The Efficient and Precision Nature Within The Cyber Physical Systems (CPS) And Industry 4.0 Technologies In Industry Operations.

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Abstract

This paper reviews the extent of the disruptive nature of Industry 4.0 technologies applied to existing manufacturing industries. The inherent efficient and precision nature presented within the Cyber Physical Systems (CPS) and the nine pillars of Industry 4.0 technologies will increasingly exploit industry operations. This development of strategies and the impact thereof is significant for the drivers impacting on competitive forces within industry as well as consumers across the globe.

The paper objective will therefore by means of research study illustrates how to (i) critically analyse the current developments of the nine pillars Industry 4.0 (ii) identify the dynamics of CPS's in the short term and (iii) how a multitude of exponential improvements can be realised for the early adopters of a digital strategy as a catalyst for increased organisational capability maturity through exponential continuous improvements and sustained innovation opportunities.

The research results obtained therefore assisted in the design and testing of a comprehensive integrated Lean Six-Sigma (LSS), Critical Success Factors (CSF's), Design For Six Sigma (DFSS) and CMMI framework interacting and supported by Industry 4.0. The developed framework is undergoing testing at an international auto manufacturer in South Africa. The framework will assist the organisation to optimise processes and product quality coupled with product performance transcending into successful capability maturity outcomes in the pursuit of increased customer loyalty.

Keywords: Capability Maturity, Continuous Improvements, Cyber Physical Systems (CPS), Industry 4.0, Industrial Internet of Things (IIOT's)

1. Introduction

Continuous Improvement remains a pursuit to perfection striving for improvement in products, services and processes. Two classifications of improvements are observed, with one characterised through incremental improvement over a period of sustained Kaizen activities and another of breakthrough improvement of all at once. The Data Science of Continuous Improvement

2. Purpose of the paper

The constant consumer demand and technology changes necessitated the review of contribution in terms of capability maturity in both service and manufacturing industries. It is observed by Jones, C., and Pimdee, P. (2017 that recent technological advances observed in the Industrial Internet of Things (IIoT's - defined as Industry 4.0 technologies) that Industry 4.0 indeed enables Lean through the deployment of smart data science.

3. Related Work

Cyber Physical Systems (CPS's) within the nine pillars of Industry 4.0 enables systems or processes to be both self-adjusting and self-regulating through the interconnected nature of modern-day systems and subsystems. This is facilitated by constant data streams with predetermined logic with human programming but increasingly more significantly in machine learning through Artificial Intelligence.

Data Science is observed as the continuing convergence of the physical and the cyber domains and is observed to be the main driver of innovation and change in all industries of the global economy. The global economy is being transformed as a result of the continued exponentially growing amount of data and the ever-increasing convergence of various low-cost technologies that are emerging through the confirmation of Information and Communication Technologies (ICT) which is responsible for the evolution of the global industrial economy. In Asia Pacific, Europe and North America, the IIOT's, Data and Services is a symbiotic link in managing energy transformation, in developing a sustainable mobility and logistics sector, in providing enhanced health care and in securing a competitive position for the leading manufacturing industry.

This article discusses the Data Science of Continuous Improvement and its impact, challenges and opportunities of digitisation and concludes with recommended policy action. The two key instruments for enhanced value creation in the CPS in Industry 4.0 are platform-based cooperation and a dual innovation strategy as observed also in Kagermann, H. (2015).

4. Research Design

The nature of this research is primarily exploratory and descriptive. The main elements of the research are formed by Phase 1 by means of thorough literature reviews in terms of emerging Industry 4.0 technologies, Lean Six-Sigma (LSS), Design For Six Sigma (DFS)S and Capability Maturity (CMMI), (note: - limited number of literature / references shown in this paper). Phase 2- survey questionnaires and interviews with industry specialists. Phase 2 targeted knowledgeable LSS and DFSS industry participants across South Africa and Internationally. The questionnaires and interviews were designed with specific research objectives to determine:

- **i.** Research Objective 1: The most significant CSF's for LSS successful deployment in an organization.
- **ii.** Research Objective 2: The most significant CSF's for successful DFSS deployment in an organization.
- **iii.** Research Objective 3: The contribution of CMM to LSS and DFSS implementation where such models have been explored.
- **iv.** Research Objective 4: The impact leadership have in achieving capability maturity.
- **v.** Research Objective 5: Designed integrated framework assisting organisations to achieve capability maturity.

