



# **Design of a quality development model for South African small manufacturers: a capability maturity perspective**

**C Miller**



**[orcid.org/ 0000-0002-2199-3860](https://orcid.org/0000-0002-2199-3860)**

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Supervisor: Prof JEW Holm

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## **ABSTRACT**

Implementing a quality management system often requires major alterations to an organisation's methods, processes, and cultures, requiring significant resource commitment and expert consultation. Consequently, and more often than not, small manufacturing organisations operate without a structured quality management system. In response, this research project sets the focus on quality management in an attempt to provide a solution to a real-world opportunity in the form of a quality management gap in the management methodology of small manufacturers. The research is conducted in a Design Science Research paradigm that delves into general quality management theory, the ISO 9001 standard for quality management systems. It also explores the characteristics of the total quality management philosophy as applied to a manufacturing operational environment. The result of this was a manufacturing-oriented framework for total quality management that was utilised in an industry survey to define a cross-sectional view of quality management among South African small manufacturers, which provided real-world context to the problem statement and allowed for practical orientation of the research design process.

As a proposed solution, this research project explored the Capability Maturity Model as a solution to make quality management more accessible and of systemic value to manufacturing SMEs. The approach was verified by ensuring that the model would instil the desired total quality management characteristic if implemented in a manufacturing context. Furthermore, the validation mechanism relied on a cross-comparative literature analysis between the Capability Maturity Model and ISO 9001, as a globally recognised standard for quality management capability and one of the most prominent quality management paradigms among South African organisations. The primary contribution of the project details an engineering management model designed to suit the needs and constraints of manufacturing SMEs. Furthermore, concluding that the Capability Maturity approach offers a quantitative perspective to the implementation of quality management, meaning that quality can be approached as a measurable attribute of the organisation.

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# 1 INTRODUCTION

Quality management systems (QMS) have gained noteworthy momentum as a systematic paradigm, demonstrating prominence within various industries, especially in manufacturing-related industries. Standardisation bodies, such as the International Organisation of Standardisation (ISO), have been at the forefront of the migration towards systematic quality management and fulfil the role of standardisation and certification. Gaining certification means that your business-related activities are governed by a management system that adheres to a framework defined by the standardisation body. A Credible QMS certification has consequently become a statement of reliability and compliance and presents as a marketable asset.

Among the most prominent of these frameworks, the ISO 9001 standard for Quality Management Systems represents the consensus of international subject matter experts on the practices and characteristics that constitute a functional QMS. Implementing this framework should thus, in theory, institutionalise a systematic culture for quality within the organisation [1, 2]. However, implementing a QMS often requires major alterations to an organisation's methods, processes, and management philosophies, which not only mandates resource commitment and systems knowledge but also requires a fundamental shift in the mindset of the organisation. Consequently, and more often than not, small manufacturing organisations often operate without a structured QMS.

In response, this study seeks to propose an engineered solution to the implementation of systematic quality management through the design of an engineering management model that not only assists with QMS implementation but also provides a framework to which an organisation can demonstrate progressive maturity. Thus, an opportunity emerged to address an identified quality management (QM) gap in small manufacturers' management methodology by implementing a structured quality management framework.

## 1.1 Document Roadmap

The following breakdown offers insight into the structure of this document. Note that the document's structure is also substantiated by the research process diagram presented near the end of Chapter 3.

- **Chapter 2 Research Problem:** Defines the research problem and discusses the real-world opportunity that underpins the research problem. The chapter then offers further validation and contextualisation of the research problem as a prerequisite to the research challenges and objectives defined in Chapter 3.
- **Chapter 3 Research Design:** Outlines the research design, which defines the research project as pragmatic and grounds it in the DSR paradigm. Following this, Chapter 3 also presents the research methodologies utilised and concludes with a layout of the research process followed during the research project.
- **Chapter 4 Quality Management:** Discusses the Quality Management philosophy and related interpretations, industry applications, and organisational impacts. Chapter 4 includes a Literature Review, a compilation of a total quality management (TQM) QMS framework, a real-world investigation, and a content analysis of the requirements of ISO 9001.
- **Chapter 5 Capability Maturity:** Discusses the capability maturity (CM) perspective and elucidates the surrounding concepts such as maturity models, CM model (CMM) archetypes, maturity levels, and process areas. Chapter 5 also discusses the interdisciplinary implementations of CMM and provides a cross-comparison between CMM and ISO 9001. Chapter 5 includes a literature review and a cross-comparison between CMM and ISO 9001.
- **Chapter 6 Design of a Manufacturing Capability Maturity Model:** Outlines the management model's design as the CMM adaption to encompass the manufacturing ontology. Chapter 6 also discusses fulfilling the research objectives and validating the design manufacturing CMM.
- **Chapter 7 Conclusion:** Offers reflection on the research challenges through a discussion of the respective solutions and shows how the research problem was addressed. Chapter 7 concludes the research project with closing remarks and proposed future directions.

## 2 RESEARCH PROBLEM

The research project documented in this dissertation explores the Capability Maturity Models (CMM) as a means to provide a path along which a small manufacturer can progress towards embedding Quality Management (QM) principles into their management methodology. The research thus explores CMM as a progressive QM implementation method, using the maturity levels of CMM as a measure of QM capability. The following section provides further context to this aim and relevance to the research direction by discussing the challenges, barriers, and opportunities relevant to the current state of QM among small manufacturers from various sources. The discussion contextualises the problem by introducing the real-world observations that commensurate the real-world opportunity as stated below, as well as the proceedings of an informal interview that was conducted with an ISO 9001 industry practitioner about the challenges experienced during the implementation of various ISO 9001 aligned Quality Management Systems (QMS) in the South African manufacturing sector. The discussion then delves into a preliminary content analysis of the various academic principles that constitute the research problem.

### 2.1 Problem Background

**Research Opportunity:** *There is an opportunity to address an identified quality management (QM) gap in small manufacturers' management methodology by considering a systematic quality management (SQM) approach.*

Initial awareness of small manufacturers' QM gap in the management methodology came through personal observation. Specifically, observations were made from personal interaction with small manufacturers that have not fully embraced a QMS framework. In the broader sense, manufacturing management (MM) is the application of manufacturing and engineering principles within a business management context. SQM means seeking customer satisfaction by embedding QM principles and best quality practices into the organisation's operations through the application of systems thinking, specifically systems engineering (SE). Thus, drawing context from the definition of a QMS, SQM is presented as a structured framework for incorporating QM; the focus on quality is shifted towards the development of the “process” rather than the “product of the process”, requiring the incorporation of various SE measures, methods, and principles. In the context of small manufacturers, a lack of SQM often results from an organisation not incorporating systems thinking and SE principles to ensure that manufactured products meet all relevant requirements and, consequently, customer satisfaction (voice of the customer) [3].

A QMS is often implemented starting with a definition of organisational context and requirements, process definitions, process measurement, process management, and, ultimately, process improvement. These are done and documented to meet quality requirements as audited in quality audits [4]. However, one of the biggest challenges is that these audits often result in superficial quality certification. Anttila and Jussila [5] asserted that the ambiguity and subjective nature of certification requirements are one of the fundamental shortfalls of the ISO 9001 certification process. Elaborating on this shortfall, Boiral and Heras-Saizarbitoria [6], provided that the majority of ISO 9001-certified SMMs actively employ external consultants to manage all aspects of their ISO 9001 certification (and specifically not the QM operations of the organisation), which they attributed to a decoupling between the QMS (as presented to the auditor) and the actual operations of the organisation. This reaffirms the presence of superficial QM implementation designed to fulfil the auditor's expectations rather than the organisation's needs. This is a significant challenge that can be rectified by ensuring that all aspects of quality are addressed in a systematic manner. Thus, in the spirit of QM, a process improvement approach is needed to implement the quality system. In turn, a measurement framework is required to ensure quality is achieved through this improvement approach, where the CMM may be of value.

The CMM was initially introduced in 1987 as a systematic management solution for software engineering by the Software Engineering Institute (SEI) of Carnegie Mellon University [7]. CMM also relies on QM and SE principles to achieve its primary objective: to measure an organisation's ability to sustainably provide services and products [8]. Keeping to the notion that process quality reflects product quality, the developers of CMM drew inspiration from well-known QM authorities: Deming, Shewhart, and Juran, as well as subsequent QM philosophies such as Total Quality Management (TQM) and Crosby's maturity grid [9]; which roots CMM in a quality-based approach to continuous process improvement. Both QM and CMM start with a definition of requirements as part of their core practice areas and lead to a subsequent alignment of process capabilities to meet these requirements, which is also a key element of SE. Therefore, it is imperative to investigate CMM, as a supplementary component of a small manufacturer's management methodology, as a means to implement QM on a measurable scale while relying on systems thinking and SE principles to define, characterise, measure, and improve the core manufacturing business processes and MM capabilities.

To consolidate the problem background, Figure 2-1 outlines the known and unknown aspects of the research problem. Firstly, it is established that Systems Theory and Engineering are foundational to both CMM and TQM. Importantly, these concepts are thus treated as foundational paradigms to QM and CMM and are not referred to or analysed as independent concepts; rather, the concepts were discussed in relation to their relevance to QM and CMM. Returning to Figure

2-1, TQM is a mature QM philosophy that is well known for manufacturing applications and consists of valid quality principles that are implemented through interpretation and evaluated through audits or assessments against a standardised reference such as the ISO 9001 standard [10]. On the other hand, CMMs focus on the development of process areas and are known as structured, progressive, and measurable frameworks for process improvement that provide a structured growth path.

The unknown aspects that had to be addressed are the coherence, possible synergy, and interaction between CMM and TQM; at the onset of the research, it was not clear whether a compatibility between CMM and TQM existed and whether such a compatibility could be used to produce a QM solution. Furthermore, research on the general real-world applicability of the CMM had yet to be conducted; specifically for an application that is not within its development domain of Information Technology (IT), and also for the specialised application of South African small manufacturing. With that being said, prior studies on CMM have shown the value of using capability maturity models for real-world applications such as the management of security systems and as a valuable model framework for the measurement of real-world systems [11] as well as for the analysis of South African local municipalities in terms of capabilities related to energy metering management systems. This provided sufficient evidence for its value to research focusing on management systems and motivated further consideration of the CMM as a solution to the real-world opportunity stated in Section 2.1.

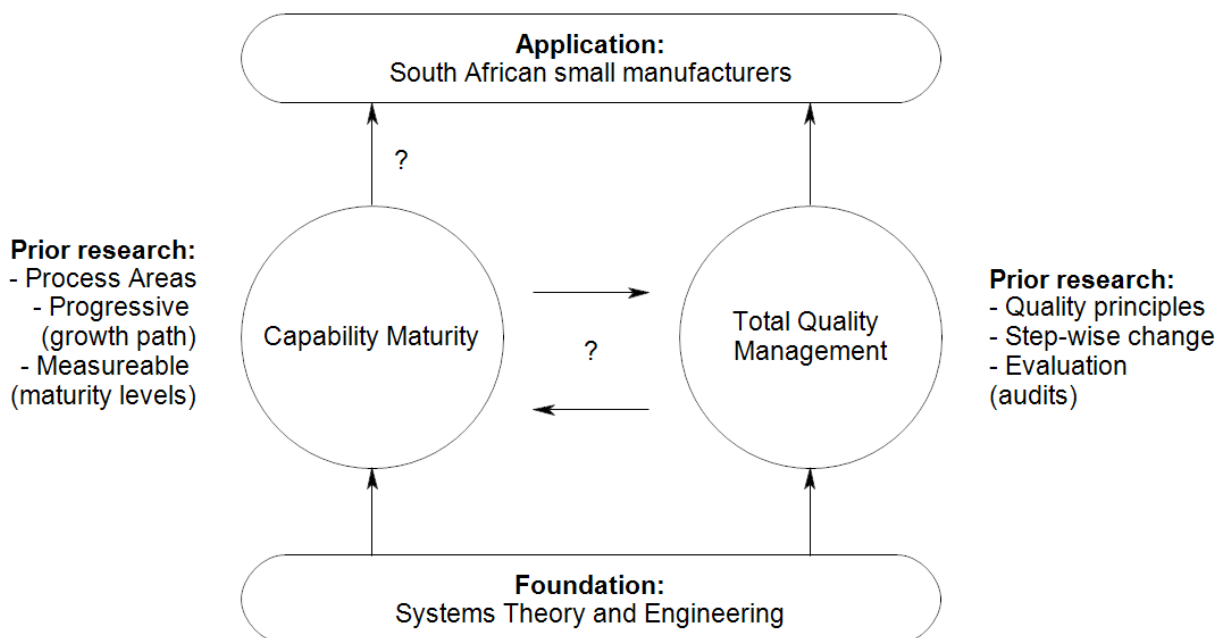


Figure 2-1: Problem outline

**In summary:** CMM contains several quality enabling tools and provides structured frameworks for achieving process standardisation, risk management, total organisational commitment, consistency of outcome, quantitative management, fact-based decision making, and ultimately process improvement. These characteristics are often cited as the goals, benefits, and objectives of both QM and ISO 9001. Additionally, the organisational capabilities developed at higher maturity levels strive towards institutionalising advanced management techniques such as quantitative management, causal analysis and resolution, optimisation, and organisational innovation, to which the prerequisite levels lay a foundation of support functions and structures needed to facilitate these techniques. The significant overlap raises the question of whether CMM could potentially form a superset of the SQM paradigm, or vice versa. Similar to the latest version of ISO 9001:2015, risk-management is also a foundational element of CMM, and in a sense, process maturity improves the organisation's ability to identify risks and opportunities and make fact-based decisions on mitigation or innovation. There is thus clear support for the opportunity to investigate a CMM as a value-adding framework for the sustainable implementation of a QMS. A significant reason thus exists to investigate CMM based on its inherent ability to measure maturity on distinct levels, which provides a growth path with a distinctly progressive nature [12].

## **2.2 Informal Industry Interview**

The informal interview was focussed on the practitioner's involvement in assisting South African manufacturers with ISO 9001 certification readiness as part of the Technology Localisation Implementation Unit (TLIU) programme. The TLIU is an initiative of the Department of Science and Technology (DST) hosted by the Council for Scientific and Industrial Research (CSIR) [13]. The TLIU was mandated to implement various interventions in support of the DST's Technology Localisation Plan (TLP), focusing on enhancing the competitiveness of the South African manufacturing sector. Thus, an ISO 9001 certification readiness programme emerged as the consultation of ISO 9001 QMS implementation and certification readiness for South African manufacturing organisations.

The practitioner was involved with 19 South African manufacturing companies, of which 14 were small manufacturers, 4 were medium to large, and 1 was a large manufacturing organisation. The following points summarise the observations and lessons learnt during the programme, which are formalised in the form of question responses:

- **What were the common challenges and constraints experienced during QMS implementation among the small manufacturers?**

*“Initially, awareness and general knowledge of ISO 9001 was a significantly lacking aspect. Companies were unaware of what ISO 9001 is, how to use it, or how to use a system. In some instances, company representatives were under the impression that ISO 9001 was an online finance management tool. There was also significant reluctance to accept responsibility for maintaining a QMS, it was seen as unnecessary administrative work. Especially among smaller companies in which the owner was responsible for performing the QM related tasks because all other resources were fully utilised to produce revenue. Resistance to change presented a significant barrier. The general maintenance of such a system presented additional strain on, mostly, understaffed organisations within a difficult sector for small manufacturers.”*

- **Do you have any recommendations on the implementation of a SQM solution?**

*“Practicality will increase the overall suitability of a QMS. Companies often failed to formulate an understanding of how systems relate to their operations. The system should cater to the need to make implementation practically presentable. Within the current economic status, many SMMEs are focussed on survival and will only consider QM, if survival requires certification to satisfy customer mandate. A QMS should thus offer true assistance and demonstrate early benefit. As soon as it becomes an administrative burden, it will not be treated as a sustainable solution. In this sense, a systematic implementation might already provide some value to SMMEs without the need for a dedicated quality manager. Most of the companies involved in the initiative only participated because it was free or because their clients required it. To the participating SMMEs, it was merely a tick-box activity, while only the larger companies approached the initiative as an opportunity to improve.”*

**In summary:** *The most significant challenges experienced among small manufacturers during the QMS implementation initiative were awareness, a systems knowledge gap, resistance to change, resource limitations, and a reluctance to lean into the administrative requirements of implementing a system of this nature.*

**“Survival mode”:** *The survival mode notion speaks to the significance of the resources constraint surrounding the small business environment that is also continually exclaimed in literature in that it not only applies to the availability of resources to fund a QMS implementation effort but also to the deficiency of the human resources required to manage or accept responsibility for the implementation of a QMS without significantly impeding the organisation’s ability to generate revenue.*

### 2.3 Initial Literature Review

Continuing the narrative established in the informal interview, several fundamental barriers must be considered when presenting a QM solution to a small manufacturing organisation. Mhlongo and Daya [14], elaborating on these barriers, have highlighted several common challenges South African SMMEs face. Among others, they listed a lack of leadership, failure to adopt new technology, and resource availability. Various studies have further attributed resources to a common challenge SMMEs face and one of the most significant inhibitors of implementing QMS [2, 15]. QMS are resource-intensive in the short term, yet the benefits are long-term [16]. The cost of implementing a certifiable QMS thus immediately negates its affordability to smaller organisations and, coupled with notoriously long-term benefits, diminishes its feasibility [15]. Furthermore, when considering the systems knowledge gap, it is essential to remember that QMS standards and methodologies are commonly written to be “one size fits most”, with generic requirements applicable to a range of operational implementations [10]. This means that, although comprehensively written, these methodologies were mainly developed with large organisational applications in mind and require situational interpretation, which complicates implementation and limits pragmatism in the context of small manufacturing organisations.

Revisiting the practitioner’s observations, small manufacturers often misunderstand the function of a QMS as an ad-hoc administrative task related to satisfying the requirements of an audit without giving thought to the system of characteristics that are being established. Additionally, small manufacturers are rightfully reluctant to engage due to the apparent requirement of total organisational reform, which often entails external consultations and multiple pre-audits before any means of perceived value (in the case of ISO 9001 certification) can be realised. Considering this, the need thus exists to interpret the QM within a South African manufacturing ontology whilst considering the unique SMME environment. This requires contextualisation of the QM paradigm within the South African small manufacturing environment; to them, the solution should seem unequivocally feasible, be understandable or interpretable within the context of their operations (meaning that it should be grounded in a *manufacturer’s ontology*), and it should demonstrate practical benefit. The *motive* of implementation is an exceedingly important aspect of a QM effort, and it is thus imperative for the previously mentioned requirements to be sufficed to ensure the viability of the proposed solution. With the potential downfall of a skewed motive already being mentioned (referring to superficial QMS certification), the following paragraph elaborates more on the importance of correctly positioning the motive of implementation.

Following a survey focussed on South African SMMEs, Ramdass and Nemavhola [2] presented customer demand as the leading motive for attaining an ISO 9001 certification instead of improving the organisation [2]. They elaborate on this assertion by providing that QMS certification

has become a trade requirement and that organisations view it as a costly means to stay competitive rather than a means for system improvement. To further build on the impact of motive, various researchers have highlighted the fundamental importance of motive to the success of a QMS [2, 17]; if the motivation is merely to gain certification for reputational merit, then the attempted implementation will unnecessarily constrain the organisation's resources for nothing more than an affectation of a QMS [17, 18]. *In short, the motive should be an internal commitment to improving the organisation rather than a commitment to the external benefits.* Nascimento *et al.* [19] also stated that despite the pervasive merit coupled with ISO 9001 certification, consumers still face the challenge of discerning certified manufacturers with genuinely mature processes, which provides a market-based perspective on the potential value of a multileveled, measured QM approach.

In this regard, the CMM offers an incremental approach comprised of progressive maturity levels defined by a framework of methods focussed on process improvement. Doss *et al.* [20] highlighted that although QM paradigms speak to certain elements of improvement, none of the traditional approaches consider improvement through a process maturity lens. Returning to ISO 9001, Ramdass and Nemavhola [2] noted a gap in the mindset of South African manufacturers regarding QM. They suggested investigating other approaches to supplement the systemic value of an ISO 9001 certification. Supporting this statement, researchers from various countries and research perspectives have identified similar shortfalls in the ISO 9001 certification process and have also suggested a need for a conjunctive implementation between ISO 9001 and a systems-based QM approach [2, 21, 18], some of which have also provided grounds for compatibility [21].

Various studies have validated the value that South African small manufacturers might enjoy from embracing a sound QMS. These benefits included a reduction in manufacturing costs through less time wastage and reworks, improved teamwork, higher productivity, better customer satisfaction and customer retention, the enablement of continuous improvement, and an overall improvement of organisational collaboration, all of which are usually summarised as the benefit to remain in business, remain competitive, and remain relevant [3].

**In summary:** *Although ISO 9001 represents a globally recognised metric for quality management systems, the research community still suggests enhancing the systemic value of an ISO 9001 certification by adding value from an accepted structured paradigm. Thus, real-world evidence supports further investigation of CMM as a QM implementation framework. However, there also remains an opportunity to further contextualise QM to the small manufacturer by considering the manufacturer's ontology, the survival mode notion, the systems knowledge gap, resistance to change, and the motive for implementation. Furthermore, there is definite support for implementing SQM among small manufacturers, and this support mainly manifests in the benefits, capabilities, and characteristics identified and defined by the research community.*

### 3 RESEARCH DESIGN

This research project aims to present and investigate the capability maturity perspective and related management principles as a candidate solution to the identified QM gap in the small manufacturer's management methodology. The solution is presented in the form of a designed, pragmatic, and real-world management model formed through the application of the research design discussed below.

#### 3.1 Research Objectives

The research objectives are presented below in the form of the design requirements, per the Design Science Research (DSR) paradigm, that the management model should fulfil. These objectives are formulated to ensure that the resulting management model fully addresses the real-world opportunity as contextualised in the preceding section and is useable to a small manufacturing implementor.

The management model should thus:

- *Embed quality management principles and best quality practices into the operations of a small manufacturing organisation;*
- *Demonstrate compliance with the ISO 9001:2015 standard for quality management systems as a minimum requirement;*
- *Present a structured growth path towards quality management that realises value at the process's end and along the path.*

#### 3.2 Research Strategy

To follow up on the initial outline presented in Figure 2-1 and with the additional context of the research problem provided in Sections 2.2 and 2.3, the following section presents a research strategy to address the real-world opportunity. This strategy thus presents the gaps in the current state body of knowledge surrounding the research problem and presents these gaps as the research challenges that need to be addressed through the research project. To do so, Figure 3-1 builds on the diagram presented in Figure 2-1, presenting how the observed real-world problem has been transformed and introduced into the research environment and how the known aspects are plotted in relation to the research.

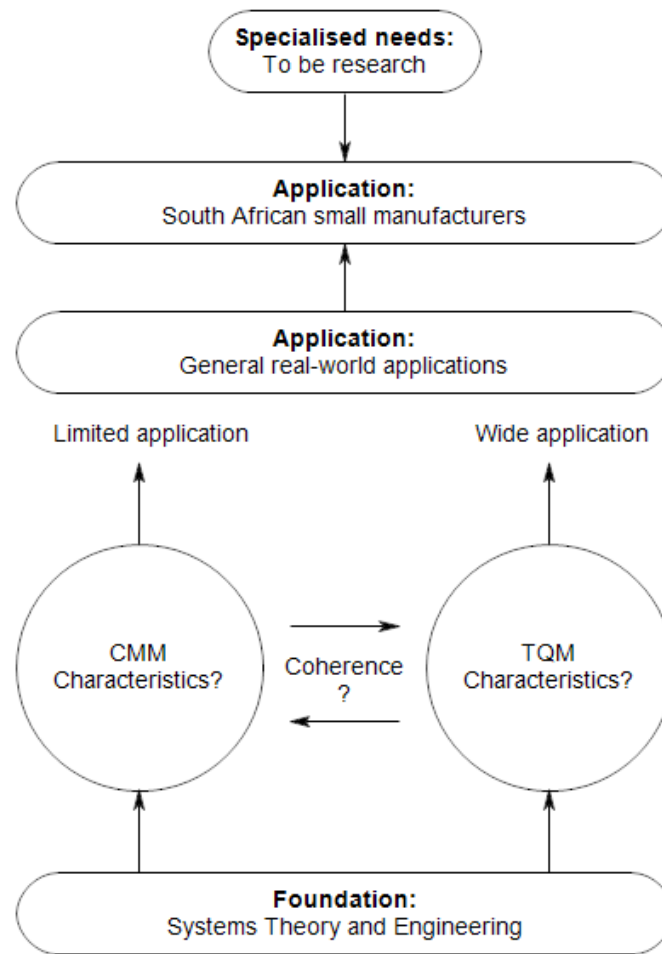


**Figure 3-1: Research strategy**

The specific application of South African small manufacturers requires the identification of specialised needs for the design of quality development model. These needs include the practical considerations, limitations, challenges, barriers, opportunities, and requirements related to the current state of QM among South African small manufacturers. From prior research, industry interview, and literature, the known barriers include resistance to change, resource limitations, and a lack of systems knowledge and awareness. These barriers are often exacerbated by a lack of QM interpretations that speak to small manufacturers' challenges. Additionally, the current state of QM among South African small manufacturers and subsequent definition of need is still largely unexplored. The desired QM characteristics of South African small manufacturers that have embraced a sound QM approach are not clearly defined and there exists limited contextualisation of the QM philosophy to a South African small manufacturing application. In this regard, the following research challenges can be highlighted:

- 1) Detailed definition of need not clear for QM in small South African manufacturers.
- 2) Limited QM contextualisation among South African small manufacturers.

Turning the focus to the interaction between CMM and TQM, both concepts have general real-world applications. However, TQM exists as a mature philosophy that have appreciated a much wider range of interdisciplinary and industry-wide applications, whilst the CMMs' applications have been relatively limited to the IT domain. Nonetheless, as observed and supported by literature, there are fundamental overlaps between the objectives of a CMM implementation and a QM commitment. The CMM exists as a thoroughly defined framework that details various process areas to be developed and improved, as well as the respective improvement methods. On the other hand, QM methodologies exist as well-defined paradigms with a less descriptive description of the method and more of the desired characteristics. At the onset of this research, the CMM perspective was still an unconventional approach in the manufacturing domain that was yet to be adapted for a small manufacturing QM application. However, at the onset of this research it was still unclear to what level a coherence between CMM and TQM existed and whether there was an applicability of the CMM to the manufacturing domain. If so, it was also unclear whether or how this applicability could be used to synthesise a quality development model that speaks to the specialised need of a South African small manufacturing application. Given this, the following research challenge could be defined:

3) Can the CMM be repurposed to general real-world applications other than IT systems?

Many researchers have alluded to common shortfalls in the ISO 9001 certification process, which contributes to QMS certifiability through superficial implementation without any real systemic value to the organisation. These shortfalls are often linked to misinterpreting the ISO 9001 standard or an opportunistic pursuit for QMS certification. Consequently, various researchers have recommended the implementation of other QM methodologies to supplement the systemic value of an ISO 9001 certification. However, a subsequent investigation of the ISO 9001 certifiability of a QMS that had been created from a methodology other than the ISO 9001 standard has appreciated less attention. Existing literature comparing CMM to the ISO standard for quality management systems, and vice versa, is relatively outdated and based on previous versions of the standard (e.g. ISO 9000:1998, ISO 9001:2001). Nonetheless, these studies provide an optimistic view of the certifiability of a CMM-based QMS, at least as a seminal validation source. Thus, a comparison between the current states of the two models is supported by literature and is yet to be explored. *Validation that an organisation that embraces a CMM approach can structurally align itself with ISO 9001:2015 certification requirements must be given foundation and demonstrated.*

- 4) How can the CMM and QM be integrated to address ISO 9001 standard compliance?
- 5) Can a progressive growth path with feedback be realistically defined to meet ISO 9001 compliance?
- 6) Can a newly defined CMM framework meet ISO 9001 requirements for small South African Manufacturers?

### **3.3 The Research Validation Matrix**

In order to validate research, the original research challenge must be valid and, in line with addressing a valid engineering research problem, address a real-world challenge. In addition, valid literature resources must be consulted and combined with the task of data acquisition, validation, and analysis used to elucidate the actual challenge (analysis) and potential solutions to these challenges constructed (synthesis). Throughout, it is necessary to trace the research challenges (requirements) through the research process towards solutions (characteristics) – this is the intended purpose of the Research Validation Matrix (RVM) used in the QRM methodology [22].

A validation matrix for this research was defined by identifying research challenges particular to this project and providing evidence of their validity. The sources of information, research challenges, literature topics, and research solutions that describe the research challenges and literature focus areas are presented below on the RVM. This represents the research project scope and ensures that the literature discussions remain focused, aligned with the research paradigm, and relevant to the research challenges. Refer to table Table 3-1 below, where the top half of the RVM is shown as the path from problem identification to research challenge definition and validation.

The Quality Research Management (QRM) research methodology requires a definition of research challenges that are formulated through an initial investigation effort to identify the opportunities and shortfalls related to the research problem [22]. These challenges should provide a clear link between what the research aims to achieve (research objectives, synthesised research artefacts, knowledge contributions) and what aspects of the real-world problem should be addressed or overcome to achieve it. Coinciding with the DSR paradigm, the research challenges defined below were formulated through investigation of the affected research environment firstly by real-world observation and subsequently by conducting an initial literature review and an informal industry interview.

- Real-world observation from industry participation:

The real-world observation was initially made through participation in industry, specifically working as a ground-level employee at a small manufacturing company before pursuing an engineering degree, and then again working as a junior mechanical engineer at another small manufacturing company. It was apparent, both in presence and in retrospect, that these small manufacturers could benefit from engineering management, systems thinking, process management, etc. However, the limiting factor was engineering knowledge, resource availability, and reluctance to change. This observation became more substantiated through a discussion with an industry expert as well as an initial literature review.

- Informal interview with an industry expert:

The industry interview was an informal discussion with an industry practitioner that was limited only to practitioners' involvement in the implementation of ISO 9001 in South African small manufacturing companies. The value added was the practical, real-world experience on the challenges, constraints, and barriers to entry related to a QMS implementation among small manufacturers.

- Initial literature review:

The initial literature review focussed on providing sufficient evidence to validate the research direction and to motivate the applicability of the capability maturity perspective. The value of a QM approach as well as the typical challenges, constraints, and limitations of such an approach was substantiated through the initial literature review; specifically, through sources discussing QM in South African applications and small manufacturing applications. The capability maturity perspective was motivated through literature discussing the utilisation of the CMM for various general real-world applications [23, 11, 24].

Please note that a “down” arrow links a source reference for the real-world problem to the upper left of the matrix to one or more research challenges. This introduces traceability between observations, expert inputs and interviews, and high-level research findings from content analysis and formalised research in terms of the clearly defined challenges:

- 1) Detailed definition of need not clear for QM in small South African manufacturers (align with industry)
- 2) Limited QM contextualisation among South African small manufacturers
- 3) Is CMMI applicable to general real-world applications other than Information Technology systems? (repurpose CMM)
- 4) How can CMM and QM be integrated to address ISO 9001 standard compliance? (need)

- 5) Can a progressive growth path with feedback be realistically defined to meet ISO 9001 compliance?
- 6) Can a newly defined CMM framework meet ISO 9001 requirements for small South African Manufacturers?

In order to provide more information from literature, different literature topics were defined as indicated in the RVM:

- 1) Quality Management and Quality Management Systems in both theory and application as a central literature theme for this research project;
- 2) Systems theory and Engineering theory as the foundation for both quality and capability maturity;
- 3) The ISO9001 Standard as an absolute reference to an industry standard;
- 4) Capability Maturity Models in both theory and application as a growth path model.

As discussed above, the arrows in cells link research challenges to literature focus areas. In the forward path, up-arrows show that literature resources support the research challenges (showing relevance).

**Table 3-1: RVM – Research Challenges**

|                            |                                                       |                                                                                   |                                                                      |                                                                                                  |                                                                          |                                                                                                  |                                                                                                    |
|----------------------------|-------------------------------------------------------|-----------------------------------------------------------------------------------|----------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|
| <b>Sources</b>             | Observation from Industry                             | ↓                                                                                 |                                                                      | ↓                                                                                                |                                                                          |                                                                                                  | ↓                                                                                                  |
|                            | Informal Interview with Expert                        | ↓                                                                                 |                                                                      |                                                                                                  |                                                                          |                                                                                                  |                                                                                                    |
|                            | Initial Literature Review                             |                                                                                   |                                                                      | ↓                                                                                                | ↓                                                                        | ↓                                                                                                |                                                                                                    |
| <b>Research Challenges</b> |                                                       | Detailed definition of need not clear for QM in small South African manufacturers | Limited QM contextualisation among South African small manufacturers | Is CMMI applicable to general real-world applications other than Information Technology systems? | How can CMM and QM be integrated to address ISO9001 standard compliance? | Can a progressive growth path with feedback be realistically defined to meet ISO9001 compliance? | Can a newly defined CMM framework meet ISO9001 requirements for small South African Manufacturers? |
| <b>Literature Topics</b>   | Quality Management and Systems Theory and Application | ↑                                                                                 | ↑                                                                    |                                                                                                  |                                                                          |                                                                                                  |                                                                                                    |
|                            | Systems Theory and Engineering Theory                 |                                                                                   |                                                                      | ↑                                                                                                |                                                                          | ↑                                                                                                |                                                                                                    |
|                            | ISO 9001 Standard                                     | ↑                                                                                 |                                                                      |                                                                                                  | ↑                                                                        | ↑                                                                                                | ↑                                                                                                  |
|                            | Capability Maturity Theory and Application            |                                                                                   |                                                                      | ↑                                                                                                | ↑                                                                        |                                                                                                  | ↑                                                                                                  |

### 3.4 Research Paradigm

Researchers can become overwhelmed by the information, techniques, and methods available when engaging in a multifaceted research endeavour. Navigating through a body of knowledge, deciding on an investigation approach, and applying appropriate techniques to find a suitable solution may seem complicated and time-consuming. It is thus imperative to compile a sound research design based on a known research paradigm that grounds the research to a system of basic beliefs and steers the process of knowledge development consequent to a research effort. A known research paradigm is accompanied by well-defined and accepted assumptions (herein also lies the philosophical positioning of the research) that will aid the researcher in identifying meaningful research directions, developing an appropriate research strategy, precisely communicating findings, and offering a concise definition of contribution. Buys *et al.* [25], mention five philosophical positions relevant to business research: positivism, post-positivism, interpretivism, critical theory, and pragmatism. Revisiting the context of the research problem (to provide a pragmatic solution to the implementation of QM in a real-world environment), the research can be positioned as pragmatic with elements of interpretivism. **Pragmatism** is the study of real-world issues through which research is guided heavily by practical considerations. Pragmatism emphasises the pursuit of practical solutions and is associated with qualitative, quantitative, and mixed-research methods [25]. The **Interpretivist** philosophy is typically more inductive and is grounded in the belief that reality is socially constructed and can be sufficiently understood by interpretation and in-depth qualitative methods [25].

**To Elaborate:** *The research detailed in this dissertation explores how existing QM processes, principles, and best practices are conceptualised and understood within the field of manufacturing management. This means interpreting how the known facets of QM are structured within a manufacturing management ontology. Furthermore, the research then aims to address a real-world opportunity by synthesising a management model guided by a methodological framework provided by the CMM perspective and informed by the manufacturing quality management ontology. The synthesis of the model was, in essence, the application of inductive reasoning through a comparative lens, as it required an in-depth comparison between the implementation of CMM, the desired organisational outcome of QM, and the requirements for compliance with the ISO 9001 QMS standard. This was done to ensure that the resulting model situates as an accompanying management tool that does not attempt to reform a small manufacturer's organisational structure completely but offers a more comprehensible and approachable growth path towards a QM pursuit.*

### 3.4.1 Design Science Research

Buys et al. [25] outlined a “roadmap to business research” focussed on aiding researchers to conceptualise and plan a research design based on proper academic principles for research in organisational-related applications. The roadmap provides several validated research tools, concepts, and methods researchers can utilise to perform academically sound research. As depicted in Figure 3-2, the research should be grounded in a known Research Paradigm, a Theoretical Foundation, and associated with an accepted Research Philosophy. Subsequently, the research process should be articulated through an appropriate research methodology actioned by valid research methods, data analysis techniques, and communication formats [25].

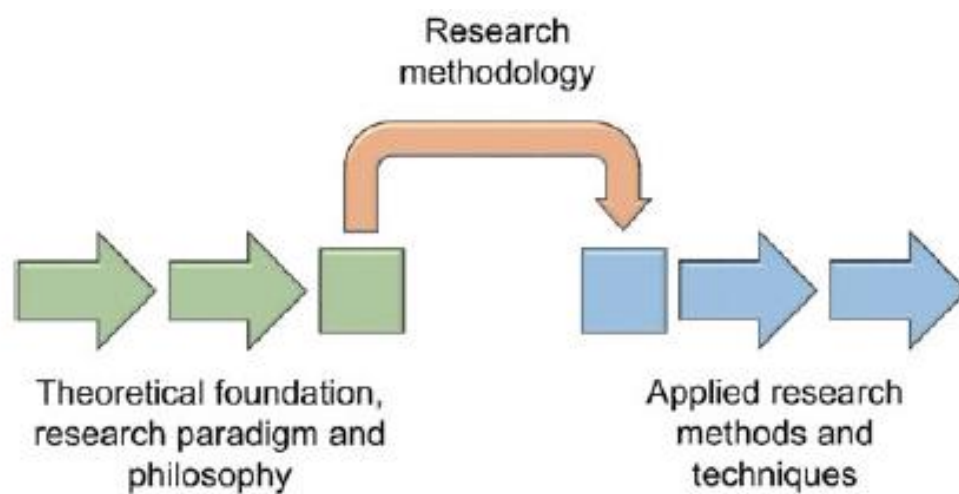


Figure 3-2: Research Process [25]

A **Research Paradigm** is the lens through which a researcher views the research problem [25]; it is described as the characteristics common to a field of study that portray how an understanding of the theories, practices, and methods may be achieved. With the pragmatic positioning of the research defined in the previous discussion, this section formally grounds the research in the **Design Science Research (DSR)** Paradigm.

**Design Science (DS):** DS is described as an extension of pragmatism in that it applies to research that addresses a real-world problem by creating a research artefact as a solution to the problem [25]. Subsequently, DSR is a research paradigm that utilises the principles of design for conducting research that is focused on producing a research artefact as a solution to an observed real-world problem [26, 27]. Presented in Figure 3-3, Hevner [26], defines the DSR paradigm as the iterative execution of three working cycles: the Relevance Cycle, the Design Cycle, and the Rigor Cycle.

- **Relevance Cycle:** As the entry point of DSR, the Relevance Cycle provides context to the research project by the definition of requirements [26]. These requirements orient the research efforts and provide a basis for validating the solution produced at the end of the research [26]. To demonstrate relevance, DSR mandates an interface between the research and the affected environment; an analysis of need ensures the integration of real-world considerations and requirements to the research process.
- **Rigor Cycle:** The Rigor Cycle employs diligent consideration of existing knowledge to instil value in the knowledge contributed by the study. As depicted in Figure 3-3, the Rigor Cycle interfaces the knowledge base (KB) with the research as the extraction of existing information into the synthesis, thus facilitating value addition in the subsequent contribution of information to the KB.

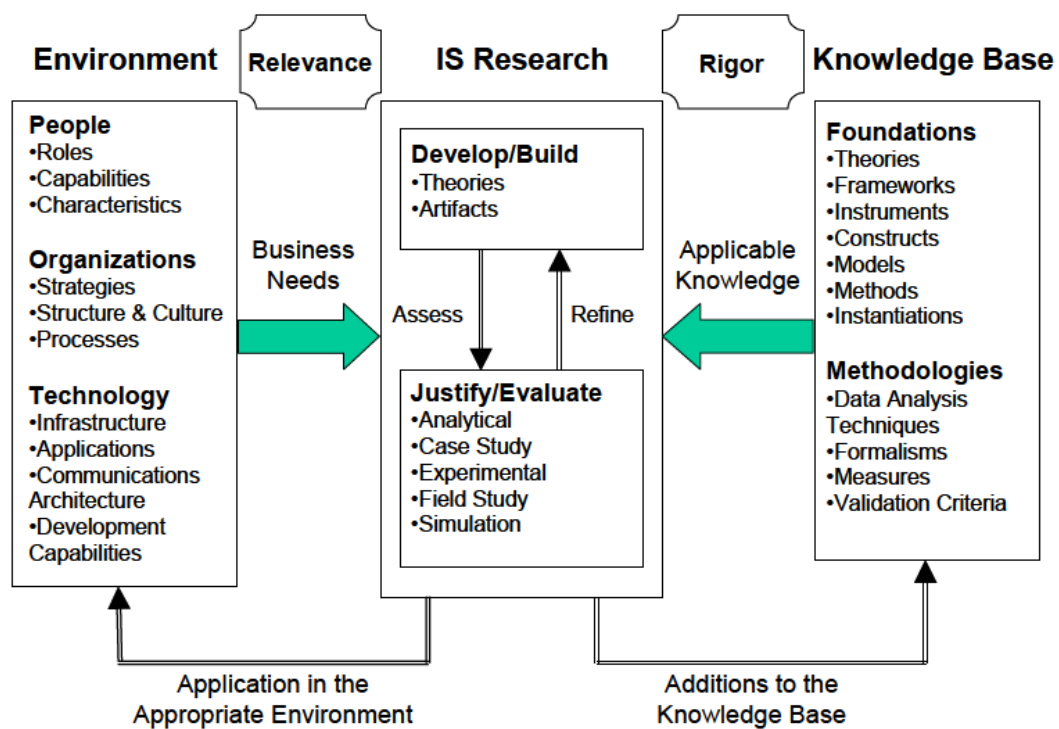


**Figure 3-3: Three Cycle Approach to DSR [26]**

- **Design Cycle:** The Design Cycle is depicted as the conjunction between the Relevance and Rigor Cycles. It is the iterative process of developing and evaluating a creative solution to the requirements of the real-world problem by extracting methods, techniques, and relevant information from the knowledge base.

