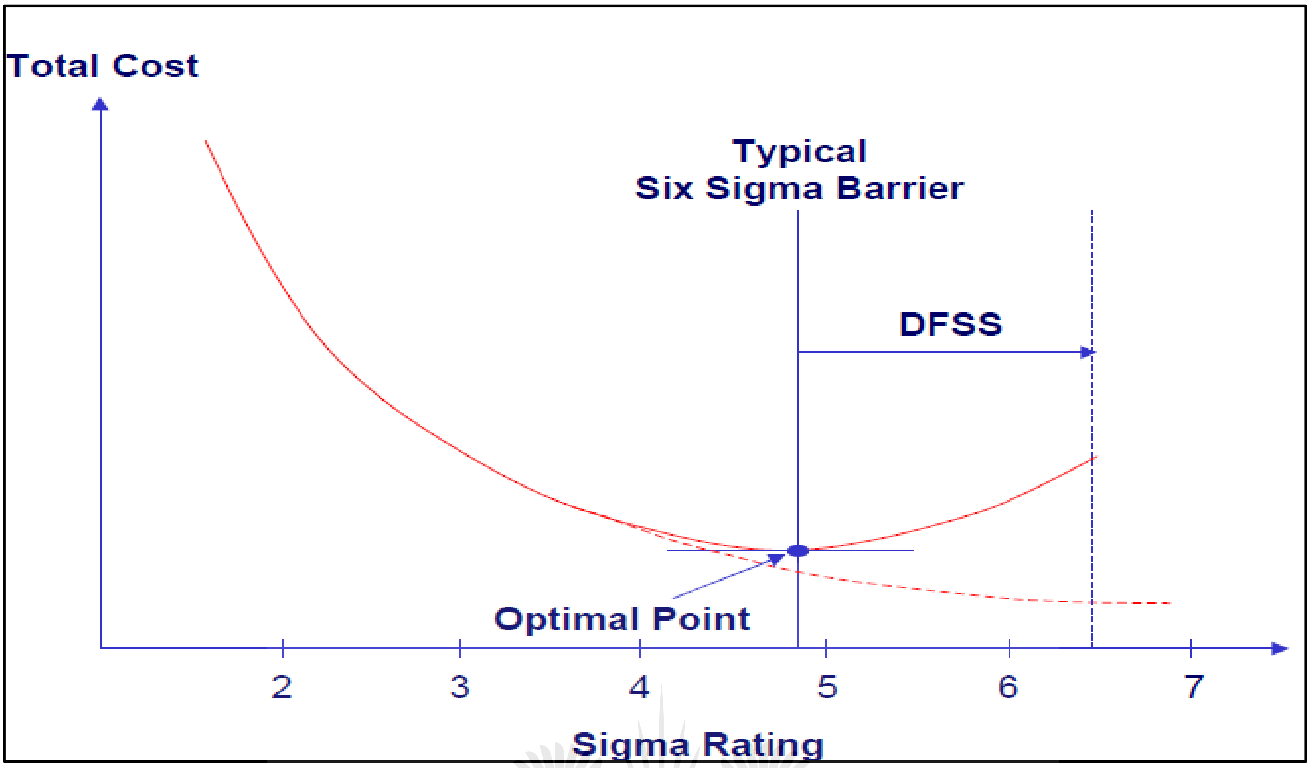

Figure 23: Sigma rating cost curve relationship with and without DFSS, Source www.asq.org

Tennant, G. (2002) reports that industry naturally associates DFSS with the DMADV methodology directed at new product and process imperatives. DFSS similar to LSS has evolved into a defined structured methodology but used to a lesser degree within the industry, with the exception of product design organisations. VOC and CTQ metrics are key inputs during the design phase which has the opportunity during development to unlock significant time and financial savings reported in Mesec, A. (2005). During a DFSS DMADV is the verification step differentiating from LSS.

The main *objective of DFSS is not to replace existing design methods* but rather complement those with a specific project scope of achieving a higher sigma level of quality than what the product and or process historically delivered.

DFSS complements design efficiency and optimising design resources whilst creating capacity for additional innovation and new product developments reported in Crevelin, C.M., Slutsky, J.L. and Antis, D. Jr. (2003); Yang, K. and El-Haik, B.S. (2009). DFSS has proven to deliver both qualitative and quantitative results through VOC and QFD in Mesec, A. (2005). In addition DFSS enables reduced project timing during Monte Carlo type projects and associated expenses and facilitates seamless DOE efficiency gains are realised in further project cost and delivery time reductions. Defects and time-to-failure are not the main metrics of DFSS. Table 9 compares and lists the DMAIC in Six Sigma with DMADV in DFSS.

Table 9: DMAIC and DMADV constituents and comparison. Source www.isixsigma.com (2017).

Methodology	Phase	Activity
DMADV	Define	Defining the design goals based on customer needs and the corporation strategy
	Measure	Measurement and identification of critical characteristics, product and production process capability
	Analyse	Analysis in order to develop and design alternatives, and evaluate design capability to select the best design
	Design	Designing the details, optimize the design, and plan for design verification
	Verify	Design verification, arrange pilot models, and implement in the production process
DMAIC	Define	Defining the problem or improvement opportunity versus technical and/or business requirements, goal setting and defining the project boundaries
	Measure	Measuring the current process or product performance, defining the input/output variables of the process, and validating the measurement system
	Analyse	Searching for key factors that have the biggest impact on performance and determine the root causes of problems
	Improve	The improvement activities should be identified to optimize the outputs and eliminate or reduce defects and variation
	Control	Implementing and monitoring the solution to make sure the achievements are sustained

DFSS deployment acts as a development tool and allows for synergy between low cost, high quality and fast development speed of designs for new products and processes. It offers structure during design supported by a significant arsenal of statistical tools and project management with order and definition in Mesec, A. (2005).

Research in Lara, J.L. (2012) observes that DFSS constituents are required to actively pre-empt potential deviations and mitigate defects as opposed to being reactive. DFSS by design reveals financial ambitions central to its DNA reducing cost drivers and maximising customer and process owner's satisfaction metrics Methodologies for DFSS deployment are inclusive of but not limited to **DMADV** and **IDOV**. DMADV is combined with IDOV highlights unique attributes in DFSS in Figure 24 as reported in Sokovic, M. and Pavletic, D. (2007).

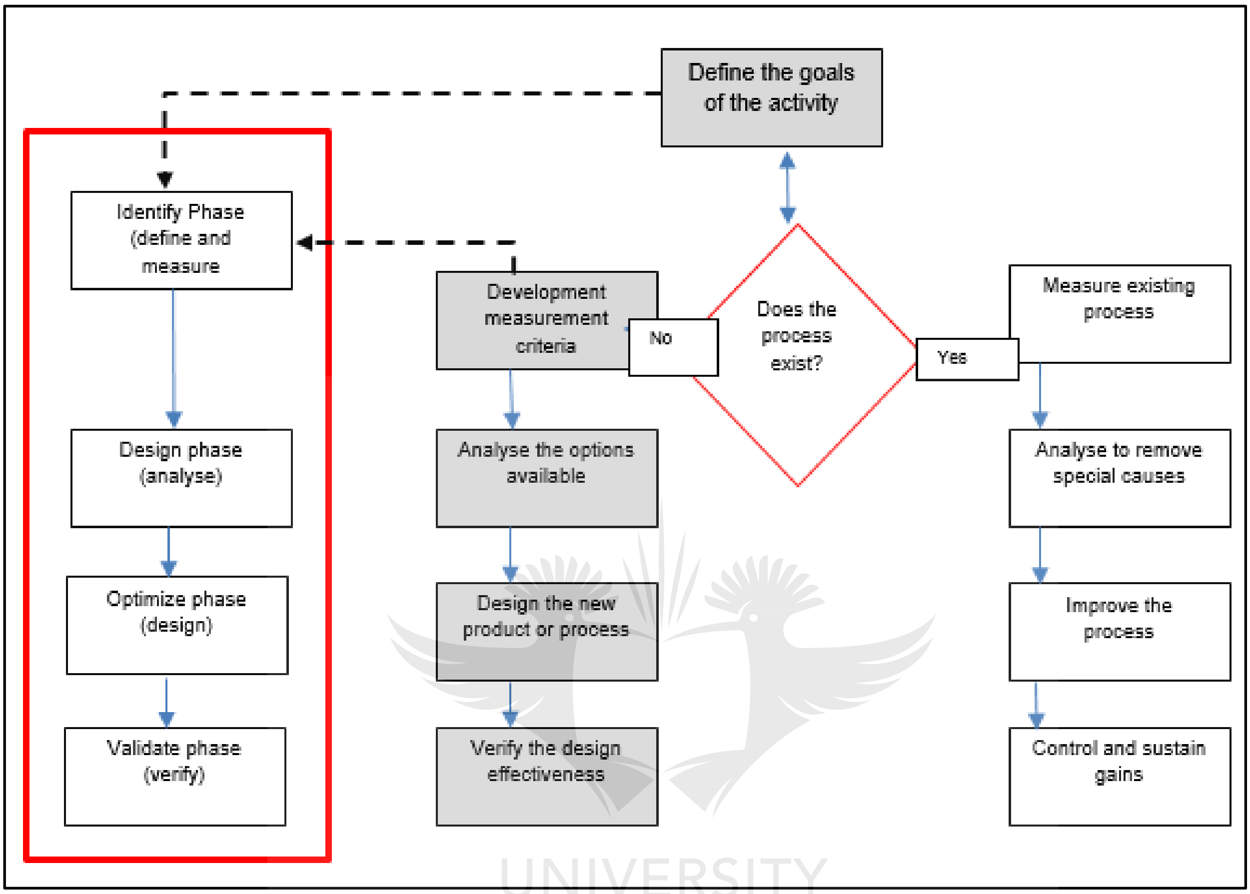

Figure 24: The extent of DMADV with IDOV is added, source: www.isixsigma.com

DMADV is observed in Cooper, R.G. (2001) where it also reveals the low levels of new product design ideas translating into successful new product development averaging four out of seven. Product launches are mostly operating at 4 sigma level even when deploying Six Sigma improvements at the product and process design level and resulting in new products being centre to businesses' problem management space. The question emerges about successful DFSS deployment that the organisation has to be at a certain maturity capability level, which will be evaluated further in this document. Successful DFSS deployment requires Six Sigma program maturity which has reached a critical level of maturity according to Yang, K. and El-haik, B. (2003). The level of maturity will be determined through the Maturity Capability Model Construction.

3.5.3 CMMI, LSS and DFSS

In other attempts to integrate CMMI, LSS and DFSS is it observed [also in Beardsley, G. (2005)] that there are different strategies for such implementation, where the CMMI and LSS include such choices as implementing an internal process standard comprising all models of interest and implementing process areas as LSS and DFSS projects. Seen in Figure 25 a notable phenomenon in CMMI adoption is that the organisational collection of processes gets larger before it gets smaller. This has been shown pictorially in a presentation about the joint use of the CMMI and LSS and maturity level evolution over time.

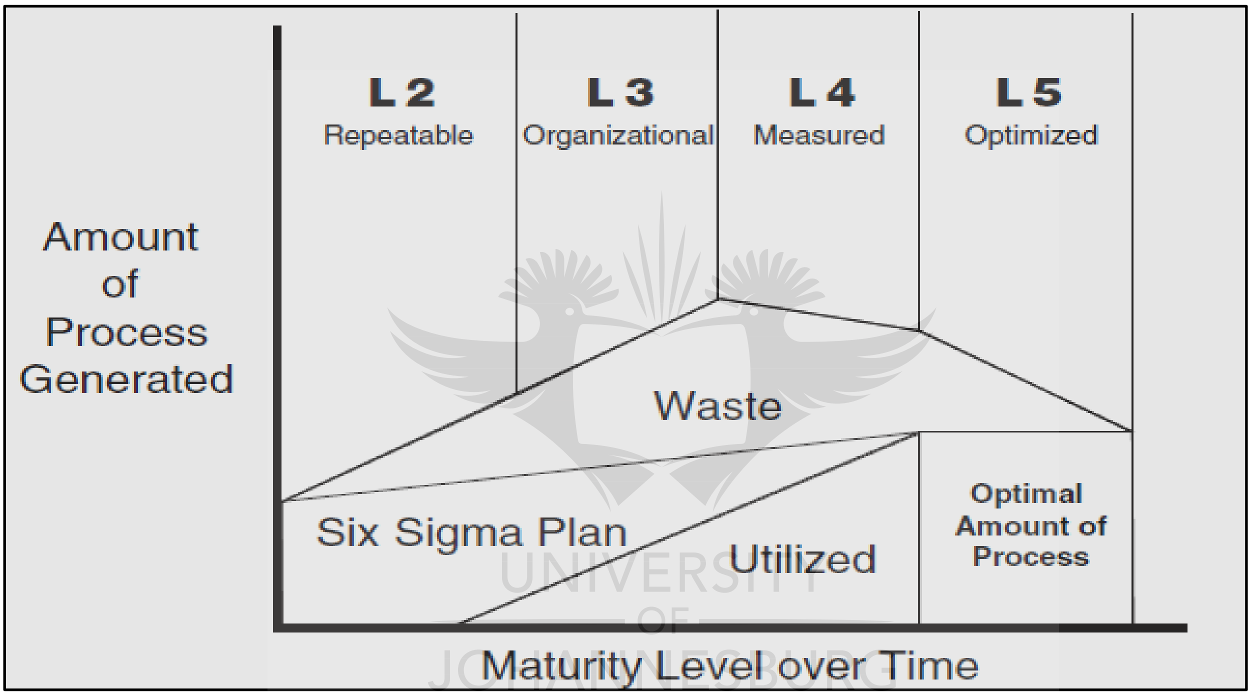

Figure 25: Implement CMMI-based processes as Six Sigma projects. Source: Beardsley, G. (2005).

The number of process generated increases up to the attainment of level 3 maturity and then a notable reduction in waste generated manifests itself with the attainment maturity levels 4 and 5 when combining Six Sigma and CMMI.

3.5.4 Joint integration CMMI, LSS and DFSS

According to Nayab, N. (2011) it is observed that CMMI and LSS complements Kaizen continuously within an organisation where LSS does lean towards process variation reduction and optimisation CMMI seeks to establish and improve basic organisational processes not limited to product and process design. CMMI as a CMM has the ability to integrate with LSS and DFSS due to the complementary CI nature of both designs.

CMMI, LSS and DFSS should not be in competition as CI strategies but an integrated deployment can afford the organisation rapid results in the areas where CMMI, LSS or DFSS are deployed jointly to improve the quality and maturity of processes.

An integrated framework will be discussed in Chapters 5, 6 and 7 and in CMMI and LSS/DFSS. Such integration could take four approaches in Nayab, N. (2011):

Approach 1 Separate deployment by implementation of initially a CMMI framework to establish structure followed by a staged LSS implementation.

Approach 2 Separate deployment by implementation of initially a LSS deployment and acting as model of control followed by CMMI to define a GAP analysis in processes which require intervention.

Approach 3 Joint deployment of CMMI and LSS combining Approaches 1 and 2.

Approach 4 Deployment of CMMI to a maturity level 3 and integration of LSS to achieve level 4 and 5 maturity.

No single approach is proposed and all should be based on organisational maturity and also capacity for deploying change methodologies independently and jointly [in Siviy, J. M., Lynn Penn, M. and Stoddard, R. W. (2008a)].

3.6 Shareholder Metrics – CSR and Financial metrics including ROI

Corporate Social Responsibility in Zeng, M. (2016), a key factor in sustainability and long term business success and LSS and DFSS, enables improved competitive advantage through constantly innovating faster and producing more economically and maximising ROI. Shareholders seek to maximise ROI and operational performance improvements are linked to profitability. The ultimate category is the Business Factor. This category divides into two success factors: the financial benefits and Business Strategy. The financial benefits success factor refers to the concept of a positive financial impact from the improvement implementation. Similar to other improvement concepts, LSS and DFSS with CMMI requires an initial financial investment. The ROI must be positive to entice the organisation to transform to the new setting. The size of the initial investment and the magnitude of the return could be topics of additional investigation. However, the importance in selling LSS and DFSS as a concept that will enhance the overall financial well-being of the company cannot be disregarded. Therefore, the representation of LSS and DFSS projects has a decisive role in the selection of the project. The measure of benefits will serve as an enticement tool to the members of the organisation in conveying the message of change.

Lean Six Sigma in Chakraborty, A. and Tan, K.C. (2012) reaches its full potential only when projects are linked to the CEO's strategic objectives and are used to drive the most basic of business goals, such as shareholder return. Often a failure for high impact LSS and DFSS is the absence in organisations who do not even have metrics like ROI and Net Present Value (NPV) in the index. They are written by very competent quality or manufacturing specialists whose experience is remote from the challenges faced by a CEO. The result: the CEO's strategy drives tactical execution through Lean Six Sigma and adoption of DFSS in support of achieving higher levels of LSS reducing DPMO.

3.7 The significance of CMM/ISO 9000 in respect of Lean, TOC, Six Sigma, DFSS, Agile and BPR

Tables 10 and 11 illustrate the significant aspects of the differing CI methodologies and their respective properties. Table 10 summarises the aspects of the same methodologies by ancestry, purpose and structural characteristics and finally in Table 11 we find defined appropriate deployment and anticipated CI outcomes.

Table 10 highlights the various approaches. ISO 9000 and CMM is combined and both the Tables have been adapted to substitute TQM with ISO 900 and CMM as both management system and Capability Maturity domain considering the evolution and similarities. The six various approaches are 1. Lean; 2. ISO 9000/CMM; 3. DMAIC - Six Sigma; 4. TOC; 5. Agile Manufacturing and 6. Business Process Re-engineering (BPR).

These six approaches are designed to facilitate customer satisfaction improvements in customer satisfaction relative process activities in Pegels *et al.* (2005). In addition it is observed that TOC is widely used in the industry, mainly because of its potential in identifying problems and optimising them, achieving process improvements in terms of productivity and efficiency. Draman *et al.* (1998) studied a successful implementation of TOC in an industry whose primary products were custom-formulated paints. This study is relevant because it shows how the change in the working philosophy can have a great impact in optimising a manufacturing process. Cost was the major driver for TOC adoption where Six Sigma and Lean deployments did not focus on throughput rates, although this can be a KPI in DMAIC.

Theory of Constraints in Hohmann, C. (2014) does not measure customer satisfaction, it identifies and explores constraints that can impact on the customer delivery, and it is a predecessor in the supply chain. Table 10 depicts the various differences in history and goals and Table 11 illustrates the key features and respective core concepts.

Table 10: CI Approaches with historical overview and goals contributing to customer satisfaction improvement. Source: Bozdogan, K. (2015): MIT Systems Engineering ESD Working Paper.

Key /Approach	Lean	ISO 9000 /CMM	Six Sigma	TOC	Agile	BPR/DFSS
History	Since late 1940s (emphasis on developments since mid-1990s)	Since early 1980s	Since mid-1980s	Since mid-1980s	Since early 1990s	Since early 1990s
Goal	• Deliver value to multiple stakeholders • Build long-term dynamic network-wide capability for sustained competitive advantage	• Meet customer expectations • Improve profitability and shareholder value	• Increase customer satisfaction • Create economic wealth (higher profitability and shareholder value)	• Maximize throughput • Improve net profits	• Enhance enterprise flexibility and responsiveness • Thrive in a fast-paced, uncertain, environment	• Improve customer satisfaction • Enhance enterprise performance

In almost all of the six approaches the customer experience is an objective which remains a key driver for implementation except Lean which seeks value creation to all stakeholders with employee respect and achievement of a long term organisational capability and competitive advantage.

The defining features between the six approaches are found in Lean creating flexibility and Agile seeking redesign of processes to be both more responsive to customer's needs.

Table 11: CI Approaches and significant contribution to customer satisfaction improvement Source: Bozdogan, K. (2015): MIT Systems Engineering ESD Working Paper.

Core Concepts	• Adopt a holistic view of the networked enterprise • Stress long-term thinking • Deliver customer pulled best lifecycle value • Eliminate waste towards the goal of creating value • Ensure stability and synchronized flow • Develop collaborative relationships and mutually-beneficial network-wide governance mechanisms • Foster a culture of continuous learning • Evolve an efficient, flexible & adaptive enterprise	• Understand and fulfil customer expectations • Concentrate on process management to reduce sources of variation • Focus on continuous quality improvement • Ensure heavy leadership involvement • Establish close links to customers & suppliers • Develop an "open" organisation • Foster worker training, empowerment and fulfilment	• Adopt customer focused culture • Reduce all sources of variation • Pursue disciplined, structured, approach to process improvement • Practice proactive, data-driven, management •Emphasise teamwork	• Improve workflow (throughput) in the production system • Concentrate on key leverage points (constraints) offering greatest performance improvements • Protect production line against interruptions • Ensure people learn better and faster	• Anticipate and meet customer needs • Deliver tailored solutions to customers • Evolve adaptive, flexible & efficient enterprise • Establish virtual organisation s • Enhance ability to thrive in a fast-paced & uncertain environment	• Reinvent enterprise through fundamental rethinking of enterprise processes • Pursue radical ("clean sheet") redesign of existing business processes • Seek breakthrough process solutions

Table 11 continues to summarise the core concepts in CMM, ISO 9000 frameworks and the core of Lean, TOC, Six Sigma, DFSS, Agile and BPR methodologies within CI. In evaluation of the core concepts for the six methodologies the quest is to continuously improve and acknowledge the common thread which will be explored in CSF measurement for LSS and DFSS during CI deployments.

BPR allows the organisation to question existing practices similar to DFSS which is often a secondary CI strategy when TOC, Lean, Agile or Six Sigma fails to deliver the necessary desired customer and organisational *operational metrics*. It is important when improvement required does not offer the required VOC or QFD sigma quality it is advised to perform a BPR or DFSS project.

Tables 12, 13 and 14 depict the review of the focus areas, implementation methods and the mode of improvement and changes and the contribution of ISO 9000 and CMM reflection of core business process which is central to the focus of its intended design and Lean, TOC, Six Sigma with BPR/DFSS focussing on enterprise processes which often overlap, and Agile focuses rather on the integration of the enterprise but also the creation of virtual organisations as required.

Table 12: Six CI approaches and respective focus, Source: Bozdogan, K. (2015): MIT Systems Engineering ESD Working Paper.

Key /Approach	Lean	ISO9000/ CMM	Six Sigma	TOC	Agile	BPR/DFSS
Focus	• Focusing on all enterprise operations, processes and functions • Emphasis on creating robust value propositions and value exchanges among stakeholders • Managing complex inter-dependencies throughout the networked enterprise (information flows, knowledge sharing, network-wide learning & capability-building)	• Determining customer expectations • Focus on core business processes • Integration of design, development & production operations • Establishing strong links to suppliers	• Concentration on specific prioritised business processes • Focus on reducing all sources of variation to improve quality, increase efficiency & shorten cycle time	• Concentration on production processes • Focus on the *weakest point* (constraint) impeding workflow and causing both delays & inefficiency	• Concentration on effective enterprise integration to support manufacturing • Focus on delivering high-quality, low-cost & innovative tailored solutions to customers • Creating virtual organisations, as needed, to reduce cost & cycle time	• Concentration on enterprise processes, not on organizational structures, tasks, jobs or people • Focus on "clean sheet" redesign of specific processes

Table 13 elaborates with a top down approach common to all of the approaches, however, Berry, O. (2017) differs in the deployment within Ford where the Lean approach adopts the Japanese inverted organisational process where leadership supports and engages staff in Kaizen related activities removing all forms of waste identified.

Table 13: Six CI approaches and implementation comparison, Source: Bozdogan, K. (2015): MIT Systems Engineering ESD Working Paper.

Implementation	• Top-down directive process involving strong leadership support & engagement • Using structured process (frameworks, roadmaps) for enterprise-level continuous improvement & planned systemic change • Use of outside experts (providing facilitation, mentoring, training, implementation services) or internally managed process	• Top-down directive process involving heavy multi-level management participation • Using a portfolio of practices, tools & techniques to implement continuous improvement • Use of outside experts (providing facilitation, mentoring, training, implementation services) or internally managed	• Top-down directive process involving structured management engagement (project champions, sponsors) • Using DMAIC (Define, Measure, Analyse, Improve, Control) as the dominant implementation method • Largely internally managed process with support/facilitation by outside experts	• Top-down directive process involving management participation • Using structured process employing *focusing steps* (to remove constraints), ten-step *Decalogue* for system-wide management, and "drum-buffer-rope" production scheduling method for managing production line • Mostly internally managed process with support /facilitation	• Top-down directive process led by top management • Emphasis on enterprise integration, training & education, and empowered teams • Building effective information infrastructure • Forming virtual organisations • Mostly internally managed process, with possible support from outside	• Top-down directive process involving management participation (e.g., as process owners) • Generally pursuing a structured multi-step implementation process (Mobilisation, Diagnosis, Redesign, Transition) • Facilitation by outside experts or internally managed

Table 14 continues with describing the various modes of CI within the six approaches, which are largely similar in varying degrees of change.

Table 14: Six CI approaches and mode of improvement and change comparison, Source: Bozdogan, K. (2015): MIT Systems Engineering ESD Working Paper.

Mode of Improvement and change	• Continuous process improvement; gradual incremental change; planned systemic enterprise change & realignment	• Continuous process improvement; gradual incremental change	• Continuous process specific improvement; incremental change (in discrete small or large steps)	• Continuous operational improvement; incremental change	• Continuous process improvement; incremental change (in small or large steps)	• Process-specific continuous improvement; incremental change (in small or large steps)

Employing Tables 10 and 11 and also 12, 13 and 14 in these constructs, complementary relationships between the Lean, Six Sigma, TOC, Agile, BPR and DFSS can be summarised as follows:

- Lean, TOC and Six Sigma integrates optimising the process through a combination of constraint recognition, waste elimination and quality focus for desired sigma quality. Distinctions made are similar to distinctions observed in Roth, A. Schroeder, R.G., Huang, X. and Kristal, M. (2008) between *practices* and *performance* in their examination of the relationships between Lean and Six Sigma. It must be stated that distinction is not made between the practices or principle composition or the deployment at differing levels. It is also noted that this general distinction is lacking across principles and practices which can be construed as actual practices in the industry and here the author observes [in Bessant, J., and Caffyn, S. (2001) and Albiwi, S.A., Antony, J., and Arshed, N. (2014)] the business maturity prominence in determining the capability of the target organisation to enable the potential of the desired improvement approach.
- Lean, TOC and Six Sigma does appear to have organisation level practices which can sustain total CI approach even though it includes practices with a customer, and process-centred focus which is inclusive of design and development of new products and processes. Organisation level approach is observed in Hoshin Kanri with policy deployment which ignores the necessary organisational maturity to succeed in an integrated CI program.
- LSS enables a duality implementation for both change program with a focus on CI but also support for nurturing maturity from inexperienced into mature and *experienced but in isolation*. Six Sigma and Lean does not harvest the reduction in process waste with quality improvement in a singular approach. The supporting contributions presented in DFSS with QFD and VOC metrics does however. LSS is in a position to satisfy CI in Black Belt projects in varying organisational and functional levels. Incorporating TOC and TPM enables visualisation of flow and constraints which can be mitigated often without Capex.
- The relationships between the Lean, TOC and Six Sigma are interlinked and often used in unison depending on the optimisation directive that is required to be

improved. As a result of varying levels of success it is necessary to critically evaluate the CSF's for successful deployment in particular LSS and DFSS. These methodologies represent the very first two of the five Research Objectives identified in Chapter 1. Additional tools deployed are error proofing where zero failure is mission critical. Also DFSS tools such as QFD, Taguchi, Classic, Shainin and full factorial DOE, CTQ, VOC / Kano model and DFR can deployed.

- Deploying DFSS tools in development or when break-through Sigma quality is required it inherently complements the CI strategy. The controls and staging is often not consistent with the intent of the tools applied. It can be regarded as the primer for the Research Objectives 3, 4 and 5 and the respective contributions of leadership and capability maturity.
- Central to Lean we observe JIT and Jidoka as a result of standardised work and creation of flow through removal of Muda in the supply chain. [DFSS (when applied timeously during development) enables LSS outcomes through robust process design and inherent DFR strengthening of product and process manufacturing and processing stages.] VSM during delivery continuously identified opportunities to improve key customer and cost metrics whilst improving sigma quality.
- DMAIC and DMADV method for process improvement with VSM establishes a platform for CI in process and products affecting customer metrics. Both DMAIC and DMADV are generically-structured problem-solving methods for either existing processed or new designs with the use of advanced statistics that can function effectively within CMMI which allows for the regular review of process maturity and CI process improvement success. Infused with Agile and Scrum there is the potential for greater product development quality and time to market a competitive possibility as part of an integrated CI toolbox.
- In the adapted examination of TOC, LSS, CMMI/ISO9000, DFSS, Agile manufacturing and BPR propose the chances of synergistic interactions and CI strategy appear complementary and feasible, which will be examined in Chapter 5.

During evaluation of CI methodologies it emerges [in Bozdogan, K. (2015)] his analysis and comparison of commonality, but also differences that significant synergy exists between methodologies although the journey to reach CI differs. LSS combined with TOC presents a significant set of CI tools in Pyzdek, T. and Keller, P. (2014) and also deduced is that they form both literature research and adapted research in Tables 3.4a-c and 3.5a-c.

The research in both interview and survey questions will seek to determine greater clarity on the interrelationships that exist between CI methodologies but also leadership, management contribution and also capability maturity. Increased comprehension of CI improvement methodologies and the convergence of disruptive connected technologies are presented in Industry 4.0 which has the potential to rapidly offset the negative productivity growth and facilitate greater levels of HMI integration.

The contribution of AI and other *Industry 4.0 technological developments* which align with increased speed and quality metrics will only be truly known in the near future. What is clear is the ability to replicate process capability much better than human machine interfaces. This reality supports the emerging reliability properties offered in automation. Research in this document will seek to propose an integrated CI maturity framework incorporating maturity capability and maximising CI effectiveness and ROI metrics.

3.7.1 Maturity Capability Model

Organisational motivation (reviewed in Literature reviewed in Chapter 2) begins the road to CI for a variety of reasons, ranging from regulatory compliance, and loss of business or market share, as well as entrance requirement to business such as CMMI level 3 cited as a minimum requirement with clients. The research questionnaire and interviews in Chapter 5 will seek to confirm motivation of the respondents to embark on the CI journey but also the maturity of the respondents' CI deployments.

The value of CI is in sustaining such methodologies over time, similar to compound interest. It is therefore compounded value and this should be driven by performance needs as opposed to compliance metrics and ultimately sustained customer loyalty and revenue stream actualisation.

Organisations often look to their leadership for guidance finding it necessary to select from a variety of CI tools that should yield the desired outcome. This research document will endeavour to propose an integrated framework for consideration for such organisations across industries.

The EFQM Excellence model has matured in the past two decades and proved its credibility in relation to its purpose of intent to recognise excellence in maturity in quality of products produced. Porter, L.J., Tanner, S.J., (2004) observe the value of a maturity framework such as the EFQM model which enables process maturity comparisons within an organisation compared against set criteria similar to the maturity models presented in EFQM, MBNQA and CMMI.

3.8 Conclusion

In viewing the industry application and research results it is evident that two distinct channels of further research remain:

Firstly, it emerges that there are two domains which warrant additional research. They are: firstly cognisance of the provision for environmental contributions influencing organisational change and secondly – the tactics deployed considering the forces influencing incremental change and organisational evolution between control and knowledge management in both short term (current efficiency and improvements) and long term (long range future maturity capability and capacity) needs. TLS combined with elements of Agile, Scrum and DFSS does pose a theoretical but also a dynamic framework and, herein CMM, and in particular, industry adoptions of CMMI in both ICT and manufacturing. It poses a path to gain conceptual traction but also practical industry relevance where the organisation is observed consisting of purposeful complex adaptive systems whilst adopting a construct of organisational architecture as pivotal conceptual CMM towards developing a sustainable and inclusive comprehension of *the design of organisations* and their CI strategy. An organisational framework for developing, validating and reviewing a different future scenario for organisation design outcomes, can sacrifice an optimised solution strategy. This could be by means of DOE's permitting parallel awareness of the dynamics and multilevel setting, content and evolutionary change is possible with the advent of Industry 4.0 technologies such as augmented reality, Big Data computing, IIOT and the use of computational organisation modelling and simulation techniques.

The rules that will govern the creation of the future organisational CI strategies will inevitably see increased levels of technology convergence and use of Big Data with increased Agility in response to VOC metrics and mass customisation with minimal stock and rapid delivery made possible by technologies such as augmented reality and 3D printing which in essence will represent the ultimate JIT solution with *make to order* as opposed to any inventories.

Secondly, there remains a necessity for industry practitioners to employ by means of detailed selection from the most appropriate CI tools. Decision making such as this is based on organisational maturity, which is possible through the adoption of a frameworks such as CMMI, EFQM, MBNQA, etc. This can be realised through the development of an organisational framework within concepts and tools adopted through the development of practioner maturity within organisational maturity capability.

The evidence of industry's adoption of Industry 4.0 is tangible in the levels of increased automisation enabling processes and organisations to deliver higher levels of self-adjusting, regulating product and processing lines. DFSS contribution along with TLS within a CMM will be explored in both questionnaire and interview research and in particular the significance of Agile and Scrum inclusion in possible reducing project effort within CMMI.

These CI tools and similar methodologies have evolved and will continue to evolve with organisations fine tuning their CI strategies and increased standardisation if these methodologies are observed in ISO 13053-1/2 (Quantitative Methods in Process Improvement – Six Sigma Part 1 and Part 2), ISO 17258 (Benchmarking), ISO 18404 (Lean and Six Sigma), ISO/CD 20575-1 (DFSS), ISO /IEC 26515 (Agile and Scrum), ISO/TS 269 (Innovation) and ISO 16355-1 (QFD).

The historical approach to CI requires a rethink incorporating Industry 4.0 technologies converging with proven improvement methodologies such as LSS and DFSS within a structure that maximises ROI and also develops the organisation's learning ability through building capability maturity. Industry needs have changed and an organisation cannot exclusively migrate to a higher level of operating excellence without considering the need to adapt and grow knowledge internally and also by collaborating externally.

In Pellissier, R. (2001) we find that the author realised more than a decade ago, the changing organisation as a direct result of IT and convergence in industries necessitated that an organisation is becoming a living organism. It becomes a continuously changing structure in response to its environment. The changes are caused by both technology and market needs in the Quantum Organisation. In developing the CI strategy for the convergence of technologies is it clear that additional opportunities and challenges will present themselves to organisations in the future and organisations should learn how to approach CMM and CI tools selection as a strategy within a controlled and mature context. Such a strategy means by harnessing Industry 4.0 pillars and recognising sustainability needs with automisation.

Chapter 4 will describe the research methodology which seeks to develop interview and survey questionnaires. Also the statistical tools and techniques deployed for the five Research Objectives will be identified.

Chapter 4

4.0 Research Methodology

4.1 Introduction

Research presented in Chapter 2 and Chapter 3 summarises comprehensively, evolutionary and uses an in-depth discussion of existing CI and CMM researched literature presented in industry. The researched literature was analysed and previously researched critical success factors pertaining to successful Six Sigma deployment (and also certain research areas) were identified to be included in the proposed maturity capability model.

This chapter will entail a description of the methodology that will be employed to conduct the proposed research as discussed. The research rationale, design, steps and methodology used to conduct the research is proposed in Figure 26. Both the selection and utilisation of quantitative research methodologies and inductive and deductive reasoning in the research process are discussed. This includes specific steps that will be executed to confirm the outcome of questions presented in the five Research Objectives. The purpose of the utilisation of expert opinions, research phases as well as structuring of questionnaires, will be set out.

4.2 Research framework

In the assessment and research of this thesis the aim is to understand the CSF's for LSS and DFSS projects. A further Research Objective is to understand the contributions a CMM will have when designing an instrument for industry application incorporating the advantages seen in Agile and Scrum interlayered with DFSS and TOC. The answer will depend on clarity gained by considering five distinct Research Objectives answering the hypothesis. Five Research Objectives will assist in defining both the Analysis and Design for an integrated framework.

This study consists of the following parts: conceptual review; hypothesis of problem and observations. The focus of the thesis is:

a. to apply previous literature research on CSF's and remove incoherent and incorrect deductions

b. to integrate new and existing knowledge and propose new adapted theory to support CMM framework
c. to consist of not only observed but also empirical inputs
d. to use both qualitative and quantitative inputs when answering the five Research Objectives
e. retain independence from bias and to include logic and facts
f. to use recognised process methodology to support analysis and accuracy
g. to present inclusive and comprehensive data, source acknowledgement, definitions, recommendations, conclusions and accurate recording.

4.3 Research methodology and design

The research methodology is a mixed design which includes both quantitative and qualitative research methods. The term "mixed method" refers to an emergent methodology of research that advances systematic integration of both Quantitative and Qualitative research designs. The basic premise of this method will seek to be more complete and to synergistically utilise data whilst allowing for separate data collection and analysis which improves the reliability and validity of results. The prominence of this method and its popularity is observed in Creswell, J.W. and Plano, C.V.L (2011). Quantitative Reliability will be used where research results and data can be confirmed to be concise and stable. Qualitative Validity of research results will be used and will be compared to establish whether the results are consistent with the Research Objectives of the hypothesis.

4.3.1 Quantitative Research

Pellissier, R. (2007) maintains that to conduct an investigation it is practical and relevant to perform a quantitative research analysis. The **Survey** is chosen as one of the research methods and it is characterised through the detailed collection of data resulting from structured and unstructured questionnaires. Data sampled and quantified in a collection at a certain time juncture allows the researcher to examine the variables and association as described by Bryman, (1989) and also reported in Babbie, E.R. (2016).

Advantages of using a questionnaire method are reported in Saris, W.E., and Gallhofer, I.N. (2007) to be more economical and simplistic. Questions included are extensive as required, not limited to any division, hierarchical level or functional area enabling graphical representation of results and comparison of data sets.

The schematic presented below in Figure 26 describes the research framework and the questionnaire used as a tool to collect data over a time horison of six months due to the availability of the respondents in an online survey format, using survey monkey. The questionnaire is presented as a survey to a variety of industry specialists as part of the research strategy. The research approach is inductive and based on positivism aimed at respondents that are intricately involved with CI and LSS and DFSS tool deployment. Positivism as a knowledge system is based on recognising observable phenomena (positive facts) that can be described by respondents who have experience in the field covered by this research project.

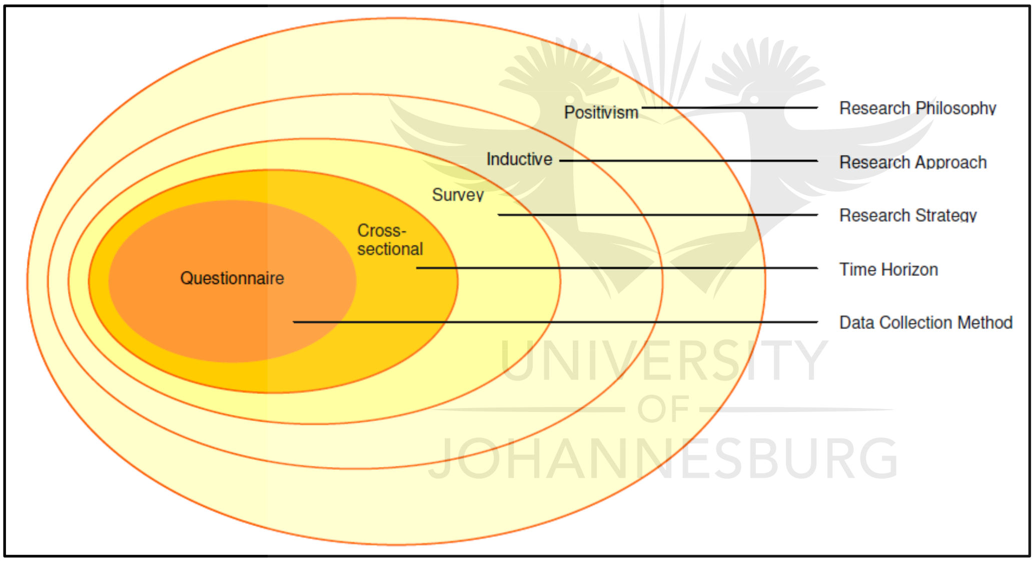

Figure 26: Research Design.

Hard data and responses (without leading the respondents) were chosen for the quantitative questions and based on facts responded to by the target sample group. Leedy, P.D. Ormrod, J.E. (2010) in Vermeulen, A. (2011) postulate the selection of quantitative research for: (a) measurement of an objective reality which is measurable; (b) familiarity of the target research group with quantitative survey methodology; (c) the survey question used is both confirmatory and predictive; (d) abundance of literature; (e) significant details are included in the survey; (f) time constraints for survey; (g) availability and ability to work alongside with respondents is not very good; (h) structural need is vital; (i) capability is hampered for subject matter requiring significant deductive and statistics and (k) the style of research is scientific and consists largely of a technical nature.

4.3.2 Pre-experimental Design

Experimental design was chosen which allows for the exploration of the cause and effect (causal) associations identified in this research target group similar in Vermeulen, A. (2011) where these factors are deemed to have adverse bearing on the research undertaken and confirmed also in Mouton, J. (2001). Differing opinions exist amongst industry practitioners on what methodology or sets of methodologies are to be used in a CI strategy and it is also herein where the contribution of a CMM will be explored.

During pre-experimental design it is not possible to demonstrate causal relationships where Leedy, et al. (2010) highlights the dependency of the relationships of both dependant and independant variables. It is further postulated that the researcher in finite experimental research manipulates independent variables in order to relate the impact on other independent variables. Leedy, et al. (2010) argued that contrary to experimental design, greater levels of control are possible to be obtained through true experimental design affecting internal validity more positively.

The author and researcher adopted a randomised control group targeting specifically industry practitioners and leadership impacting CI programs and teams. Different methods apart from a specific intervention and confounding variables is observed in Leedy et al. (2010) in a survey. These variables are found to pose problems when attempts are made at deriving conclusions in terms of the casual nature between relationships in survey results and with post intervention completion.

4.3.3 Pre-experimental Sampling

Two groups of sampling data are classified being both probability and non-probability data [in Pellissier, R. (2007)]. The importance of managing this process in a scientific staged approach is very significant since the research results depend on accurate sample data.