In addition to the five research objectives the paper is designed to (i) critically analyse the current developments of the nine pillars Industry 4.0 (ii) identify the dynamics of CPS's in the short term and (iii) how a multitude of exponential improvements can be realised for the early adopters of a digital strategy.

5. Critical analysis of the nine technological pillars observed in Industry 4.0

The nine technological pillars observed in Industry 4.0 are (i) **Industrial Internet of Things (IIOT's**) - embedded computing enables field devices to communicate and interact both with one another with more centralised controllers including decentralise analytics and decision making in terms of enabling real-time responses; (ii) **Cyber Security** – closed and unconnected cyber systems are no longer the norm with increased levels of interconnected devices necessitating the increased need for robust cyber security protocols; (iii) **The Cloud** – increased levels of data interchange across the organisation, assets and supply chain as a characteristic of Industry 4.0.; (vi) **Additive**

Manufacturing (AM) – categorising a process by which digital 3D design data is used to build up a component in layer upon layer of material deposits; (v) **Augmented reality** - based systems that support a variety of services, such as selecting parts in a warehouse and sending repair instructions over mobile devices.; (vi) **Big Data Analytics** - has emerged as a simile for many varying business intelligence (BI) and application-related applications.;(vii) **Autonomous Robots** - autonomous robots are intelligent machines capable of performing tasks in the world by themselves, without explicit human control or command; (viii) **Simulation** – during the design phase, 3D simulations of products, materials, and production processes with increasing modelling and accuracy whereby these simulations also replicate virtual organisations and operations. This real-time data replicates the physical world in Cyber Physical Production System (CPPS) such as equipment, products, process and human interaction. and (ix) **Horizontal and Vertical System Integrations** – where several of the world's most technological IT systems are still not integrated in totality. This include Supply Chain Management (SCM) and visualising real time SCM issues inclusive of functional areas such as logistics, quality, R&D, engineering, production and service.

Figure 1 depicts the 9 pillars of Industry 4.0 that supports both LSS and DFSS methodologies in using Big Data computing, Autonomous Robotics, Design Simulation, System Integration, Internet of Things, Cybersecurity, Cloud Computing, Additive Manufacturing and Augmented Reality that enables cost, reliability and speed parameters.