Research focussing on synthesising Maturity Models (MM) is effectively conducted within the DSR paradigm. Wendler [23] agrees that DSR addresses three important aspects of MM research, namely:

- The creation of a novel, derived, or adapted MM as a research artefact;
- An intended application to a real-world situation or environment;
- The utilisation of validated models, methods, and principles.

Considering this, the diagram presented in Figure 3-4 below outlines a derived DSR framework that illustrates how the DSR paradigm was applied to align the research project documented in this dissertation. Herein also lies the classification of the **Research Environment**, and the **Theoretical Foundation** that underpins the research project.

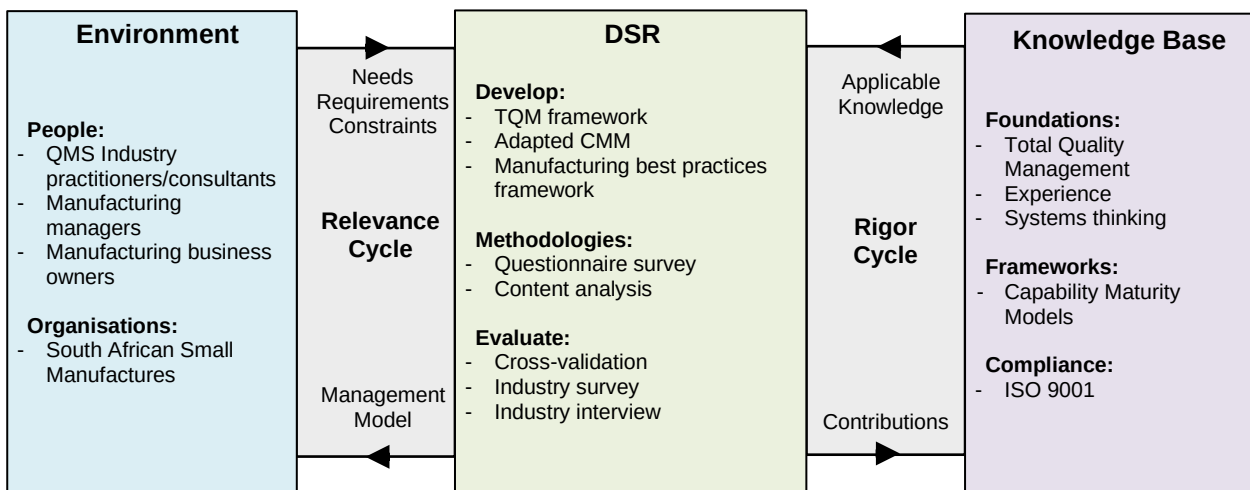


Figure 3-4: Derived DSR framework (adapted from Figure 3-3 [27] for this research)

### 3.5 Research Methodologies

A Research Methodology refers to the systematic process followed during the research project used to extract meaningful information from the field/discipline of research and to rationalise what was learned into meaningful contributions. Considering this, the research methodologies discussed below were applied within the DSR paradigm as a means to manage the research challenges, information sources, and proposed solutions (as provided by QRM) as well as to provide concepts for analysing, finding solutions, validating, and ultimately refining a researched solution (as provided by ADR).

- **More detail on Quality Research Management as a methodology**

The foundation of the QRM is based on four principles: Quality Management, Systems Engineering, Project Management and Communication [22]. QRM focuses on optimising the research process by emphasising the need for constant traceability of research requirements. The objective of QRM is to leverage a quality management approach to constantly align the research activities with the requirements that support the research project. QRM provides a valuable method of managing and ultimately presenting the formulated research challenges and solutions. Implementation of the QRM yields a research validation matrix (RVM) that offers a holistic representation of the research project, referring again to the representation in Table 3-1, which details the initial RVM for this research project.

- **Action Design Research**

Whilst the DSR paradigm outlines the formulation of a validated solution to a real-world problem, Sein *et al.* [28] argue that traditional Design Science alone lacks the holistic fundamentals to accommodate the continuous refinement of a research artefact that is the inevitable result of real-world application. Proposing a solution to this assertion, Sein *et al.* [28] defined the ADR approach as a strategy for producing knowledge throughout the process of synthesising and implementing a solution. In essence, the ADR framework leverages the dynamic nature of a research artefact in its developmental stages to pre-empt continuous industry evolution, effectively instilling a characteristic of continuous improvement. The challenge of ADR is to retain the essence of the scientific process whilst being flexible enough for continuous development. Sein *et al.* [28] proposed an ADR framework, modelling a four-stage implementation approach that is supported by seven principles:

The initial stage detailed in the framework is the formulation of an observed problem into a formal problem statement, complete with requirements and expected research deliverables. The second stage employs the BIE (Build, Intervention and Evaluation) strategy to design a solution to the stated problem. The third stage entails the evaluation of the design and reflection on the knowledge generated. The fourth stage contextualises the results and facilitates communication of the findings.

### **3.6 Research Process**

The design of a management model is a multi-faceted endeavour that requires the implementation of multiple research methods and techniques. The research project thus relied on various research methods, as is often the case with a pragmatic research effort [25].

The following section provides a breakdown of the research process and a brief description of the methods and techniques utilised. Importantly, although the methods elaborated on below are relevant to the philosophical positioning of the research project and associated assumptions, most of the applied research methods, decisions, and techniques were contained inside the DSR paradigm and the continuous consideration of the practical needs of the research environment.

The research project is presented by two critical paths (one of which follows Quality Management and the other following Capability Maturity) that converge during the design of the management model. Thus, the roadmap, as illustrated below, presents the structure of this dissertation. The diagram below shows the roadmap (please see the next page):

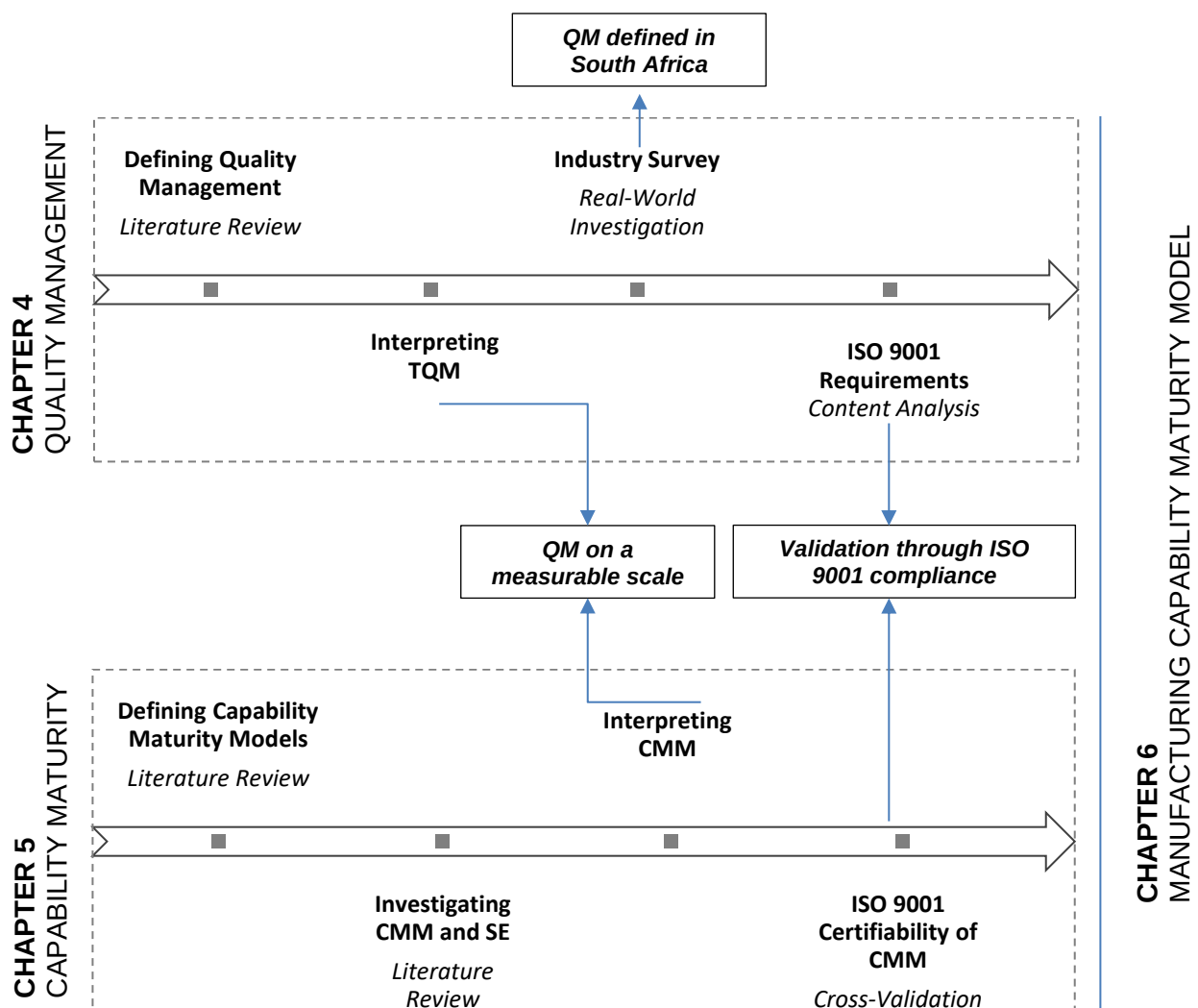


Figure 3-5: Overview of Research Process

- **Defining Quality Management within the Manufacturing Ontology**

*Qualitative Archival Research*

A literature review of the QM philosophies and principles and a literature review of academic works detailing QM and, more specifically, TQM were systematically conducted to understand the application of QM and the characteristics of a QMS. This relied on research regarding the development history of QM, seminal design applications, and current interpretations of QM's desired characteristics, principles, and best practices. To further explore the application of QM within a small manufacturing environment, the research relied on literature detailing real-world studies on the interpretation and structuring of the TQM philosophy through small manufacturing applications. This allowed for the identification of a TQM framework of characteristics and practices based on the interpretations of various researchers within the field.

- **Conducting an Industry Survey**

*Exploratory, Mixed-Method, Cross-sectional, Questionnaire Survey*

The real-world research activities included an industry questionnaire survey. Given the research challenge of the poorly defined current state of QM implementation in the South African manufacturing environment, the premise of the survey was to offer a cross-sectional view of QM among South African small manufacturers. The framework used to achieve this goal seeks to define the presence of TQM characteristics rather than quantify its effect; for this reason, a questionnaire survey was used as the data gathering medium. The survey results allowed for a contextualisation of the current state of QM among South African small manufacturers. *The design of the questionnaire and the data analysis techniques utilised are discussed in more detail in Chapter 4.*

- **Conducting an ISO 9001 Requirements Analysis**

*Content Analysis*

The ISO 9001 standard, relevant industry interpretations, auditing and appraisal methods, and comparative studies (ISO 9001 vs TQM) were explored to understand what the standard requires, and how it is applied, audited, certified, and sustained. The main contribution of this section is the interpretation of the “shall” ISO 9001 requirements as the mandatory requirements that a small manufacturer should adhere to if compliance is to be achieved.

- **Defining and Interpreting the Capability Maturity Perspective**

*Qualitative Archival Research*

Like QM, CMM is a well-developed concept with various versions, archetypes, and interpretations. Understanding what constitutes the approach, how it is implemented, and how it is evaluated thus relies on systematic literature exploration of the model of the associated process areas.

Fundamental concepts such as process maturity, organisational maturity, and organisational capabilities are also explored herein. Further effort was made to understand how the various process areas of the CMM perspective would integrate into a manufacturing environment and which process areas would remain relevant while also considering how a small manufacturer would interpret a management model presented on a CMM framework.

- **Exploring the ISO 9001 Certifiability of the CMM**

*Qualitative Archival Research and In-depth Cross-Comparison*

To substantiate the implementation of the CMM perspective as a QM solution to small manufacturers, this research relied on previous studies, cross-comparisons, case studies, and academic sources to provide literature verification that it can be done. Given that the seminal structures of ISO 9001 and the CMM are both based on TQM principles with common objectives, overlapping practices and similar measures of compliance [12, 29], the assertion can be made that an organisation should experience similar reform from implementing one or another. However, given the conceptual difference, being that one is an audited standard and the other is a process improvement model, an in-depth cross-comparison was required. Thus, this part of the research focuses on the synergetic implementation of CMM, ISO 9001, and TQM to provide a viable solution to small manufacturers through an in-depth cross-comparison between the CMM and ISO 9001.

### **3.7 Conclusion**

Chapter 3 outlines the research design for this research project, which was compiled through the guidance of a research roadmap for research applied in a business/organisational setting [25]. The philosophical positioning of the research is pragmatic as it seeks to find a solution to the real-world opportunity to address the QM gap in the management methodology of small manufacturers. The solution requires the development of a research artefact in the form of an adapted CMM suited to a small manufacturing application. Consequent to creating a real-world research artefact, the research is rooted in the DSR paradigm, as presented in Figure 3-4. The Research Objectives and Research Challenges related to the research project are defined and presented on a Research Validation Matrix (RVM) as outlined by the QRM methodology [22], which links the context of the research problem, as discussed in Chapter 2, to the structure and discussion topics of this dissertation. The dissertation is presented in an unconventional format, which is also described in Chapter 1; however, the rationale behind the format is presented in Figure 3-5, which depicts the logical order of the research process and presents the critical path of development.

## 4 QUALITY MANAGEMENT

Chapter 4 delves into the Quality Management paradigm and discusses the principles, philosophies, characteristics, and techniques relevant to Quality Management (QM), Total Quality Management (TQM), and ISO 9001 (refer to Figure 3-5 in the previous chapter). Chapter 4 starts with a literature study that first introduces QM, then discusses the current state of the QM ontology and a discussion of manufacturing applications, thus providing insight into the concepts and interpretations of QM relevant to the research project. Chapter 4 then drills into the ISO 9001 standard by outlining the standard's structure and an interpretation of requirements based on literature and available auditing methods. Finally, the final section of Chapter 4 consolidates the investigation into QM by presenting a derived TQM characteristics framework as the result of previous research studies concerning the implementation of QM among small manufacturers and the utilisation of this framework to conduct a real-world survey. In conclusion, this chapter outlines critical components of a QM study and provides the desired TQM characteristics relevant to a small manufacturing application, guidance on the ISO 9001 compliance component of the proposed solution and provides context to the South African small manufacturing environment through a cross-sectional investigation into the current state of QM implementation.

### 4.1 Literature Study

#### 4.1.1 Defining Quality Management

Quality management, as it is known and implemented today, is the result of centuries of paradigmatic evolution, from the standardisation of techniques implemented by craftsmen in the Middle Ages to leveraging the systemic capabilities of quality-centric systems to stimulate organisational growth. The history of QM can briefly be summarised by a few pivotal movements [30].

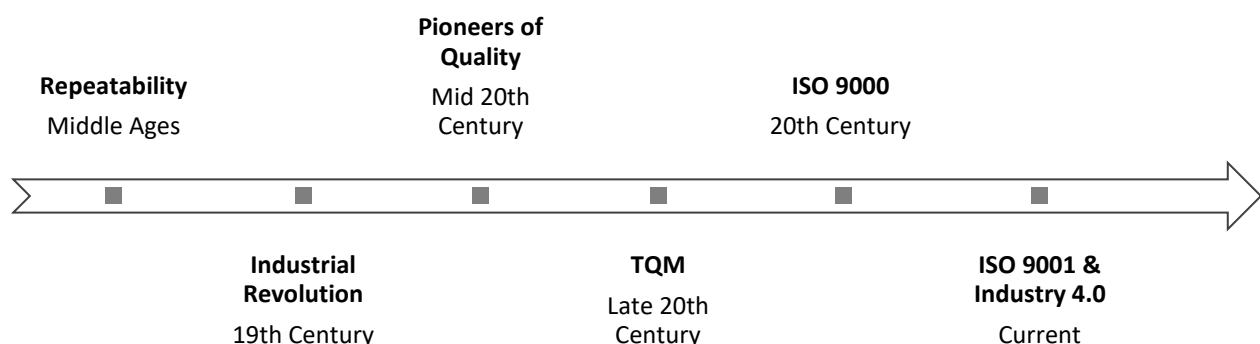


Figure 4-1: Evolutionary milestones of Quality Management

- **Repeatability** sees the recognition of best practices and techniques used among craftsmen during the Middle Ages, inadvertently standardising processes to achieve more repeatable outcomes.
- The **Industrial Revolution** piloted the shift from craft to factory, which catalysed reform of the quality paradigm. Quality was starting to be recognised as a management tool that was institutionalised through inspection and finding solutions to defects. However, quality was still a subject of management and not yet a management paradigm.
- The **Pioneers of Quality**, W. Edwards Deming, Walter A. Shewhart, Joseph Juran, and Phillip Crosby are credited as the most influential individuals of quality management. During the early and mid-20th century, their efforts introduced statistical control and the notion of process-based management of quality. At this point, the quality paradigm was instilled with engineering prowess. Statistical evaluation and control opened the door to the scientific method, and the focal shift from product to the process involved Systems Engineering.
- Succeeding the work of Deming, **Total Quality Management (TQM)** was the pivotal shift towards a fundamental systems-based approach. TQM emphasised an organisation-wide focus on quality, requiring the integrated contribution of all facets, departments, and people of the organisation. Shifting quality from departmental activities to an organisational mindset focused on a unitary goal: customer satisfaction and continuous improvement.
- With quality management becoming an increasingly adopted concept, the quality paradigm was transformed into a certifiable system of requirements, namely **ISO 9000**. Developed by ISO, the key concepts of quality (customer focus, risk-based thinking, process approach, and strategic implementation) were incorporated into a framework of best practices for quality management systems, which was elevated to certification criteria.
- **ISO 9001, Lean & Industry 4.0 (dubbed Quality 4.0)**, are at the epicentre of modern quality management. With the focus on developing well-defined systems for quality, quality management is seeing another fundamental shift that corroborates with the rise of Industry 4.0. Now more than ever, organisations need to leverage the capabilities of a systems approach to adopt new methods and technologies to remain market-relevant.

The pursuit of ISO certification remains an indispensable requirement, with certification becoming an ever-increasing criterion for market-related decision-making.

Deming and Crosby similarly defined quality as the conformance to a standard suited to the expectations and requirements of the customer [31]. Juran, like Deming, was a pivotal individual in the post-war quality revolution in Japan. His work pioneered the facet of planning and following a top-down approach, emphasising the need for total top management commitment to the success of quality. Juran summarised his perception of quality as “fitness for use,” which is interpreted as meeting the customer's functional needs and ultimately leading to customer satisfaction [31]. On the other hand, Shewhart pioneered the dimension of quantitative management and continuous improvement and was responsible for the Plan-Do-Check-Act cycle (PDCA), which finds its place as an esteemed tool amongst management philosophies. His perception of quality was rooted in the reduction of variability through statistical control. These definitions and, thus, the philosophies that they represent follow a common fundamental: customer satisfaction should be the objective of QM. However, this beckons the question: how do we apply quality management in this sense, and how does it benefit? The fundamental approach to QM manifests as a meta-framework that calls for a situational application. Meaning that it is defined by a set of characteristics that are institutionalised in the form of quality practices. These characteristics represent the key organisational capabilities that enable both customer satisfaction and, in more recent developments, continuous organisational improvement. Formally defined by the principles of philosophies such as TQM, Six Sigma, ISO 9000, and Kaizen, these characteristics form the foundation of general QM theory.

To further build on the understanding of QM, it does not only mean producing a product in a standardised, repeatable manner but also the continuous satisfaction of changing requirements [15]; which also becomes apparent when considering recent developments of QMS standards such as ISO 9001 in which Continuous Improvement has been a central theme [32]. A quality approach should thus offer more than just repeatability; it should also adopt a systematic focus that addresses the quality of the process rather than the quality of the product.

#### **4.1.2 Quality Management Principles**

Quality Management Principles are the fundamental beliefs, values, and approaches that have been defined as the basic norms of QM [21, 33]. Understanding these principles is imperative to defining and finding value in TQM and ISO 9001 interpretations. The principles discussed below are based on the Eight Primary Elements of TQM [34]. Presented in Figure 4-2, the eight

principles are Customer focus, Employee involvement, Process-centred, Integrated systems, Strategic approach, Continuous improvement, Fact-based decision-making, and Communication.

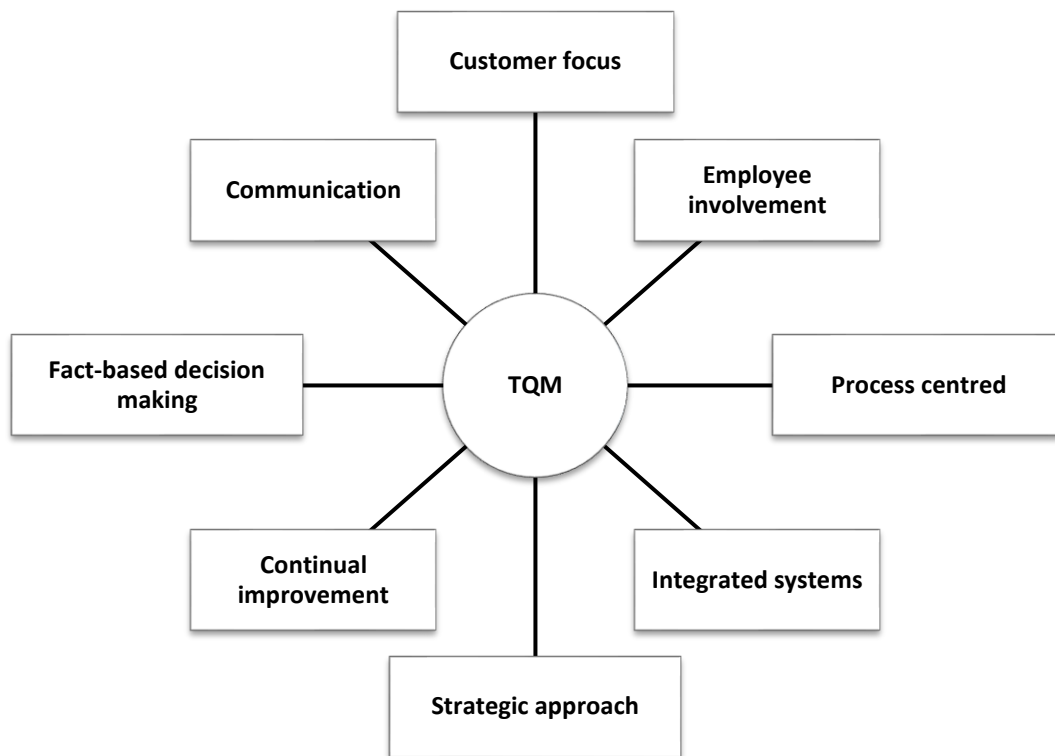


Figure 4-2: Eight Primary Elements of Total Quality Management [34]

TQM is described as a management approach that is focused on customer satisfaction and continuous improvement through unanimous organisational effort [21, 34]. TQM places the focus on creating a culture for quality by combining a process-oriented management approach with total organisational involvement, an attribute that it had inherited from its foundational theory, Deming's 14 Points on Quality Management [35]. In general, Deming's contributions, including his 14 Points remain seminal pieces of literature in the world of quality.

➤ **Deming's 14 Points Summarised [36]:**

- Cease dependence on inspection activities alone to ensure quality, instead improving the quality of the production process.
- Don't be afraid to adopt a new philosophy.
- Institutionalise leadership, recognise the role that people play in the capabilities of the organisation and institute training, skills development, education, and improvement.
- Create constancy of purpose and motivate the pursuit to continuously improve.

- Create a unanimous sense of accountability and involve the entire workforce to contribute to organisational transformation.

The following discussion elucidates QM using the principles presented in Figure 4-2 as the structure for discussion. This will provide insight into the fundamentals behind QM as well as how to approach it.

#### **4.1.2.1 Customer-focused:**

Being customer-focused means giving due consideration to the requirements of the customer. These requirements represent an amalgamation of needs, expectations, constraints, regulatory compliances, and stakeholder incorporation. From a systems perspective, being customer-focused leans toward the definition of need and management of perception. The customer's need provides criteria for a solution that offers a clear objective that can be integrated into the system's environment, providing a basis for project planning, risk-based thinking, process measurement, and, ultimately, fact-based decision-making.

Furthermore, the evaluation of customer feedback, experience, and quantified satisfaction should offer an introspective view of the organisation's capabilities. This helps in identifying nonconformances and drives decision-making in all facets of process management [37]. Conclusively, the continuous pursuit of customer satisfaction solidifies sustainable growth within the organisation through a unitary goal.

ISO 9001 details a process in which the organisation's context is defined, which subsequently leads to the definition of stakeholders, including the customer. Through the definition of stakeholder requirements, the system is given its initial strategic direction, which emphasises managing the customer [32]. Nonetheless, for ISO, bridging the gap between the organisation and the customer is the first step of QMS implementation.

#### **4.1.2.2 Employee Involvement:**

A common theme among quality management philosophies is creating a culture for quality. One of the underlying arguments of Deming's model is recognising human resource as the most important asset to a flourishing culture for quality [35]. Additionally, Juran's emphasis on the importance of top management commitment is also heavily weighted when it comes to employee involvement. To avoid ambiguity and to mitigate resistance to implementation, management needs to be clear and concise about the objectives and expectations of the QMS. This means properly defining a strategic direction and incorporating organisational feedback into the

implementation planning. An involved organisation will be a less resistive organisation and will become a smarter organisation, which will be an invaluable asset for continuous improvement.

**Approaching Employee Involvement:** TQM interpretations emphasise employee involvement through awareness, motivation, and the establishment of accountability [38, 34]. Enabling a workforce to contribute to developing a quality approach is the cornerstone of creating a culture for quality within the organisation. This means motivating quality, training, and knowledge dispersion across departmental boundaries and demonstrating that QMS implementation will benefit the organisation rather than constraining it.

With that being said, one of the most essential aspects of employee involvement is knowledge dispersion and skills development. It focuses on the workforce's overall knowledge, purpose, and motivation to describe an organisation's capability to improve itself and ensure sustainable management. Deming's model emphasizes the involvement of the workforce, which is a mitigator for some of the general downfalls of a superficial QMS [39].

#### 4.1.2.3 Process-Centred

Understanding and adopting a process approach has become an integral part of QM. TQM underlines the need to be process-centred, which is discussed as defining the organisation's processes, defining the input and output requirements, measuring these processes, and managing accordingly [34]. Processes should form the fundamental description of the organisation's architecture, meaning that a series of well-defined processes can describe the entire organisation.

A process-centric approach is a fundamental aspect of most of QM's principles, characteristics, and practices as it lays the foundation for numerous functions and capabilities. The ISO 9001 standard presents the following diagram of how the standard incorporates a process-centric approach:

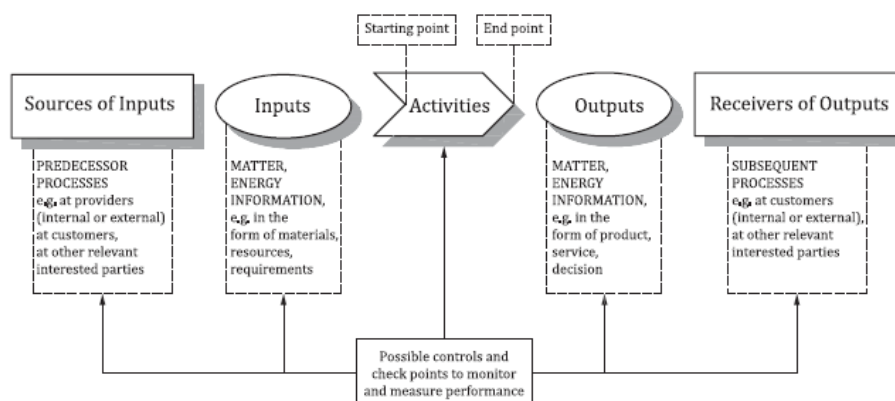


Figure 4-3: ISO 9001 Representation of a process approach to QM [32]

#### **4.1.2.4 Integrated Systems**

This principle describes the adoption of Systems Thinking within a QM context. It requires understanding that all of the organisation's functional areas, departments, and processes are contributors to the attributes of the QMS and exist collaboratively. Constantly interfacing with one another, one process's output is another's input. As the sequel to adopting a process-centred approach, integrated systems will focus on utilising process definitions to understand how the different areas of the organisation collaborate to contribute to the objectives of the QMS.

#### **4.1.2.5 Strategic Approach**

Especially valuable to the implementation of quality within small manufacturers. It is important to provide a systematic, practically measurable solution so that organisations can make informed decisions about their implementation efforts. A strategic approach is necessary on account of the complexity involved with implementing a QMS.

#### **4.1.2.6 Continual Improvement**

As stated before, continuous improvement has been a highlighted characteristic of a contemporary QM. With developments in Industry 4.0 and ever-changing regulatory requirements, the manufacturing industry has seen a tremendous acceleration in market-related developments. Thus, it is necessary to have smarter ways of operation to remain competitive in a continuously changing landscape. The essence of continual improvement is to create a malleable system in which risks, opportunities, and system feedback lead to organisational innovation. TQM literature provides that an analytical approach to managing risks and opportunities is required, and that innovative solutions are necessary [34]. A crucial prerequisite is thus the application of quantitative process management techniques. However, in light of the resource constraint coupled with implementation among SMMEs, emphasis should be placed on utilising system agility in an attempt to harness meaningful improvements at earlier stages of implementation.

As previously noted, a formative concept to the notion of continuous improvement has been the PDCA cycle, also known as the Shewhart or Deming cycle. Shewhart originally proposed it in his book, *Statistical Method from the Viewpoint of Management Practices*, in which he described the structure of the PDCA cycle as the result of keeping to the notion that continuous evaluation of practices is elemental to the evolution of an organisation [30]. Deming's contribution to the adoption of the PDCA cycle came by motivating the Japanese industry to adopt the PDCA cycle as complementary to other quality management methodologies [40].

The American Society for Quality (ASQ) defines the PDCA cycle as an iterative model for change management that is helpful when implementing change or working towards continuous improvement. Presented in Figure 4-4, the PDCA cycle is defined by four iterative steps [40]. An important attribute of the PDCA cycle is that it solidifies continuous improvement through standardisation. As soon as a viable solution to a problem is achieved, the solution is standardised and institutionalised to avoid future occurrences and ensure continuous growth.

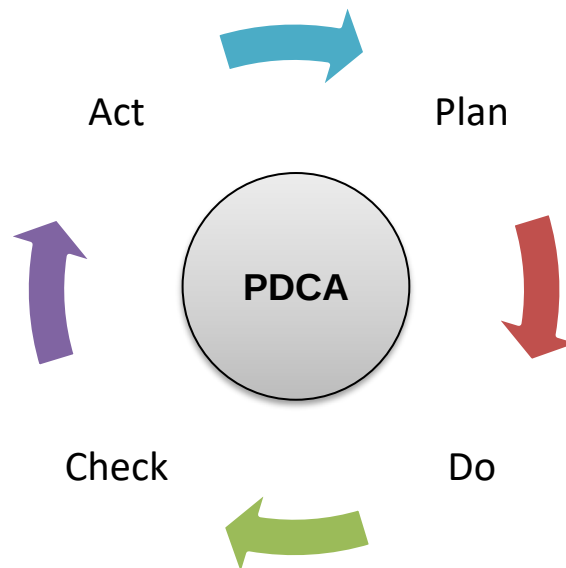


Figure 4-4: PDCA Cycle

- **Plan:** Identify a problem, risk or opportunity, analyse the observation and define the planned changes needed to address the observation;
- **Do:** Develop and implement a solution to satisfy the planned changes or improvements;
- **Check:** Evaluate outcomes of changes, analyse results, and document the lessons learnt;
- **Act:** Reflect on the results and act based on the lessons learnt. If successful, standardise the solution; if not, then repeat the process.

#### 4.1.2.7 Fact-Based Decision Making:

Being process-centred, implementing systems thinking, and quantitative management, fact-based decision-making is a form of risk-based thinking in that any management-related decision deemed relevant to the QMS is subjected to the data and knowledge made available by the QMS. This principle sets the focus on considering what is known about the organisation to make decisions influencing the organisation. Thus, the use of data and evidence complements experience and intuition in the decision-making process.

The prerequisite to implementing fact-based decision-making is a well-defined organisational context from which relevant information sources are known as well as a quantitatively capable system that generates meaningful system information. Properly planning and implementing fact-based decision-making should benefit the implementation of only measuring what is needed.

#### 4.1.2.8 Communication

Open and accessible communication channels are an essential part of QM as they directly influence the effectiveness of production flow. This characteristic complements total employee involvement, top management commitment, and relationship management between suppliers and customers. Management will benefit from communicating the intent of organisational innovation.

#### 4.1.3 Desired Organisational Impact of Quality Management

Turning the focus to the value of QMS implementation in a manufacturing setting, QM practices can be defined as effective if they improve organisational performance; in the context of the study, organisational performance is interpreted as meeting expectations, performing operationally and financially, and achieving organisational goals [21, 41]. Hendricks and Singhal [41], noted three areas of organisational performance that should benefit from quality practices: cost of quality, customer satisfaction, and organisational innovation.

Improving these areas should, in return, reduce manufacturing expenses by reducing the time and costs of production and reproduction, increase business viability through customer retention and elevated reputability, and ultimately enable sustained growth through defined and malleable processes [41, 42]. Table 4-1 below summarises the most significant findings of the studies considered for defining a TQM framework. These studies boast empirical findings of the effect of TQM on organisational performance and provide validity for their respective interpretations.

**Table 4-1: The Organisational Impact of Quality Practices**

| Information Source       | Operational Performance | Product Quality | Financial Performance | Customer Satisfaction |
|--------------------------|-------------------------|-----------------|-----------------------|-----------------------|
| Lakhal et al [38]        | ↑                       | ↑               |                       |                       |
| Lakhal [21]              | ↑                       |                 |                       |                       |
| Hendricks & Singhal [41] |                         |                 | ↑                     | ↑                     |
| Forza [43]               |                         | ↑               |                       |                       |
| Anil & Satish [42]       |                         |                 |                       | ↑                     |

➤ **Operational performance**

Lakhal *et al.* [38] provided empirical evidence that TQM practices positively influence organisational performance. Practices that focussed on providing system infrastructure enabled the core practices (defined in their study as practices related to quality tools and techniques) to add value to the operational and financial performance of the organisation. This sentiment has driven the focus on enablement applied in this study, as it provides a practical example of the pitfall of superficial implementation. Lakhal [21], provides additional evidence in another practical application of the framework that the practices related to organisational commitment and employee training correlated to operational performance.

➤ **Product quality**

Using the absence of defectiveness and product competitiveness as the criteria for product quality, Forza [43] found that practices relating to the following characteristics of TQM had a significant impact on product quality: continuous improvement, process management, supplier management, quality feedback, documentation of production procedures, and flow of information. In agreement, Lakhal [21] found that practices that institutionalise quality tools and techniques significantly influence product quality if enabled through infrastructure.

➤ **Financial performance**

Barker and Cagwin [44], found a positive relation between financial performance and TQM practices, specifically focussed on institutionalising the following characteristics: management commitment, customer focus, supplier relations, employee training, employee commitment, and internal cooperation. However, Hendricks and Singhal [41] provide evidence that organisations only start to exhibit financial benefit from a QMS 2 to 3 years are committed to implementation.

➤ **Customer satisfaction**

As the criteria for successful implementation, customer satisfaction is a principal aspect of QM. Anil and Satish [42] presented empirical evidence through an industry survey that a commitment to TQM practice positively influences overall customer satisfaction. They also highlighted the impact of systematic customer feedback measurement on improving satisfaction. In their study, they defined 10 critical characteristics of TQM to be analysed in relation to customer satisfaction. Of the 10 factors analysed, 6 were identified as having a significant relation to customer satisfaction: customer focus, supplier quality management, information and analysis, quality assurance, process management, and knowledge management.

#### **4.1.4 Defining Quality Management Systems**

With an understanding of the fundamentals of QM, attention can be directed to the systematic aspect of implementing QM. The true value of a quality approach comes from the requirement to adopt systems engineering tenets with customer satisfaction as the objective. The statement, a culture for quality, means that the characteristics of quality should be an integral part of the attributes of the organisation. Implementing a QMS should thus be synonymous with adopting a quality mindset that shapes and influences the entire organisation's management philosophy and decision-making approach, which requires systems thinking.

The American Society for Quality (ASQ) offers the following definition of a QMS [45]:

*A QMS is a formalised system that documents processes, procedures, and responsibilities for achieving quality policies and objectives. A QMS helps coordinate and direct an organisation's activities to meet customer and regulatory requirements and improve its effectiveness and efficiency on a continuous basis.*

Regardless of the requirement of documentation, a common pitfall for systems such as ISO 9001 is its interpretation of it as a series of paper exercises. Applying systems thinking mitigates this through an emphasis on complete integration. To reiterate, the value of a QMS does not lay within the documented meta-description of processes but with the systemic attributes that are embedded in seeking system definition.

##### **4.1.4.1 Quality Management and Systems Engineering**

A system, as defined by Blanchard and Fabrycky is [46]: is “an assemblage or combination of functionally related elements or parts forming a unitary whole”. They elaborate on this definition by stating that a system consists of three facets, namely components, attributes, and relationships. The components are the individual elements of the system, while the relationships are the interactions between the components, and the attributes are the properties of the individual components as well as the properties of the system as the result of the cooperative relationships [46]. Relevant to QM, the attributes of the system are related to the systemic capability of managing customer requirements and contributing to continuous improvement; also consistent to the definition of a QMS provided by ASQ [45], the components that cooperate to form these attributes are the people, knowledge, procedures, processes, policies, and methods used to manage towards customer satisfaction and continuous improvement.

The term Systems Engineering (SE) describes an amorphous idea that does not have a universally accepted definition [46]. However, Blanchard and Fabrycky do provide some definitions from reputable sources [46]: INCOSE provides a holistic definition of the term and defines systems engineering as: “an interdisciplinary approach to enable the realisation of successful systems”. The EIA (Electronic Industries Alliance) offers a more elaborate definition which details the act of integrating people, products, and process solutions to customer satisfaction. The IEEE (Institute of Electrical and Electronic Engineers) defines it as: “an interdisciplinary collaborative approach to derive, evolve and verify a life-cycle balanced system solution which satisfies customer expectations and meets public acceptability”.

The result of applying the SE to achieve an objective is an engineered system that combines human resources, technology, information, and processes to achieve a predefined objective within a known operating environment. This means catering to the needs and requirements of the implementer. INCOSE formally defines an engineered system as [47]: “A system designed or adapted to interact with an anticipated operational environment to achieve one or more intended purposes while complying with applicable constraints”.

***In Summary:*** *In the context of QM, a QMS is the result of applying systems thinking to the QM principles and practices, facilitates the integration and understanding of the relationships and interactions between the different processes, methods, policies, and procedures typical to the institutionalisation of the QM principles. The institutionalisation and operationalisation of these principles lead to the formulation of desired QMS characteristics used to describe the effectiveness of a QM implementation endeavour.*

#### **4.1.5 Quality Management System Characteristics**

The following section turns the focus to the institutionalisation of QM principles. As mentioned before, QM is institutionalised by applying quality management practices. These practices are catered to the requirements and capabilities of the implementer and are defined as the decisions, activities, and approaches typical of a QMS [43]. The TQM framework used in this study is based mainly on the interpretation put forth by Lakhal *et al.* [38] in a study aimed at defining the impact of TQM practices on the performance of manufacturing organisations. To do so, they developed a conceptual quality management model through meticulous research of various TQM interpretations to compile a list of distinct quality practices commonly related to organisational performance. The conceptual model was then subjected to a real-world analysis, and the result was a refined model of generic characteristics of quality management along with each institution's respective institutionalisation practices.

In addition, the TQM interpretations used in various studies aimed at different facets of manufacturing were also considered. Table 4-2 presents the characteristics of TQM delineated in these studies. The practices that constitute these characteristics will be presented in more detail in Table 4-2, and their use as a research instrument in an industry survey will be discussed. Table 4-2 also references the characteristics of QM defined by ISO 9001-oriented studies, demonstrating commonality between the fundamental approaches of TQM and ISO 9001 practitioners.

