A QUALITY ENGINEERING FRAMEWORK FOR AUTOMOTIVE MANUFACTURING SMEs

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ABSTRACT

Compared to large automotive manufacturing organisations, SMEs within the industry significantly differ in their business models and operations environments and are generally too constrained to dedicate their limited financial and workforce capabilities to the implementation of the often capital-intensive, complex, laboriously demanding, time-consuming and expert-biased industry standard and mainstream quality systems. The goal of this research was to explore the development of a novel quality engineering framework, which is tailored to SMEs' general available resources and characteristics, and essentially features the highest-level properties of maximised organisation-wide strategy to achieve a robust, scalable quality-focused manufacturing environment cost-effectively. To achieve this goal, it was necessary to (1) identify the time-dependent variants of quality performance, (2) map out the factors that cause non-Quality Management System (QMS) compliant firms to deliver less quality target value better than firms in the QMS league, (3) identify the variables that impede the hybridisation and implementation of QMS, (4) identify human-biased vectors of quality data deviations (vQDD), and (5) convert the findings in (1) to (4) into key input parameters required for the development of the proposed framework.

To extract original objective input data empirically, this study took a paradigm shift by viewing automotive manufacturing as a social phenomenon, so far underestimated or uncharted, with which personnel or social (human) actors interact to socially construct knowledge and reality based on their experiences with the quality dimensions and quality system structures. This research utilised a pragmatic and concurrent transformative mixed-methods design approach for the primary quantitative and qualitative data acquisition from non-probabilistic cohorts of consumers of automobile products and services, and experts across automotive manufacturing and service sectors in Africa, Asia, Europe, the Middle East, and North America. The data collection instruments were formalised for (1) Quality Dimensions – mapped against Management Role, Quality of Service, Continuous Monitoring and Emerging Technologies, and (2) Indices of Quality Performance – oriented on QMS Knowledgebase, Quality Design, Standards Implementation and Responses to Threats. The outcomes were translated and coded into functional requirement (FR) notations and their corresponding plausible design parameters (DP). The hierarchies of their FR-DP decomposition were identified and exhausted. The application of Axiomatic Design Theory was extended to integrate the results as key input parameters for the development of a novel QMS-based quality engineering framework, which is tailored to the resources and characteristics of SMEs. The subsequent review of the quality

engineering framework substantiated the comprehensibility, scalability and applicability of the framework.

The outcome of this research, which evolved methodically from the synthesis of the findings extracted from the empirical data, shows that a significant amount of quality issues arises as a result of social (human) actors' adversarial or apathetic behaviours towards quality goals within the social construct of automotive manufacturing organisations. This body of knowledge is also complemented with plausible sets of mitigation solutions mapped against human-oriented vQDD. The framework further highlights a preference for (1) countermeasures against customer-centric demand uncertainties, (2) alignment with industry standard quality procedures, and (3) reconfigurability and robustness in order to capture and address any emerging issues during the initial design, in-process and or post-process stage. The analysis and relevance of the overall findings is evidenced by the possibility to integrate them to address SMEs' general need for a flexible-to-implement, cost-time-resource-effective and easily adaptable quality framework. This draws the conclusion that this quality engineering framework provides a well-structured methodology to action-guide SMEs within the automotive manufacturing industry to establish their in-house, customised, and robust QMS for quality implementation across all facets of their manufacturing operations at minimal costs. Furthermore, the scalability and reconfigurability nature of the framework, which falls within the current understandings of the dynamics of automotive quality engineering, shows that it is not only for SMEs but can also be extended and adopted for its application in large automotive manufacturing organisations and other sectors.

DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of the University of Gloucestershire and is original except where indicated by specific reference in the text. No part of the thesis has been submitted as part of any other academic award. The thesis has not been presented to any other education institution in the United Kingdom or overseas.

Any views expressed in the thesis are those of the author and in no way represent those of the University.

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Signed: Date: 03.08.2022

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DEDICATION

I dedicate this thesis to my Grandmother Anna-Balleh Tanwin-Gorduoh; and to my lovely wife Melanie (Mel) Flowers.