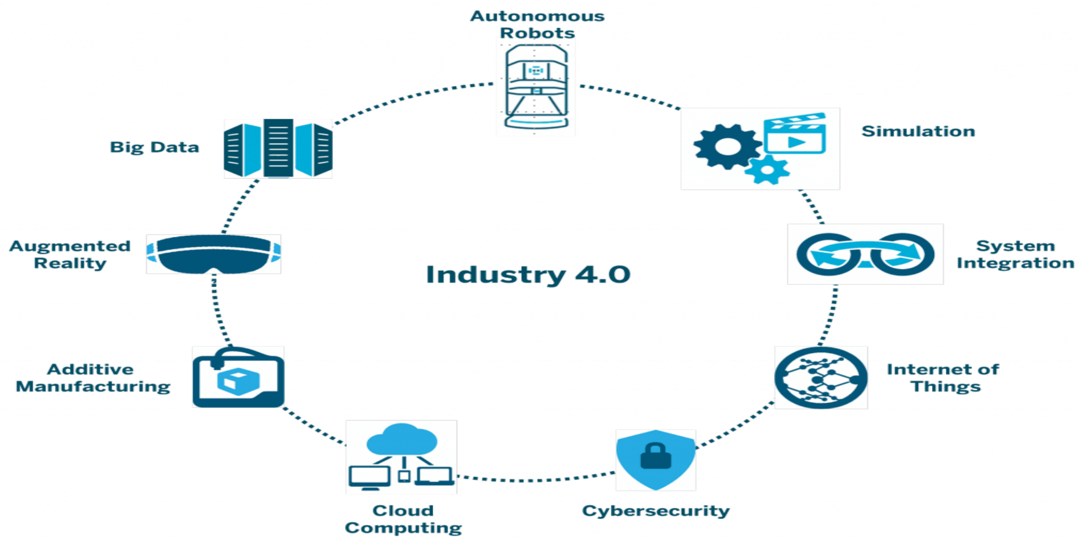

Figure 1. Industry 4.0 and 9 technological pillars presented in Cyber Physical Systems (CPS).

All the above ensures that Industry 4.0, companies, departments, functions, and capabilities are increasingly evolving into a cohesive, data-integrated networks evolve and enable truly automated value chains.

6. CPS dynamics and industry relevance

The term Cyber-Physical System (CPS) originated at the National Science Foundation (NSF) in the United States around 2006 in Gunes et al. (2014) which depicts a variety of complicated multi-functional interdisciplinary advanced technologies which are known to be physically-aware of their functionality and integrated in various industries. This integration is not only limited to observation, communication and control aspects of the physical systems from the multi-disciplinary and multi-functional viewpoint. CPS take advantage from the integration of cloud-based and Service-Oriented Architecture (SOA) to deploy end-to-end support from the cradle to the grave perspective. CPS can interact with all the hierarchical layers of the automation pyramid (i.e. ERP, MES, SCADA, PLC, field level) and are able to empower the exchange of information across all the phases, resulting in a better product-service development considering product and process efficiency, timing and sigma quality.

It emerges to be very significant that CPS have the potential to impact massively globally in terms of economy and society and therefore industrialist operating in CPS and Industry 4.0 domains take note of future developments. Furthermore, several challenges should be addressed such as privacy, security, dependability, genitive abilities, human interaction, ubiquity, standardisation, robust connectivity and governance.

7. Exponential impact of Industry 4.0 technologies

To determine the extent of Industry 4.0 technologies on industries and societies is not very simple due to the nature of the CPS and its inherent nature to accelerate operations, improve quality constantly trough self-regulation, real-time-measurement producing flawless processes and products, maximising yields with exceptional levels of flexibility and Lean Six Sigma personified.

Some maturity models have already been developed for determining Industry 4.0 capabilities. These models explore both readiness for Industry 4.0 and maturity of organisations in the production and manufacturing industries.

8. Research findings

The research results obtained assisted in the design and testing of a comprehensive integrated LSS, CSF's, DFSS and CMMI framework interacting and supported by Industry 4.0. The framework assist organisations to optimise processes and product quality coupled with product performance transcending into successful capability maturity outcomes in the pursuit of increased customer loyalty.

The CSF's contributing to effective LSS deployment was confirmed in comparing previous literature reviews of 31 similar research documents. Research survey results obtained across multiple industries (Financial, Insurance, Pharmaceutical, ICT, Aerospace, Automotive, etc.) and participant responses from global geographical origins (Asia, USA, Canada, Europe, South Africa, etc.) inclusive of interviews with industry specialist to determine geographical assisted in identifying industry relevance of CSF's and LSS.

Table 1 summarises CSF rankings according to Cronbach's alpha. The survey results confirmed Management commitment as the single most important CSF in achievement of successful LSS deployment. The significant changes in CSF ranking is observed in the 2016 survey results where the increased prominence in ranking position is found in CSF's number 4, 5, 6 and 8 compared to earlier research in Laureani, A. and Antony, J. (2012). Interviews conducted also confirmed that the metrics should not be exclusively linked to financial improvements but also customer LSS metrics in CSF number 4. LSS staff selection has emerged as a significant CSF including Myers Briggs personality testing on Black Belts and Master Black Belts in similar research conducted in Thompson, S.J. (2007) determining TJ personality profiles as more suited for Six Sigma project leadership than other personality types in ranking CSF number 5.