Sampling is selected to assure that the responses obtained are from industry practitioners who are familiar with the concepts analysed in both CI practices and CMM domains. The sampling design to be used in the measurement phase is based on non-probability sampling and incorporating judgmental sampling during the research phase. The target group of participants were identified as a result of the hypothesis and the Research Objectives identified facilitating a controlled study [as observed in Cooper, D.R. Shindler. P.S. (2011)]. The sample group was required to conform to criteria such as:

a. Persons actively participating in or responsible for CI program deployment
b. Persons doing a business process maturity review and using measurement methodology
c. Persons employed in a variety of industries to assure cross industry review, observation and validity
d. Users of a variety of technologies (both hard and soft) to assure considerations are made for advances made in both are included for review
e. Persons in industries that are working towards a Six Sigma methodology and also industries that are working in higher levels of Sigma product and process performance.

A sample of two hundred (200) people was approached to be part of the study of which 72 people agreed to participate in the survey questionnaire. All participants are regarded as being experienced in Lean, Six Sigma, DFSS, TOC, Agile and Scrum methodologies and CMM frameworks at management level and all are highly qualified industry professionals. There is a balanced participation of individuals representing top and middle managers of both manufacturing and services industries from a wide spectrum of functional departments or business units in organisations observed in Cooper, D.R. and Shindler. P.S. (2011). The functional positions of participants is displayed in Table 15 – Functional Positions of Participants.

Table 15: Functional Positions of Participants in online survey.

	Table 4.1 Functional roles of survey respondents				
	Functional Roles	**Frequency**	**%**	**Valid %**	**Cume %**
Valid	Academic	2	1,0	2,8	2,8
	ANALYST	3	1,5	4,2	6,9
	BB	27	13,5	37,5	44,4
	CEO / Director	6	3,0	8,3	52,8
	CMMI Auditor	2	1,0	2,8	55,6
	Consultant	2	1,0	2,8	58,3
	CRM	1	0,5	1,4	59,7
	Engineering / Product Development	3	1,5	4,2	63,9
	Finance	2	1,0	2,8	66,7
	HR	0	0,0	0,0	66,7
	IT	2	1,0	2,8	69,4
	Logistics	1	0,5	1,4	70,8
	MBB	7	3,5	9,7	80,6
	Operations	2	1,0	2,8	83,3
	OPEX / CI / Industrial Eng.	5	2,5	6,9	90,3
	Owner	0	0,0	0,0	90,3
	Project	2	1,0	2,8	93,1
	Quality	1	0,5	1,4	94,4
	Other	4	2,0	5,6	100,0
	Subtotal	72	36,0	100,0	
Missing	System	128			
Grand Total		200			

Participants were requested to complete an online questionnaire focusing on both CMM and CI tools seen in Annexure A using survey monkey consisting of 41 questions. The interview questionnaire included a range of 22 questions. Both CMM and CI tools were central in shaping the questionnaire designs using a mixture of yes, no, 5 point Likert scale for the survey and more open ended questions in the interview questionnaire to allow structure but also freedom where questions may not be comprehensive for the respondents to answer accurately. The levels were identified by Curtis, B, Alden, D, Curtis, B. (2006), with reference to - CMM and Organisational Maturity and Capability Measurement in Curtis, B. and Alden, J. (2007) and Curtis, B. and Alden, J. (2006).

Key areas included in the online survey questionnaire ranged from:

1. Demographics and biographical data of survey respondents
2. CI Maturity in LSS and DFSS
3. Maturity model use and type
4. Resources for LSS and DFSS
5. Training and development
6. Leadership contribution and support
7. Financial metrics
8. Hoshin Kanri deployment
9. Functional areas affected for both LSS and DFSS
10. CI program success in terms of increased yield/revenue and cost reductions
11. Lean tool deployment
12. LSS tool deployment including TOC
13. DFSS tool deployment including Kano, Process simulation, QFD, Agile and Scrum
14. Reasons for LSS/DFSS deployment
15. Industry 4.0 readiness
16. CSF's for LSS
17. CSF's for DFSS
18. Reasons for LSS/DFSS program failures
19. Rewards/recognition system linked to CI program
20. Innovation and support process

Key areas covered in the interview questionnaire ranged from:

1. Demographics and biographical data of survey respondents
2. Reasons for CI strategy
3. KPI's
4. Training
5. Critical Success Factors for LSS and DFSS deployment
6. CI Maturity levels and People Capability Maturity measurements
7. DFR, DFX, DFSS
8. Supply chain SLA and contribution
9. CMMI, EFQM, MBNQA contributions to CMM

10. Leadership contribution within LSS and DFSS
11. TOC, Agile and Scrum contributions to CI and QFD
12. Financial metrics
13. Reasons for CI program failures
14. Open ended recommendations to CI in TLS and DFSS

Questions were rated according to the Likert scale. Different scales types are available but the one chosen for this survey questionnaire was the five-point Likert scale which are scaled as follows:

5 Point = Strongly Agree
4 Point = Agree
3 Point = Neutral
2 Point = Disagree
1 Point = Strongly Disagree

Participants evaluated each question based on personal perceptions of individual organisation's abilities regarding Business Process Capability. Table 16 displays Items related to the five (5) levels of Business Process Capability and low and high maturity levels.

Table 16: Levels of Business Process Capability – Low and High Maturity.

Low Maturity		**High Maturity**
Un-coordinated, isolated projects		Co-ordinated BPM Activities
Low BPM Skills	**5. Optimised**	High BPM Expertise
Key Personnel		Organisational Wide Coverage
Reactive	**4. Managed**	Proactive
Manual	**3. Repeatable**	(Meaningful) Automation
Internally Focused		Extended Organisation
Low Resourcing	**2. Defined**	Efficient Resourcing
Naive		Comprehensive Understanding
Static	**1. Initial State**	Innovative

The questionnaire included a range of questions relating to whether the organisation considers Capability Maturity; whether it is measured, which CMM is used and then perceived benefits of using a Capability Maturity Model in support of CI Strategy.

4.3.4 Empirical Phase

The researcher researched the CSF's for LSS deployment in existing Literature review of thirty-one similar research documents reviewed in Chapter 2, which was used as an input for the survey questionnaire construction but also to guide the researcher for construction of the focus of the questionnaire developed for interviews with industry specialists. No research for CSF's for DFSS could be found on any data bases and internet searches, quite possibly due to the uniqueness and possibly industry immaturity in DFSS deployment. The questionnaires are shaped to ask open-ended questions but also to the respondents to rank the CSF's in order of perceived importance. The quantitative results will be compared with the qualitative responses obtained in the interviews and will seek to find the levels of correlation between survey and interview responses.

4.3.5 Development of adapted CMM

In Vermeulen, A. (2011) and Slack, N. Chambers, S. Johnston, R. Betts, A. (2009) the major reason for CI programs is cited to be born out of the necessity to remain competitive and using an assessment of actual and required performance. This assessment (also referred to as a GAP analysis) guides the user in assessing the Capability Maturity of the organisation.

To improve business performance in Slack, N. Chanbers, S. Johnston, R. (2010) they defined two aspects which are current performance levels and goal performance. Multiple dimensions of an organisation require evaluation and all processes and functional areas are required to be measured. The strategy of how to tranform the existing status to a future state requires a regular review. CMMI has been developed for this purpose and is discussed in Chapter 2 with its origins in Crosby, B. (1979) QMMG. The development of a CMM requires a review of existing CI methodologies often used as stand alone approaches to achieve increased levels of ROI and reduced waste streams.

The development of an integrated and adpated CMM will endeavour to establish a model that is current with existing Industry 4.0 developments and advances made in systems integration of tangible and intangible value propositions such as connected and autonomous vehicles. The integrated approach for both software developer and manufacturer will be assessed for integration of CMMI, Agile and Scrum to align with tradional EFQM, MBNQA, CMM's to explore the complementary natures of TLS and DFSS.

Data collected in survey responses used scaled questions in Fox, W. Bayat, M, S. (2007) and formatted in order for the respondents to answer reasonably presenting their answer on a scale. Numerous questions in the survey are summarised in a *5 point Likert scale* and stressing the importance of deciding on a specific response [observed in Leedy, P.D. Ormrod, J.E. (2010), Cooper, D.R. Shindler. P.S. (2011) and Vermeulen, A. (2011)].

4.4 Validity

Validity in Leedy, P.D. and Ormrod, J.E. (2010) of a measurement instrument is directly linked to and dependent upon the scope of the measurement.

In both research and BPCM instrument design in Vermeulen, A. (2011) [and also observed in Leedy, P.D. and Ormrod, J.E. (2010)] the following are types of validity:

a. Face validity for a specific characteristic
b. Content validity representing the necessary population of the content measured
c. Criterion validity and to which degree the achieved results correlate with each other and
d. Construct validity to which degree an instrument measures a specific characteristic that is not possible to be observed but is assumed to be based on human behaviour.

A detailed explanation for content, criterion related and construct validity includes the following:

Content validity – defines the nature of the measuring methodology and the comprehensiveness of the questions designed to probe the Research Objective and hypothesis [in Saunders et al., (2009), Sekaran, U. and Bougie, R. (2013) and Terre Blanche et al., (2012)]. The measuring method is a framework which requires a researcher to include all aspects of the topic under investigation to be representative of the content evaluation.

Literature review is an acknowledged technique deployed in formal research to ensure that sufficient subject content is considered when designing a measuring method.

Criterion associated validity – is a term assigned to confirm the association of the measuring method to establish relationship/s within known criteria and conditions. Predictive analytics is a desired outcome during the establishment of criterion-associated validity which assists in establishing necessary differentiation which can distinguish data and questions for purposes of analysis.

The construct validity aims to satisfy the purpose of its design intent and its inherent construct composition. Saunders et al., (2009) and Sekaran, U. and Bougie, R. (2013). Creswell, R. (2014) all caution against the risks when research fails to accurately define questions and data variables and is confirmed in Sullivan, G.M. (2011) also confirming the necessity for verification of the measuring method applied to the research evaluated.

Leedy, P.D. and Ormrod, J.E. (2010) also caution researchers to demonstrate measurement instrument validity in accordance with the scope and objectives of the research. The instrument is required to:

a. Multitrait (also known as a multimethod strategy) is the term used where two or more different approaches are used to measure two different characteristics
b. Table representing the measurement instrument with a sample that represents the domain of test. In Leedy, P.D. and Ormrod, J.E. (2010) the researcher is regarded as the person who designs and creates a two-dimensional model grid that illustrates the specific subjects and associated behaviours representing the subject topics whilst the researcher continues to develop a testing methodology representing the subject topics and associated behaviours in the respective contributions
c. Carry out judgment (discern) through a population of industry expertise (expert practitioners) who are requested both to critique content and validity of its intended design.

A combined approach of the above criteria was deployed by the researcher to validate the measurement instrument. A standard questionnaire was developed for both questionnaires according to the example found in Leedy, P.D. and Ormrod, J.E. (2010) and reliability is assured by the researcher through the rigour of reliability testing using inter-rater reliability test with one or more randomly participant selections was used to evaluate the performance of the CMM and or CI strategy.

4.5 Style of measurement

Scales of measurement considered included Guttman, Thurston, equal weighted items and the Likert Scale. The adopted style used is a mixture of both open-ended answers to allow response freedom and Likert scale, which allows for different response formats, such as (never to always), degree format (not at all to very much) and the agreement format (strongly agree to strongly disagree). The reason the researcher adopted this format for parts of the research survey in an online questionnaire using Survey Monkey Inc. (2017) is the geographical and time zones variations of the respondents.

4.5.1 Structure Phase A – Online survey and interview design

The survey determines the relevance of both maturity capability and CSF's for effective TLS deployment to design a framework to complement Lean towards capability maturity. Phase A will also determine the CSF's for DFSS. The input to CSF's determination are both based on previous research and also new emerging CSF's perceived to be of importance although not widely confirmed within industry. See appendix A. – Survey questionnaire.

The Survey includes a combination of Likert scale type questions but also not limited to Likert scale type questions allowing for open-ended questions to avoid limiting responses from the target group.

Questions are relating to Leadership, CI tools, CSF's for LSS and DFSS toward maturity capability strategies:

I. Biographical information of respondents
II. Industry types

III. Maturity levels

IV. Popular Maturity models

V. Resources strategy

VI. Mentoring and coaching of resources

VII. Leadership and Hoshin Kanri deployment

VIII. Effective ROI, EBITDA, ROCE and project tracking metrics

IX. KPI’s and feedback loop

X. Functional areas deployed CI in LSS and DFSS

XI. Function areas impact of CI in LSS and DFSS

XII. Effectiveness

XIII. Agile and Scrum, Lean, LSS, DFSS, etc. tool selection

XIV. Reasons for LSS, DFSS CI strategy

XV. Supply base CI

XVI. Rewards system

XVII. Customer satisfaction, VOC, CTQ and QFD

XVIII. Innovation, Individual creativity, honesty and rapid response

XIX. Succession planning

XX. Employee satisfaction

XXI. Share survey results

The survey questionnaire example in Table 17 deploys a 5 point Likert scale type scoring system for ease of establishing both mean scores for CSF’s and also to enable Cronbach’s alpha which will be used to rank CSF’s and compare the survey results to that of previous literature review results for LSS. DFSS results are new and no previous comparison is possible, except comparison made to subject matter covered in Motorola DFSS training curriculum used as reference in Chapter 5.

Table 17: Example extracted from Phase A – Questionnaire

Phase A:	This section gives a broad overview of CSF's towards for LLS and DFSS towards capability maturity.					
	Survey questions – Survey monkey online questionnaire used	In our organisation the following is:				
	What is the relevance or importance of the following criteria's for CSF?	Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
1	11. Please rate the following statement: Executive leadership is committed LSS and or DFSS?	1	2	3	4	5

The interview questionnaire is aimed at establishing confirmation about existing CSF literature and survey question results which are restricted in feedback due to the limitations of a survey by design. The author here seeks to soundboard new emergent CSF's for discussion and also maturity development and methodologies deployed or considered by industry practitioners toward capability maturity.

Annexure B represents the interview questionnaire shared with respondents that are participants to the survey but not exclusively a requirement. Industry experience and CI and CMM program experience were the critical criteria for participation and availability for an interview which typically is planned to have a duration of 60 to 90 minutes to complete, which was determined during some initial testing with industry respondents.

4.5.2 Structure Phase B – CSF determination and CMM development

The analysis of both survey and interview results will enable the researcher to construct a CMM which is applicable to the modern day industries with increased levels of automisation and Industry 4.0 technological advances. Integration of software and hardware necessitates the integration of CI methodologies originating from both hardware and software domains.

4.6 Item Evaluation process

Items for inclusion and exclusion will be evaluated by the researcher during this evaluation process phase. Inclusive in this evaluation process are:

- Correlation and inter item correlation;
- CSF's for LSS and DFSS
- Validity
- Internal consistency reliability and Item scale correlation where:
  a) Validity in the establishment and confirmation of test measures and its intended design and test are established.
  b) Reliability testing for both the Survey and Interview questionnaire (instruments) responses is reliable and statistical deductions comparable to the mean and variance within confidence intervals.

Standard correlation is used to deduce correlation between item result and total results in the item test with item discrimination. SPSS (2017) and Minitab 17 software is used for both analysis and correlation of Likert scale questions in the survey and inclusion in CSF determination and CMM design in Phase B (Chapter 6) and then finally framework design contribution in the concluding Chapter 7.

4.7 Factor Analysis

According to Vermeulen, A. (2011) in Kline, P. (2014) factor analysis is a combination of methods deployed when evaluating intricacies in relationships in underlying constructs and influence of responses of a selection of variables measured. The significance in factor analysis can be observed in the duality of both ordinary and interval information. Correlation and scatter plots can enable the researcher to establish co-variances and linearity of data sets analysed.

It is important to examine the covariance between observed results when factor analysis is performed. It is also noted [in Yong, G. and Pearce, S. (2013) in De Coster, J. (1998)] that results that are observed to display a high level of correlation, whether positive or negative are likely to be influenced by the same factors and inversely where they are relatively uncorrelated are probably influenced by different factors.

4.7.1 Overview of Factor Analysis

Factor analysis is the summation of measuring instruments and methods with a primary focus on establishing the influence of measured variables within a set of defined, observed and measured constructs.

Tabachnick, B. G., and Fidell, L. S. (2007) identify [similar to DeCoster, J. (1998)] two types of factor analysis being either exploratory or confirmatory when utilised in a measuring instrument and they are:

1. Confirmatory Factor Analysis (CFA) [in Jackson, D. L., Gillaspy, J. A., Jr., and Purc-Stephenson, R. (2009)] establishes if a defined construct group has meaningful effect on the manner in which responses are anticipated or predicted.
2. Exploratory Factor Analysis (EFA) [in Matsunaga, M, (2010)] establishes the impact and association of measuring constructs have in analysis of a group of responses.

EFA [in Vermeulen, A. (2011)] reports to have the following objectives:

1. Determine the *quantity* of common factors impacting a group of measures.
2. Determine the *relative strength* in associations between each and every individual factor and the respective measured surveyed.

The researcher selected EFA to both identify the DNA of the researched constructs as well as inherent responses within a specific subject. Similar to Vermeulen, A. (2011) the purpose of using EFA *in this research* is to establish:

a) responses in a *specific* subject area and the relative nature of the constructs
b) the *arrangement* of subject and questions
c) whether factor results which are *aligned* with the underlying constructs for additional applications are produced.
d) proof of the *dimensionality* of a measurement scale.

4.8 Analysis of discrete data - Marginal Homogenity

This test of marginal homogeneity is applied to determine the observable variances in ranking but also weighting priority factors and occurrence factors when constructing a maturity framework in Phase B. In Vermeulen, A. (2011) Kendall's tau measure of correlation is deployed to determine both the strength and symbiosis in two data measures but also values ranging from ± 1 to +1 with a positive correlation indicative of where the ranks of variables increase together whilst a result where the correlation indicates that the relation in a metric increases another decreases. It can assist in answering questions such as why ROI results differ from early stages of a LSS or DFSS organisation evolving from CMMI level three to CMMI level five.

Spearman's rank correlation holds more industry acceptance than Kendall's tau although it does not claim to have better rank correlation or statistical characteristics. In research it is accepted that both *Kendall's tau* and *Spearman's rank correlation* compute to very similar results and similar conclusions are deduced.

In the process of interpreting both *Kendall's tau* and *Spearman's rho* results perfect correlation is represented by 1, where -1 points to optimum negative correlation and 0 represents no correlation. Spearman's rho popularity in research stems from the ease of transposing numerical rank order results and calculating a *Pearson correlation* when dual comparisons are made.

4.9 Spearman Correlation

Correlation presented in Spearman rho measures consistency [in Gravetter, F.J. and Wallnau, L.B. (2009)] and typically will measure x and y (two variables) and determine the strength of the linear relationships. Spearman's rank correlation enables the researcher to determine both the strength and the relationship between variables and the associated effect that a data set imposes on another.

Both SPSS and Minitab 17 will be used to measure Spearman's rho and subsequently also *Pearson correlation* on the Likert designed survey questions. The research will seek to establish the relationships between several survey questions designed to confirm and answer the five Research Objectives presented by the hypothesis, which will be accepted when ranging from -1 to +1 and inversely *rejected* when R's are 0.

4.10 Kaiser-Meyer-Olkin Measure (KMO).

Kaiser-Meyer-Olkin (KMO) test in Hair, J. F., Black, W. C., Babin, B. J. and Anderson, R. E. (2010) and Hair, J.F., Black, W.C., Babin, B.J. and Anderson, R.E. (2014) all seek to establish the appropriateness of a result applicability to a set of measures when conducting Factor analysis. KMO seeks to establish variation values ranging from 0 to 1 in proportional variability in variables which may or may not be common. It is accepted that the lower values increases the contribution of the measurements within Factor analysis. KMO results are classified as 0.00 to 0.49 being unacceptable; 0.50 to 0.59 being miserable; 0.60 to 0.69 being mediocre; 0.70 to 0.79 being middling; 0.80 to 0.89 being meritorious and 0.90 to 1.00 being marvellous.

In Vermeulen, A. (2011) in SPSS the Kaiser-Meyer-Bartlett's test of data Sphericity seeks to establish the suitability of factor analysis with a value of 0.6 or more. The *Bartlett's Test of Sphericity* has reference to the significance of the research and seeks to confirm validity and suitability of responses recorded in the research problem and in *Factor analysis* to be classified as suitable. *Bartlett's Test of Sphericity* must be less than 0.05 and importantly when the observed significance is 0.0000 the hypothesis should be rejected.

4.11 Cronbach Reliability Analysis

The Cronbach reliability analysis will be used to confirm of the survey questionnaire's validity. Cronbach's alpha scores will be used to compute each construct (anticipated benefits and the CSF's of LSS deployment) and establish relevant internal consistency where a variety of subjects are reviewed in an instrument observed. Most important is where the results obtained in reliability a coefficient of 0.90 is seen as excellent, values of 0.80 is regarded as very good and values of 0.70 are classified to be acceptable.

Cronbach's Alpha [in Gliem, J.A and Gilem, R.R. (2003) in Vermeulen, A. (2011)] in Likert type scales is observed when Cronbach's Alpha is greater than 0.6 seen in Table 18 below.

Table 18: Internal consistency in Cronbach's Alpha, Source: Scientific Electronic Library Online, http://www.scielo.org.za

Cronbach Alpha	Internal consistency
$\alpha \geq 0.9$	Excellent (high-stakes testing)
$0.7 \leq \alpha < 0.9$	Good (low-stakes testing)
$0.6 \leq \alpha < 0.7$	Acceptable
$0.5 \leq \alpha < 0.6$	Poor
$\alpha < 0.5$	Unacceptable

Cronbach's Alpha is used to indicate the homogeneity of the items of test and it is accepted by Tavakol M, Dennick R. (2011) that test displaying strong internal consistency measurements should show only moderate correlation among items achieving readings of 0.70 to 0.90. It is also observed in Vermeulen, A. (2011) that when correlations between items are too low then it is probable that they are observing different characteristics and therefore should be excluded in a test; where item correlation is too high, it is probable that some items are not relevant and should be excluded from the test.

4.12 Interpretability

The value of factor analysis is presented when a number of variables are analysed in both empirical criteria and in theory, thus it allows the research hypothesis to be relevant and meaningful. The application of statistics for the Likert scale type survey questions permits this research to quantifiably establish relationships and conclusions in Chapter 5, but also in Chapters 6 and 7 when the theoretical framework is created out of a summary of conclusions drawn in the data analysis and associated conclusions drawn from the results. Validity and Reliability of data will establish what data is accepted and included in the confirmation of the five Research Objectives which formulate the foundation and structure for the hypothesis.

The data evaluation and analysis will guide the researcher in this decision on what data sets are to be included and which are to be excluded through a review process of correlation, regression analysis and validity of items, internal consistency and scale correlation considering internal consistency. The establishment of the five Research Objectives (such as CSF's determination in both LSS and DFSS deployments, Leadership and CMM contribution within LSS, DFSS and general CI strategy) is necessary to formulate a *"recipe"* and *theoretical Capability Maturity Model* which can be implemented for organisations and Industry 4.0 technology symbiosis.

4.13 Participants: criteria

The sampling design is *random probability sampling* during phase A of the research survey questionnaire distribution directed at Industry specialist within the continuous improvement functional area. Specialists, leadership, program managers who are tasked with business and operational improvements which can ensure meeting the criteria that participants possess the necessary skillset and knowledge maturity to be able to answer the survey questions and interview questions are selected and directed at a total of 200 organisations. Differing industries across nationalities were included in the target group. Further filtering was done through the following:

- University research
- ASQ
- ISixSigma

- German Six Sigma Club
- European Six Sigma Club
- Indian Six Sigma Statistical Quality Control and Operations Research Unit (SQC & OR Unit)
- Lean Institute
- Six Sigma portals
- DFSS portals and specialist
- CMMI portals and specialists
- Industry Consultants
- LSS, DFSS and CMMI conferences, events, news releases, articles and print media.

Establishing a list of organisations and the designated contact e-mail addresses, the interview questionnaires along with a link to the survey monkey web address was e-mailed to the recipients. Dates and times were requested whereby the interview questionnaire could be reviewed and discussed for the necessary elaboration.

Random *probability* sampling is used during sampling design followed by *judgmental* sampling in the study. Members had to conform to the desired knowledge pool and experience criteria in the research pursuit to determine the CSF's in LSS and DFSS to maximise ROI culminating in a CMM.

The criteria for selecting participants required the following traits:

- Active participants in Process Improvement using the LSS and DFSS methodology.
- Active participants in monitoring and evaluating EFQM and or CMMI levels of BPM.
- Process administrators, owners, analysts, consultants, optimisation/industrial engineers and project managers.
- A wide range of Leadership tasked with KPI improvement through LSS/DFSS and or CMMI management to maximise ROI.
- A range of Belts practitioners ranging from Green, Black and including Master Black Belt certified operators.

Note: The response rate was 36% which is higher than most similar surveys will yield.

4.14 Conclusion

Chapter 4 describes both research methodology and tools designed to obtain, structure, disseminate and critically (with the aid of quantitative tools) analyse the survey data questionnaire and results received. In Chapter 5 *survey data item factor analysis* will assist in combining the interview results and the contribution of qualitative research results in confirming the hypothesis and ultimately supporting the five Research Objectives of this research document.

Descriptive statistics will be compiled and discussed in *Chapters* 5 and 6 in confirming the intent of the five stated Research Objectives to enable the *design of an integrated* and *theoretical framework* proposed for the *advances* in *Industry 4.0 technologies* towards *capability maturity*.

Chapter 5

5.0 Analysis

5.1 Introduction

The primary focus in Chapter 5 is the analysis, and statistical validity confirmation of the data and results obtained from both the online survey questionnaire and interview responses provided by the respondents. The analysis of the results is the determination of answering the five Research Objectives stated in Chapter 1, which concludes phase A of the research document and provides input for phase B (Chapter 6) which is the construction of an integrated CMM framework for an integrated approach to CI towards Capability Maturity.

This chapter further aims to establish the contribution of CMM to both LSS and DFSS deployment and how Leadership impacts on achieving capability maturity, concluding with a proposal, namely how an integrated framework will assist organisations to achieve capability maturity.

Chapter 5 aims to identify the CSF's for both LSS and also DFSS tools and also compares the results of the survey respondents with literature review results and responses of interview respondents.

Survey data is further investigated in subsequent interviews and also sharing and sound boarding emerging knowledge and patterns in correlation of data sets obtained. In addition constant reference is made to the extensive literature reviews of tools and techniques including previous CSF's research undertaken in relation to the respective Research Objective. In Chapter 6 Phase B will shape the emergent CMM as a result of Phase A study part 1 (Survey results) and part 2 (Interviews) and as a result of the analysis in Chapter 5.

The research results from Chapter 5 are significant in developing a CMM framework which incorporates a host of improvement tools merging Industry 4.0 applications and product solutions. The use of interconnected products is increasing and labour productivity has been decreasing necessitating a framework which merges Software CI tools with Hardware CI tools proposed by literature and explored in this research document. Leadership remains central to establishing a sustainable framework toward capability maturity

5.2 Survey and Interview responses matrix for research

The results and findings will now be presented to answer the hypothesis through the five Research Objectives through analysis of data and information obtained from phase

The strategy to answer all five Research Objectives is seen in Table 19 and Table 20 below which are also matrixes connecting the respective questions for both interviewee and survey respondents.

Table 19: Research Objective matrix for interview responses.

Research Objective No	Research Objective Description	Respondent interview responses															
1	What are the most significant CSF's for LSS employment in an organisation?	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
2	What are the most significant CSF's for DFSS employment in an organisation?	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
3	What are the contribution of CMM to LSS and DFSS implementation where such models have been explored?	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
4	What impact does leadership have in achieving capability maturity?	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
5	How will an integrated framework assist organisations to achieve capability maturity?	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P

No DFSS

No CMM

All the respondents for Research Objective 2 with the exception of respondents C, G, I and J reported to have DFSS as part of their CI strategy and could comment accurately on the deployment of DFSS, which relates to 75.0% of the sample of industry specialist's opinions received during the interviews. All the respondents for Research Objective 3 with the exception of respondents A, C, D, I, J, and L reported to have some form or another of CMM as part of their CI strategy within their organisations which calculates to 62.5% of the sample of industry specialists' opinions received during the interviews. Each interview was originally scheduled to be completed in approximately one and a half hours but none were completed in a period of less than two hours and significantly respondent P's interview lasted three hours as a result of the knowledge shared with respect to LSS, DFSS, CMM, PCMM and also the invaluable contribution of Industry 4.0 to complement their CI strategy. The willingness of all the interview respondents were most professional and engaging and their responses will be dealt with in depth in this Chapter.

Table 20 maps out the survey questions in a matrix relating to the five different Research Objectives which will assist with the analysis of the hypothesis towards capability maturity.

Table 20: Research Objective matrix for survey questions.

RO No	Research Objective Description	Survey Questions applicable to Research Objective (RO)																																					n
1	What are the most significant CSF's for LSS deployment in an organisation?					8	9	10		12	13	14	15	16	17	18	19	20	21	22		24	25		27	28	29												19
2	What are the most significant CSF's for DFSS deployment in an organisation?				7	8	9	10		12	13	14	15	16	17	18	19	20			23	24		26	27	28	29												19
3	What are the contribution of CMM to LSS and DFSS implementation where such models have been explored?	4	5	6										16								24						30								38			7
4	What impact does leadership have in achieving capability maturity?								11													24							31	32	33	34	35	36	37		39	40	11
5	How will an integrated framework assist organisations to achieve capability maturity?		5	6																		24										34	35	36		38		40	8

Table 20 details the research focus in the number of survey questions relating to CSF establishment in both LSS and DFSS CI deployments. The contribution of CMM supporting both Research Objectives one and two are further explored in Research Objective three with seven questions. Research Objective four and the interrelationships contribution is evaluated through eleven questions. Research Objective five consists of eight questions shaped to increase the researcher's comprehension of how an integrated CMM can assist organisations to achieve capability maturity.

Section 5.3 details the source data and biographical data of the respondents in both the survey and the interview questionnaires.

5.3 Biographical data of participants

In totality 72 responses were received from a target population of 200 respondents (consisting of a group of varying industries as described in questionnaire design and target group identification) which represents 36% respondents from the total group which is acceptable for the purposes of this study. In addition 16 from a list of 50 industry specialists agreed and have participated in *interviews* in support of the Research Objectives and the required validation process, resulting in 32% representation which was largely positively affected due to availability of both the researcher and the interviewees.

The Table below Table 21 is a summary of the respondent biographical data which participated in the interviews in Part 2 of phase A.

Table 21: Interviewee Participants' biographical data.

Research respondent	Functional Role	Industry
A	Master Black Belt and Opex	Automotive
B	Master Black Belt and Quality Director	Automotive
C	Supply Chain Director	Packaging
D	Master Black Belt	Chemical
E	Master Black Belt	Consulting
F	Black Belt	IT
G	Black Belt and Operations Director	Transport
H	Master Black Belt	Insurance
I	Black Belt	Banking
J	Master Black Belt	Fleet
K	Master Black Belt	Aerospace
L	Master Black Belt	Pharmaceutical
M	Master Black Belt	Food
N	Master Black Belt	Logistics
O	CEO	Manufacturing
P	Vice President Operations	Automotive

Availability dictated the responses and interviews scheduled with these industry specialists and for reasons of time limits during this phase of the research was limited to these respondents.

The five respective Research Objectives will be investigated and analysed in details separately.

5.4 Data presentation and analysis: Research Objective 1

What are the most significant CSF's for LSS successful deployment in an organisation?

The survey asked the respondents to *identify* the CSF's for successful LSS deployment and also *rank* them in order of importance in survey question number 25. The results obtained can be observed in Table 22.

The survey responses reveal that the CSF identified in order of importance are 1st Management Commitment, 2nd Linking LSS to business strategy, 3rd Linking LSS to HR Rewards., 4th Linking LSS to customer. 5th Selection of staff for LSS, 6th LSS Financial accountability, 7th Resources available to the LSS team, 8th Extending LSS to the supply chain. The balance of the CSF's are also significant and will be analysed further, recording of responses less than 25%.

The CSF's will be explored using Cronbach's alpha and ranked accordingly.

Table 22: LSS CSF's identified by survey responses and ranked by survey group in question Q25.

Ranking	CSF	n	%
1	Management Commitment	51	70,83
2	Linking LSS to business strategy	39	54,17
3	Linking LSS to HR rewards	35	48,61
4	Linking LSS to customer	33	45,83
5	Selection of staff for LSS	32	44,44
6	LSS financial accountability	25	34,72
7	Resources to LSS team	22	30,56
8	Extending LSS to SC	21	29,17
9	Project Management Skills	17	23,61
10	LSS training	16	22,22
11	Tools and Techniques	15	20,83
12	LSS Projects prioritisation	11	15,28
13	Organisation infrastructure	9	12,50
14	Cultural Change	8	11,11
15	Leadership Style	6	8,33
16	Communication and awareness	6	8,33
17	Others	6	8,33

The interviewees were all asked to identify the most significant CSF's for LSS successful deployment and the following responses were recorded:

"Senior leadership and management involvement remains instrumental in supporting and providing access to resources….." (Respondent A).

"Strategy communication by senior management, LSS program reviews are very important to the functional areas within the organisation and also the inclusion of the SC where such capabilities exist and can be supported….." (Respondent B).

"Management support and also training throughout the organisation is often responsible for program execution…" (Respondent C).

"Linking LSS to strategy and also holding staff accountable for improvement projects has a significant impact in roll out, and also leadership and project prioritisation can often influence program success…" (Respondent D).

"Resource allocation and strategic support by leadership team is make or break in project selection…" (Respondent E).

"Senior leadership and commitment, shared visions and goals and genuine customer focus…" (Respondent F).

"In my experience total Management commitment, resource provision and program selection…" (Respondent G).

"Teamwork, strategy infused with continuous improvement and senior management commitment to projects…" (Respondent H).

“Cultural change, project selection and focus by BB on projects and leadership support…” (Respondent I).

“Strong focus on customer satisfaction metrics and quality performance in both process and product quality and management support for program delays…” (Respondent J).

“Leadership by example, regular review of Operating KPI’s driving the DMAIC process and financial metrics in belt projects…” (Respondent K).

“Suitable trained GB and YB in support of dedicated BB’s, too many BB’s are not dedicated and project focus is diluted, management commitment to resource and project support remains pivotal for resource and project support…”(Respondent L).

“Change management maturity of leadership, including vital support to project teams and belts deployed along with resource allocation in support of ROI program maximisation…” (Respondent M).

“Integrating vision and performance metrics to validate journey progress when leadership meets, reviews and holds team members accountable for ROI achieved or not achieved…” (Respondent N).

“Nurturing vision through strategy deployment in program selection and deployment…” (Respondent O).

“Leadership and management, without a question. Our leadership team are expected by our FPS (Ford Production System) to support and attend set meetings to support the various functional teams in achieving LSS objectives. When we embarked on integrating our global FPS five years ago, we were already implementing LSS in all our functional areas but without

Cadence and Time and Data management, this has however facilitated focus on improvement and developing capacities in our core leadership on the assembly lines and supporting functional areas. Previously we would react with a DMAIC for a problem, now we have cadence and continuously review KPI's, resolve lagging KPI's or escalate, depending on the process metric we wish to influence and or improve…" (Respondent P).

The CSF's determined by the survey revealed the majority (62%) of respondents stating that an emerging industry trend is currently evolving within the adoption of ISO 18404: 2015 which functions with ISO 135053-1 and ISO 13053-2 which has been in public use since 2011. Herein ISO 18404:2015 defines the competencies for the attainment of specific levels of competency with regards to LSS in individuals, e.g. Black Belt, Green Belt and Lean practitioners and their organisations. Yellow Belt is not included in ISO 18404:2015 and it excludes Design for Six Sigma for reasons of complexity at this stage, whereas VDA QMC has a defined curriculum for accredited DFSS certification for professionals as adopted by the German council for Six Sigma.

For these Research Objectives in the online survey the respondents both guided and asked to rank prominent CSF's in LSS and DFSS deployments based on their professional experience.

Figure 27 illustrates the industry distribution after the completion by the respondents of question 2 of the online survey with manufacturing, automotive, aerospace and finance occupying the highest number of responses from the original two hundred organisations.

A review of the survey results regarding CSF's are seen with their mean importance and standard deviation given in Table 24 where Table 23 describes the internal consistency of varying levels of Cronbach's alpha ranging from less than 0.5 as unacceptable to greater and equal to 0.9 as excellent, equal to and greater than 0.7 but less than 0.9 as good, greater and equal to 0.6 but less than 0.7 as acceptable, greater or equal to 0.5 but less than 0.6 as poor and less than 0.5 as unacceptable.

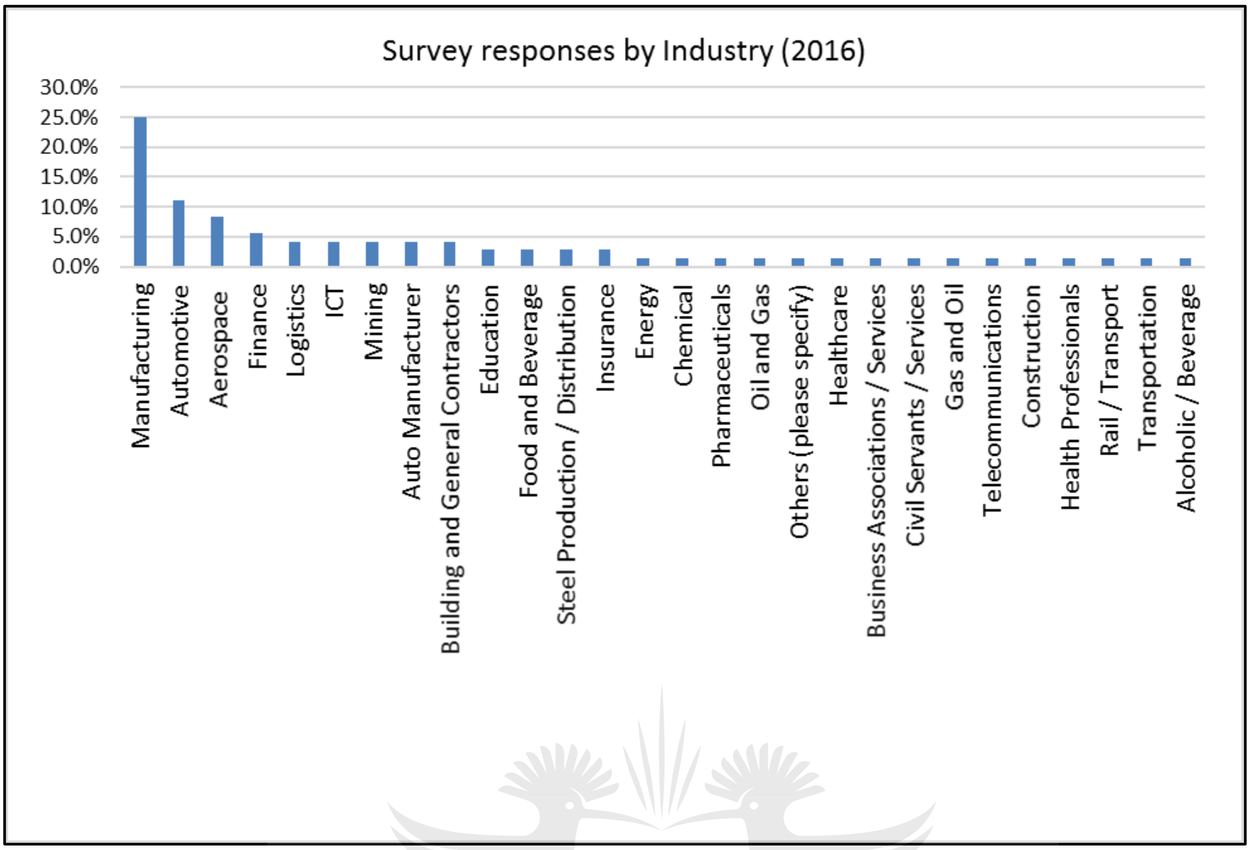

Figure 27: Industry respondent's distribution by industry. Source: Survey questionnaire 2016-2017.

The results from the survey is consistent with the industries requested to participate in the survey, which also reflects the early adopters and the origination of LSS in Automotive but also widely adopted in repetitive high volume manufacturing.

Table 23: Cronbach's Alpha for internal consistency

Cronbach Alpha	Internal consistency
$\alpha \geq 0.9$	Excellent (high-stakes testing)
$0.7 \leq \alpha < 0.9$	Good (low-stakes testing)
$0.6 \leq \alpha < 0.7$	Acceptable
$0.5 \leq \alpha < 0.6$	Poor
$\alpha < 0.5$	Unacceptable

In Table 24 All of the mean ratings are above 3.750, except for CSF's labelled as others with mean ratings below 3.750 and therefore, the majority of the respondents have rated the importance of the CSF for LSS deployment as above average (3.750 › 2.500). The five most important CSF's cited across the companies are found to be management commitment (4,764) 1st, linking LSS to business strategy (4,583) 2nd, linking LSS to HR Rewards (4,444) 3rd, linking LSS to customer (4,417) 4th and selection of staff for LSS (4,389) 5th. The balance of the CSF's are noteworthy and should not be ignored by executives and program leaders in their LSS CI journey, herein again LSS prioritises support and resource allocation, which are strategic functions of leadership and management.

Table 24: LSS CSF's, Mean Ratings of Importance and Cronbach's alpha from 2016 Survey in Survey Monkey and Industry specialist interviews.

CSF No	CSF Description LSS	Mean Rating	Std. Dev	Rank	Cronbach's alpha
1	Management Commitment	4,764	0,593	1	0,92891
2	Linking LSS to business strategy	4,583	0,666	2	0,92134
3	Linking LSS to HR rewards	4,444	0,729	3	0,85714
4	Linking LSS to customer	4,417	0,765	4	0,85021
5	Selection of staff for LSS	4,389	0,832	5	0,84572
6	LSS financial accountability	4,347	0,891	7	0,84335
7	Resources to LSS team	4,319	0,869	8	0,83933
8	Extending LSS to SC	4,292	0,830	9	0,83699
9	Project Management Skills	4,208	0,992	10	0,83395
10	LSS training	4,111	0,897	11	0,83309
11	Tools and Techniques	4,083	0,835	12	0,83253
12	LSS Projects prioritisation	4,042	0,971	13	0,83106
13	Organisation infrastructure	3,903	0,842	14	0,83083
14	Cultural Change	3,833	0,904	15	0,82289
15	Leadership Style	3,875	0,821	16	0,82144
16	Communication and awareness	3,792	0,934	17	0,81959
17	Others	3,125	0,978	18	0,79703

In terms of a successful CI deployment strategy and also in the establishment of a capability maturity framework does the ranking and considering of CSF's for LSS pose a significant contribution and here the top 10 ranked CSF's and the movement of CSF No 4,5,6 and 8 into the top 10 are observed in Table 25.