**Table 4-2: QMS Characteristics based on TQM and ISO 9001 Researcher Interpretations**

|                                 | <b>Authors</b>                    | <b>Journal</b>                                                           | <b>QMS Characteristics</b>                                                                                                                                                                                                                                                                                   |
|---------------------------------|-----------------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Total Quality Management</b> | <b>Lakhal et al. [38]</b>         | Quality Management Journal                                               | Top management commitment and support, Organisation for quality, Employee training, Employee participation, Customer Focus, Quality system improvement, Information and analysis                                                                                                                             |
|                                 | <b>Anil P., Satish K. [42]</b>    | Total Quality Management                                                 | Leadership and Top Management Commitment (LTMC), Customer Focus (CF), Supplier Quality Management (SQM), Continuous Improvement (CI), Employee Empowerment (EE), Education and Training (ET), Quality Information Analysis (QIA), Quality Assurance (QA), Process Management (PM), Knowledge Management (KM) |
|                                 | <b>Anderson A. [48]</b>           | International Journal of Quality & Reliability Management                | Leadership, Quality vision and plan, Process control and improvement, Product Design, Quality audit and evaluation, Supplier quality management, Education and training, Customer focus                                                                                                                      |
|                                 | <b>Gadenne D., Sharma B. [49]</b> | Australia and New Zealand Academy of Management International Conference | Top Management Philosophy, Measurement and Open Organisation, Process Improvement Efficiency, Close to Customers, Close to Suppliers, Operational Marketing Improvement, Employee Empowerment, Employee Training, and Entering an AQC Award.                                                                 |

|          |                         |                                                           |                                                                                                                                                                                                                                                                                               |
|----------|-------------------------|-----------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ISO 9001 | Aslan E., Ilkay M. [15] | International Journal of Quality & Reliability Management | Top management leadership, Customer orientation, Quality system processes, Human resources applications, Supplier relations, Process control and improvement                                                                                                                                  |
|          | Almeida et al [50]      | International Journal of Quality & Reliability Management | Top management commitment, Team commitment, Training, Responsibilities and authorities defined, Schedule for implementation, Quality culture, Resources availability, Integration between departments, Unbureaucratic management system, People awareness regarding the ISO 9001 significance |

#### 4.1.6 TQM Characteristics and Best Practices

Lakhal [20] also conducted a study on 176 manufacturers investigating the relationship between ISO certification, TQM practices, and organisational performance. In this study, he provides empirical evidence that both TQM practices and an ISO QMS influence organisational performance and further suggests that the model supports the notion that ISO certification benefits the efficacy of TQM efforts. The TQM framework presented in Table 4-3 below details the characteristics and respective practices that have been commonly used in the studies considered and detailed in Table 4-2. The framework results from the inductive interpretation of numerous studies to identify the characteristics and practices that have been identified as relevant and beneficial to a TQM interpretation within a manufacturing management environment.

Table 4-3: TQM Best Practices Framework [21, 48, 42]

| TQM Characteristics |                           | Best Practices |                                                                      |
|---------------------|---------------------------|----------------|----------------------------------------------------------------------|
| F1                  | Customer Focus            | F11            | Establishment of customer requirements                               |
|                     |                           | F12            | Customer-oriented quality objectives                                 |
|                     |                           | F13            | Continuous market research                                           |
|                     |                           | F14            | Investigate customer satisfaction                                    |
|                     |                           | F15            | Requirements are managed and continuously integrated into the system |
| F2                  | Top Management Commitment | F21            | Establishment of quality management commitment (Policies)            |
|                     |                           | F22            | Committed to allocating resources to quality                         |
|                     |                           | F23            | Management is accessible to the organisation                         |

|           |                                  |            |                                                                            |
|-----------|----------------------------------|------------|----------------------------------------------------------------------------|
| <b>F3</b> | <b>Organisational Commitment</b> | <i>F31</i> | Quality objectives are disseminated throughout the company                 |
|           |                                  | <i>F32</i> | Enable employee contribution to the QMS                                    |
|           |                                  | <i>F33</i> | Employees are motivated to contribute to the QM commitments                |
|           |                                  | <i>F34</i> | Supplier quality management                                                |
|           |                                  | <i>F35</i> | Established quality assurance protocols                                    |
|           |                                  | <i>F36</i> | Products are tested according to defined procedures                        |
| <b>F4</b> | <b>Employee Training</b>         | <i>F41</i> | Established internal training program                                      |
|           |                                  | <i>F42</i> | Employees are educated on the QMS                                          |
|           |                                  | <i>F43</i> | Established succession training                                            |
|           |                                  | <i>F44</i> | The training program is assisted through governmental organisations (SETA) |
| <b>F5</b> | <b>Process Management</b>        | <i>F51</i> | The physical flow of manufacturing processes are defined                   |
|           |                                  | <i>F52</i> | Processes are defined by standardised procedures                           |
|           |                                  | <i>F53</i> | Process performance metrics are measured (omitted)                         |
|           |                                  | <i>F54</i> | Risk analyses are implemented in the decision-making process               |
| <b>F6</b> | <b>Information and Analyses</b>  | <i>F61</i> | Data is converted into interpretable information                           |
|           |                                  | <i>F62</i> | Information is made available to relevant employees                        |
|           |                                  | <i>F63</i> | Quantitative information and facts form the basis of decision-making       |

#### 4.1.7 To Summarise

This section explored the QM philosophy and contextualised an accepted QM paradigm for a small manufacturing application. It was determined that a QM paradigm is typically defined by a set of principles institutionalised through best-quality practices and the development of organisational QM characteristics. The TQM philosophy, a widely accepted and seminal approach to QM, was further explored through industry applications and various interpretations done by researchers in the field of manufacturing. The research provided that there is commonality in the definition of the desired organisational characteristics resulting from implementing TQM through a manufacturing lens (as presented in Table 4-2). This means that researchers have tested or utilised similar models, interpretations, and implementations of TQM and have reached similar conclusions. Knowing this, a framework of the TQM characteristics and related best quality practices that have been tested and validated as having a beneficial impact on a small

manufacturing organisation could be derived. This TQM framework, as presented in Table 4-3, is the foundation for the TQM Industry Survey discussed in the following section and the primary interpretation used to align the CMM adaption with known, validated, and accepted QM principles.

Regarding the practical considerations related to a small manufacturing implementation, if leveraged correctly, the relative simplicity of a smaller organisation could offer an opportunity to reduce the complexity of a QM implementation, meaning that the initial onset of developing a QMS might be alleviated by the early development of core capabilities that assist with further development. Given this, Deming's emphasis on total employee involvement is a heavily weighted practical consideration for QM implementation among SMMEs. People are the most valuable assets to a small manufacturer; thus, early commitment, involvement, enablement, and competence are crucial to a QMS's sustainability and overcoming the change management and administrative hurdles exclaimed in Chapter 2.

## 4.2 Industry Survey

**Note to the reader:** *At this stage in the research project, it was apparent that there is a lack of QM contextualisation in the South African manufacturing industry, especially for small manufacturing applications. Consequently, researchers, managers, or practitioners aiming to understand and implement QM within a South African manufacturing SMME need to rely on similar interpretations from different countries to characterise their QM interpretation. The Industry Survey is thus situated to follow the Literature Study as it builds on the QM foundation of the research project and further elucidates the current state of QM among South African small manufacturers beyond what was available in the literature.*

### 4.2.1 Survey Premise

**Purpose:** Section 4.2 details a QM-oriented industry survey that was conducted on South African small manufacturers. The survey offers a cross-sectional exploration of the South African manufacturing industry, the contribution of which is qualitative in that it describes the current state of QM implementation of South African small manufacturers.

**Theoretical Foundation:** The theoretical foundation of the survey is based on the TQM philosophy and related interpretations discussed in the preceding literature study. The framework used to develop the survey is presented in Table 4-3. The survey was thus focused on determining the presence of institutionalisation of TQM best practices and characteristics rather than quantifying its effect; for this reason, a Questionnaire was used as the data gathering method. Using a questionnaire to collect evidence is common among researchers in management, quality management, and ISO 9001 [42, 21, 38]. Researchers have employed a

survey to define QM's qualitative characteristics, presence, and institutionalisation in almost all instances.

**Participants:** The inclusion criteria for the survey were South African manufacturers that fall within the South African Department of Small Business Development's definition of an SMME [51]. Several potential participants were approached, and 27 viable participant data sets were subsequently yielded. The participating companies were represented by an owner, manager, or QM consultant (if applicable), as they are expected to have a holistic knowledge of the processes and procedures of their company. Regardless of the notable limitations of using individual perceptions to define system characteristics, using a manager's perception is a common approach researchers use [38, 52, 41, 50]. The culture of an SMME is often the product of the manager/owners' views, methods, and experience [49]; thus, interpreting their perception often leads to an understanding of the organisation's culture.

#### 4.2.2 Data Collection

As mentioned before, the survey attempts to measure the institutionalisation of QM within a participating organisation by using a questionnaire. The questionnaire should thus allow for a form of quantification, which in this case was Likert-type questions used to measure the perception of a manager, owner, or consultant. The measurement basis was provided by a derived TQM framework of QM characteristics and respective best practices based on similar frameworks used in organisational research focussed on manufacturing management, SMME's, and QM. The survey also depended on a series of qualitative questions used to distinguish datasets into groups to make meaningful conclusions based on categorical differences (such as, industry of operation, ISO 9001 certification, and presence of a quality manager). The following section briefly discusses the synthesis of the derived TQM framework, the questionnaire design, the classification and literature support of data analysis techniques, and the data validation techniques used.

The initial survey invitations were distributed via email, telephone discussions, and in-person approaches. Potential participants were provided with an information package as per the informed consent requirements of proper research ethics and were provided with a link to a web-based questionnaire hosted on *QuestionPro*. The survey efforts generated 27 viable data sets; 8 participants were ISO 9001 certified, of which only one participant was certified for less than 2 years and did not have a dedicated quality manager. This means that 26% of participants were both ISO 9001 certified and managed by a dedicated quality manager/consultant. Among the 19 participants without certification, only 6 had a dedicated quality manager. The variable groups defined in Table 4-4 consisted of the following breakdown: 30% in G1 (certified), 22% in G2

(managed), and 48% in G3 (unmanaged). The participants were given nine options to choose their relevant industry type. The majority of participants were from the metal and mechanical industries, accounting for 66% of the responses. 11% were from the automotive industry, 8% from the food or medical industries and 15% selected Other.

*From the above, it is observed that there is a significant gap in the certification status of small manufacturing companies, with only 30% of participants holding current certification. The barriers to certification are well defined in the literature and include factors discussed in Section 2.3 and supported by additional contemporary literature emphasising the difficulties encountered when creating a monitoring program [53].*

#### 4.2.3 Data Analysis

The questionnaire in Annexure A – Survey Questionnaire consisted of two sections; in the first, participants were asked if they were ISO certified and were subsequently asked to indicate the duration of certification. Participants were then asked if they had a dedicated and trained quality manager (either internal or consulting). These questions enabled the grouping of the participants to be consistent with the definitions in Table 4-4. The second section of the questionnaire consisted of five-point Likert-type questions focused on the TQM framework. Participants were asked to rate the applicability of statements focused on operationalising quality practices to their organisation. This structure is consistent with the work done by Lakhal [21], Ilkay & Aslan [15], and Forza [43] in studies that quantified QM characteristics and subsequent practices based on Likert-type responses.

**Table 4-4: Categorical variable classification**

| Groups | QMS Designation | Description                                                                                                     |
|--------|-----------------|-----------------------------------------------------------------------------------------------------------------|
| G1     | Certified       | Participants that have both mature QMS certification (more than 2 years) as well as a dedicated quality manager |
| G2     | Managed         | Participants that have a dedicated quality manager but do not have QMS certification                            |
| G3     | Unmanaged       | Participants without any QM initiatives (neither certification nor a dedicated quality manager)                 |

Single-item, Likert-type responses are most appropriately treated as ordinal data, representing a scaled perception [54]. However, the mean or sum of multiple Likert-type responses that are focused on a common characteristic can be treated as interval data and used to describe the characteristic quantitatively [55]. Treating Likert data as interval data means that it can be analysed using parametric statistical techniques such as the student's t-test. Clason and Dormondy [56] stipulate that parametric procedures may be applied to Likert-type data if the

objective of the analysis is location and not quantification. Additionally, de Winter and Dodou [57] tested various five-point Likert data sets with various distributions using both the student's t-test and the Mann-Whitney-Wilcoxon (MWW) approach. They found that there was no significant difference between the parametric t-test approach and the nonparametric MWW. Norman [54] further supports this claim as he provides evidence that the robustness of parametric tests is enough to compensate for an ordinal source.

**Relevant to the survey:** The characterisation of the quality management practices, as described by the central tendency of the institutionalisation-focused questions, can thus be quantified using mean values from the survey data. The groups defined in Table 4-4 can then be compared by analysing the respective means of each group to be validated through the student's t-test.

The t-test calls for the formulation of a null hypothesis to be accepted or rejected depending on the resulting p-value (rejected for p-value > 0.05 for a significance level of 5%). The null hypotheses in this study focused on comparing the means of the quality management facets of each group defined in Table 4-5.  $F_i \bar{X}_n$ , thus represents the mean scoring of group n for quality management facet  $F_i$ . Various variations of the t-test exist, each suited to the type of research, data, and desired outcome. The goal of the t-tests was to compare the means of two groups per null hypothesis, as defined in Table 4-4. The independent t-test with equal variances assumed was thus used for the analysis [58].

**Table 4-5: Null hypotheses**

| Hypothesis      | Mean Comparison                 | Description                                                                                                                               |
|-----------------|---------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| H <sub>01</sub> | $F_i \bar{X}_1 = F_i \bar{X}_2$ | System certification does not offer any additional presence of TQM practices if there is a dedicated quality manager.                     |
| H <sub>02</sub> | $F_i \bar{X}_2 = F_i \bar{X}_3$ | A dedicated quality manager does not offer any additional presence of TQM practices when compared to a system without any QM initiatives. |
| H <sub>03</sub> | $F_i \bar{X}_1 = F_i \bar{X}_3$ | System certification does not offer any additional presence of TQM practices as compared to a system without any QM initiatives.          |

#### 4.2.4 Data Validation

The Cronbach Alpha coefficient is a metric used to determine the reliability of a data set by quantifying the internal consistency of a scale variable calculated as the mean or sum of ordinal items [59]. The Cronbach Alpha reliability test is thus applicable to any research attempt that relies on scale data, hence its importance for Likert-type questionnaires. Cronbach's Alpha coefficient is reported as a value between 0 and 1, and the reliability of the data is confirmed with alpha greater than 0.7 (for exploratory research purposes) or 0.8 (for applied research) [59].

Table 4-6 presents the results of the Cronbach Alpha reliability test for the six quality management facets respectively. **F5 – Process Management** was initially flagged with a Cronbach alpha of 0.531. Item F53 was subsequently omitted from the data set as its deletion increased the alpha to 0.692. F53 represented the operationalisation of process measurement.

**Table 4-6: Cronbach Alpha Reliability Test**

| <b>Quality Management Facets</b> | <b>Alpha</b> |
|----------------------------------|--------------|
| F1 – Customer Focus              | 0.768        |
| F2 – Top Management Commitment   | 0.701        |
| F3 – Organisational Commitment   | 0.843        |
| F4 – Employee Training           | 0.718        |
| F5 – Process Management          | 0.692        |
| F6 – Information and Analysis    | 0.780        |

#### 4.2.5 Results

Table 4-7 below presents the questionnaire results as the mean scoring of the QM facets and the quality practices of each, respective to the QMS designations. The t-tests results are also presented, relevant to the comparisons made for each null hypothesis. The results of the null hypotheses are discussed below.

**Hypothesis 1:** It should be noted that all the certified participants included in the t-test were certified for at least 2 years and had a dedicated quality manager. The only degree of freedom relevant to the first null hypothesis is thus QMS certification status. G1 and G2 performed similarly in terms of mean scoring. The null hypothesis could not be rejected for any of the six quality management facets. Thus, QMS certification did not offer a statistically significant difference in the presence of TQM facets when compared to managed, yet-to-be-certified systems.

**Hypothesis 2:** The null hypothesis could be rejected for four out of six quality management facets. A quality manager thus significantly influences the presence of TQM facets in a manufacturing QMS. The facets that did not prove statistically significant were Top Management Commitment as well as Information and Analysis, of which both groups had a relatively low mean scoring.

**Hypothesis 3:** The null hypothesis could be rejected for all six quality management facets. This suggests a significantly larger presence of TQM-aligned practices within a mature certified QMS than in an unmanaged QMS. Additionally, compared to G3, G1 demonstrated stronger significance for more quality management practices than G2. Suggesting that regardless of the outcome of the first hypothesis, there is evidence of improved TQM presence in achieving mature certification.

**Table 4-7: Independent student's t-test**

| Quality Management Characteristics & Practices                       | Mean        |             |             | p-values    |              |              |
|----------------------------------------------------------------------|-------------|-------------|-------------|-------------|--------------|--------------|
|                                                                      | G1          | G2          | G3          | H1          | H2           | H3           |
| <b>F1 - Customer Focus</b>                                           | <b>4.23</b> | <b>4.24</b> | <b>3.68</b> | <b>0.46</b> | <b>0.004</b> | <b>0.007</b> |
| Customer-oriented quality requirements                               | 4.43        | 4.42        | 4.12        | 0.48        | 0.117        | 0.117        |
| Establishment of customer requirements                               | 4.57        | 4.50        | 3.46        | 0.43        | 0.021        | 0.004        |
| Continuous market research                                           | 4.43        | 4.17        | 4.08        | 0.17        | 0.359        | 0.106        |
| Investigate customer satisfaction                                    | 4.07        | 4.33        | 3.73        | 0.16        | 0.006        | 0.134        |
| Requirements are managed and continuously integrated into the system | 3.65        | 3.76        | 2.99        | 0.36        | 0.016        | 0.082        |
| <b>F2 - Top Management Commitment</b>                                | <b>3.58</b> | <b>3.50</b> | <b>2.90</b> | <b>0.29</b> | <b>0.04</b>  | <b>0.017</b> |
| Establishment of quality management commitment (Policies)            | 3.67        | 3.50        | 2.92        | 0.37        | 0.091        | 0.100        |
| Committed to allocating resources to quality                         | 3.50        | 3.33        | 3.00        | 0.36        | 0.198        | 0.095        |
| Management is accessible to the organisation                         | 3.57        | 3.67        | 2.77        | 0.41        | 0.023        | 0.070        |
| <b>F3 - Organisational Commitment</b>                                | <b>3.99</b> | <b>4.00</b> | <b>3.36</b> | <b>0.48</b> | <b>0.017</b> | <b>0.005</b> |
| Quality objectives are disseminated throughout the company           | 3.93        | 4.17        | 3.77        | 0.20        | 0.130        | 0.260        |
| Enable employee contribution to the QMS                              | 4.00        | 3.83        | 3.33        | 0.31        | 0.062        | 0.010        |
| Employees are motivated to the QM commitments                        | 3.57        | 3.58        | 2.62        | 0.49        | 0.020        | 0.030        |
| Supplier quality management                                          | 4.08        | 4.00        | 3.38        | 0.42        | 0.035        | 0.014        |
| Established quality assurance protocols                              | 4.36        | 4.42        | 3.69        | 0.46        | 0.105        | 0.020        |
| Products are tested according to defined procedures                  | 4.36        | 4.08        | 3.38        | 0.19        | 0.023        | 0.001        |

| Quality Management Characteristics & Practices                        | Mean        |             |             | p-values    |              |               |
|-----------------------------------------------------------------------|-------------|-------------|-------------|-------------|--------------|---------------|
|                                                                       | G1          | G2          | G3          | H1          | H2           | H3            |
| <b>F4 - Employee Training</b>                                         | <b>3.22</b> | <b>2.79</b> | <b>2.02</b> | <b>0.15</b> | <b>0.004</b> | <b>0.0002</b> |
| Established internal training program                                 | 4.14        | 3.17        | 2.08        | 0.04        | 0.022        | 0.00001       |
| Employees are educated on the QMS                                     | 3.57        | 3.50        | 2.62        | 0.45        | 0.072        | 0.010         |
| Established succession training                                       | 2.86        | 3.17        | 2.08        | 0.23        | 0.010        | 0.026         |
| The training program is assisted by governmental organisations (SETA) | 2.29        | 1.33        | 1.31        | 0.10        | 0.468        | 0.097         |
| <b>F5 - Process Management</b>                                        | <b>4.02</b> | <b>3.80</b> | <b>3.18</b> | <b>0.24</b> | <b>0.007</b> | <b>0.0003</b> |
| The physical flow of manufacturing processes are defined              | 4.50        | 4.58        | 3.77        | 0.39        | 0.008        | 0.016         |
| Processes are defined by standardised procedures                      | 4.14        | 3.83        | 3.62        | 0.34        | 0.345        | 0.200         |
| Process performance metrics are measured (omitted)                    | 4.43        | 4.00        | 3.08        | -           | -            | -             |
| Risk analyses are implemented in the decision-making process          | 3.43        | 3.00        | 2.15        | 0.18        | 0.017        | 0.007         |
| <b>F6 - Information and Analyses</b>                                  | <b>3.55</b> | <b>3.33</b> | <b>2.59</b> | <b>0.33</b> | <b>0.052</b> | <b>0.005</b>  |
| Data is converted into interpretable information                      | 3.50        | 3.25        | 2.35        | 0.33        | 0.061        | 0.004         |
| Information is made available to relevant employees                   | 3.43        | 3.67        | 3.15        | 0.37        | 0.223        | 0.291         |
| Quantitative information and facts form the basis of decision-making  | 3.71        | 3.08        | 2.27        | 0.12        | 0.068        | 0.0002        |

#### 4.2.6 Reflecting on TQM in South Africa

##### ➤ F1 (Customer Focus)

The dominant practices for Customer Focus were customer-oriented quality requirements, validation of post-production product quality, proactive investigation of customer satisfaction, and being up-to-date on industry-related knowledge. The practices that differentiated managed systems from unmanaged systems were the establishment of customer requirements as well as the continuous management of any changes in requirements. There was, however, an overall lack of reintegration of customer feedback and reporting of customer satisfaction.

### ➤ F2 (Top Management Commitment)

Top Management Commitment was among the lowest-scored facets, with all three groups failing to exhibit sufficient presence of quality-oriented resource allocation and accessibility of management to the organisation. Referring to Table 4-8, G1 displayed a commitment to the establishment of QM policies, while G2 relied more on quality assurance and engineering policies. Interestingly, the unmanaged systems often relied on technical specifications and industry norms for quality guidelines.

An observed benefit of certified systems was a significant decrease in overall management dependency, signifying the benefit of reduced managerial responsibilities in a mature QMS. Employees were less likely to require daily task allocations, and performance relied less on the constant presence of management. G1 were also more likely to make use of defined SOP's (Standard operating procedures) and written task appointment methods instead of a verbal management approach.

**Table 4-8: Policies in manufacturers**

| <b><i>Policy</i></b> | <b><i>G1<br/>n = 7</i></b> | <b><i>G2<br/>n = 6</i></b> | <b><i>G3<br/>n = 13</i></b> |
|----------------------|----------------------------|----------------------------|-----------------------------|
| Quality Management   | 100%                       | 33%                        | 31%                         |
| Quality Assurance    | 71%                        | 67%                        | 23%                         |
| Employee Training    | 86%                        | 50%                        | 8%                          |
| Engineering          | 43%                        | 67%                        | 0%                          |
| Other                | 14%                        | 17%                        | 38%                         |

### ➤ F3 (Organisational Commitment)

Organisational Commitment refers to the organisation's awareness, motivation, and enablement to commit to the QMS. Following the results of Top Management Commitment, there was an overall lack of employee motivation/incentive to actively contribute to QM as well as to the innovation of the organisation.

The differentiating characteristics between managed and unmanaged systems were organisational awareness and employee enablement. There was also a discernible difference in the presence of defined quality assurance protocols and the implementation of planned internal quality inspections. Referring back to the results of Customer Focus, all three groups alleged to implement product quality validation meticulously; however, only G1 and G2 demonstrated evidence of planned and defined quality assurance procedures. This proliferates the expectation

that G3 views postproduction quality inspections as an ad hoc process to reduce the frequency of product returns rather than as a reflection of the performance of the manufacturing process.

#### ➤ **F4 (Employee Training)**

All three groups exhibited poor presence of Employee Training. G1 did, however, present higher in terms of an established training program, but this could be the result of the ISO auditing process. The ISO 9001 standard requires documented evidence of organisational competence, including a plan to evaluate and develop necessary competency [10]. There was also an observed overall lack of succession training. More often than not, SMMEs rely on the knowledge of experienced workers or managers; a lack of established succession of knowledge could thus have dire effects on the performance of the organisation. To provide further insight to the observation, participants were asked to rate the dependency of their performance on individual input, to which the average result was relatively low for G1 (2.5), yet higher for G2 and G3 (3.9). This result aligns with the reduced management dependency observation as there is expected to be a better dispersion of knowledge with the use of SOPs; G1 thus inadvertently applies a form of succession training.

SMMEs rarely overcome the cost hurdle in the pursuit of QMS implementation, a statement that has incessantly been cited. The utilisation of a relevant SETA (Sector Education and Training Authority) could offer both the development of internal training objectives whilst offering financial subsidies. Admittedly, SETA utilisation does come with a set of administrative duties, but there is value in making employee training more affordable and accessible [60]. Questionnaire results suggest a severe inadequacy in utilising SETA services; however, whether this is due to awareness, difficulty/reluctance in the SETA registration process or other factors is yet to be determined.

#### ➤ **F5 (Process Management)**

All three groups displayed a good presence of the definability of physical processes, suggesting that the representatives had a good idea of the process layout of the organisation they represented. Managed and certified systems had a notably larger presence in the standardisation of procedures and protocols. Also, they exhibited a larger presence of the capability to coordinate resources and trace a product's lifecycle. Thus, there is a good understanding of the manufacturing processes among managed and certified systems.

Although **F53** was omitted from the t-test, it is still worthwhile to mention that certified systems were more likely to implement process measurement. However, when asked if they had measures in place to determine the cost of poor quality or whether the actual cost of production is ever

compared to the cost of quotation, only G2 presented sufficient scoring. Additionally, the most significant gap was using a risk management approach. None of the groups significantly rated risk management as an integral part of their decision-making process.

➤ **F6 (Information and Analysis)**

Information and Analysis builds on the Process Management facet. The measurement of processes requires data analytics to describe process characteristics, which are necessary for quantitative management and continuous improvement. There was an observed lack of the use of quantitative management methods among manufacturers. Statements regarding data interpretation, statistical analysis, and performance representation were among the lowest-rated statements in the questionnaire. Suggesting that process data is not adequately converted to system information for quantitative management. Quantitative management and fact-based decision-making are thus poorly applied facets.

#### **4.2.7 To Summarise**

Results suggest that South African manufacturers exhibit a customer-oriented culture and recognise the importance of product quality assurance. They also possess the underlying infrastructure to inspect the quality of a product but lack the systemic capabilities required for continuous improvement. From a TQM perspective, there is a definite increase in the presence of quality practices in both managed and certified systems, as opposed to unmanaged systems. Managed systems exhibit a sufficient infrastructure for implementing change management, managing supplier quality, testing and validating product quality, and defining their relevant manufacturing processes. However, the identified gap hindering South African manufacturing SMMEs from global excellence is the application of applied management techniques such as risk-based management, quantitative process management, and continuous improvement.

With that being said, the observed lack of a risk-based approach might also be the largest chasm between a small manufacturer and ISO 9001 certification readiness, given that the 2015 version of the standard is rooted in risk-based thinking and requires a demonstration of continuous improvement. Table 4-9 summarises the discussion of results and offers a high-level mapping of the current state of quality management among South African manufacturing SMMEs from a TQM perspective. The table also serves as a gap identification of the TQM practices that South African manufacturers do not commonly implement.

Table 4-9: TQM in South Africa

|    | Current State                                                                                                                                                    |                                                                                                                                                                                                                    |                                                                                                                                              | Desired State                                                                                                                                      |
|----|------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
|    | Unmanaged                                                                                                                                                        | Managed                                                                                                                                                                                                            | Certified                                                                                                                                    | TQM Aligned                                                                                                                                        |
| F1 | <ul style="list-style-type: none"> <li>- Quality requirements are customer-oriented.</li> <li>- Manufacturers are up to date with industry knowledge.</li> </ul> | <ul style="list-style-type: none"> <li>- Customer requirements are established.</li> <li>- Customer satisfaction is continuously investigated.</li> <li>- Changes in customer requirements are managed.</li> </ul> |                                                                                                                                              | <ul style="list-style-type: none"> <li>- Act on customer feedback.</li> </ul>                                                                      |
| F2 | Insufficiently applied                                                                                                                                           |                                                                                                                                                                                                                    | <ul style="list-style-type: none"> <li>- Established commitment through QM policies.</li> </ul>                                              | <ul style="list-style-type: none"> <li>- Quality enabling resource allocation.</li> <li>- Management is accessible to the organisation.</li> </ul> |
| F3 | <ul style="list-style-type: none"> <li>- The organisation is aware of quality requirements and objectives.</li> </ul>                                            | <ul style="list-style-type: none"> <li>- Supplier quality is managed.</li> <li>- Defined product testing procedures</li> </ul>                                                                                     | <ul style="list-style-type: none"> <li>- Employees can contribute to the QMS.</li> <li>- Established quality assurance protocols</li> </ul>  | <ul style="list-style-type: none"> <li>- Incentivise QMS contribution</li> </ul>                                                                   |
| F4 | Insufficiently applied                                                                                                                                           |                                                                                                                                                                                                                    | <ul style="list-style-type: none"> <li>- Established internal training program</li> </ul>                                                    | <ul style="list-style-type: none"> <li>- QMS specific education</li> <li>- Succession training</li> </ul>                                          |
| F5 | Insufficiently applied                                                                                                                                           | <ul style="list-style-type: none"> <li>- Processes are physically definable.</li> </ul>                                                                                                                            | <ul style="list-style-type: none"> <li>- Process measurement</li> <li>- Standardisation of operating and manufacturing procedures</li> </ul> | <ul style="list-style-type: none"> <li>- Risk-based management</li> </ul>                                                                          |
| F6 | Insufficiently applied                                                                                                                                           |                                                                                                                                                                                                                    | <ul style="list-style-type: none"> <li>- Fact-based decision making</li> </ul>                                                               | <ul style="list-style-type: none"> <li>- Data analysis and interpretation</li> <li>- Availability of process information</li> </ul>                |

**Inference:** It is evident that there is a gap to be addressed in small manufacturing, with 48% of participants not actively managing quality and 70% lacking a formal quality system. There is value in incremental implementation for bringing about change to an organisational culture, implementing a comprehensive monitoring system, and ultimately limiting the financial shock of such changes [13]. As a result, to bring about structured incremental change, a clear growth path towards sustainable quality management is a critical requirement. The value proposition to a small manufacturer, as supported by the survey responses and the barriers and constraints of quality management, is that the growth path must be clear regarding goals, process, time, and cost. This gap and challenge thus present an opportunity for a continuous growth model towards quality management, with incremental change being a characteristic of a CMM [61].

Referring back to the barriers to QM discussed in Section 2.3, namely, a lack of leadership (which is also related to motive), failure to embrace new technologies [14], resource availability and cost of implementation [2, 15], a lack of awareness or knowledge of management systems [10], and poor motive for implementation [2, 17]. These barriers are also consistent with the barriers that companies typically need to overcome to attain certification to various standards (e.g. cost of certification, challenges with purchasing or adopting new technology, changing cultures, building supplier relationships, and creating a monitoring system) [53].

Considering these barriers in conjunction with the lacking aspects of QM among South African small manufacturers, as defined through survey responses, further supports the opportunity of addressing the QM gap in the management methodology of small manufacturers by presenting quality as a structured framework (to address the challenges related to systems implementation) that is based on an incremental improvement methodology (to ease the barriers of cost, change, motive) with the value addition being a growth path towards the institutionalisation of QM and related applied management methods such as risk management, process management, and continuous improvement.

### 4.3 ISO 9001 Requirements Analysis

**Note to the Reader:** *With the QM philosophy discussed, understood within the manufacturing ontology, and contextualised to the South African small manufacturing industry, the reader's focus is turned to ISO 9001. At this stage, the discussion on QM and QMS development is sufficient, such that the requirements of ISO 9001 can be interpreted, and their application to a small manufacturer can be deduced.*

**Why is this important?** *ISO 9001 has been a fundamental theme in discussions from the beginning of this dissertation as it plays a central role in presenting value (in the form of certifiability) and validity (in the form of compliance) to the research project, being a globally recognised standard for Quality Management Systems, demonstrating compliance is an essential contributor to ensuring the validity of the model.*

#### 4.3.1 Defining ISO 9001 Standard for Quality Management Systems

The International Organisation of Standardisation (ISO) is a globally recognised industrial and commercial standardisation authority. ISO develops and publishes standards, which are described as frameworks of best practice based on the consensus of subject matter experts [62]. Many ISO-published standards, like ISO 9001, have become credible frameworks for certification, meaning that organisations that demonstrate adherence to the requirements of the relevant

standard can be certified to that standard as a statement of compliance. Relevant ISO certification has become synonymous with quality, reliability, and compliance. ISO 9001 certification, for instance, is credibly recognised in more than 170 countries and is thus, arguably, a global metric for quality capability [63].

**ISO's Description of ISO 9001** [64]: This standard is based on several quality management principles, including a strong customer focus, the motivation and implication of top management, the process approach and continual improvement. Using ISO 9001 helps ensure that customers get consistent, good quality products and services, which in turn brings many business benefits

**A Summarised Development History:** ISO has published numerous QMS standards, which started with the ISO 9000 standard in 1987 along with its normative standards, ISO 9002, ISO 9003, and ISO 9004; these standards were collectively referred to as the ISO 9000 family of standards [65]. Since then, the QMS standard itself has been revised and republished in 2000, 2008, and 2015. An important note is that the ISO 9001:2000 version was a critical juncture in the standard's development as its focus was pivoted to a process-oriented approach instead of its precursors' documentation-based approach [66]. The principles of 9002 and 9003 were subsequently integrated into this version [66]. The most actively used ISO QMS standards today are thus 9001 and 9004, to which 9004 is not a requirement for certifiability. Manufacturers pursuing QMS certification need only consider ISO 9001, with 9004 offering additional requirements for internal benefit only [64].

#### **4.3.2 ISO's Quality Management Principles**

Similar to the Eight Principles of TQM, the ISO 9000 series is built on a set of principles referred to as the seven quality management principles of ISO 9000 [10, 67]. To avoid the monotony of discussions regarding quality management principles, the following ISO definitions will only be summarised while considering the nuances specific to ISO as opposed to TQM [67].

**Customer Focus:** Combining customer interaction with understanding the needs and expectations of interested parties contributes to creating value. Thus, the focus is on meeting and exceeding current and future customer requirements. Being customer-focused is the alignment of organisational direction (goals, objectives, plans, and policies) with customer requirements, and it is rewarded by customer loyalty, customer retention, and elevated reputation.

**Engagement of People:** Involve employees and enable them to contribute to the capability of quality management. An empowered and competent workforce will be less resistant to change whilst being an invaluable asset to organisational capability. Furthermore, workforce satisfaction benefits organisational innovations through creativity, initiative and collaboration.

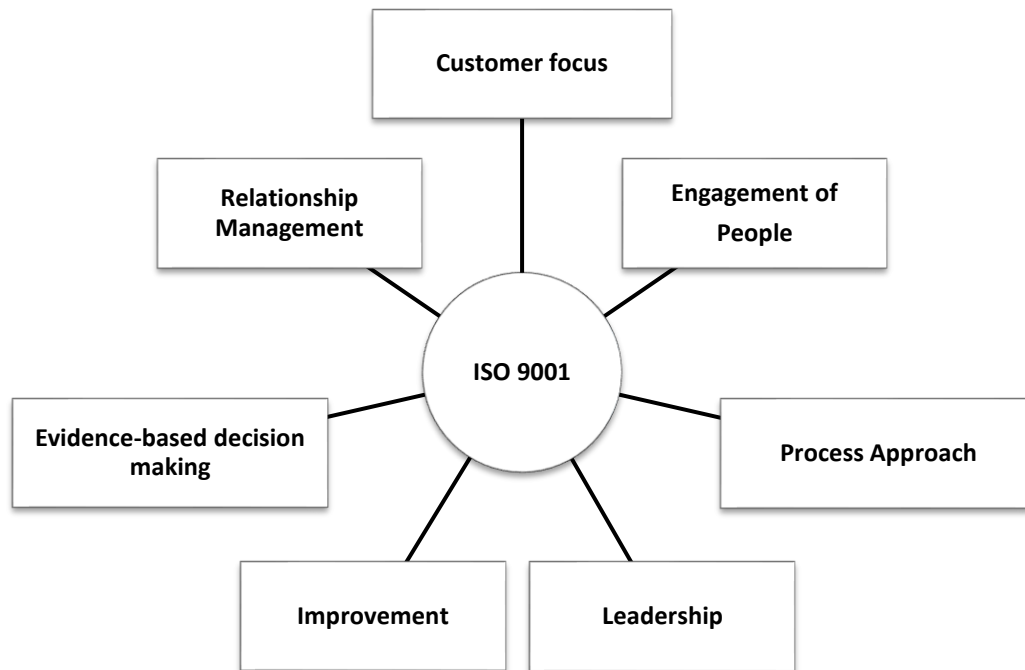


Figure 4-5: The seven quality management principles of ISO 9000 [10, 67]

**Process Approach:** Tasks are performed more predictably, and output is achieved more efficiently when approached as a system of interrelated processes. Understanding the processes of the organisations and the relationship between processes will help manage the attributes of the system, enabling optimisation and more efficient use of resources.

**Leadership:** Establish organisational purpose by demonstrating management commitment. Create an engaging environment that enables employees to achieve organisational goals. Align the strategic direction, processes, and resources with the achievement of objectives. Leadership essentially motivates efficiency and coordination between functional areas.

**Improvement:** Organisations need to possess the capability to continuously improve, which includes improvement of organisational capabilities, process efficacies, and ultimately, customer satisfaction. A focus on improvement allows for the anticipation of risks and opportunities, harnessing incremental improvements to drive innovation.

**Evidence-based Decision Making:** Decisions are based on data, evaluation, risk assessment, and consideration of multiple sources of information. Evidence, information, and comprehension of the cause-and-effect of risks will reduce the uncertainty of the decision-making process. Evidence-based decision-making seeks to reduce dependence on individual perception, interpretation, or discretion to make decisions and rather rely on objective facts.

**Relationship Management:** Another element of sustained success is that the organisation should manage relationships with and between interested parties, including customers, suppliers, stakeholders, and employees. Whether internal or external, interested parties have a definite influence on the success and performance of the QMS. Continuous management will lead to the identification of improvements, risks, opportunities, and constraints. Awareness of external parties and their situations will assist in preventing risks.

#### **4.3.3 The Requirements of ISO 9001**

The process of gaining certification can be summarised in two steps [4]: develop and implement a QMS that complies to the requirements of the ISO 9001 standard and subsequently subject the QMS to an audit performed by an accredited certification body. If successful, the certification body will grant certification, which is typically renewed every three years [4]. The following subsection delves into the requirements, expectations, and organisational elements that an auditor will look for in a QMS audit. The auditor's perception of the organisation's certifiability will be based on observations that are deduced through relevant expertise, best judgement, the guidance of the ISO 9001 standard and various auditing tools. Certification readiness thus requires a perception of certifiability, meaning that certain elements, structures, procedures, and capabilities should be presented in a manner that demonstrates the maturity of the QMS in alignment with the auditor's expectation. This necessitates the interpretation of the ISO 9001 standard and subsequent formulation of requirements for certification that can be incorporated into the management model framework. These requirements have been sourced from the standard itself and from various ISO 9001 audit tools and checklists [10].

The ISO 9001 standard is presented in a clause-based structure that details the requirements for certification. The clauses are equivalent to the quality management characteristics in that they are the operationalisation of quality management principles. Unlike its precursors, the most recent version of the standard adopts a strict systems-oriented approach and incorporation of risk-based thinking, prompting a noteworthy reform to the certification auditing process [68]. Organisations are now required to present clause-based evidence of implementation and demonstrate the integrated functionality of the institutionalised processes and procedures. This, in theory, mitigates the problem of superficial implementation; however, certification is still subject to the

auditor's view. The seven clauses are Context of the organisation, Leadership, Planning, Support, Operation, Performance evaluation, and Improvement. As depicted in Figure 4-5, the clauses are fundamentally rooted in a process-oriented approach and are integrated with the PDCA cycle [32]. Similar to TQM, the customer is a primary objective of ISO 9001 and complying to the standard models a system that, from ISO's perspective, delivers continued customer satisfaction [10].

Note that the following discussion provides a comprehensive overview of the certification criteria detailed in the ISO 9001 standard. This requires a shift in the discussion's narrative from a descriptive nature (intent on providing comprehension) to a discussion of the mandate as it shifts from what "can" be done to operationalise the quality management principles to what "shall" be done to demonstrate QMS certifiability (shall is indicative of mandator certification requirements) [10].