Table 1. Survey results in Critical Success Factors determination for Lean Six Sigma Deployment.

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

8.1 Research Objective 1: The most significant CSF's for LSS successfu**l deployment in an organization.**

It is noted that LSS financial accountability (umber 6) emerged as prominent CSF and is ranked at position 7 where more than half of the respondents in both survey and interviews confirmed the importance of linking LSS metrics with financial metrics. This typically would include divisional and organisational annual financial reports. Additionally, Extending LSS to the SC (number 8 - ranked in 9th position) will not be practical if Linking LSS to customer (number 4), Selection of staff for LSS (5) or even 6 Sigma Quality when the supply chain is not delivering similar sigma metrics with their input processes. This aspect is the single highest risk to the attainment of Six Sigma quality and metric targets. Interviews conducted confirm Industry 4.0 as a significant technological enabler of achievement of both Lean and Six Sigma objectives.

8.2 **Research Objective 2: The most significant CSF's for successful DFSS deployment in an organization.**

The CSF's determined for effective DFSS deployment was limited to the survey results and the responses obtained from interviews conducted is illustrated in Table 2 illustrate notable is the significance of VOC and Kano analysis tool. The Cronbach's alpha result of 0.8600 and a mean rating of 4.077. LSS Organisation maturity illustrate a ranking of 2nd with a mean rating of 4.295. Leadership and management commitment are also prominent in the Cronbach's alpha ranking in 7th position with a mean rating of 4.525. CSF's 12, 13 and 15.

Table 2. Critical Success Factors identified for DFSS deployment

CSF Description DFSS	Mean Rating	Std. Dev	Rank	Cronbach's alpha
VOC / Kano Analysis tool use	4,077	0,613	1	0,8600
LSS Organisation Maturity	4,295	0,715	2	0,8589
DFR / DFM capabilities	3,988	0,702	3	0,8552
TRIZ knowledge	4,198	0,743	4	0,8520
Design and Tollgate reviews	3,892	0,232	5	0,8518
DOE capability	3,813	0,694	6	0,8516
Leadership and management commitment	4,525	0,495	7	0,8513
Maturity in Agile and Scrum	4,392	0,676	8	0,8463
QFD and CTQ design integration	3,948	0,232	9	0,8449
Risk identification and mitigation	3,798	0,659	10	0,8418
Supplier and Technology Process Capabilities	3,122	1,014	11	0,8407
Product Innovation	3,279	1,098	12	0,8382
Process Innovation	3,045	0,967	13	0,8353
BB and MBB BOK (MSA, Multiple Regression Analysis, DOE)	3,386	0,967	14	0,8312
People Innovation	3,507	0,944	15	0,8242
Dedicated DFSS practioners	3,648	0,802	16	0,8238
Design Engineering and Design Tool knowledge/use	3,636	0,822	17	0,8232
DFMEA reviews of multi-disciplinary teams	3,623	0,857	18	0,8231

The significance of Maturity of Agile and Scrum ranked in 8^{th} position with a mean rating of 4.392 during product development holds relevance in research conducted when Agile and Scrum was combined with both CMMI level 1 and level 5 maturity seen in Figure 2.