Table 25: Top 10 LSS CSF rankings and movements from 2016 survey compared with previous research summarised in Laureani, A. and Antony, J. (2012).

CSF 2016 Survey Ranking	CSF Description LSS	CSF Lit Rev ranking	CSF Movement
1	Management Commitment	1	0
2	Linking LSS to business strategy	5	+3
3	Linking LSS to HR rewards	9	+6
4	Linking LSS to customer	12	+8
5	Selection of staff for LSS	18	+13
6	LSS financial accountability	17	+11
7	Resources to LSS team	4	-3
8	Extending LSS to SC	11	+3
9	Project Management Skills	8	-1
10	LSS training	2	-8

Linking LSS to customer and customer needs emerges as an overlap of Hoshin Kanri policy deployment and the associated DFSS input requirements for VOC, QTC and QFD, which is also confirmed in Research Objective 2.

Selection of staff for LSS deployment ranked 5th and improved movement of 13 positions resonate with research conducted in Thompson, S.J. (2007) and in Ehrlich, (2002) where extended testing was done on personality types and concluded the importance of LSS staff selection. The selection of BB candidates need to be as stringent as selecting a person to work for the organisation in itself. Personality tests were deployed and the prominent Myers Briggs Personality types surveyed were predominantly (37.5 %) from T (Thinking) and J (Judgemental) categories. Detailed conclusions here will require additional research but should not be ignored as a possible screening mechanism during selection for Black Belt candidates.

In Figure 28 the literature reviews in Chapter 2 from data from previous research documents summarising the CSF's with the 2016 research results and compared for correlation. It emerges in both previous and current research that the most significant CSF's for LSS deployment are confirmed in the 2016 survey results.

Ranked 8th by the 2016 survey result is another new entrant in the top 10 CSF's compared to previous results ranked 11th extending LSS to the supply chain and reinforced by respondent E an experienced industry trainer, consultant and GE trained MBB stated in an interview that "one cannot have 2 or 3 sigma quality inputs and then expect delivering 4, 5 or even Six Sigma outputs. Including the SC into the company strategy for a LSS journey is necessary to achieve organisational LSS maturity. Process sigma of the process intent is all that is possible and without additional redesign of the process with DFSS activities will the sigma quality remain at best at process intent."

The extension of LSS to the supply chain is confirmed in interviews with respondent B and P working with a global Auto Manufacturer where problematic suppliers are required to deploy their own BB's and LSS program, but can be supported by the customer's BB pool where such capacities exist, until such time as the supplier has developed the necessary capability maturity to become self-sustained.

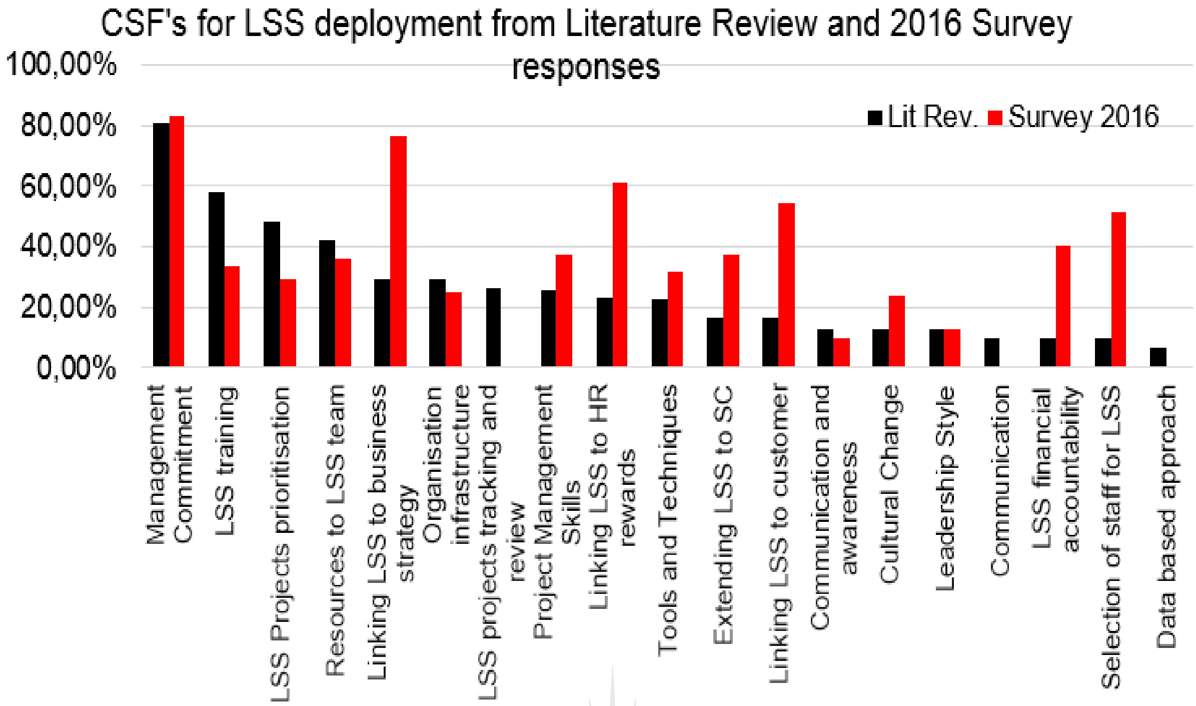

Figure 28: Data presentation of survey results for CSF's observed for Six Sigma compared to CSF's observed in literature reviews

CSF 4, 5, 6 and 8 are the new addition to the top 10 as discussed but also must be noted that the sample size of 200 with only 72 respondents could change if the sample size was bigger. However, the sample size was targeted to be authoritarian within the CSF's evaluated and it was confirmed in the interviews with all the respondents that all change initiatives starts and fails with management commitment.

Table 26 represents Questions 10, 12, 13, 14, 19 and 20 derived from the online survey questionnaire and the contributions for both LSS and DFSS towards CMM. These questions support the answering of both Research Objective 1 and Research Objective 2 to establish the contribution and CSF's for both LSS and DFSS deployment and industry acceptance observed in interviews from the industry specialists.

Table 26: LSS and DFSS Likert Style Survey questions used in 2016 survey.

Q No	LSS and DFSS Likert Style Survey questions Research Objective 1 and 2
10	Please rate the following statement: Effective mentoring and coaching are provided for Belts and key staff working on LSS and or DFSS projects.
12	Please rate the following statement: LSS/DFSS projects Status and ROI are tracked effectively from inception until fruition.
13	Please rate the following statement: We effectively measure financial metrics ROI/ROAM/ROCE/EBITDA for LSS /DFSS projects.
14	Please rate the following statement: All LSS/DFSS projects are linked to Hoshin Kanri / Strategy deployment.
19	Please indicate your company's effectiveness to reduce cost deploying LSS/DFSS.
20	Please indicate your company's effectiveness to INCREASE revenue whilst deploying LSS/DFSS.

Table 27 summarises the support structures based on Likert scale questions where all the respondents in the sample group agree to strongly agree for Q10 relating to effective mentoring and coaching with a mean result of 3,458 and Q12 has a mean result of 3.75 with a mean result of 3.903 regarding executive leadership again similar to the CSF determination in both survey and interview questionnaires in correlation with literature reviews done and compared in Graph 5.2. Question 12 has a mean score of 3.75 and Question 13 and 14 both results of 3.542 respectively relating to financial metrics and tracking of LSS and DFSS projects. Question 19 and 20 both have high mean scores of 3.9861 and 3.847 related to the effectiveness to both reduce operating costs but also increase revenue for the organisation deploying LSS and DFSS.