**Table 4-10: ISO 9001:2015 Document layout [10, 63, 5]**

|                        |                                                        |                                                                                                                                                            |
|------------------------|--------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Nomenclature</b>    | <b>Clause 1:</b><br><i>Scope</i>                       | Describes the scope of the International Standard as well as the expectations for certification.                                                           |
|                        | <b>Clause 2:</b><br><i>Normative References</i>        | References the normative documents that describe the fundamentals and vocabulary used in the International Standard.                                       |
|                        | <b>Clause 3:</b><br><i>Terms and Definitions</i>       | References the normative documents that describe the terms and definitions used in the International Standard.                                             |
| <b>QM Requirements</b> | <b>Clause 4:</b><br><i>Context of the organisation</i> | Requirements detail the alignment of the organisation's business environment with the QMS.                                                                 |
|                        | <b>Clause 5:</b><br><i>Leadership</i>                  | Involvement of top management and integration of ISO requirements into operational processes. Alignment of policy and objectives with strategic direction. |
|                        | <b>Clause 6:</b><br><i>Planning</i>                    | Focusses on planning and incorporates risk-based thinking to the establishment of quality objectives that can be measured and/or evaluated.                |
|                        | <b>Clause 7:</b><br><i>Support</i>                     | Focuses on establishing support functions through resources, competence, and communication.                                                                |
|                        | <b>Clause 8:</b><br><i>Operation</i>                   | Details requirements that enable processes to achieve quality objectives, customer expectations, and organisational requirements.                          |

|                                                   |                                                                                                                                                                          |
|---------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Clause 9:</b><br><i>Performance evaluation</i> | Incorporation of both quantitative performance measures (process measurements, data analysis) and qualitative performance reviews (management reviews, internal audits). |
| <b>Clause 10:</b><br><i>Improvement</i>           | Harness system information, management reviews, and risk-based thinking to identify and realise opportunities for improvement.                                           |

#### 4.3.3.1 Clause 4 (Context of the Organisation)

Defining the Context of the Organisation requires the establishment of a QMS Scope and an organisational strategic direction, as well as subsequent definition and consideration of the internal and external issues relevant to the implementation/management of a QMS. This includes internal and external stakeholders, customers, and legal and regulatory bodies. In doing so, the organisation can identify the constraints, risks, opportunities and influencing factors that might impede the execution of expectations. The primary goal of Clause 4 is to establish a well-defined scope for the QMS that should facilitate the definition of organisational quality objectives. With a strategic direction in place, the organisation can start planning for quality.

**Table 4-11: Clause 4 Summary of Requirements [32]**

***The Organisational Shall:***

- Identify the interested parties relevant to the QMS, as well as define their requirements
- Monitor and review the necessary information about the interested parties
- Identify internal and external issues relevant to the organisation's ability to meet requirements
- Define a scope for the QMS that sets the boundaries of the standard's requirements within the organisation.
- Demonstrate establishment of the QMS along with maintaining and improvement efforts
- Identify and define processes by inputs and outputs, sequencing and integration, performance measurement strategy, resource requirements, assigned authority, and procedures for managing risks, opportunities and improvement
- Document support of operations of processes as well as process review results

#### 4.3.3.2 Clause 5 (Leadership)

The objective of Clause 5 is to inaugurate organisational commitment by the establishment of QMS authority and accountability to facilitate the drive towards implementation. Clause 5 enables top management to lead by example and demonstrate commitment to enabling a culture for quality, which is exhibited as an organisational quality policy. A core characteristic of both TQM and ISO is the involvement of people [10, 34]; Clause 5 utilises a defined strategic direction to foster a sense of responsibility among organisational areas.

Table 4-12: Clause 5 Summary of Requirements [32]

##### ***The Organisational Shall:***

---

Demonstrate how management establishes leadership, commitment, and accountability to the QMS

Establish a quality policy and objectives that are aligned with the QMS

Demonstrate communication of the policies and objectives to the organisation as well as demonstrate integration of the QMS requirements into the organisation's processes

Demonstrate commitment and action to ensure resource availability

Demonstrate engagement, motivation, and involvement of the organisation to the commitments of the QMS

Present a strategy for reviewing the performance of the QMS

Demonstrate continuous commitment to customer satisfaction

Establish QMS related roles, responsibilities and authority to ensuring that the QMS performs as intended.

---

#### 4.3.3.3 Clause 6 (Planning)

The objective of Clause 6 is to utilise the definition of organisational context and organisational objectives to compile and manage a QMS implementation plan. This includes planning for the processes and activities required to meet organisational objectives as well as determining what resources will be required. Clause 6 also introduces the risk-based thinking element into the QMS as thorough planning requires consideration of the risks and opportunities related the QMS plan. Ultimately, the requirements of Clause 6 aims to avoid ambiguity by offering a clear and planned path towards quality institutionalisation as well as to ensure meaningful allocation of resources and pre-emptive mitigation of risks.

**Table 4-13: Clause 6 Summary of Requirements [32]**

***The Organisational Shall:***

---

Provide a strategy to identify, evaluate and address risks and opportunities within the scope of the QMS

Determine the impact of planned changes, risk mitigations, and improvements on the conformance of products

Present a plan to validate the effectiveness of mitigation actions

Present a plan to ensure competence of designers

Provide documented quality objectives that align with the quality policy, are measurable, relevant to enhancing customer satisfaction

Demonstrate communication, monitoring and constant updating of the quality objectives

Provide systematic planning for changes that includes consideration of, resource requirements, purpose and consequences, how authority is allocated to action the changes and how the changes influence QMS integrity

---

**4.3.3.4 Clause 7 (Support)**

Support mainly focussed on resources, competence, organisational awareness, communication, and management of information; Clause 7 thus aims towards enablement. With the objectives defined, processes planned, and risks mitigation strategies in place, the requirements of Clause 7 should enable the organisation to meet and manage expectations. Meaning that processes receive the required resources, the workforce is aware of the expectations and are competent to meet them, tools and machinery are in place. Communication structures and general information management serve as the vehicle used to manage validate support structures.

**Table 4-14: Clause 7 Summary of Requirements [32]**

***The Organisational Shall:***

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Determine and provide the resources required for establishment, maintenance and improvement. It is important to note that this is relative to the organisation and should feed the organisations implementation plan, rather than the clauses of the standard

Provide evidence and method of determining the human resources, infrastructure and environment for implementation required to fulfil the QMS planned objectives

Demonstrate resource allocation method (validate allocations, ensure appropriate allocation, and monitor allocation effectiveness). Provide documented information of validity of monitoring & measurement resources

Provide method to determine and maintain the organisational knowledge required for the operation of processes as well as method to determine how the gap between current organisational knowledge and required organisational knowledge

Demonstrate determination of the required skills, education, and competence of the organisational as well as provide evidence of competence

Demonstrate method of establishing organisational awareness and communication both internal and external

Due to the emphasis placed on documentation, ISO 9001 also requires a mature documentation control and management procedure

---

ISO 9001 relies on documentation to provide a description of the QMS, which includes documents describing the QMS and documents pertaining to the organisation's operations. Although the development and maintenance of documentation are the pitfalls of ISO 9001 among SMMEs, it is an essential part of demonstrating the organisation's maturity to both the auditor and the organisation itself.

ISO 9001 mandates the following QMS descriptive documents [69, 10]:

- Quality Policy
- Quality Objectives
- Scope of the QMS
- Process descriptions
- Internal review reports

Keen [69], provided the following summary for the mandatory documentation requirements detailed in the ISO 9001 standard. ISO 9001 mandates the documentation of results, records, and evidence of procedural implementation but does not place as much emphasis on the documentation of the procedures itself.

- Monitoring and measuring equipment calibration records
- Product/service requirements review records
- Design and development outputs review records
- Design and development inputs records
- Design and development controls records
- Design and development outputs records
- Design and development changes records
- Product characteristics to be produced
- Records about customer property
- Production change control records.
- Records of conformity of product with acceptance criteria
- Records of nonconforming outputs
- Monitoring measurement results
- Internal audit program
- Internal audits results
- Management review results
- Results of corrective actions

#### 4.3.3.5 Clause 8 (Operation)

Clause 8 focuses on the organisational lifecycle from defining design requirements to post-delivery activities. Operation requires planning; it incorporates project management into the implementation of the QMS as the organisation is required to refine customer and organisational requirements into process requirements and criteria. It ensures that processes are well-defined with input requirements, processing capability, and output requirements. Clause 8 is also where design comes into play as it requires not only consideration of product requirements but also the design and planning of input, control, outputs, and change management to ensure traceability.

**Table 4-15: Clause 8 Summary of Requirements [32]**

##### ***The Organisational Shall:***

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Present documented information to demonstrate how processes were planned (as detail in Clause 6) and executed according to the plan to ensure conformity of the output

Demonstrate some level of control over outsourced processes

Demonstrate establish customer communication procedures

Demonstrate mature capability to develop requirements and verification of organisational capability against requirements commitment

Validate adherence to customer requirements

Present documented information on review and traceable change management applied to requirements

Present documented information on the communication of requirements to personnel as well as any changes to requirements

---

#### 4.3.3.6 Clause 9 (Performance evaluation)

Performance evaluation is the natural continuation of defined and measured processes and is also the prerequisite to continuous improvement. Clause 9 details the requirements of analysis, performance monitoring and evaluation. However, the focus is not solely on quantitative system information; continuous qualitative review and internal auditing of the performance of the QMS are required. It requires a bidirectional focus on both the customer and the organisation. Customer satisfaction is reviewed, QMS implementation is reviewed, and overall operational performance is reviewed. The value added through performance evaluation is the identification of organisational innovations. Clause 9 facilitates sustained maturation through beneficial feedback practices.

Table 4-16: Clause 9 Summary of Requirements [32]

***The Organisational Shall:***

---

Determine what needs to be measured/monitored among the organisation's processes and structures, how and when to measure and how to evaluate and communicate the results

Demonstrate how analyses are used to determine conformance, process performance, and improvement opportunities

Determine how to measure and evaluate customer satisfaction and how to elicit customer feedback

Demonstrate capability to analyse data from various sources (process measurement, industry data, etc.)

Provide evidence of incorporating analysis results into management review

Conduct internal audits to determine continuous conformance to the ISO 9001 standard. However, in the SMME application this will be a continuous process rather than a launched effort

Present documented information of management reviews which includes evaluation of QMS facets, such as KPI's, process performance, customer satisfaction, effectiveness of QMS implementation, and actions taken to address nonconformances, risks, opportunities and issues

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**4.3.3.7 Clause 10 (Improvement)**

Theoretically, an organisation should have a well-defined system that produces information in the form of, process analytics, presence of defects or nonconformances, customer satisfaction, success of implementation, and overall organisational capability. Management would have access to all of the information required to know where and what impedes growth. Clause 10 seeks to utilise this information as the basis for decision-making. Meaning that it harnesses the holistic definition of the organisation created by the feed of information to address the risks and opportunities that might lead to organisational innovation. *An important characteristic of the auditing approach is that it relies on identifying and addressing nonconformities as a form of continuous improvement.*

Table 4-17: Clause 10 Summary of Requirements [32]

***The Organisational Shall:***

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Provide a strategy for selecting opportunities for improvement, considering the risks, significance, and relevance to customer satisfaction of the opportunities

Demonstrate how nonconformance are reacted to and the actions taken to evaluate, find solution and implement solution

Provide documented information on the nonconformities identified, which details the nature of nonconformance and the results of the corrective action

Demonstrate how continual improvement is achieved/actioned

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#### 4.3.4 To Summarise

Regardless of the evidence of the value of a systematic QM approach, quality management systems remain a polarising subject and studies that stand in contention to the implementation of both ISO and TQM quality systems, as well as the link between the two, should also be considered. Some argue that the benefits of QMS implementation do not outweigh the costs [2], whilst others lean more towards the high rate of failed implementations as a demotivation for a quality approach [70]. Yet, an intriguing observation that seems common among studies flaunting positive results is the motive and duration of QMS commitment. To elaborate, Aslan and Ilkay [15], found that ISO 9001 systems that have been certified for at least 2 years provided stronger indications of improved performance, granted that the motive for certification was internal. Wali and Boujelbene [71] also stated that the organisational innovation culture is key to a successful TQM implementation. Furthermore, Gadenne and Sharma [49] argue that developing countries are more prone to turn ISO 9001 for QM implementation than the TQM philosophy. Hence, ISO 9001 certification distinguishes between a managed QMS and an unmanaged QMS. Numerous researchers have explored the link between both ISO 9001, TQM, and organisational performance, of which many have argued that ISO certification is a step towards the implementation of TQM [2, 21], suggesting TQM as an end result of a QM endeavour. Sun [18] argued that for a successful QMS, companies should combine ISO quality standards, TQM, human resources, and strategic management.

There is principled intent behind the ISO 9001 certification process that truly benefits organisational competitiveness, given that there is a genuine motive for certification. This research project intends to incorporate ISO 9001 compliance into the expectations of the management model. It is thus essential to consider the auditor's perspective whilst avoiding the common pitfalls of superficial implementation. Focusing too much on satisfying the clauses of the standard narrows the vision of the QMS; chasing certifiability rather than the value of a quality approach will inhibit the organisational creativity and innovation that it is supposed to motivate. Corroborating the introductory statements of this document, Antilla and Jussila [5] referenced concerns raised by the ISO Central Office in 1994, stating that the push towards ISO 9001 certification as a mere brand of quality corrupts the essence of the standard. This again emphasises the importance of motive to the internal commitment of any QM endeavour. It is thus essential to apply the characteristics of TQM as supplementary to the ISO 9001 requirements, especially when considering the operational environment and specific characteristics of manufacturing SMMEs.

#### **4.4 Conclusion on Quality Management**

Chapter 4 has discussed various facets, principles, and elements of the QM philosophy as the theoretical foundation of this research project. The literature review has disseminated the TQM philosophy and described its interpretation as a set of accepted QM characteristics based on the principles of TQM and institutionalised through best-quality practices. TQM is an internationally recognised management framework of quality principles [34] that has been interpreted by various researchers as the integration of quality practices that have been related to organisational performance. An investigation of industry studies and implementations of the TQM philosophy has provided evidence that adopting a TQM approach to the institutionalisation of QM can impact a small manufacturing organisation in various aspects, such as organisational performance, financial performance, improved product quality, etc. Also, through Literature, the validated interpretations of the TQM characteristics within the manufacturing ontology were identified and subsequently applied in the real-world Industry Survey. The interpretations focused on defining TQM characteristics and best practices commonly related to beneficial organisational impacts within a manufacturing application [41, 42, 21, 38]. These interpretations thus provided a validated foundation to define a framework of TQM characteristics and practices that suits the ideal manifestation of QM within a manufacturing SMME.

The Industry Survey and the interview (discussed in Chapter 2) explicitly aimed at contextualising the research to South African manufacturing SMMEs. Whilst the literature review was predominantly focused on QM among manufacturers, the Industry Survey provided sufficient insight into the current state of QM among South African manufacturing SMMEs and addressed the current lack of QM contextualisation to South African manufacturing SMMEs. In this regard, the discussion in Section 4.2.6 and the summary provided in Table 4-9 are important contributions to the practical considerations of adapting the CMM to suit a manufacturing implementation.

## 5 CAPABILITY MATURITY

### 5.1 Literature Study

Initially introduced by the Software Engineering Institute (SEI) and Carnegie Melon University in 1987 and officially published as a formalised model in 1991 [7], the Capability Maturity Model (CMM) was developed as a process improvement framework for software engineering. However, keeping to the notion that process quality reflects product quality, the developers of the CMM drew inspiration from Deming, Shewhart, and Juran, as well as subsequent philosophies such as TQM and Crosby's maturity grid [9]; this roots the model in a quality-based approach to process improvement. The following literature study delves into the CMM and surrounding content and literature detailing CMM adaptations and industry applications in domains unrelated to soft engineering.

#### 5.1.1 Understanding Maturity Models

The underlying philosophy of organisational maturity favours the notion that similar to people, organisations experience maturation, become more complex, and become more capable with the continuation of time. Maturity Models (MM) leverage this notion by presenting maturation characteristics on a standardised framework [46]. In other words, organisations that manage to remain in business naturally become more capable of traversing their relevant economic landscape by becoming more proactive in addressing problems [72], more efficient at managing risks and capitalising on opportunities, and better at understanding requirements and meeting expectations. Thus, MMs can be described as a synthesised method of presenting this overall betterment on a standardised scale so that organisations can recognise where their capabilities are situated and receive guidance on how to progress. Providing a good method of quantifying how well organisational functions, systems, and processes are developed illuminates a path for continued development.

**Maturity Models in QM:** *The concept of maturity isn't a novel ideology in the QM ontology; one of the first officially published maturity frameworks was Crosby's maturity grid [73]. Proposed in 1979, Crosby's maturity grid details 5 levels of maturity that describe process quality management and is considered to be among the seminal contributions to modern maturity models [19, 23]. However, despite the prevalence of QM as a management paradigm and the prominence of CMM as a management strategy, there still seems to be an absence among TQM and ISO 9001 literature regarding the use of a maturity-based approach; specifically, in using the CMM as a SQM solution to a small manufacturing setting.*

MMs as a management tool are situated in the General Systems Theory (GST) discipline and were initially proposed as a solution to describe the attributes of complex systems across interdisciplinary borders [46]. However, a universal definition of what maturity models are and what a state of “maturity” actually means often varies. Referring to the official definition of the CMM: *“The CMM is a framework representing a path of improvements recommended for software organisations that want to increase their software process capability”* [7]. The foundation of a CMM is typically described as a sequential structure of a fixed number of levels that start with a level describing basic system attributes and progress towards sequential levels of increasing system complexity [74]. Through interpreting the value of describing a system using levels of maturity, three helpful organisational views come to mind: A descriptive view that defines the current standing of the systems, a prescriptive view that offers guidance for continued development, and a comparative view in that organisations are evaluated against a consistent criteria which allows for standardised benchmarking.

The fundamental takeaway of understanding MMs is thus that stages of organisational aptitude should define them; these stages should be inherently progressive and should be based on measurable criteria which can be relatable to organisational structures (e.g. an aptitude for process standardisation should be backed by physical process definitions in the organisation). Importantly, a maturity model should have a clear goal that is defined as either seeking completeness (suggesting a “final” organisational state) or seeking perfection (in which case progression will never stagnate) [23]. In this regard, the CMM seems to favour a pursuit of perfection given the emphasis on organisational innovation and continuous optimisation exclaimed to in higher maturity levels. Fortunately, this is also a fundamental focus of QM and ISO 9001.

#### **5.1.1.1 CMM Maturity Level Descriptions**

Figure 5-1 below depicts the five maturity levels of the CMM, namely Initial, Managed, Defined, Quantitatively Managed, and Optimised. These maturity levels are described in more detail in the discussions that follow.

- *Level 1:* The **Initial** level describes an organisation as unpredictable, ad hoc, and reactive. Organisations operate with poorly defined processes, and the consistency of outcomes is mostly achieved through individual heroics and experienced managers. Level 1 organisations neglect to implement basic management practices, with the most significant risk being the presence of uncertainty.

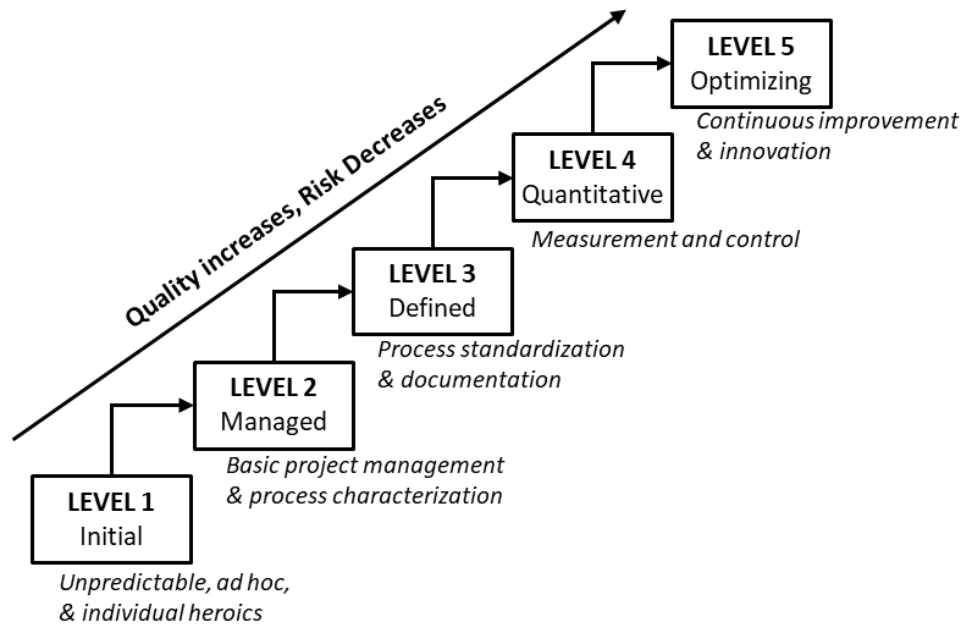


Figure 5-1: CMM Levels [72]

- **Level 2:** The **Managed** level focuses on establishing basic project management within the organisation as well as the required infrastructure for further development of more advanced functions and process areas. Implementing basic management practices achieves the repeatability of outcomes to create a foundational structure for governance, such as the definition of policy and standard operating procedures. The organisation does this by reflecting on experience and lessons learnt through similar projects, which enables the organisation to identify and document the practices that assisted with successful outcomes.
- **Level 3:** A **Defined** organisation is characterised by standardised and well-documented processes. Level 3 organisations have defined and documented their core business processes and understand the integration between functional areas. A distinct characteristic of Level 3 is the operation of processes according to organisational definition rather than individual discretion. The CMM recognises Level 3 as a significant leap towards functional maturity, as the characteristics describe an organisation capable of further improvement with decreased management input.
- **Level 4: Quantitatively Managed** defined processes and greater process control in place, organisations can seek to implement more advanced management strategies (quantitative, root-cause analyses). The quality and performance of processes and products become measurable metrics used to classify various system characteristics. The organisation establishes an information-based management approach and starts collecting, presenting, and using quantitative system information for decision-making.

- *Level 5:* An **Optimising** organisation focuses on continuous improvement by making informed decisions. At an optimising level, best engineering practices are used to exploit system information to identify opportunities, weaknesses, and risks. Innovation can thus be sought as organisations have the means to make informed, quantitative decisions about incorporating new methods and technologies.

### 5.1.2 The Capability Maturity Model

Since its introduction, the CMM model has been developed into various revisions and archetypes, such as: The 2001 Capability Maturity Model Integration (CMMI) a revised version of the software-oriented CMM; the 2010 CMMI for Development (CMMI-DEV) an archetype of CMM more suitable for an organisational application and not contextually bound to the software domain; and the most recent CMMI V2.0 which introduces the first significant alteration to the original CMM structure [75, 76, 23]. It is worth noting that the original CMM exists as a comprehensive model detailed in a 500-page document that describes each maturity level, common feature, category, process area, related practices, and goals [7]. Additionally, the model is supported by various guidelines, technical documents, and interpretations. It would thus be impractical to detail the entire CMM in this dissertation. However, the following section provides an overview of the structure as well as a brief discussion of each as relevant to the research project.

#### 5.1.2.1 Overview of Structure

The foundation of the CMM is comprised of levels of maturity, which provides a structured method to assess, refine, and optimise organisational capabilities. Each maturity level is a defined progressive plateau of the preceding levels and is characterised by capability criteria [9]. Each level contains a set of Process Areas (PAs) that, when institutionalised, collectively establish a characteristic or capability [77]. Referring to Figure 5-2 below, the PAs are subsequently defined by clusters of related goals that are institutionalised into the organisation's operations through various practices.

**In Summary:** The PAs thus provide the structural components of the CMM, the Goals can be interpreted through a QM lens as the Attributes, Characteristics, or Requirements being institutionalised, and the Practices are the operationalisation of these Characteristics. However, the CMM is structured in an additional layer of interpretability; discussed below are the PA Categories, which group PAs into featured areas of related institutionalisation. These categories are highlighted in the CMM discussion.

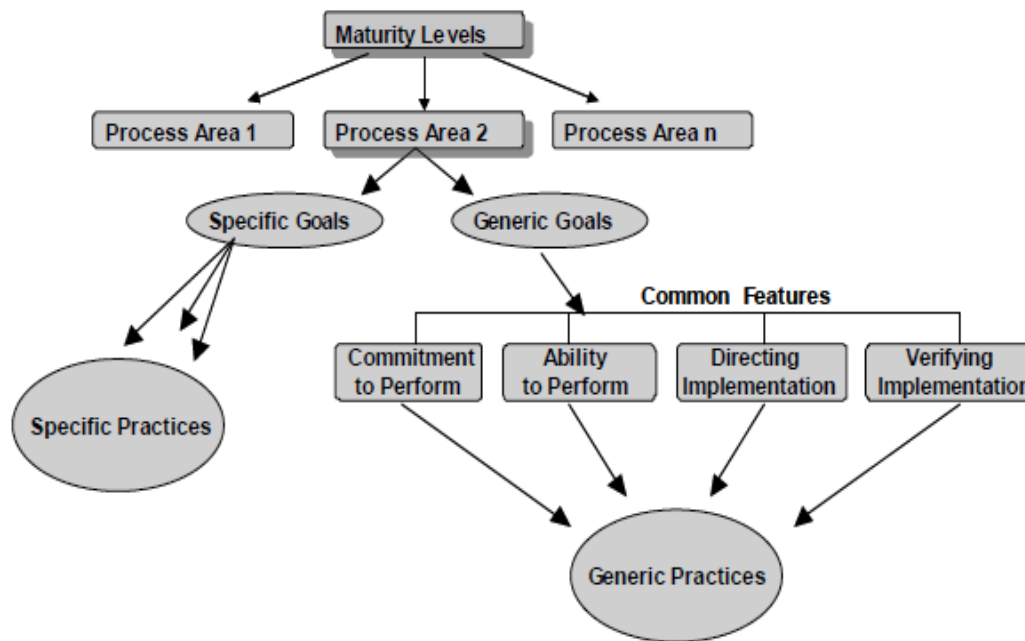


Figure 5-2: Model Overview of CMM [61]

The CMM addresses process improvement by developing four featured areas in an organisational or process structure: Process Management; Project Management; Engineering; and Support. Each featured area is called a Process Area Category and is used to explain the relationships among PAs. Understanding these featured areas thus assists in understanding the purpose and strategic positioning of each PA and how it ultimately contributed to the implementation of the CMM.

Similar to the representation provided in Table 5-1 below, the structure of CMM is often presented as a mapping of each PA to its associated maturity level as well as its relevant category. This aids the holistic overview of the model and assists in understanding what the CMM aims to institutionalise at each maturity level and how organisational capability development flows and cascades through the maturity progression. It is imperative to recognise that each PA will in some way interact with others regardless of its category or grouping. However, understanding the key relationships between PAs and recognising how one PA produces capabilities for another will assist with successfully applying the CMM.

**Important:** To retain the integrity of the description of the CMM, the Categories and associated PAs described below are discussed in the same format as presented in the CMMI-DEV 1.3 technical report with minimal rewording or rephrasing.

Table 5-1: CMM Process Areas [61]

|                 | Common Features                                                                                                                                      |                                                                                                                                                                                              |                                                                                                                                                                                                             |                                                                                                                                                |
|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|
|                 | Process Management                                                                                                                                   | Project Management                                                                                                                                                                           | Engineering                                                                                                                                                                                                 | Support                                                                                                                                        |
| Maturity Level  | Process Area Mapping                                                                                                                                 |                                                                                                                                                                                              |                                                                                                                                                                                                             |                                                                                                                                                |
| 5. Optimising   |                                                                                                                                                      |                                                                                                                                                                                              |                                                                                                                                                                                                             | <b>CAR</b><br><i>Causal Analysis &amp; Resolution</i>                                                                                          |
| 4. Quantitative | <b>OPP</b><br><i>Organisation Process Performance</i>                                                                                                | <b>QPM</b><br><i>Quantitative Project Management</i>                                                                                                                                         |                                                                                                                                                                                                             |                                                                                                                                                |
| 3. Defined      | <b>OPF</b><br><i>Organisation Process Focus</i><br><b>OPD</b><br><i>Organisation Process Definition</i><br><b>OT</b><br><i>Organisation Training</i> | <b>IPM</b><br><i>Integrated Process Management</i><br><b>RSKM</b><br><i>Risk Management</i><br><b>IT</b><br><i>Integrated Teaming</i><br><b>ISM</b><br><i>Integrated Supplier Management</i> | <b>REQD</b><br><i>Requirements Development</i><br><b>TS</b><br><i>Technical Solution</i><br><b>PI</b><br><i>Product Integration</i><br><b>VER</b><br><i>Verification</i><br><b>VAL</b><br><i>Validation</i> | <b>DAR</b><br><i>Discission Analysis &amp; Resolution</i>                                                                                      |
| 2. Managed      |                                                                                                                                                      | <b>PP</b><br><i>Project Planning</i><br><b>PMC</b><br><i>Project Monitoring &amp; Control</i><br><b>SAM</b><br><i>Supplier Agreement Management</i>                                          | <b>REQM</b><br><i>Requirements Management</i>                                                                                                                                                               | <b>MA</b><br><i>Measurement and Analysis</i><br><b>PQA</b><br><i>Process Quality Assurance</i><br><b>CM</b><br><i>Configuration Management</i> |
| 1. Initial      |                                                                                                                                                      |                                                                                                                                                                                              |                                                                                                                                                                                                             |                                                                                                                                                |

#### 5.1.2.2 Process Management

The purpose of Process Management in the CMM is to establish and develop a capability for documented process standardisation, learning new best practices, and developing organisational process assets. Similar to the process-centred principle in QM theory, this aims to establish an organisational process-oriented focus and the necessary infrastructure for a documented and quantitative management approach. The PAs related to Process Management are [7, 61]:

- *OPF* – The purpose of Organisation Process Focus is to establish organisational accountability for process-related activities, understand the current capacity of organisational processes, and plan and deploy process improvement. The practices related to OPF include defining organisational areas relevant to the CMM implementation, defining the stakeholders and contributors, and establishing management through policy (again, practices heavily related to ISO 9001).
- *OPD* – The purpose of Organisational Process Definition is to develop and maintain a set of organisational processes and process assets that contribute to the improvement of process performance. Herein also lies practices that enable process standardisation and definition through documentation.
- *OT* – Organisational Training aims to enable and improve workforce contribution by developing the skills and knowledge required to perform tasks efficiently and contribute effectively to the continuously developing culture, as caused by a CMM implementation. Practices detailed in OT include a definition of training requirements and the establishment of a scheme to meet these requirements.

**Important:** *Considering that a culture change is a significant endeavour, it is paramount to keep the workforce well-trained, knowledgeable, and skilled. Deming also recognised this importance, as the human factor is often cited as an imperative contributor to QM success and is also a heavily featured requirement of ISO 9001.*

- *OPP* – Organisational Process Performance is used to measure and monitor the performance of processes to establish a quantitative understanding of the core organisational processes and make informed decisions on investing in process improvement.

### 5.1.2.3 Project Management

The Project Management category addresses the need for planning, monitoring, control, and risk management. The PAs associated with project management introduce the concept of supplier management, monitoring progress, and ensuring proper execution of tasks. The Project Management feature also introduces the risk management approach to the organisation. The PAs include the following [7, 61]:

- *PP* – Project Planning aims to establish project plans for implementation, improvement, and change. This involves engaging with stakeholders, considering organisational objectives, establishing a plan, and establishing commitment and accountability. In a QM sense, PP can be utilised to plan QMS development and fulfil the Organisational Context and Planning clauses of the ISO 9001 standard.

- *PMC* - Project Monitoring & Control monitor project implementation progress in relation to the plan and implement corrective action if project performance deviates from the plan or if progress yields insufficient organisational improvement.
- *SAM* - Supplier Agreement Management assists with managing suppliers and outsourced services. SAM minimises project risk by establishing expectations, supplier criteria, and evaluation methods to ensure that materials, components, and services do not compromise quality.
- *IPM* - The purpose of Integrated Project Management is to establish an integrated environment involving the organisation, managers, and stakeholder into project planning and developing organisational processes. This ensures a coherent, defined project management approach tailored from the organisation's standard process and related process assets, described in the Organisation Process Definition.
- *RSKM* - Risk Management provides techniques for identifying, understanding, and evaluating risks. Risk management is also a consistent element of the ISO 9001 standard. Developing a capability for risk management is a tool for inevitable improvement if it is actioned with the correct tools and techniques.
- *QPM* – Quantitative Project Management aims to establish, monitor, and manage quantitative quality and process performance objectives. This includes developing meaningful performance measures, determining appropriate analytical techniques, and conducting root cause analyses on deviations to project performance.

#### **5.1.2.4 Engineering**

Notably, the Engineering category establishes a product/customer-oriented input into the process development and improvement strategies. The PAs associated thus apply to developing products, services, or solutions and introduce the proper development and management of customer requirements. The PAs associated are [7, 61]:

- *REQM* - Requirements Management establishes practices that assist with understanding the needs and expectations of customers, managers, and stakeholders and focuses on managing a mutual understanding between the organisation and the stakeholders.
- *REQD* – The purpose of Requirements Development is to elicit customer requirements, analyse these requirements in relation to organisational capacity and product development, and subsequently disseminate these requirements into appropriate organisational requirements (customer requirements, product requirements, and component requirements).
- *TS* – The purpose of Technical Solution is to provide solutions to requirements either selected, designed, or implemented. The CMM refers to solutions as an encompassing term referring to products, product components, processes, etc. TS thus includes selecting or designing solutions that satisfy requirements, evaluating these solutions, and manufacturing or implementing these solutions.

- *PI* – Product integration aims to assemble product components into a unitary customer deliverable or singular product that satisfies the customer's requirements. In a manufacturing sense, this can be applied to developing final assemblies, sub-assemblies, and individual in-house manufacturing processes that contribute to the final manufactured product. PI includes properly defining the interfaces between processes and sub-processes and understanding how one process's output influences another's input. PI also involves testing and commissioning of products made from components manufactured by various organisational processes.
- *VER* – Verification aims to ensure that products, components, and services meet their relevant requirements. This can apply to products, processes, sub-processes, and sub-assemblies and may occur during the design, manufacturing, and integration of products. Verification minimises the potential for customer dissatisfaction and also allows for early identification of non-conformances.
- *VAL* – Validation aims to demonstrate that a product, solution, or process fulfils its intended purpose within its intended environment. CMM describes the difference between VAL and VER as follows: Validation demonstrates that you have done the right thing, and Validation shows that you have done it right [61].

#### 5.1.2.5 Support

The PAs associated with the Support category establish support for developing and maintaining processes, products, and, importantly, other PAs. The Support categories thus facilitate the knowledge and documentation needs related to performing processes, thus establishing organisational tools that can be used for all other PAs. The PAs associated with Support are [7, 61]:

- *MA* – The purpose of Measurement and Analysis is to develop, establish, and maintain a measurement capability that is used to support information and quantitative PAs such as QPM and PMC. MA thus produces vital information from data yielded through process performance measurement.
- *PQA* – Process Quality Assurance aims to provide an objective view of processes and products. PQA ensures quality by providing all organisational and operational levels with the needed insights, feedback, and product/process development visibility.
- *CM* – Configuration Management aims to establish and document definable aspects of products, processes, or components and employ configuration control to ensure the integrity of the products, processes, or components. CM includes keeping all of the alterations or changes made to any critical aspect of a product, process, or component under control and traceable and providing accurate representations of the most current configurations.

- *DAR* – Decision Analysis and Resolution aims to develop and employ evaluation methods and processes to analyse potential decisions, identify alternatives, and make selections based on organisational information and established criteria.
- *CAR* – The purpose of causal analysis and resolution is to select process outcomes and determine the causes of these outcomes and related actions to improve process performance. A critical capability of *CAR* is to identify the cause of defects, deviations, and non-conformances and take corrective action to avoid future reoccurrences.

### 5.1.3 Interdisciplinary Applications of the CMM

**Note to the Reader:** *The preceding section has outlined the core aspects required to describe the structure, goals, and purpose of the CMM and to understand how and why the implementation of the process areas contributes to process improvement. However, at this point, it is necessary to shift the focus to how the CMM is used instead of how it is defined. The following section thus builds on the understanding of the CMM and facilitates practical understanding by discussing various industry applications of the CMM from the literature.*

As mentioned before, the CMM originates from the software engineering and information technology domain [7]. Nevertheless, the CMM has been used as a preferred approach in MM development in various other domains as well; Wendler [23], attests to this by linking the CMM to numerous interdisciplinary applications, stating also that most of these applications are in some way derived from the CMM. With more than 20 identified application domains by 2010, of which a majority were based on design-oriented research efforts, the CMM thus has proven its worth as an interdisciplinary tool [23].

However, despite this interdisciplinary prevalence, the CMM is still highly favoured in the software engineering domain, with some applications in project management, education, construction, business intelligence, etc. Apart from recent developments, minimal attempts have been made to apply it in a manufacturing setting, not to mention a small manufacturing environment. With that being said, the Capability Maturity approach has only recently started gaining momentum in the manufacturing world, especially in the wake of emerging keywords such as *Continuous Improvement* [20], *Industry 4.0*, *Intelligent Manufacturing* [78], *Manufacturing Autonomy* [79], and even *ISO 9001*. Research studies and design-oriented research projects relating the CMM to the manufacturing industry are as recent as 2017 to 2023, with researchers using the model to improve targeted areas in the manufacturing domain, such as optimising the remanufacturing process, supporting TQM continuous improvement [80], and incorporating intelligent manufacturing or autonomous manufacturing capabilities [78].

A research challenge which is not explicitly addressed in the literature but needs to be overcome is the “as is” transferability of the CMM to the manufacturing domain. Doss *et al.* [20] conducted a survey to provide evidence on the compatibility of the CMM as an industrial process improvement model; however, the results were partially inconclusive, with only significant evidence of compatibility found in the second and fifth levels of the CMM. A vital consideration in this regard is that the implementation of the CMM, similar to QM paradigms, remains highly situational and interpretive.

To this end, the researchers who have managed the most success from an interdisciplinary CMM implementation are those who have applied some form of informed reasoning when deciding which elements of the CMM are irrelevant to their domain and how the model can be tailored to suit the terminology, concepts, and ontology of the applicable domain [81, 78, 80, 82]. In doing so, these researchers commonly propose and provide a tailored adaptation of the CMM specific to their application or respective research problem.

#### **5.1.4 To Summarise**

Section 5.1 has discussed the content, structure, and literature surrounding the CMM as well as its transferability to an interdisciplinary application. Considering first the structure of the CMM, the PAs are positioned as the building blocks of the CMM that each address, develops, or enables a crucial aspect of organisational capability. Reading through the PA descriptions, it already becomes evident that the CMM aligns with TQM and provides a comprehensive description of the relationships and interactions between the PAs and how the CMM contributes to an organisational growth path towards QM.

This section also provides evidence that the CMM is suitably implemented in applications outside of the software domain but that an adaption of the model is typically required to transfer the concepts, descriptions, methods, goals, etc. that underpin the model to an interdisciplinary domain. The research focussed on creating such adaptations is typically conducted within the DSR paradigm, with practical considerations, ontological requirements, and researcher experience playing central roles in conceptualising adapted CMM [23]. Furthermore, concluding a study on the compatibility between CMM and the continuous improvement facet of TQM, Doss *et al.* [20] professed an optimistic view on the application of the CMM to provide a method to the TQM philosophy. However, they supported the notion of adapting the model and using only necessary process areas.

## 5.2 Cross-Validation Between CMM and ISO 9001

**Note to the Reader:** Up to this stage in the research process, it has already been established that fundamental overlaps exist between the CMM, TQM, and ISO 9001. Given that the seminal structures of ISO 9001 and the CMM are both based on TQM principles with common objectives, overlapping practices and similar measures of performance [12, 29], the assertion can be made that an organisation should experience similar reform from implementing one or another. However, given that there is still a conceptual difference, one is an audited standard, and the other is a process improvement model diligent. The following section thus formally draws a link between the CMM and ISO 9001 compliance and is situated at the end of Chapter 5 as it provides validation of the CMM through its compliance with the globally recognised QMS standard.

The following section substantiates the ISO 9001 compliance of a QMS that resulted from implementing a CMM-inspired model framework. This was done by first considering the notable comparisons that various researchers, including the authors of the CMM, did. Herein lies the evidence that there was, at the very least, a significant alignment between the two models during developmental stages, thus verifying seminal sources. However, considering the depth and comprehensive scope of the CMM, the argument can be made that the CMM rather exists as a superset of the QMS standard, suggesting that the CMM offers an overarching solution to the institutionalisation of QM that encompasses ISO 9001 compliance [83].

Nonetheless, the focus is then shifted towards more recent comparisons between the more recent archetypes and revisions (CMMI and ISO 9001:2015), as well as more in-depth cross-validation between the implementation of the CMM and the requirements of the ISO 9001 standard. Herein lies validation of the ISO 9001 compliance of the CMM as well as a definition of the necessary considerations as to how the CMM might be used to achieve a compliant QMS.

### 5.2.1 Exploring the Relationship Between ISO 9001 and CMM

Exploration into comparative analyses between the CMM and ISO 9001 is a relatively limited subject among academic works, especially comparisons between more recent versions. However, the researchers attempting this undertaking have reached similar conclusions. Their findings have commonly supported the notion that a CMM approach aligns with ISO 9001 by concluding that, among others:

- The CMM and ISO 9001 are complementary, and an integrated implementation reduces the overall risks and cost of QMS development rather than straining it;

- The CMM is a much more comprehensive and detailed representation of QM that encapsulates the requirements of the standard [12, 83];
- Comparing the CMM to the requirements of ISO 9001 suggests that CMM level 2 already aligns the organisation with most of the ISO 9001 requirements [84, 12];
- The CMM offers significantly more depth in terms of quantitative management, process definition and control, as well as organisational enablement [83, 29];
- The ISO 9001 standard emphasises customer focus, specific documentation requirements, and the establishment of QM authority within the organisation [84].