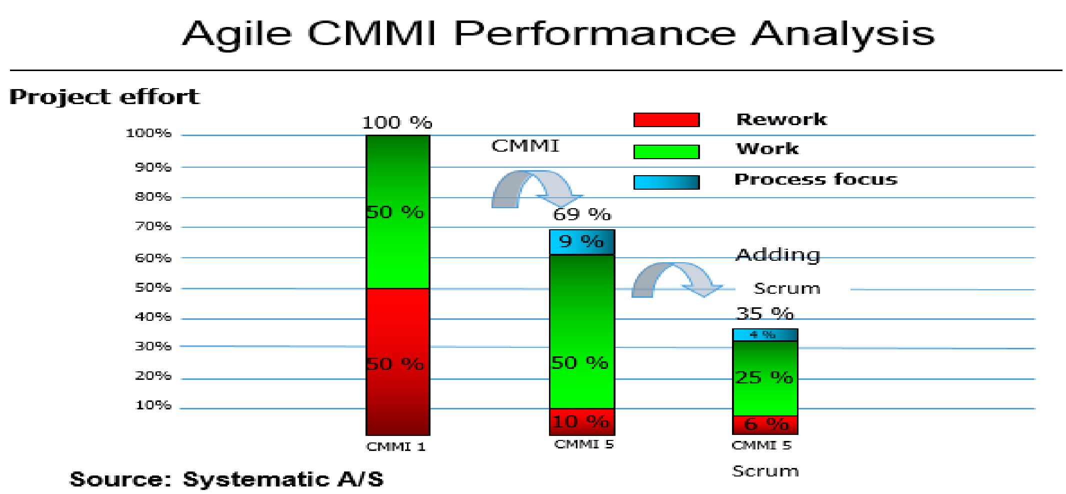

Figure 1. Agile CMMI Performance Analysis when combined with Scrum and varying CMMI maturity levels

Sutherland, J. et al (2007) also reflects that the breakthrough results achieved at Systematic is attributed them being the only Scrum company in the world appraised at CMMI level 5 integrated with Lean. It should be noted that CMMI will improve the Sigma Quality but not the rate of production, Scrum enables project delivery and speed increases. Industry 4.0 presents increasing levels of continuous and sustainable improvements being realised as a result of Cyber Physical Systems made possible with quantum computing and Big Data and real-time predictive analytics.

8.3 Research Objective 3: The contribution of CMM to LSS and DFSS implementation where such models have been explored.

Industry 4.0 presents several supporting enablers to Capability Maturity Model and to LSS and DFSS methodologies as illustrated in figure 1. It is noted that Lean in Toyota Production System (TPS) seeks to support the two pillars in Muda reduction in the achievement of the two TPS which are (i). Just-in-Time (JIT) and (ii) JIDOKA (Autonomation).

The research results obtained in both survey and interview results confirm the contributions as significant and confirmed by both interview respondents who are CMM users inclusive of those respondents who does not have such a framework implemented. All recognises the principles of basic CMM in identifying gaps which can be resolved and in turn improve any CI strategy.

8.4 Research Objective 4: The impact that leadership have in achieving capability maturity.

Leadership is the key enabler for providing vision and Akao, Y. (1988): - Hoshin *Planning: Policy Deployment for Successful TQM*, sustained resources for the achievement of Innovative Black Belt projects such a designed with inputs from McKinsey and Company at Clariant.

In Geissbauer, R. Vedso, J. and Schrauf, S. (2016) also maturity and Industry 4.0 awareness increases with organisational size and complexity. Industry 4.0 is disruptive and with an Industry 4.0 strategy afford the organisation competitive position significantly improved to improve LSS metrics reported in Kolberg, D. and Zuhlke, D. (2015) who report the necessity for an integrated framework for Lean Automation and Industry 4.0.

The absence of leadership is also reported to be 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 researched in researched objective 1 and 2. DFSS is only possible with sustained mature LSS deployment and the development of the necessary organisational stability. Leadership requires awareness and drive 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 building a competitive advantage when integrated in a framework as proposed by Kolberg, D. and Zuhlke, D. (2015) such as the framework proposed in Figure4. 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.

8.5 Research Objective 5: Designed integrated framework assisting organisations to achieve capability maturity.

A Capability Maturity Model (CMM) addresses the capabilities of a business process and the entire organisation, expressed as overall maturity, to deliver higher performance over time. The present study has elaborated on the theoretical model components to specify what is being measured by a CMM. The proposes integrated framework titled CMMI 4.0 was developed to consist of staged Continuous Improvement implementation using CMMI maturity and Industry 4.0 technologies to facilitate the integration of improvement methodologies and best practices available in the 9 pillars of Industry 4.0 in Table 3.