Table 27: Descriptive statistics Q10, 12-14, 19 and 20 and mean ratings.

```
Welcome to Minitab, press F1 for help.
Retrieving project from file: 'C:\Users\albert.viljoen\Documents\1 PhD\1
Thesis\Questionnaires\Research Objective 1 and 2.MPJ'
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Descriptive Statistics: Q_10; Q_12; Q_13; Q_14; Q_19; Q_20

Variable	Total Count	N	N*	CumN	Percent	CumPct	Mean	SE Mean	TrMean	StDev	Variance
Q_10	72	72	0	72	100	100	3,458	0,120	3,469	1,020	1,040
Q_12	72	72	0	72	100	100	3,7500	0,0984	3,7813	0,8350	0,6972
Q_13	72	72	0	72	100	100	3,542	0,115	3,594	0,978	0,956
Q_14	72	72	0	72	100	100	3,542	0,128	3,594	1,087	1,181
Q_19	72	72	0	72	100	100	3,9861	0,0979	4,0469	0,8306	0,6899
Q_20	72	72	0	72	100	100	3,847	0,100	3,906	0,850	0,723

Variable	CoefVar	Sum	Sum of Squares	Minimum	Q1	Median	Q3	Maximum	Range
Q_10	29,50	249,000	935,000	1,000	3,000	3,000	4,000	5,000	4,000
Q_12	22,27	270,0000	1062,0000	2,0000	3,0000	4,0000	4,0000	5,0000	3,0000
Q_13	27,61	255,000	971,000	1,000	3,000	4,000	4,000	5,000	4,000
Q_14	30,69	255,000	987,000	1,000	3,000	4,000	4,000	5,000	4,000
Q_19	20,84	287,0000	1193,0000	1,0000	4,0000	4,0000	4,7500	5,0000	4,0000
Q_20	22,10	277,000	1117,000	1,000	3,000	4,000	4,000	5,000	4,000

Variable	IQR	Mode	N for Mode	Skewness	Kurtosis	MSSD
Q_10	1,000	3	25	-0,05	-0,76	0,782
Q_12	1,0000	4	33	-0,24	-0,44	0,8380
Q_13	1,000	4	31	-0,63	0,35	0,824
Q_14	1,000	4	24	-0,41	-0,42	0,817
Q_19	0,7500	4	39	-1,19	3,00	0,7394
Q_20	1,000	4	39	-0,83	1,10	0,472

In Table 28 can we observe the correlation in Pearson r value but also rho values in Spearman correlation in Table 5.8 for questions 10, 12-14, 19 and 20. Positive linear relationship is observed between questions 10 and 12; questions 13 and 14; questions 10 and 19; questions 19 and 13; questions 20 and 10; questions 20 and 14 and also questions 20 and 19. Strong positive linear relationships are only observed where the absolute value $r \geq 0.7$ in questions 10 and 14; questions 12 and 14; questions 13 and 14; questions 10 and 19; questions 12 and 19; questions 14 and 19 and finally with questions 10 and 20. No moderate ($r \geq -0.5$) to strong ($r \geq -0.7$) linear relationships are observed in any of the questions.

Table 28: Pearson correlation P values Questions 10, 12-14, 19 and 20.

Matrix Plot of Q_10; Q_12; Q_13; Q_14; Q_19; Q_20

Correlation: Q_10; Q_12; Q_13; Q_14; Q_19; Q_20

	Q_10	Q_12	Q_13	Q_14	Q_19
Q_12	0,087				
	0,468				
Q_13	-0,055	0,134			
	0,648	0,263			
Q_14	0,002	-0,019	0,038		
	0,989	0,872	0,751		
Q_19	0,041	-0,005	0,148	-0,038	
	0,733	0,966	0,214	0,749	
Q_20	0,001	-0,074	-0,204	0,091	0,137
	0,995	0,535	0,086	0,448	0,253

Cell Contents: Pearson correlation
P-Value

The observed correlation coefficient is significant where the p value alpha / α ≥ 0.05 presented in Table 28 on questions 10 and 12; questions 10 and 13; questions 12 and 13; questions 10 and 14; questions 12 and 14; questions 13 and 14; questions 10 and 19; questions 12 and 19; questions 13 and 19; questions14 and 19; questions 10 and 20; questions 12 and 20; questions 13 and 20; questions 14 and 20 and also questions 19 and 20.

In Table 29 the evaluation of the monotonic relationship between variables is done through Spearman correlation. The strength and direction of the monotonic relationship across the questions and the variables in the results are positive for Q10 and Q12; Q12 and Q13; Q10 and Q14; Q13 and Q14; Q10 and Q19; Q13 and Q19; Q14 and Q20 and also Q19 and Q20. The strength and direction of the monotonic relationship across the questions and the variables in the results are negative in Q10 and Q13; Q12 and Q14; Q12 and Q19; Q14 and Q19; Q10 and Q20; Q12 and Q20 and also Q13 and Q20.

Table 29: Spearman R value for questions 10, 12-14, 19 and 20.

Spearman Rho: Q_10; Q_12; Q_13; Q_14; Q_19; Q_20

	Q_10	Q_12	Q_13	Q_14	Q_19
Q_12	0,091				
	0,446				
Q_13	-0,060	0,147			
	0,614	0,218			
Q_14	0,018	-0,016	0,086		
	0,880	0,894	0,473		
Q_19	0,042	-0,028	0,106	-0,050	
	0,726	0,815	0,377	0,677	
Q_20	-0,068	-0,089	-0,230	0,048	0,207
	0,571	0,456	0,052	0,688	0,081

Cell Contents: Spearman rho
P-Value

For Spearman correlation coefficient analysis it is observed over a range of -1 to +1 and the larger the Spearman coefficient the stronger the relationship between the variables being analysed. Where the absolute value of 1 equates to ranked order data to be perfectly linear and also the larger the coefficient the stronger the relationship which is being analysed. It is also important here to observe that the sign of the coefficient determines the direction of the relationship being analysed, where both increase or decrease together the coefficient is therefore positive and the line in the scatter plot (when made) is positive and will then slope upwards and in turn where one variable increases whilst the other decreases the coefficient is negative and the scatter plot (when made) is negative.

In the Table 29 results, the Spearman correlation between questions 10 and 12 (rho 0,091); 12 and 13 (rho 0,147); 10 and 14 (0,018); 13 and 14 (rho 0,086); 10 and 19 (rho 0.042); 13 and 19 (rho 0,106); 14 and 20 (rho 0,048) and 19 and 20 (rho 0,207) which indicates a progressive positive relationship in-between the variables. The Spearman correlation between questions 10 (-0,068); 12 (-0,089) and 13 (-0,230) relative to question 20 variables are negative, which indicates that one is increasing whilst the other is decreasing, confirming linearity between the questions.

It is also not appropriate to conclude that measured and analysed changes in one variable causes a change in another variable only. Very strict and controlled experiments can then determine whether a relationship is causal or not.

Research Objective 1: is now established and confirmed through the previous literature reviews, interviews and industry specialist participant survey analysis of descriptive statistics what are the most significant CSF's for LSS successful deployment within and organisation as observed in Table 25 and in addition the KMO test will conclude in section 5.11 Bartlett's Test of Sphericity for factor analysis.

5.5 Data presentation and analysis: Research Objective 2

What are the most significant CSF's for successful DFSS deployment in an organisation?

In this section survey questions 7-10, 12-20, 23, 24, 26-29 a total of 19 are analysed and designed to answer Research Objective 2 determining the CSF's for successful DFSS deployment.

The interviewees were asked to identify the most significant CSF's for successful DFSS deployment from experience and rate on the survey questionnaire from the list of CSF's listed.

As observed in Table 19 all of the respondents for Research Objective two with the exception of C, G, I and J have DFSS as part of their CI strategy and could comment accurately on the deployment of DFSS, which relates to 75% of the industry specialists opinions interviewed as stated previously. Each interview was scheduled to be one hour in duration, but none were finished in a period of less than one and a half hours.

Excellence (in communication, quality, delivery, administration and service performance) is promoted as reported by both survey respondents and interviewees because maturity improves constantly and the focus is on improving the customer relationship and value through constant review of VOC and QFD data.

"Creating a behaviour based vision for the early stages of DMADV in DFSS rollout where leadership support is tangible for DFSS innovation and process redesign….." (Respondent A).

“Integrated communication plan and regular reviews after DFSS has been launched validating Cp and Cpk indices and field failure reviews…..” (Respondent B).

No DFSS tools currently deployed…” (Respondent C).

“The chemical industry is more forgiving to say that of the automotive industry and often more than 3 and 4 sigma quality is not required, we do have dedicated Innovation Black Belts working on completely leading teams to redesign existing products and the processes that produce them deploying DFSS…” (Respondent D).

“Higher quality than “process entitlement” is seldom required. At GE where I did my training before entering consulting we initially made the structural error when substituting design function with DFSS, which not at all envisaged to substitute an organisation's functional design area. DFSS is more suited to function as a KPI monitor and tool method as opposed to replicating the design function. DFSS is therefore a methodology to complement design functionality and teams as opposed to compete or replace such existing design practices. Higher Sigma quality such as 7, 8, 9 or even 10 sigma is seldom required, unless this is the process entitlement envisaged in the design….” (Respondent E).

“Our DFSS experience and foundation stem from combining QFD and VOC metrics in our project approaches using Scrum in Agile projects to systematically test and mitigate process and software errors through frequent testing…” (Respondent F).

“No DFSS experience or requirements at this stage of deployment…” (Respondent G).

“DFSS have been combined within both services and product project management applying components of Agile tracking CMMI even though it is originated in the software industry have we been fortunate to effectively reduce project lead times over the past decade including improved project cost…(Respondent H).

“No DFSS experience or requirements at this stage of deployment…” (Respondent I).

“No DFSS experience or requirements at this stage of deployment…” (Respondent J).

“Most of our processes are required to yield quality levels that exceeds the typical 5 and 6 sigma barriers due to the nature of our products flying all over the world and human lives are at stake in the event of product failure. We have a standardised development and testing regime developed over years of manufacturing aircraft, both civil and military applications of course, where we through cross functional teams perform extensive DFR and DFSS cycles during concept design and validation before partnering only with validated process capable suppliers who we entrust to manufacture our products, which also require 100 quality conformance…” (Respondent K).

“The business recipe from concept to market is in our well documented and controlled design and processing procedures supported by management. The nature of our product being pharmaceutical requires flawless quality in market quality and we have several gates in place to ensure stable processes and hygiene levels are maintained to the respective HACCP requirements. New product design and also process design uses many of the DFSS tools deployed but it’s not called DFSS even though the outcome is of a 7 or 8 sigma quality.…”(Respondent L).

“We are centred on legal risk mitigation and DFSS in both process safety and QFD requires that we follow global practice and corporate standard recipes and we maintain the quality with 5 and 6 sigma consistently. Leadership expects us to follow procedures and report on deviations since product will not be fit for consumption and result in unhappy market response and possible product re-call in the event that HACCP violations are allowed to escape. Improving process quality from 4 sigma is often subject to DFSS review to improve existing processing techniques due to plant age not always yield the similar sigma quality as our

European and USA facilities. I would summarise our DFSS is limited but importantly remains the adherence to rules and then DFSS tool use.…" (Respondent M).

"We are necessitated to improve service levels to our clients and the VOC remains a significant input tool to our DFSS approach where we employ measures CTQ integrating QFD just to stay abreast of the competition. Our journey started when we were awarded a contract with a large multinational and they had a supply condition in terms of our CI program, which had to be clear and show maturity in development and a list of methods deployed, which LSS and DFSS was listed. We had to invest in Black Belts for the DFSS approach where some of our automotive and pharmaceutical clients insisted on a 98% OTD which was subject to substantial penalties in the case of non-achievement. Management remained adamant we want to maintain this business relationship and our savings have been significant, even though our DFSS journey remains in its infancy have we grown into designing processes and client solutions with significantly higher quality levels than the historic 3 and 4 sigma levels of operating…"(Respondent N).

"I think I recall Woods, R. (2010) who suggested through some research that CEO at the Richard Paxton from Alacer Group as a financier was fascinated by the fact that a typical LSS project would yield returns of $500-600k whereas a typical DFSS project will yield anything upwards from $20m and they realised $500m in process improvements using DFSS, which got me and my team paying attention and extended our LSS journey into our process and product design departments. This approach and observations also concur with financial reporting now includes ROI for both DFSS and LSS projects and our limitations at present is the number of MBB;s at our disposal, we need more and we are training them but we don't have enough BB's which we are also training along with company-wide GB's and YB's. We need more and although we can source these resources from the market we believe in internal development as cornerstone to building future capacity.…" (Respondent O).

"Global FPS structured approach requires an Interim Containment Action (ICA) to be raised for a concern, mitigated through an 8D or multiple 8D's if necessary to establish Root Cause and resolve with a Permanent Corrective Action (PCA) and if not resolved, escalated to DMAIC for a Six Sigma project and when this fails DFSS tools with a dedicated Master Black Belt is assigned with the necessary support as identified, result from this project is constantly shared with Senior management and the selected Product Development (PD) teams. The skillset from the MBB's, possible BB's and GB's included and regular review of accurate information combined in a cross functional team setting provides for a powerful combination, which resolves both process and design issues.…" (Respondent P).

Survey results observed for DFSS CSF's are shown in Figure 29 derived from ranking open ended responses from survey questionnaire in question 26 where it was allowed that the survey respondents could list the most significant CSF's influencing successful DFSS deployment. There was no literature available for CSF's for DFSS to **compare** these empirical survey results and these are only representative of the sample group of respondents.

From the survey results a greater number of CSF's are identified for DFSS implementation, which also again confirms the absence of published research done with DFSS as a CI strategy. Furthermore the number of CSF's presented in the survey also made allowance for non-prescriptive CSF's for DFSS to be added in addition to the ones already proposed in the survey questionnaire.

Table 32 summarises the Minitab calculated statistics for the CSF's identified in the survey and interviews for successful DFSS deployment, where the results summarised in Table 32 also ranks the CSF's according to the highest Cronbach's alpha result obtained from Tables 5.9 and 5.10 analysing the CSF's from the survey results.

In question 7 summarised in Figure 29 constructed from survey results identify that only 15.3% of the survey respondents have adopted DFSS as part of their CI and Innovation strategy, which was confirmed also among the interviewee participants.

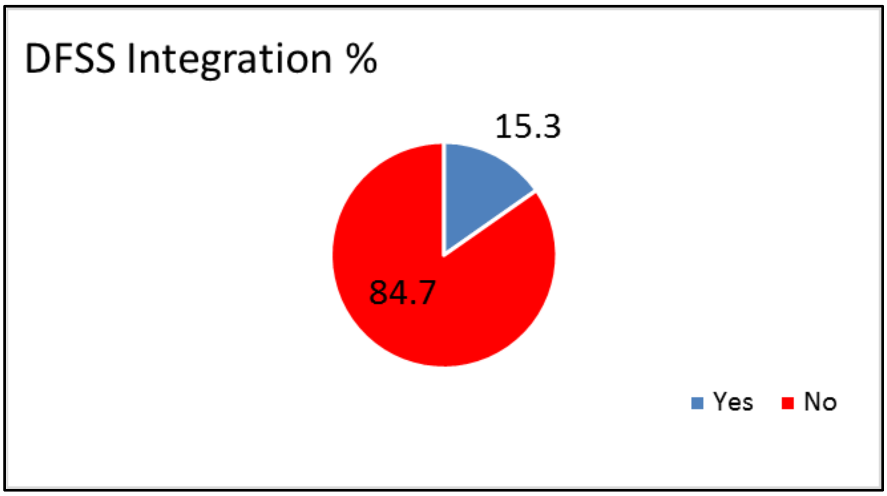

Figure 29: Survey results DFSS adoption rate observed in survey results.

Table 30 and Table 31 display the descriptive statistics (mean and standard deviation) derived from 2016 survey questionnaire and Minitab for CSF's identified and observed for DFSS deployment

Table 30: DFSS CSF's Standard deviation and Mean scores measured in 2016 survey.

Variable	Total Count	Mean	StDev
Leadership and management comm	72	4,525	0,495
Agile and Scrum skills and matu	72	4,392	0,676
LSS Organisation Maturity	72	4,295	0,715
TRIZ and TOC knowledge	72	4,198	0,743
VOC / Kano Analysis tool use	72	4,077	0,613
DFR / DFM capabilities	72	3,988	0,702
QFD and CTQ design integration	72	3,948	0,232
Design and Tollgate reviews	72	3,892	0,417
DOE capability	72	3,813	0,694
Risk identification and mitigat	72	3,798	0,659
No DFSS	72	3,661	0,800
Dedicated DFSS practioners	72	3,648	0,802
Design Engineering and Design T	72	3,636	0,822
DFMEA reviews of multi discipli	72	3,623	0,857
People Innovation	72	3,507	0,944
BB and MBB BOK (MSA, Multiple R	72	3,386	0,967
Product Innovation	72	3,279	1,098
Supplier and Technology Process	72	3,122	1,014
Process Innovation	72	3,045	0,967
Gate reviews	72	2,906	0,996
Strategy linkage to policy depl	72	2,833	0,949
Tolerance setting and tolerance	72	2,785	0,925
Others	72	2,604	1,106
Total	72	82,961	9,045

Cronbach's alpha = 0,8482

Table 31: DFSS CSF's Cronbach's Alpha, adjusted standard deviation scores measured in 2016 survey.

Omitted Variable	Adj. Total Mean	Adj. Total StDev	Item-Adj. Total Corr	Squared Multiple Corr	Cronbach's Alpha
Leadership and management comm	78,437	9,003	0,0581	0,6512	0,8513
Agile and Scrum skills and matu	78,570	8,828	0,2859	0,5735	0,8463
LSS Organisation Maturity	78,666	9,102	-0,1189	0,4437	0,8589
TRIZ and TOC knowledge	78,764	8,927	0,1177	0,4658	0,8520
VOC / Kano Analysis tool use	78,885	9,170	-0,2362	0,3578	0,8600
DFR / DFM capabilities	78,973	9,019	-0,0022	0,4245	0,8552
QFD and CTQ design integration	79,013	8,916	0,5451	0,7263	0,8449
Design and Tollgate reviews	79,069	9,035	0,0002	0,2963	0,8518
DOE capability	79,149	8,940	0,1127	0,3398	0,8516
Risk identification and mitigat	79,163	8,738	0,4353	0,4685	0,8418
No DFSS	79,301	8,342	0,8681	1,0000	0,8249
Dedicated DFSS practioners	79,313	8,320	0,8944	1,0000	0,8238
Design Engineering and Design T	79,326	8,300	0,8973	1,0000	0,8232
DFMEA reviews of multi discipli	79,338	8,282	0,8792	1,0000	0,8231
People Innovation	79,455	8,258	0,8164	0,8111	0,8242
BB and MBB BOK (MSA, Multiple R	79,576	8,378	0,6600	0,7066	0,8312
Product Innovation	79,682	8,436	0,5089	0,5986	0,8382
Supplier and Technology Process	79,839	8,541	0,4522	0,5976	0,8407
Process Innovation	79,916	8,458	0,5705	0,5371	0,8353
Gate reviews	80,055	8,732	0,2632	0,5590	0,8491
Strategy linkage to policy depl	80,128	8,639	0,3821	0,2958	0,8436
Tolerance setting and tolerance	80,177	8,687	0,3415	0,3757	0,8452
Others	80,357	8,507	0,4371	0,5187	0,8419

Tables 32 and 33 rank the CSF's according to Cronbach's alpha from highest to lowest and also in grey shaded columns are the CSF's identified with mean scores lower than 3.75, which delist these CSF's (No 20 and 22) from the top 10 Cronbach alpha ranked and elevates CSF no 7 (QFD and CTQ design integration) and CSF no 10 (Risk identification and mitigation). It must be stated that the selection of a top 10 is also purely based on this research document, so additional research should be conducted to improve the industry and methodology validity.

Table 32: DFSS CSF's ranked according to Cronbach's alpha and Means scores of ≥ 3, 75 extracted from Table 30 obtained from Minitab and 2016 survey results.

CSF No	CSF Description DFSS	Mean Rating	Std. Dev	Rank	Cronbach's alpha
5	VOC / Kano Analysis tool use	4,077	0,613	1	0,8600
3	LSS Organisation Maturity	4,295	0,715	2	0,8589
6	DFR / DFM capabilities	3,988	0,702	3	0,8552
4	TRIZ and TOC knowledge	4,198	0,743	4	0,8520
8	Design and Tollgate reviews	3,892	0,232	5	0,8518
9	DOE capability	3,813	0,694	6	0,8516
1	Leadership and management commitment	4,525	0,495	7	0,8513
20	Gate reviews	2,906	0,996		0,8491
2	Agile and Scrum skills and maturity	4,392	0,676	8	0,8463
22	Tolerance setting and tolerance design BOK	2,785	0,925		0,8452
7	QFD and CTQ design integration	3,948	0,232	9	0,8449
21	Strategy linkage to policy deployment	2,833	0,949		0,8436
23	Others	2,604	1,106		0,8419
10	Risk identification and mitigation	3,798	0,659	10	0,8418

Table 33: DFSS CSF's ranked according to Cronbach's alpha and Means scores of ≥ 3, 75 extracted from Table 30 obtained from Minitab and 2016 survey results.

18	Supplier and Technology Process Capabilities	3,122	1,014		0,8407
17	Product Innovation	3,279	1,098		0,8382
19	Process Innovation	3,045	0,967		0,8353
16	BB and MBB BOK (MSA, Multiple Regression Analysis, DOE)	3,386	0,967		0,8312
11	No DFSS	3,661	0,8		0,8249
15	People Innovation	3,507	0,944		0,8242
12	Dedicated DFSS practioners	3,648	0,802		0,8238
13	Design Engineering and Design Tool knowledge/use	3,636	0,822		0,8232
14	DFMEA reviews of multi-disciplinary teams	3,623	0,857		0,8231

Statistical analysis such as Cronbach's alpha provides for confirmation in the analysis of internal consistency for questionnaire data. Principle Component Analysis allows the research in Tables 32 and 33 to act as a reduction technique from a large group of variables in CSF identification for DFSS, which in itself is classified as a more advanced statistical methodology than LSS although less frequently used for reasons such as LSS program and organisational maturity.

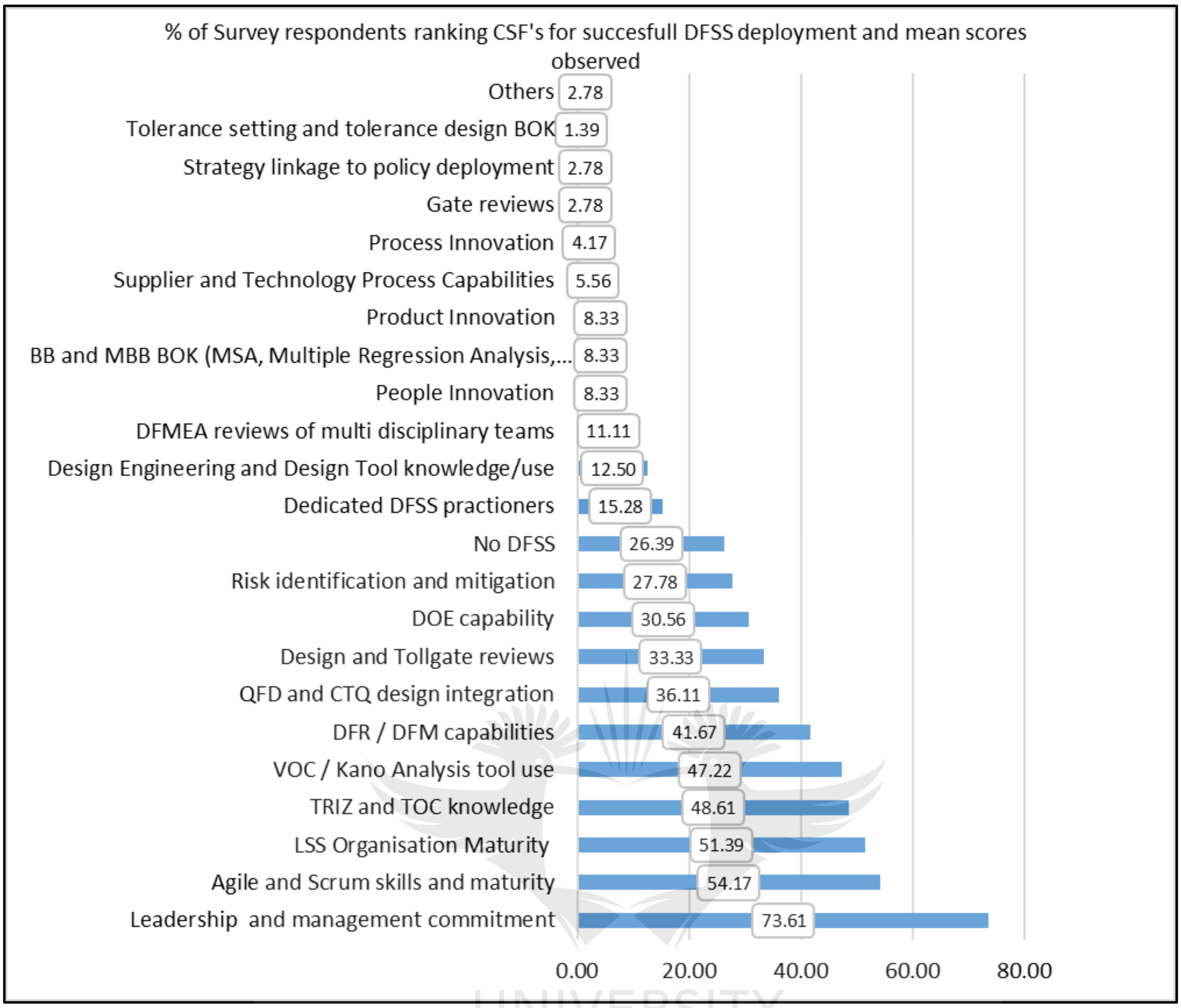

Figure 30: CSF's identified in Survey responses for successful DFSS deployment ranked by mean scores observed and survey percentage responses recorded.

The survey responses clearly show Leadership and management commitment the most prominent CSF based on mean score of 4,525 identified by the survey respondents as seen in Figure 30. The inclusion of Agile and Scrum, TRIZ and TOC knowledge along with LSS organisational maturity, VOC / Kano Analysis, DFR / DFM capabilities, QFD and CTQ design integration and DOE is prominent since these are both management tools of the Design process including Risk identification and mitigation tactics in DFSS. Agile suggests both a need for responsiveness in design needs and within the confines of TOC of what is possible. Survey respondents reflected without question that the contribution of leadership supporting the very costly process for DFSS projects which are not always a guarantee for breakthrough innovations. Because of the cost implications the respondents A, B, D, E and K cited project selection which has not been listed or identified as a CSF for DFSS deployment in the survey but confirmed during the interview process. Project selection should therefore be considered and included in future research for DFSS CSF's confirmation and review.

The responses received from the interview questionnaire supports CSF's identified for DFSS and maturity capability is reported to be an **underlying obstacle** that is only mitigated through the creation of the organisational body of knowledge through capacity development of skilled professionals familiar with DFSS techniques and in particular the supply chains' ability to also participate with the necessary maturity and capacities of capability. Respondents A, B, D, E, F, L, M, O and P confirmed supplier directives in developing Black Belts to accurately and progressively enable their respective organisations to improve and measure quality performance as a business continuation mandate. It some cases it is also the practice to place a Black Belt or Master Black Belt with the supplier whilst the capability is developed along with the other Belts. This was also reported as a corrective and reactive measure deployed by both Ford and Toyota plants. On closer examination when asked why the respondents would confirm that a higher quality yield was expected than process or supplier process was delivering, **required immediate intervention** but also review of existing processes. DFSS is then also deployed with the supplier in question to ensure risk mitigation. Again the VOC and QFD emerges prominent and directive in the event of process quality or service delivery failure.

From this Chapter is it concluded that the most prominent CSF's are identified in Table 32 and Table 33 although cited by interview respondents that project selection should be considered as a CSF partly due to the possibility of project failure and the associated high costs with development of new products and processes.

The ever present reports of the contribution of leadership and management achieving the highest means rating result in the survey is also confirmed by the interview respondent responses.

The establishment of the ISO standard ISO 16355-1 (– Application of statistical and related methods to new technology and product developments in Part 1: General principles and perspectives of Quality Function Deployment (QFD) in 2015) aligns with the CSF VOC / Kano Analysis tool use ranked 1st and QFD and CTQ design integration 7th CSF in Table 32.

QFD and VOC approaches are both included within this ISO standard starting with customer expectations and needs and importantly not with what the organisation is or can produce at the present, therefore it is imperative to listen to the customer needs and wants (CTQ) seeking customer delight.

Two significant CSF's confirmed here also require further research. The first one is observed in the contribution Scrum within Agile project management has a CSF, which could also possibly to be used as a mitigation tool for the very costly nature of DFSS projects. The second significant emerging CSF which warrants further research is LSS Organisation maturity, suggesting that although organisations may be selectively using several DFSS tools. It does however not ensure successful DFSS deployment and this is also confirmed by both US and European training providers for DFSS such as ASQ and VDA QMC requiring candidates to be conversed and mature with LSS tools and projects.

In Table 34 is it observed from interviewing respondents F (IT industry), K (Aerospace industry) and I (Banking) in training used at Motorola's DFSS and CMMI training curriculum the similarities with CSF's reported by respondents in Survey responses where 9 of the 22 CSF's are included in the training as separate topics, confirming that the validity of the CSF's but also that more research should be done for organisations seeking to successfully deploy DFSS as part of their CI strategy. A respondent from Motorola was scheduled for an interview but needed to cancel and was not available again during the period of completion of this research document.

Table 34: Extract from Motorola's DFSS training curriculum and highlighted in yellow are CSF's identified in Table 32 and 33.

Week 1 Topics	Week 2 Topics	Week 3 Topics
DFSS Overview	Critical parameter management	Linear and multiple regression
CDOV Process	DFMEA / DFR /DFM	RSM
DFSS tools and project management	Basic Stats (statistics package)	Monte Carlo
VOC / Kano Analysis	Hypothesis testing	Robust design
QFD	Confidence intervals	Tolerance optimisation
First Principle Modelling (Monte Carlo)	ANOVA	CPM
Pugh	MSA	Architecture and design based software reliability modelling
DFSS Scorecards	SPC	Reliability growth testing and modelling
Six Sigma and CMMI synergies	Design and Process	Motorola Lab's TRAMS (Test Planning using fuzzy logic)
Parametric SW project forecasting	Statistical capability analysis	Taguchi Noise Testing
Requirements management processes	DOE	Small memory management
Developing SW operational profiles	Full factorial designs	Throughput and timing analysis
SW Quality Attribute Workshops	Fractional factorial designs	Orthogonal Defect Classification
Attribute-Driven SW Architecture	Modelling	Advanced SW inspection
Active Reviews for Intermediate Designs	Advanced DOE	Human error analysis
SW Architecture Trade-off Analysis Method (ATAM)		Cleanroom Software Engineering
Cost/Benefit Analysis of Architecture Decisions		Agile/Extreme Programming
Software Product Line Planning and Execution		SEI Personal and Team Software Process and relationships to DFSS
		Usability engineering
CSF X 2	CSF X 1 and top 10 Cronbach rank	CSF X 1 Survey in top 22 Cronbach rank

"We follow a similar approach to Motorola where only skilled Black Belts are used in training them for CMMI and DFSS multi-model implementation…" (Respondent F).

Knowledge of ISO 9000 and CMMI Scampi audit requirements are also trained with the DFSS candidates also confirming multi model approaches at SEI and Motorola.

Research Objective 2: is now established and confirmed through the limited literature reviews for DFSS CSF's, interviews and industry specialist participant survey analysis of descriptive statistics what are the most significant CSF's for DFSS successful deployment within and organisation as observed in Table 32 and Table 33 constructed with inputs from Table 34 and in addition the KMO test will conclude in section 5.11 Bartlett's Test of Sphericity for factor analysis.

5.6 Data presentation and analysis: Research Objective 3

What are the contributions of CMM to LSS and DFSS implementation where such models have been explored?

This Research Objective is designed in the answering of both the interview questions by the respondents and Questions 4, 5, 6, 16, 24, 30 and 38 as seen in Figure 31 Research Objective matrix for survey questions. The interviewees were asked about the contribution of CMM to LSS, DFSS or CI program implementation where such models have been explored and here there were only 6 of the 16 interviewees (which calculates to 37.5% of the interviewees) who have reported CMM deployment in various stages of maturity as identified in Figure 31 in the Research Objective matrix for interview responses.

Question 4 in the survey was designed to establish CI maturity of the respondents and is observed in LSS and or DFSS Maturity observed from the survey results in Figure 31 confirms the global trend that momentum after the year 2000 is observed with the organisations surveyed and in particular General Electric was also included in the survey as they were seen as one of the pioneers along with Allied Signal and Motorola.

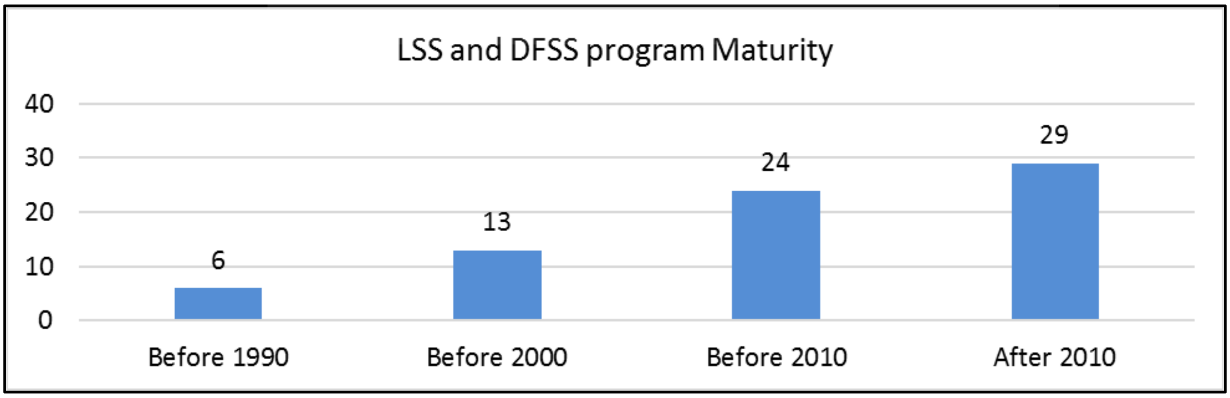

Figure 31: LSS and DFSS journey maturity reported by respondents.

The majority 53 of the 72 (74%) respondents' LSS and DFSS journeys only started after the year 2000 covering the last 16 years whereas the balance of the 19 of the 72 respondents (26%) can be observed as early adopters between 1987 and the year 2000.

Question 5 asked the survey respondents if they were measuring their CI maturity and a large portion ≥ 18% of the respondents were not measuring maturity of the CI strategy through any model, mostly linked to project tracking. Research Objective 5 will further expand on the survey results on how an integrated framework will assist organisations to achieve capability maturity.

Questions 6 asked the respondents where they are in fact measuring capability maturity, which models they are using (seen in Figure 32).

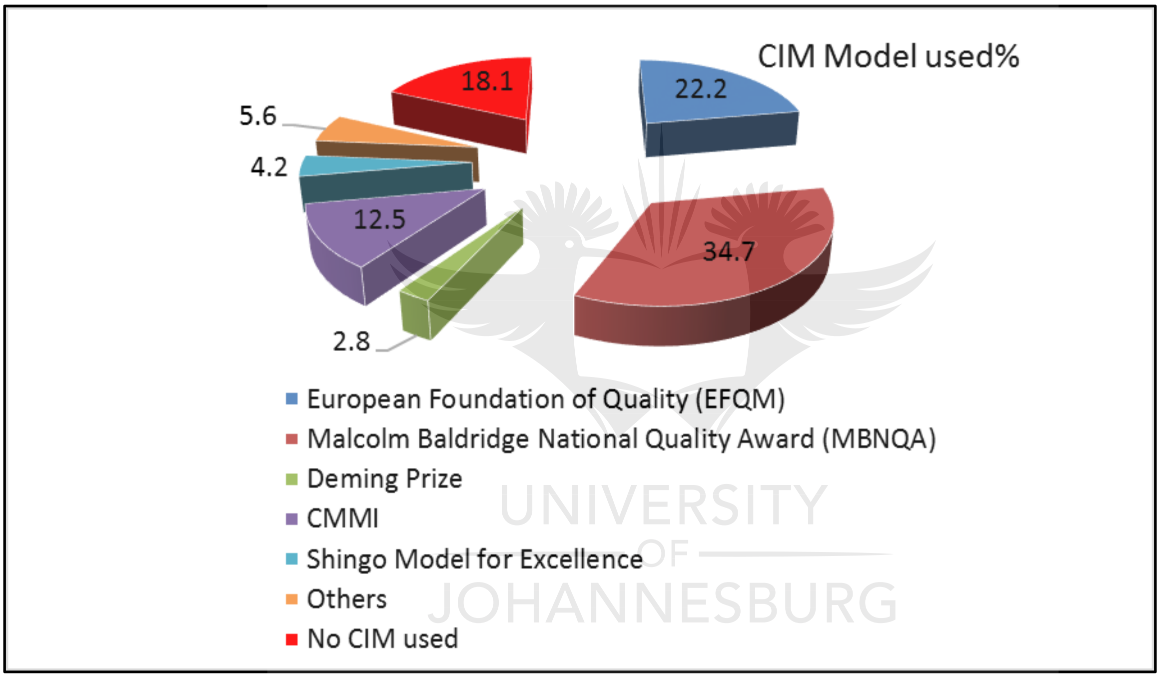

Figure 32: Maturity model adoption from online survey results.

Most reported model in use was the MBNQA at 34,7%; followed by the EFQM at 22,2% ; followed by **18,1** % reporting **no CIM model deployment**, followed by CMMI at 12,5%, followed by others grouped at 5,6%, followed by Shingo at 4,2% and Deming prize at 2,8%.

The two maturity models in use with the most responses are also limited to manufacturing organisations based on the responses received. Noteworthy is the CMMI respondents are not limited to the software and ICT industries also representing manufacturing.

Question 16 asked the respondents which functional area of CI program was the most significant improvement in LSS deployment which is represented in Figure 33.

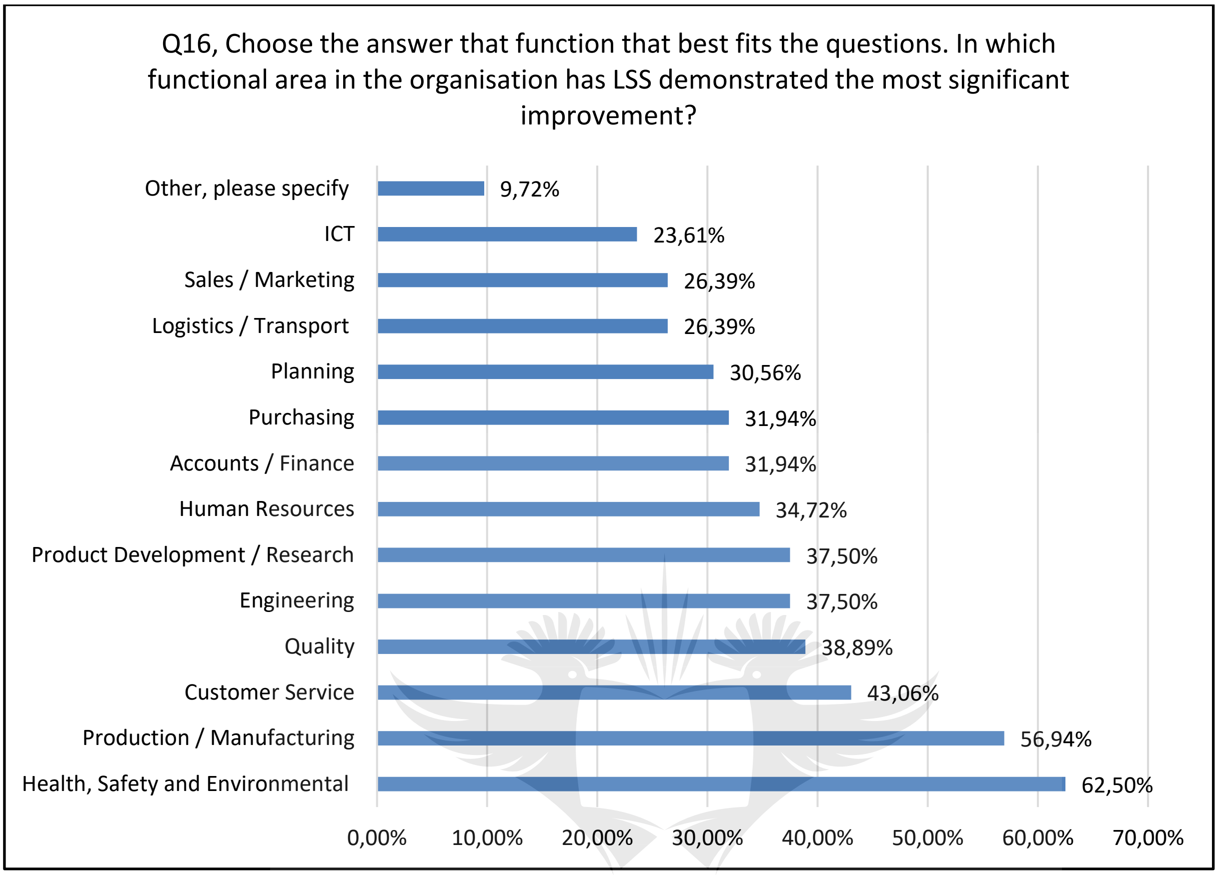

Figure 33: Functional areas demonstrating the most significant improvements in LSS deployment.

Interesting is that the highest reported benefit in CI was not made in the traditional manufacturing function but within Health, Safety and Environmental functions at 62,50% followed by Production, manufacturing at 56,94%; then Customer Service at 43,06% and Engineering 37,5% and Product development also at 37,5%. The significant representation across the functional areas suggest organisational wide integration of LSS as opposed to quality and production, again also showing maturity in CI from respondents reporting on their organisations and experience.

Interviewee responses besides questionnaire answers were also obtained and respondents were asked to share their opinion on functional area and LSS improvement.

“No CMM experience or advanced plans to institute such models at this stage of CI maturity,” however, another 8 respondents indicated that although they did not have any means of measuring their maturity capability they were of the opinion that it could assist them in closing CI targets not yet achieved. Some of the respondents stated that as long as you are maintaining a CI program with LSS and or DFSS “it really does not matter if you measure the maturity, you are improving anyhow…” (Respondent B, Respondent C, Respondent D, Respondent G, Respondent I, Respondent J, Respondent L, Respondent M and Respondent N).

“CMM is part of our global program through the EFQM model, which we all follow for almost a decade and it has been integrated into our company DNA where the global plants compete for who does the best. We find it very valuable and visualises opportunities for improvement ensuring consistency levels are maintained…” (Respondent A).

“As a consultant I have seen some of our clients, particularly in the banking, insurance and pure IT industries, modelling their abilities on CMMI and limited applications with manufacturers in both the US and Europe as part of corporate strategy exposed to EFQM and MBNQA. In most cases they have not integrated their LSS and DFSS programs but they are administered largely by the same teams deploying LSS and supporting DFSS programs. It seems more of a challenge for our clients to develop the necessary critical mass in terms of GB’s and YB’s to support the few BB’s they have deployed on projects…” (Respondent E).

“CMMI maturity and SCAMPI audits are part of our business as a result of our international parent who competes frequently for Software contracts with US government departments, although we are servicing Africa and Middle east region we are required to comply with corporate policy and it has brought another level of maturity review, we were not familiar with historically …” (Respondent F), which led to further research with Agile and CMMI performance analysis was confirmed by responses obtained from respondent K (Aerospace) which successfully reduced project effort within their operations after implementing CMMI, Agile and later Scrum within Agile. Both respondents K and F could not quantify their organisational project effort reduction, which both cited as significant and the fact that the lead time reductions was almost 30% in time to market with the inclusion of Scrum. Secondary research results was obtained in the absence of organisational results from respondents F and K. The results reported in Figure 34 are therefore considered as unique and not representative of either organisation, which also warrants further analysis for repeatability and consistency. Customer satisfaction levels were also reported to be improved attributed to the increased quality and reduced rework in the process.

CMMI level 1 maturity project effort of 100% consisting of 50% rework and 50% work is reduced to 69% total project effort when CMMI level 5 maturity is achieved combined with an increase from 0 to 9% process focus. The addition of Scrum with Agile reduces the total project effort to only 35% whilst reducing work to 25% and rework to only to 6% with a reduced process focus of 4%. Substantial CI results were reported at the Nasa IT summit (2010) refer to Figure 34 which supports the emerging contribution of Scrum in Agile combined with CMMI as an integrated CMM. Note 6% rework is not close to Six Sigma but closer to 3 Sigma, which suggests further (TLS) DMAIC and (DFSS) DMADV could complement the project quality even further.

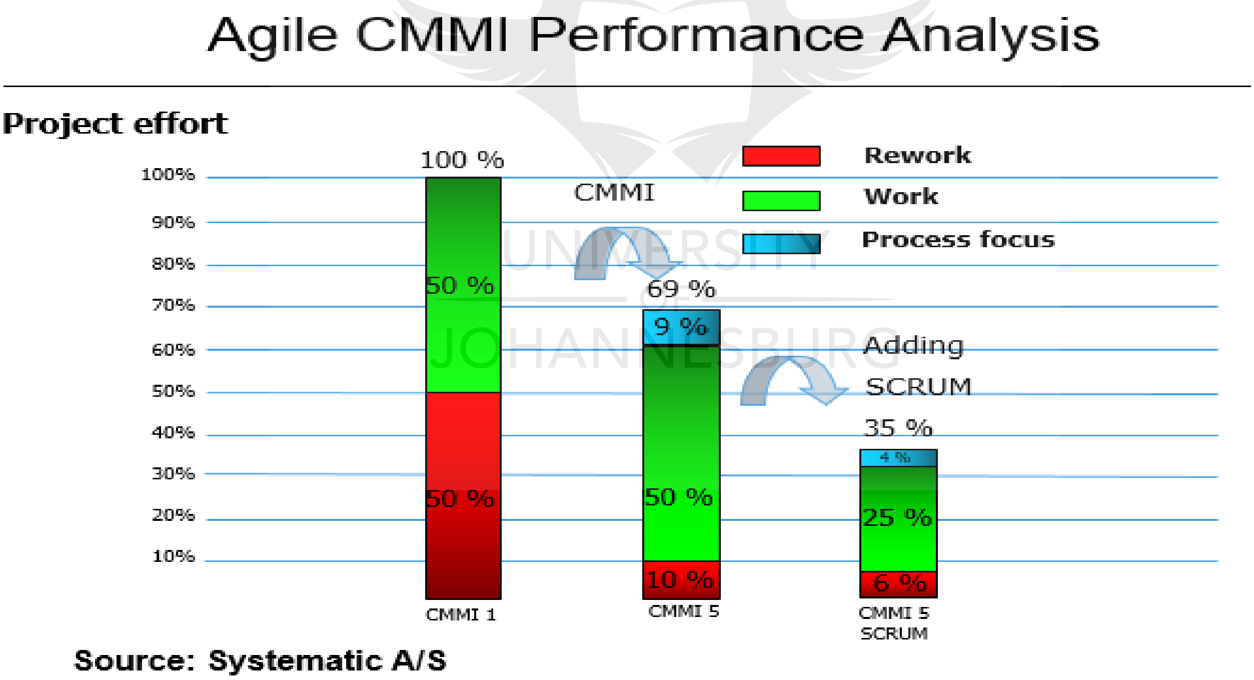

Figure 34: Reported Agile project efforts improvements through staged adoption of CMMI level 1, CMMI level 5 and CMMI level 5 combined with Scrum, Source: AgileDigm (2010) Nasa IT Summit.

The most notable reductions are combining both CMMI level 1 to level 5 evolution, adding Scrum. The adoption by the industry players that are not exposed to pure programming as a core business function limits the industry applicability to services and in particular software which was not exclusively one of the Research Objectives of this hypothesis.

“We also have been exposed to several maturity models including the MBNQA, the EFQM and also the rigorous CMMI SCAMPI C audits with our clients including airlines across the globe but more importantly the integration of both Software and Hardware technologies in aircraft construction and flight operations. It does make provision for establishing gaps in terms of approaches, which is in essence the function of any audit, but more importantly as a global standard your improvement maturity is validated throughout the organisation with regular feedback as part of the audit reviews…” (Respondent K).

“In our manufacturing divisions we have seen very little realised benefits with our EFQM audits and we agreed that with our focus being on building or CI capacity we will maintain our focus there although it must be said that the EFQM report made reference to CI inconstancies within our divisions, which is what I understand in essence a Maturity Model attempts to gauge, so early days for us there …” (Respondent O).

Question 24 wanted to know from the respondents what the Strategic reasons to embark on a LSS / DFSS journey were and the responses are seen in Figure 35.

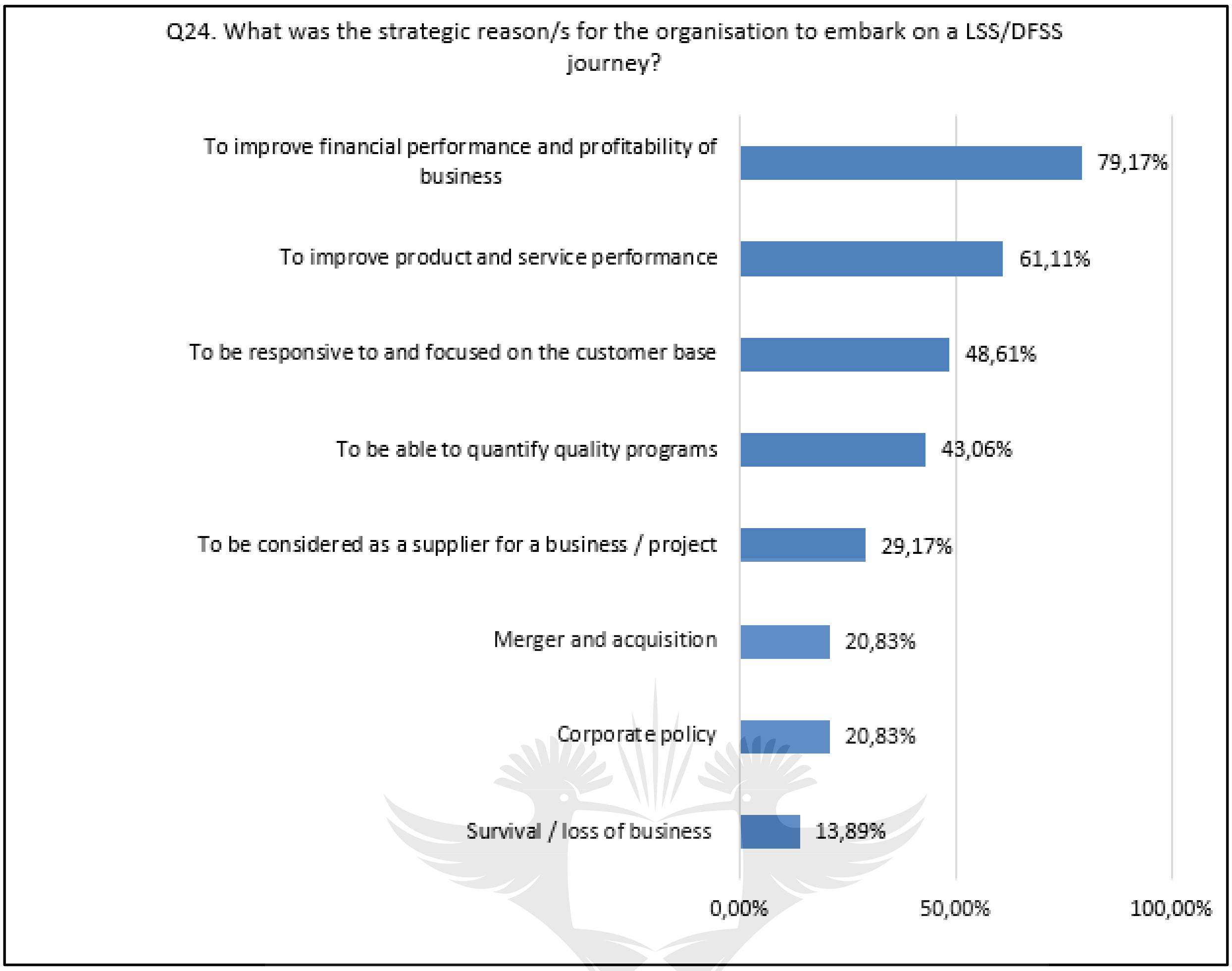

Figure 35: Strategic reasons to embark on an LSS/DFSS journey extracted from Survey responses.

It emerges that profitability (79.1%); service and product improvement (61.11%) and responsiveness and focus on customer base (48.61%) occupy the top three positions. It is interesting to note that Merger and acquisition received the same response as corporate policy (20, 83%) confirming maturity in one fifth of the respondents manifesting LSS/DFSS integral to Hoshin Kanri in company policy. Savings made in functional areas can be seen in respondents reported savings from annual reports and interviews. See Table 35 which summarises reported recent savings from annual reports for public companies from the **survey** and **interview** participants where the data is available and reported as such.

Table 35: Reported savings and improvements in functional areas across industries obtained from annual reports and interview responses from respondents.

Company / Projects	Metric / Measures	Benefits / Savings
Clariant	Cost Savings 2015	$142m
General Electric	Savings 1997-2015 Savings per belt	Est $15bn $538k
Ford	Savings 2000-2012 Savings per belt	$8,3bn $263k
Samsung	Savings and growth	$1,5bn
Brembo	% of sales	1.1%
ZF	% of sales	1.2%
Motorola	2005-2014	$15bn
Huawei	Financial	$1,5-2bn
Denso	% of sales	0.8%
Cigna Corp	Medical	$1,8bn
Bombardier	% of sales	0.9%
Xerox	Financial	$150m pa
BASF	Financial (% of sales) Environmental ($)	0.7% $241m
Airbus/EADS	Financial	$300m pa $400k per project
Jaguar / Land Rover (JLR)	Financial	0.65% ROS
Boeing	Water Consumption Financial	113,400l per day $300m pa
TRW	Automotive	1.5% ROS

Question 30 relates to organisation strategy maturity where respondents were asked in business excellence whether if at all organisational and divisional levels the vision was clearly communicated. The results are seen in Table 36 where the majority of respondents (70%) agree and 20% strongly agree with only 10% citing they are neutral.

Table 36: Descriptive statistics – Q30 Survey questionnaire – Organisation vision communicated to all levels and functions.

Descriptive Statistics: Q30

Variable	N	N*	Mean	SE Mean	TrMean	StDev	Variance	CoefVar	Sum	Sum of Squares
Q30	72	0	4,6111	0,0780	4,6875	0,6620	0,4382	14,36	332,0000	1562,0000

Variable	Minimum	Q1	Median	Q3	Maximum	Range	Mode	N for Mode	Skewness	Kurtosis
Q30	3,0000	4,0000	5,0000	5,0000	5,0000	2,0000	5	51	-1,47	0,88

With a mean score of 4,611 it is possible to deduce from respondents that at least 90% of the respondents perceive the visions to be clearly communicated to all departments and levels.

Question 38 relates to organisation sustainability and employee well-being and whether the key factors are measured to their satisfaction and motivation was determined to both monitor and improve the work environment. The results are seen in normal distribution of respondents who Strongly Agree (20%); majority of them Agree (60%); and a minority who are Neutral (5%) and a larger group that Disagree (15%) observed in results in Table 37.

Table 37: Descriptive statistics – Q38 Survey questionnaire – Kea factors relating to employee well-being, satisfaction and motivation determined and measured to improve the work environment.

Descriptive Statistics: Q38

Variable	N	N*	Mean	SE Mean	StDev	Variance	Sum of Squares	Minimum	Q1	Median
Q38	72	0	3,9167	0,0984	0,8350	0,6972	1154,0000	2,0000	4,0000	4,0000

Variable	Q3	Maximum	Mode	N for Mode	Skewness	Kurtosis
Q38	4,0000	5,0000	4	43	-0,89	0,66

The mean result measured from the respondents is 3.9167 with a standard deviation of 0.8350 which also supports the maturity in sustainability of the company through workforce sustainability.