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I owe Professor Shujun Zhang deep gratitude for without his incessant help it would not have been possible for me to complete this thesis. As my Principal PhD Supervisor, he has not only evidently demonstrated how much he believes in what I can deliver but he has also always been available and ready to engage me with guidance and very helpful directional pointers to getting this right. I am very much obliged and remain ever grateful. I am also very thankful to Dr. Martin Wynn, my Second PhD Supervisor, for his constructive guidance during my doctorate research journey.

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Chapter 1 Introduction

SMEs in manufacturing seek to adopt a myriad of quality systems on the premise of exceeding customer expectations. Despite attempts to optimise quality engineering processes within the automotive manufacturing industry, challenges in quality design implementation, coupled with the lack of a capable workforce and financial constraints, have continued to adversely interfere with SMEs implementation of quality systems and have thereby exposed the inadequacies of existing quality implementation processes (Cole, 2010; Guinot et al., 2017; Liu et al., 2017; Mahdavi et al., 2007; Shin et al., 2014; Topaloglu & Gokalp, 2018). The existing QMS-based industry standards and quality systems, furthermore, do not offer a how-to process to guide implementation (Silva, 2017) which do not make them a user-friendly, easy-to-adopt process, especially for SMEs. Furthermore, currently existing quality frameworks are not designed to adapt to changing customer requirements and enable continous assessments and improvements after the design stage. In order to address these capability gaps, the aim of this research is to investigate the causes for variations in quality deliveries and identify the barriers to QMS and related quality standards implementation within the context of the automotive manufacturing operations that can cause the finished product, for example, to deviate from the expected quality result. This will culminate in the proposition of a new engineering quality system framework. The significance of this research is that the proposed quality engineering system framework will equip SMEs in the automotive manufacturing, manufacturing production, engineering service, and assembly domains with the tools to derive an optimal in-house quality management system. This new approach will help identify the barriers that inhibit product and service conformance to specifications and the implementation of quality engineering and maintenance systems.

1.1 Research question and objectives

In order to derive the proposed novel quality engineering system framework, the following research questions were formulated:

> *Why do automotive manufacturing organisations vary systematically in quality performance over time? (RQ1)*

> *Why do manufacturing organisations, whose primary objective is to maximise the value of quality-oriented processes and automobile products, deliver*

significantly less than those organisations that have attained quality management system (QMS) certification? (RQ2)

How can automotive manufacturing organisations overcome the variables that impede the hybridisation and implementation of engineering quality management system (QMS)? (RQ3)

The three research questions informed the derivation of the following research objectives (RO):

RO1: To review the existing quality systems and investigate the associated quality indices with respect to the implementation mechanics that cause a product to fall out of specification (OOS).

RO2: To propose a new method for deriving a quality engineering system framework to optimize manufacturing quality systems for SMEs.

RO3: To validate the applicability of the new quality engineering system framework via a review by an automotive manufacturing SME.

RO4: To develop the new quality engineering system into a standard for the SME manufacturing sector by documenting its process and procedures.

This research is guided by the research questions and objectives, with Chapters 4 and 5 focusing on the findings for RQ1 and RQ2 respectively that are integrated in Chapter 6 for the purpose of addressing RQ3. Seeking to optimise manufacturing quality systems for SMEs, the thesis culminates in the development of a new quality engineering system framework in Chapter 7.

1.2 Research methodology

The vectors of quality data deviation are often biased by social (human) actors, whose attributes or decision-making patterns can impact the manufacturing operations quality results. The epistemological stance of the study is interpretivism, as its paradigm posits that the quality culture in the manufacturing industry is socially constructed through the interaction of individuals. The research ontology will draw on constructionism, with respect to the nature of reality the social actors construct (Bryman & Bell, 2011; Crotty, 1998; Grix, 2004; Saunders et al., 2012).

To achieve the research objectives and philosophical stance, the study will take a multiple approach to data collection, analysing and integrating the findings, in contrast to the limitations that a single method presents in exploring a research problem. A multiple or mixed-method approach will enable exploration of the proposed new quality engineering system framework as a new phenomenon, data collection via any available technique, and adopt continuous interpretation to influence the phases in the research process (Tashakkori & Teddlie, 2010).

1.3 Contribution to theory and practice

Al-Jalahma (2012), Asher (1992), Dassisti (2010), Hansson and Klefsjö (2003), Mohd Yusof and Aspinwall (2000), Talib et al. (2011) and A. J. Thomas and Webb (2003), among many others, developed quality engineering frameworks designed to alleviate the barriers that inhibit the implementation of quality systems. However, the methodologies adopted by the authors have a number of limitations particularly in the context of failure to incorporate dependent variables such as top management decision mechanisms, systemic structure and organisation-wide motivational factors that may inhibit objectivity in the validation of the operational feasibility of the quality models.