Table 3. Industry 4.0 Primary Industry Benefits.

i	ii
Productivity	Flexibility
1. Automation	1. Robitics and manufacturing agility
2. Asset utilisation	2. Responsive to customer needs
3. Improved productivity	3. Varying design and volume mix
iii	iv
Quality	Speed
1. Autonomation in real-time	1. Product Devleopment Speed increased
2. Self-regulating process quality	2. Agile and Scrum = rapid development to market
3. Errors are pre-empted and avoided	3. Simulation increases accuracy and development
a. Increased safety through automation	d. Reduce resource utilisation (Water, Energy. Etc)
b. Improved ergonomics in worklpace design	e. Increased innovative capabilities
c. Collaboration improved through data analytics	f. Artificial Intelligence improved decision making

Similar observations are reported for Industry 4.0 and CPS which implies Lean manufacturing in Sanders, A., Elangeswaran, C. and Wulfsberg, J. (2016).

9. Integrated Capability Maturity Framework (CMMI 4.0)

CMMI 4.0 – fugure 4,. represents the Integrated Capability Maturity Framework designed and developed to harness the varying Continuous Improvement methodologies. It focuses on both hard and software industries due to the need for improved speed and agility in the design of end products to market execution inclusive of a constant increased connectivity of CPS and consumer solutions where one methodology becomes the constraint as opposed to the needed improvement solution.

The Capability Maturity Model has been labelled CMMI 4.0 due to the compositions and the direct link to Industry 4.0 enabling technologies to achieve high yield sigma product quality, JIT deliveries, Jidoka process management and ultimately maximising Return on Investment (ROI) for improvement projects.

The framework in Figure 3 uses a basis of CMMI level 1 to 5 maturity whilst making provision for Theory of Constraints, Lean and Six Sigma to be utilised throughout all maturity stages and the respective ISO standards developed to also guide the user in effective deployment. Maturity level and maturity model use is not of key importance although this is recommended to become and remain an Innovative and self-regulating industry participant.

Maturity level of CMMI level 2 is a minimum standard although CMMI level 3 is the suggested maturity level for sustained data driven decision making in reviewing existing and new process and product development and often also an industry requirement for the supply chain. The increased contribution in innovation possibilities within DFSS and CMMI at maturity levels 4 and 5 warrants further research, not included within the scope of this research document.

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 Schlaepler, 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.