From the survey and interview results and responses in Research Objective 3 the emerging results are clear in that a capability maturity model can and will assist an organisation implementing LSS, DFSS and any other CI derivatives of and hybrid CI systems deployed. CMMI, EFQM and MBNQA are also the most prominent maturity models already deployed by many organisations in both services and production industries. The contribution of adding Scrum and Agile in CMMI also suggests further analysis and inclusion in the proposed capability maturity model.

5.7 Data presentation and analysis: Research Objective 4

What impact does leadership specifically have in achieving capability maturity?

Questions (11, 31-37 and 39-40) in Matrix for Research Objectives seen in Table 20 were designed to assist with establishing the 4th Research Objective and the establishment of the impact of leadership in the process of organisational maturity achievement.

The interviewees were asked to comment on and share their experiences relating to what impact leadership does have in the evolution of achieving Capability Maturity.

Question 11 from the survey asked the respondents to rate the statement: Executive leadership is committed to LSS and DFSS which are also important for Research Objective 1 and 2 respectively. The results are seen in Table 38 and Figure36.

Table 38: Descriptive statistics for Q11 – Executive leadership commitment to LSS and DFSS.

Descriptive Statistics: Q11

Variable	N	N*	Mean	SE Mean	StDev	Variance	Sum of Squares	Minimum	Q1	Median	Q3
Q11	72	0	4,264	0,124	1,048	1,098	1387,000	1,000	4,000	5,000	5,000

Variable	Maximum	Mode	N for Mode	Skewness	Kurtosis
Q11	5,000	5	42	-1,31	0,73

From the survey is it observed that a very high mean score of 4.264 confirms the contribution of leadership to both LSS and DFSS strategy execution and also that the respondents are sure that they are experiencing high levels of executive leadership commitment within their organisational CI deployments. Reponses by the survey respondents to question 11 were largely positive and in agreement with executive leadership commitment to LSS and DFSS shown in Figure 36.

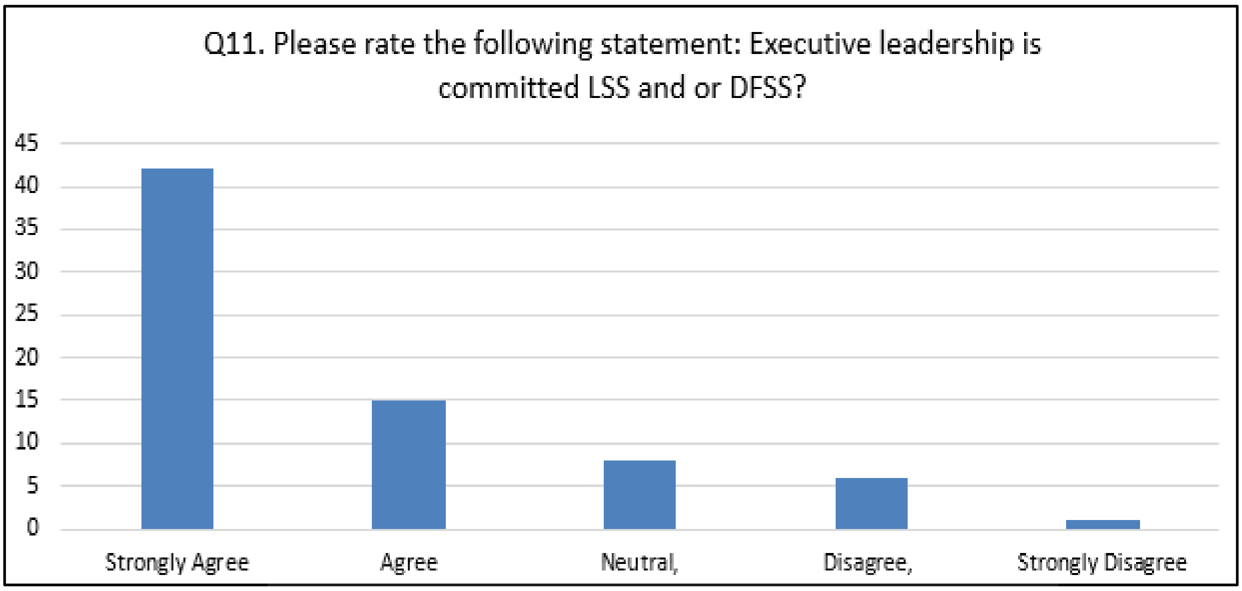

Figure 36: Online survey responses for Executive leadership commitment to LSS and DFSS.

Descriptive statistics are combined for questions 11, 31-37 and 39-40 and can be seen in Table 39 (Standard Dev and Mean); Table 40 (Pearson Correlation) and Table 41 (Cronbach's Alpha).

Table 39: Descriptive statistics questions 11, 31-37 and 39-40 determining the impact of leadership towards capability maturity.

Descriptive Statistics: Q11; Q31; Q32; Q33; Q34; Q35; Q36; Q37; Q39; Q40

Variable	N	N*	Mean	SE Mean	StDev	Variance	CoefVar	Sum of Squares	Minimum	Q1
Q11	72	0	4,264	0,124	1,048	1,098	24,58	1387,000	1,000	4,000
Q31	72	0	4,125	0,120	1,020	1,040	24,73	1299,000	2,000	4,000
Q32	72	0	2,556	0,165	1,403	1,969	54,90	610,000	1,000	1,000
Q33	72	0	3,986	0,104	0,880	0,774	22,08	1199,000	1,000	4,000
Q34	72	0	4,3750	0,0802	0,6805	0,4630	15,55	1411,0000	3,0000	4,0000
Q35	72	0	4,6389	0,0635	0,5388	0,2903	11,61	1570,0000	3,0000	4,0000
Q36	72	0	3,389	0,147	1,251	1,565	36,91	938,000	1,000	2,000
Q37	72	0	3,847	0,141	1,195	1,427	31,05	1167,000	1,000	4,000
Q39	72	0	4,2500	0,0514	0,4361	0,1901	10,26	1314,0000	4,0000	4,0000
Q40	72	0	4,3056	0,0730	0,6198	0,3842	14,40	1362,0000	2,0000	4,0000

Variable	Median	Q3	Maximum	Range	Mode	N for Mode	Skewness	Kurtosis
Q11	5,000	5,000	5,000	4,000	5	42	-1,31	0,73
Q31	4,000	5,000	5,000	3,000	5	32	-1,08	0,09
Q32	2,000	4,000	5,000	4,000	2	25	0,47	-1,24
Q33	4,000	4,000	5,000	4,000	4	45	-1,50	3,08
Q34	4,0000	5,0000	5,0000	2,0000	5	35	-0,63	-0,66
Q35	5,0000	5,0000	5,0000	2,0000	5	48	-1,14	0,31
Q36	4,000	4,000	5,000	4,000	4	27	-0,43	-0,94
Q37	4,000	5,000	5,000	4,000	4	33	-1,12	0,36
Q39	4,0000	4,7500	5,0000	1,0000	4	54	1,18	-0,63
Q40	4,0000	5,0000	5,0000	3,0000	4	41	-0,67	1,40

Table 39 combines the descriptive statistics for all the questions designed to determine Research Objective 4 relating to leadership impact towards maturity capability where all the Mean scores are above 4, except for questions 32, 33, 36 and 37. Question 32 in Figure 36 shows the normal distribution where organisations are constantly conducting internal and external reviews of the impact of Industry 4.0 on the organisation and a classic M distribution in the histogram is observed where the data from the respondents who agree and strongly agree (34,72%) and those who disagree and strongly disagree (62,5%) are divided but also achieving the lowest mean result of 2,556 and the greatest standard deviation if 1,403 from the questions relating to Research Objective 4. Additional questions relevant to Industry 4.0 where not asked in the survey, which could also reveal more scope for future research. The interviews where more open-ended questions were asked also confirmed this.

Questions 33-37, 39 and 40 display mean results greater than 3.75 with the respondents being in agreement with the questions relating to leadership commitment towards capability maturity.

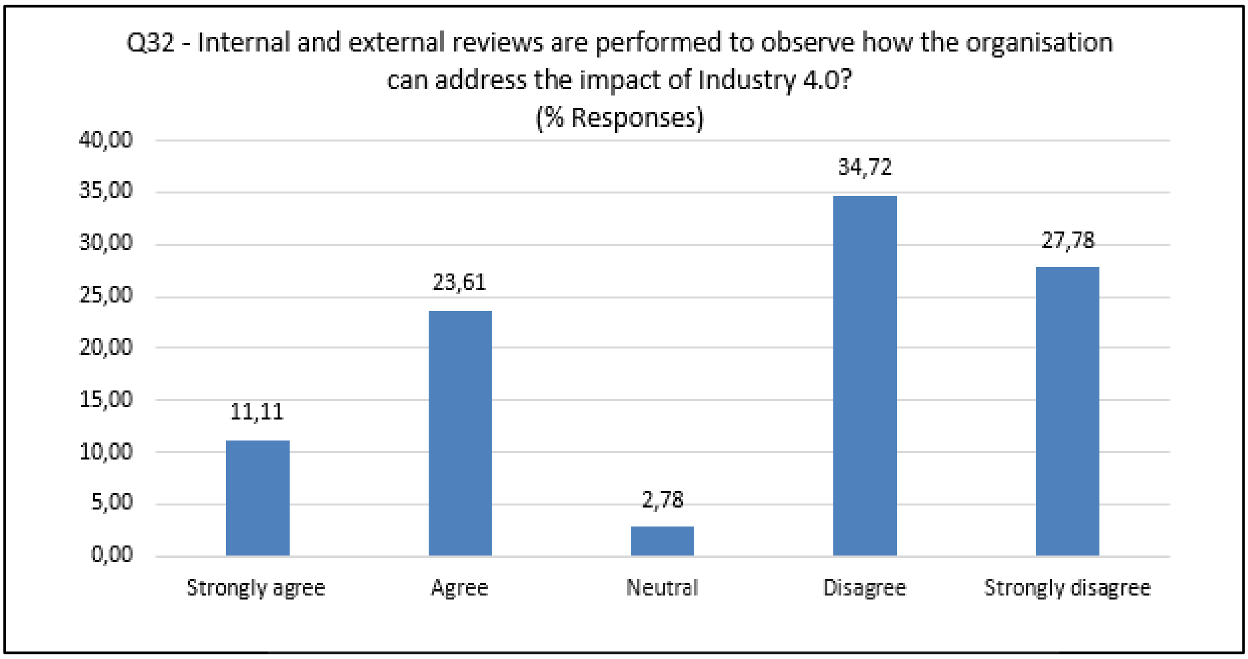

Figure 37: Q32 Percentage of online survey responses differing on organisational ability to address the impact of Industry 4.0.

Table 40 summarises the Pearson correlation for Questions 11, 31-37, 39 and 40. The weakest correlation is observed between questions 35 and 39 where r = 0.390 followed by questions 11 and 40 at r = 0,408, which is still moderately positive and the balance of the questions relating to leadership impact on capability maturity with large postive relationships observed in these questions.

Table 40: Descriptive statistics (Pearson correlation) for questions 11, 31-37 and 39-40 determining the impact of leadership towards capability maturity.

Correlation Matrix

	Q11	Q31	Q32	Q33	Q34	Q35	Q36	Q37	Q39
Q31	0,904								
Q32	0,694	0,768							
Q33	0,813	0,834	0,691						
Q34	0,867	0,906	0,782	0,785					
Q35	0,870	0,775	0,679	0,702	0,759				
Q36	0,898	0,855	0,854	0,811	0,869	0,859			
Q37	0,910	0,929	0,791	0,869	0,834	0,788	0,870		
Q39	0,408	0,499	0,783	0,633	0,534	0,390	0,645	0,561	
Q40	0,720	0,763	0,855	0,783	0,793	0,672	0,771	0,787	0,651

Cell Contents: Pearson correlation

Item and Total Statistics

Variable	Total Count	Mean	StDev
Q11	72	4,264	1,048
Q31	72	4,125	1,020
Q32	72	2,556	1,403
Q33	72	3,986	0,880
Q34	72	4,375	0,680
Q35	72	4,639	0,539
Q36	72	3,389	1,251
Q37	72	3,847	1,195
Q39	72	4,250	0,436
Q40	72	4,306	0,620
Total	72	39,736	8,195

Results for Cronbach's alpha illustrated in Table 40 relate to the set of questions relating to leadership's impact on achieving capability maturity, which was very high where α=0.9589 for the group and the lowest result calculated as 0.9501 which remains very high for item analysis to determine how well all of the questions measuring leaderships impact in achieving capability maturity. The results show that Cronbach's alpha is quite high: 0.95890. The researcher can trust the questions in the survey and those that assess the same construct, leadership impact towards capability maturity to be reliable.

Table 41: Descriptive statistics questions (Cronbach's Alpha) 11, 31-37 and 39-40 determining the impact of leadership towards capability maturity.

Cronbach's alpha = 0,9589

Omitted Item Statistics

Omitted Variable	Adj. Total Mean	Adj. Total StDev	Item-Adj. Total Corr	Squared Multiple Corr	Cronbach's Alpha
Q11	35,472	7,240	0,8984	0,9456	0,9511
Q31	35,611	7,247	0,9193	0,9290	0,9502
Q32	37,181	6,973	0,8461	0,9293	0,9577
Q33	35,750	7,424	0,8617	0,8753	0,9530
Q34	35,361	7,576	0,9023	0,8852	0,9537
Q35	35,097	7,744	0,8254	0,8104	0,9578
Q36	36,347	7,009	0,9385	0,9431	0,9501
Q37	35,889	7,070	0,9318	0,9329	0,9500
Q39	35,486	7,910	0,6381	0,7971	0,9630
Q40	35,431	7,662	0,8498	0,8461	0,9560

The survey results were largely confirmed in the interviews held relating to leadership's impact and contribution towards the achievement of capability maturity and will now include the responses received from the survey interviews:

"It can be argued that both leadership and resources are central to the achievement of capability maturity. Maturity is a natural outflow with building capacity and capacity is only possible when resources are available to train and develop staff to sustain the necessary maturity levels. Embracing technology such as additive manufacturing and 3D printing afford our development teams *reduced development cycle time* and *speed* to market. Previously these technologies were not available, and our leadership is committed to constantly modernising development and manufacturing technology with Industry 4.0 developments…" (Respondent A).

"Industry 4.0 technologies enables our leadership to embrace manufacturing trends and consumer behaviours rapidly, our Ford Ranger Pick-up truck has active collision avoidance software, a first in this segment. Leadership that allows the employees to connect customer desires with available technology is fantastic. Leadership who is central to all events, are either the leaders or the saboteurs (actively or passively) fortunately I have the privilege to work with a host of dynamic leaders both in the UK and South Africa for our prestigious brand. In the supply chain I have often experienced dynamic LSS teams constantly fighting leadership for momentum in DMAIC projects and also often leadership supporting their BB's and MBB's….." (Respondent B).

"All of us are required to take a lead in all our CI activities, we as leadership provide the tools and the resources to improve, maturity is the nett result when we sustain the improvements we champion and the KPI's we are entrusted to manage and improve. Simulation of designs before production and Big Data enables us already in terms of Industry 4.0 to provide customised solutions faster than previously with conventional physical test samples, we simulate, validate and deliver to the clients in short succession.…" (Respondent C).

"Automation allows for processes to become more stable and maintain sigma quality, Industry 4.0 have not been embraced comprehensively in our organisation but the senior management is evaluating and approving new technology proposals made by the staff frequently. Leadership in our organisation is central to all CI change methods, my current employer is a large multinational chemical supplier and competition is fierce, McKinsey and Company assisted our leadership's request to develop a recipe to become more innovative as a strategic imperative, which led to the establishment of a MBB Innovation functional role. The Innovation MBB or IMBB has full management and leadership support in our journey beyond basic LSS, our maturity is a direct result of brave and dynamic leadership…" (Respondent D).

"Technology improvements such as the ones presented in Industry 4.0 allows for rapid and repeatable production cycles, where the process quality is not known of a new technology solution does the costly redesign for failed projects often hinder further development resulting in 3 and 4 process designs occupying the place of design that requires 5 or even 6 sigma quality. As stated earlier process entitlement is what it is and Industry 4.0 with automation and real time measurement and process adjustments allows for higher process yields. Leadership in our client base across industries are largely focussed on developing capacity and capabilities in their CI journey few of them has matured to the inclusion of maturity models and rather because of a lack of knowledge instead of poor leadership. As a consultancy we often encourage our clients to progress first with LSS and expand to include components of DFSS for DMAIC projects requiring DMADV and we advise and support the rapid adopters and implementers of a maturity framework / CMM such as EFQM, MBNQA, Shingo and CMMI, etc... "(Respondent E).

"As stated earlier in our discussion with my previous employer we started with measuring capability maturity which was often derailed due to policy failure where no support and interventions were made when senior functional leaders did not support key process evolutions, this was frustrating and non-value adding to the CI practitioners. This is not the case at my present organisation, management and leadership has made it a KPI in the monthly reports and are always interested to know what the status of the most recent maturity level is. Industry 4.0 presents an exciting period for the IT industry, Artificial Intelligence and software that can analyse big data rapidly and make decision accordingly allows for speed and progress not previously thought possible, LSS yields are such as customer personalisation is one metric that is a direct beneficiary of reviewing customer purchases decisions, value, type and locations to predict future consumer behaviours, software is assisting executives with predictive analytics for both individual and clustered consumers…" (Respondent F)

"We use connected tracking as an example of Industry 4.0 integration for all our deliveries and we have options where clients can select to be tracking certain deliveries in real-time through RFID technology and GPS positioning, which interfaces with client ERP system and can also alert through EDI any potential delays or early deliveries through real time ASN's. Maturity is experience and knowledge combined which gives us speed or breaks our speed. Our clients are global players and make strategic decision on partnering with us or they need us to deliver all of their products on time and cost effectively whilst minimising risk, our LSS teams are constantly seeking (with their DMAIC approach improvements in cost reduction and speed improvements) customer satisfaction for us in the outcome of leadership applied effectively, otherwise what else are we doing here…" (Respondent G).

“We have programs that develop our leadership maturity, without developing leadership capability maturity, organisation capability maturity will not be attained or sustained, organisation DNA depends on culture and value creation, we have regular set sessions where we review DMAIC project progress such as financial and customer retention metrics, customers in the insurance business can be very loyal when they are treated as valuable and also in turn do significant damage through social media when they are aggrieved and not treated with the necessary professionalism, our staff motivation is linked to product design and delivery, it’s easy to sell great products, DMAIC allows us to make products offered by our competitors more innovative and rewarding for our clients, maturity is sustained effort and strategy, leadership supports and values maturity. Disruptions are anticipated in our industry where autonomous driving will result in a rapid decline in road accident claims and also the repair industry will be affected, Industry 4.0 technology will enhance our predictions for claim probabilities through increased real time risk profile adjustments and in turn also reward clients who have proven through Big Data analytics to be more responsible than others…” (Respondent H).

“Money has become a commodity and the differentiator in banking is client retention and relationship management, we…”have several developmental programs internally and also partnering with universities locally to develop leadership skills for our managers, some skills come naturally and we have learned similar to management techniques these can be taught and rehearsed, the maturity of our leadership is a major contributor into improving our banking capability maturity. The advent of a number of cryptocurrencies will be impacting on our revenue streams which allows for more suppliers to enter the market. Our investment division is already using Industry 4.0 AI software and quantum computing logic to determine buy and sell decisions faster and increasingly more accurate than our most talented brokers” (Respondent I).

“Being one of the largest fleet operators we are always looking to find ways to improve, LSS in DMAIC projects highlighted our lack of project management skills and low project management maturity. Industry 4.0 has not really been absorbed or the associated potential impacts studied at our organisation. Management identified requests from Black Belts that not only the BB’s but also GB’s in support functions required a higher level of project management skills.

Leadership which rapidly responds to organisational change management program deviations is not possible with organisational maturity, twenty years ago we would have told the teams solve your own problems, these days we are listening to our employees and clients much more attentively, we have become more mature and our sustained profitability attests to our ability to listen, interpret and respond timeously…" (Respondent J).

"Autonomous planes is a reality in waiting and developments are more advanced than most people are aware of. Quantum computing and process technology speeds are key drivers in software development that can actuate and respond to necessary required weather and aircraft dynamics. Most pilots train for years to achieve proficiency as commander of a commercial or military aircraft, software is not commercially available to replace these highly skilled individuals and we see an evolution of HMI where pilots will in the near future actively fly with AI in the cockpit, Industry 4.0 is integral to our future strategy. We design and simulate and perform infinite test to validate Murphy without risking human lives. Our manufacturing supply chain and partners are already producing aircraft parts with 3D printing devices at a fraction of the speed and cost usually associated with such components. Aviation is a high precision, high performance and competitive landscape, combined with our weapons aviation divisions it poses a real challenge to remain at the top of the bidding ladder, we really have less than a dozen global players and we are all competing for the same clients. Commercially we see the Chinese also developing their own commercial and military aircraft and bidding for space program tenders. The challenge to our leadership is real and changing constantly, we have to be good technically, and leadership results have to be brilliant in innovation often the key differentiator when costs are not on our side. Our maturity determines our innovation curve and program delivery to remain relevant and competitive, CMMI and Agile additions to our organisation have proven to reduce development costs and time, a great idea that you do not industrialise rapidly remains just that, a great idea…" (Respondent K).

"Industry 4.0 developments are used within our development teams, where they simulate drug manufacture and some consumer test potential outcomes before seeking animal and later human trials. What is amazing in predictive analytics that when the software makes a mistake in a prediction, once updated with the new test results, it rapidly assists the teams in modifying the DOE and through reduced test cycles can accelerate product development. The culture of the organisation and the nature of our business with significant medical compliance and drug testing routines dictate responsibility to both the drug companies we produce for and also the consumer of the medicines, leadership and ethics in our industry needs a sustained symbiotic relationship, margins are only possible and sustainable through constant improvement in developing new innovative products within the framework of maturity, improvements upon improvement are required once a new innovative product has passed all the legislative testing and then efficiency determines ROI when combined with sales…"(Respondent L).

"Industry 4.0 for us is limited to automation in our processing facilities, it does reduce labour cost and safety in some areas is assured due to no human host contacting with sensitive food types. Senior leadership nurtures and support the lower levels of leadership. Establishing and maintaining the CSF's for your organisation within your specific industry is often a significant evolution, fine tuning design, processing and distribution can be realised economically when organisational maturity is established, leadership paves the way without question…" (Respondent M).

"JIT and low, but the correct, stock volumes are results of careful planning, with Industry 4.0 technology production cycles and runs are tailored to consumer need and not warehousing or stock holding aggregate demand. Lean becomes increasingly possible due to real time tracking of deliveries. Industry 4.0 enables JIT with greater accuracy. We are evaluating automated parcel picking/selection in our warehouses for forklift trucks directed by the arrival of delivery vehicle ID technology and the shipment collection where a cost benefit study is underway with one of our teams. This is done by people at present, it will lower our production cost and increase the speed of dispatch. Our managers are expected to deploy strategy based on aggressive quarterly targets, these are only possible when you are running, when we have many mistakes and customer complaints we slow down, lose customer and money. Leadership needs to monitor the KPI's but more than this need to coach employees in responding almost autonomously to market needs, by the time we see and react the opportunity is lost and maturity of our staff in their jobs provides an edge and customers appreciate employees who are empowered to answer their needs immediately without constantly seeking permission from another person, that does not work anymore, our LSS teams work with similar levels of autonomy…" (Respondent N).

“Industry 4.0 is already changing the way we design, develop and manufacture products and goods. Our manufacturing divisions are automating everything that has a quality risk, LSS is not an option, clients want zero defect and cost effectiveness. Industry 4.0 in our organisation has 4 distinct focus functional areas for now being: Production, Research and Development, IT and Maintenance. Leadership, it starts with us and it ends with us, employees require a framework to belong and function within, we can extract significant higher levels of performance when we enable and empower these individuals and also teams. Maturity is an outcome over time, it’s never quick and it requires regular review and sometimes organisational course correction. When we have no stability in new projects the maturity is low, DFSS are allowing us to launch new products with much more stability, and previously it was harder and more expensive…” (Respondent O).

“It’s everywhere, we embrace it, at every opportunity and included in our DMAIC approach, if we can automate cost effectively, we implement such technology rapidly. Connectivity in our maintenance teams when engaged with Condition Based Maintenance of fault finding using their electronic Tablets for diagnostics and communication to the status and extent of repair.

We are in particular excited by the advent of GDIA, which in essence allows big data from all facilities and all suppliers value chains to visualise the flow, the cost and effectively allows real time benchmarking within our group of global plants, previously this would take a team months, knowledge sharing and access to information enables us to be more competitive cost effectively.

Our Automation continues with increased use of robot technology and the most recent introduction is automated paint inspection and diagnostics through camera inspection previously done by humans and only 40% effective. The computer driven camera solution compares the image, rapidly by means of comparing digitised observation image to master data and with the aid of an algorithm makes a decision to accept, reject and also adjust in real time the necessary process parameters to reduce failures and rework cost, increasing speed, flow and ultimately customer satisfaction metrics…” (Respondent P).

It is possible to deduce from analysis of Research Objective 4 that leadership influences organisational ability to achieve capability maturity. Leadership responses are furthermore seen in survey results from Figure 37 and also divided where 34.72% respondents confirm those actively evaluating Industry 4.0 opportunities whereas the majority of the survey respondents 62.5% are not actively pursuing Industry 4.0 technology opportunities as part of their corporate strategy. Almost every interviewed respondent with the exception of respondent J are in various stages of implementing and evaluating Industry 4.0 opportunities to complement LSS and DFSS CI programs. The interview responses reflect Industry 4.0 absorption as a matter of course and also report improving organisational relevancy and maturity in combining technology and innovation. Leadership that is not aware of the impact of Industry 4.0 in the supply chain risk losing out on quality and speed to market opportunities and in turn reduces the capability maturity.

5.8 Data presentation and analysis: Research Objective 5

How will an integrated framework assist organisations to achieve capability maturity?

Questions relevant to the establishment of how an integrated framework can and will assist organisations to achieve capability maturity are seen in Table 20, which deal with questions 5,6, 24, 34-36, 38 and 40.

Figure 38 identifies the respondents in the survey distribution of CIM maturity model distribution in a histogram that shows (as established in Research Objective 3) that only 18,1% of the respondents reported are not using any of the integrated maturity frameworks.

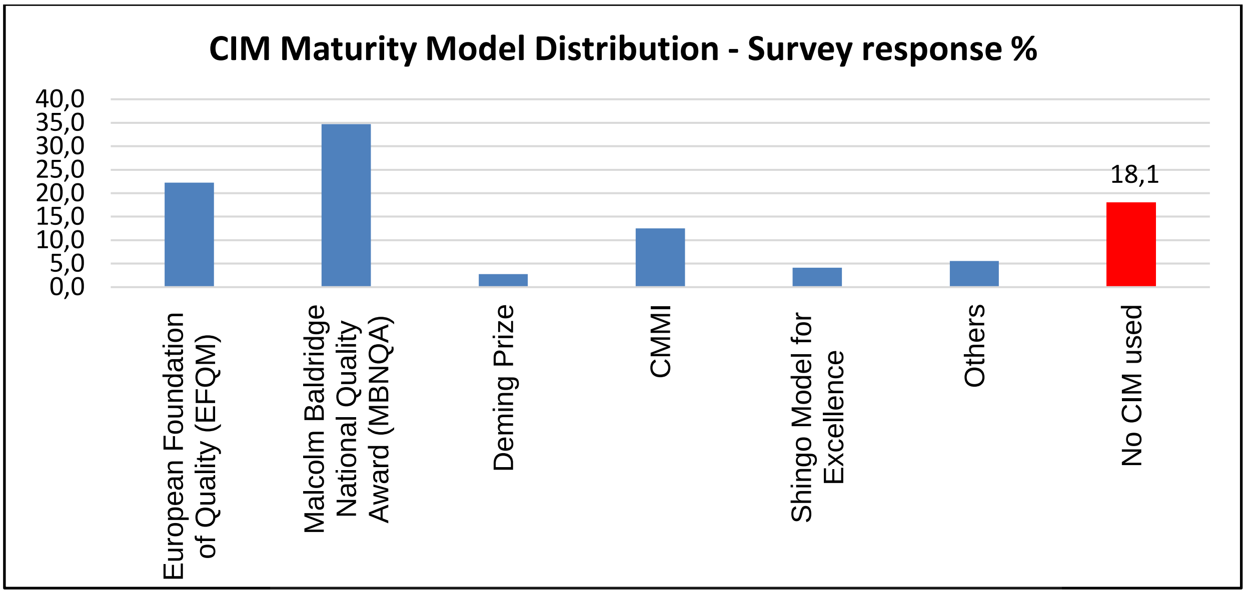

Figure 38: CIM Maturity model histogram - % of survey respondents by maturity model.

The interviewees were also asked how an integrated Capability Maturity Model assists organisations in their journey in achieving Capability Maturity.

The representation across the spectrum of respondents reveals that 81.9% of the respondents measure CIM Maturity with the inclusion of a known capability maturity model as seen in Figure 38 and 18.1% are not using any type of reference maturity framework. It is observed that LSS and DFSS maturity is not measured and tracked by all of the respondents and could be extended for future research.

In survey Question 7 evaluating Research Objective 2 – it was observed that DFSS Integration shows a significant distribution skewed towards DFSS integration, only found in 15.3% of the organisations, which suggest lower levels of CMM maturity, possibly only Level 1 or 2 observed in survey and interview responses.

Resources deployed:

In review of question 8 and 9 earlier in this Chapter under Research Objectives 1 and 2 it can be seen in the following two graphs that both a large number of part time but also full time resources are reported to be deployed industry respondents. The data is important because it demonstrates the commitment and effort with trained resources deployed to improve the organisations in the operations.

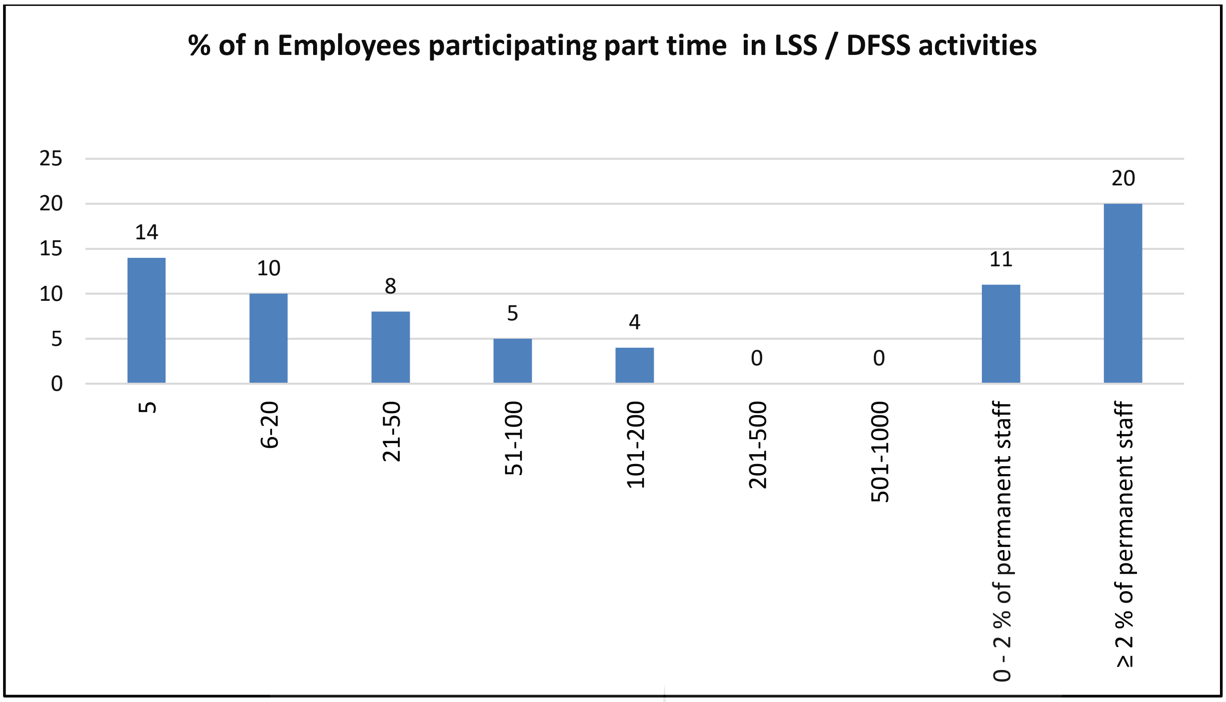

Figure 39: Percentage resources deployed for LSS and DFSS activities.

Figure 40 (on page further on) represents and revisits question 9 stating how many full time resources (BB's and MBB's) reported to be deployed in LSS and DFSS projects.

During the interviews it emerged that respondents A, B, E, F, N and K reported collectively in similar fashion that initially, when they launched their LSS and DFSS CI programs, **dedicated resources was not an** integral part of the CI strategy with dual job portfolios often being occupied by the BB's and MBB's where this was expectation rather than the exception but with time and high yield Belt projects delivering ROI in LSS and DFSS projects were strategic decisions made that suppported resource allocation for dedicated full time CI practitioners. "BB's have shared responsibilities but MBB's are dedicated resources….." (Respondent P).

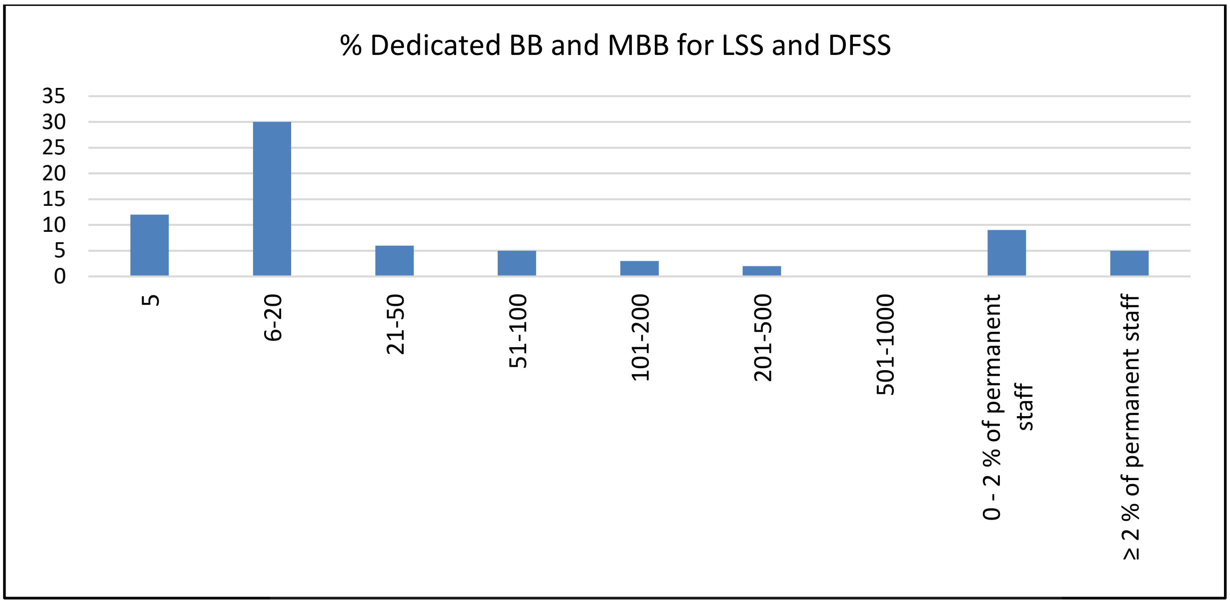

Figure 40: Survey responses - % Dedicated resources deployed for LSS and DFSS activities.

Total HR resources in terms of all Belts, Yellow, Green, Black and Master Black Belts see a shift to as high as 20% of total organisational staff reported by some respondents in Figure 35 participating in LSS / DFSS projects.

Questions 34-36, 38 and 40 are Likert scale type questions with the median scores 4 and above and mean scores between questions ranging from 3,389 in question 36 to 4,6389 for question 35 displayed in Table 42.

Table 42: Research Objective 5 Descriptive statistics Mean and Standard deviation.

Descriptive Statistics: Q34; Q35; Q36; Q38; Q40

Variable	N	N*	Mean	SE Mean	StDev	Variance	CoefVar	Sum of Squares	Minimum	Q1
Q34	72	0	4,3750	0,0802	0,6805	0,4630	15,55	1411,0000	3,0000	4,0000
Q35	72	0	4,6389	0,0635	0,5388	0,2903	11,61	1570,0000	3,0000	4,0000
Q36	72	0	3,389	0,147	1,251	1,565	36,91	938,000	1,000	2,000
Q38	72	0	3,9167	0,0984	0,8350	0,6972	21,32	1154,0000	2,0000	4,0000
Q40	72	0	4,3056	0,0730	0,6198	0,3842	14,40	1362,0000	2,0000	4,0000

Variable	Median	Q3	Maximum	Range	Mode	N for Mode	Skewness	Kurtosis
Q34	4,0000	5,0000	5,0000	2,0000	5	35	-0,63	-0,66
Q35	5,0000	5,0000	5,0000	2,0000	5	48	-1,14	0,31
Q36	4,000	4,000	5,000	4,000	4	27	-0,43	-0,94
Q38	4,0000	4,0000	5,0000	3,0000	4	43	-0,89	0,66
Q40	4,0000	5,0000	5,0000	3,0000	4	41	-0,67	1,40

Table 43: Research Objective 5, Descriptive statistics for Pearson correlation.

Covariances: Q38; Q34; Q35; Q36; Q40

	Q38	Q34	Q35	Q36	Q40
Q38	0,697183				
Q34	0,454225	0,463028			
Q35	0,321596	0,278169	0,290297		
Q36	0,906103	0,739437	0,579030	1,564945	
Q40	0,377934	0,334507	0,224570	0,597809	0,384194

Correlation: Q34; Q35; Q36; Q38; Q40

	Q34	Q35	Q36	Q38
Q35	0,759			
	0,000			
Q36	0,869	0,859		
	0,000	0,000		
Q38	0,799	0,715	0,867	
	0,000	0,000	0,000	
Q40	0,793	0,672	0,771	0,730
	0,000	0,000	0,000	0,000

Cell Contents: Pearson correlation
P-Value

Questions 34-36, 38 and 40 all display a strong positive relationship where the Pearson values for *r* are all above 0,5 and range from r = 0.672 for questions 35 and 40 to r = 0.867 for questions 36 and 38. A linear relationship is observed in all of the questions and no outliers are present in the calculated results.

Questions 34 -36, 38 and 40 subjected to Spearman's rank-order correlation which was performed in assessing the interaction between these questions 34 -36, 38 and 40 from the target group of 72 respondents. There was a moderate positive association between all the questions which is statistically significant, rho values range from 0.611 to 0.872.

In addition the questionnaire was also employed to measure the construct, how an integrated framework can assist organisations achieving maturity capability, which consisted of five questions. The results achieved with Minitab displayed a strong value of internal consistency, as determined in the Cronbach's alpha as well as the tau-equivalent reliability calculation of 0.9238 seen in Table 44.

Table 44: Research Objective 5 Descriptive Statistics for Cronbach's alpha.

Item and Total Statistics

Variable	Total Count	Mean	StDev
Q34	72	4,375	0,680
Q35	72	4,639	0,539
Q36	72	3,389	1,251
Q38	72	3,917	0,835
Q40	72	4,306	0,620
Total	72	20,625	3,609

Cronbach's alpha = 0,9238

Omitted Item Statistics

Omitted Variable	Adj. Total Mean	Adj. Total StDev	Item-Adj. Total Corr	Squared Multiple Corr	Cronbach's Alpha
Q34	16,250	2,992	0,8873	0,7959	0,8959
Q35	15,986	3,151	0,8266	0,7434	0,9158
Q36	17,236	2,412	0,9355	0,8947	0,9128
Q38	16,708	2,865	0,8610	0,7696	0,8944
Q40	16,319	3,094	0,8003	0,6629	0,9133

During interviews held with all interviewees they were asked how an integrated framework would assist organisations towards maturity capability which was reported as follows:

"It certainly will identify your progress towards attaining strategic goals and these will be decided by senior management, I am sure it could assist us although we are not currently using a maturity framework only our KPI's….." (Respondent A).

"We do use an integrated maturity framework, it is relative, as long as we improve….." (Respondent B).

"We do not have an integrated framework but it should help but we are confident we should first understand where we need to build required people capacity before we can extend the CI program and increase our capability maturity…" (Respondent C).

"Not required, as long as we improve our set of KPI's. It is true though that almost any framework and in particular EFQM and CMMI offers the tools to score and evaluate your maturity and also lack of maturity through stating the areas where improvement is required…" (Respondent D).

"We have achieved a number of industry milestones when we started our CI journey but we did not make good progress at a variety of stages for a variety of reasons but with the help of an external consulting firm we embarked on implementing the EFQM model, which really made a difference to our progress made, especially with lower level Belts and other functional areas…" (Respondent E).

"We are using CMMI and it made little difference in the early stages to our rapid growth and CI strategy. With our increased resource allocation for CI projects and the regular review of progress against target it has become increasingly clear customer delight is only possible through details questioning yourself and your supply chain in terms of what does the customer want and herein we developed faster project delivery times when Agile and Scrum training for project leads became the norm. We could deliver accurately and on time and CMMI was highlighting project delivery and development of core competencies in this functional are …" (Respondent F).

"We are part of a large multinational and we follow a framework developed by a contracted external consultancy which is based on EFQM but adapted for the transport industry…" (Respondent G).

"As a major insurer we need to benchmark our processes such as client management for the variety of product and services provided, we also need to use a platform to measure ourselves against our competitors and we have a system in place based on CMMI but not as detailed as set out in CMMI with the intrinsic SCAMPI audits which I am familiar with although it is very tough to reach level 4 let alone level 5…" (Respondent H).

"We do not use a model, we could benefit, not sure which model we could use and also as a result of multiple mergers and ownership changes in the past two decades CMMI may be a consideration, we do have colleagues from other banks who have suggested we evaluate a maturity framework…" (Respondent I).

"Maturity models are valuable in identifying what the current status quo is and we could benefit over and above consolidating Black Belt projects and compare ROI's achieved. I am not sure which model we could follow.…" (Respondent J).

"We are using CMMI, without it we would not know where we are in either product development life or market cycles. We also contractually insist on CMMI maturity level 3 compliance for our supply chain, without the necessary maturity they put us at risk and we are all about risk. Nurturing brand name and our products are supplied from a variety of sources in the supply chain which includes hardware, software and integrated software solutions…" (Respondent K).

“The pharmaceutical industry is governed by a host of legislation which includes ISO standards and those set by the brands we manufacture for, as a contract pharmaceutical manufacturer we are constantly subjected to legal and client audits, which also provides us with a rating of compliance to the set standard. A framework for achieving capability maturity may assist us in improving, not sure what is required…” (Respondent L).

“Yes it does, the impact is not immediate upon implementation, it takes time to manifest, develop capacities and capabilities take time and resources and such a framework is constantly re-evaluating KPI’s for people, products and processes throughout its life cycle. We have adopted the EFQM model and being a multinational producer of a variety of FMCG products also subjected to stringent HACCP requirements…” (Respondent M).

“A maturity framework was developed by an external party and it is used for evaluating our KPIs which is part of our DNA moving millions of parcels daily across the globe, time is money and you can’t afford to miss the boat, we are competing against other global industry participants and you are as good as your last delivery. We also monitor site performance in a variety of KPI’s and their scorecards are compared to support lower levels of desired performance with rapid action…” (Respondent N).

“It is simply another form of audit to comply over and above the regular ISO management standards with a set of desired best practices, we started out with CMMI at level 2 few years back but have matured to level 4 with a total overhaul of our HR, Payroll and customer satisfaction metrics, we also see the benefit in customer satisfaction KPI improvements since inception…” (Respondent O).

“We focus in the FPS (Ford Production System) on the inputs of all our processes, we have the following Pillars S, Q, D, C, M, M and E which is shown in Figure 41. This basic composition of Lean Tools complemented by Time and Data management visualises KPI’s and allows us to focus on the exceptions rather than all the data.

In addition we are constantly benchmarking with our other plants and have improved our Things Gone Wrong (TGW) per 1000 vehicles from 3rd worst quality globally in 2012 to number 1st in quality in 2017.

We also observed in our Lean metrics certain staff was failing repeatedly, which is not the case in our other plants until we identified a gap in people capability maturity and we developed a screening test to complement our recruitment and selection process called TTS. Now we are seeing people capability closing the process performance gaps previously unresolved, recruitment for personality is as important as for other skill sets to maintain the necessary cadence in Kaizen in the plant…" (Respondent P).

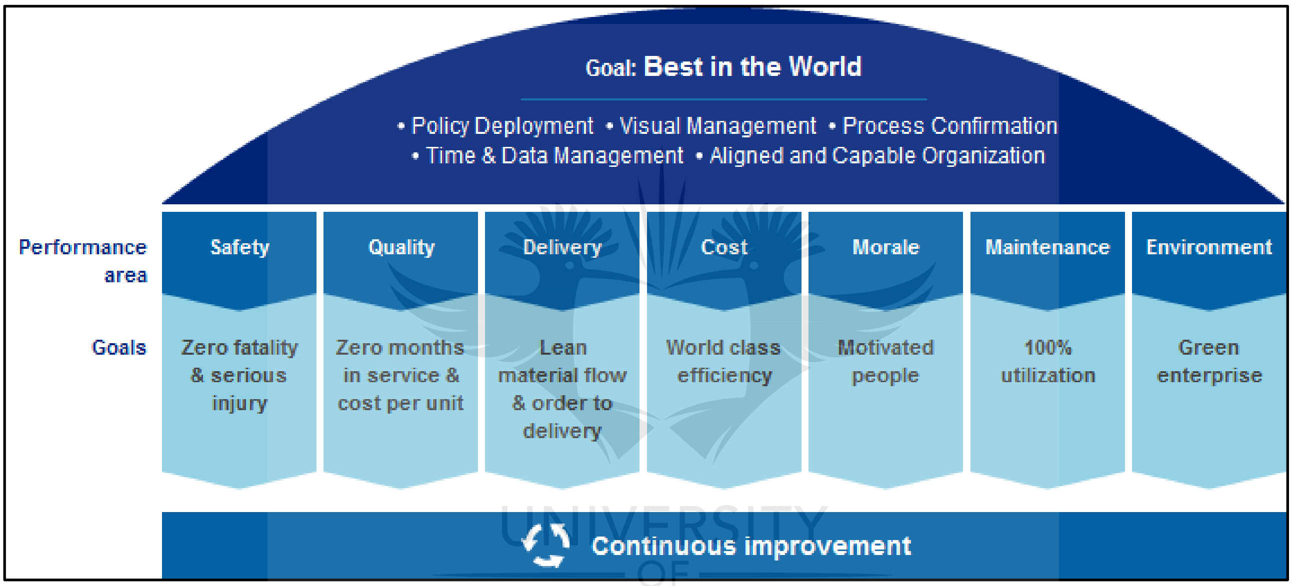

Figure 41: Ford Production System incorporating Lean, Six Sigma and Design For Six Sigma by Pillar / Performance area.

From the interviews it can be established that 6 (37.5%) of the 16 interviewees do not currently use a maturity framework but even among those 5 of the 6 is of the opinion that a maturity framework could assist their organisations to achieve improved LSS and DFSS results through the inclusion of an integrated framework in the CI strategy.

5.9 Business Process Maturity Capability Model (BPMCM)

As discussed in the Literature review previously in Chapters 2 and 3, Capability Maturity Model (CMM) is a development model created as a result of study conducted from organisations that were contracted to the US Department of Defence who initiated the study and provided the funding in 1989 [observed in Humphrey, W.S. (1993)]. During the preceding period of development it was obvious that mature level 5 design and product development was not achieved at the place of work, which was a significant motivating factor for Humphrey, W.S. (1993) to develop CMMI [confirmed in Dwolatzky, B. (2017)]. The model originated within the software industry but found wider applications within other business fields. The precursor of staged maturity model within the IT industry was observed and Nolan, R.L. (1973) who documented the stages of a growth model for IT organisations and projects. The first model that followed by Humphrey, W.S. (1993) was developed over the 27 years he worked at IBM. The final product was developed from an Air Force study to use objective evaluation from software subcontractors' process capability maturity and this first model was derived using the Maturity Grid developed by Crosby, P.B. (1979) in *Quality is Free*.

Where Humphrey's approached differed from Crosby was his approach as based on staged evolution of software development practice rather than measuring maturity of each separate development process independently. The respondents in both the survey and the interviews were asked several questions relating to both Capability Model integration and CI program maturity measurement. Table 45 summarises both survey responses and interviewee responses relating to the prominence of Capability Model integration and the classification of others, included categories both "none" and "other models" showing the prominence of BPMCM for 18.94% for survey respondents and interviewees 31.25%.

Table 45: Combined Maturity Capability Model deployment for survey target group and interviewees.

BPMCM	% Survey respondents	% Interviewee respondents
(EFQM)	22,22	12,50
(MBNQA)	34,72	6,25
Deming	2,78	0,00
CMMI	12,50	25,00
Shingo	4,17	0,00
No CMM	18,06	31,25
Others	5,56	25,00

A larger sample may change the results recorded in Table 45 and the relevance of Table 46 can provide input for further future research. The results of the summary of Quality Systems, CI methods and CMM deployed in Table 46 will be discussed in concluding part of Chapter 5 and the contribution towards capability maturity.

Table 46: Summary of Quality Systems, CI methods and CMM deployed by interview respondents.

Research respondent	Functional Role	Industry	Capability
A	Master Black Belt and Opex	Automotive	LSS, DFSS, CMM, IATF 16949 / ISO 9001
B	Master Black Belt and Quality Director	Automotive	LSS, DFSS, IATF 16949 / ISO 9001
C	Supply Chain Director	Packaging	LSS, IATF 16949 / ISO 9001
D	Master Black Belt	Chemical	LSS, DFSS, IATF 16949 / ISO 9001
E	Master Black Belt	Consulting	LSS, DFSS, CMM, IATF 16949 / ISO 9001
F	Black Belt	IT	LSS, DFSS, CMM, Agile / Scrum, IATF 16949 / ISO 9001, ITIL / ISO/IEC 20000
G	Black Belt and Operations Director	Transport	LSS, IATF 16949 / ISO 9001
H	Master Black Belt	Insurance	LSS, DFSS, IATF 16949 / ISO 9001