As with the existing myriad of quality assurance systems that often blame manufacturing failures on manufacturing processes and machining operation settings, the previous studies also point to the manufacturing system as the main agent for quality indices without reference to top management's culture of rejecting, reluctance or apathic attitudes towards quality concepts. The latter is the gap within the existing myriad of manufacturing quality systems this research will seek to address.

To identify and analyse the aspect of personnel or (top) management culture of exhibiting reluctance towards quality concepts, a quality system's deviation from the expected optimised manufacturing quality results will be coded as vectors in the categories of personnel adversarial behaviours, organisational role, organisational or management attitudes, quality performance indicators, core quality capabilities, and technical expertise. Analysing the relationships between the fundamentally human-biased core variables characteristic of these vectors will help to further determine and develop the correlation between the dependent variables (internal and external stakeholders, and the manufacturing environment) and independent variables (organisation-wide interconnected quality culture); and the analysis of a set of functional needs that will be formulated based on the responses of research participants from manufacturing organisations and that of the cohort of consumers.

The proposed work is of importance to the SME manufacturing industry in that it will seek to incorporate human-biased quality culture into a customisable quality system, contrary to existing manufacturing systems that are designed to count mainly on manufacturing systems settings to optimise quality in the outcome. Unlike subject-related previous studies by Colledani and Tolio (2011) and Kim et al. (2010) that were void of robustness and agility, this research will be designed to exhibit the agility required for engineering quality systems to coevolve with human operator complexities or demand pattern uncertainties. To achieve this, the proposed new engineering quality system will feature a number of quality taxonomies that will assess operational variables during any significant changes in the manufacturing organisation. The new engineering quality system will be customisable in-house by adopting SME manufacturing companies.

1.4 Thesis overview

This thesis has the following structure:

Chapter 1 introduces the research topic and presents the aim and objectives for this research. It further provides an overview of the research design and presents its contribution to the existing body of knowledge and practice.

Chapter 2 identifies and reviews literature on quality systems and their associated factors of implementation failures within the automotive manufacturing operations sector. It assesses different concepts, quality methods and tools relevant to these research objectives and discusses their practical implications. This will help to map out the parameters of quality process and implementation variants within the automotive manufacturing industry and identify relationships between the relevant independent and dependent variables.

Chapter 3 builds on the identified quality implementation shortfalls within automotive manufacturing SMEs and the large organisations in Chapter 2 and develops the initial design of the proposed quality engineering framework, applying Axiomatic Design (AD) methodology. It then provides the philosophical worldview and paradigms used to guide the research and outlines the selected research design, methods and the facets of mixed-methods research selected for this study.

Chapter 4 analyses, examines and discusses the research findings that seek to answer why automotive manufacturing organisations vary systematically in quality performance over time (RQ1).

Chapter 5 analyses, examines and discusses the research findings with regard to the factors that are responsible for less quality value deliveries (RQ2) and establishes the differences in approaches between organisations' quality systems and expected output.

Chapter 6 integrates and discusses the findings of RQ1-based Chapter 4 and RQ2-oriented Chapter 5.

Chapter 7 produces the new engineering quality system by optimising the initial design first conceptualised in Chapter 3, on the basis of the research findings and thereby addresses RQ3.

Chapter 8 presents the documentation, standardisation process and applicability of the QX engineering framework and the outcome of the QX design review.

Chapter 9 summarises the main findings, identifies the contribution and limitations of this research and proposes future studies.

Chapter 2 Literature Review

2.1 Introduction

This Chapter identifies and reviews literature in the context of myriad of quality systems and their associated factors of implementation failures within the automotive manufacturing operations sector. The operations of an automotive manufacturing organisation or system span across a wide range of functional domains such as design, development, manufacture, marketing and supply of either automobile parts or vehicles or both (Koren, 2010). The automotive manufacturing of parts or components and vehicles is defined collectively as an automobile product. With reference to Koren's (2010) classifications, this review defines an automotive manufacturing system as the engineering, operations and design activities or processes in the automotive product development, manufacturing process and manufacturing resource domains (APDMPMR). More specifically, the key objective of this Chapter is to review existing quality systems with respect to their implementation and associated quality indicators that cause an automotive process or product to fall out of specification (OOS). As the majority of automotive manufacturing quality problems are triggered by variation in quality characteristics, a myriad of quality systems is reviewed relative to their concepts and approach. This will help map out the parameters that cause adverse impact of input variation on an automotive manufacturing system’s desired output. This will address Research Objective 1 (RO1) stated in Chapter 1 (p. 2).