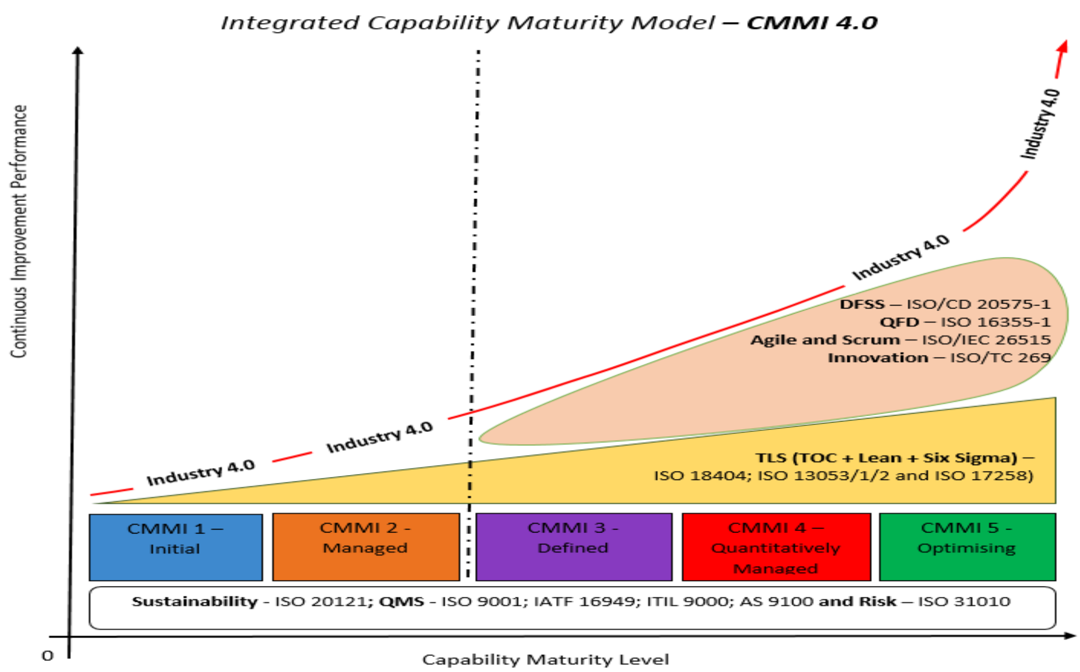

Figure 3. CMMI 4.0 - Integrated Capability Maturity Model developed to harness multiple Continuous Improvement methodologies within CMMI.

The constant review of Industry 4.0 as enablers to increased cost and customer satisfaction metrics are pivotal in achieving CMMI level 4 and 5 but also economically.

The CMMI 4.0 framework includes a plethora of existing ISO standards and some in advance stages of review and development, affording the user a navigation map in achieving increased levels of Continuous Improvement with a linear increase in organisational maturity capability.

10. Conclusion

The final graphical representation of an integrated framework constructed (figure 3) was) made possible with analysis of standardised tools available and inputs in Phase A. 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. 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 assist organisations to achieve Capability Maturity (Research Objective 5).

It is concluded that the theoretical integrated Capability Maturity Model proposed in Figure 4 (CCMI 4.0) as well as the five Research Objectives identified and assessed are valid and provides for 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.

Final note is that 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 CSF's identified but also their ranking of importance.

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Biography / Biographies

Andre Vermeulen is a Senior Research Associate at the Post-Graduate School of Engineering Management in the Faculty Built and Engineering Management at the University Johannesburg, South Africa. He earned DPhil Engineering Management from University Johannesburg and presently supervise numerous doctoral and master's students. Dr. Vermeulen completed research project in An Analytical Instrument to Measure the Status of An Organisation Business Process Capability. His research interests include manufacturing, simulation, optimization, reliability, scheduling, manufacturing, lean, Lean-Six Sigma, and Business Process Capability. He has presented numerous papers and articles over the years at IEOM, IAMOT, PICMET and IEEE.

Jan Harm C Pretorius obtained his BSc Hons (Electrotechnics) (1980), MIng (1982) and DIng (1997) degrees in Electrical and Electronic Engineering at the Rand Afrikaans University and an MSc (Pulse Power and Laser Physics) at the University of St Andrews in Scotland (1989), the latter *cum laude*.
He worked at the South African Atomic Energy Corporation (AEC) as a Senior Consulting Engineer for fifteen years. He also worked as the Technology Manager at the Satellite Applications Centre (SAC) of the Council for Scientific and Industrial Research (CSIR). He is currently a Professor and Head of School: Postgraduate School of Engineering Management in the Faculty of Engineering and the Built Environment. He has co-authored mora than 200 research papers and supervised over 39 PhD and 220 Master's students in Electrical Engineering and Engineering Management. He is a registered professional engineer, professional Measurement and Verification (M&V) practitioner, senior member of the Institute of Electrical and Electronic Engineering (IEEE), fellow of the South African Institute of Electrical Engineers (SAIEE) and a fellow of the South African Academy of Engineering.

Albert J Viljoen is a General manager in their Super Factory for a large corporate business in South Africa. He was awarded his D. Phil Engineering Management from the University of Johannesburg and he also lectures part time at two universities. Dr Viljoen completed a research project and developed a capability maturity model depicting the exponential improvement possibilities within Industry 4.0 in combining the model in CMMI, and methodologies such as Lean, Six Sigma, Design for Six Sigma, Agile, Scrum and Theory of Constraints collectively based on organisational maturity. His research interests include Physics, Mechatronic Engineering and the ever-increasing influence on society in the Digital present and future states. He has published papers and articles at IAMOT and SAIIE. A series of 9 papers are currently under development for each one of the 9 pillars found within Industry 4.0 with a publication timeline of 2018-2020.