#### **5.2.1.1 CMM vs ISO 9001**

McClanahan and Saiedian [29], compared the CMM to the ISO 9001 standard from a software process quality perspective and highlighted the fact that both the CMM and ISO 9001 are based on TQM principles with significant overlapping practices and common measures of compliance and performance. Similarly, Paulk [12, 77], one of the leading authors of the C, extensively compared the CMM and the clauses of an earlier version of the standard, ISO 9000. He summarised his findings by stating that every Key Process Area (KPA) in level 2 strongly related to most of the requirements of ISO 9000 and that every other KPA of the CMM was at least in some way related to ISO 9000. On the other hand, Bamford and Deibler [84] provided an assessment-based comparison rather than an interpretation-based comparison in a study that applied a CMM appraisal questionnaire to a hypothetical ideal ISO 9001 organisation and vice versa. The result suggested that the requirements of ISO 9001 are mostly satisfied between CMM Levels 2 and 3, corroborating Paulk's claims [12]. They elaborate on their findings by stating that the CMM appraisal process requires significantly more detail, especially regarding implementing quantitative management, standardisation, and technology.

#### **5.2.1.2 ISO 9001 vs CMM**

Paulk [12] alluded that an ideal ISO 9001 organisation should be between CMM Levels 3 and 4; however, he attributed the variability in the interpretations of the standard's requirements to the elusiveness of a direct comparison, stating that a Level 2 organisation could likely already achieve certification. Moreover, a significant aspect of the standard is the emphasis on mandatory documentation requirements. These requirements detail the documentation of all policies, objectives, processes, procedures, and records relevant to the scope of the QMS [69]. Collectively referred to as the organisation's Quality Manual, these documents are one of the primary deliverables that are presented during a certification audit. Although not directly addressed by the CMM, it still provides a comprehensible solution through the application of the Configuration

Management (CM) PA. CM requires thorough and relevant documentation of the enterprise architecture, process flows, processes, procedures and all of the information relevant to the organisation's core operations. Thus, if properly leveraged, the practices related to CM can be used to yield the “artefacts” required to demonstrate system compliance.

### **5.2.2 Synergy Between CMM and ISO 9001**

A noteworthy limitation of the studies considered is that they all compared the CMM to earlier versions of the ISO 9001 standard. However, the most recent version of the standard is expected to be even more aligned with the CMM, given that the revision from 2008 to 2015 was a reform of the structure of the standard rather than its content, which also prompted a stricter application of a systems approach. Regardless, the conclusions provide literature supporting the synergy between ISO 9001 and the CMM.

Although the ISO standard details an explicit set of requirements, implementation and also subsequent certifiability can be subjected to a degree of variability. The variability mainly depends on the auditor as well as the different interpretations of what the requirements necessitate in the context of the implementer [5]. The auditor's perspective is subjected to various influences such as experience, knowledge, and background that will affect the perceived requirements of certifiability. For instance, auditors will lean more towards a stricter assessment of process integration, process control, statistical techniques, and quantitative capabilities (indicative of Level 4 CMM PAs), whilst some auditors might already be satisfied with evidence of consistent measurement (which could be satisfied by CMM Level 2 PAs such as Measurement and Analysis), it all depends on how the standard is interpreted [12].

Nonetheless, based on comparisons from the literature, the preliminary assumption is made that implementing a compliant QMS would entail using the CMM for methodological guidance on the operationalisation of QM through implementing the systems tools, practices, and goals detailed for each PA. The ISO 9001 standard would provide strategic direction for implementation decision-making, and the auditing for compliance would offer a review of QM implementations. This means that ISO 9001 would be used as a complementary framework for validating the CMM implementations rather than as an implementation framework itself. Note that this assumption was also present in the compilation of Figure 5-3, which depicts the synergy between the CMM and ISO 9001 in an implementation strategy as described above.

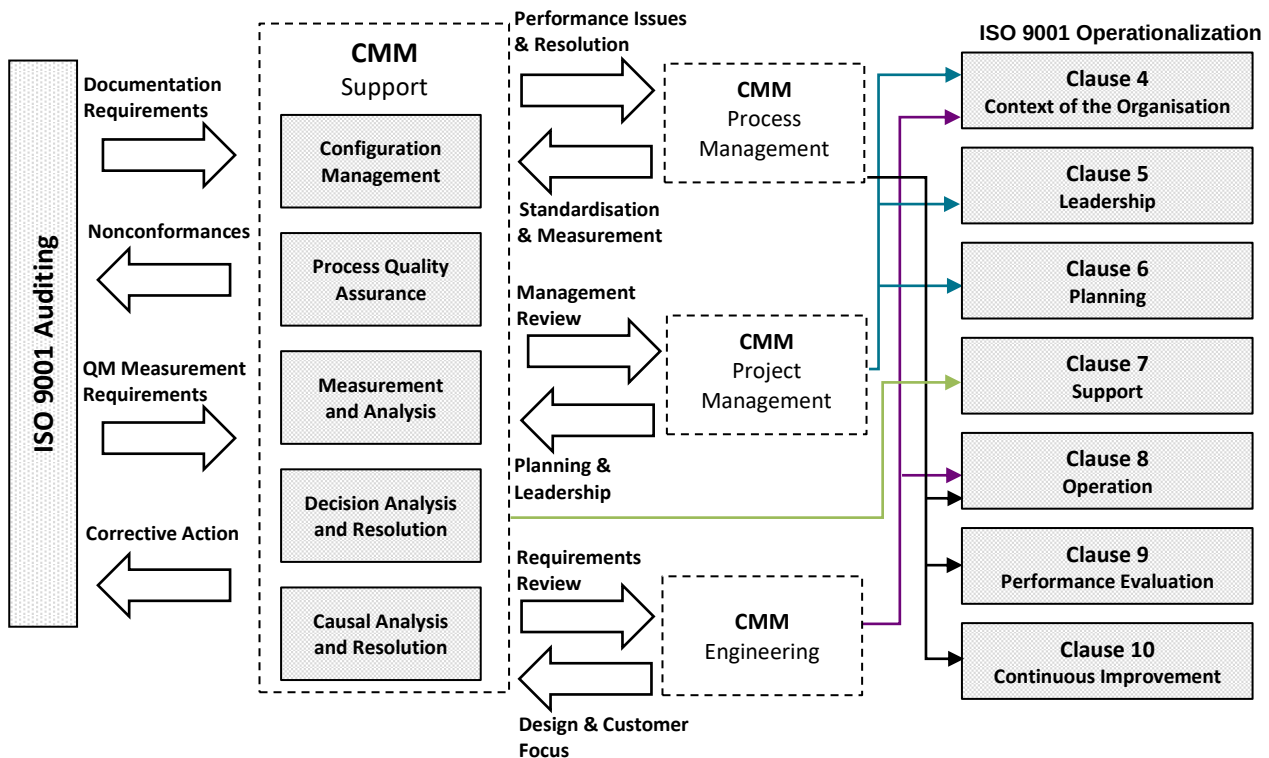


Figure 5-3: Synergy between CMM and ISO 9001:2015 (Original contribution)

The diagram presented in Figure 5-3 outlines the synergy between the common features of the CMM and the clauses of the ISO 9001 standard, which serves as a mapping as to which aspects of the CMM satisfy relevant clauses of the standard and how the standard can be positioned to offer strategic direction to a CMM implementation. This will ensure compliance with operational decision-making and the organisational processes developed during the implementation of the CMM.

The process areas related to the support features of the CMM form the most “direct” interfaces with the ISO 9001 standard. This is where the meta-description of the QMS lies and where all of the ISO 9001 artefacts will be generated. Given that support is also the interface between strategic direction, enablement, and operationalisation of the ISO 9001 standard, it is safe to assume that the ISO 9001 requirements will most likely find relevance through the support Process Areas of CMM.

The CMM emphasizes commitment through policy and enablement through resources [7]. Interpreting this, in conjunction with Figure 2, from an ISO 9001 perspective, thus means that CMM leads to the following in an organisation:

- Employs advanced management techniques related to quantitative management and statistical control, which, according to quality pioneers such as Deming and Shewhart, are the essence of a continuous improvement approach;
- Involves stakeholders, defines customer requirements and governs operations through planning, policy and leadership (Clauses 4, 5 and 6);
- Provides infrastructure, resources, and support to meet the requirements (Clause 7) consistently;
- Verifies all aspects of the customer solution and validates the product (Clause 8);
- Satisfies the quantitative requirements of process performance evaluation and process quality assurance (Clause 9);
- Is capable of identifying nonconformances and defining root causes thereof (Clause 9 and 10);
- Applies deductive reasoning, risk-based thinking, and fact-based decision-making to addressing nonconformances (Clause 10);
- Employs documented, managed and traceable procedures to take corrective action and ensure continuous improvement (Clause 7 and 10).

### 5.3 Defining Requirements for the CMM Adaptation

**Note to the Reader:** *At this stage of the research process, it is possible to relate the characteristics and inherent properties of the CMM to the requirements of the small manufacturing application as well as to the ISO 9001 standard. The work that has been presented up to this point has verified the use of the CMM as a QM solution for small manufacturers. Herein also lies the properties of the CMM that offer value to a QM implementation which are the properties that should be evident in the designed manufacturing adaptation of the CMM. These properties and characteristics serve as an elaboration of the research objectives defined in Section 3.1 and are thus defined in this section as the high-level requirements that the model should adhere to and validated against.*

The adaptation requirements are presented in Table 5-2 below. Each requirement is also related to one or a combination of the CMM, TQM, and ISO 9001 characteristics. The purpose of this is to illustrate what the rationale behind the requirement is and where it comes from. For instance, CMM, TQM, and ISO 9001 are all inherently structured frameworks; thus, by inference, the manufacturing adaptation should also provide a structured framework.

**Table 5-2: CMM Adaptation Requirements**

| <b>Requirements</b>                                                    | <b>CMM</b> | <b>TQM</b> | <b>ISO 9001</b> |
|------------------------------------------------------------------------|------------|------------|-----------------|
| Provide a structured framework                                         | X          | X          | X               |
| Be progressive for incremental growth                                  | X          |            |                 |
| Be pragmatic and systematic                                            | X          |            |                 |
| Be measurable to allow feedback                                        | X          |            | X               |
| Based on TQM and ISO 9001 principles                                   |            | X          | X               |
| Verified to meet ISO 9001 comprehensively                              | X          |            | X               |
| Institutionalise QM best practices sourced from TQM, ISO 9001, and CMM | X          | X          | X               |

#### **5.4 Conclusion on Capability Maturity**

Chapter 5 has addressed two of the research challenges defined in Chapter 3. Firstly, the challenge concerning transferring the CMM to the manufacturing ontology was addressed by discussing how researchers typically approach an interdisciplinary utilisation of the CMM. It was thus determined that researchers typically adapt the CMM to suit an interdisciplinary application by starting with the traditional CMM as a foundation and building or adapting the model through in-depth comparison and inductive reasoning guided by practical considerations, ontological requirements, information from the applicable domains, and researcher experience. Considering this, the research challenge is sufficiently addressed by providing that the CMM can be adapted to the manufacturing ontology by deciding which PAs are relevant to a manufacturing application, how these PAs need to be adapted to encapsulate the terminology of the manufacturing domain, and which QM or manufacturing characteristics are not sufficiently addressed in the CMM and require the formulation of novel PAs. Furthermore, Chapter 5 addressed the challenge of the ISO 9001 compliance of a CMM, to which Section 5.2 offers a solution. The cross-validation between ISO 9001 and the CMM has provided evidence, from the literature, that the CMM encapsulates the ISO 9001 standard and that a management model based on the CMM can sufficiently align an organisation with the ISO 9001 standard. Given the discussions in Section 5.2, it is evident that there is a complementary alignment between the implementation of CMM and the requirements of ISO 9001.

Following a CMM route will align an organisation with the ISO 9001 standard and equip it with robust systemic capabilities to accommodate the variable perceptions or interpretations of an audit. Combining this with the systematic, measurable implementation methodology further motivates the application of a Capability Maturity perspective as a QM solution to manufacturing SMMEs. CMM is not just a superset of ISO 9001 but also a measurable approach.

Finally, the CMM is a progressive, structured management model in which the PAs, Goals, and Practices encapsulate most of TQM and ISO 9001. Importantly, some elements of CMM do not mesh well with the manufacturing ontology and, specifically, a small manufacturing environment, and it also lacks the emphasis on a customer-oriented culture required by ISO and TQM. However, the CMM can and has been successfully adapted to suit various applications, meaning that it can similarly be adapted to focus on developing and improving organisational processes within QM criteria and incorporate more directly the ISO 9001 requirements.

## 6 DESIGN OF A MANUFACTURING CAPABILITY MATURITY MODEL

**Note to the Reader:** Chapter 6 consolidates the research efforts detailed in Chapters 4 and 5 as it discusses the design of the management model, which in the context of this research project is more appropriately described as synthesising an adapted CMM as a QM solution to small manufacturers. This means that this section describes the result of using the fundamental form of the CMM (detailed in Chapter 5) and imposing specific alterations and adaptations as informed by the TQM philosophy (described in Chapter 4), the South African small manufacturing context (determined in the industry survey), and ISO 9001.

### 6.1 Capability Maturity as a Structured QM Framework

The accomplishments in the preceding chapters are consolidated here, and the following discussion refers to the critical paths presented in Figure 3-5 as well as the RVM presented in Table 3-1 to substantiate the Capability Maturity perspective as a QM solution relevant to small manufacturers. The QM literature study, which has assisted in establishing the theoretical foundation, has outlined the current state of QM research and industry studies of QMS implementation. Herein lies the definition of what constitutes a suitable TQM interpretation and how the QM principles transfer to the manufacturing ontology. An analysis of real-world implementations has also elucidated the conditions required for a sustainable TQM approach summarised by motive, time, and resources. Additionally, the review has facilitated the formulation of a framework of QMS characteristics that have consistently been cited as having beneficial impacts on manufacturing organisations in the form of organisational performance, financial performance, product quality, and customer satisfaction.

The Industry Survey has highlighted the need for a QM solution among South African small manufacturers given that only 30% of participants had a relevant QM certification. Additionally, the survey further contextualised the South African small manufacturing application (also summarised in Table 4-9), results of which have supported the opportunity for a structured approach to QM that can offer both a measured growth paths towards QM as well as assist manufacturers with the development and implementation of advanced management methods and recognised best practices. As a result, the CMM has been highlighted as a value-adding management tool, and as for its compatibility to an industrial setting, during the developmental phases of the CMM, the SEI was involved with both software development organisations as well as non-software organisations to identify best quality practices and methods [7]. The CMM was a structured process improvement framework developed by considering industrial best practices. Furthermore, maturity strives toward applying advanced management methods such as process

performance management, risk management, and quantitative management, to which the lower maturity levels aim to establish the foundations that facilitate these techniques.

Risk management is also an emphasised characteristic of the CMM approach while process maturity improves the organisation's ability to identify risks and opportunities and make informed decisions on mitigation. Like many other management models, CMM places significant emphasis on top management commitment and defines various supporting roles for implementing process improvement. The CMM is, therefore, a quality enabling tool that provides a structured framework for achieving customer satisfaction, process standardisation, risk management, total organisational commitment, consistency, quantitative management, fact-based decision-making, and ultimately, continuous improvement, all of which are characteristics that are often cited as the goals, benefits, and objectives of both TQM and ISO 9001.

***In Summary:*** *The structured approach of the CMM fundamentally aligns with the need of small manufacturers for an SQM solution that offers a more beneficial growth path towards QM that does not rely on total organisational reform before any means of benefit is realised. Furthermore, the generic goals, PAs, and practices of the CMM overlap with the aims and objectives of both TQM and ISO 9001. The cross-comparison between ISO 9001 and CMM has been validated through compliance. This means that, at its core, the CMM is a QM-enabling tool that can be used and adapted to address the opportunity of the QM gap in the management methodology of small manufacturers.*

With the focus on Capability Maturity, the literature review discussed in Chapter 5, which details the CMM as well as industry applications, provides evidence that the CMM may be adapted to institutionalise the desired characteristics of an application outside of the software engineering domain as well as guidance on how researchers and practitioners have used the CMM to varying degrees of success. These interdisciplinary applications are typically achieved by adapting the CMM to suit the conditions, terminologies, and purpose of the application, highlighting that the CMM model is seldom transferred “as-is” between disciplines. Therefore, adaptations to the CMM are typically driven by researcher experience and specific ontological requirements or practical considerations. Emphasis is placed on practical considerations because maturity model design projects are usually pragmatic research endeavours aimed at specific real-world applications [23], as is the case with this research project. This also implies that the adaptations have varied significantly, with some researchers making minor adaptations and omitting process areas. In contrast, others have started with the maturity levels and completely redefined the approach.

Nonetheless, the insight gained has assisted in transferring the CMM to the manufacturing ontology and adapting the model's scope to suit a smaller organisational application.

Turning the focus to validation through compliance, the ISO 9001:2015 Standard for Quality Management Systems has been significantly present in discussions throughout this dissertation. The final section of Chapter 4 provides a breakdown of the clause-based structure of the standard and an analysis of the requirements for compliance. It also references various industry interpretations, TQM studies, and manufacturing implementations related to ISO 9001. Herein lies crucial insight into the applicability of ISO 9001 as opposed to a TQM-based approach as well as the interpretations of how compliance to the standard is achieved in various settings. Continuing with the focus on ISO 9001, based on being a globally recognised standard for quality management, the standard is situated as an absolute reference to which verification of the designed manufacturing CMM is demonstrated. The cross-comparison between the CMM and ISO 9001 has provided ample evidence of the validity of adopting a CMM approach to develop a QMS. The results have shown that most of the CMM facets significantly align with the ISO 9001 standard and expand by addressing facets not included in the standard. This implies compliance with the result of using the structured CMM approach as well as the defined framework of the method that the CMM offers to propose a QM solution to a small manufacturer. The diagram presented in Figure 6-1 below provides an overview of the design strategy and depicts how the various elements consolidated in the preceding section have been positioned in the design of the management model.

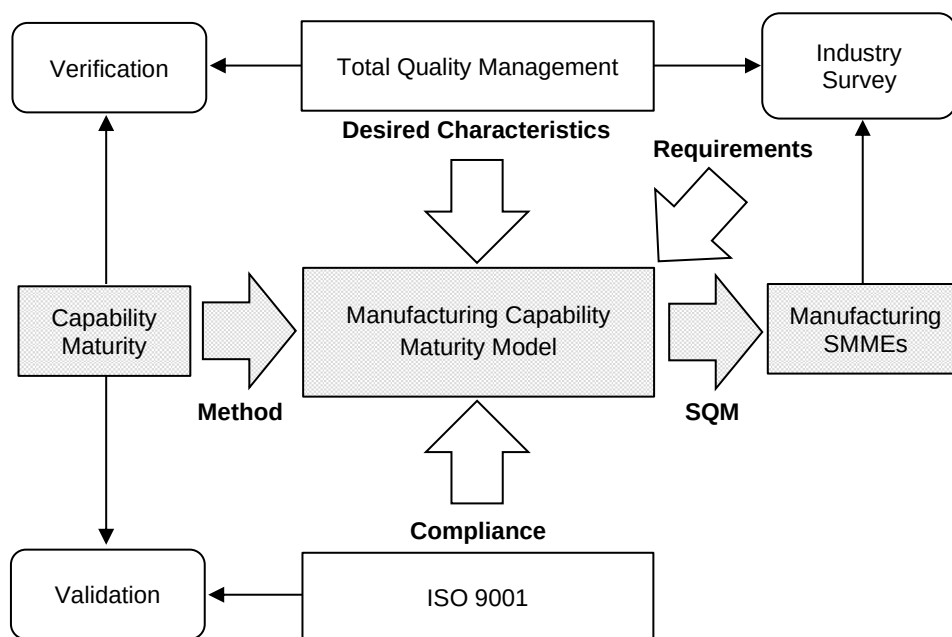


Figure 6-1: Solution design process

## 6.2 Adapting the CMM to a Manufacturing Ontology

**Note to the Reader:** Regardless of the section heading, the following section discusses the CMM's adaption and the design and structure of the Manufacturing CMM (MCMM) itself. The discussion is structured so that the layers that constitute the model, similar to the depiction in Figure 5-2, can be discussed systematically, and direct reference to relevant adaptations can be made.

The Manufacturing Capability Maturity Model (MCMM) is discussed in this section as the CMM. This adaption is described by considering the diagram in Figure 6-2 below. The fundamental approach and structure of the MCMM are consistent with the original CMM, as outlined in Section 5.1.2. However, the MCMM consists of various derived elements, which are foundational to the CMM but have been adapted to encapsulate specific manufacturing terminologies, goals, or practices as informed or influenced by TQM, ISO 9001, or practical considerations.

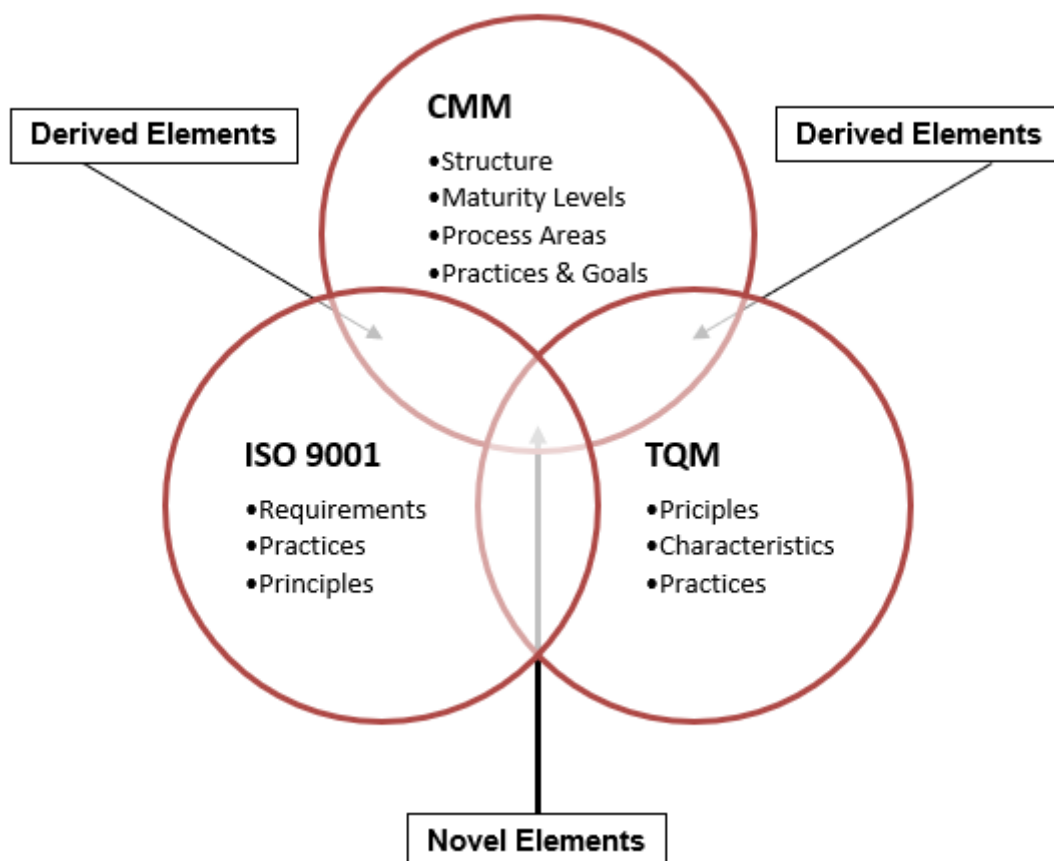


Figure 6-2: CMM Informed Adaptation

The MCMM also consists of novel elements representing the efforts made to ensure that the MCMM satisfies its purpose, remains useable to small manufacturing organisations, and fulfils the objectives of the research problem. The novel elements are thus additions made to the original CMM. With reference to Figure 6-2, the novel elements are presented in the middle of the Venn diagram because, upholding the integrity of the CMM, the additions are sufficiently informed or influenced by the CMM, TQM, and ISO 9001 as well as appropriately positioned within the model such that its function can be realised.

### 6.2.1 Manufacturing Capability Categories

Refer to Figure 6-3 below, where the design is initiated by defining the Process Area categories for the MCMM. These categories are fundamentally based on the categories discussed in Section 5.1.2. and are referred to as the Manufacturing Capability Categories (MCC). The adaption made to the original model is a subdivision of the Project Management and Support categories to emphasise and facilitate certain QM aspects, such as defining and continuously managing organisational objectives.

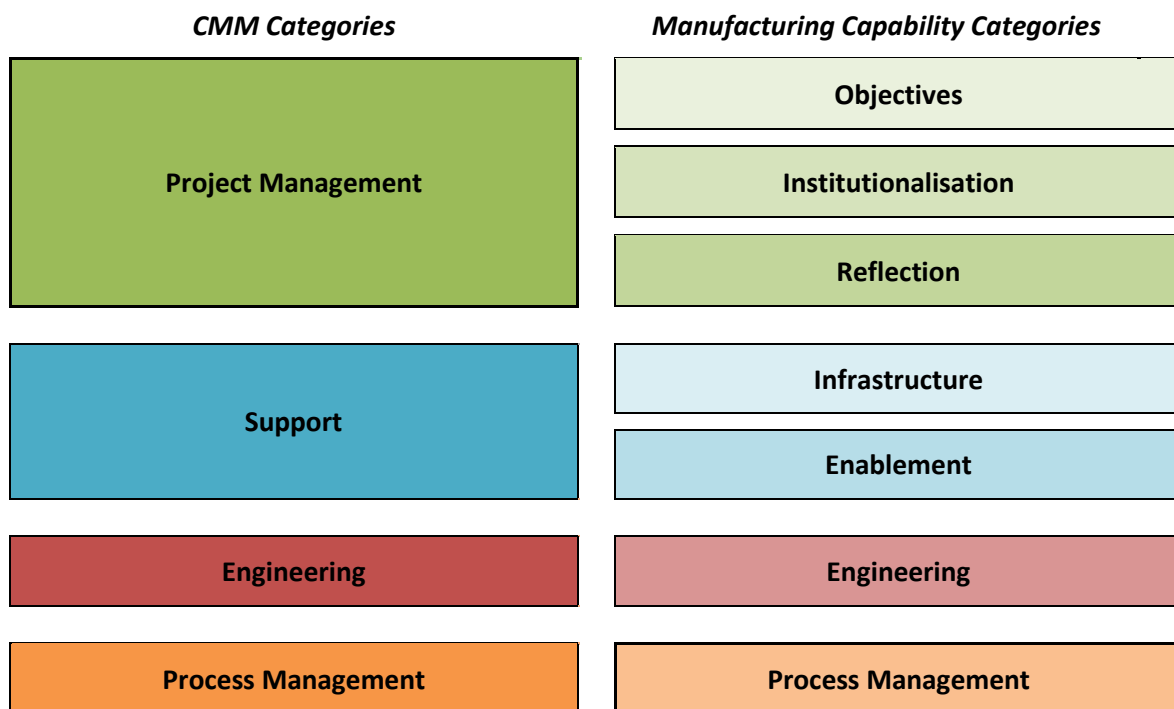


**Figure 6-3: Definition of Manufacturing Capability Areas from CMM Common Features**

Similar to the previously mentioned practical consideration, the Institutionalisation category is positioned as a “management aid” as it separates the act of planning from the act of doing and provides an additional dimension for evaluating how well objectives, goals, and strategic directions are riveted into the organisation. Furthermore, given the typical operational environment of a small manufacturing firm, the institutionalisation category assists managers in

more directly delegating certain QM-related responsibilities to an administrative unit to alleviate the human resources constraint and the administrative duties related to QM. The Institutionalisation category also embeds a TQM consideration, given the significant emphasis placed on Institutionalising TQM principles. The final MCC derived from the original Project Management category is the Reflection category, which is influenced by the need to mitigate detachment between the QMS and the organisation and accommodate novel process areas such as Sustained Customer Focus and Fact-based Decision Making. Given the emphasis placed on being customer-focused by both TQM and ISO 9001, the Reflection category established a more direct relationship between objectives and customer relations, such as customer feedback, customer issues, customer opportunities, market research, and quality issues. Finally, the Reflection category also facilitates the ISO 9001 requirement for identifying and finding corrective action for overall quality and QMS-related non-conformances.

The MCCs derived from the Support CMM category are Enablement and Infrastructure. These MCCs are also rooted in practical consideration and assist an implementer with distinguishing between supporting quality and enabling quality. On the one hand, supporting quality means the manufacturing process flow is supported by commitment, awareness, documentation procedures, supplier management procedures, necessary resources, and sufficient control. The process owners also have access to the knowledge required to successfully complete or contribute to the completion of process tasks. On the other hand, enabling quality refers to the assurance that operations are not hindered by factors such as poor process integrity, insufficient skills or competence, and in a more practical sense, a lack of machinery, appropriate tools, or maintenance. Enablement will also aid the implementation of quality improvement initiatives by facilitating organisational training, introducing new technologies, and improving process integrity measures.

**Important:** *Although the derived MCCs stem from various practical, ontological, or compliance considerations, the collective application still encompasses the scope of the original category, therefore preserving the CMM philosophy during the adaption process. For instance, the process areas related to Objectives, Institutionalisation, and Reflection still facilitate the purpose of the Project Management within the model's scope in that process areas, such as project planning, risk management, management and control, etc., still form the foundation of the categories.*

The Engineering and Process Management MCCs are very closely related to the original archetypes defined in the CMM. The goals, methods, and process areas of these categories relate to the manufacturing ontology and the desired characteristics of the TQM. The concepts

described and the capabilities developed are thus assumed to be sufficiently embedded within the overall understanding of manufacturers.

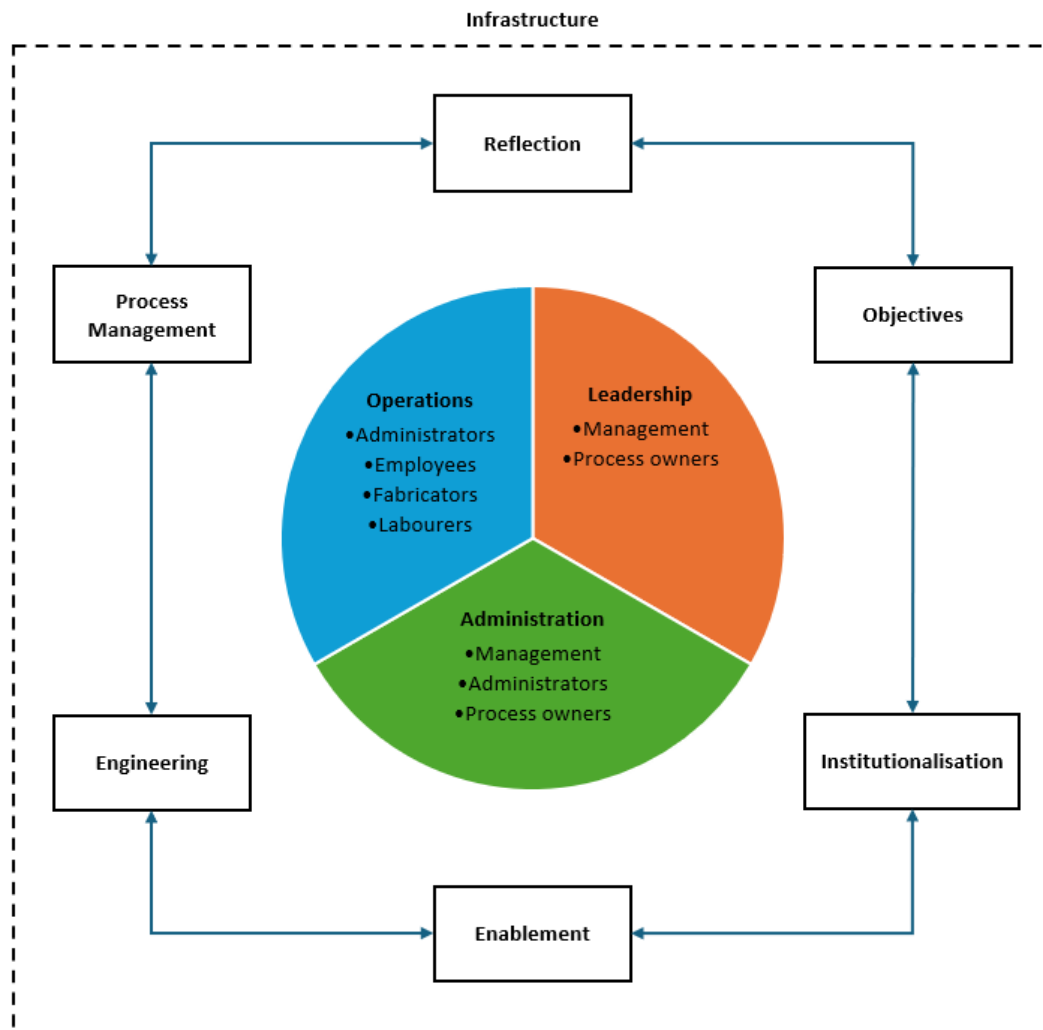


Figure 6-4: Organisational Layout of the MCCs (*Original Contribution*)

### 6.2.2 Manufacturing Process Areas

The following section defines each MCC's Manufacturing Process Areas (MPAs). Similar to the CMM structure discussed in Section 5.1.2, the MPAs are the structural components of the MCMM. However, a foundational difference is that certain MPAs, in contrast to the traditional CMM PAs, have been defined as recursive system Components, meaning that the organisational practices related to the MPA, as well as certain key relationships, will progress and further evolve as the organisation matures and processes become more defined, measured, and controlled.

Furthermore, the MPAs are classified as either **Novel** or **Derived**. Novel means that it is an originally defined process area aimed at institutionalising a certain characteristic of the TQM paradigm that the traditional CMM does not necessarily address or fulfil certain requirements

specific to the model's application as a small manufacturer's solution. Although originally defined, the Novel MPAs are heavily influenced by the principles and practices of TQM, various compliance considerations related to ISO 9001, and practical considerations related to the model's real-world application. The Derived MPAs stem from and are closely related to the traditional CMM, CMM-DEV, or CMMI 2.0 and have been adapted to suit the manufacturing application. Importantly, the process area adaptations have not fundamentally altered the key relationships of the original model to retain the integrity of the CMM approach. This is also evident when considering the key relationship flow diagrams presented in the following sections, which are largely based on the diagrams provided in the CMM model description document [61].

#### 6.2.2.1 Objectives

The Objectives category incorporates leadership, planning, strategy, and commitment to the organisation. This category is defined as the “starting point” of implementing the model as it establishes a foundation for commitment and compiles an organisational scope through a QM lens. This initiates an understanding of what a QMS implementation will entail and substantiates integration with proper project planning, policies, goals, and, ultimately, objectives (operational and quality). The basic operational objectives are based on the fulfilment of customer requirements, whilst more advanced operational objectives are based on process improvements. The basic quality objectives focus on establishing the QMS and institutionalising best quality practices, while advanced quality objectives aim to progress organisational maturity along the MCMM scale. The responsibility of operationalising the Objectives category lies with leadership and administration.

##### ➤ Novel Process Areas:

- **Strategic Direction (SD):** To establish a characteristic of leadership through top management commitment, which is demonstrated through policy, as well as to produce organisational goals and objectives and to commit time and resources to their achievement. This MPA is recursive in that managers of advanced organisations would use SD to interface with organisational information produced by quantitative capabilities, causal analyses, risk management, and organisational performance efforts to substantiate the goals, objectives, and commitments.

##### ➤ Derived Process Areas:

- **Project Planning (PP):** To employ project management principles to establish a well-defined organisational scope and subsequent plans for QMS implementation. PP establishes top management consideration of the time, resources, and risks associated with QMS implementation. Relative to ISO 9001 compliance, this MPA produces an organisational context definition and planning. PP is not defined as recursive; however, the capability for planning will be developed at an earlier maturity level and remain a relevant MPA throughout organisational progression.

- **Organisational Innovation (OI):** As derived from the Organisational Innovation and Deployment PA in the CMM, this MPA aims to initiate organisational innovation. The initial focus is on orienting the organisation to a more quality and process-centric culture, whilst more advanced organisations will utilise OI and interact with Enablement MPAs to introduce new methods, procedures, and technologies for the betterment of operations. This PA is also recursive so that organisational reform can be introduced and systematically evolved into a characteristic of Continuous Improvement.

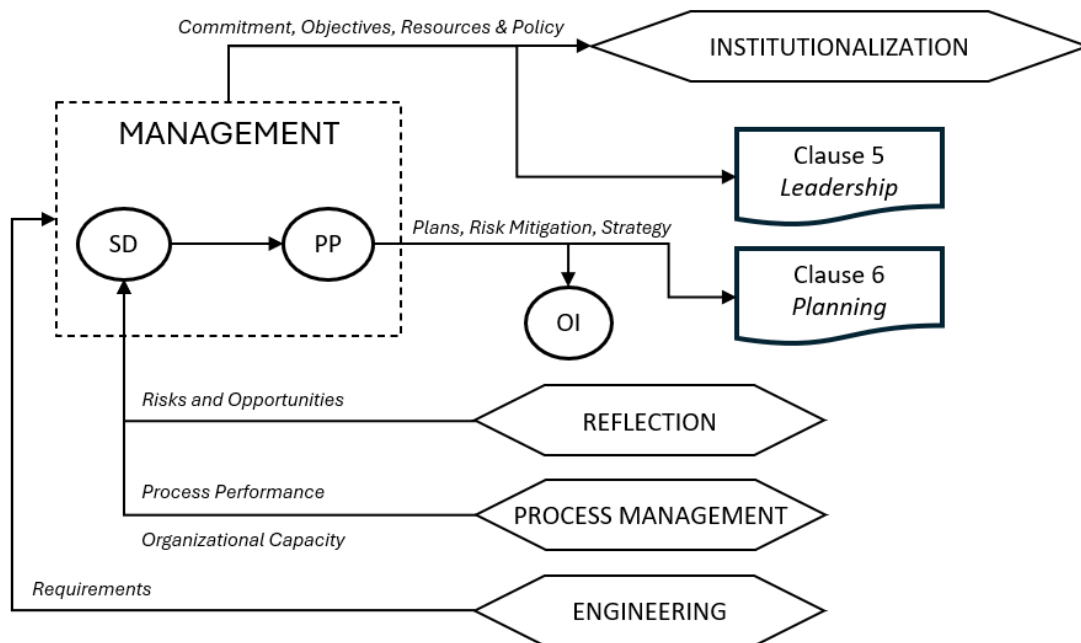


Figure 6-5: Objectives Key Relationships Flow Diagram (Original Contribution)

### 6.2.2.2 Institutionalisation

Institutionalisation is fundamentally derived from project management but also incorporates project management and systems engineering principles. This MCC focuses on establishing and maintaining the QMS and subsequently managing the institutionalisation of the desired quality management characteristics. The MPAs associated with Institutionalisation assist with bringing the plan into action and solidifying commitment to a QM implementation from all relevant contributors and stakeholders. Importantly, disseminating organisational goals and quality objectives remains a leadership responsibility; however, the Institutionalisation of MCC allows organisational involvement and administrative contribution.

➤ **Novel Process Areas:**

- **Systems Implementation (SI):** To incorporate the principles of systems engineering to ensure successful implementation of the QMS. SI is a novel PA inspired by the systems knowledge gap and the “survival mode” barrier associated with small manufacturing implementations. The practices associated with SI aim to assist with identifying critical roles, core business processes, and necessary systems attributes related to the organisational scope and QM objectives.
- **Organisational Commitment (OC):** As a partial derivative of the OPF PA, OC aims to elicit commitment and facilitate organisational contribution to the QMS implementation effort. This MPA draws inspiration from the organisational commitment and employee involvement characteristics referred to in TQM, as well as the notion that properly managed motives are significant contributing factors to the success of a QMS. OC interacts with the Objectives category for objectives, direction, and policies, which is disseminated through awareness, process-specific policies, shared responsibilities, quality-based key performance indicators, and change management.
- **Resource Management (RM):** To institutionalise best practices for eliciting process resource requirements, allocating, managing, and monitoring resources during QMS implementation and maturity progression. RM interacts with various MPAs to elicit resource requirements and with PP and OMC to allocate and monitor resources. Also contained herein is the capability to compare planned resource usages with actual resource usages that interact with IA and OPP and process resource measurement requirements (e.g., energy usage, material usage, manufacturing time).

In terms of manufacturing, RM also facilitates the monitoring of the cost of manufacturing vs the quoted amount, which should benefit the organisation's financial performance and further assist in identifying unnecessary resource usage as well as potential savings initiatives.

- **Knowledge Management (KM):** To document, manage, and maintain the knowledge necessary for contributing to the successful completion of core organisational processes and to manage the knowledge produced by organisational QM efforts and QMS implementation. This MPA is derived from the TQM characteristics for knowledge management, the ISO 9001 requirement for informed employees, and the small manufacturer's need to reduce the dependence on individual heroics for successful outcomes through creating and disseminating organisational knowledge.