A study by Horváth and Szabó (2019) suggests that large manufacturing organisations have higher driving forces, lower barriers to new technologies and a competitive edge than small and medium-sized enterprises (SMEs), while Smit et al. (2016) and Braun et al. (2020) report that ill-preparedness is one of the underlying factors that hinder SMEs from delivering superior manufacturing quality, Mcmahon (2001) and Mittal et al. (2018) assert that limited financial resources are the agents that retard SMEs’ bid to exceed customers’ expectations. Although automotive manufacturing SMEs significantly stimulate economic growth through employment creation, investments and exports, lack of capable workforce and financial constraints, however, are a core contributor to the pressures SMEs face in the expectation to deliver at high quality standard (Hiregoudar & Soragaon, 2011; Mcmahon, 2001; Mittal et al., 2018; Narottam et al., 2020; Pavletic et al., 2006; Rana & Kaushik, 2018). This Chapter is of particular significance to SMEs in the automotive manufacturing sector, in that the outcome of this study will be used to propose a new quality engineering framework in Chapter 3 that SMEs can adopt to create ideal quality-focused manufacturing operations. This will align with the expectation of Research Objective 2 (RO2), stated in Chapter 1 (p. 2).

One of the globally accepted enablers of engineering quality in the automotive manufacturing industry is the International Automotive Task Force's IATF 16949:2016 standard. Charged with auditing organisations within the context of the quality management system (QMS), the IATF 16949:2016 standard is described as an ad-hoc consortium of major global automobile manufacturers and automotive trade organisations (Bacoccini, 2016). This literature review will focus on the barriers to QMS and related quality standards implementation within the context of the automotive manufacturing operations, particularly across the APDMPMR domains.

The outcome of this literature review is to help map out the parameters of quality process and implementation variants within the automotive manufacturing industry and identify relationships between the relevant independent variables (such as organisational culture, hierarchical barrier, management construct, etc.) and the identifiable dependent variables (myriad of quality dimensions). Situated within the research objectives (ROs) and research questions (RQs) outlined in Chapter 1 (p. 1f), and context of proposing and developing a new quality (excellence) engineering framework, the author designed the mind map in Fig. 2.1 to guide the structure and process of the literature review.