I	Black Belt	Banking	LSS, IATF 16949 / ISO 9001
J	Master Black Belt	Fleet	LSS, IATF 16949 / ISO 9001
K	Master Black Belt	Aerospace	LSS, DFSS, CMM, Agile / Scrum, IATF 16949 / ISO 9001, ITIL / ISO/IEC 20000
L	Master Black Belt	Pharmaceutical	LSS, DFSS, IATF 16949 / ISO 9001
M	Master Black Belt	Food	LSS, DFSS, IATF 16949 / ISO 9001
N	Master Black Belt	Logistics	LSS, DFSS, IATF 16949 / ISO 9001
O	CEO	Manufacturing	LSS, DFSS, CMM, IATF 16949 / ISO 9001
P	Vice President Operations	Automotive	LSS, DFSS, CMM, IATF 16949 / ISO 9001

LSS -
DFSS -
CMM -
Agile / Scrum -
IATF 16949 / ISO 9001 -
ITIL / ISO/IEC 20000 -

It is observed (when combining the two research groups) that the CMMI responses are largely originating from the integrated manufacturing and IT industry respondents whereas EFQM and MBNQA are largely representative of all types of produce and manufacturing industries and also supports observations in reviews by Maier *et al.* (2010).

It can be observed that the varying percentage can be attributed to the smaller sample size evaluated for interviewee respondents as opposed to the survey respondents. The interviewed candidates were also largely based in South Africa whereas the survey included respondents from across the globe.

Technological and computing integration of systems and Human and Machine Interfaces (HMI) as a result of Industry 4.0 is necessitating a revisit of the existing strategy for the implementation of a CI maturity model. This process creates uncertainty navigating the range of diverse requirements by a variety of bodies. The review of these diverse requirements is seen in Moore, J.W. (1999) or a taxonomy of improvement frameworks in Halvoren, C.P. and Conradi, R. (2001), and Paulk, M.C. (2008).

Another taxonomy suggested by Paulk, M.C. (2008) pertains to management philosophies, such as ISO 9000 QMS and Total Quality Management relationship with EFQM and MBNQA CMM's. Herein CMM's are reported and classified for deployment as both tools for assessing maturity and improvement. QMMG reviewed in Chapter 2 depicts early CMM emerging contribution to visualise and quantify maturity through a scale of capability.

Becker *et al.* (2009) proposed a recipe for maturity framework development in a structured approach in comparing six maturity models for the management of organisations, whereas Mettler, T. and Rohner, P. (2009) proposes the management and setting of parameters that govern the processes. Whilst Kohlegger *et al*. (2009) proposes a hybrid constructed from 16 different maturity models and Van Steenbergen *et al.* (2010) proposes a set of questions leading emergence of modern CMM's. Maier, et al. (2012) through the scoping the basic constructs of these models proposes CMM assessments and regular review and support of their maturation phases.

The framework the author proposes with this research document using PDCA in ISO 9001 as the basic Lean tool and in the development of a CMM for the successful deployment of LSS and DFSS is *additional support for organisational approach and maturity* found in research conducted by Beardsley, (2005) when researching and designing joint implementation of CMMI and Six Sigma. The research conducted by Beardsley, (2005) further suggests that four different paths can be considered with a joint approach as a starting point for CMMI and LSS deployment and performance.

The researcher also proposes the substitution of LSS with TLS and combines it, similar to TLS observed in Hohmann, C. (2014), constituted from the constructs of incorporation of TOC + Lean + Six Sigma reported previously in both Chapters 2 and 3.

The Industry 4.0 framework towards capability maturity starts with one of two evolutionary combinations (TLS and CMMI) to be further adapted in Chapter 6 with the staged inclusion off

ISO Standards in current use or draft format observed in requirements for sustainability, innovation, DFSS, Agile and Scrum, QFD, Systems and software engineering, PDCA updated ISO 9000 series and Information technology security management.

Initial framework towards capability maturity considers four paths for capability maturity framework in combining CMMI with Six Sigma in Beardsley, G. (2005) in Figure 42 which represents stage 1 of integrated framework design.

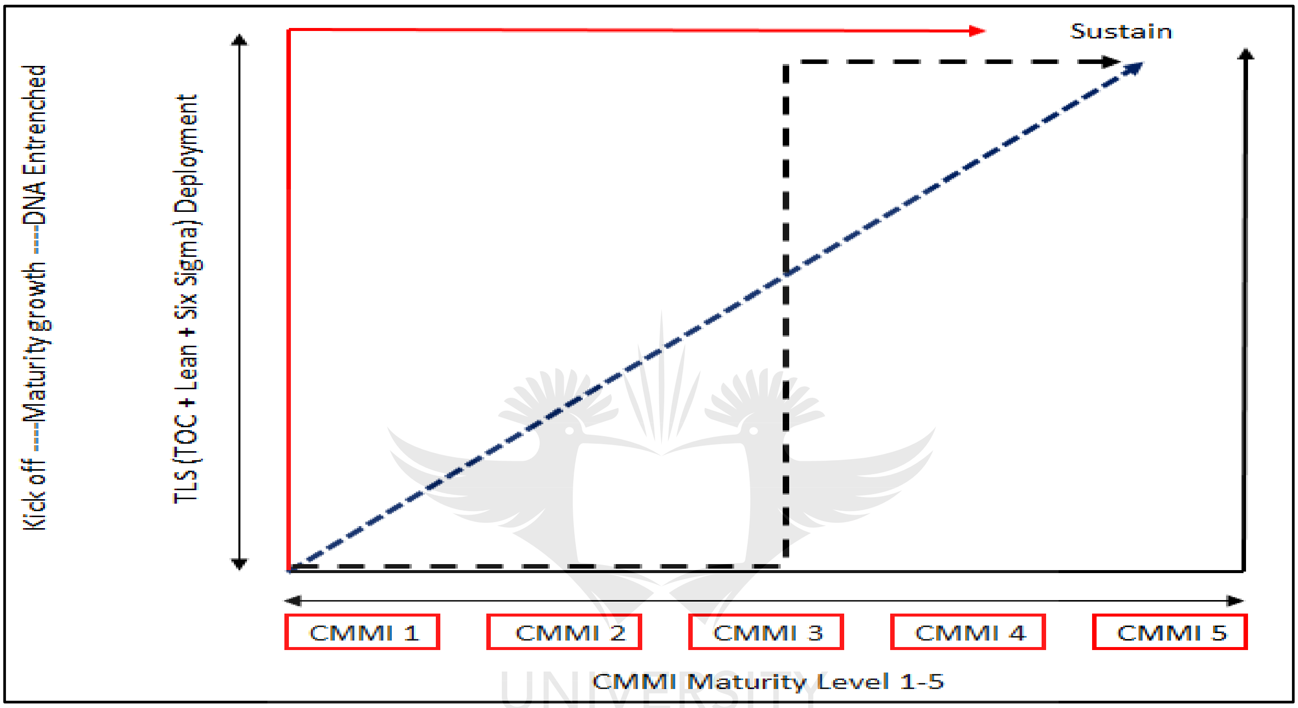

Figure 42: Design of integrated framework stage 1 - CMMI and TLS implementation scenarios adapted from Hohmann, C. (2014) and Beardsley, G. (2005) model.

Scenario 1: Black solid line –Identifies the CMMI to implementation to high maturity and then TLS and here the CMMI is observed as central to organisational governance in both modelling and TLS methodology used only in isolation to assist with implementation within specific processes and disciplines. Once high maturity is reached TLS is formally adopted as the process for the continuation of CIM.

Scenario 2: Red Solid line – Organisation institutionalises TLS to maturity followed by CMMI. With this approach TLSS becomes the model of order with CMMI and other supporting improvement standards selected to eradicate unwanted process deviations.

Scenario 3 – (Blue dash): Simultaneous implementation and institutionalisation CMMI and TLS from inception and the two initiatives alternate as governance model. Example observed here is TLS leads organisation to deploy selected CMMI areas which dictates a Lean process infrastructure. CMMI could provide leadership to the organisation to rapidly identify CSF's and opportunities for TLS frameworks.

Scenario 4 – (Black Dash): CMMI is implemented to level 3 followed by TLS roll out and joint implementation. This path requires that the organisation first establishes its defined processes (similar to ERP and ISO 9001 implementation) and then extracts the TLS tools for the achievement of high maturity.

The author finds further support in Beardsley's (2005) examination of question through joint deployment and the strategic advantage or TLS first, then CMMI or vice versa or tandem implementation. The research suggests that the choice of path to pursue depends mostly on the organisation's circumstances and in particular organisational maturity capability when deciding to deploy synergistic, rather than parallel or independent implementation.

The research conducted by Beardsley, G. (2005) was aimed at the software industry and does not consider what initiatives are already manifested in the organisations outside of software development. The researcher will elaborate on the CSF's in managing TLS and DFSS projects. Further research conducted displays high levels of failures in TLS projects in the face of international and multiple industry comprehension of the predecessors and CSF's necessary for successful TLS and DFSS deployments. Program failures remain common but are abandoned prior to reaching any level of maturation within an organisation "When they are making money even without LSS or DFSS deployments, it is very hard to convince leaders to do differently or persist with LSS or DFSS deployments and advance CI with increased maturity…"(Respondent E)

Significant LSS program deployment successes are reported in both literature and research results obtained from this research document and summarised in Table 55 constructed from inputs obtained during the interview reports and literature reviews in Carleton, S.A. (2016); Harry, M.J. et al (2010); IsixSigma.com (2017); European Six Sigma Club; German Six Sigma organisation; BMGI, McKinsey and Company; and PWC consultancies.

Various reasons exist for failures in LSS and DFSS projects compared to general project failures which are often common. The CSF's identified are not failure causes but there are factors that can assure success (but also inversely cause delays and even contribute to total project failure) observed in research in Anbari, F.T. and Kwak, Y.H. (2004), Harry, M.J. et al (2010) and Carleton, S.A. (2016) exploring key contributing factors responsible for failures. All of these authors concur that CSF's identified in previous literature reviews and research results established in Chapter 5 offers a practical guideline for LSS and DFSS methodology implementation and sustainment. Furthermore these CSF's are based on extensive literature reviews, discussions with Six Sigma leaders at several organisations that have implemented the Six Sigma method, and observations of systemic improvement projects.

Anbari, F.T. and Kwak, Y.H. (2004), Harry, M.J. *et al* (2010) and Carleton, S.A. (2016) carefully analyse and synthesise the lessons learned from successful management of Six Sigma projects and their potential applications in managing traditional projects. It considers further improvements to the methodologies used for managing Six Sigma projects, and addresses wider applications of these promising practices to organisational change management. Safty, S.E. (2013) and also Wasage, C. (2017) also discuss challenges, shortcomings, obstacles and pitfalls in the application of the Six Sigma method. It charts a course for further research into this important area of roles and responsibilities during LSS deployments but also project management whilst reinforcing CSF's necessary for LSS deployments and also more advanced TRIZ and DFSS methodologies.

Tables 47, 48, 49, 50, 51, 52, 53 and 54 (on the following pages 200-207) depict a summary of the widespread adoption of LSS for 400 prominent organisations and institutions. A more comprehensive list is available from the Six Sigma Institute (2017) where voluntary certification and program participation is recorded.

Further research could be applicable in comparing performance type DMAIC and also ROI/ROS metrics achieved, DFSS opportunities realised, Agile and Scrum KPI's and CMM status and respective maturity level.

The various performance areas and category of improvements are reported in Table 55.

What is noticeable in the results table and also confirmed by interview respondents A-H, K, L, N and O are their references to the increased use of DMAIC outside the typical quality and manufacturing domains such as project to shipment time and inventory metric reductions. Dow

Chemical made significant cost savings in the 2010-2014 financial period and also observed in Table 55 are the large numbers of global chemical companies deploying LSS successfully, including Clariant with the aid of a McKinsey and Company designed LSS BB and Innovation MBB CI strategy, realising savings of $144m in 2015 FYE from Six Sigma projects which represents typical saving compared to sales in excess of 2%.

Table 47: List of Companies with LSS programs T1-50

No	Company Name	Industry
1	3M	Industrial
2	Ab Inbev	FMCG
3	ABB	Industrial
4	Abbott Laboratories	Pharmaceutical
5	ABSA	Financial
6	Accenture	ICT
7	ADDITIVE	ICT
8	ADIDAS	Sports and Leisure
9	Adolph Coors	FMCG
10	Advanced Micro Devices (AMD)	ICT
11	Aegon	Financial
12	Aerospace Corp	Aerospace
13	Aetna	Insurance
14	AFM	Financial
15	AGCO	Industrial
16	Agfa Healthcare	Industrial
17	Agilent Technologies	Biotechnology
18	AIG (American International Group, Inc.)	Insurance
19	Airborne	Aerospace
20	Airbus	Aerospace
21	Alcoa	Resources
22	Allen Bradley	Electronics
23	Allied Signal, Ampex	Electronics
24	Allstate	Insurance
25	Alphabet Carlease B.V.	Financial
26	Alstom	Industrial
27	Amazon.com	Retail
28	American Express	Financial
29	American Standard	Industrial
30	Amgen	Pharmaceutical
31	Ammeraal Beltech Manufacturing B.V.	Industrial
32	Anglo American	Resources
33	ANWB	Logistics
34	Apple	ICT
35	Aramco Overseas Company	Industrial
36	Ardacon Consulting B.V.	Consulting
37	Argenta Spaarbank N.V.	Financial
38	ASML Netherlands B.V.	Industrial
39	Aspen Pharmacy	Pharmaceutical
40	ASQ	Society
41	AT&T	Telecommunications
42	Auto Body Shops	Automotive
43	Autoliv	Automotive
44	B/E Aerospace	Aerospace
45	BAE Systems	Aerospace
46	Bank of America	Financial
47	Bank of Australia	Financial
48	Bank of Montreal	Financial
49	Bank of New York Mellon	Financial
50	Barclays	Financial

Table 48: List of Companies with LSS programs T51-100

No	Company Name	Industry
51	Barloworld	Diversified
52	BASF SE	Chemical
53	Baxter Pharmaseal	Pharmaceutical
54	Bayer	Healthcare
55	BD Kiestra	Industrial
56	BD Medical	Industrial
57	Beatrice Foods	FMCG
58	Bechtel corporation	Construction
59	Bell Helicopter	Aerospace
60	Berkshire Hathaway	Insurance
61	Binckbank N.V.	Financial
62	BIS Industrial Services	Industrial
63	Black & Decker	Industrial
64	BMW	Automotive
65	BOAL Group	Industrial
66	Boeing	Aerospace
67	Bombardier	Aerospace
68	Borden	FMCG
69	Borealis Kallo N.V.	Chemical
70	Bosch Transmission Technology B.V.	Automotive
71	BPFbouwinvest	Financial
72	Brembo	Automotive
73	Bridgestone	Diversified
74	British Petroleum	Energy
75	Briks advies	Services
76	Bristol Meyers – Squibb	Pharmaceutical
77	British Airways	Airline
78	British Telecom	Telecommunications
79	Brunel	Consulting
80	Bryn Mawr Hospital	Healthcare
81	Bureau Tromp	Consulting
82	Callaway Golf	Sports and Leisure
83	Canon	Diversified
84	Carl Zeiss AG	Industrial
85	Caterpillar Inc.	Industrial
86	Cellular 1	ICT
87	CHEP Benelux N.V.	Logistics
88	Chevron	Energy
89	Chevron Phillips Chemical Company	Chemical
90	CIGNA	Insurance
91	Citicorp	Financial
92	City of Austin and Dallas, TX	Government
93	Clariant	Chemical
94	Clorox	FMCG
95	Coca Cola	FMCG
96	Computer Sciences Corporation	ICT
97	Concern voor Werk	Services
98	Conseco	Insurance
99	Consol Glass	Industrial
100	Continental Automotive GmbH	Automotive

Table 49: List of Companies with LSS programs T101-150

No	Company Name	Industry
101	Convergys	Services
102	Coolblue	Logistics
103	Cooper Tire & Rubber Company	Diversified
104	Coopervision	Healthcare
105	Council of	Government
106	Council of Kent County and North Ayrshire	Government
107	Credit Management & Investor Solutions B.V.	Financial
108	Credit Suisse	Financial
109	Cummins	Industrial
110	CZ	Financial
111	Damco	Logistics
112	Dannon	FMCG
113	De Baak	Consulting
114	De Lage Landen International B.V.	Financial
115	De processpecialisten	Consulting
116	Deere & Company	Industrial
117	Defense Mapping Agency	Services
118	DEKRA Certification B.V.	Services
119	DELA uitvaart en Levensverzekeringen N.V.	Financial
120	Dell	ICT
121	Delnosa (Delco Electronics in Mexico)	Industrial
122	Delta Lloyd	Financial
123	Denel	Defence
124	Denso	Automotive
125	Deutsche Telekom	Telecommunications
126	DHL	Logistics
127	Digital Equipment Corp	ICT
128	DJO Global	Biotechnology
129	Dow Chemical	Chemical
130	DPD N.V./S.A.	Logistics
131	Dr. W. Kolb Nederland B.V.	Industrial
132	Drivers Village	Automotive
133	DSV	Logistics
134	DTM Corp	Industrial
135	Du Pont	Diversified
136	Duma Travel	Services
137	EA Sports	ICT
138	Eastman Kodak Company	Chemical
139	Easyjet PLC	Aviation
140	Eaton	Industrial
141	eBay	Retail
142	Ecolab Inc.	Energy
143	ECT Delta Terminal B.V.	Logistics
144	Electric Power Sector	Energy
145	Electronic Systems Center	Services
146	Eli Lilly	Pharmaceutical
147	Elite Parking Services	Automotive
148	Elvia Reisverzekeringen	Financial
149	EMC Corporations	ICT
150	EOH	ICT

Table 50: List of Companies with LSS programs T151-200

No	Company Name	Industry
151	Ernest and Young	Consulting
152	European Six Sigma Club	Services
153	Evonik Industries	Industrial
154	Fagro	Consulting
155	Falkbeer Groep Business Consultants B.V.	Consulting
156	FedEX0	Logistics
157	Festo AG & Co. KG	Industrial
158	Fiat Chrysler Automotive	Automotive
159	Florida Dept. of Corrections	Services
160	FNB	Financial
161	Ford Motor Company	Automotive
162	FrieslandCampina Cheese & Butter	Food
163	Fujitsu	ICT
164	GEC Marconi	Electronics
165	General Dynamics	Aerospace
166	General Electric	Diversified
167	General Motors	Automotive
168	Glencore	Resources
169	Goldman Sachs	Financial
170	Greenway Automotive	Automotive
171	Grow Group	Food
172	GSK	FMCG
173	HAAS Automation	Diversified
174	Harvard University	Education
175	Hazeltine Corp	Electronics
176	Heemskerk	Food
177	Heineken	Food
178	Hellofresh	Services
179	Het Financiële Dagblad B.V.	Financial
180	Het Zuiderlicht	Consulting
181	Hewlett packard	ICT
182	HITACHI	Diversified
183	Honeywell	Diversified
184	Huawei	Telecommunications
185	Huntsman Corporation	Chemical
186	Illinois Tool Works	Industrial
187	Imperial	Diversified
188	Imtech Traffic & Infra	Services
189	ING	Financial
190	Intel	ICT
191	Intermedius	Consulting
192	Internet Solutions	ICT
193	Inventec	ICT
194	ISS Integrated Facility Services B.V.	Services
195	IT Infotheek	ICT
196	ITT Industries	Industrial
197	ITvisors	Consulting
198	JEA, Inc.	Energy
199	John Crane Indufil B.V.	Industrial
200	Johnson & Johnson	Pharmaceutical

Table 51: List of Companies with LSS programs T201-250

No	Company Name	Industry
201	Kaiser Aluminum	Industrial
202	Kempen Capital Management N.V.	Financial
203	Keyrail	Logistics
204	Kisuma Chemicals B.V.	Industrial
205	Kraft General Foods	FMCG
206	Kuehne + Nagel	Logistics
207	Kwik-Fit Nederland B.V.	Services
208	L'Oréal	FMCG
209	Larson & Darby, Inc	Engineering
210	Laser Magnetic Storage	ICT
211	Launch! Human Capital Management	Consulting
212	Lear Astronics	Aerospace
213	Leaseweb B.V.	Financial
214	Lego	Sports and Leisure
215	Lenovo	ICT
216	Lenox China	FMCG
217	LG Corporation	Industrial
218	Lincoln National	Insurance
219	Littton Data Systems	ICT
220	Lockheed Martin	Aerospace
221	Loparex	Industrial
222	Los Alamos National labs	Defence
223	Maersk	Logistics
224	Mahle Industrial Filtration	Industrial
225	MAN Truck en Bus	Industrial
226	Mansystems Nederland B.V.	ICT
227	Martin Marietta	Resources
228	MasterCard	Financial
229	McDonnell Douglas	Aerospace
230	McKesson Corporation	Healthcare
231	McKinsey and Company	Consulting
232	Merck	Pharmaceutical
233	Merck KGaA	Diversified
234	Merix	Financial
235	Miami University	Education
236	Microsoft	Technology
237	Minitab	ICT
238	MIT (Massachusetts Institute of Technology)	Education
239	Mitsubishi Polyester Film GmbH	Industrial
240	Molenaar & Lok Consultancy	Consulting
241	Monsanto Company	Agriculture
242	Morgens	Consulting
243	Motorola	ICT
244	MTU-online	ICT
245	Multi-choice	Multimedia
246	Mumbai's dabbawalas	FMCG
247	NASA	Aerospace
248	Nat'l Institute of Corrections	Government
249	Nat'l Institute of Standards	Services
250	Nat'l Semiconductor	Electronics

Table 52: List of Companies with LSS programs T251-300

No	Company Name	Industry
251	Natural Gas Pipeline Company of America	Energy
252	Nedbank	Financial
253	Nestle	FMCG
254	NIBC Bank N.V.	Financial
255	Nic Oud	Services
256	Nigerian Breweries	Food
257	Nike	Sports and Leisure
258	Nissan	Automotive
259	Nokia	Telecommunications
260	Northrop Corp	Telecommunications
261	Northrop Grumman	Aerospace
262	North-western Mutual	Insurance
263	Nvidea	ICT
264	O^2	Telecommunications
265	Office for National Statistics UK	Government
266	Orica	Chemical
267	PAC	Industrial
268	Paccar	Automotive
269	PACE	Services
270	PACT Process Solutions	Consulting
271	Panasonic	Electronics
272	Parker Hannifin	Industrial
273	Parkview Hospital	Healthcare
274	Penn State University	Education
275	Pentagon	Government
276	Pfizer	Pharmaceutical
277	Pharmacia	Biotechnology
278	Phelps Dodge	Industrial
279	PolyOne Corporation	Chemical
280	Pontes Group	Services
281	Precision Motors Deutsche Minebea GmbH	Industrial
282	Principal Financial	Insurance
283	Proctor and Gamble	FMCG
284	ProExc	Consulting
285	Prologis	Logistics
286	ProRail	Logistics
287	proXcel GmbH	Services
288	Prudential Financial	Insurance
289	PSA Finance Nederland	Financial
290	PWC (Pricewaterhousecoopers Pvt. Ltd.)	Consulting
291	Quadrant Systems Ltd	Aviation
292	Ramtron Corp	Electronics
293	Raytheon	Diversified
294	Renault	Automotive
295	Reynaers Aluminium	Industrial
296	RICOH	ICT
297	Rio Tinto Alca	Resources
298	Robert Bosch Security Solution Pte Ltd	Industrial
299	Roche Pharmaceuticals	FMCG
300	Rockwell Collins	Automotive

Table 53: List of Companies with LSS programs T301-350

No	Company Name	Industry
301	Rohm & Haas	Chemical
302	Royal Mail	Services
303	Saab Aerostructures	Diversified
304	SABMiller	FMCG
305	Samsung	Electronics
306	Sanlam	Financial
307	Santam	Insurance
308	Santander	Financial
309	SARS (South African Revenue Service)	Government
310	Sasol	Energy
311	SCAW Metals	Industrial
312	Schering-Plough	Pharmaceutical
313	Schmit Toegangssystemen B.V.	Services
314	Seagate Technologies	Electronics
315	Sears	FMCG
316	Seegrid	Automotive
317	SGL Carbon	Diversified
318	Shimano	Industrial
319	Siemens	Electronics
320	Skanska	Construction
321	Society of Plastics Engineers	Society
322	Sodexo	Services
323	Software AG	ICT
324	Solar Optical	Industrial
325	Sony	Electronics
326	Southland CNC	Automotive
327	Standard bank	Financial
328	Starwood Hotels & Resorts Worldwide	Tourism
329	Statsoft GmbH	IT
330	St-Ericsson	Industrial
331	Storage Tek	Services
332	Sumitomo	Industrial
333	Syndion	Services
334	Synobsys Nederland B.V.	ICT
335	TATA Consultancy Services	Consulting
336	Taylor Research group	Telecommunications
337	TaylorMade Golf	Sports and Leisure
338	Tele2	ICT
339	Tesla	Automotive
340	Tessco	ICT
341	Texaco	Energy
342	Texas Commerce Bank	Financial
343	Texas Dept. of Transportation	Government
344	Texas Instruments	Electronics
345	Textron	Aerospace
346	The Belgium Chocolate Group	Food
347	The Swaziland Revenue Authority	Government
348	The Vanguard Group	Financial
349	Tigger fish	FMCG
350	Timken	Industrial

Table 54: List of Companies with LSS programs T351-400

No	Company Name	Industry
351	Titleist	Sports and Leisure
352	TMC Manufacturing Support	Consulting
353	TNO	Consulting
354	TomTom	Industrial
355	Toshiba	Electronics
356	Toyota	Automotive
357	Trane	Industrial
358	Transnet	Logistics
359	Trigion Beveiliging B.V.	Services
360	Trilations	Consulting
361	Truworths	Retail
362	TRW	Automotive
363	UECompression	Energy
364	Ultratech Stepper	Electronics
365	Unilever	FMCG
366	Unilin	Industrial
367	Unipart	Logistics
368	United States Air Force, Army, Marine Corps, Navy	Government
369	United technologies	Aerospace
370	UnitedHealth Group	Insurance
371	University of California San Diego	Education
372	University of Cincinnati Cancer Institute	Education
373	University of North Carolina	Education
374	University of South Carolina	Education
375	UPS	Logistics
376	USAA	Insurance
377	Van Gansewinkel Groep	Industrial
378	Van Lanschot Bankiers	Financial
379	Van Leeuwenbuizen	Industrial
380	Venturn	Consulting
381	Ventus Information Management B.V.	ICT
382	Verbatim	Diversified
383	Verizon Communications	Telecommunications
384	VetiPak	Food
385	VFM Facility People	Consulting
386	VISA	Financial
387	Vodafone	Telecommunications
388	Volt Information Services	Consulting
389	Volvo Cars	Automotive
390	Vopak EMEA	Logistics
391	Wabco GmbH	Industrial
392	Walbro Automotive	Automotive
393	Wal-Mart	Retail
394	Wipro	ICT
395	Woningstichting SWZ Zwolle	Services
396	Wyeth	Pharmaceutical
397	Xerox	Services
398	Xstrata	Resources
399	York International	Industrial
400	ZF	Automotive

Table 55: Typical LSS process improvement benefits 1997-2014 across industries, Carleton, S.A. (2016) and annual reports.

Company / Projects	Metric / Measures	Benefits / Savings
Motorola (2006-2012)	In process defects	150 times reduction
Raytheon / Aircraft Integration systems (2009-2013)	Inspection time	88% reduction
GE/Railcar 2012 - ongoing	Repair turn around	62% reduction
Allied Signal laminates (2006-2012)	Capacity Cycle time Inventory OTD	50% Improvement 50% reduction 50% reduction Improved to 100%
Allied Signal brake pads (2010-2012)	Concept to shipment time	Project time reduced from 18 to 8 months
Hughes aircraft missiles systems group / wave soldering (2005-2010)	Quality Productivity	1000% improvement 500% improvement
General Electric (1997 – 2012)	Financial	$700m pa
Motorola (1999 – 2010)	Financial	$15bn total
Dow chemical / rail (2010-2014)	Financial	$2.5bn
DuPont / Yerkess plant (2007-2013)	Financial	$2m pa
Telefonica Spain 2001	Financial	$30m pa
Texas Instruments (2009-2014)	Financial	$600m pa
Johnson and Johnson (2000-2009)	Financial	$500m pa

The results from Research Objective 5 present benefits where an integrated framework has been used for TLS and DFSS deployment supported by survey and the responses to interviews. Results are not limited to ROI buts also in other losses and cost drivers in the organisation. Furthermore, it emerges from respondents in research survey and interviews that organisations could benefit tremendously from an integrated framework even though they don't have such or any deployed at present.

5.10 Conclusion on research questions

Capability maturity frameworks often remain merely **a good academic document at best** with limited practical applications seen absorbed in industry. The hypothesis in designing a capability maturity model is relevant and many will follow after this research paper has been filed away in the archives.

This research identified five Research Objectives in pursuit of designing a **sustainable** maturity model **adapted** to be used across hard and software industries as a result of the rapidly evolving technologies with the advent of Industry 4.0.

Continuous Improvement methodologies, such as Lean, Six Sigma, Theory of Constraints, Design for Six Sigma, Agile and Scrum are required to evolve with technological advances and **Industry 4.0 technologies enable** with ever **increasing interconnectivity** the successful execution of these methodologies. Systems and Sub-systems will continue to *autonomously self-measure* and *self-regulate* at rapid rate and agility in the supply chain. They will continue to increase at extremely high levels of precision and accuracy with *reduced cost and inefficiencies* resulting in zero or very low levels of waste (Muda, Mura and Muri).

Capability Maturity frameworks with Industry 4.0 presents **increased synergies** for the dynamic adopters in the supply chains when combined with powerful and industry tested TLS, DFSS, Agile and Scrum methodologies.

5.10.1 Research Objective 1 – What are the most significant CSF's for LSS successful deployment?

Research survey questions 8-10, 12-22, 24-25 and 27-29 in the research survey were designed to compare both survey results and respondent interviews to determine the CSF's for LSS deployment. The answer to the above first question was established from (i) the survey questions, (ii) interview information reported and (iii) also knowledge compared to similar research conducted in 31 other literature reviews in Chapter 2.

Management Commitment remains unchanged as the single most important CSF, which enables or prevents LSS effective deployment. Other significant CSF's in the top ten ranked according to Cronbach's alpha were: 1. Management commitment, 2. Linking LSS to business strategy; 3. HR rewards; 4. customer linkage to LSS; 5. selection of staff for LSS; 6. financial accountability; 7. resources; 8. inclusion of supply chain to the program; 9. project management skills and 10 training which reinforces ongoing maturity in LSS deployments.

Table 24 ranks the CSF's for LSS and from 1 to 16 are achieving high mean results of ≥ 3,792 and Cronbach's alpha 0,92891 to 0,81959 for the same set of LSS CSF's; also confirming that over and above Management Commitment, the significance of the other CSF's are not to be discounted at any stage of LSS deployment. The shift in rankings from the survey results and literature reviews (summarised in Table 24) confirms the increasing need to extend LSS to other stakeholders over such as supply chain and employee HR rewards.

Selection of LSS staff also highlights the necessity for a robust approach in recruitment. Interview with respondent B reported the significance of supply chain capability maturity and his view is confirmed in interview respondent E whereby 2 sigma inputs from the supply chain will present a problem where the customer (as observed by respondent B) requires 4 or 5 sigma process output. It is simply *not possible to achieve 5 or 6 sigma quality without the supply chain matching similar sigma quality inputs.*

5.10.2 Research Objective 2 – What are the most significant CSF's for successful DFSS implementation in an organisation?

Research survey questions 7-10, 12-20, 23-24 and 26-29 in the research survey were designed to compare both survey results and interview responses to determine the CSF's for DFSS deployment. No previous literature could be found in any of the searches on the internet and any of the academic data bases and therefore only limited comparison could be made to other sources. The following top ten CSF's were established in the survey as reported in Table 32 and Table 33 adapted in Table 34 with the inclusion of a Motorola DFSS training curriculum's subject fields such as;

1. VOC and Kano analysis;

2. LSS maturity within the organisation;

3. DFR / DFM capabilities;

4. TRIZ and TOC knowledge;

5. Design and tollgate reviews;

6. DOE capability;

7. Leadership and management commitment;

8. Agile and Scrum skills and maturity;

9. QFD and CTQ design integration and

10. Risk-identification-and-mitigation.

Further research is required because of it is:

i) L**imited sampling** in this research document and

ii) The fact that some respondents reported ***they do not have DFSS planned or deployed at present***.

Interview responses from respondents F and K also provided support for 9 of the 22 fields identified as potential CSF's for DFSS deployment.

5.10.3 Research Objective 3 – What are the contributions of CMM to LSS and DFSS implementation where such models have been explored?

Research survey questions 4-6, 16, 24, 30 and 38 were designed to determine the value of a CMM in both a LSS and DFSS CI strategy deployment. The contributions are significant and also confirmed both by interview respondents who are CMM users, and also those respondents who do not have such a framework implemented. They recognise the principles of basic CMM in identifying gaps which can be resolved and in turn could improve any CI strategy. CMMI emerged as a very prominent maturity model in more than pure software respondent's responses in the interviews.

Seven questions from the survey were designed to explore Research Objective three and 18% of the survey respondents reported not to have any CMM framework deployed in their CI strategy. Interview responses also reported that CMM was irrelevant as long as the organisation is either deploying LSS or as long as LSS and DFSS improvements are realised. Other respondents concurred that a CMM framework can assist in the identification of CI strategy gaps, which could then be mitigated based on the nature of the gap identified in such a CMM gap analysis. Respondent P remarked that CMM is more important that both LSS and DFSS.

Noteworthy respondents K and F reported significant project lead time deductions of almost a third of the normal time to customer with the inclusion of Scrum and CMMI. Secondary research made during the interviews (reflected in Figure 34) summarises even greater project effort reductions through CMMI maturity improvements from CMMI level 1 to CMMI level 5. Important here is the addition of Agile and Scrum, which results in ***meaningful and highly efficient project effort, cost and time reductions.***

5.10.4 Research Objective 4 – What impact does leadership have specifically in achieving capability maturity?

Research survey questions 11, 24, 31-37, 39 and 40 were designed to determine Research Objective 4. Leadership has a significant impact to both LSS and DFSS and achieving capability maturity as reported in survey and interview results. It is confirmed as the first CSF in LSS and the seventh CSF in DFSS deployment. It could be argued that due to the higher level of maturity derived from LSS migration to advance tools (such as DFSS) the contribution of leadership and management commitment is less prominent as a CSF than with LSS deployment. The survey questions identified that leadership has a highly significant contribution in achieving maturity capability.

Industry awareness and responsiveness to Industry 4.0 in the regular review of the impact of Industry 4.0 appear to be divided into two distinct categories of responses; those who **do** and a significant portion of those who **do not** consider the impact, which may be assigned to a variety of reasons not explored during research undertaken in this document.

5.10.5 Research Objective 5 – How will an integrated framework assist organisations to achieve capability maturity?

Research survey questions 5, 6, 24, 34-36, 38 and 40 were designed to determine what is the value to organisations should an integrated CMM be used with CI strategies such as LSS and DFSS. Significantly, most respondents from both survey and interviews are in agreement with research done in Beardsley, G. (2005) whereby the combination of a LSS and/or a DFSS staged CI program within a framework such as CMMI will assist the organisation towards achieving capability maturity. Similar results are possible in other frameworks such as EFQM and MBNQA and they also act as catalysts to enable maturity and then also as a support mechanism to nurture lower maturity levels such as 1 and 2. The majority of survey respondents reported some type or maturity framework already in use and only 18.1% of the respondents were not using a maturity framework as seen in Figure 38. Only 15.3% of the survey respondents reported to be deploying DFSS as part of their CI and development strategy, which correlates with the lower levels of CMM maturity associated with LSS and only higher levels of maturity associated with DFSS deployment. Interviews also identified that several DFSS tools are used by organisations that are also not deploying DFSS fully or even formal LSS. These organisations are all clustered in automotive and aerospace industries.

5.11 Kaiser-Meyer-Olkin (KMO) Test

Sampling adequacy index and suitability for CSF determination and statistical analysis for LSS and the CSF for each variable associated in factor analysis and also establishment of levels of correlation between variables was done with the application of Kaiser-Meyer-Olkin (KMO) and Bartlett's test statistic as observed in Hair, J.F., Black, W.C., Babin, B.J. and Anderson, R.E. (2014) for Multivariate analysis.

Table 56 reflects the SPSS results for KMO Measure of Sampling Adequacy and Bartlett's test of Sphericity statistics. KMO values varying between 0 and 1 indicate that the sum of partial correlations is relative to the sum of correlations.

In Vermeulen, A. (2011) we learn that IBM it is suggested that if KMO < 0.5 the variables require corrective action; remedial action, either deleting the "offending variables" or including other variables related to the offenders.

From the results in Table 56 the KMO (Bartlett's test of Sphericity tests) it was observed that the KMO value was 0.846 which can be considered to be good, indicating that factor analysis is useful for variables under review. No remedial action is required as the KMO value is <0.50.

The Bartlett's test indicates the strength of the relationship among variables and tested if the null hypothesis of the variables in the population correlation matrix is uncorrelated. The Bartlett test should be significant (i.e., a significance value of less than <0.05); indicating that the variables are correlated highly enough to provide a reasonable basis for factor analysis. The observed significance level in the test is 0.0000 and is small enough to reject the hypothesis. It is concluded that the strength of the relationship among variables is strong enough to proceed in factor analysis for the data.

From the result output, it was determined that the solutions cannot be rotated and the researcher proposes that all the variables be retained as identified and no Critical Factors will be eliminated or grouped for Critical Success Factors in LSS.

Table 56: KMO and Bartlett's Test

Keiser-Mayer-Olkin and Bartlett's Test		
	KMO Measure of Sampling Adequacy	0.846
Bartlett's Test of Sphericity	Approx. Chi-Square	682.546
	Df	51
	Sig.	0.000

5.12 Conclusion and answer to primary objective and research hypothesis.

The analysis of Research Objectives 1, 2, 3, 4 and 5 is that a CMM can and will assist organisations with a Continuous Improvement strategy. The detailed analysis of identifying the CSF's for both LLS and DFSS successful CI program and proposing a CMM framework inclusive of constituents from both hard and software domains is a new approach for growth in worker productivity.

All five Research Objectives have been researched and analysed in support of the hypothesis, namely to ***establish*** and ***propose*** a maturity framework that is universally applicable across industries for organisations that need to manage their own Continuous Improvement

Operational strategy. This is to be done while taking cognisance of their maturity and associated capability where an ever evolving convergence of inter-connected-technologies (presented in Industry 4.0) necessitates the review of how tangible and intangible consumer products, service, design and development of such *products and service* integrate for both hard and software industries.

The identification of the CSF's for both LSS and DFSS *change management programs* is of importance because they can guide leadership, management and teams in managing the key result areas (KRA's) for effective LSS and DFSS deployments. In analysing the Five Research Objectives, survey responses and interviews conducted confirmed the contribution of **leadership** towards achieving **capability maturity** but also how an integrated framework can assist **organisations** to achieve **capability maturity**. One set of tools is not always the solution, and here complex organisational challenges throughout innovation, design, creation and delivery with the advent of **Industry 4.0 require an integrated approach to Continuous Improvement**.

Technological advancement in the pillars observed in the **nine pillars of the Industry 4.0** act as a catalyst for ***potentially increasing*** labour productivity, quality, speed to market and ultimately customer satisfaction levels ***exponentially***. The integrated maturity framework provides for organisational CI and ***labour productivity improvement*** through joint application of CMM / ISO standards and Industry 4.0 technological advancements in the following activities and goals:

1. Process improvement based on a process model
2. Reduced risk and structure for prioritising activities
3. Selection of CI tools and strategy
4. Functional organisational stability
5. Organisational sustainability
6. Increased Innovation opportunities

The study undertaken was to establish the CSF's for LSS, DFSS and then to design an integrated framework for CMM and also appreciate and emphasise the contribution of both **Leadership and a CMM** to an organisation's **Continuous Improvement Strategy**. Many organisations fail to successfully deploy an integrated CI strategy. The contribution of an integrated CMM (which consists of constituents from ISO9000 / IATF 16949, Innovation, Sustainability, DFSS, TLS, Agile and Scrum) has been evaluated based on the Five Research Objectives set as a result of the hypothesis design.

Chapter 6 will present the construct of the integrated framework based on research findings in Chapter 5 and various literature reviews for TLS and DFSS capability maturity.

Chapter 6

6.0 Phase B - Design and development of integrated Capability Maturity Framework

6.1 Introduction

In this research document and the awareness increase in the maturity of Industry 4.0 it is cited in Ranneberg, K. (2016) who remarks as chair of the ISO Strategic Advisory Group (SAG) that Industry 4.0 observes standards leveraging IoT technologies to create more efficient, responsive, make-to-order systems.

“Because there are an increasing number of physical interfaces which are delivering both physical but also service related products, Standards are needed to avoid bottlenecks for bringing products to market. There is certainly a big role for standards on the architectural design of Industry 4.0 smart manufacturing to coordinate workflows and processes.”

The traditional CI model requires the agility and the tools for the integrated and increasingly connected organisations and supply chains of the future.

6.2 Implementation issues with TLS (TOC + Lean + Six Sigma)

Lean implementation sees failure rates as high as 50%, let alone combining methodologies such as TOC and Six Sigma, which each has a high level of failure where leadership, Hoshin Kanri (policy deployment) and linkage to functional and individual KPI’s are not inclusive of the deployment strategy. Linking LSS and TLS to business strategy as the 2nd highest ranked CSF after Management commitment confirms the significance as a CSF achieving a mean rating of 4.764 as observed in Table 24. Resources as CSF was ranked 7th in the Cronbach’s alpha result of 0.83933 and a mean result of 4.319, which is seen as significant considering the CSF ranking for extending LSS to both customer (ranked 4th) and supplier (ranked 8th), which also confirms respondent P stating:

“Limited Black Belt capacity results in our inability to assist with much needed LSS support in both DMAIC deployments for both customer quality analysis and also supplier delivery disruptions. YTD we have lost already 2,500 units at a significant loss of sales (R1bn / $76m) and cost increases of R200m / $15m for the first 8 months of 2017, more Black Belts would have reduced this level of mistakes, which occurs every year, unless you have a defined approach …..” (Respondents A and P).

The realisation emerges with increasing clarity that capability maturity is a journey but also only possible when capacity has been developed and created for deployment. Table 24 ranked CSF’s for LSS into 17 factors with others ranked as 17th with a mean result of 3,125 and the second lowest was communication and awareness which achieved a mean score of 3,792 which remains high on the five point Likert scale used.