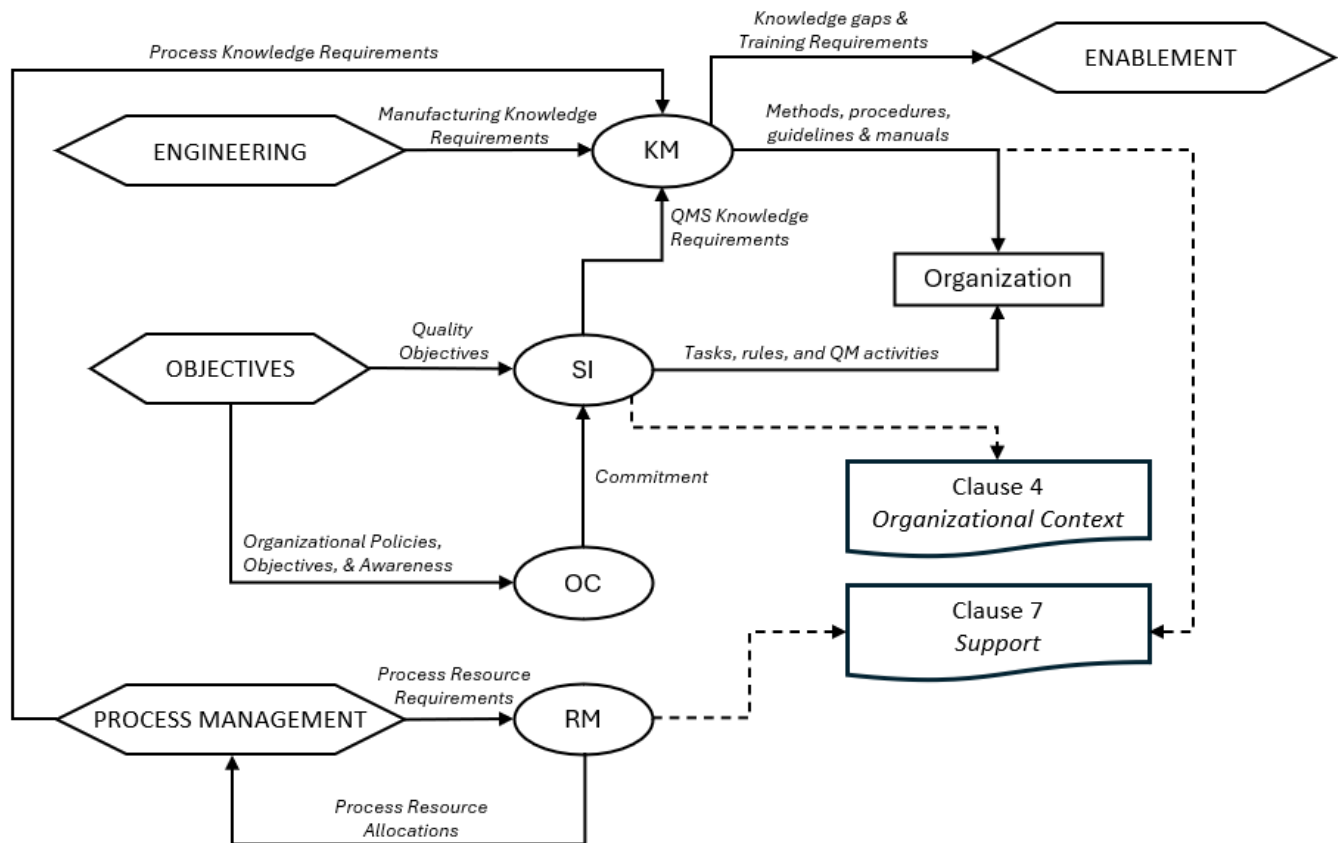


Figure 6-6: Institutionalisation Key Relationships Flow Diagram (Original Contribution)

### 6.2.2.3 Infrastructure

Infrastructure is a derivative of the Support CMM category and focuses first on establishing the necessary structure for management to facilitate the QMS implementation and related administrative duties. The purpose of Infrastructure is to assist with navigating the imminent organisational changes and documentation responsibilities that come with a QM commitment. Ideally, it should thus facilitate a flow of information and knowledge throughout the various operational levels of the organisation. Information flow is achieved by establishing the necessary communication channel between core business processes, standardising documentation procedures, and imposing responsibility for maintaining documentation practices. Infrastructure differs from Institutionalisation as it focuses more on doing than managing, meaning it focuses on creating a tangible environment rather than propagating a quality for culture.

➤ **Derived Process Areas:**

- **Configuration Management (CM):** To establish methods, responsibility, and management of all configuration management duties and related documentation. The traditional purpose of CM is to establish the integrity of a product by maintaining updated descriptions of the configurations of a product, solution, or process. This allows for documented and traceable alterations to the designs, components, technologies, attributes, assets, and methods related to products, solutions, and processes. However, given the thoroughly documented foundation developed as a consequence of CM and that it describes all of the critical aspects of quality, the CM PA is positioned as a fundamental Infrastructural PA as it provides a method of developing, storing, and maintaining meta-descriptions of the QMS.
- **Organisational Management and Control (OMC):** To provide a means to manage core organisational processes and track the organisation's QM-related performance and progress. OMC relies on the documented plan developed by PP to monitor tasks, activities, and responsibilities related to the implementation of the QMS. OMC also produces methods and results for internal management reviews and, for more advanced organisations, facilitates internal auditing and control. OMC thus satisfies the internal review requirements of the ISO 9001 standard.
- **Risk Management (RSKM):** To enable the identification of potential issues, risks, non-conformances, and opportunities before they occur and determine appropriate mitigation. RSKM is positioned in as an Infrastructure MPA as it is a continuous, integral aspect of QM. The operationalisation of RSKM includes a strategy for identifying risks, analysing/evaluating the risks, and taking subsequent action to avoid or mitigate the risks. RSKM interacts with OMC as a medium to monitor and control QMS implementation-related risks, with TS for risks related to fulfilling customer requirements and with PP for risks related to stakeholder satisfaction.

The RSKM MPA further complements QMS implementation with a continuous focus on risk management. Given the emphasis placed on risk management as a holistic characteristic of the ISO 9001 standard, the practices related to RSKM focus on developing a capability for performing risk management in all aspects of the organisation such that it can be applied in various other MPAs. Like the CM MPA, RSKM will thus become an integrated attribute of the organisation.

- **Supplier Management (SM):** To manage the procurement of products, raw materials, components, and technologies, as well as the outsourcing of manufacturing-related tasks and services, as well as the agreements and relationships with suppliers. SM is derived from the Supplier Agreement Management PA and aims to monitor the quality of system aspects sourced from outside of the organisation. SM is significantly influenced by the ISO 9001 guidelines on managing supplier relations.

#### 6.2.2.4 Engineering

The Engineering MCC establishes engineering management and design methods into the system to ensure that customer needs and expectations are sufficiently translated into requirements and subsequently ensures that these requirements are satisfied through an appropriately designed, planned, validated, and documented solution. Engineering thus underpins the objectives of MCC in that the understanding and quality of customer and stakeholder requirements undoubtedly influence the fundamental objective of the QM, which is to be customer-focused and meet the requirements of the customer. The requirements definition includes a thorough understanding of the needs and expectations of stakeholders, customers, and new market ventures. These requirements need to be understood within the context of the organisation's operations, capabilities, limitations, and capacities to translate into viable organisational objectives, quality objectives, and various requirements. Also addressed in the Engineering category is the verification and validation of solutions and subsequent refinement of requirements. An adaption to the traditional Engineering CMM category is that more emphasis is placed on post-production customer involvement and feedback integration as a post-production interface. This customer interface is facilitated through the Reflection MCC, specifically the Sustained Customer Focus MPA, and it establishes a more direct interaction between customer satisfaction and the management of requirements.

##### ➤ **Novel Process Areas:**

- ***Manufacturing Processes (MP):*** To standardise manufacturing and define, document, and disseminate accepted manufacturing tasks, procedures, processes, manuals, and guidelines. Herein are also the skills, knowledge, estimations, resources, and equipment required to complete or contribute to the completion of the manufacturing process. The documentation produced by MP enables the translation of requirements and TS into the manufacturing environment as well as a definition of manufacturing-related performance measures. Detailed descriptions will also enable the identification of risks and opportunities and facilitate more detailed causal analyses as they are developed in more advanced maturity levels. MP interacts with REQD, TS, and PI as the basis for writing procedures and with REQM and CM for managing documentation and procedure alterations.

##### ➤ **Derived Process Areas:**

- ***Requirements Development (REQD):*** To elicit, understand, and analyse customer needs and expectations to formulate customer requirements. Also addressed is identifying stakeholders' needs, goals, and constraints, which are used to formulate organisational requirements. Requirements are a central theme in the management model and are disseminated throughout the organisation in various forms (product requirements, quality objectives, organisational objectives, performance measures, etc). The REQD MPA thus

places emphasis on a thorough definition of requirements by considering not only the solution to the requirements but also the capability of the system that produces it.

- **Requirements Management (REQM):** To manage the development, translation, and dissemination of requirements as well as the configurations of requirements resulting from alteration. REQM ensures that requirements are adequately documented and continuously aligned with organisational capacity, design activities, manufacturing procedures, and organisational performance. REQM also facilitates the interaction between Engineering MPAs and various other organisational areas.
- **Technical Solution (TS):** To select, design, and produce appropriate solutions to fulfil requirements; this MPA focuses on formulating solutions to the requirements by utilising known engineering methods. Importantly, TS applies not only to the design of products but also to the design of processes, procedures, and organisational structures to provide solutions to identified risks, opportunities, and innovations. TS interacts with VER to verify the functionality and feasibility of proposed solutions and with PI to integrate the solutions into the applicable environment. TS is derived from the CMM, which primarily aims to provide a solution to a need. The MCMM is interfaced with KM, emphasising documenting accepted design procedures and previously verified and validated solutions. In doing so, TS becomes more standardised and at more advanced maturity levels, manufacturers are expected to identify risks before the solution is implemented and be able to trace non-conformances, customer or quality issues back to the development of the solution.
- **Product Integration (PI):** To integrate solutions with applicable environments and create an integration environment for products or components produced by individual manufacturing processes. PI is derived from the PI PA and facilitates the physical steps, tasks, and activities related to the manufacturing of the products and to the implementation of processes or procedures. Solution is thus used to describe the outcome of applying TS, meaning that it can refer to a physical product as a solution to a customer need or to a process update as a solution to an organisational objective. PI interacts with OPD and MP to facilitate manufacturing standardisation and with VAL, VER, and REQD to ensure that the outcome satisfies requirements.
- **Verification (VER):** To ensure that the product meets the design requirements' criteria and that it will offer a sufficient solution. This entails the establishment of a verification environment, verification criteria, and verification procedures. Verification is applied to selected solutions and applied accordingly.
- **Validation (VAL):** To demonstrate that a solution fulfils customer needs and meets stakeholder expectations. As influenced by TQM, VAL also focuses on demonstrating process quality by ensuring that the processes have functioned as intended. VAL thus ensures that the product, process, or procedure adequately addresses the needs and expectations of customers and stakeholders. VAL is interfaced with SCF to ensure continuous customer focus at the engineering and requirements development level.

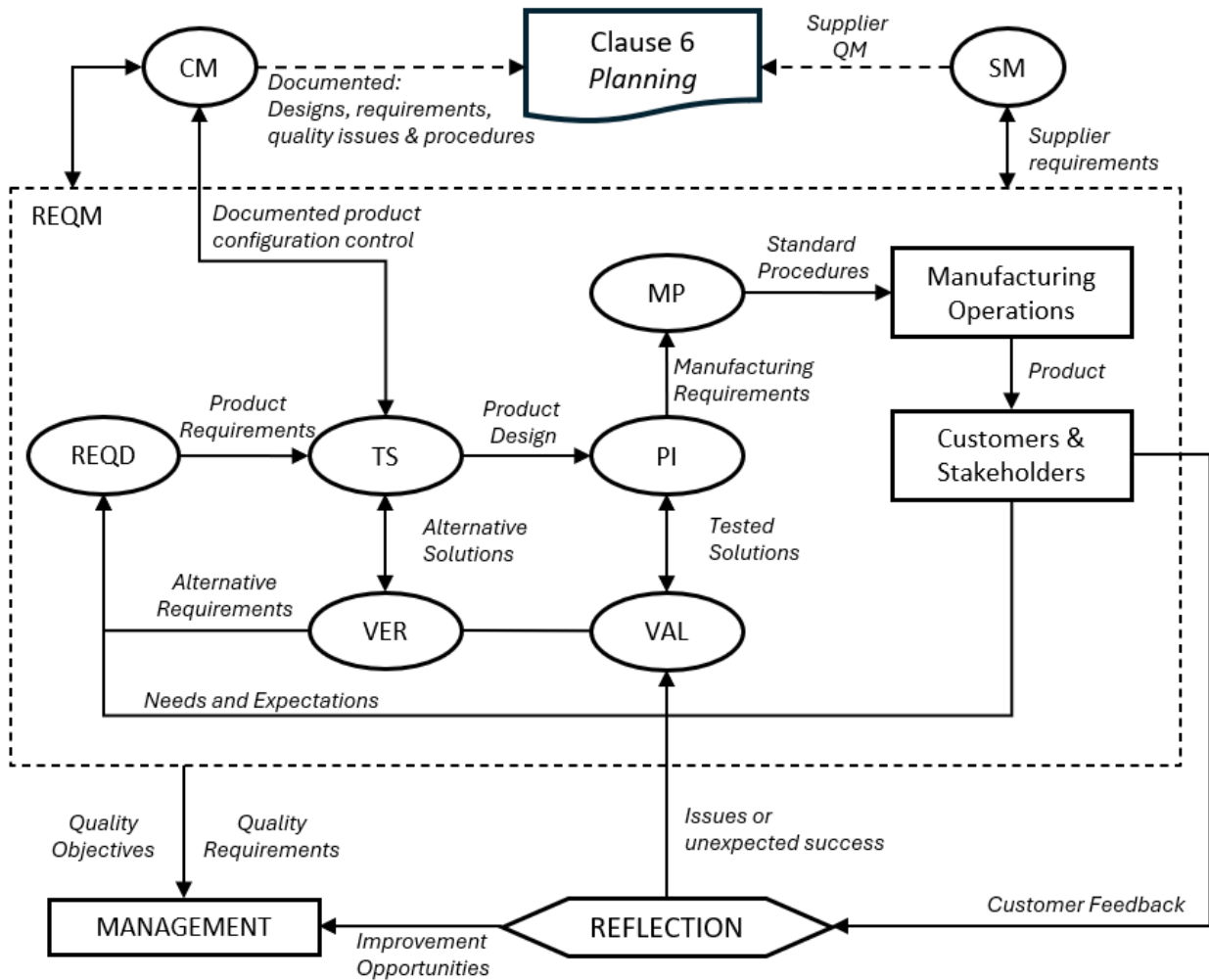


Figure 6-7: Engineering Key Relationships Flow Diagram (Adapted from CMM [61])

### 6.2.2.5 Process Management

Process Management seeks to define, plan, deploy, measure, monitor, control, and improve organisational processes. The CMM provides that a *managed process* is a process that is performed according to plan and policy, executed by competent people, supported by the necessary resources, is monitored and reviewed, and involves all relevant stakeholders [61]. The basic operationalisation of Process Management thus facilitates the standardisation and development of managed processes. The CMM further builds on the definition and provides that *defined processes* are managed processes that are tailored to the organisation with a clear description of the purpose, inputs, criteria, activities, roles, measures, verification procedures, outputs, and exit criteria [61] (Note the similarity to the definition used by ISO 9001 as illustrated in Figure 4-3). More advanced maturity levels will thus incorporate the development of defined processes.

➤ **Novel Process Areas:**

- **Information and Analysis (IA):** To develop and establish methods of analysing, interpreting, and disseminating organisational process data and information and to ensure that this information is useable, meaningful, and disseminated to relevant organisational structures. This is done by selecting meaningful data collection, measurement, analyses and reporting methods. IA interacts with various MPAs and with management as it contributes to data-driven decision-making (as encapsulated by fact-based decision-making) and with OPP, OPM, and the Objectives MCC.

➤ **Derived Process Areas:**

- **Organisational Process Definition (OPD):** To develop and establish process definitions, standardise working procedures, knowledge requirements, and general rules or guidelines for process execution. This is done to facilitate process standardisation and achieve controlled execution and predictability of outcomes. The main deliverable of OPD, as defined in CMM, is a set of “standard processes” [7]. OPD is not defined as a recursive MPA but will build on the elements of organisational process focus embedded in the OC MPA to establish defined processes from managed processes. Manufacturing processes are encapsulated within the OPD.
- **Organisational Process Performance (OPP):** To identify and select core business processes from the set of standard organisational processes that are critical or linked to the organisation's quality objectives and to define these processes quantitatively. This entails the establishment of process measurements, process baselines, performance metrics, and process models that enable quantitative performance management. OPP thus requires established quantitative objectives as a prerequisite and should be coupled with well-established process definition and data analysis capabilities. OPP interacts with IA for the measurement and analysis of data and with OPM as the facilitation of quantitative management.
- **Organisational Process Management (OPM):** To quantitatively manage organisational goals, objectives, and progress and to establish a quantitative understanding of the organisation with confidence in a predictable management approach. This requires harnessing OPP and appropriate statistical techniques to extract information from data. OPM also facilitates monitoring processes' performance and root cause analyses based on system information and process data. Derived from Quantitative Project Management, OPM helps establish and manage quantitative quality metrics based on process performance measurements.

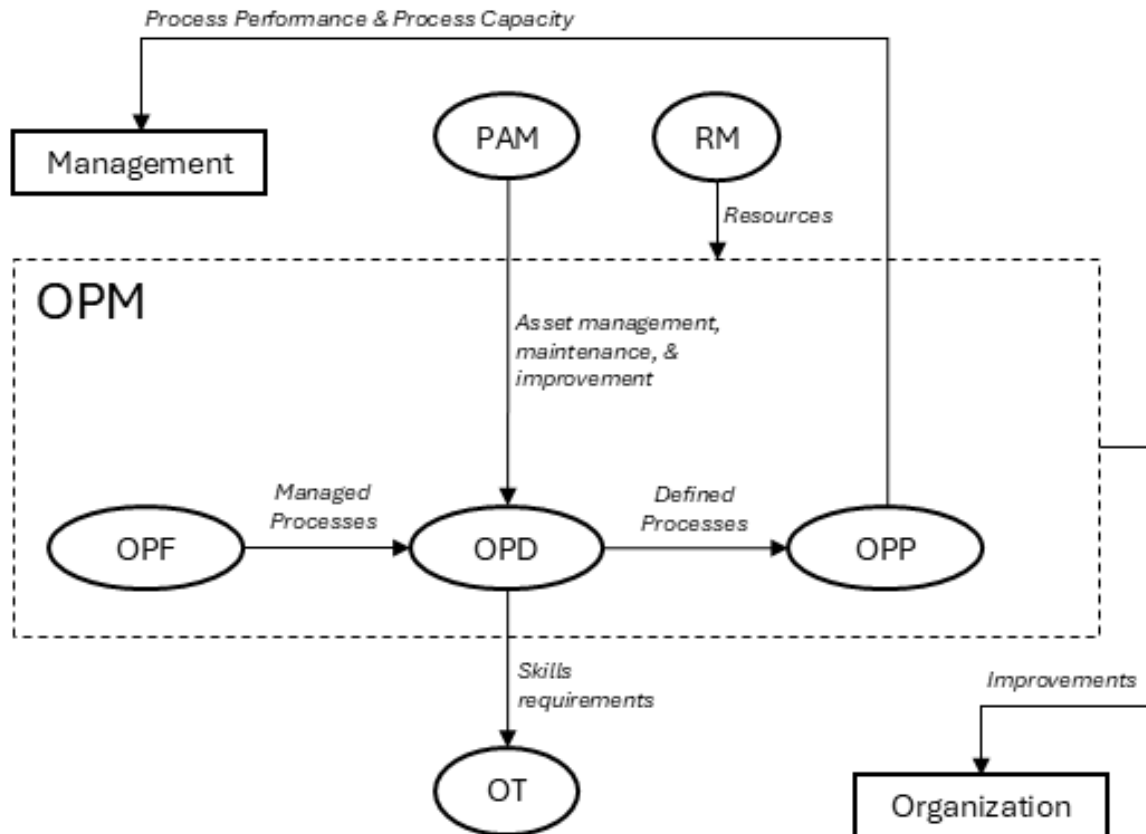


Figure 6-8: Process Management Key Relationships Flow Diagram (Adapted from CMM [61])

#### 6.2.2.6 Enablement

The Enablement category focuses on enabling organisational quality, the fulfilment of objectives, and maturity progression. This includes developing workforce skills and competence, stimulating a continuous culture for improvement, developing of process assets, and maintaining process integrity.

##### ➤ Novel Process Areas:

- **Asset Management (AM):** To establish, develop, and maintain a full lifecycle management capability to ensure that processes and processes are developed, deployed, *maintained*, managed, and decommissioned at end of life. In the manufacturing sense, AM ensures that the assets required for core manufacturing processes (e.g. tools, equipment, machinery, software, etc.) are maintained, monitored, and managed. This would require defining the process assets and determining their effectiveness for lower-maturity organisations. For a more mature organisation with quantitative capabilities, AM facilitates condition monitoring, preventative maintenance, decommissioning, and data-driven improvement.

➤ **Derived Process Areas:**

- **Organisational Training (OT):** To elicit training needs from various organisational areas, to identify the gaps in skills, knowledge, and capabilities of the organisation and employ proper training to enable individuals to contribute to the efficacy of their operations and fulfil their roles effectively. OT also focuses on developing and dispersing QM-related knowledge and aims to assist in establishing a “smart” quality culture. Smart in the sense that QM knowledge and terminologies are not ringfenced to leadership or administrators such that the concept of QM becomes integral to the ethos of the workforce.

#### 6.2.2.7 Reflection

As the most crucial interface between operations and leadership, the Reflection MCC facilitates continuous development and overall improvement. Reflection categorises MPAs that mandate an introspective view of the organisation to ensure the quality of processes being developed and used. Reflection also utilises the QMS knowledge produced to identify and analyse non-conformances and organisational innovations. Reflection draws inspiration from the Check and Act items of the PDCA cycle.

➤ **Novel Process Areas:**

- **Sustained Customer Focus (SCF):** To establish and sustain a customer-oriented approach, the SCF aims to continuously involve customer consideration during and after the manufacturing process by eliciting customer engagement and feedback, remaining up to date with the needs of the market, and ensuring that requirements remain customer-centric and up to date with feedback. SCF also facilitates considering quality issues or reworks in the PQA method. The SCF MPA is heavily influenced by TQM and draws from the emphasis placed on being customer-focused.
- **Organisational Decision Making (ODM):** To establish a recursive capability for utilising the information produced by the QMS to make informed decisions regarding organisational development. FDM is a recursive MPA in that the information used to make decisions reflects the organisation’s maturity. Less mature organisations will produce information through employee feedback, management reviews, and lessons learnt during QM attempts, while more advanced organisations will produce quantitatively backed information, predictive analyses, and risk-based options.

➤ **Derived Process Areas:**

- **Causal Analysis and Resolution (CAR):** To find the cause of non-conformances, quality issues, negative feedback, defects and deviations, process issues, or reworks, as well as to find resolution and determine corrective action. CAR focuses on identifying causes for issues and determining, by analysis, the proper corrective actions. However, given the fundamental capability related to CAR, it will also play a vital role in explaining the reason for unforeseen success by determining how it happened and how it can happen again. CAR is thus also positioned as a mechanism for understanding lessons learnt. This MPA

fundamentally requires a well-developed QMS that is capable of producing enough relevant information to compile informed corrective action.

- **Process Quality Assurance (PQA):** To objectively evaluate the quality of processes and products and ensure that process outcomes meet quality-oriented criteria. This entails identifying key quality areas, defining quality criteria (e.g., components or process inspections), and documenting quality- and performance-related issues. The internal auditing requirements and self-assessment requirements of ISO 9001 influence the practices of PQA.

### 6.2.3 Manufacturing Capability Maturity Levels

The following section uses the in-depth analysis from Annexure B (also discussed in Section 0) as well as real-world observations from industry to define maturity levels relevant to the MCMM. In order to define these levels, it was necessary to align existing CMM levels within a manufacturing ontology. The achievement of this goal required the application of practical considerations and systems thinking to provide logical order to the implementation lifecycle of the model. This meant defining the maturity levels and related MPAs according to the structure provided by the CMM, whilst being mindful of how a small manufacturer with limited time, resources, and systems knowledge would view and interpret the framework. Also, a heavily weighted consideration was the feasibility of developing QM characteristics at each stage of the implementation lifecycle. In doing so, two fundamental requirements were addressed, one being that due priority could be given to the earlier development of necessary support structures to ease the financial impact and incrementally bridge the systems gap related to the development of a monitoring system, as required by higher maturity levels.

With the MCCs substantiated with defined MPAs and established key relationships, this section guides the implementation lifecycle of the model. Each maturity level is defined (as derived from the original maturity levels detailed in the CMM [7]) and contextualised in terms of TQM alignment, ISO 9001 compliance, and the small manufacturer's application. These contexts should guide interpreting what each level is set to achieve and how it fits into the path towards QM. This section describes each level individually, starting with Level 1 and working through the succeeding levels. Level 1 is defined as the manufacturing QM baseline, of which the definition was significantly influenced by practical consideration, the Industry Interview and, more so, by the Industry Survey. Levels 2 to 5 are the developmental levels in which the MPAs are operationalised, and the structure of the QMS is developed. In addition to the contextualisation referred to earlier, these levels are also summarised in terms of the relevant MPAs, TQM characteristics developed, and SQM artefacts produced.

**QMS Artefacts:** The tangible, formal, or useable items produced by the operationalisation of MCCs and MPAs. The QMS artefacts are thus the deliverables or byproducts created through process implementation, including policies, procedures, guidelines, manuals, registers, records, reports, etc. Herein are the QMS documents and descriptions and fulfilment of the mandatory documents required for ISO 9001 compliance. Notably, the term *QMS Artefact* encompasses both the “*Documented Information*” term described in the ISO 9001 standard [64] as well as the “*Process Documentation*” term used in the CMM [7].

#### 6.2.3.1 Level 1: Initial (Baseline)

**Definition:** *Manufacturing is unpredictable, and processes are performed ad hoc.* The system is highly reactive, and quality is characterised by unexplained variability. Successful output often depends on individual heroics, and repeatability can only be achieved through the capabilities of individuals. Processes and procedures are actionable but not tangibly defined or managed.

**The small manufacturer’s context:** Revisiting the *Industry Survey*, a significant observation was that small manufacturers demonstrated the ability to assure quality and meet the customer’s expectations but lacked the systemic capabilities for continuous improvement. Additionally, an observation that the Industry Interview highlighted is the unknowing implementation of systems and processes; smaller manufacturers often have tried and tested ways of doing things, which are often undefined and unmanaged, but success is achieved through employee or manager experience. Therefore, it is assumed that South African small manufacturers are at Level 1, with some of Level 2 and 3 operational capabilities.

#### 6.2.3.2 Level 2: Repeatable

**Definition:** *Processes are managed.* Planning, procedures, and management are based on experience, especially from the success and lessons learnt from previous projects. Institutionalizing basic project management methods, such as compiling a project/implementation plan, defining requirements, and assigning responsibilities, establishes systems awareness and a foundation for the QMS. The foundation is established by formulating an organisational context and pre-empting management through policy. Furthermore, documenting capabilities and defining the manufacturing environment facilitate the repeatability of product manufacturing.

**TQM Alignment:** Quality still relies on constant management and individual capability. Level 2 TQM is characterised by establishing organisational involvement. The institutionalisation of quality practices is initiated by defining policies, goals, and objectives and driven by organisational awareness. However, process knowledge still rests with individuals or discrete groups.

**ISO 9001 Pursuit:** Level 2 facilitates the definition of fundamental QMS descriptions, namely an organisational context, a scope, and stakeholder requirements. The path to achieving fully-fledged Level 2 status requires the definition of organisational objectives, organisational awareness, and involvement of the employees.

**The small manufacturer's context:** For an established small manufacturer driven by industry experience, the focal areas of achieving Level 2 will be to develop an organisational context, recognise the processes being implemented, and involve the organisation to ensure the ability to satisfy customer requirements. The practices related to achieving Level 2 are largely centred around establishing systems capabilities and Infrastructure. It is important for small manufacturers to emphasise employee contribution and avoid ringfencing QM to a single person or department, it should be an organisational effort.

**Table 6-1: Mapping Manufacturing Maturity Level 2**

| MCC                         | MPA             | TQM Characteristic         | SQM Artefacts                                                                                                                                                               |
|-----------------------------|-----------------|----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Objectives</b>           | SD<br>PP<br>OMC | Top management commitment  | <ul style="list-style-type: none"> <li>- Defined QMS scope</li> <li>- Implementation project plan</li> <li>- Organisational objectives</li> </ul>                           |
| <b>Institutionalisation</b> | SI<br>OC        | Organisational Involvement | <ul style="list-style-type: none"> <li>- Quality policy</li> <li>- Assigned responsibilities</li> <li>- Awareness methods</li> </ul>                                        |
| <b>Infrastructure</b>       | CM<br>SM<br>AM  | Support Supplier QM        | <ul style="list-style-type: none"> <li>- Defined suppliers list</li> <li>- Documentation platform &amp; responsibility</li> <li>- Asset registers and tool lists</li> </ul> |
| <b>Engineering</b>          | REQD<br>REQM    | Process Approach           | <ul style="list-style-type: none"> <li>- Stakeholders defined</li> <li>- Customer needs defined</li> <li>- Customer and stakeholder requirements</li> </ul>                 |
| <b>Reflection</b>           | SCF<br>PQA      | Customer Focussed          | <ul style="list-style-type: none"> <li>- Customer feedback methods</li> <li>- Basic PQA inspection registers</li> </ul>                                                     |

### 6.2.3.3 Level 3: Defined (Interpretable)

**Definition:** *Processes are defined.* Core business and manufacturing processes are defined and standardised. Thus, processes are characterised by resource requirements, interfacing, execution procedures, and expected deliverables. Necessary resources also enable processes, and management can initiate quality assurance measures for processes. Level 3 facilitates control over critical manufacturing facets such as cost, schedule, verification, validation, and product lifecycle.

**TQM Development:** Processes are defined and characterised by consistency, meaning that the organisation is fully process-centric and more advanced management methods such as risk management, process measurement, and fact-based decision-making can be institutionalised. With defined core business processes and a clear direction for QMS implementation, more strategic organisational training can be implemented to support meaningful employee involvement. Critical process knowledge requirements can thus be transferred to create organisational capability and no longer centres on individuals and teams.

**ISO 9001 Pursuit:** Within Level 3, managers and implementers can start interpreting the ISO 9001 standard within the context of their organisation and processes. Organisational definitions, systems understanding, and risk management align significantly with the ISO 9001 standard. These facets, as well as the SQM Artefacts, will assist in understanding what the standard requires. Giving due consideration to the standard at Level 3 will also complement a Level 4 pursuit as it would provide guidance on, what to measure, how to measure it, and how to document findings.

**The small manufacturer's context:** Progressing through Level 3 shifts the focus to process definition, engineering management, and systems engineering. As a result, Level 3 is the most demanding level to achieve and presents the most significant learning curve. In the pursuit of Level 3, an organisation should recognise the value of incremental improvement and come to terms with the fact that maturity will not be an immediate attainment. However, the model requires incorporating risk management and certain value engineering elements to present earlier identification of non-conformances and organisational innovations to realise benefits.

Progressing from Level 2 to Level 3, a small manufacturer will need to leverage the organisational quality mindset cultivated in Level 2 to elicit employee contribution. An organisation will spend most of its QM efforts developing process definitions as it is essential to thoroughly define the organisation as a prerequisite for maturity Level 4.

**Table 6-2: MPA Maturity Level 3 Mapping**

| MCC                         | MPAs                           | TQM Characteristic                                                        | SQM Artefacts                                                                                                                                                                                                                                                     |
|-----------------------------|--------------------------------|---------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Objectives</b>           | SD                             | Top management commitment                                                 | <ul style="list-style-type: none"> <li>- Process/section specific policies and objectives</li> <li>- Continuously update organisational information procedures</li> </ul>                                                                                         |
| <b>Institutionalisation</b> | RM<br>KM<br>OC                 | Organisational involvement<br>Knowledge management                        | <ul style="list-style-type: none"> <li>- Process/task-based risk assessment capabilities</li> </ul>                                                                                                                                                               |
| <b>Infrastructure</b>       | RSKM<br>OMC                    | Support<br>Risk management                                                | <ul style="list-style-type: none"> <li>- Standard risk management procedure</li> </ul>                                                                                                                                                                            |
| <b>Engineering</b>          | REQD<br>TS<br>PI<br>VAL<br>VER | Customer focussed<br>Risk management<br>Knowledge management              | <ul style="list-style-type: none"> <li>- Commitment to requirements</li> <li>- Established verification methods</li> <li>- Established validation methods</li> <li>- Standardised design procedures and estimates</li> <li>- Defined product lifecycle</li> </ul> |
| <b>Process Management</b>   | OPF<br>OPD                     | Process approach                                                          | <ul style="list-style-type: none"> <li>- Awareness, commitment and training requirements for a process centric approach</li> <li>- Standardised process documentation</li> </ul>                                                                                  |
| <b>Enablement</b>           | OT<br>PAM                      | Employee training<br>Process approach                                     | <ul style="list-style-type: none"> <li>- Document employee skills, and training requirements</li> <li>- Defined process asset and resource requirements</li> </ul>                                                                                                |
| <b>Reflection</b>           | PQA<br>FDM                     | Customer focussed<br>Fact-based decision making<br>Continuous improvement | <ul style="list-style-type: none"> <li>- Identification of superficial non-conformances and customer dissatisfaction</li> <li>- Risk-based decision making</li> </ul>                                                                                             |

#### 6.2.3.4 Level 4: Managed (Auditable)

**Definition:** *Manufacturing performance, process performance, and process quality are quantified characteristics within the organisation.* Level 4 harnesses the defined nature of Level 3 to identify and measure critical organisational/operational attributes. The measured data is analysed and utilised in the decision-making process. Performance metrics define process capacity, and corrective action is focused on addressing quantitative deviations from these metrics. Mitigation strategies for risk and opportunities are now quantifiable, facilitating predictive decision-making capability and sustaining continuous improvement.

**ISO 9001 Pursuit:** Level 4 is the auditable level, and the organisation will be sufficiently aligned to consider ISO 9001 certification. With the focus of Level 3 to establish process standardisation and related documentation habits, Level 4 sees incorporating corrective actions, internal audits, and system reviews. It is also assumed that by supplementing the MCMM with guidance from the ISO 9001 standard, the measurement and analysis strategies will be aligned with ISO 9001 requirements for QM evidence. Importantly, although the findings of the cross-validation discussed in Chapter 5 suggest that the ISO 9001 standard is mostly encapsulated between Levels 2 and 3, with the addition of novel MPAs and recursive process areas, the MCMM only truly aims to assist the small manufacturing environment and build compliance through systemic value rather than creating another ISO 9001 checklist.

**The small manufacturer's context:** The central theme of Level 4 can be described by two sentiments, firstly by Deming [85]: "Uncontrolled variation is the enemy of quality". A Level 4 organisation thus employs meaningful quantitative management. This is meaningful because process measurement is done according to a strategy focused on controlling process variability and applying statistical control to organisational areas that are significant to product quality. Emphasis is placed on taking due time to plan process measurement, as a metering strategy remains expensive regardless of how it is approached. Given the resource constraint related to a small manufacturing implementation, it is thus imperative to avoid unnecessary quantitative implementation attempts.

Secondly, Shewhart famously stated that [86]: "original data should be presented in a way that will preserve the evidence in the original data for all the predictions assumed to be useful". The data resulting in process measurement should offer an objective view of the performance of the process by applying the correct statistical analysis and interpretive methods. The most difficult part of Level 4 will thus be the steep learning curve of meaningfully using performance metrics, measurable KPIs (Key Performance Indicators), and data to enable quantitative management.

**Table 6-3: MPA Maturity Level 4 Mapping**

| MCC                       | MPAs            | TQM Characteristic                                   | SQM Artefacts                                                                                                                                                                                                     |
|---------------------------|-----------------|------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Objectives</b>         | OI              | Continuous improvement                               | <ul style="list-style-type: none"> <li>- Corrective actions and non-conformances</li> <li>- Performance reviews</li> </ul>                                                                                        |
| <b>Infrastructure</b>     | RKSM<br>OMC     | Support<br>Supplier QM                               | <ul style="list-style-type: none"> <li>- Performance-based risk assessments</li> <li>- Corrective actions</li> <li>- QMS performance reviews</li> <li>- Internal QMS audit reports</li> </ul>                     |
| <b>Process Management</b> | OPP             | Information and Analysis                             | <ul style="list-style-type: none"> <li>- Process performance registers</li> </ul>                                                                                                                                 |
| <b>Enablement</b>         | IA<br>OT<br>PAM | Information and Analysis                             | <ul style="list-style-type: none"> <li>- Process measurement strategy</li> <li>- Process data</li> <li>- Quantitative training requirements</li> <li>- Statistical technique and data analysis methods</li> </ul> |
| <b>Reflection</b>         | FDM             | Continuous improvement<br>Fact-based decision making | <ul style="list-style-type: none"> <li>- Fact-based corrective actions, innovations, and opportunities</li> </ul>                                                                                                 |

#### 6.2.3.5 Level 5: Improving

**Definition:** A Level 5 organisation is entirely process-centric and focused on continuous improvement. The focal point of decision-making shifts from a reaction to risks and non-conformances to organisational innovation, exploration, and novelty. Identifying system issues and taking corrective action to any related risks, opportunities, or nonconformities gravitates towards an autonomous attribute of the system. The organisation, specifically the people, continuously strive towards improvement and innovation, making quality an inherent and motivated aspect of manufacturing.

**The small manufacturer's context:** Continuous improvement is the pursued state of TQM, ISO 9001, and CMM. An organisation seeking Level 5 maturity will innovate by utilising fully defined, standardised, measured, and integrated processes, a competent workforce that is fully enabled to contribute to the organisation's improvement, and practices common to global excellence. Although continuous improvement and organisational innovations are defined as holistic properties that are implemented throughout maturation, Level 5 views the organisation as the epitome of optimisation. This means that management becomes less involved with addressing system issues and can be more involved with organisational innovation. The organisation can now more confidently look outward for improvement opportunities by reacting to new market needs and novel technologies.

**Table 6-4: MPA Maturity Level 5 Mapping**

| MCC            | MPAs | TQM Characteristic                                     | SQM Artefacts                                                                                                                                             |
|----------------|------|--------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
| Objectives     | OI   | Top management commitment                              | <ul style="list-style-type: none"> <li>- Advanced innovation strategies</li> <li>- Continuous improvement</li> </ul>                                      |
| Infrastructure | AM   | Process-centric                                        | <ul style="list-style-type: none"> <li>- Quantitative condition monitoring registers</li> <li>- Preventative/predictive maintenance strategies</li> </ul> |
| Reflection     | CAR  | Information and Analysis<br>Fact based decision making | <ul style="list-style-type: none"> <li>- Causal analyses of non-conformances</li> <li>- Organisational innovation opportunities</li> </ul>                |

#### 6.2.4 Manufacturing Practices Framework (Cross-Validation Matrix)

The Manufacturing Practices Framework (MPF) is the final layer of the MCMM, which provides a method of implementation and measurement of progress. The framework is presented in Annexure B, *following an extensive and in-depth analysis as part of this research*, and illustrates how each MPA is operationalised by implementing ordered CMM practices, TQM best practices, and ISO 9001 practices. The MPF is presented in a tabulated format to improve comprehension and ensure that it is an actionable framework that can be used as a supportive instrument throughout the implementation of the MCMM. The logical order of the table assists with interpretation by persons with minimal systems knowledge, and the amalgamation of QM into a tabulated framework presents QM in a measurable format.

##### 6.2.4.1 Compiling the Manufacturing Practices Framework

To compile the MPF, the purpose, the descriptions, practices, and specific goals of each PA detailed in the CMM were analysed and interpreted. On the other hand, the clauses, best practices, and requirements of the ISO 9001 standard were also analysed and interpreted. Starting with the **Derived MPAs**, the practices and goals stipulated for the institutionalisation of each sourced PA were analysed and cross-referenced to a clause in the ISO 9001 standard as well as a desired TQM characteristic. Each of the CMM goals, practices, and descriptions were also interpreted for their direct or derived applicability to a small manufacturing application; this interpretation was driven by experience, insight, and by the specialised requirements identified through survey, literature, and an analysis of the application of the ISO 9001 standard and the TQM philosophy within the manufacturing ontology.