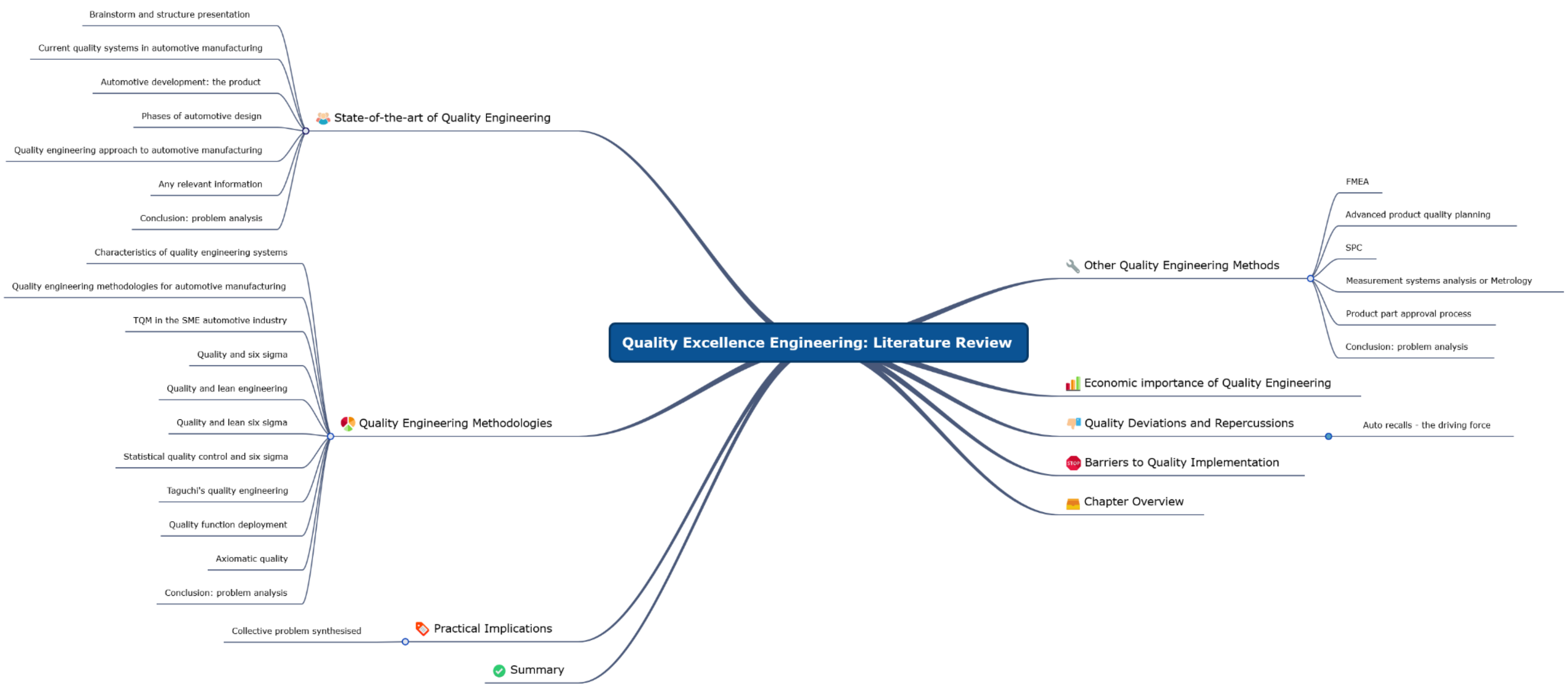


Fig. 2.1: Mind map developed to guide the structure and process of the literature review (by author)

The literature review was carried out by reviewing academic/scholarly articles, peer-reviewed research journals and conference papers, international automotive regulatory bodies' reports and documents, Quality Management System (QMS) based documents on ISO families of quality standard procedures, and subject-related textbooks and web-based content. This Chapter presents a review of quality techniques that are usually employed across the manufacturing APDMPMR domains.

The review opens with clarifying what is understood by quality engineering in manufacturing in Section 2.2, away from its rather broad concepts. In order to situate the literature review within the context of this study, Section 2.2 also outlines the approach to selecting the relevant literature that essentially covers the state-of-the-art of quality engineering, quality engineering methodologies, barriers to quality implementation, and economic importance of quality engineering in relation to quality deviations (also referred to as quality indicators) and associated repercussions (such as auto recalls).

Section 2.3 provides insights into the economic importance of quality engineering in the context of financial implications as a consequence of quality failures, that result in auto recalls for example. The Section highlights the costly impacts of auto recalls to both the manufacturing organisation and the consumer. It is important to understand the economic importance of how quality failures can expose automotive manufacturing organisations to reputational damage and to seek to identify the shortcomings and address them adequately. This will provide valuable insights into core quality dimensions and to help in roadmapping the development of a new Quality (eXcellence) engineering framework (or QX Engineering Framework).

Section 2.4 examines a myriad of core quality tools and methodologies as listed in Fig. 2.1, illustratively branching from the Quality Engineering Methodologies and Other Quality Engineering Methods. The barriers to quality implementation and the potential triggers of deviations from the QMS requirements are also presented in Section 2.4. In reviewing various methods used for modelling quality systems in Section 2.5 and the operational research approach (see Section 2.6) taken to identifying quality issues, critical factors that reduce manufacturing quality processes to fall out of specification (OOS) and their respective practical implications are identified. Section 2.7 presents a summary of the Chapter, featuring capability gaps.