TOC has been criticised since Goldratt wrote the goal and failed to release the algorithm used in his theory of optimum performance training system. TOC is widely used in improvements but not in particular where DFSS or LSS has been implemented and matured it has failed to demonstrate its contribution in significant academic literature in Snyder, D. and Gupta, M. (2009), which is contrary to statements made and survey results measured during the research results in Chapter 5. Contrary to Lean (which empowers employees) it is argued by Nave, D. (2002) that TOC fails to achieve empowerment but supported in constraint identification in Mukherjee, S.M. and Chatterjee, A.K. (2007) and confirmed in responses from interviewees in Chapter 5.

All of the CSF’s identified remain important, but in particular the top 10 CSF’s as listed in Table 24 ranked in Cronbach’s alpha results to consider when deploying LSS. The contribution of CSF’s to CI strategy success is a significant aspect irrespective of program maturity …..” (Respondent D).

Ranking of the CSF’s allows management and CI program leaders to shape and support program deployment with greater effectiveness, but is not going to ensure program success mentioned in Harry, M. J. *et al.* (2007).

6.3 Implementation issues with DFSS

Evaluating the results from Table 32 identifying the CSF's for DFSS, implementation is the contribution of LSS organisation ranked 2nd in Cronbach's alpha with a result of 0.8589 and a mean rating of 4.295 is significant, whereas the contribution of Leadership ranked is only observed in 7th position, which differs from its reported and recorded contribution in TLS deployment. Respondents F and K reported DFSS deployment maturity is as a result of LSS maturity and necessary buy in from stakeholders are already past *typical change program resistance stages* and of increased significance is the use of DFSS tools observed in results for CSF ranked 1st, 3rd, 4th, 5th, 6th, 8th and 10th position respectively in Table 32.

Reported previously in section 5.5 and displayed in Table 33 it is observed from interviewing respondents F (IT industry), K (Aerospace industry) and I (Banking) in training used at Motorola's DFSS and CMMI training curriculum the similarities with CSF's reported by respondents in Survey responses where 9 of the 22 CSF's are included in the training as separate topics, both confirming the validity of the CSF's. It also suggested that more research should be done for organisations seeking to successfully deploy DFSS as part of their CI strategy. The correlation in one organisation's training curriculum constituents and the CSF's determined the survey results from Table 33 and Table 34 are not conclusive but rather *indicative* that the maturity of the BB and MBB within the organisation is linked to their abilities in DFSS tool selection and application.

Very few failures were reported in the survey where implemented. In summary skills, of BB's, GB's, and even YB's and TLS, project maturity is low. The CSF's identified are also inversely responsible for *DFSS program deployment risk*. Unlike the results from Research Objective 1 where management commitment is the number one CSF in both this and also 31 other research documents, it (management commitment) is in the top 10 ranked in 7th position as a CSF. The presence of organisational LSS maturity is ranked 2nd behind VOC and Kano analysis with means score of more than 4 respectively on the 5 point Likert scale. It is possible that although management commitment is ranked 7th that this rank could be due to the LSS maturity and significant management commitment already manifested. DFSS maturity is a result of management commitment already present in LSS deployment and an increased focus on skills of BB's and MBB's reported to be more prevalent in DFSS deployment.

6.4 Implementation issues with CMMI and ISO, Agile and Scrum

Hyat, M. and Qureshi, M.R.J. (2015) concluded the following in their research measuring the effect of CMMI, ISO 9001 in an Agile and Scrum framework where the Scrum model historically as stand-alone CI technique delivered poor quality. "QFD/VOC and Kano analysis are necessary metrics which enables the product development teams to respond to market and warranty data for existing and future models.…" (Respondent P).

The research and statistical findings observed in Table 57 (research findings) that there is significant and very strong correlation between CMMI, Agile and Scrum when infused with ISO 9001 and DMADV (DFSS) and not Six Sigma or Lean Six Sigma. The research was limited to organisations within the Asia Pacific region and should be expanded to include a greater sample of geographic regions.

Table 57: Mean and Standard Deviation values in Hyat, M. and Qureshi, M.R.J. (2015) compared with analysis of questionnaire for impact analysis in CMMI in Agile and Scrum framework with survey results in DFSS CSF's in Table 32.

		Table 32 DFSS survey results				Research from Hyat, M. and Qureshi, M.J.R. (2015)		
Q. No	Requirements Analysis	CSF #	n	Mean	Std. Dev	n	Mean	Std. Dev.
1	Requirements analysis and gathering	5	72	4.077	0.613	50	4,5	0,65
2	International standards					50	4,1	0,70
3a	Project Planning					50	4,1	0,76
3b	Quality of products	7	72	3.948	0.232	50	4,2	0,62
3c	Requirements Management	20	72	2,906	0,996	50	4,0	0,62
3d	Validation of requirements	8	72	3,892	0.232	50	4,2	0,67
3e	Infusion of CAR					50	3,9	0,83
4a	Customer Focus					50	4,1	0,71
4b	Scrum Management	2	72	4,392	0.676	50	4,0	0,97
4c	Review Input					50	4,1	0,71
4d	Reviewing Output					50	4,0	0,76
4e	Customer Satisfaction					50	4,2	0,62
4f	Determination of requirements	5	72	4.077	0.613	50	4,1	0,83
5	Six Sigma – DMADV Design for Six Sigma	12	72	3,648	0,802	50	3,9	0,81

Although not exactly the same factors and requirements were measured it was possible to compare broadly CSF's recorded and analysis in DFSS survey with research conducted in CMMI, Quality and Agile Scrum model with DFSS. It is observed that 50% of the requirements established in the 2015 research document has strong correlation for identified DFSS CSF's and also in terms of mean scores reported, using a five point Likert type scale. Some of the requirements reported during this 2015 research document are ambiguous and also duplicated in terms of the CSF's established and reported in DFSS survey. More accurate further deductive analysis is possible due to the absence of maturity considerations or leadership contribution in framework design and deployment.

6.5. Implementation issues with CMMI and ISO Standards

Preparation and analysis of the organisation competitive issues are required and often known but not included in transformation and implementation phases. A consideration for the needs for CIM program and also problems driving these needs is required. A thorough review of costs and resource allocation can be overlooked or under-calculated, including infrastructure requirements and people's culture and organisational maturity to learn. The communication process needs to succeed to enhance awareness and organisational understanding. The CI team capacity and resource building requires extensive attention from management to transform organisation into a ***learning organisation.***

6.6 Implementation issues with Agile and Scrum

6.6.1 Implementation issues with Agile

Agile and Scrum skills and maturity as a CSF in DFSS deployment are ranked according to Cronbach's alpha in 8th position in Table 34 based on survey respondents with a mean rating of 4.392. These results are not conclusive but supportive that maturity contributes significantly to Agile and Scrum deployment and also observed in Table 34 in Motorola's DFSS training curriculum. "There is a definite required organisational mind set change and adaption to daily Scrum activities with cross functional teams…." (Respondent K).

"One danger in Agile and Scrum is restricting self-organisation which is fundamental to allow sprints (one month projects) and prevent command and control Agile behaviours impeding progress.…" (Respondent F).

Another warning is issued by the following: "Agile processes (Scrum, Open Agile, Kanban, etc.) are critical for making quick project progress in early stages of projects but without developing engineering practices concurrently, creates complete slow down or even shutdown due to (TDD, ATDD and Pair Programming), then the team will soon end up hip deep in Technical Debt which is project progress without much needed project testing, so it becomes unqualified results which may fail completely and results in (cost and time debt) partial or total project failure. .…" (Respondent F).

"A further issue is warned against that commitment to stay within the rules of project validation whilst progressing and not at the expense of testing can result in a dilution of project control and outcome.…" (Respondent K).

6.6.2 Implementation issues with Scrum

Resistance to change can be a launch failure issue. Lack of understanding as a result of poor campaigning and information transmission to staff impacts negatively on project management as opposed to much needed process ownership. The organisation's failure to adapt to the changing roles and *incomplete agile activities* impact on Scrum results. Agile and Scrum as a definitive CSF in the DFSS survey achieved a mean rating of 4.392 with a standard deviation of 0.676, which is very high compared to the other DFSS CSF scores recorded in Table 32. Survey data in Table 57 [in Hyat, M. and Qureshi, M.R.J. (2015)] reflects a significant mean rating of 4.0 and standard deviation of 0.97 confirming the importance of Scrum and Management during product development.

Integrating Agile and Scrum with CMMI requires an understanding that (at higher levels of maturity Agile and Scrum) focus on project deliverables, whereas CMMI is concerned with organisational maturity. Henriques, V. and Tanner, M. (2017) in Gren, L. Torkar, R. and Feldt, R. (2015) observe that an Agile structured maturity framework will be required to supplement CMMI for higher maturity level projects, which is a clear divergence in goal objective of CMMI. The contribution of CMMI is difficult to ignore where industry adoption grew 17% globally in 2015 with 28% growth in the US remaining its biggest market extending to over a 100 countries worldwide. "CMMI organisations report an adoption rate of 70% of Agile and Scrum practise and is not limited to the software industries.…" (Respondent K).

6.7 Design of Framework

CMMI origins and weighting "favours" *process improvement* as the key predecessors to product improvement. Measuring CMMI maturity in SCAMPI A, B or C provides a gap analysis of organisation or program maturity, which becomes the basis for further improvements. LSS and DFSS provides the toolbox where project selection for improvement is expedited through numerical values in opportunity cost in project selection. Where the opportunity cannot be calculated accurately an estimate based on ROI ranking is selected to decide on which projects to proceed with immediately linked to capacity and customer urgency where most needed.

SEI uses a similar framework depicted in Figure 43 which represents stage 2 of the design for staged implementation of Six Sigma and CMMI which is similar to the four scenarios proposed in Figure 42 (stage 1) adapted with TOC and Lean.

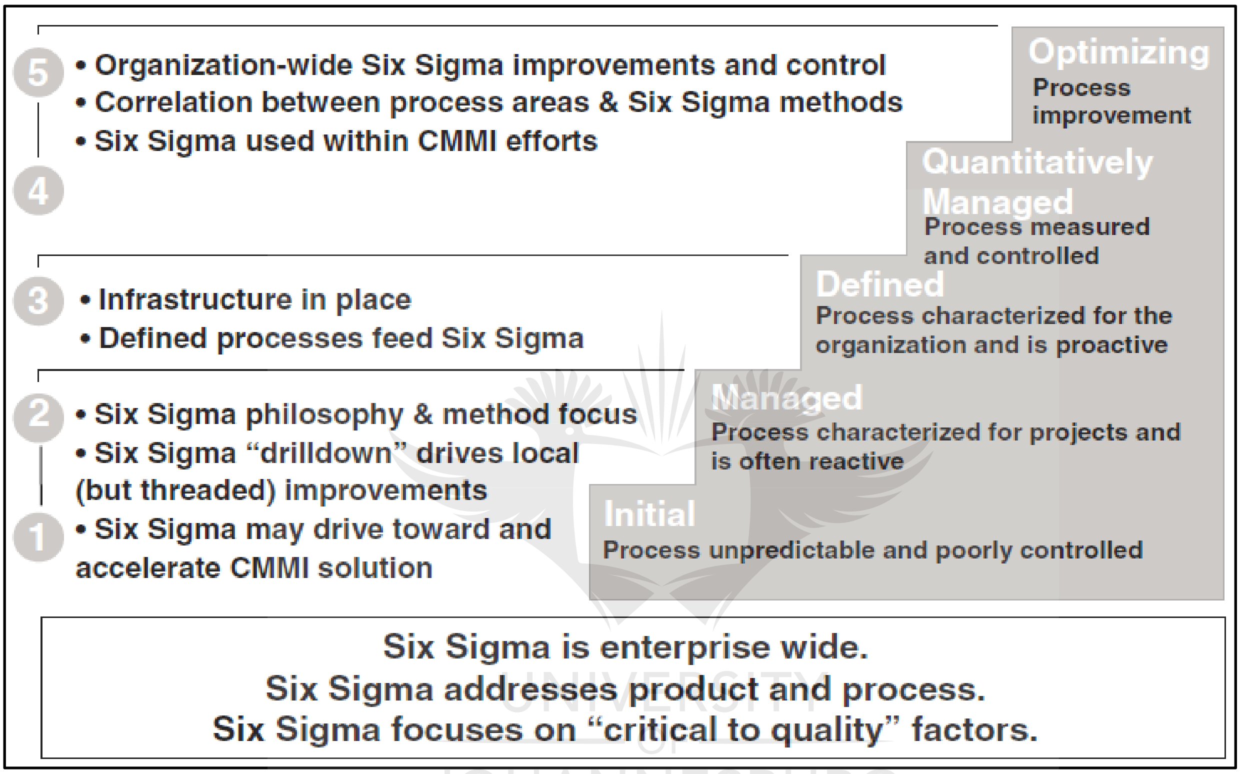

Figure 43: Design of integrated framework stage 2 - CMMI and Six Sigma staged considerations for applicability and corresponding maturity level.

The practical application of a multi-model CMM for an integrated CI strategy can be manifested into PDCA which has already seen widespread industry adoption in Quality and Business management standards by ISO in ISO 9001:2015 and IATF 16949:2016 reported in Figure 43 staged with corresponding CMMI Level 1 to 5 maturity. Figure 42 proposes 4 differing scenarios combining TLS (adapted from pure Six Sigma) and CMMI, which is not limited as staged in Figure 42 and reflected in scenario 3 (Blue dash) with simultaneous implementation of and institutionalisation of CMMI and adapted TLS. The basic framework selected therefor is the stages in Figure 42 as adapted to include TOC with Lean and Six Sigma infused with CMMI in scenario 3 which also aligns with Figure 43 although represented without Lean and TOC.

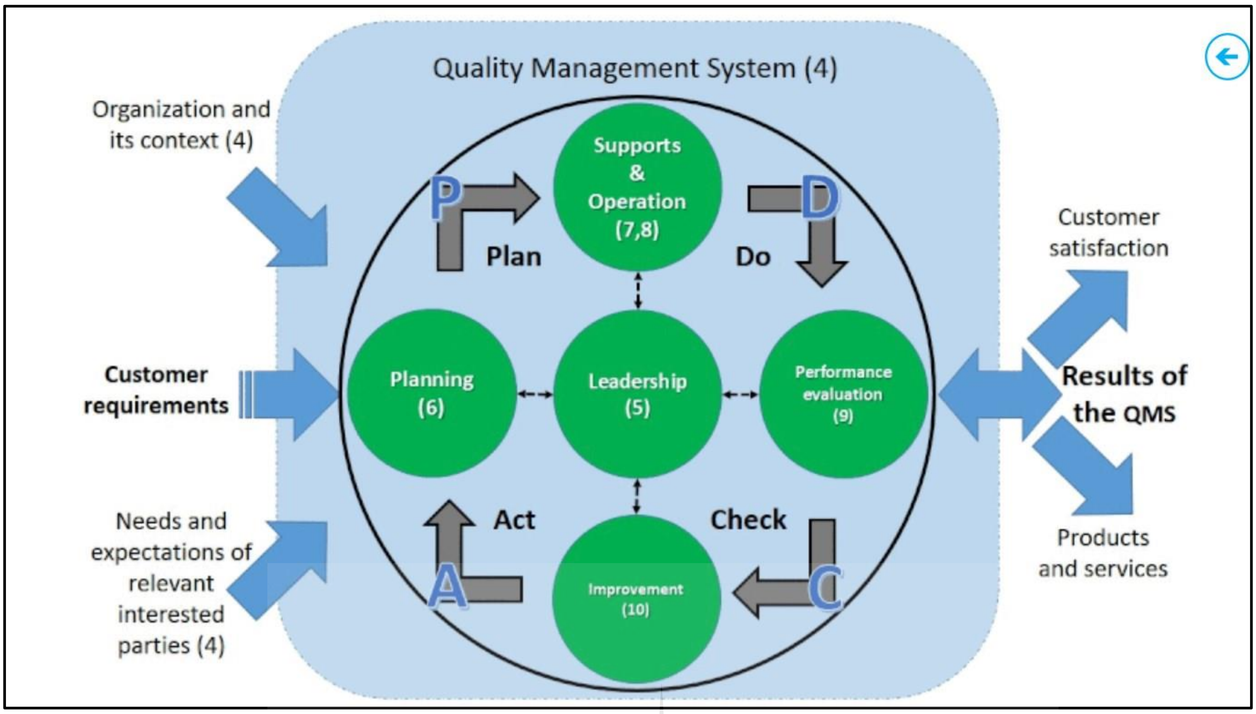

Figure 44: ISO 9001:2015 and IATF 16949:2016 PDCA Cycle QMS system. Source: www.iso.org.

Leadership remains central to the PDCA approach and it is herein that TLS, DFSS, Agile and Scrum within CMMI is proposed in selecting tools based on phases of project maturity. Element 6 Planning postulates provision for DFSS, Scrum and Agile whereas Improvement element 10 in Figure 44 makes provision for TLS and a host of improvement methodologies. The PDCA cycle does not limit the deployment of CI tools which can be applied in all the other elements such as Element 5 Leadership, Element 7 Support; Element 8 Operation and Element 9 Performance Evaluation whilst applying SIPOC in every business and project aspect. Element 4 is the basis where CMMI has an opportunity to track each and every aspect of business and project performance in a complementary manner. Chapter 7 will propose a final CMM model for a CI strategy adapted onto the PDCA QMS where Figure 42 is central to the core CI strategies in element 10 in Figure 44 where CMMI is integrated with TLS.

6.8 Construction of a Hybrid Capability Maturity Framework.

Innovation and Operational Excellence manifest a competitive advantage in new product development activities. The key drivers for the establishment of such a competitive advantage depends on Capability Maturity coordinating much needed high levels of management support. The integration in a hybrid capability maturity model adapted from traditional manufacturing and software industries lays the foundation for the proposed capability maturity model titled "CMMI 4.0".

The proposed roots are found in CMMI but adapted for the inclusion of Agile and Scrum, TLS and DFSS resulting in the creation of increased capacity through increased maturity which feeds into research and development of newer, faster, better innovation value propositions cementing the organisations competitive advantage in their respective industry.

"Synergies exist in value propositions delivered by McKinsey (in designing a framework) work for their clients such as Swiss based chemical multinational organisation Clariant ($6bn pa) headquartered in Switzerland in the process of merging with Huntsman ($10bn pa) head-quartered in the US included in the research with a clear distinction between Black Belts and Innovation Black Belt functional areas…." (Respondent D).

This synergy does, however, not address the emerging need for inclusion of DFSS, TOC, Agile and Scrum through a capability maturity framework acting as a catalyst for improvement such as CMMI. The need for an inclusive hybrid framework is necessitated by the industries that are automating in the torrent of Industry 4.0 technologies deployed at a rapid rate whilst producing integrated connected products and services such as Autonomous driving and autonomous investment decisions made on behalf of humans. Figure 45 proposes the basket or constituents of CI tools for this inclusive CMM adapted from both physical and cyber physical industries.

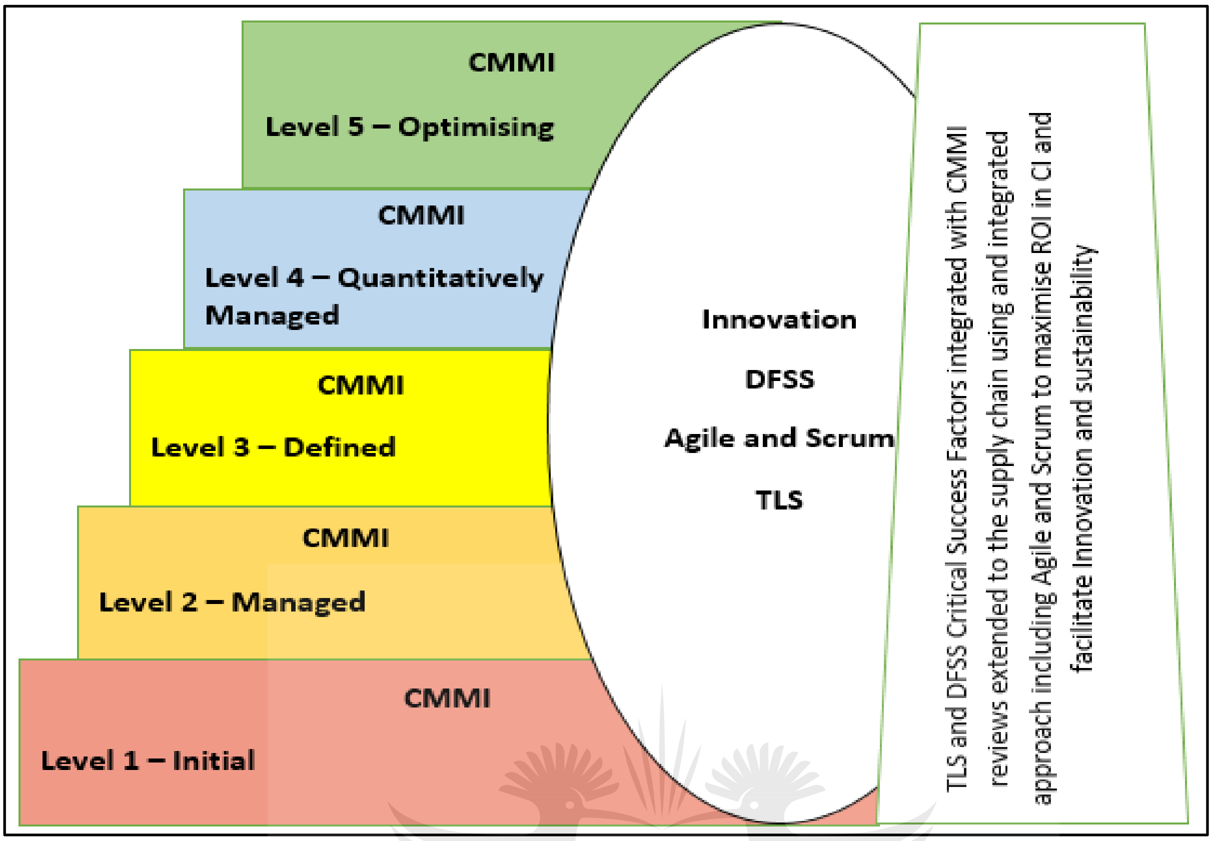

Figure 45: CMMI adapted with constituents to include TLS, DFSS, Innovation Agile and Scrum.

CMMI adapted is thus presented as the proposed capability maturity model in Figure 46 for consideration in both manufacturing and services industries to maximise effectiveness in the continuous improvement and organisational excellence journey. The model is proposed and although maturity stage relevancy is observed as crucial and maturity level evolution determines selection of CI tools. The model provides for the adaption of all the industry-adopted and research-tested tools that facilitate increased capability maturity and much needed innovation to complement existing efficiency improvement achievements.

Figure 46 depicts the selection of positioning of CI primarily aimed at Element 10 and ISO 9001 derived PDCA process approach for continuous improvement In Figure 47 TOC is extrapolated with Lean constituents as a central approach and again not providing for Agile and Scrum, DFSS or Six Sigma. Integrating all of these approaches is presented in an adaption of Figure 43 (ISO Element 10); Figure 42 (constituents); Figure 47 (Lean and TOC) and Figure 48 which is labelled CMMI 4.0 - Integrated Hybrid CMM.

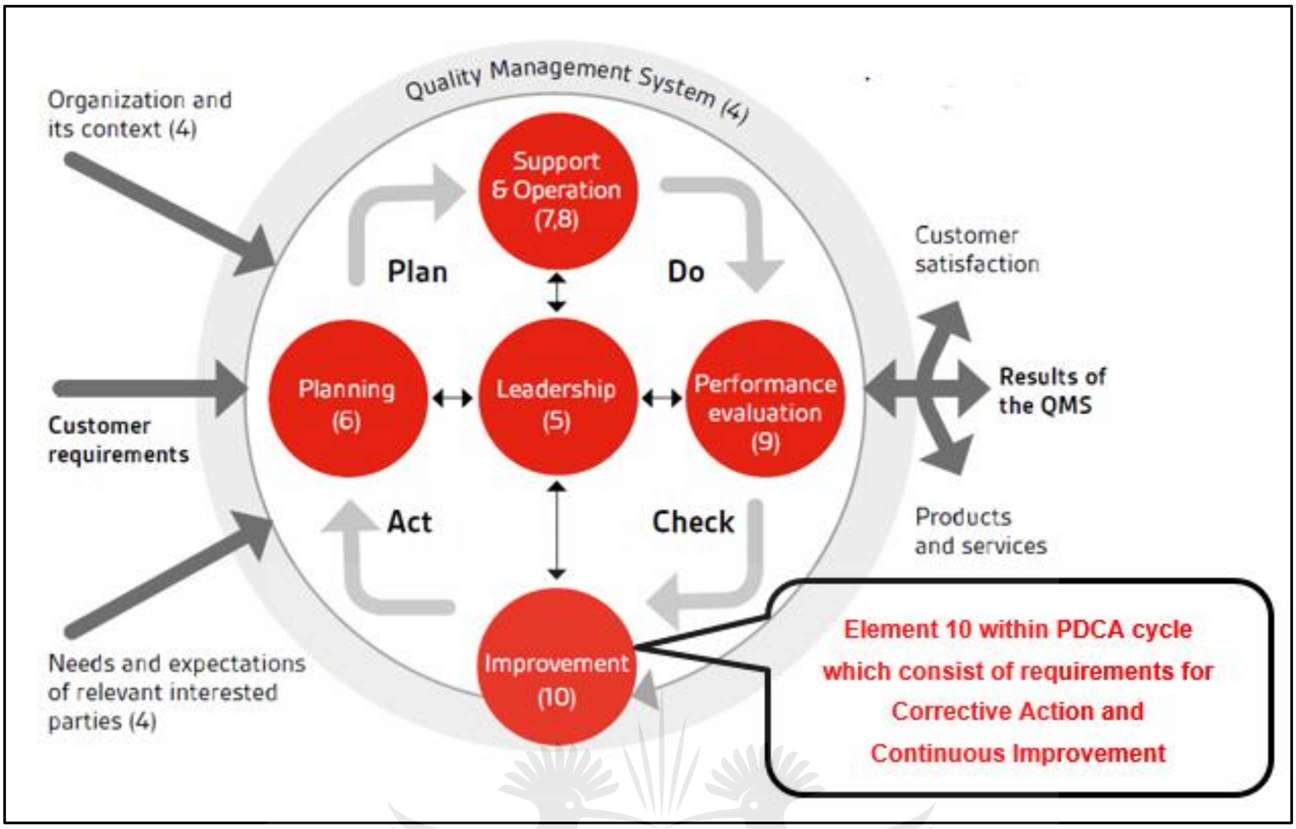

Figure 46: ISO 9001 / IATF 16949 PDCA Model for CI. Source: www.iso.org

In achieving a Lean CI structure removing waste and reducing inventory optimally is TOC and Lean proposed in Figure 47 as a constituent of element 10 Improvement. However, we often, experience a need to restore orignal process intent and corrective action is required after FMEA. Process controls did not envisage such process failure, hence the need to adapt model from Figure 45 further to be more inclusive of problem solving tools such as DMAIC and DMADV.

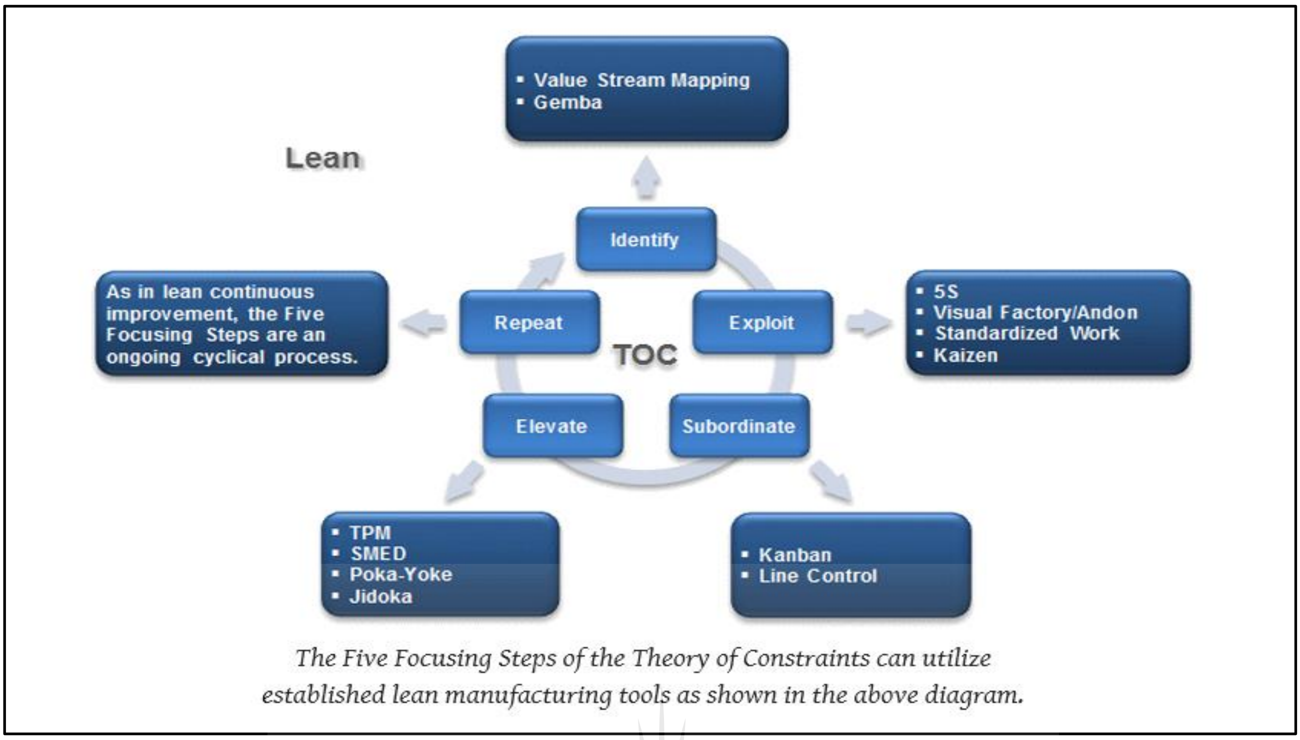

Figure 47: TOC and Lean CI framework proposed for CI within Element 10 from Figure 46.

The unplanned and unforeseen events and process opportunities are not fully addressed in the framework proposed in Figure 46 and requires rigorous data analysis made possible with DMAIC and DMADV infused with Agile and Scrum but not as stand-alone not synchronised, herein CMMI can embrace all tools, techniques and iterations of project and process design and realisations in Figure 48 increasingly made possible with the aid of Industry advances in Big data collection, assimilation and analytics.

In Figure 48 the researcher is proposing a holistic and sustainable framework for organisations across a variety of industries to both select and deploy tool sets inclusively or selectively as a combination of tools suited for the respective organisational paradigm whilst considering capability maturity realities. The basis for structure is proposed in an ISO 9000 and CMMI based management framework which embraces the PDCA approach to all processes and defined steps for organisational development. The framework details CMMI maturity levels to be used to develop and track organisational capability and maturity in conjunction with the ISO framework. This hybrid CMM is complementing the organisation structure for all aspects of improvement management based on known and mature best practices developed by CMMI and ISO as the foundation for CI tool selection and deployment.

The framework furthermore extends into proposed tool selection aligned with CMMI maturity levels 1-5 for TLS (ISO 18404; ISO 13053/1/2 and ISO 17258), irrespective of maturity level achievement and added also for sustainability and risk management requirements are ISO 20121 and ISO 31010, which is in support of the framework proposed in Figure 44 and Figure 48. This CI integrated hybrid CMM is possible and seen as a much needed framework with increasingly TBL metrics expected from stakeholders such as shareholders, customers, employees and environments where the organisation creates and distributes products and services in a safe and responsible value proposition confirmed by results derived from the special survey data and subsequent industry specialist interviews in this research document.

The framework in stage 3 combining stage 1 and stage 2 then suggests for CMMI level 3 and above maturity the selection and deployment of advanced Innovation, Agile and Scrum and DFSS and their respective ISO standards currently available for guidance in ISO 26515; ISO 20575 and ISO/TC 269.

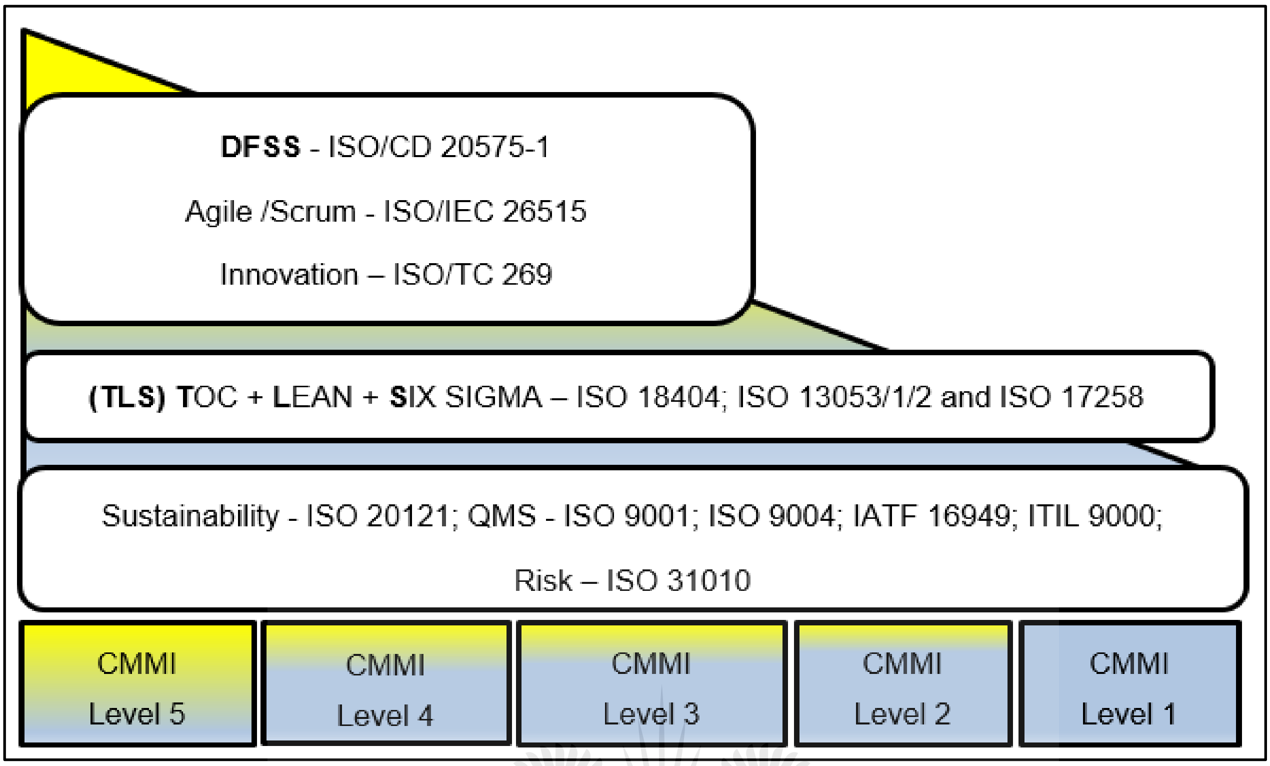

Figure 48: Design of integrated framework stage 3 (Stage 1 + Stage 2) - Integrated Hybrid Capability Maturity Model (CMMI 4.0) - adapted to include various CI constituents for the disruptive Industry 4.0 Exponential Technologies, Element 10 (Improvement) from IATF 16949/ISO 9001.

Again the research suggests high levels of maturity that support successful deployment of DFSS, Agile/Scrum and Innovation improvement methodologies and techniques to assure effective organisational absorption within an Industry 4.0 environment with this CMMI 4.0 adapted CMM.

The dynamics of changing and future markets require a connected model that embraces the IoT's and the ability to navigate between the physical and the cloud environment. Industry 4.0 dynamics proposes a connected service and manufacturing environment where traditional EFQM and MBNQA CMM's require an evolution similar to CMMI, which also allows for this transition by design and its significant ICT and advanced manufacturers adoption. The name of CMMI² is appropriate as stated previously and observed Industry 4.0 exponential use of technologies.

6.9 Industry 4.0 and proposed integrated hybrid framework (CMMI 4.0)

Financial institutions and ICT are the first adopters of CMMI and already have to consider their operating landscape changing with the advent of AI (Artificial Intelligence) in automation of investment banking decisions to outperform the market and typical analyst decisions observed in the research. The prominence of automation routine tasks are evolving where increased complex tasks are being studied, programmed and through rigorous Agile and Scrum techniques standardised.

Investment banker and fund manager at the Man group (managing the largest hedge fund in the world) states in AI: "If you look at macro or index decision-making you then become more quantitative but when you look at individual companies, the disaggregation makes it more complicated to be purely quantitative so that's where we want to focus the discretionary input."

Lagrange, P. (2017) also proposes that, similar to the previous industrial revolution where you're using the machine to enhance your discretionary process, data mining, polling, modelling and managing momentum are examples of where machines have an advantage over humans. This is concurred in Wintermeyer, L. (2017) that AI within investment banking already uses AI in routine modelling and predictions with large quantities of data reviews made possible with constantly evolving algorithms and forecasting methods to reduce risk and maximise ROI for both the organisation and the customer. He further postulates that even in its most advanced state **AI still requires human intervention** either through making a decision, (which can be automated) or in the creation, modification and testing of the algorithm. The future of active management is in **augmented intelligence**. Portfolio managers will not increase in numbers, a reduction will be inevitable in the next decade where **AI** will further **reduce cost and improve accuracy** and customer and organisational metrics.

The proposed framework again offers potential solutions to manage this inevitable change in industry, because the organisations are required to compete with accurate forecasts when using AI and herein again the advantages of Scrum within Agile (delivering accurate fast high yield sigma) solutions will be pivotal in success or failures in the final product. CMMI 4.0 integrated within the development of the software will possibly mitigate and manage risk by designing extremely high levels of sigma probability. DFSS again offers with TLS proven techniques to standardise the approach and select multiple tools for test validation and design accuracy.

6.10 Industry 4.0 disruption and Capability Maturity

It becomes clear from the literature reviews, survey questionnaire analysis and interviews conducted that the emergent and future organisations will increasingly be required to be a very agile learning organisation to constantly scan the environment and increase agility in responding to constant changes in markets and exponential technologies to remain relevant and competitive. The capability maturity of the organisation will either enable the organisation to be flexible and responsive to increased customer mass customisation or not. The constant increase in competitiveness from industry where the early systems such as ISO, ITIL, CMMI, TLS and DFSS and also technology adopters **will** capitalise on consumer behaviour **or it will not** and lose markets which they may have previously controlled. Time to market will be crucial and product development cycles will required rapid and accurate DFSS, DFR and Agile aspects during the development phase. CMMI offers a baseline for industry but as stated requires the flexibility offered in rapid iterations of testing posed in Scrum in Agile.

Industry disruption predicted are – for example insurance companies have large portions of their revenues streams based on risk for vehicle accidents. Initially built-in accident avoidance systems will reduce accidents and eventually autonomous driving will **disrupt the entire supply-chain** for repairs and claims industries. Further disruptions are already observed in being tested where AI and adaptive learning software can predict future company performances replacing investment analyst and fund managers in the investment industry. Governments already are increasingly observing the effect crypto-currencies transactions that cannot be taxed with ease and ultimately requires increased levels of organisation disclosure for transactions realised. The capability maturity of these industries will become increasingly prominent as the speed of Industry 4.0 technology absorption will exponentially change and disrupt almost every industry.

Human jobs are already being replaced by robots for the past decade as observed in Fanuc in Japan is **using industrial robots to manufacture other industrial robots** and the factory is only staffed with four humans workers per shift. Philips in the Netherlands are using robots to produce electric razors where the human component is outnumbered 14 to 1 and Canon has been phasing out human labour for reasons of quality and efficiencies since 2013 with the trend increasingly being explored and invoked by industry as can be seen in Figure 49 according to Tilley, J. (2017).

Figure 49 illustrates the diverging trend in global labour cost increases and the associated decline in robot prices competing for similar tasks typically performed by human operators.

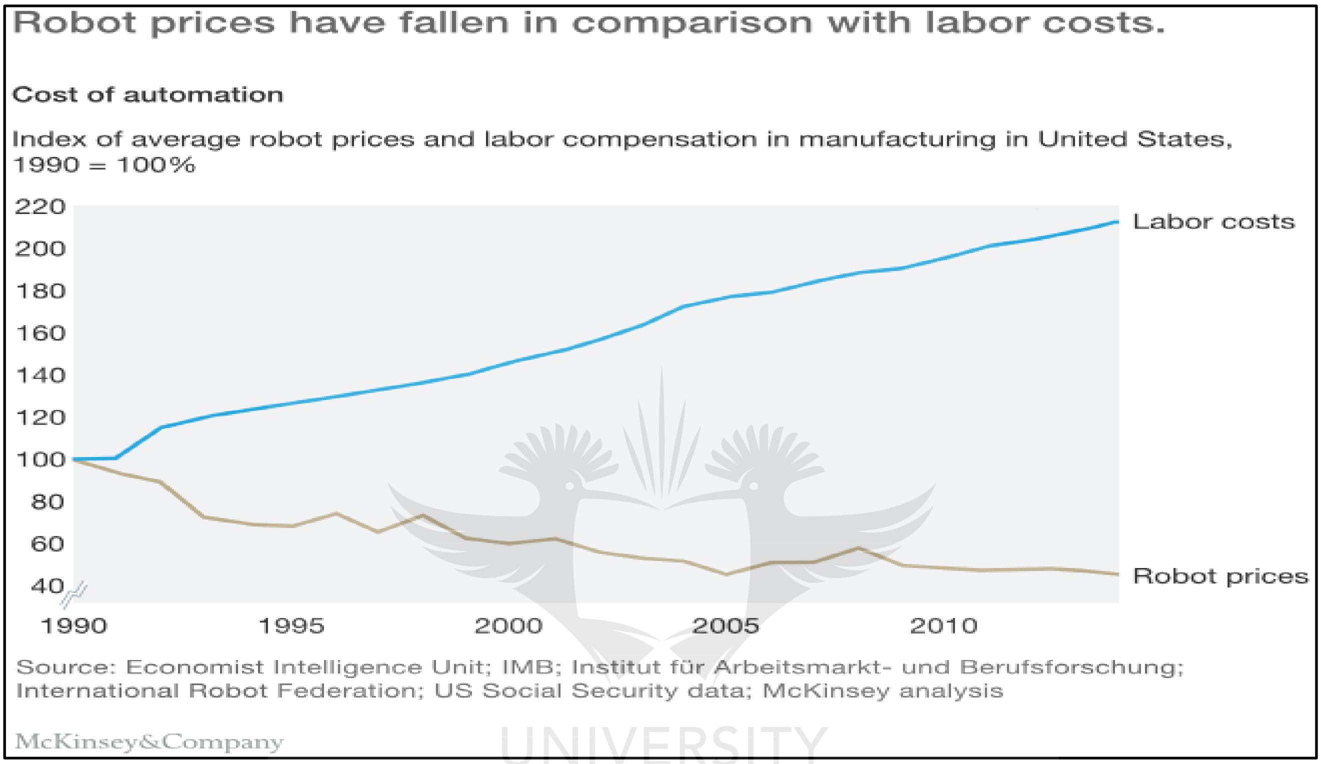

Figure 49: Falling robot prices in comparison with escalating labour cost, McKinsey and Company (2017). http://www.mckinsey.com/business-functions/operations/our-insights/automation-robotics-and-the-factory-of-the-future?cid=soc-web

Automation and Industry 4.0 will increasingly affect organisations operationally but also in turn integrate with technology reducing process variation through increased reliability and process repeatability. Technology brought with Big Data in the IIoT's requires an integrated operation and for this an integrated CI strategy linked to organisational maturity. The hybrid framework proposed in this Chapter is an amalgamation of CI tools that have already been successfully deployed individually and in combination fashion. The opportunity for integration has never before been as significant and necessary as now.

6.11 Conclusion

The adaption of an integrated framework allowing for both applicability in services and manufacturing renders the proposed model universally acceptable to all if not most industries. Cognisance must be given to the factors and in particular the Critical Success Factors affecting CI tool deployment.

The contribution of associated organisational and practioner maturity has been demonstrated in Research Objectives one to five. The rapid changes in disciplines in both physical manufacturing, ICT and AI (Artificial Intelligence) require a model that consider both tangible and non-tangible industries' best practices to be merged with user interfaces such as HMI (Human Machine Interface) and LIDAR (Light Imaging Detection And Ranging) as used in autonomous driver vehicles, with electronics and software becoming **self-aware**, driving the vehicle safely without human control it does consist of a series pre-programmed algorithms and **AI logic that determine a course of action** and to enable both the customer and provider of a value proposition to deliver sustained CI and value to the consumer.

Numerous CI solutions have evolved over time but none of them addresses the current industry maturity, migration of technology and consumer behaviour into a solution that can **bridge the spaces** between tangible and non-tangible industries. Case in point are **active safety systems** such as autonomous vehicle operation and collision avoidance based on physical electronic detection methods combined with Artificial Intelligence acting upon sensors to save human lives.

In the multiple supply chains with both diverging and converging core technologies and competencies, not all ascribe to the same CI methodology. The need for a framework with a technology inclusive approach becomes an emergent necessity where existing models only consider some industries and not the converging product being produced. The integrated hybrid CMMI 4.0 framework merges the traditional CMMI with TLS and DFSS methodologies facilitating not only CI and organisation excellence activities but tracking and measurement of both tangible and non-tangible products and services.

Awareness and organisational maturity and the adoption of Agile and Scrum's contribution to accelerate CI program development speed with high-quality metrics can be a competitive advantage where embraced holistically.

Chapter 7 will now conclude the research document and propose recommendation for future research.

Chapter 7

7.0 Conclusions and Recommendations

7.1 Introduction

In the quest of ***striving for business perfection*** or ***excellence*** it is inevitable that the quantification (measurement) of excellence is determined, so it remains the intent of this research document to propose a capability maturity framework for industry application to integrate and present a practical solution to the achievement of excellence in CI program deployment through *maturity capability determination* and *frequent maturity review*.

The traditional prevalent industry approach for actualising improvement is through the adoption and deployment of suitable Lean, Six Sigma, Design for Six Sigma, Agile and Scrum tools within an ISO and CMMI derived structure or maturity framework. Organisations with a defined CI strategy, may follow a more structured approach, which often defines the selection of prominent CI tools, migrating into more technical tools with the use of statistics, specialist and software solutions that are common practice.

Industry leaders and specialists included in literature reviews, survey and interviews confirm that the formal approach is the current approach and also in the future where the key measure is originating from the external sources in QFD, VOC and sustainable inputs and the CI strategy that delivers ROI will be driving innovation and improvement. The primary objective of this research study was to determine the CSF's for both LSS and DFSS which ensures a Lean operational strategy where all Muda, Mura and Muri have been eliminated or reduced to minimum levels through calculation of minimum economic levels. The reason why CI tools outside the traditional space of CI were considered and included was due to the imminent impact of Big Data processing computing power made possible through the advances of technology classified as key constituents of Industry 4.0.

The research was structured in two distinct phases where phase A was to determine the CSF's for both LSS and DFSS deployment, the contribution of a capability maturity model to maximise effectiveness of CI strategy, the contribution of leadership and an adaption of CI tools and techniques used historically in the software domain to be considered for integration into a hybrid CMM applicable across industries using ISO standards ensuring sustainability. Phase

A was a combination of literature reviewed in Chapters 2 and 3 and analysed in Chapter 5 through all five Research Objectives. Phase A provides input through targeted survey questionnaires across industries aimed specifically at industry specialists tasked with CI strategy construction, program management and/or CI program implementation. Phase B was the construction of a CMM framework derived from inputs in phase A which came from a research survey and industry specialist interviews.

Phase B was constructed in the later part of Chapter 5 and the body of Chapter 6 as a result of establishing the two prominent CI tool CSF's as central to the first two Research Objectives. Further inputs were acquired through Research Objectives 3, 4 and 5. Research Objective 3 expanded the results of Research Objective 1 and 2 further through establishing the contribution of implementing a Capability Maturity Model in conjunction with CI tools from CSF's in both LSS in Research Objective 1 and DFSS in Research Objective 2. The contribution of leadership within each CI tool was also explored in Research Objective 4, which ranked in the top 10 for both Research Objective 1 and 2 respectively. Research Objective 5 was designed to establish the potential contribution an integrated CI framework will (or should) have in organisations achieving capability maturity.

The final phase B is designed to incorporate the results from all five Research Objectives to design, construct and propose an integrated framework assisting organisations to establish and/or improve capability maturity which can increase their competitive position through improving their CI deployment effectiveness within the rapid changing Industry 4.0 operational landscape.

7.2 Conclusion on Research Objectives

Figure 50 illustrates the final graphical representation of an integrated framework constructed in Phase B (Stage1+2 = stage 3) made possible with the input parameters in Phase A and the analysis of standardised tools available to the industry through specialist (such as CMMI and ISO) organisations.

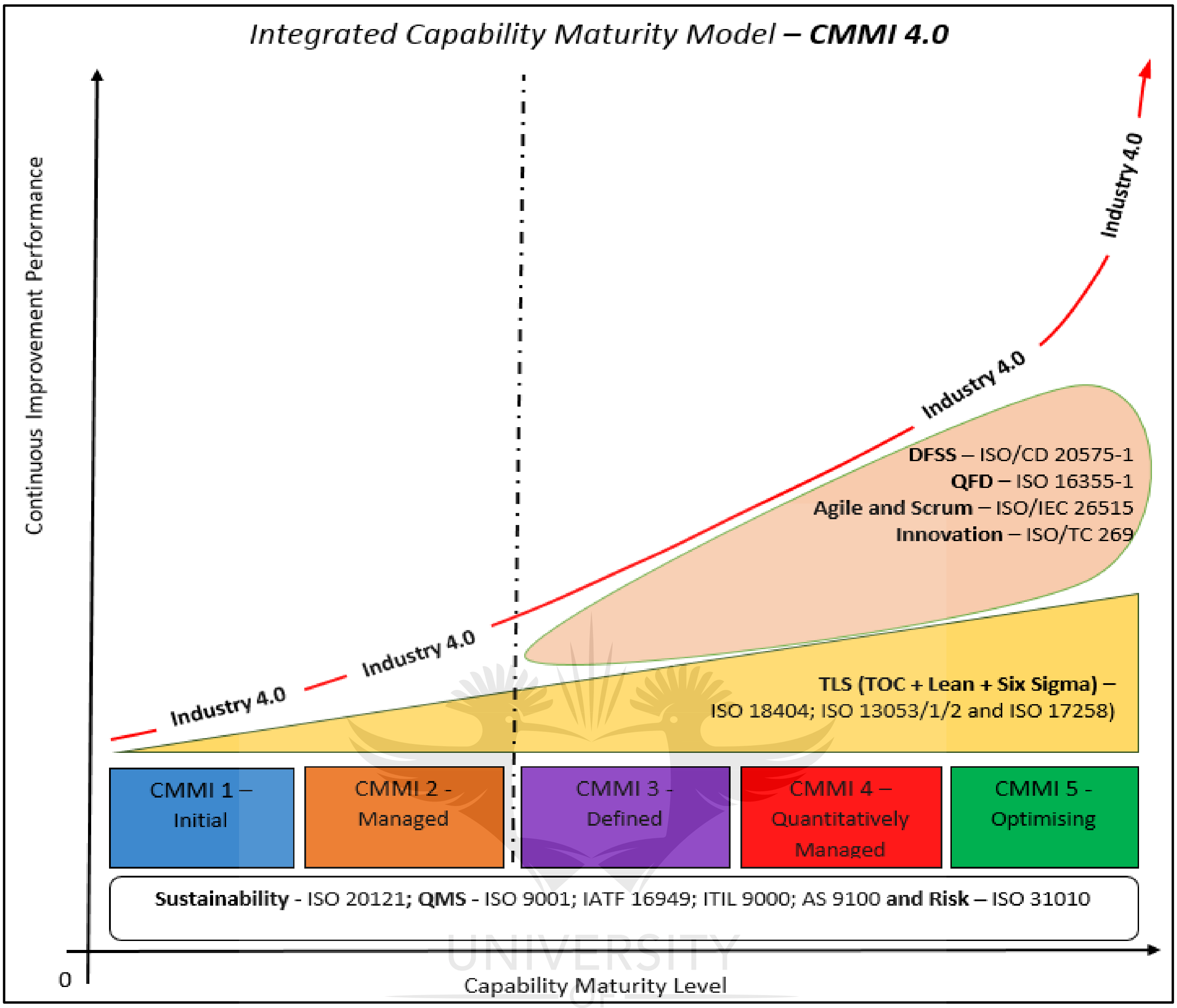

Figure 50: Integrated Hybrid Capability Maturity Model (CMMI 4.0) - adapted to include various CI constituents for the disruptive Industry 4.0 Exponential Technologies, Element 10 (Improvement) from IATF 1694 and ISO 9000 deploying the PDCA cycle as foundation.

Industry 4.0 is described as the catalyst for breaking the declining labour productivity growth reported in Chapter 1 in Figure 4 and also in a longer trend period as displayed in Figure 51 seen below. The **fourth industrial revolution** is the current revolution in technology and interconnectivity touching our daily lives. The rapid increases in automation will drive productivity to unprecedented levels, which is pivotal in our ever-increasing need for speed, cost and quality improvements. The ***quantification of the potential exponential improvements*** presented in Figure 50 and the inclusion of Industry 4.0 technologies when combined with constituents in this framework presented can only be determined in additional and further focussed research.

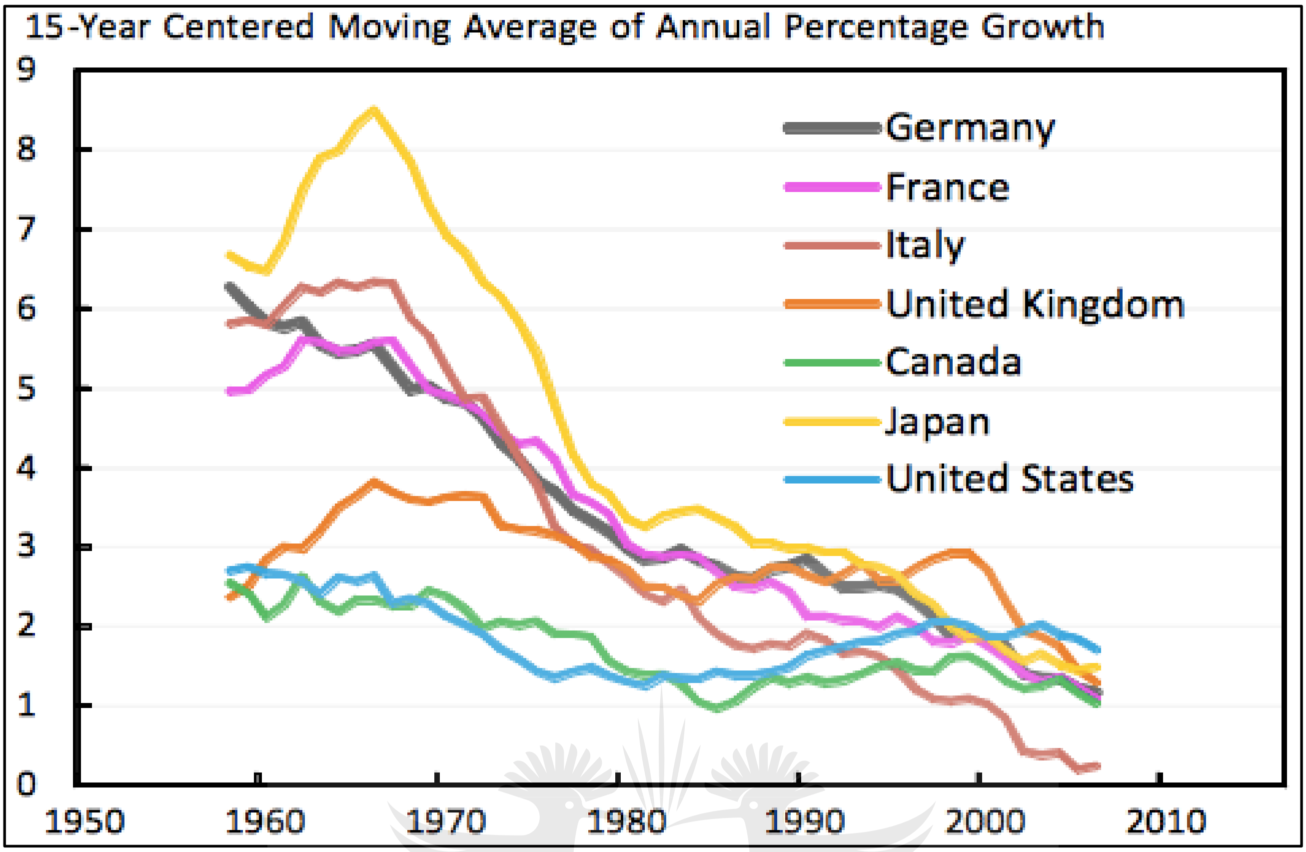

Figure 51: Declining Labour productivity growth 1950-2010, Source www.oecd.org (2017).

Figure 49 confirms the relevance to the impact of declining labour productivity and the advent of Industry 4.0. The trend observed in the continued increase in labour cost diverging with the declining cost of robotics (which is what automation does) and also argued reported according to Weil, D.N. (2007) were Industry 4.0 will result in a continuous reduction in manual labour (loss of jobs) but enable an increase of productivity (cost and quality metrics) and facilitate improved (i) real time data, (ii) process stoppage and (iii) automatic corrections resulting in increasing sigma quality to levels not experienced before. Industry 4.0 is the turning point to the long decline of labour productivity growth observed in Figure 51. Robots will take over jobs done by people who are prone to make mistakes in a world where increasingly less mistakes are tolerated.

Rubmann, M. (2015) *et al*. they describe the 9 foundational changes observed in the 9 pillars of Industry 4.0 which will result in increased efficiencies in design, collaboration and production throughout the supply chain increasing organisational competitiveness. LSS aims to reduce process variation, remove waste and maximise productivity. Industry 4.0 enables achievement of these aims through technology and less reliance on human errors in routine tasks. The CSF's for Industry 4.0 deployment and organisational absorption should be a key consideration for designers, manufacturers and suppliers of goods and services. Such is the (Robotic and Artificial Intelligence) future that is envisaged by this researcher in analysing the present state of affairs in industries globally.

7.2.1 Research Objective 1:

What are the most significant CSF's for LSS successful deployment in an organisation?

In the Literature study (Chapter 2) Laureani, A. and Antony, J. (2012) reviewed 31 research documents establishing the CSF's for Six Sigma and what was also established is inclusive of Lean tools in the majority of studies which refers to LSS. The development of ISO 13053-part 1 and 2 in Boulanger, M. (2011) cites that improvement throughout the organisation is possible with realising improved operational efficiencies and increased levels of customer satisfaction, yet many organisations either exit before program maturity is reached or avoid implementation entirely. In evaluation of the list of multinational Six Sigma companies and also ones that are listed on the fortune 500 list of companies is it becomes clear that the leadership and management are committed to CI strategy in a **proven structured approach**. The development and distribution of several ISO standards confirms the international community's need for a standardised approach for LSS (Lean Six Sigma).

In Laureani, A. and Antony, J. (2012) in Figure 17 they cited **management commitment** as the most significant CSF in LSS program deployment which correlates with results from both survey respondents and interview responses recorded in Chapter 5.

Anthony, J. and Banuelas, R. (2002) with Coronado and Athony, J. (2002) observed the CSF's correlate with the results recorded in Table 22 for 9 of the 15 CSF's identified where management commitment achieved a mean score of 4.764 and Cronbach's alpha result of 0.92891. Kwak, Y.H. and Anbari, F.T. (2006) also confirm in their research similar results centring on management support and management processes which provides a foundation for LSS deployment including extension to **supply chain** and **training and commitment** strengthening the CI policy and strategy.

The ISO standards such as ISO 13053 part 1 and part 2, ISO 18404 and ISO 17258 have been developed in response to an industry seeking standards, guidance and a roadmap for effective LSS deployment. The ISO organisation series of standards enables organisations to have a constant reference to a set standard encompassing the body of knowledge necessary for a CI for LSS practitioners across industries and functional areas. The standardisation (a basic principle in Lean and TPS) allows access to a set of standards accessible to all and also the primary motivation for the inclusion in the proposed integrated hybrid CI framework in CMMI 4.0 in Figure 50. (The CSF's necessary for effective CI deployment with LSS). As proposed TLS CI strategy (adapted from LSS) requires **management commitment** and **support** for all the other CSF's identified in Table 22 and Table 24. Maturity in both awareness and support (of the CSF's identified in this research for effective TLS deployment, including previous research correlating similar CSF's) will determine program success for organisations adopting a TLS CI strategy.

7.2.2 Research Objective 2:

What are the most significant CSF's for successful DFSS deployment in an organisation?

No similar or previous research could be found in any of the prominent academic and industry data bases searched. The researcher constructed the DFSS related questions in the survey questionnaire which was developed with inputs from respondents during the interviews held due to the low level of public and academic knowledge available for DFSS CSF's. Table 32 and Table 33 reveal the results of the combination of interviews and survey responses and DFSS questions posted with CSF's listed by the survey questionnaire and also added by survey respondents. What emerges as a common thread in the results are the customer centricity, organisational LSS maturity and DFSS tool repertoire observed in CSF's rankings 1st, 2nd, 3rd, 4th, 5th, 6th, 8th, 9th and 10th with Leadership and management commitment ranked 7th. The rankings in Cronbach's alpha may be argued as less important but rather that all of the CSF's identified are important. What emerges as more significant is the inclusion of CSF ranked 8th which is **Agile and Scrum skills maturity** historically limited to IT service industries. The CSF's identified in the survey with the highest mean scores were 1st Leadership and management commitment at 4.525; 2nd Agile and Scrum skills and maturity at 4.392 and 3rd