To design, compile, and integrate the **Novel MPAs** into the practices framework certain aspects and requirements that were not sufficiently addressed through the CMM or elements deemed necessary for a small manufacturing application were identified and defined as discussed in Section 6.2.2. The practices were sourced from ISO 9001 and best practices known or commonly related to the TQM philosophy (reference to Table 4-3) as well as more recent archetypes of the CMM, such as CMMI 2.0. Significant thought was given to what the CMM does not address or insufficiently emphasises and how these gaps or opportunities might be filled. In knowing this, practices were identified and interpreted (as was done with the definition of the Derived MPAs) and used to substantiate each Novel MPA respectively. Note, that the practices used were not novel, and all were sourced as validated, known, or industry-accepted practices, or characteristics. Integrating and strategically placing the Novel MPAs also required significant consideration of the practicality of the model framework by inferring how the model will be interpreted and approached when given to a small manufacturer and what the purpose of the MPAs are.

Given the steps taken to design and compile the MPF, it is thus, by design, validated through being a comprehensive framework based on the validated CMM framework that encompasses the requirements of the ISO 9001 standard as an absolute reference to an acceptable QMS and also embodies the TQM philosophy. All of the practices, goals, and descriptions were obtained from validated sources and the cross-referencing provides an in-depth view of how the MPF, and consequently the MCMM, fulfils the objective of systematically institutionalising the principles of the TQM philosophy as well as demonstrating comprehensive compliance to an absolute reference, the ISO 9001 standard.

#### **6.2.4.2 Method of Interpretation**

The MPF is structured to be read from left to right and implemented from the top downward. Considering Figure 6-9, which provides an example of how the MPF is structured, each MCC is listed in the very left-hand column and related to an MPA in the column adjacent to the right. The MPAs are related to a set of Operationalisation Practices, which are, in the same row, provided with various Practice Identifiers (Maturity Level, TQM Alignment, ISO 9001 Alignment, and Practice Origin). This means that the operationalisation of each MCC is defined from left to right, and the Maturity of the MPAs is measured from top to bottom.

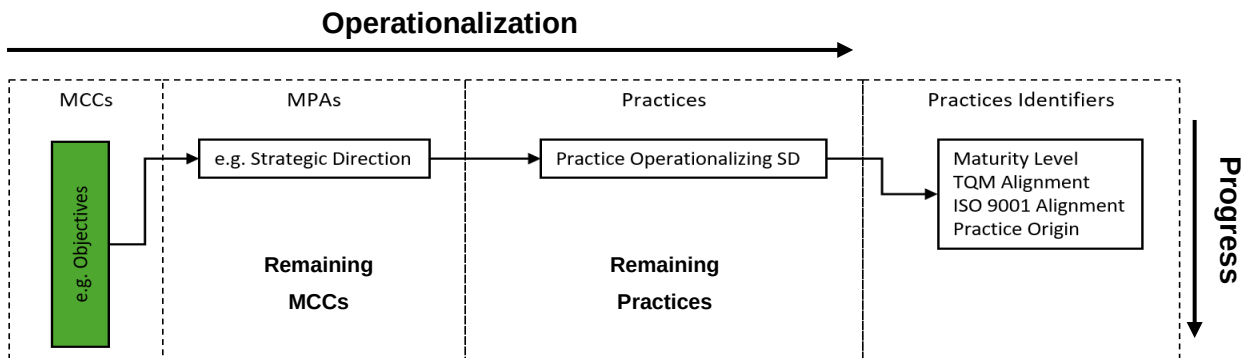


Figure 6-9: Interpreting the MPF (Annexure B)

### ➤ Measuring Quality

Referring back to a fundamental benefit often used to motivate maturity model, being that MMs offer a structured path that can be used to evaluate a current state in relation to a defined desired state as well as to a need for a measured growth path mentioned in Chapter 2 and reaffirmed in the industry. The MPF presents a unique attribute in that the organisation's current state can be evaluated and its quality capability can be weighed against a predefined baseline. To elaborate, each MCC is defined by various MPAs that cooperate with various other MCCs and MPAs across organisational processes with the fundamental aim to contribute to the QM capability of the organisation as a unitary whole. Meaning that the individual MPAs satisfy, in part, the requirements, facets, characteristics, and elements of the QM paradigm and only collectively form a unitary QM capability.

*Thus, presenting an implementation framework that considers the logical maturation of an organisation and aims at progressively developing QM capability means that the very “Progress” resulting in following the defined path can be defined as a measure of Organisational Quality.*

## 6.3 Discussion

**Note to the Reader:** This discussion is positioned after the development of the model as it provides retrospective insight on how the MCMM compares to the original CMM and assists with rationalising the adaptations that were made. Also described within this discussion are the original contributions made by the researcher through the addition of derived capability categories, novel process areas, and additions to the key relationship process diagrams.

### **6.3.1 Revisiting the Adaptation of the CMM**

The CMM provided not only the foundational structure of the MCMM, but the principles, practices, and goals encapsulated within the model have been imperative in ensuring the model's capacity to guide small manufacturers through a QM growth path towards a state of continuous improvement. The following section discusses the MCMM, its structure, the novel elements, and the derived elements. It provides insight into how the components of the CMM were used to develop the structure of the MCMM, as well as how TQM and ISO 9001 have influenced the adaptation of original elements or the synthesis of novel elements.

#### **6.3.1.1 Reflection on the Manufacturing Maturity Levels**

The structure of the MCMM is consistent with the model structure of the CMM outlined in Figure 5-2. It consists of 5 maturity levels (Initial, Repeatable, Defined, Managed, and Improving), and each presents a definition of the stages of growth that the MCMM proliferates. Importantly, the maturity level definitions were subjected to minimal alteration. Instead of redefining each maturity level to incorporate TQM and ISO 9001, each level was interpreted through a QM lens, meaning each level was provided with a TMQ alignment statement, an ISO 9001 compliance statement, and a small manufacturer's implementation guide. Therefore, the spirit of pursuing QM through the CMM was retained whilst the required TQM and ISO 9001 contributions for each level could be informed.

#### **6.3.1.2 Reflection on the Manufacturing Process Areas**

Also consistent with the structure of the CMM, each maturity level is substantiated through various process areas that each address an element or facet of the process improvement strategy. Within the process areas of the MCMM lies the most original contributions and novel work. Firstly, the CMM groups the PAs into functionally related areas referred to as Categories. The MCMM adopts a similar approach. However, the Project Management and Support categories have been respectively subdivided into Objectives, Institutionalisation, Reflection and Infrastructure, and Enablement. These derived categories aim to clear the purpose for each area of the MCMM, and given the systems knowledge gap, it assists the implementor in understanding which organisational areas contribute to quality. Secondly, although most of the MPAs are consistent with their original purpose and definition in the CMM, all of them have been adapted or rephrased to encapsulate the manufacturing ontology better. Therefore, process areas that are not original contributions are referred to as derived MPAs. The novel MPAs on the other hand, have been defined mostly as informed through TQM, ISO 9001, and practical considerations; however, the CMM, related principles, and systems thinking have played a vital role in positioning and integrating the novel MPAs to ensure meaningful contributions to the overall development.

➤ **Novel Manufacturing Process Areas:**

- Strategic Direction
- Systems Implementation
- Organisational Commitment
- Resource Management
- Knowledge Management
- Information and Analysis
- Asset Management
- Manufacturing Processes
- Sustained Customer Focus
- Organisational Decision Making

**Important:** *The novel MPAs are informed, derived from, and inspired by various TQM and ISO 9001 principles, practices, methods, etc. Therefore, the content and structure of these MPAs are not entirely novel contributions. However, their incorporation, positioning, and integration into the CMM can be defined as novel contributions from this research project. Moreover, the value of using these MPAs to create a quantifiable growth path towards quality is evident.*

### **6.3.1.3 Reflection on the Manufacturing Practices Framework**

The MPF is the final and most crucial aspect of the model's value to a small manufacturer. In essence, it provides an interface between the MCMM and an implementor as it presents a multifaceted tool that can be used to measure, evaluate, guide, and validate the MCMM. To elaborate, the structured format of tabulating the practices of the MCMM allows an implementor to measure organisational quality, evaluate the organisation's progress in relation to the critical QM areas (e.g. by the maturity of individual MPAs and MCCs), and present organisational capability as a measure of maturity.

Furthermore, the task-based phrasing of the management framework provides practical guidance on how to implement, develop, and deploy each MPA. Implementors who know where they are in relation to maturity can determine and plan what needs to be done to develop recursive or static MPAs further, thus strategically increasing organisational maturity. The MPF, therefore, fulfils the DSR requirement of providing a practical solution that can be interpreted by an academic audience for evaluation and understood by a practical audience for guidance.

Finally, the practices detailed in the MPF stem from either the CMM, TQM, or ISO 9001. However, if a meaningful link can be made, each practice is related to either or both ISO 9001 and TQM. The result provides a cross-validation matrix that presents, to the most fundamental level of the model, how the MCMM fulfils ISO 9001 compliance and aligns an organisation with the TQM philosophy.

### 6.3.2 Validation of the Research Objectives

The following discussion revisits the research objectives and provides consolidation on how the MCMM or MPF satisfies the requirements related to the research objectives. Note that the research objectives are substantiated by the work presented in Chapters 4 and 5; for instance, demonstrating compliance with the ISO 9001 standard as an absolute reference is substantiated by the requirements analysis presented in Section 4.3.

- ***Embed quality management principles and best quality practices into the operations of a small manufacturing organisation.***

Firstly, from the discussions in Chapter 4, it is known that the result of institutionalising the principles of TQM and operationalising best quality practices is the formulation of organisational or QMS characteristics. These characteristics contribute to organisational quality through improved performance, product quality, and customer satisfaction. The commonly used interpretations of these characteristics within small manufacturing applications are presented in Table 4-3. This research objective is satisfied through consideration of the cross-validation matrix, which relates each practice of the MCMM to a TQM best practice or characteristic as well as by the maturity level descriptions in which the TQM characteristics are related at a high-level to the MPAs. Furthermore, references are made throughout the text to the overlapping goals, practices, and objectives between TQM and CMM, which are also discussed in Section 6.1.

The research project thus provides verifying evidence through literature that the CMM and TQM overlap and that using the CMM as the basis for the MCMM will fundamentally align the approach with TQM. Finally, validation of the embedment of QM principles through implementing the MCMM is demonstrated by reflecting on the cross-validation matrix, the maturity level descriptions, and the TQM-inspired Novel MPAs.

- ***Demonstrate compliance to the ISO 9001:2015 standard for quality management systems***

In part, this objective presented various challenges in defining what ISO 9001 compliance means in the context of small manufacturers and what it consists of. The requirements analysis discussed in Section 4.3 provided vital insight into how the ISO 9001 standard is interpreted, implemented, and ultimately audited. Verification is again presented through literature, and a cross-comparison

between the ISO 9001 standard and CMM is discussed in Section 5.2. This provided evidence that the seminal version of the CMM and ISO 9000 were fundamentally aligned with researchers suggesting that the CMM offers an encompassing ISO 9001 strategy that not only satisfies that standard's requirements at lower maturity levels but also offers more in terms of method, advanced management techniques, and quantitative capabilities.

However, the ISO 9001 requirements played an essential role in validating the MCMM against a globally accepted framework of quality management systems. This is again demonstrated by the cross-validation matrix presented as part of the MPF, which relates each practice to the fulfilment or partial fulfilment of an ISO 9001 requirement. Further compliance is demonstrated by considering the QMS Artefacts defined for each maturity level. The QMS artefacts encompass the system's documentation requirements for ISO 9001.

- ***Present a structured growth path towards quality management.***

This objective speaks to the small manufacturing application and distinguishes between a generalised management model and a management model suited to a small manufacturing organisation. With reference to the closing remarks of Chapter 2, the solution should cater to the challenges faced by small manufacturers (e.g. systems knowledge gap, resource and personnel limitations), be approachable in the sense that it does not present an administrative burden, and not be susceptible to common pitfalls of QM and ISO 9001.

In this regard, MMs are a method of presenting any organisational attribute or capability as a growth path. The CMM builds on this by providing various layers of structure to this growth path, which both improves the approach's comprehensibility and provides targeted organisational evaluation.

### **6.3.3 Validation Limitations**

A noteworthy limitation related to maturity model research, which this research project is not exempt from, is the validation-related complexity. Wendler [23] attests to this by highlighting the fact that maturity model research projects are mostly conceptual with minimal attempts at empirical validation. However, it is important to remember the time and commitment required to demonstrate the model's performance in an organisational setting. To achieve this, several organisations have to be wholly committed to its implementation, and in the spirit of ADR, this will likely lead to partial model validation and model improvements.

*The researcher trusts that validation against a validated standard (ISO 9001), TQM and CMM best practices, and industry feedback from a real-world survey is considered sufficient research validation. Strong validation would include a longitudinal study while weak validation would not have included validated theoretical and real-world references. Therefore, this research is considered to fall between weak and strong simply for lack of a longitudinal study (due to time and practicality limitations).*

However, the preceding discussion reflecting on the research objectives has demonstrated validation of the model's intended function as a management model to incorporate QM into the management methodologies of small manufacturers. As a potential future development of this research, by using the desired TQM organisational impacts (organisational performance, financial performance, and customer satisfaction) the eventual efficacy of the model can be validated over time through a longitudinal investigation and quantification of these impacts.

## 7 CONCLUSION

The research project presented in this dissertation addresses an identified quality management gap in the management methodology of small manufacturers by considering a systematic quality management approach. This was achieved by utilising the CMM as an accepted structured paradigm for process improvement and adapting the model to suit a QM implementation within a small manufacturing organisation. The adaption required an in-depth understanding of how the principles of TQM are interpreted, developed, and applied to manufacturing processes, as well as of the practical considerations, constraints, and opportunities related to small manufacturing implementations. On the other hand, the CMM had to be understood in the context of an interdisciplinary application to facilitate the transfer of the structure, tools, methods, and techniques that constitute the CMM to the manufacturing domain. Thus, reflecting on the research design, as rooted in the DSR paradigm, the Rigour cycle provided guidance into a critical review of the body of knowledge that underpins the research environment, which enabled the establishment of a theoretical foundation consisting of the concepts, theories, and frameworks that would in turn in situate as the information applied in the adaption of the CMM. Guidance from the Relevance cycle, as presented in Figure 3-3 and Figure 3-4, also motivated the need to substantiate the South African small manufacturing context by implementing an industry survey. The result of this was the contextualisation of QM among South African manufacturing SMMEs, which contributed to the practical requirements and considerations in adapting the CMM and also contributed to the body of knowledge in the form of QM characteristics that are typical to manufacturing SMME both with, and without ISO 9001 certification. The research process yielded various insights and findings, which are presented in the following section, where a discussion is conducted on the findings and contributions formulated through the conceptualisation of a Manufacturing Capability Maturity Model.

### 7.1 Presenting Research Solutions

The following section revisits the research challenges defined in Chapter 3 and discusses how each challenge was addressed. Note that the research solutions are presented on the RVM presented in Table 7-1, which is the completed version of the RVM presented in Table 3-1. To briefly revisit the purpose and description of this RVM, the arrows in cells link research challenges to literature focus areas (referring to the up arrows in the literature topics section), and also link literature focus areas to research solutions (referring to the down arrows in the literature topics section). In Table 7-1, the down arrows thus present the areas of knowledge that have contributed to the development or identification of the research solutions, providing a demonstration of rigor. The presented research solutions are also linked to the research tasks or steps taken to identify

and formulate the research solutions. Subsequently, the up-arrows in the research tasks section link each research solution to a task or action performed to formulate the research solutions, providing a demonstration of design, analysis, or synthesis. Consequently, the research project is holistically presented and validated; meaning that each research challenge is traceable from the point of its formulation from a single or multiple valid sources to the research conducted to define the current state of literature related to the research challenge and ultimately to the formulation of a respective research solution as formulated by performing valid or appropriate research or design methods.

The research validation matrix thus shows:

- How each research challenge aligns with the research solutions on a one-to-one basis;
- Research challenges and solutions rely on literature for analysis and synthesis;
- How each research solution is developed into specific solutions through tasks;
- The adaptation of CMM to become an integrated MCMM solution.

The research solutions, in order of the respective research challenges, are:

- 1) A Valid TQM interpretation for a small manufacturing application;
- 2) Defined need and desired QM characteristics for South African small manufacturers;
- 3) A CMM-DEV adaptation can be conceptualised to suit a general real-world application;
- 4) The alignment between CMM, QM, and ISO 9001 provides basis for compliance;
- 5) Follow a pragmatic approach to define manufacturing maturity levels and MPAs;
- 6) Follow a pragmatic approach to compile of an ISO 9001 aligned manufacturing practices framework.

To facilitate the discussion on the research solutions and provide reflection on the research within the DSR paradigm, the diagram presented below in Figure 7-1 reflects on the flow of the research project, ultimately leading up to the design and validation of the MCMM. Note, that the reader is briefly referred back to Section 3.2 (Research Strategy) as the diagram below builds on the research strategy presented in Figure 3-1 and provides clarification on how the research was conducted in alignment with the strategy outlined in Figure 3-1 and how the sections of this document have contributed to the research outcome.

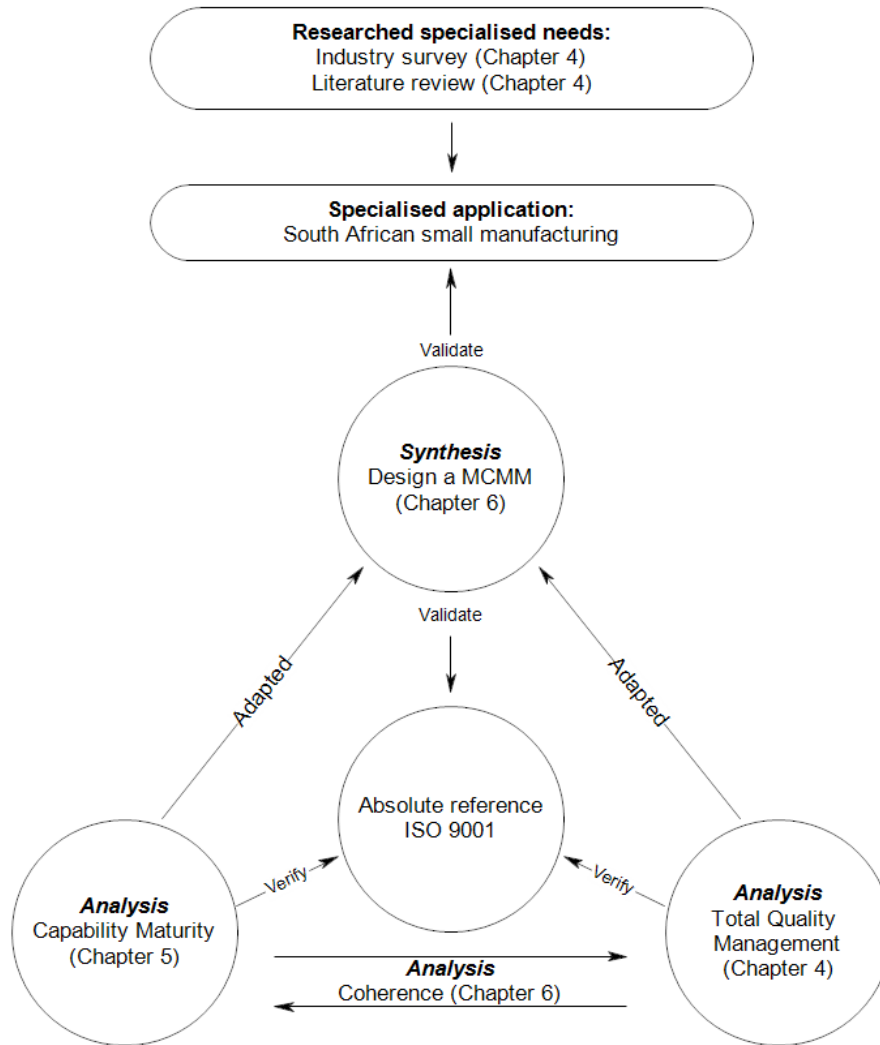


**Figure 7-1: Research outcome**

TQM is positioned as the representative instantiation providing a theoretical foundation for the QM philosophy that is applied throughout the research project. In this regard, DSR facilitated a rigorous analysis of literature and content pertaining to interpretations of the principles of TQM and its application relevant to small manufacturing. This assisted with formulating an understand on how the principles are integrated into the core business and operational processes of small manufacturers and how this integration facilitates the development of QM characteristics. The result of which is the TQM framework of desired characteristics and related best QM practices relevant to the institutionalisation of the TQM principles in a small manufacturing application (referring to Table 4-3), therefore contributing the following solution to the first research challenge:

- 1) A Validated TQM interpretation for a small manufacturing application.

A challenge that became evident after the initial conceptualisation of the research problem was the limited availability of literature that contextualises and described QM in a South African small manufacturing application. In response, a real-world industry survey based on TQM was conducted. The results further elucidated the South African small manufacturing context and assisted in further defining the related QM need. Herein lies an original contribution of a cross-sectional analysis of the current state of QM implementation among South African small manufacturers and a mapping of the applied QM methods and principles that these manufacturers typically fail or neglect to implement. It was found that South African manufacturing SMMs were sufficiently customer-focused, especially in the sense that quality assurance capabilities are well-developed. However, the observed gap was our interpretation of results and inference suggested the lack of implementation of applied management techniques such as risk management, quantitative management, and causal analysis and resolution. Furthermore, the survey provided that only 30% of participating companies were, at the time of the survey or at some point before the survey, ISO 9001 certified.

## 2) Defined need and desired QM characteristics for South African small manufacturers.

We then turned the focus to the coherence between CMM and QM as depicted in Figure 7-1. In essence, the research challenge concerned with the general real-world applicability of the CMM to the manufacturing domain sought verification of the CMM as a solution to the QM gap in the small manufacturer's management methodology. The challenge was thus to demonstrate the transferability of the CMM to the manufacturing ontology as well as provide sufficient evidence for its useability as a management tool to small manufacturers. This was achieved through literature in which it was found that the CMM can be sufficiently adapted to various real-world applications that are not bound by the IT domain. This is especially evident when considering the CMMI for Development archetype of the model, which already provides a versatile instantiation of the general CMM suited for interdisciplinary interpretation.

The CMM was firstly verified through literature as being a process improvement model that encapsulates most of the principles of the ISO 9001 standard, with the exception being an insufficient customer focus, a lack of establishing a quality authority, and a lack of certain specific documents that are mandatory within the ISO 9001 standard. Similarly, TQM endeavours to achieve ISO 9001 compliance are relatively well known with sufficient evidence suggesting that an ISO 9001 certification is benefited from a TQM approach. As a result, it is possible to use ISO 9001 as an absolute reference to validate the MCMM, also providing the following solutions:

- 3) A CMM-DEV adaptation can be conceptualised to suit a general real-world application.
- 4) The alignment between CMM, QM, and ISO 9001 provides basis for compliance.

The final ISO 9001 compliance of the synthesised MCMM is demonstrated through the cross-validation property of the MPF. Therefore, this research project revisited seminal comparisons between CMM and ISO 9000 and has provided clear support for the complementary implementation of CMM and ISO 9001. The research has thus provided an original contribution in the form of a comprehensive, in-depth cross-validation matrix as presented in Annexure B and as described in sections of Chapter 6. As discussed in Section 6.2.4.1 this matrix was compiled by an in-depth analysis of the purpose, goals, and practices of each PA detailed in CMM and adaptation thereof relevant to the manufacturing ontology and small manufacturing application.

Subsequent steps taken to compile the MPF entailed an in-depth analysis of the clauses, requirements, and principles of the ISO 9001 standard which assisted in cross-referencing the requirements for ISO 9001 compliance to the derived or adapted CMM PAs (referred to as the MPAs) used in the design of the MCMM. This was facilitated through a pragmatic interpretation of both CMM and ISO 9001 as well as a continuous consideration of relevance to the small manufacturing application, as facilitated by the DSR relevance cycle.

The MCMM is thus firstly, validated through:

- Verified through comprehensive compliance to the ISO 9001 standard (as a valid and absolute reference) as the reference to the development of a suitable QMS used in this research;
- Verified as a suitable CMM adaptation through adherence to the requirements for a model to be a CMM as defined in Section 5.3;
- Verified as a SQM solution to small manufacturers through a link to industry considerations and by the fulfilment of the research objectives defined in Section 3.1 and discussed in Section 6.3.2.

In this regard, the research solutions are:

- 5) Follow a pragmatic approach to define manufacturing maturity levels and MPAs.
- 6) Follow a pragmatic approach to compile of an ISO 9001 aligned manufacturing practices framework.

**Table 7-1: RVM – Conclusion**

|                            |                                                                       |                                                                                   |                                                                                   |                                                                                                 |                                                                           |                                                                                                  |                                                                                                    |
|----------------------------|-----------------------------------------------------------------------|-----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|
| <b>Sources</b>             | Observation from Industry                                             | ↓                                                                                 |                                                                                   | ↓                                                                                               |                                                                           |                                                                                                  | ↓                                                                                                  |
|                            | Informal Interview with Expert                                        | ↓                                                                                 | ↓                                                                                 |                                                                                                 |                                                                           |                                                                                                  |                                                                                                    |
|                            | Preliminary Content Analysis                                          |                                                                                   | ↓                                                                                 | ↓                                                                                               | ↓                                                                         | ↓                                                                                                |                                                                                                    |
| <b>Research Challenges</b> |                                                                       | Detailed definition of need not clear for QM in small South African manufacturers | Limited QM contextualisation among South African small manufacturers              | Is CMM applicable to general real-world applications other than Information Technology systems? | How can CMM and QM be integrated to address ISO9001 standard compliance?  | Can a progressive growth path with feedback be realistically defined to meet ISO9001 compliance? | Can a newly defined CMM framework meet ISO9001 requirements for small South African Manufacturers? |
| <b>Literature Topics</b>   | Quality Management and Systems Theory and Application                 | ↑↓                                                                                | ↑                                                                                 |                                                                                                 |                                                                           |                                                                                                  | ↓                                                                                                  |
|                            | Systems Theory and Engineering Theory                                 |                                                                                   |                                                                                   | ↑↓                                                                                              |                                                                           | ↑↓                                                                                               | ↓                                                                                                  |
|                            | ISO 9001 Standard                                                     | ↑↓                                                                                |                                                                                   |                                                                                                 | ↑                                                                         | ↑                                                                                                | ↓↑                                                                                                 |
|                            | Capability Maturity Theory and Application                            |                                                                                   |                                                                                   | ↑↓                                                                                              | ↑↓                                                                        | ↓                                                                                                | ↓↑                                                                                                 |
| <b>Research Solutions</b>  |                                                                       | A valid TQM interpretation for a small manufacturing application                  | Defined need and desired QM characteristics for South African small manufacturers | A CMM-DEV adaptation can be conceptualised to suit a general real-world application             | The alignment between CMM, QM, and ISO 9001 provides basis for compliance | Follow a pragmatic approach to define manufacturing maturity levels and MPAs                     | Follow a pragmatic approach to compile an ISO 9001 aligned manufacturing practices framework       |
| <b>Research Tasks</b>      | Analyse the TQM philosophy (Analysis)<br><b>Chapter 4.1</b>           | ↑                                                                                 |                                                                                   |                                                                                                 |                                                                           |                                                                                                  |                                                                                                    |
|                            | Conduct a real-world industry survey (Analysis)<br><b>Chapter 4.2</b> | ↑                                                                                 | ↑                                                                                 |                                                                                                 |                                                                           |                                                                                                  |                                                                                                    |
|                            | Analyse the CMM (Analysis)<br><b>Chapter 5.1</b>                      |                                                                                   |                                                                                   | ↑                                                                                               |                                                                           | ↑                                                                                                |                                                                                                    |
|                            | Validate CMM through ISO 9001 compliance<br><b>Chapter 5.2</b>        |                                                                                   |                                                                                   |                                                                                                 | ↑                                                                         |                                                                                                  | ↑                                                                                                  |
|                            | Design and synthesise the MCMM (Synthesis)<br><b>Chapter 6.2</b>      |                                                                                   |                                                                                   |                                                                                                 |                                                                           | ↑                                                                                                | ↑                                                                                                  |
|                            | Design and compile the MPF (Synthesis)<br><b>Chapter 6.2</b>          |                                                                                   |                                                                                   |                                                                                                 |                                                                           |                                                                                                  | ↑                                                                                                  |

## **7.2 Concluding Remarks**

In conclusion, the management model synthesised in this dissertation provides a highly informed, pragmatic, and comprehensible approach to quality management within a small manufacturing environment. The structured and progressing nature of the model plots the development of QM capabilities, processes, and characteristics to a growth path, which, in turn, infers a property of organisational evaluation and measurement within quality criteria. The model is thus geared towards being an encompassing QM tool. The integration of individual process areas that collaborate to substantiate the structure of the model also facilitates versatility in that practitioners, implementors, and managers can utilise the entire model to evaluate and assist a poor-performing organisation to achieve a higher maturity or only certain aspects of the model can be used to contribute to an already well-performing organisation. The research has thus contributed to a more comprehensive understanding of the adaption of the CMM to the manufacturing domain and utilising it to achieve compliance with a globally recognised standard. The research has also demonstrated how the definition and integration of novel elements can assist with transferring the CMM across various domains.

In terms of personal reflection, through being motivated to consider the capability maturity perspective as a potential solution to an observation and consequently being drawn to explore the challenges, intricacies, and opportunities related to the capability maturity model, this research endeavour has been a significant opportunity for personal development which has allowed the researchers to broaden their understanding of organisational research. Considering this and hoping to inspire future capability maturity endeavours, the researchers express an optimistic view of the significant potential of the CMM as a useful enabling tool.

## **7.3 Limitations and Future Research**

The management model was designed to accommodate the specific constraints and requirements of manufacturing SMMEs by incorporating the best TQM characteristics defined from the literature, the requirements for ISO 9001 certifiability, and the methods of a CM framework. However, the MPF requires one or more situational applications to demonstrate operational validity and undergo refinement. Keeping with the principle of reciprocal shaping of the ADR strategy, the model offers a meta-description of implementing and approaching QM from a CM perspective as validated by meeting ISO 9001 minimum requirements. Therefore, the MPF practices must still be proven rigid and will likely require refinement through repetitive industry application. Also, the priorities of quality enablers within a South African context still need to be verified in use cases. In doing so, researchers can apply the principle of Guided Emergence to refine the framework of practices within the model to represent beneficial implementation.

As for other prospective interdisciplinary applications, the versatility of the CMM demonstrated in this research can be harnessed to extend the interdisciplinary adaption beyond the quality domain and use it to instil an engineered approach to other management-related challenges such as energy and sustainability. Given the current energy-related challenges faced in South Africa and globally, there is an opportunity to apply a capability maturity perspective to energy management. This recommendation follows an observed industry norm of pursuing an integrated systems certification encompassing three ISO standards, namely, ISO 9001 (Quality Management Systems), ISO 50001 (Energy Management Systems), and ISO 14001 (Environmental Management Systems). The similarity between these standards offers an opportunity to broaden the scope of the CMM adaption to establish such an integrated management system.

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## ANNEXURE A – SURVEY QUESTIONNAIRE

### Section 1 – Multiple Choice Questions:

Participants were asked to choose the option/options that best suited their organisation.

1. *Within which industry do you operate?*

- ☐ Metal Industry
- ☐ Mechanical Industry
- ☐ Electronic Industry
- ☐ Automotive Industry
- ☐ Chemical Industry
- ☐ Food Industry
- ☐ IT Industry
- ☐ Textile Industry
- ☐ Medical Industry
- ☐ Other

2. *Are you currently ISO 9001 certified?*

- ☐ Yes
- ☐ No
- ☐ Historic Certification

2.1. *If yes, how long?*

- ☐ <1 Year
- ☐ >1 Year and <2 Years
- ☐ >2 Years

3. *How often are inefficiencies or problems identified on your manufacturing floor?*

- ☐ Not Often
- ☐ Often
- ☐ Very Often

1. *How often does your company apply market research to modify production requirements?*

- ☐ Never
- ☐ Seldomly
- ☐ Regularly

2. *How would you define the level of production management present within your company?*

- ☐ Production processes are purely reactive and consistently micro-managed.
- ☐ Production processes are continuously reviewed with the focussed-on improvement.
- ☐ Production processes are measured and managed by analytics.
- ☐ Production processes have a planned flow from input to output.
- ☐ Production processes are managed using the company's standard operating procedures and acceptable estimates.

3. *The successful output of your manufacturing activities rely on a critical resource and/or individual input?*

- ☐ Resource
- ☐ Individual
- ☐ Both

4. *How often do you employ the assistance of external quality management entities such as consultants or auditors?*
  - ☐ Never
  - ☐ Only when required by a client or tender
  - ☐ At least once every 2 to 3 years
  - ☐ More than once every 2 to 3 years
  
5. *Does your company have a trained individual directly responsible for Quality management?*
  - ☐ Yes
  - ☐ No
  
6. *How do most of your new customers learn about your company?*
  - ☐ Company advertisement
  - ☐ Company reputation
  - ☐ Referral
  
7. *Does your company have any of the following policies?*
  - ☐ Quality Management Policy
  - ☐ Quality Assurance Policy
  - ☐ Employee Training Policy
  - ☐ Production Engineering Policy
  - ☐ Other
  - ☐ Not Applicable

## Section 2 – Matrix Questions:

Participants were asked to rate the applicability of the following statements to their operations. Option provides ranged from 0 – Strongly Disagree to 5 – Strongly Agree.

| Questions |                                                                                                                |
|-----------|----------------------------------------------------------------------------------------------------------------|
| 1         | Your company has a form of configuration management for changes in customer/regulation requirements.           |
| 2         | Your company has channels in place that enables employees to communicate with top management.                  |
| 3         | Your employees are educated on how they may identify problems within their working environment.                |
| 4         | Sales representatives are motivated to actively investigate and report on the satisfaction of their customers. |
| 5         | Your company has measures in place to determine the overall cost of poor quality.                              |
| 6         | Your company has quality objectives in place based on customer requirements or industry standards.             |
| 7         | Employees are given verbal instructions to the tasks they are expected to complete.                            |
| 8         | Changes in customer requirements are fully documented.                                                         |
| 9         | You have standard procedures in place to address deviations between production costs and invoice costs.        |

|    |                                                                                                                                |
|----|--------------------------------------------------------------------------------------------------------------------------------|
| 10 | Your sales representatives have means of communicating production concerns.                                                    |
| 11 | Your company is up to date with industry knowledge to keep your production up to standard.                                     |
| 12 | Major decisions regarding company development are made based on the outcome of a risk analysis.                                |
| 13 | The foreman/ floor manager has access to the performance trends of the various processes on the manufacturing floor.           |
| 14 | The actual cost of manufacture is often compared to the invoiced cost of the product.                                          |
| 15 | Your company follows a root cause analysis methodology to identify problems causing deviation in the quality of your products. |
| 16 | Your company actively measures the performance or health status of its production activities.                                  |
| 17 | Production planning is based on product baselines and requirements.                                                            |
| 18 | Tasks are given to your work force using written job cards.                                                                    |
| 19 | Employee initiative is recognised and rewarded.                                                                                |
| 20 | Before manufacturing starts, the customer's requirements are fully captured and formally agreed upon.                          |
| 21 | Your sales team follows a standardized procedure to report on customer dissatisfaction.                                        |
| 22 | Repeated activities are documented as Standard Operating Procedures.                                                           |
| 23 | The performance of your production activities are representable by performance trends and/or error rates.                      |
| 24 | Your company consults quantitative trends during the decision-making process.                                                  |
| 25 | Your company has an internal training and development program for its employees.                                               |
| 26 | The points of contact between your production activities can be represented on a flow diagram.                                 |
| 27 | Your company has a process in place to fulfil changes in product requirements.                                                 |
| 28 | The lifecycle of a product as it passes through the stages of manufacturing can be traced bidirectionally.                     |
| 29 | Your employees regularly report problems within their working environment.                                                     |
| 30 | Machine operators can easily report faulty equipment.                                                                          |
| 31 | Your company motivates innovative thinking among its work force.                                                               |
| 32 | Postproduction quality inspections are done according to written protocols.                                                    |
| 33 | Your company has planned internal Quality Inspections.                                                                         |
| 34 | Your employees are aware of the quality your company tries to uphold.                                                          |

|    |                                                                                                              |
|----|--------------------------------------------------------------------------------------------------------------|
| 35 | Your company is proactive in reducing its overall material waste and energy usage.                           |
| 36 | Your company has a form of succession training in place.                                                     |
| 37 | Risk mitigation strategies are considered before decisions are made.                                         |
| 38 | Your manufacturing floor can be broken up into distinctive activities and represented on a flow diagram.     |
| 39 | Your company makes use of statistical analyses to evaluate the performance of your production.               |
| 40 | Instructions are given to your workforce on a daily basis.                                                   |
| 41 | Productivity depends on the consistent presence of management on your manufacturing floor.                   |
| 42 | New designs are signed off by a certified entity (Either in-house or external).                              |
| 43 | You are able to track and coordinate critical dependencies on you manufacturing floor.                       |
| 44 | Production is often bottle-necked or delayed due to slow moving processes.                                   |
| 45 | Your company is registered at a relevant SETA (Sector Education & Training Authority).                       |
| 46 | Company decisions are made based on top management's discretion.                                             |
| 47 | Potential suppliers are scrutinised with a written selection criteria.                                       |
| 48 | Top management is committed to allocating the required resources to internal improvement.                    |
| 49 | Finished products are validated to ensure that they meet functional requirements.                            |
| 50 | Due to a lack of time, problems are only addressed as they occur.                                            |
| 51 | Manufactured items are checked to see if it meets customer requirements.                                     |
| 52 | Your company has little insight on the internal workings of its suppliers.                                   |
| 53 | As a manager you feel that you receive all the data you need to make informed decisions within your company. |
| 54 | Estimates such as time and material costs that are used to quote customers is based on industry experience.  |
| 55 | Customer requirements form the foundation used to define the required functionality of your products.        |
| 56 | Your company measures performance by profit margin and timeliness.                                           |
| 57 | You have defined testing procedures for the products that leave you manufacturing floor.                     |
| 58 | Your company rarely outsources quality inspection activities.                                                |