2.2 Quality engineering

It is important to clarify what is understood by quality engineering, as the term broadly presents a number of concepts for manufacturing process improvement. A report in the *Quality and*

Reliability Engineering International Journal (Vining et al., 2016) described quality engineering in manufacturing in the context of applying industrial statistical methodologies and a myriad of techniques and tools to improve the quality and manufacturing of products and processes. Vining et al. (2016) suggested that quality engineering can take the forms of (1) process monitoring and control, (2) experimental design and analysis, (3) quality tools and methods, and (4) quality management implementation. The literature on (1) process monitoring and control, and (2) experimental design and analysis will not be reviewed but is available from the following references: Jones and Nachtsheim (2009), and Woodall and Montgomery (2014). This review will cover (3) quality tools and methods, and (4) quality management implementation aspects of quality engineering, as these are the main areas of interest to this study.

As there is a vast amount of research and wealth of writing which is relevant to quality engineering frameworks (Baba et al., 2006; Belcher et al., 2018; Braun et al., 2020; Deros et al., 2009; Knechtges & Decker, 2014), in this Chapter the author will concentrate on:

1. A selective review of research which is relevant to the objectives of this study outlined in Chapter 1 (p. 2). The author will examine this critically in order to identify the key barriers to quality implementation in automotive manufacturing.
2. The role of human factors (also social actors) as vectors of quality data deviations (vQDD). Also known as quality indicators, a vQDD is any medium or activity that causes a manufacturing process or an automobile product to deviate or depart from the target quality value or conformance to specifications. This aspect of the research focus is to derive knowledge necessary for the development of the proposed QX Framework.

With respect to the two areas above, the next Section will concentrate on the cost implications associated with quality issues. The findings from the correlation between cost and quality indicators in Section 2.3 will premise the need to factor the development of a vQDD traceability model into the proposed QX framework design. This component will not only lend a mitigation solution against the variants of quality dimensions but also enable organisations to track the agents that potentially vary quality processes within automotive manufacturing organisations.

2.3 Economic importance of quality indicators

Understanding the economic significance of quality indicators is one of the most critical to customer satisfaction key input variables this study will incorporate into the process mapping for the development of the proposed QX Engineering Framework. In their quest to exceed customer expectation as well as stay competitive, automotive manufacturing SMEs tend to adopt existing quality tools. However, a number of uncontrollable human factors within the manufacturing organisation can adversely interfere with the appropriate quality implementation process. As a consequence of this, auto parts failure or functional defects, for example, can lead to significant financial losses and a damaged brand reputation.

In highlighting the cost consequence of a quality failure and the probability of its occurrence as illustrated by auto recalls, Guinot et al. (2017) reported the use of Monte Carlo simulations to establish the average costs of severity in quality failure at each level of occurrence. However, Guinot et al.'s (2017) model underestimated the warranty costs that accrued and their findings were constrained by deriving the cost data mainly from government and academic surveys. Additionally, the power of the validation of the cost data did not reveal the severity of the associated failure mode and effects analysis (FMEA). This agrees with the findings of Cole (2010), Liu et al. (2017), Shin et al. (2014) and Topaloglu and Gokalp (2018) on the negative impact of recalls on automotive manufacturing organisations.

McElroy (2006) reported that Ford Motor Company’s sales declined to 10.5 million units by 1982 with its stock price plummeting to 70% due to quality issues. Forbes (2014) noted General Motors’ legal problems over its 1.62 million models from 2005-2007 due to faulty ignition switches, and Toyota’s agreement to a $1.2 billion penalty over its claims of an unintended acceleration that prompted a recall of over 10 million vehicles. Similarly, subjecting Takata Corporation’s air bags to a massive recall did not only cost the Japanese automotive manufacturing company a loss of ¥2.9 billion (US $25.3 million), but it also compromised the ¥25 billion net profit they had projected for the year.

There is a continued debate over global warming and atmospheric particulates from vehicular exhaust, prompting governmental regulatory bodies to advocate for a departure from vehicular dependency on fossil fuels. The campaign to promote a greener environment is pressuring the automotive industry to come up with energy-and-resource-efficient designs of manufacturing systems and a holistic substitution of combustion engines by electrical machines (Klocke et al., 2012). In order for automotive manufacturing organisations to realise economies of scale within such requirement, Klocke et al. (2012) argued that production of the required electric drives must include a variety of manufacturing technologies that incorporate, for example, cost-intensive DIN 8580 — an automotive manufacturing process standard which features a range of manufacturing activities such as primary forming, stamping of magnetic strips in lamination stack, joining, coating, and machine tooling.