LSS Organisation Maturity at 4.295. Correlation was also observed in the construction of Table 34 which was constructed using Table 32 and Table 33 survey results and a Motorola DFSS training curriculum wherein 9 of the 22 CSF's were found to be listed as integral to the DFSS curriculum. The contribution of organisational maturity, such as LSS maturity, supported by leadership and management commitment also enables DFSS tool capability maturity which becomes extremely specialised when designing new innovative products and or processes as reported by the responses received from the interviews. Axiomatic design was not identified as a CSF by either the survey or interview respondents although cited in Yang, K. and El-Haik, B. (2008) who worked on identifying the following four DFSS prerequisites which aligns with CSF's in Tables 32, 33 and 34:

1. Top and medium level management commitment
2. PMS (Program Management System) which details the design life cycle and design algorithm
3. DFSS project resources in company KPI scorecards deployed as a health check of corporate health and maturity, centre to the frame research and also Research Objective 3
4. Determine a DFSS deployment structure which: develops GB maturity; defined project scope and KPI's; match BB'S to scope projects; linkage of DFSS to finance metrics, BB resources dedicated for DFSS and tracking X pattern where DMAIC projects volumes reduce whilst DMADV/ICOV project levels increase and offset LSS projects.

DFSS CSF's and deployment goals are therefore predicted to maximise the utilisation of DFSS MBB capabilities; focussing on VOC/QFD metrics; developing capability maturity of GB's and BB's and maximisation of BB capability aligned with targets relative to DFSS maturity.

Significant time and development cost savings are reported in Agile combined with Lean for Scrum [in Justice, J. (2015)] where the F35 in traditional design recorded $143bn cost over runs and the Similar SAAB JAS 39E Gripen in **Agile design** completed total development at a fraction of the F-35 cost at $20bn. Unit cost for SAAB are $43m compared to increased F-35 cost escalating from $273m to $337m. **Extensive use of Scrum in Agile** is reported with Microsoft X-Box, Boeing, Ericsson, Magna International Automotive and John Deere for new development projects. Strong **leadership** is (central to **Agile and Scrum)** is the capability of doing twice the work in half the time. Innovation in a similar fashion is a result of sustained strong **leadership** and DFSS deployment. Scrum [in Sutherland, J. (2015)] provides a platform for learning and a learning organisation is positioned extremely favourably for Innovation when combined with DFSS capability maturity factual knowledge concurred by interview respondents F, I and K.

Constant innovation is possible through iteration in Scrum and Agile approaches with strong leadership [in Kelly, B. (2012)] driving iterative processes and sustainable innovation and much needed organisational maturity which becomes possible from CMMI level 3 maturity. Leadership remains central to DFSS, Innovation, Organisational learning with Agile and Scrum development included in the CI framework starting with any project listening to the VOC and using Kano Analysis. The balance of DFSS tool identified in Tables 32, 33 and 34 supports the realisation of customer needs.

7.2.3 Research Objective 3:

What is the contribution of CMM to LSS and DFSS implementation where such models have been explored?

Significant benefits are derived from the contribution of a CMM framework within organisations deploying such a maturity framework, where respondents reported only 18% did not use any type of maturity framework in the survey results. This was similarly reported in the responses made by the interviewees. The distribution of CMM ranged from EFQM, MBNQA to CMMI all of which have origins in the Crosby Maturity Grid discussed in Chapter 2. What is of greater significance is the additional reduction in project effort and associated time and cost reductions when combining Success Factors from Research Objective 2 such as Agile and Scrum and increased capability maturity levels observed in CMMI in Figure 34 in Chapter 5. The organisational freedom afforded to a team using **Agile** allows for faster testing and responses to project and customer needs and satisfaction levels. Rework levels are reduced drastically saving time and cost. The strategic reasons for embarking on a CI strategy with LSS and or DFSS is reported as primarily to improve financial metrics and product or service metrics seen in Survey results in Figure 35. The organisational reported savings in Table 35 confirms the significance of LSS and DFSS program deployment across industries and functional areas.

Survey question 30 explored the organisational strategy maturity through communication clarity and more than 90% of the respondents reported clear communicated vision supporting maturity in leadership and vision achievement.

Survey Question number 38 explored and confirmed through the survey responses that when organisational sustainability and employee well-being as key factors are measured and managed it does result in improving the work environment.

CMMI provides a foundation for an integrated CI framework when combined with TOC+LEAN+SIX SIGMA (TLS). Development of the proposed framework with inclusion of the adapted CI framework proposed in Figure 42 in Hohmann, C. (2014) and Beardsley, G. (2005) is possible when combined with the four different staged approaches which is central to the integrated hybrid CI framework proposed in this research document in Figure 50 observed in scenarios 1, 2, 3 and 4.

High levels of *capability maturity provide an organisation and project teams true capacity and flexibility*, where an organisation which is constantly in a **fire fighting mode** and responding to variations in delivery of products and services such a team **does not have this capacity** available and requires stability in internal processes afforded by and integrated framework deploying CI tools. Such tools as TLS and DFSS with the inclusion of Agile and Scrum methods can be applied where appropriate. Increased levels of innovation is possible when the organisation has stability made possible with maturity in organisational processes.

7.2.4 Research Objective 4:

What impact does leadership have specifically in achieving capability maturity?

Survey questions 11, 31-37, 39 and 40 established the impact that leadership has on organisational capability maturity achievement. Question 11 achieved a mean result of 4.264 (where a respondent's response signalling significant leadership support and commitment to LSS and DFSS program deployment is necessary) similar to results obtained in Research Objective 1 in Table 23 and Research Objective 2 in Tables 32, 33 and 34. Interview responses reinforced the impact and necessity of Leadership in effective and sustainable CI deployment. Figure 36 reflected the survey respondent's responses for executive leadership commitment to LSS and DFSS deployment. Interview respondents across industries reported and confirmed similar results to the survey that competent leadership is a critical catalyst for achieving capability maturity.

Industry 4.0 awareness (observed in survey responses in the results from Question 32) displayed two distinct groups seeking to establish the respondent's situational awareness (through internal and external reviews) of the impact of Industry 4.0 on both the organisation and the industry. Figure 37 shows the distribution of answers by the respondents in the histogram where the data from the respondents who agree and strongly agree (34.72%) and those who disagree and strongly disagree (62.5%) are divided but also achieving the lowest mean result of 2.556 and the greatest standard deviation if 1.403 from the questions relating to Research Objective 4. This meant that industry **awareness to the nine pillars presented within Industry 4.0 is not as widely known** as reflected in the survey and interview results.

Similar maturity levels of understanding is also reported in Bentley, C. (2016) where only 27.87% of respondents were *fully aware* of the dynamics of Industry 4.0 and only 33.61% respondents were *somewhat aware* and significantly 38.52% were *not aware at all*.

In Geissbauer, R. Vedso, J. and Schrauf, S. (2016) also we find that maturity and Industry 4.0 awareness increases with organisational size and complexity. Industry 4.0 is disruptive and with an Industry 4.0 strategy the organisation competitive position significantly improved to enhance LSS metrics. This strategy is reported in Kolberg, D. and Zuhlke, D. (2015) who report stress the **necessity for an integrated framework for Lean Automation and Industry 4.0.**

The **absence of leadership** is a key challenge combined with a necessary digital operations vision. "Leadership impact" on achieving organisational maturity is significant in both LSS and DFSS CI initiatives found in Research Objective 1 and 2.

DFSS is only possible with sustained, mature LSS deployment and the development of the necessary organisational stability. Leadership requires acute awareness and drives internal and external reviews for Industry 4.0 organisational impact. Capability maturity should not exclude the impact of **technology which acts as a key Lean enabler** and significant speed, quality and cost benefits in building a competitive advantage when integrated in a framework as proposed by Kolberg, D. and Zuhlke, D. (2015) (such as the framework proposed in Figure 7.1). Leadership therefore has a major contribution to make in achieving the desired capability maturity through CI strategy deployment and the inclusion of Industry 4.0 technology strategy.

7.2.5 Research Objective 5:

How will an integrated framework assist organisations to achieve capability maturity?

The analysis of Research Objective 5 in survey questions 5, 6, 24, 34-36, 38 and 40 was directed at establishing the contribution of a CMM towards maturity capability. The Pearson values for *r* were all above 0.5 and ranged from r = 0,672 for questions 35 and 40 to r = 0.867 for questions 36 and 38 confirming linear relationship observed in all of the questions and no outliers were present.

A Spearman's rank correlation was performed to assess the association between the questions 34 -36, 38 and 40 from a sample of 72 respondents. There was a moderate positive association between all the questions, which is statistically significant, because rho values range from 0,611 to 0,872.

A high level of internal consistency, as determined by a Cronbach's alpha calculation of 0.9238 is observed in Table 44. The interview results differed from the survey responses recorded in Figure 38, whereby 18.1% survey respondents reported not to be using any form of CMM and 40% of the interviewees reported that they were not using any form of CMM. What was noticeable amongst the interview respondents was the awareness of a CMM's probable contribution towards capability maturity with another 83% of them remarking they see their organisations' CI strategy benefitting from a CMM but were also not sure which framework to consider should this become part of the CI strategy.

7.3 Conclusion of Hypothesis

The results of the extensive empirical research undertaken confirm the validity of the research objectives. The research objectives' reliability and inter-correlation for CSF's identified are high and acceptable in Chapter 5.

This would apply to all of the Research Objectives such as CSF's confirmation for LSS and CSF's establishment for DFFS (Research Objectives 1 and 2), the Contribution of CMM to LSS and DFSS implementation (Research Objective 3), the significance of Leadership in achieving

Capability Maturity (Research Objective 4) and how an integrated framework assists organisations to achieve Capability Maturity (Research Objective 5)

It is concluded that the theoretical integrated Capability Maturity Model proposed in Figure 48 and Figure 50 as well as the five Research Objectives identified and assessed are valid. These objectives provides for a construct of a hybrid Continuous Improvement framework. This assumption is based on organisational capability maturity proposed in CMMI and ISO standards necessary for the dynamics of the technology influx presented to organisations in Industry 4.0.

7.4 Limitations of the study

The primary motivation for the study was to establish the common causes for some LSS program failures whilst other organisations are extremely successful with LSS deployments as part of their CI strategy. In the research for higher levels of organisational ability using advanced CI techniques such as TOC, DFSS, Agile and Scrum the need was identified for an integrated Capability Maturity Model which can be used in conjunction with Leadership support and awareness of the CSF's for both LSS and also DFSS failures to present a platform for implementation. It emphasises the importance of ***leadership*** support.

It is observed that numerous organisations do not embrace either DFSS, Agile Scrum, CMM or TOC as part of their CI strategy. The impact of Industry 4.0 technology on organisational improvement is vast but unfortunately also not understood by many organisations. The limited responses for DFSS deployment suggest that the CSF's determined in the research document requires additional research and could change the nature of the CSF's identified but also refers to their ranking of importance.

The productivity impact of Industry 4.0 and labour productivity falls outside the Research Objectives and thus also not part of the hypothesis presented.

7.5 Contribution of the study

Despite the research available for the benefits of Capability Maturity Models there is not a specific solution for both manufacturers and service providers in the face of Industry 4.0. Nor is there a specific solution where the IIOT's and the increased interconnectivity of both physical and cyber physical systems require a standard integrated CMM which is available to functional areas within an organisation who are producing Software and Hardware domains to a single user or market. The infusion of technologies presents challenges for both domains and although the CMMI 4.0 (hybrid CMM) simplifies the staged selection of CI tools and techniques physical implementation will present challenges not considered or evaluated at present.

The necessity to avoid costly CI strategy deployments and to change programs is clear. ***Not pursuing an integrated approach could impede on organisational sustainability, innovation and competitive domain positions.***

The framework proposes a selection of staged ISO standards within CMMI, which will determine the status of the organisational business and operational processes. It also allows for the determination of an action list of where improvements are necessary and the assessment of maturity of various CI tools (such as TLS, DFSS, Agile and Scrum deployed through constant Hoshin Kanri deployment and KPI reviews) for technologies and products required for Industry 4.0.

7.6 Recommendations for further research

This research has shown that **the contribution of Capability Maturity Models success** pivots on leadership and a holistic approach throughout the supply chain, resulting in maturity and organisational process stability for effective CI tool deployment. The contribution of technological advances such as the nine pillars presented in Industry 4.0 will continue to influence consumer and industry behaviours.

The impact of Industry 4.0 and the continued decline in *labour productivity "growth"* in Figure 51 is uncertain even in the face of rigorous and analytical projections. Industry 4.0, proposed as an enabler for CMM in TLS and DFSS, will require additional research and analysis of the influx of interconnected technologies throughout the supply chain in both services and manufacturing industries. The continuous improvement possibility within the nine pillars of

Industry 4.0 technology in Figure 20 is also not clear and the associated impact in achieving Lean with future Labour productivity growth is not fully known in the absence of published domain research.

Hawkins, S.E. (2014) and Musk, E. (2016) caution that when AI and machines become "self-aware" and overtake human intelligence the risks through predictive analytics to the human race will increase in a manner we cannot fathom to predict. The impact of this "self-awareness" should not be ignored and should receive further attention and research. The aim in continuously improving all aspects of life should not be at the expense of life as we know it.

The impact of maturity models within the 4th Industrial revolution will continue to manifest its relevancy and only a thorough understanding of the divergence of technologies and industries through maturity models will enable practitioners to harvest the full benefit of the interconnected business world.

Industry impact studies for Industry 4.0 and organisational capability maturity could establish the organisational GAP analysis as stated in Slack, et al. (2010). Impact research in Schlaepfer, R.C. and Koch, M. (2015); Otto, H.P. (2016); and in Geissbauer, Vedso, J. and Schrauf, S. (2016) underlines the significance and the necessity to *comprehensively position* and also *strategically adjust* the organisations' position to use Industry 4.0 technology to improve the customer relationship, market penetration, operational efficiency such as cost and speed and ultimately secure a sustainable and integrated organisational CI strategy inclusive of capability maturity.

Current developments are observed in ZF (ZF Friedrichshafen AG, also known as ZF Group and abbreviated as ZF) who are partnering with Baidu in Sommer, S. (2017) because strategically they are partnering with a leading Artificial Intelligence technology, Big data and Cloud based service product solutions which are pivotal in the innovative technology required for autonomous vehicles safe and efficient operation. Patented technology in their ZF ProAI solution is the infusion of such information with other big data from car-to-X communication is possible and available as an integrated solution to OEM car manufacturers as a one stop solution provider.

Wu, R. (2017) reports that rapid increase in the demand for reliable, integrated, autonomous driving and telematics will increase both Baidu and ZF competitiveness in China. Challenges faced in autonomous driving solutions relate to the reformation of industrial structure, innovation and technology whereby the **vital symbiotic relationship** is central to accelerating physical market utilisation and business commercialisation. This project Apollo will emphasise integrating technology and business partners to deliver market demand of autonomous solutions based on vehicle and hardware systems. Scrum and Agile within CMMI are Baidu CI tools whereas ZF uses LSS, DFSS in the ZF production system which increasingly depends on software solutions integrated with their hardware.

According to Marr, B. (2017) at Coca-Cola they are using AI and Big Data to "literally squeeze" all customer personal preferences out of the information it receives from social media, mobile applications, e-commerce and distribution points where the **Artificial Intelligence** is imbedded in the point of sales (including vending machines), monitoring mixing preferences and consumption behaviours. Mass customisation for the traditional Coke allows users to mix their own flavour of Cola drinks, which in turn is fed back to Research and Development for possible inclusion in new mass market products across the globe. Chambers, G. in Marr, B. (2017) remarks that Artificial Intelligence is the platform deployed to drive digital innovation and "creating intelligent experiences". More examples exist in financial, medical and aerospace industries producing physical and cyber physical solutions made possible within Industry 4.0.

Kolberg, D. and Zuhlke, D. (2015) also propose the need for an integrated framework in which Industry 4.0 and Lean Production can maximise technological advantages presented in Smart Operator, Smart product, Smart machine and Smart planner and selecting appropriate technologies to function to increase Lean with CPS, PLC and HMI integration.

As stated previously the ***quantification of the potential exponential improvements*** presented in Figure 50 and the inclusion of Industry 4.0 technologies (when combined with constituents in this framework presented) can only be determined in additional and further focussed research.

7.7 Concluding arguments

In conclusion it is clear that global organisations across a variety of industries will continue to have a need for continuous improvement to both embrace and weather the advent of Industry 4.0 in their respective competitive landscapes. Industries will also be careful to avoid the business scenarios where the CI strategy chosen only delivers maximum Return on Investment in its intended design and does not fail. It also emerges from the research that known tools and techniques individually (and in combinations) yield results. Sustaining these results and maximising these opportunities requires an integrated holistic CI framework which considers the advances in technology and also advanced products delivered which have become increasingly interconnected with its users and its environment.

Quantum computing advances in Tencer, D. (2017) propagate that real wages paid to employees have remained stagnant in factories for the past four decades and that average hourly tasks at $28ph in 2017 will be replaced by robotics at a cost of $20ph in 2020. Globalisation has less of an effect on salary earnings than automation does in the pursuit of increased levels of customer services and product reliability. In other words automation in Industry 4.0 is a threat to a large number of employees who are not skilled in other disciplines.

A paradigm shift is inevitable [predicted in Lawton, J. (2017) between the years 2045 and 2050. AI (Artificial Intelligence) which will enable computers to be both smarter and more responsive than human beings. Contrary to Spencer, D. (2017) all is not doom and gloom. Building the IIOT will further enable manufacturers to automate the analysis of critical data for decision making in a flow of continuous stream, achieving accurate algorithm-based decision making autonomously. The maturity of the organisation that has to be sustainable within this environment of big data analytics is of significance in assimilating data for quality yields of 6 sigma and higher. Such data will be a necessity to sustain Innovation of existing processes with the necessary organisational Agility to respond to stakeholders' TBL expectations. The *vision of Industry 4.0 will be achieved through robots with innate cognitive abilities and necessitating the proposed CMM* presented in CMMI 4.0 to assist with the migration to excellence through zero defect repetitiveness at efficiencies previously not envisaged.

The integration of both LSS and DFSS considering the CSF's and the need to monitor capability maturity to maximise ROI during CI program evolution is the following model proposed using the CMMI 4.0 in Figure 50 (presenting a model integrated with LSS, DFSS, TOC, Scrum and Agile components).

Innovation identified in the model is not reviewed in this paper but is a result of stability and focussed DFSS, TOC, Agile and Scrum, VOC/QFD and CTQ tool application and deployment remain pivotal to achieve successfully design new products or services. The advances in autonomous passenger vehicles has necessitated the integration of organisations such as AIG, Airbus, AMD, BMW, Boeing, Deutsche Bank, GE, ZF, Ibeo, Google, Intel, Ford, Textron, NASA, Unilever, HSBC, Microsoft, DHL, Bosch, BlackRock, Siemens, Mercedes Benz, FedEx, Man

Group, HP, IBM, Tata, Volkswagen Group and Bridgewater Associates to integrate their respective hardware and software (tangible and intangible) products into a reliable robust Light Detection and Ranging (LIDAR) solution that exceeds Six Sigma quality for reasons of safety combined with Big Data analytics observed in Industry 4.0 and AI. The organisations that are familiar with maturity models such as EFQM, MBNQA and CMMI already can capitalise where such the opportunity exists for the deployment of an integrated framework for CI across organisations, functions and product technology.

The innovation opportunities that are realised with augmented reality simulations combined with multiple DOE's and regular Agile and Scrum testing iterations will save significant cost and increase responsiveness to the market needs. Increased value will be delivered in this AI environment in Industry 4.0 continuously driving cost, process and quality improvements, reducing waste and continuously improving margins. This will furthermore accelerate the NPI process and afford the clients make-to-order and highly customised products. Lawton, J. (2017) also concurs in Essman, H. and Du Preez, N. (2009) and their general findings for their proposed model's composition to evaluate innovation capability in which an organisation will operate and continuously improve itself.

The design, development and deployment of an integrated capability maturity framework acts as a prominent catalyst for effective deployment of any continuous improvement strategy, maximising a multitude of improvement tools and techniques, cascaded across the organisation value streams and associated supply chains with the support of robust leadership and harnessing the full potential of Industry 4.0 technologies.

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Annexures

Annexure A – Online Survey in Survey Monkey (CMMI, LSS and DFSS)

Secondary Research - Copy of Critical Success Factors for Six Sigma design and deployment to complement Lean operational strategy towards Capability Maturity.

Top of Form

1. Please provide the name of your company:

2. Please select which one of the following industry sectors best describes your organisation scope: w 0

3. What is your job title?

4. Please indicate in what period the LSS/DFSS journey initiated:

- Before 1990
- Before 2000
- Before 2010
- After 2010

5. Does your organisation measure its Continuous Improvement Maturity (CIM)?

- Yes
- No

6. If your organisation measures CIM, please select a Maturity Model below:

- European Foundation of Quality (EFQM)
- Malcolm Baldridge National Quality Award (MBNQA)
- Deming Prize
- CMMI
- Shingo Model
- ITIL Maturity Model
- ISO/IEC 15504 Maturity Model
- OPM3
- COBIT
- SSE-CMM
- BPMM
- PCMM
- Other (please specify)

7. Please indicate whether if DFSS is integrated in your design and development phases of products and or service design:

- Yes
- No

8. Please indicate the number of dedicated full time resources within the organisation for LSS and DFSS (Black Belts, Master Black Belts, deployment leaders):

- 0-5
- 6-20
- 21-50

- 51-100
- 101-200
- 201-500
- 501-1000
- 0 - 2 % of permanent staff
- ≥ 2 % of permanent staff

Other (please specify)

9. Please indicate the number of employees who participate part time in LSS and DFSS activities, i.e. Yellow and Green belts:

- 0-5
- 6-20
- 21-50
- 51-100
- 101-200
- 201-500
- 501-1000
- 0 - 2 % of permanent staff
- ≥ 2 % of permanent staff

Other (please specify)

10. Please rate the following statement: Effective mentoring and coaching are provided for Belts and key staff working on LSS and or DFSS projects:

- (5) Strongly Agree
- (4) Agree

- (3) Neutral
- (2) Disagree
- (1) Strongly Disagree

11. Please rate the following statement: Executive leadership is committed to LSS and or DFSS:

- (5) Strongly Agree
- (4) Agree
- (3) Neutral
- (2) Disagree
- (1) Strongly Disagree

12. Please rate the following statement: LSS/DFSS projects Status and ROI are tracked effectively from inception until fruition:

- (5) Strongly Agree
- (4) Agree
- (3) Neutral
- (2) Disagree
- (1) Strongly Disagree

13. Please rate the following statement: We effectively measure financial metrics ROI/ROAM/ROCE/EBITDA for LSS /DFSS projects:

- (5) Strongly Agree
- (4) Agree
- (3) Neutral
- (2) Disagree

○ (1) Strongly Disagree

14. Please rate the following statement: All LSS/DFSS projects are linked to Hoshin Kanri / Strategy deployment:

○ (5) Strongly Agree

○ (4) Agree

○ (3) Neutral

○ (2) Disagree

○ (1) Strongly Disagree

15. Please indicate which of the following functional areas LSS/DFSS has been implemented successfully? (Select multiple functional areas where applicable) :

☐ Accounts / Finance

☐ Customer Service

☐ Engineering

☐ Health, Safety and Environmental

☐ Human Resources

☐ ICT

☐ Logistics / Transport

☐ Planning

☐ Product Development / Research

☐ Production / Manufacturing

☐ Quality

☐ Sales / Marketing

Other (please specify) ______

16. Choose the best fit answer. In parts the organisation where LSS has demonstrated the most significant improvement:

- Accounts / Finance
- Customer Service
- Engineering
- Health, Safety and Environmental
- Human Resources
- ICT
- Logistics / Transport
- Planning
- Product Development / Research
- Production / Manufacturing
- Quality
- Sales / Marketing
- Other (please specify)

17. Choose the answer that best fits the questions. In which functional areas of the organisation where DFSS has demonstrated the most significant improvement:

- Accounts / Finance
- Customer Service
- Engineering
- Health, Safety and Environmental
- Human Resources

- ☐ ICT
- ☐ Logistics / Transport
- ☐ Planning
- ☐ Product Development / Research
- ☐ Production / Manufacturing
- ☐ Quality
- ☐ Sales / Marketing

Other (please specify) ____________________

18. Please indicate which of the functional areas LSS/DFSS has been implemented least successfully. Select multiple functional areas if this is the case:

- ☐ Accounts / Finance
- ☐ Customer Service
- ☐ Engineering
- ☐ Health, Safety and Environmental
- ☐ Human Resources
- ☐ ICT
- ☐ Logistics / Transport
- ☐ Planning
- ☐ Product Development / Research
- ☐ Production / Manufacturing
- ☐ Quality
- ☐ Sales / Marketing

Other (please specify)

19. Please indicate your company's effectiveness to reduce cost deploying LSS/DFSS:

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

20. Please indicate your company's effectiveness to INCREASE revenue whilst deploying LSS/DFSS:

- Strongly Agree
- Agree
- Neutral
- Disagree
- Strongly Disagree

21. Please select which of the following LEAN tools are integral to the Continuous Improvement Program at your organisation: (Select Multiple if that is the case) w 0

- 5S
- Andon
- Bottleneck Analysis / Constraint Management
- Cellular Manufacture
- Continuous Flow
- Gemba (The real Place)
- Heijunka (Level Scheduling)

- Hoshin Kanri (Policy Deployment)
- Jidoka (Autonomation)
- Just-in-time and Kanban (Pull System)
- Kaizen (Continuous Improvement)
- Overall Equipment Effectiveness (OEE)
- Six Big Losses
- Total Productive Maintenance (TPM)
- Plan-Do-Check-Act (PDCA)
- Poka Yoke (Error Proofing)
- Root Cause Analysis
- Single Minute Exchange of Dies (SMED)
- Standardised Work and Takt Time
- Value Stream Mapping (VSM)

Other (please specify)

22. Please select which of the following LSS tools are integral to the Continuous Improvement Program at your organisation: (Select Multiple if that is the case):

- Deming 14 Points
- Juran's Quality Trilogy – Quality Planning, Control and Improvement
- DMAIC
- FMEA
- SPC
- SQC

- MSA / Gauge Capability Indices (Cg/Cgk)
- DOE – Taguchi, Classic and Shainin
- Machine Capability Indices (Cm/Cmk)
- Process Capability Indices (Cp/Cpk)
- Poke Yoke
- TOC
- SIPOC
- ANOVA
- MANOVA
- Supplier Demonstrated Process Capability (Cp/Cpk ≥ 1.67)

Other (please specify)

23. Please select which of the following DFSS tools are integral to the Continuous Improvement Program at your organisation: (Select Multiple if that is the case):

- DFMEA (Design Failure Mode and Effect Analysis)
- PFMEA (Process Failure Mode and Effect Analysis)
- Product FMEA (Failure Mode and Effect Analysis)
- DFM (Design For Manufacture)
- QFD (Quality Function Deployment)
- Kano Analysis
- CTQ (Critical to Quality)
- CCR (Critical Customer Requirement)
- CTX (Critical to Quality, Cost, Service Reliability)

- VOC (Voice of Customer)
- Affinity Diagram / KJ Analysis
- Benchmarking
- DOE – Taguchi, Classic and Shainin
- Process Potential Indices (Pp/Ppk)
- IDOV (Identify, Design, Optimise, Validate)
- PIDOV (Plan, Identify, Design, Optimise, Validate)
- DMADV (Define, Measure, Analyse, Design, Verify)
- Poke Yoke (Error Proof 0ppm)
- Process Simulation
- Agile / Scrum
- Supplier Partnering
- Primavera / Prince 2 / Arena
- TRIZ analysis
- Pugh Matrix
- Validation Techniques
- Problem Solving Techniques
- RBT (Risk Based Thinking)
- Systematic Risk Identification, Categorisation and Mitigation
- Risk: Analysis; Pedigree; Testing, Analysis and Severity
- Cross Functional Team Deployment
- Generic and Detailed Design Scorecard

- Rapid Prototyping
- Weibull Analysis
- Design Reviews
- System Engineering

Other (please specify) ______

24. What was the strategic reason/s for the organisation to embark on a LSS/DFSS journey?

- To be responsive to and focused on the customer base
- To improve product and service performance
- To improve financial performance and profitability of business
- To be able to quantify quality programs
- To be considered as a supplier for a contract
- Survival / loss of business
- Corporate policy
- Merger and acquisition
- Innovation
- Improve customer satisfaction
- Research and development
- Quality requirements

25. What are the 5 most important Critical Success Factors for successful LSS implementation, please rank in order of importance?

26. What are 5 most important Critical Success Factors for DFSS implementation, please rank in order of importance w 0

27. What are the 5 most common reasons many organisations avoid implementing LSS/DFSS?

28. Does employees receive compensation / rewards for Successful LSS/DFSS projects?

- Yes
- No

29. Is LSS/DFSS projects linked to a KPI's for individual or group employees?

- Yes
- No

30. Business Excellence Survey - Please rate which answers is a best fit to your organisation Organisational vision is clearly stated and communicated to every employee in every division at every level:

- (5) Strongly Agree
- (4) Agree
- (3) Neutral,
- (2) Disagree
- (1) Strongly Disagree

31. Leadership is constantly evaluating new ways to sustain and grow the organisation:

- (5) Strongly Agree

- (4) Agree
- (3) Neutral,
- (2) Disagree
- (1) Strongly Disagree

32. Internal and external reviews are performed to observe how the organisation can address the impact of Industry 4.0:

- (5) Strongly Agree
- (4) Agree
- (3) Neutral
- (2) Disagree
- (1) Strongly Disagree

33. Regular discussion and review are performed to observe how the organisation can address and minimise the negative impact of products, services, processes and sites to the environment and community:

- (5) Strongly Agree
- (4) Agree
- (3) Neutral
- (2) Disagree
- (1) Strongly Disagree

34. Regular tracking and assessment of customer needs and requirements and associated satisfaction levels:

- (5) Strongly Agree
- (4) Agree

(3) Neutral

(2) Disagree

(1) Strongly Disagree

35. Customer complaints are recorded, analysed and appropriate improvement actions are instituted to prevent recurrence:

(5) Strongly Agree

(4) Agree

(3) Neutral

(2) Disagree

(1) Strongly Disagree

36. Individual initiative, innovation, rapid response, cooperation and effective honest communication is encouraged:

(5) Strongly Agree

(4) Agree

(3) Neutral

(2) Disagree

(1) Strongly Disagree

37. Succession plans for leadership and management positions and career progression plans for employees are developed:

(5) Strongly Agree

(4) Agree

(3) Neutral

(2) Disagree

- (1) Strongly Disagree

38. Key factors related to employee well-being, satisfaction and motivation are determined and monitored to improve the work environment:

- (5) Strongly Agree
- (4) Agree
- (3) Neutral
- (2) Disagree
- (1) Strongly Disagree

39. Initiatives are integral to improve quality of our processes, products and services:

- (5) Strongly Agree
- (4) Agree
- (3) Neutral
- (2) Disagree
- (1) Strongly Disagree

40. Operations and overall organisational performance metrics deploying a wide range of information (e.g. financial, customer satisfaction, employee satisfaction, environmental, suppliers and key processes) are tracked daily:

- (5) Strongly Agree
- (4) Agree
- (3) Neutral
- (2) Disagree
- (1) Strongly Disagree

41. Please indicate if you want a copy of this survey results by supplying your e-mail address in the space below, if not just leave it blank.

Thank you for your participation in this thesis survey. / Vielen Dank für Ihre Teilnahme an dieser

Annexure B Interview Questionnaire

Critical Success Factors for Six Sigma design and deployment to complement Lean operational strategy towards Capability Maturity

Doctoral Thesis Secondary research – interviews with Industry Specialist for Lean, Lean Six Sigma, Design for Six Sigma and Capability Maturity Models.

Year: 2016-7

Student: AJ Viljoen

Tel: +27 60 961 1760

E-mail: albert.viljoen@autoindustrial.co.za or albertviljoen247@gmail.com

Dear recipient of this research questionnaire, please review the following questions and answer to the best of your knowledge and experience to date. You can return the questionnaire and also propose times and dates (GMT) with contact details for telephone or skype interview where this is suitable to your work schedule. Your intimate knowledge and experience will be most useful in understanding LSS, DFSS and CMM beyond Critical Success Factors required in the strategy towards Capability Maturity.

Date of interview:____

Contact details of interviewee: (Tel No:)____________________________

(E-mail:)____________________________

Skype details:____

Your time: UTC/GMT:____

Local Time of interview: UTC/GMT +2 hours (South Africa)__________________________

1. Survey Link: https://www.surveymonkey.com/r/5K5FJGT

Questions in addition to the Survey questions:

1. Please confirm your name, title and organisation name?

Name:

Title:_______________________________

Organisation name:__________________

2. Please can you explain your organisations CI strategy w.r.t. LSS and DFSS approach from inception to its current state, including training, Belt certification, change management and project management?

3. What are the key KPI's in your organisations CI / LSS/DFSS approach?

4. Does your organisation make use of Kano Model and Analysis (1. Must be requirements, 2. One dimensional requirements and 3. Attractive requirements) to support QFD? If yes please explain the process and the reasons?

5. How does field performance and customer needs survey data integrate with product development?

6. Is a higher quality than Six Sigma required (3.4 dpmo)? If so how is this managed?

7. Is lessons learned from LSS projects relayed back to DFSS activities, if so how?

8. Is change management and organisational maturity within the projects measured? If so how?

9. Is PCMM (People Capability Maturity Model) assessments part of the organisations KPI's?

10. Does DFR (Design For Reliability) and DFX (DFM Design For Manufacture) and DFR combined formulate part of DFSS activities? If so please explain?

11. Does DFSS extend to the SC (Supply Chain), if yes, how is it deployed?

12. In terms of organisation maturity how would you rank the following: DFSS, Lean, Six Sigma, CMM, from no 1 being most important and 4 least important? Please motivate each answer.

13. Do you see CMM's such as CMMI, MBNQA and EFQM contributing to the contribution of CIM programs such as DFSS and LSS, if yes, please explain?

14. Do you observe in your experience that there could be a benefit in The Change Management Maturity Model Audit (CMMMA) as an effective tool to improve maturity? Do you agree with the following statement, if so, please explain "An audit does not in itself improve effectiveness, but it helps companies identify gaps and quick wins and provides inspiration to improvement?"

15. Leadership often is significant in achieving business strategy, how would you describe your leadership approach in the CI, LSS and DFSS approach?

16. Describe the significance of financial metrics in LSS and DFSS projects relating to ROA, ROI, ROE, EBITDA, ETC?

17. Please can you comment on linking individual and team performance to LSS/DFSS objectives and the contribution of a reward system linked to projects realised.

18. Why do you see many organisations avoid LSS and DFSS as a strategy?

19. Why do you believe so many organisations fail with implementation of LSS and DFSS strategies?

20. How do you see CI evolving in the near future?

21. What is your organisation’s approach w.r.t. Industry 4.0technologies?

22. How do you foresee these technologies impacting on:

a) Consumers

b) Your business

23. What is the broad 5 year strategy for the organisation?

24. What is the biggest areas of risk in achieving your intended business strategy?

25. How do you and the team manage and mitigate these strategic risks?

26. What is your strategy on sustainability and development?

27. How does your organisation nurture innovation?

28. Is there anything you would like to suggest that could contribute to the research undertaken here and the industry?

Thank you for your participation in this research interview.

Vielen Dank für Ihre Teilnahme an diesem Forschungsinterview