## ANNEXURE B – MANUFACTURING PRACTICES FRAMEWORK (CROSS VALIDATION MATRIX)

| MCC        | MPA                       | ID     | Maturity | Task Definition                                                                                                                                                                                      | TQM                    | ISO 9001    | SOURCE   |
|------------|---------------------------|--------|----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|-------------|----------|
| Objectives | SD<br>Strategic Direction | SD 2.1 | 2        | Establish, document, and communicate an organisational level quality policy that states the organisation's overall commitment towards providing and improving quality.                               | F21                    | 5.2.1       | ISO 9001 |
|            |                           | SD 2.2 | 2        | Define, document, and communicate a framework of organisational quality objectives within the context of the organisation that are aligned with the achieving quality capability maturity.           | F21                    | 6.2         | ISO 9001 |
|            |                           | SD 2.3 | 2        | Consider the risks, opportunities, and organisational obstacles related with institutionalising quality and achieving quality objectives.                                                            | F21                    | 6.2         | ISO 9001 |
|            |                           | SD 2.4 | 2        | Conduct an organisational awareness campaign to communicate management's quality intent and to institutionalise awareness of the new quality-oriented direction.                                     | F31                    | 5.2.2 / 7.3 | TQM      |
|            |                           | SD 2.5 | 2        | Conduct and integrate quality related knowledge into organisational information sessions (e.g. workshops and toolbox talks) to institutionalise quality related knowledge and objectives.            | F41                    | 7.2         | CMM      |
|            |                           | SD 2.6 | 2        | Consider organisational feedback and ensure that there is clear understanding of the organisational expectations and that the objectives are realistically achievable.                               | F21                    | 6.2         | CMM      |
|            |                           | SD 2.7 | 2        | Establish a commitment of resources (funding, staff, training, etc) necessary for developing, supporting, performing, improving, and achieving the objectives.                                       | F22                    | 7.1         | CMM      |
|            |                           | SD 2.8 | 2        | Define, document, and communicate performance indicators that can be monitored/evaluated such as goals, targets, or incentives that are aligned with achieving the quality objectives.               | F63                    | 9           | CMM      |
|            |                           | SD 3.1 | 3        | Establish process area specific policies (training, engineering, production, quality assurance, etc.) with clear and relevant objectives for each process area of the manufacturing system.          | F21                    | -           | CMM      |
|            |                           | SD 3.2 | 3        | Define, document, and implement a procedure to update organisational information sessions to ensure awareness of new methods, procedures, or strategic directions.                                   | F32                    | 7.1 / 7.3   | CMM      |
|            |                           | SD 4.1 | 4        | Define, document, and communicate measurable organisational performance indicators such as defect rates, resource usage, process performance that are aligned with achieving the quality objectives. | F33                    | 9.1         | CMMI 2.0 |
|            |                           | SD 4.2 | 4        | Continuously review the performance indicators of manufacturing and ensure satisfaction of quality objectives.                                                                                       | F33                    | 9.3         | CMMI 2.0 |
|            |                           | SD 4.3 | 4        | Identify, document, and find solution to any issues relating to the satisfaction of quality objectives and performance indicators.                                                                   | Continuous Improvement | 10          | CMMI 2.0 |
|            |                           | SD 5.1 | 5        | Continuously update the organisational policies and objectives as processes mature and new objectives can be sought.                                                                                 | Continuous Improvement | 10          | CMMI 2.0 |

| MCC                  | MPA                             | ID     | Maturity | Task Definition                                                                                                                                                                                                                                                           | TQM                    | ISO 9001   | SOURCE   |
|----------------------|---------------------------------|--------|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|------------|----------|
|                      | PP<br>Project Planning          | OI 2.1 | 2        | Establish an organisational work breakdown structure to establish and disseminate the tasks, activities, and responsibility relevant to achieving quality objectives                                                                                                      | F2/F3                  | 6          | CMM      |
|                      |                                 | PP 2.2 | 2        | Define and establish a project lifecycle which can reflect the pursuit to a higher maturity level meaning that the project lifecycle starts with an evaluation of maturity and ends with the achievement of objectives required to progress to a following maturity level | F2/F3                  | 6          | CMM      |
|                      |                                 | PP 2.3 | 2        | Establish a cost estimate for achieving quality objectives                                                                                                                                                                                                                | F2/F3                  | 6          | CMM      |
|                      |                                 | PP 2.4 | 2        | Establish and commit to a budget and timeline for achieving quality objectives                                                                                                                                                                                            | F2/F3                  | 6          | CMM      |
|                      |                                 | PP 2.5 | 2        | Identify and manage the risks or risk factors that threaten the budget or timeline, as well as potential negative impacts on the organisation                                                                                                                             | F2/F3                  | 6          | CMM      |
|                      |                                 | PP 2.5 | 2        | Establish the following project parameters: resources required, skills required, stakeholder involvement, commitment, and review plans                                                                                                                                    | F2/F3                  | 6          | CMM      |
|                      |                                 | PP 3.1 | 3        | Continuously review the project parameters according to the OMC descriptions of organisational monitoring and control                                                                                                                                                     | F2/F3                  | 6          | CMM      |
|                      | OI<br>Organisational Innovation | OI 3.1 | 3        | Establish a structure to collect, identify and review organisationally identified risks, opportunities, and nonconformities.                                                                                                                                              | Continuous Improvement | 9.3 / 10.1 | CMM      |
|                      |                                 | OI 3.2 | 3        | Review organisational capability and identify aspects or areas of quality that require improvement, alteration, implementation.                                                                                                                                           | Continuous Improvement | 9.3 / 10.1 | CMM      |
|                      |                                 | OI 3.3 | 3        | Identify opportunities that offer feasibility and fall within organisational capability                                                                                                                                                                                   | Continuous Improvement | 9.3 / 10.1 | CMM      |
|                      |                                 | OI 3.4 | 3        | Identify and provide the resources necessary to implement organisational innovations.                                                                                                                                                                                     | Continuous Improvement | 9.3 / 10.1 | CMM      |
|                      |                                 | OI 4.1 | 4        | Deploy, implement, and institutionalise projects, practices, and alterations that will improve organisational maturity.                                                                                                                                                   | Continuous Improvement | 9.3 / 10.1 | CMM      |
|                      |                                 | OI 4.2 | 4        | Continuously review organisational capability, strategic direction, and sustainability of quality efforts at defined intervals, after achieving organisational improvement.                                                                                               | Continuous Improvement | 9.3 / 10.1 | CMM      |
| Institutionalization | SI<br>Systems Implementation    | SI 2.1 | 2        | Determine the organisational tasks, workflow, project plans required to achieve organisational objectives.                                                                                                                                                                | -                      | 6.2        | CMM      |
|                      |                                 | SI 2.2 | 2        | Assign staff, resources, and review procedures to system implementation related tasks.                                                                                                                                                                                    | -                      | 6.2        | CMMI 2.0 |
|                      |                                 | SI 2.3 | 2        | Review organisational capabilities and prioritise areas of implementation                                                                                                                                                                                                 | -                      | 6.2        | ISO 9001 |
|                      |                                 | SI 2.4 | 2        | Develop a plan and keep it updated, using the project process, the organization's process assets, and the measurement repository.                                                                                                                                         | -                      | 6.2        | ISO 9001 |
|                      |                                 | SI 2.5 | 2        | Define a risk-based approach to identify and mitigate/manage the risks associated with organisational changes.                                                                                                                                                            | -                      | 6.2        | ISO 9001 |
|                      |                                 | SI 3.1 | 3        | Define and implement system implementation planning and implementation of organisational innovations.                                                                                                                                                                     | -                      | 9.3        | CMM      |
|                      |                                 | SI 3.2 | 3        | Define and implement a review procedure to evaluate organisational capability and system implementation at organisationally defined intervals.                                                                                                                            | -                      | 9.3        | CMMI 2.0 |

| MCC | MPA                                | ID     | Maturity | Task Definition                                                                                                                                                                         | TQM | ISO 9001      | SOURCE   |
|-----|------------------------------------|--------|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|---------------|----------|
|     | OC<br>Organisational<br>Commitment | OC 2.1 | 2        | Identify the organisational individuals that will assist in institutionalising quality (e.g. managers, process owners, foremen, administrators, etc.).                                  | F2  | 5.3           | ISO 9001 |
|     |                                    | OC 2.2 | 2        | Establish the necessary authority to manage/drive the institutionalisation of quality.                                                                                                  | F2  | 5.3           | ISO 9001 |
|     |                                    | OC 2.3 | 2        | Establish a structure to enable, enforce, and incentivise reporting from authorities on performance, risks, opportunities, and issues related to the achievement of quality objectives. | F2  | 5.3           | ISO 9001 |
|     |                                    | OC 2.4 | 2        | Collect, review, and archive quality related reporting.                                                                                                                                 | F2  | 5.3           | ISO 9001 |
|     |                                    | OC 3.1 | 3        | Inform and educate the organisation on their relevant contribution to achieving quality objectives and organisational maturity.                                                         | F2  | 7.3           | ISO 9001 |
|     |                                    | OC 3.2 | 3        | Inform, educate and enable the organisation to apply a process and risk-based approach in institutionalising quality in their work environments.                                        | F2  | 5.3           | TQM      |
|     |                                    | OC 4.1 | 4        | Inform, educate and enable the work force to apply a causal methodology to identify inefficiencies or nonconformities in their relevant process area/work environment.                  | F2  | 7.1.3/7.1.4   | CMMI 2.0 |
|     | RM<br>Resource<br>Management       | RM 1.1 | 1        | Allocate resources for organisational operations.                                                                                                                                       | F22 | 7.1.3         | CMM      |
|     |                                    | RM 2.1 | 2        | Determine and provide the infrastructure and resources necessary for the implementation/institutionalisation of quality management efforts.                                             | F22 | 7.1.1 / 7.1.3 | CMM      |
|     |                                    | RM 2.2 | 2        | Consider current organisational capabilities and determine which process areas require prioritised resource allocations.                                                                | F22 | 7.1.1         | CMM      |
|     |                                    | RM 2.3 | 2        | Define and document a procedure that enables process owners to request resources for the establishment/implementation/improvement/maintenance of processes.                             | F22 | 7.1.1         | CMM      |
|     |                                    | RM 2.4 | 2        | Define and document a review procedure to determine the necessity, risks, and opportunities of resource applications.                                                                   | F22 | 7.1.1         | CMM      |
|     |                                    | RM 3.1 | 3        | Record and monitor resource allocations and determine the efficacy thereof                                                                                                              | F22 | 7.1.5         | CMM      |
|     |                                    | RM 4.1 | 4        | Utilise process performance baselines to monitor and manage resource allocations.                                                                                                       | F22 | 7.1.5         | CMM      |
|     | KM<br>Knowledge<br>Management      | KM 1.1 | 1        | Organisational knowledge is embedded in individual experience and expertise, organisational knowledge is not tangibly defined.                                                          | -   | -             | CMM      |
|     |                                    | KM 2.1 | 2        | Establish a structure for organisational knowledge management (e.g. documentation procedures for managing and institutionalising requirements, estimates, SOP's, work knowledge, etc.)  | -   | 7.1.3/7.1.4   | CMM      |
|     |                                    | KM 3.1 | 3        | Identify information requirements from external sources (regulations, market research, standards, industry norms/practices).                                                            | F43 | 7.1.6         | CMM      |
|     |                                    | KM 3.2 | 3        | Identify information requirements from internal sources (skills, work knowledge, estimations, and experience of individuals in the organisation).                                       | F43 | 7.1.6         | CMM      |
|     |                                    | KM 3.3 | 3        | Develop and keep updated information management processes and structures in line with organisational policies and standards.                                                            | -   | 7.1.6         | CMMI 2.0 |
|     |                                    | KM 3.4 | 3        | Extract, create, and induce knowledge (from information) and keep record of knowledge for organisational application.                                                                   | -   | 7.1.6         | CMMI 2.0 |

| MCC            | MPA                            | ID     | Maturity | Task Definition                                                                                                                                                                                      | TQM | ISO 9001    | SOURCE   |
|----------------|--------------------------------|--------|----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-------------|----------|
| Infrastructure |                                | KM 3.5 | 3        | Record, store, update, apply and institutionalize (train) knowledge in line with organizational policies and standards.                                                                              | -   | 7.1.6       | CMMI 2.0 |
|                |                                | KM 3.6 | 3        | Develop and keep updated management processes and structure for operational, people, and technical knowledge.                                                                                        | -   | 7.1.6       | CMMI 2.0 |
|                |                                | KM 4.1 | 4        | Extract, validate, and disseminate process knowledge from quantitative sources within the organisation (process performance analysis, measurements, etc.).                                           | -   | 7.1.6       | CMMI 2.0 |
|                |                                | KM 4.2 | 4        | Develop and keep updated an organizational information strategy (data, information, knowledge) and approach to evaluate, manage and implement information management.                                | -   | 7.1.6       | CMM      |
|                | AM<br>Asset Management         | AM 1.1 | 1        | Provide the tools, technologies, machinery necessary for organisational operations.                                                                                                                  | -   | 7.1.3/7.1.4 | CMMI 2.0 |
|                |                                | AM 2.1 | 2        | Use process definitions to identify the tangible process assets and resources necessary to enable function and quality (equipment, machinery, tools, technology, materials).                         | -   | 7.1.3/7.1.4 | CMMI 2.0 |
|                |                                | AM 3.1 | 3        | Develop, keep updated, and make the organization's process asset library available for use (in line with policy).                                                                                    | -   | 7.1.3/7.1.4 | CMMI 2.0 |
|                |                                | AM 3.2 | 3        | Develop, and keep updated a process asset monitoring/maintenance strategy.                                                                                                                           | -   | 7.1.3/7.1.4 | CMMI 2.0 |
|                |                                | AM 3.3 | 3        | Establish a procedure and environment for the organisation to report/comment on the condition of process assets and/or potential inefficiencies within their working environment.                    | -   | 7.1.3/7.1.4 | CMMI 2.0 |
|                |                                | AM 3.4 | 3        | Identify alternative solutions to process assets required for process improvements.                                                                                                                  | -   | 7.1.3/7.1.4 | CMMI 2.0 |
|                |                                | AM 4.1 | 4        | Utilise quantitative process and process quality information for condition monitoring and to update maintenance requirements of process assets.                                                      | -   | 7.1.5       | CMMI 2.0 |
|                |                                | AM 4.2 | 4        | Subject improvement of process assets to a risk assessment, feasibility studies, and fact-based decision making.                                                                                     | -   | 7.1.3/7.1.4 | CMMI 2.0 |
|                |                                | AM 5.1 | 5        | Continually update and improve process assets.                                                                                                                                                       | -   | 7.1.3/7.1.4 | CMMI 2.0 |
|                | CM<br>Configuration Management | CM 2.1 | 2        | Involve stakeholders, process owners, and administrators to establish commitment to configuration management                                                                                         | -   | 7.5.3/8.5   | CMM      |
|                |                                | CM 2.2 | 2        | Establish, maintain, and implement a configuration management strategy which includes, documentation procedures, a storage media for CM records, and authority/responsibility                        | -   | 7.5.3/8.5   | CMM      |
|                |                                | CM 2.3 | 2        | Track, manage and integrate change requests, design updates, or any alterations to processes, procedures, or products                                                                                | -   | 7.5.3/8.5   | CMM      |
|                |                                | CM 2.4 | 2        | Control and manage the configurations of organisational items as the result of alteration or change request                                                                                          | -   | 7.5.3/8.5   | CMM      |
|                |                                | CM 3.1 | 3        | Using process definitions establish and maintain process configuration descriptions (this includes all descriptions and documents related to describing the process as it is, as well as how it was) | -   | 7.5.3/8.5   | CMM      |
|                |                                | CM 3.2 | 3        | Subject the configuration management system to periodic internal reviews to establish and maintain integrity of configured items                                                                     | -   | 7.5.3/9.2   | CMM      |
|                |                                | CM 4.1 | 4        | Establish quantitative baselines for configured items (e.g. the measured performance of a process as it is)                                                                                          | -   | 7.5.3/9.1   | CMM      |

| MCC         | MPA                            | ID       | Maturity | Task Definition                                                                                                                                                                                          | TQM | ISO 9001  | SOURCE   |
|-------------|--------------------------------|----------|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-----------|----------|
| Engineering | RSKM<br>Risk Management        | CM 4.2   | 4        | Subject the CM baselines and management system to internal audits to ensure compliance to a relevant standard (e.g. ISO 100007)                                                                          | -   | 7.5.3/9.2 | CMM      |
|             |                                | RSKM 2.1 | 2        | Define risk related parameters relevant to the organisation, used to analyse and determine appropriate mitigation (parameters are the likelihood, consequence, threshold for action, and prioritisation) | F54 | 6.1       | CMM      |
|             |                                | RSKM 2.2 | 2        | Using the parameters establish related risk management documents and procedures (e.g. risk registers to assist contributors to conduct individual risk assessments)                                      | F54 | 6.1       | CMM      |
|             |                                | RSKM 2.3 | 2        | Establish a risk management strategy for the effective communication and evaluation of risks (e.g. if risks are identified, how are they evaluated, communicated to management, reviewed, and mitigated) | F54 | 6.1       | CMM      |
|             |                                | RSKM 2.4 | 2        | Disseminated risk assessment procedures and resources to relevant organisation areas and motivate risk-based thinking                                                                                    | F54 | 6.1       | CMM      |
|             |                                | RSKM 3.1 | 3        | Evaluate risks and develop and document risk mitigation plans according to the risk management strategy                                                                                                  | F54 | 9.3.1     | CMM      |
|             |                                | RSKM 3.2 | 3        | Management continuously reviews the implementation and effectiveness of risk mitigation plans                                                                                                            | F54 | 9.3.1     | CMM      |
|             | SM<br>Supplier Management      | SM 1.1   | 1        | Develop and record supplier agreements.                                                                                                                                                                  | F34 | 8.4       | CMMI 2.0 |
|             |                                | SM 2.1   | 2        | Compile a registry of externally supplied materials, processes, products, and services.                                                                                                                  | F34 | 8.4       | CMMI 2.0 |
|             |                                | SM 2.2   | 2        | Define requirements for externally supplied materials, processes, products, and services that are aligned with customer requirements and organisational objectives.                                      | F34 | 8.4       | CMMI 2.0 |
|             |                                | SM 2.3   | 2        | Define a supplier solicitation procedure to identify quality suppliers.                                                                                                                                  | F34 | 8.4       | CMMI 2.0 |
|             |                                | SM 3.1   | 3        | Define and apply verification criteria and procedures to verify supplier proposals against customer and organisational requirements.                                                                     | F34 | 8.4       | CMMI 2.0 |
|             |                                | SM 3.2   | 3        | Define and apply validation criteria and procedures to monitor the quality of supplier deliverables.                                                                                                     | F34 | 8.4       | CMMI 2.0 |
|             |                                | SM 3.3   | 3        | Develop and apply process-based requirements, criteria, and metrics to manage supplier quality.                                                                                                          | F34 | 8.4       | CMMI 2.0 |
|             |                                | SM 3.4   | 3        | Select and monitor supplier processes and deliverables based on criteria in the supplier agreement.                                                                                                      | F34 | 8.4       | CMMI 2.0 |
|             |                                | SM 4.1   | 4        | Select measures and apply analytical techniques to quantitatively manage supplier deliverables to achieve quality and process performance objectives.                                                    | F34 | 8.4       | CMMI 2.0 |
|             | MP<br>Manufacturing Procedures | MP 1.1   | 1        | Manufacturing/costing related estimates are based on individual knowledge/discretion.                                                                                                                    | -   | -         | -        |
|             |                                | MP 2.1   | 2        | Develop a repository of estimates/manufacturing procedures used in the design/development of products or product components                                                                              | -   | -         | -        |
|             |                                | MP 2.2   | 2        | Develop a repository of estimates/manufacturing procedures used to determine manufacturing costs, schedule, lead time, and effort.                                                                       | -   | -         | -        |
|             |                                | MP 3.1   | 3        | Institutionalise and make available organisational estimates and manufacturing procedures.                                                                                                               | -   | -         | -        |

| MCC | MPA                              | ID       | Maturity | Task Definition                                                                                                                                                                                         | TQM | ISO 9001    | SOURCE   |
|-----|----------------------------------|----------|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-------------|----------|
|     |                                  | MP 4.1   | 4        | Utilise process measurements, resource requirements, and quantitative results to update estimations based on organisational capability.                                                                 | -   | -           | -        |
|     |                                  | MP 5.1   | 5        | Continuously review and update estimates/manufacturing procedures as organisational capability matures.                                                                                                 | -   | -           | -        |
|     | REQD<br>Requirements Development | REQD 2.1 | 2        | Identify the external stakeholders (customers, regulatory, legal, management) that will determine product/manufacturing requirements.                                                                   | F12 | 4.2         | ISO 9001 |
|     |                                  | REQD 2.2 | 2        | Identify the internal stakeholders (process owners, managers, operators, etc.) that will influence the implementation of quality management.                                                            | F12 | 4.2         | ISO 9001 |
|     |                                  | REQD 2.3 | 2        | Engage with the stakeholders and determine their needs, expectations, and constraints.                                                                                                                  | F12 | 4.2         | ISO 9001 |
|     |                                  | REQD 2.4 | 2        | Transform stakeholder needs, expectations, and constraints into defined requirements.                                                                                                                   | F12 | 8.2.2       | ISO 9001 |
|     |                                  | REQD 3.1 | 3        | Review the defined requirements against organisational capability to ensure that the requirements can be fulfilled before a commitment is made.                                                         | F12 | 8.2.3.1     | CMM      |
|     |                                  | REQD 3.2 | 3        | Consider feedback from process owners and manufacturing contributors on whether they can adhere to the requirements and objectives (Ensure that your process is capable of meeting the requirements).   | F31 | 8.2.3       | CMMI 2.0 |
|     |                                  | REQD 3.3 | 3        | Ensure organisational understanding of the requirements and obtain commitment from process owners/project contributors to the objectives.                                                               | F31 | 8.2.3       | CMMI 2.1 |
|     | REQM<br>Requirements Management  | REQM 1.1 | 1        | Communicate customer requirements to the design and/or manufacturing managers.                                                                                                                          | F15 | 8.2.4       | CMMI 2.0 |
|     |                                  | REQM 2.1 | 2        | Develop and document a version control procedure to maintain bidirectional traceability among requirements.                                                                                             | F15 | 8.2.4       | CMM      |
|     |                                  | REQM 2.2 | 2        | Develop and document a procedure to alter/update customer requirements.                                                                                                                                 | F15 | 8.2.4       | CMMI 2.0 |
|     |                                  | REQM 2.3 | 2        | Continuously review and update customer requirements and organisational objectives to reflect organisational capability.                                                                                | F15 | 8.2.3       | CMMI 2.0 |
|     |                                  | REQM 2.4 | 2        | Document all requirements alterations and apply configuration control to enable traceability.                                                                                                           | F15 | 8.2.4       | CMMI 2.0 |
|     | TS<br>Technical Solution         | TS 1.1   | 1        | Design and manufacture are dependent on individual input/capability.                                                                                                                                    | F1  | -           | CMM      |
|     |                                  | TS 2.1   | 2        | Establish, document, and implement a design processes/stages (e.g. design, estimation and costing, review, manufacturing planning).                                                                     | F1  | 8.3.2       | CMM      |
|     |                                  | TS 2.2   | 2        | Establish, document, and make available design related knowledge (estimates, design decisions, standard procedures etc.).                                                                               | F1  | 8.3.2       | CMM      |
|     |                                  | TS 2.3   | 2        | Establish a peer review/ verification procedure to verify product designs to identify and find solution to identified risks, opportunities, and issues.                                                 | F3  | 8.3.4/8.3.5 | CMMI 2.0 |
|     |                                  | TS 2.4   | 2        | Compile, define, and maintain customer-oriented documentation and post delivery procedures to be delivered as part of the delivered product (data sheets, user manuals, maintenance instructions, etc.) | F5  | 8.3.5       | CMMI 2.0 |
|     |                                  | TS 3.1   | 3        | Develop and document standard design procedures providing guidance on decisions, considerations of regulation, and estimation procedures used to compile designs.                                       | F6  | 8.3.3       | CMMI 2.0 |

| MCC | MPA                       | ID      | Maturity | Task Definition                                                                                                                                                | TQM   | ISO 9001 | SOURCE   |
|-----|---------------------------|---------|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|----------|----------|
|     |                           | TS 3.2  | 3        | Review and validate product design against organisational capability and determine whether components should be purchased or manufacture in-house.             | F5    | 8.3.4    | CMMI 2.0 |
|     |                           | TS 4.1  | 4        | Develop alternative technical solutions, identify issues of possible areas of improvement.                                                                     | F5    | 8.2.1    | TQM      |
|     |                           | TS 4.2  | 4        | Select and pursue alternative technical solutions based on risk assessments, design verification, or validation.                                               | F5    | 8.2.1    | TQM      |
|     |                           | TS 5.1  | 5        | Implement improvements to product designs, manufacturing plans, and technical solutions identified through alterations or improvements to technical solutions. | F5    | 8.2.1    | TQM      |
|     | PI<br>Product Integration | PI 1.1  | 1        | Identify and define the procedures, processes, and task required to compile or assemble the final product or Technical Solution                                | -     | -        | CMM      |
|     |                           | PI 2.1  | 2        | Define the interfaces, interactions, requirements, verification/validation criteria, and contributions between these items                                     | -     | 8.5.1    | CMM      |
|     |                           | PI 2.2  | 2        | Establish an environment, related procedures and verification/validation criteria for the integration or assembly of these items                               | -     | 8.5.1    | CMM      |
|     |                           | PI 3.1  | 3        | Establish a method to review the compatibility between interfaces                                                                                              | -     | 8.5.1    | CMM      |
|     |                           | PI 3.2  | 3        | Establish an environment to verify, before assembly or integration, that the output of each PI item conforms to its relative requirements or criteria          | -     | 9.1.1    | CMM      |
|     |                           | PI 3.3  | 3        | Define and implement a procedure for producing the final product of Technical Solution through the integration or assembling of PI outputs                     | -     | 9.1.1    | CMM      |
|     |                           | PI 3.4  | 3        | Establish an evaluation criteria to ensure successful completion of assembly or integration activities as part of the PQA MPA                                  | -     | 9.1.1    | CMM      |
|     | VER<br>Verification       | VER 2.1 | 2        | Perform verification of designs, manufacturing plans, and process outputs, final products to ensure that requirements will be adhered to.                      | 6.1.1 | 8.3.2    | CMM      |
|     |                           | VER 3.1 | 3        | Select the critical aspects of designs, plans, processes, procedures to be verified.                                                                           | 6.1.1 | 8.3.2    | CMM      |
|     |                           | VER 3.2 | 3        | Establish verification methods/procedures that will be used (with the aim on satisfying the defined requirements).                                             | 6.1.1 | 8.3.2    | CMM      |
|     |                           | VER 3.3 | 3        | Compile a peer review preparedness procedure of the selected aspects (either internal or external).                                                            | 6.1.1 | 8.3.2    | CMM      |
|     |                           | VER 3.4 | 3        | Develop a verification criteria for the verification of designs.                                                                                               | 6.1.1 | 8.3.2    | CMM      |
|     |                           | VER 3.5 | 3        | Consider the potential risks/consequence of failing to meet requirements or failure due to the nature of the products.                                         | 6.1.1 | 8.3.2    | CMM      |
|     |                           | VER 3.6 | 3        | Record and document all identified issues along with the corresponding corrective actions                                                                      | 6.1.1 | 8.3.2    | CMM      |
|     |                           | VER 3.7 | 3        | Apply a configuration management methodology to the design documentation to ensure traceability of the changes and justifications.                             | 6.1.1 | 8.3.2    | CMM      |
|     | VAL<br>Validation         | VAL 1.1 | 1        | Test/inspect products to ensure quality before delivery to the customer.                                                                                       | -     | 8.6      | CMM      |

| MCC                | MPA                                         | ID      | Maturity | Task Definition                                                                                                                                         | TQM | ISO 9001 | SOURCE   |
|--------------------|---------------------------------------------|---------|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------|-----|----------|----------|
| Process Management |                                             | VAL 2.1 | 2        | Establish and implement product testing and validation procedures to ensure that requirements have been met.                                            | -   | 8.6      | CMM      |
|                    |                                             | VAL 2.2 | 2        | Establish and maintain an environment to support validation procedures.                                                                                 | -   | 8.6      | CMM      |
|                    |                                             | VAL 3.1 | 3        | Define inter-process validation methods at organisationally defined intervals, and sampling rates.                                                      | -   | 8.6      | CMM      |
|                    |                                             | VAL 3.2 | 3        | Define, record, and maintain the results of validation activities.                                                                                      | -   | 8.6      | CMM      |
|                    |                                             | VAL 4.1 | 4        | Analyse the results of the validation activities and perform root-cause-analyses to identify cause of defects or deviations in product/process quality. | -   | 8.6      | CMM      |
|                    |                                             | VAL 4.2 | 4        | Identify risks, opportunities and areas of improvement associated with defects and deviations in quality.                                               | -   | 8.6      | CMM      |
|                    |                                             | VAL 5.1 | 5        | Find and implement solution to the identified risks, or opportunities.                                                                                  | -   | 8.6      | CMM      |
|                    | OPD<br>Organisational<br>Process Definition | OPD 1.1 | 1        | Processes are undefined and rely on individual management and capability.                                                                               | -   | -        | CMM      |
|                    |                                             | OPD 2.1 | 2        | Define, and document a system architecture comprised of the organisational structure and compile a breakdown of processes and sub-processes.            | F51 | 8.1      | CMM      |
|                    |                                             | OPD 2.2 | 2        | Define, and document the logical order of manufacturing processes (in a process flow) and describe the interfaces between processes.                    | F51 | 8.1      | CMM      |
|                    |                                             | OPD 2.3 | 2        | Describe, and document process interfaces and resource requirements.                                                                                    | F51 | 8.1      | CMM      |
|                    |                                             | OPD 3.1 | 3        | Define, document and make available standard operating procedures for manufacturing processes and regularly repeated activities.                        | F52 | 8.1      | CMM      |
|                    |                                             | OPD 3.2 | 3        | Define, document and implement a criteria for process performance/acceptance of output that are aligned with organisational requirements.               | F53 | 8.1      | CMM      |
|                    |                                             | OPD 3.3 | 3        | Define quality related performance indicators for organisationally selected processes (e.g. process cost, time, or technical performance metrics).      | F5  | 8.1      | CMM      |
|                    |                                             | OPD 3.4 | 3        | Compile a metering, measuring, and/or evaluation strategy to monitor the performance indicators.                                                        | F51 | 8.1      | CMM      |
|                    |                                             | OPD 3.5 | 3        | Establish a procedure and provide resources to ensure validity of measuring methods/technologies are used and to maintain the measuring infrastructure. | F51 | 7.1.5.1  | ISO 9001 |
|                    |                                             | OPD 3.6 | 3        | Establish traceability of measuring related validations, verifications, and calibrations.                                                               | F51 | 7.1.5.1  | ISO 9001 |
|                    |                                             | OPD 4.1 | 4        | Record statistical data on process performance in the organization's measurement repository.                                                            | F53 | 8.1      | CMM      |
|                    |                                             | OPD 4.2 | 4        | Follow information and analysis procedures to describe and define process quantitatively.                                                               | F53 | 8.1      | CMM      |
|                    |                                             | OPD 4.3 | 4        | Compile and keep updated process performance baselines and performance trends using historic process data.                                              | F61 | 8.1      | CMM      |

| MCC | MPA                                         | ID      | Maturity | Task Definition                                                                                                                                                                                          | TQM       | ISO 9001    | SOURCE   |
|-----|---------------------------------------------|---------|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|-------------|----------|
|     |                                             | OPD 5.1 | 5        | Update process definitions, requirements and interface descriptions as processes improve and mature.                                                                                                     | CI        | 8.1         | CMM      |
|     | OPM<br>Organisational<br>Process Management | OPM 1.1 | 1        | Individuals manage the manufacturing processes and related organisational activities.                                                                                                                    | F5        | 7.1.3/7.1.4 | CMMI 2.0 |
|     |                                             | OPM 2.1 | 2        | Establish a support structure to provide process guidance, resources and assets, and implement quality alignment in processes.                                                                           | F5        | 7.1.3/7.1.4 | CMMI 2.0 |
|     |                                             | OPM 2.2 | 2        | Establish an environment for operations for relevant process areas, and production areas.                                                                                                                | F5        | 7.1.4       | ISO 9001 |
|     |                                             | OPM 3.1 | 3        | Implement process metering, measurement, and evaluation strategies/procedures.                                                                                                                           | F5        | 9.1.1       | CMM      |
|     |                                             | OPM 3.2 | 3        | Establish and provide resources to ensure the efficacy and validity of process measuring efforts.                                                                                                        | F5        | 7.1         | ISO 9001 |
|     |                                             | OPM 3.3 | 3        | Monitor and manage process resources and provide the infrastructure, people, and other resources necessary for improvement.                                                                              | F5        | 7.1.5       | ISO 9001 |
|     |                                             | OPM 4.1 | 4        | Review process outputs, process quality, and process performance and identify issues or opportunities for improvement.                                                                                   | F5        | 9.1.3       | CMMI 2.0 |
|     |                                             | OPM 4.2 | 4        | Develop, keep updated, and follow plans for implementing process improvements.                                                                                                                           | F5        | 9.3 / 10    | CMMI 2.0 |
|     |                                             | OPM 4.3 | 4        | Identify processes that offer the largest contribution to meeting organisational requirement and achieving quality objectives.                                                                           | F5        | 9.3 / 10    | CMMI 2.0 |
|     |                                             | OPM 4.4 | 4        | Explore and evaluate new techniques, methods, and technologies to identify improvement opportunities.                                                                                                    | F5        | 9.3 / 10    | CMMI 2.0 |
|     |                                             | OPM 4.5 | 4        | Utilise quantitative management techniques to make decisions regarding process improvements, risks, and opportunities.                                                                                   | F5        | 9.3 / 9.1.3 | CMMI 2.0 |
|     |                                             | OPM 4.6 | 4        | Evaluate the effectiveness of process improvement efforts by considering organisational feedback, process performance, process quality.                                                                  | F5        | 9.3 / 9.1.3 | CMMI 2.0 |
|     |                                             | OPM 5.1 | 5        | Review process baselines, performance models and quality assurance to determine potential nonconformities, risks, or opportunities for improvement.                                                      | F5        | 9.3 / 9.1.3 | CMMI 2.0 |
|     |                                             | OPM 5.2 | 5        | Update process performance models according to organisational requirements and quality objectives.                                                                                                       | F5        | 9.3 / 9.1.3 | CMMI 2.0 |
|     |                                             | OPM 5.3 | 5        | Use statistical and quantitative techniques to validate selected performance improvements against proposed improvement expectations, business objectives, or quality and process performance objectives. | F5        | 9.3 / 9.1.3 | CMMI 2.0 |
|     | IA<br>Information and<br>Analysis           | IA 3.1  | 3        | Establish a structure, and identify tools for data storage, analysis, and reporting (software packages).                                                                                                 | F53       | 9.1.3       | CMM      |
|     |                                             | IA 3.2  | 3        | Select, document, and communicate data analysis and statistical techniques to be used in quantitative process management.                                                                                | F61       | 9.1.3       | CMM      |
|     |                                             | IA 3.3  | 3        | Define, document, and communicate process performance reporting formats and methods as well as information distribution procedures.                                                                      | F61 / F62 | 9.1.3       | CMM      |
|     |                                             | IA 4.1  | 4        | Conduct data analyses, and distribute process information to relevant managers, process owners, operators.                                                                                               | F61       | 9.1.3       | CMM      |

| MCC        | MPA                                 | ID      | Maturity | Task Definition                                                                                                                                                                                           | TQM     | ISO 9001 | SOURCE         |
|------------|-------------------------------------|---------|----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|----------|----------------|
|            |                                     | IA 4.2  | 4        | Manage and store process data, measurement specifications, and analysis reports                                                                                                                           | F61     | 9.1.3    | CMM            |
|            |                                     | IA 4.3  | 4        | Review process information and consider organisational feedback to determine the efficacy of the information and analysis procedures.                                                                     | F61     | 9.1.3    | CMM            |
|            |                                     | IA 5.1  | 5        | Continuously update and implement improvements to the information and analysis procedures.                                                                                                                | F61     | 9.1.3    | CMM            |
| Enablement | OT<br>Organisational<br>Training    | OT 1.1  | 1        | Employ people capable of manufacturing or conducting manufacturing related tasks.                                                                                                                         | F4      | 7.2      | CMM            |
|            |                                     | OT 2.1  | 2        | Identify short term training needs and objectives that are aligned with organisational commitment and knowledge required for improvement.                                                                 | F4      | 7.2      | CMM            |
|            |                                     | OT 2.2  | 2        | Establish a training and skills development strategy based on training objectives.                                                                                                                        | F41     | 7.2      | ISO 9001 / TQM |
|            |                                     | OT 2.3  | 2        | Consult external sources on training ad skills development (SETA registration).                                                                                                                           | F41     | 7.2      | CMM            |
|            |                                     | OT 3.1  | 3        | Establish, document, and communicate an organisational level training policy that states the organisation's overall commitment towards planning, and providing continuous training and skills development |         |          |                |
|            |                                     | OT 3.2  | 3        | Identify and define process related information and knowledge that will enable employees to identify risks and opportunity in their relevant process areas.                                               | F41     | 7.2      | CMM            |
|            |                                     | OT 3.3  | 3        | Periodically assess the effectiveness of the training and skills development program based on process performances, identified issues or opportunities, and organisational maturity.                      | F42     | 7.2      | CMM            |
|            |                                     | OT 3.4  | 3        | Periodically update the training and information sessions as organisational capability matures and new objectives can be sought.                                                                          | F41     | 7.2      | CMM            |
|            |                                     | OT 3.5  | 3        | Record and maintain a data base of the training and skills development records within the organisation.                                                                                                   | F41     | 7.2      | CMM            |
|            |                                     | OT 4.1  | 4        | Identify individuals that will analyse, report, and/or receive quantitative information                                                                                                                   | F42     | 7.2      | CMM            |
|            |                                     | OT 4.2  | 4        | Educate these individuals in interpreting and utilising quantitative process information                                                                                                                  | F42     | 7.2      | CMM            |
|            |                                     | OT 4.3  | 4        | Record and maintain a data base of the training and skills development records within the organisation.                                                                                                   | F41     | 7.2      | CMM            |
| Reflection | PQA<br>Process Quality<br>Assurance | PQA 1.1 | 1        | Process performance and quality is undefined and unpredictable.                                                                                                                                           | -       | -        | -              |
|            |                                     | PQA 2.1 | 2        | Establish criteria that is aligned with organisational policy and customer requirements to validate process output quality and identify risks, opportunities, and nonconformities.                        | F5 / F6 | 8.7      | ISO 9001       |
|            |                                     | PQA 2.2 | 2        | Establish and maintain a procedure to deal with non-conforming process outputs.                                                                                                                           | F5 / F6 | 8.7      | ISO 9001       |
|            |                                     | PQA 2.3 | 2        | Develop lifecycle analysis procedures for performing value against cost analysis.                                                                                                                         |         |          |                |
|            |                                     | PQA 2.4 | 2        | Identify, document, and find solution to identified causes for discrepancies between quoted cost and actual cost.                                                                                         |         |          |                |

| MCC | MPA                                   | ID      | Maturity | Task Definition                                                                                                                                          | TQM     | ISO 9001 | SOURCE   |
|-----|---------------------------------------|---------|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------|---------|----------|----------|
|     |                                       | PQA 3.1 | 3        | Implement inter-process validation procedures and identify risks, opportunities, nonconformities, or areas of improvement associated with results        | F5 / F6 | 8.7      | ISO 9001 |
|     |                                       | PQA 3.2 | 3        | Establish a database of the validation results, nonconformities, and corrective actions and maintain traceability.                                       | F5 / F6 | 8.7      | ISO 9001 |
|     |                                       | PQA 3.3 | 3        | Develop a value engineering management strategy focussed on identifying cost, efficiency, performance improving opportunities.                           |         |          |          |
|     |                                       | PQA 4.1 | 4        | Objectively evaluate process performance data using organisational validation procedures.                                                                | F5 / F6 | 9.1      | TQM      |
|     |                                       | PQA 4.2 | 4        | Follow a causal analysis approach to identify process issues related with poor quality, nonconformities, or manufacturing issues.                        | F5 / F6 | 9.1      | TQM      |
|     |                                       | PQA 4.3 | 4        | Develop, and apply trade-off analyses procedures and methods based to find alternative solutions to manufacturing processes.                             |         |          |          |
|     |                                       | PQA 5.1 | 5        | Establish and maintain descriptions of historic quality issues and implemented resolutions.                                                              | F5 / F6 | 9.1      | TQM      |
|     | SCF<br>Sustained Customer Focus       | SCF 2.1 | 2        | Define a procedure/method to elicit customer feedback.                                                                                                   | F14     | 8.2.4    | TQM      |
|     |                                       | SCF 2.2 | 2        | Define a customer satisfaction criteria/rating/metric.                                                                                                   | F14     | 9.1.2    | TQM      |
|     |                                       | SCF 3.1 | 3        | Document, archive and review customer satisfaction ratings as well as any complaints or praises to identify risks, opportunities, or nonconformities.    | F15     | 9.1.2    | TQM      |
|     |                                       | SCF 3.2 | 3        | Establish a procedure/environment for sales feedback to be considered to identify manufacturing/design related concerns.                                 | F15     | 9.1.2    | TQM      |
|     |                                       | SCF 3.3 | 3        | Document, archive and review customer satisfaction ratings as well as any complaints or praises to identify risks, opportunities, or nonconformities.    | F15     | 9.1.2    | TQM      |
|     |                                       | SCF 4.1 | 4        | Use organisational root-cause analysis procedures to determine the cause and effect of a poor customer satisfaction and identify resolution.             | F15     | 8.2.4    | ISO 9001 |
|     | CAR<br>Causal Analysis and Resolution | CAR 3.1 | 3        | Select or react to defects, process issues, and nonconformities to be subjected to a causal analysis.                                                    | F5      | 8.7      | ISO 9001 |
|     |                                       | CAR 3.2 | 3        | Perform root-cause analyses of the selections and identify corrective actions, resolutions, or opportunities.                                            | F5      | 8.7      | ISO 9001 |
|     |                                       | CAR 3.3 | 3        | Establish and implement a procedure/structure to segregate nonconforming/poor quality outputs from the upstream production.                              | F6      | 8.7      | ISO 9001 |
|     |                                       | CAR 3.4 | 3        | Conduct and document a risk analysis to determine the consequence and severity of nonconforming outputs.                                                 | F7      | 8.7      | ISO 9001 |
|     |                                       | CAR 3.5 | 3        | Establish a documentation procedure to describe nonconforming/poor quality outputs as well as the outcome of any causal analyses and corrective actions. | F5      | 10       | CMM      |
|     |                                       | CAR 4.1 | 4        | Extract, and define organisational innovations to implement corrective actions, or prevent/reduce future nonconformities.                                | F5      | 10       | CMM      |
|     |                                       | CAR 5.1 | 5        | Evaluate the effect on process performance, risks, and challenges of the proposed changes.                                                               | F5      | 10       | CMM      |

| MCC | MPA                                      | ID      | Maturity | Task Definition                                                                                                                           | TQM | ISO 9001 | SOURCE |
|-----|------------------------------------------|---------|----------|-------------------------------------------------------------------------------------------------------------------------------------------|-----|----------|--------|
|     |                                          | CAR 5.2 | 5        | Record and maintain the results of causal analyses, identified resolutions, and implemented actions.                                      | F5  | 10       | CMM    |
|     | ODM<br>Organizational<br>Decision-Making | ODM 3.1 | 3        | Establish and maintain guidelines to determine which issues are to be subjected to a formal evaluation process.                           | F63 | -        | TQM    |
|     |                                          | ODM 3.2 | 3        | Establish and maintain a criteria/framework for evaluating the risks, opportunities, or challenges relevant to decision making.           | F63 | -        | TQM    |
|     |                                          | ODM 3.3 | 3        | Utilise process information-based practices (verification, validation, quality assurance, process management) to make informed decisions. | F63 | -        | TQM    |
|     |                                          | ODM 3.4 | 3        | Identify alternative solutions to address issues.                                                                                         | F63 | -        | TQM    |
|     |                                          | ODM 4.1 | 4        | Evaluate the quantitative effect of alternative solutions using the established criteria, performance metrics, and methods.               | F63 | -        | TQM    |
|     |                                          | ODM 4.2 | 4        | Make decisions based on based on formal evaluations, risk assessments, process capability, and other relevant evaluation criteria.        | F63 | -        | TQM    |