The cost implications of quality indicators are further illustrated by the adverse effects of auto recalls (Rupp, 2004) in the next section. The occurrences of auto recalls are triggered by various quality issues, including:

- Inadequacies in automotive manufacturing organisations' process models (Kehr & Proctor, 2017),
- Compromised health and safety of the automobile product's user such as the technical malfunctioning of the infamous GM ignition switch that resulted in fatalities (Eifler & Howard, 2018; Kirchhoff & Peterman, 2011),
- Supply chain quality issues such as reported by Sharma et al. (2014) in which 66% of recalls over the past 20 years were attributed to rushed design, safety analysis and vendor quality,
- Poorly implemented organisation-wide QMS, leading to vQDD that cause processes and automobile products to fall out of regulatory bodies' requirements (Eifler & Howard, 2018).

For the proposed QX Engineering Framework to be adaptable as an all-inclusive automotive manufacturing process, the knowledge pulled from the dynamics of auto recalls will help in further developing understanding of the theory and methodology required to achieve RO2 in Chapter 3.

2.3.1 Auto recalls

According to the Driver and Vehicle Standards Agency (DVSA), the UK's body responsible for the management of the vehicle safety auto recall scheme, a safety recall is duly issued (DVSA, 2014) when:

- a defect is identified to fall within the description of resulting in a risk of serious injury or death,
- a system failure is related to a defect due to design and or construction flaws,
- a defect has the likelihood to affect the safe operation of the automobile product without prior warning to the user and which may pose significant risk to the driver, occupants, pedestrians and the environment (Gokalp et al., 2019),
- process failures stimulate automotive manufacturer's voluntary recalls (Shin et al., 2014) or passive recalls (Wang & Li, 2015).

The above provision aligns with the requirements of other developed nations' automotive regulatory bodies (such as the U.S. National Highway Traffic Safety Administration (NHTSA)), which expects carmakers to familiarise themselves with the DVSA related guidance document on the implementation of a safety recall (Paulose & Kihara, 2012).

In 2010, over 20 million vehicles were recalled in the United States due to quality failures. Toyota's massive auto recalls of full model lines shone light on this issue globally (Bae & Benítez-Silva, 2011). According to Bae and Benítez-Silva (2011), the number of automobile recalls in the U.S. and elsewhere has continued to increase to several million units over the past couple of decades. The financial strain and demand for robust quality engineering in the aftermath of auto recalls account for what may have pressured Volkswagen's engineers to cheat on emissions tests in 2005. VW's engineers installed an illegal software into diesel engines simply to satisfy the U.S. Environmental Protection Agency's emissions standards (Goodman, 2015; Gorzelany, 2014).

Apart from auto parts defects, Fulbrook (2015) reported that it is commonplace that stringent government legislation's focus on controlling exhaust gas emissions that lead to atmospheric particulates and significant levels of nitric oxide, and that the need to curb high fuel dependency has become a key quality indicator in the automotive industry. As a result, auto parts that fail to adequately address these challenges are rendered as parts defects, leading to auto recalls as a consequence. It is within this parameter that new powertrains, for example, must be developed through either a diesel-powered versus hybrid or 100% electrical-power frame of reference to satisfy the requirements of the environmental regulatory authorities.

The interaction between a composite material on one part of a pedal and a time-dependent degradation-induced moisture caused 15 sticky pedal problems out of over 2 million Toyota automobiles, leading to an auto recall (Liker, 2010). According to the Six Sigma (6σ) concept, it is acceptable within the manufacturing industry to have 3.4 defects in one million manufacturing opportunities. However, Liker's (2010) report implied that an average of 3.75 defects led to a recall of one million vehicles. With a departure of a mere 0.35 defects from the standard 6σ threshold, the question is whether a sticky pedal in one very specialised, isolated design issue in less than 15 defects warrants a recall of 2 million Toyota vehicles.

The four (4) core thrusts of quality engineering management as deduced from this Section and depicted in Fig. 2.2, present an interdependent relationship due to their influence on the metrics of quality performance. These sets of parameters are of significance as their functional requirements will help identify the barriers to quality implementation, necessary for enriched RO1 and RO2. As RO1 and RO2 are related to research question 1 or RQ1 (p. 1), the outcome of the next sections will help to partly address RQ1 in the context of addressing *why manufacturing organisations vary in quality performance over time*. Therefore, the following sections identify and discuss commonly used quality tools with respect to their associated underlying factors of failures.

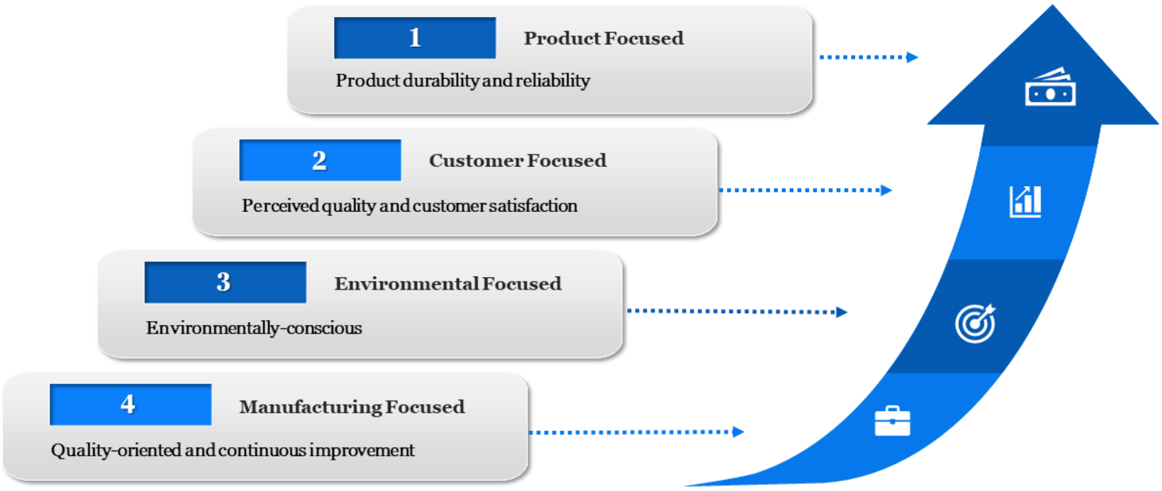


Fig. 2.2: Core thrusts of quality engineering management

2.4 Quality tools and methods for manufacturing systems

In order to achieve an overall process and automobile product quality, automotive manufacturing organisations are expected to adopt the best quality standards such as those within the ISO league. One of the internationally recognised standards for good quality management is that of IATF 16949:2016. Apart from country-specific regulatory bodies' requirements, the QMS-based IATF 16949:2016 standard is considered as the most widely used global standard for quality management in the automotive manufacturing industry. It is therefore an assurance to customers and other stakeholders that an IATF 16949:2016 certified organisation can deliver quality target values as well as gain a competitive edge while satisfying stakeholders' expectations (Bacoccini, 2016; Gruszka & Misztal, 2017; Laskurain-Iturbe et al., 2021). This Section reviews studies of quality techniques and associated implementation process failures, mapped against the expectations of IATF 16949:2016 standard and stakeholder specifications. The quality tools and quality management systems featured in this Section are as follows:

- Failure Mode and Effects Analysis (FMEA)
- Quality Management System (QMS)

- Total Quality Management (TQM)
- Quality Function Deployment (QFD)
- Axiomatic Design Framework
- Taguchi Robust Design Method (TRDM)
- Lean and Six Sigma
    - Lean Six Sigma (LSS)

The data derived from this Section will help to gauge the development process of the proposed QX Framework as well as address aspects of RO1, RO2, RO4 and RQ3 (p. 1f).

2.4.1 Failure mode and effects analysis (FMEA)

Following the mandate for automotive manufacturing organisations to transition from ISO 9000 to IATF 16949:2016, the implementation of the core quality planning tools such as Failure Modes and Effects Analysis (FMEA), Production Part Approval Process (PPAP), Advanced Product Quality Planning (APQP), Measurement System Analysis (MSA), Statistical Process Control (SPC) and related quality systems have become prevalent (Brannstrom-Stenberg & Deleryd, 1999; Elg et al., 2008; Rohani et al., 2009).

Introduced to the automotive industry in the late 1970s by Ford Motor Company, FMEA was deployed in the design stage to identify system weaknesses in order to minimise risk of failure occurrence. It is a quality diagnostic and planning tool often implemented in compliance with IATF 16949:2016 procedures as well as the preceding ISO 9001, QS9000 and TS 16949 standards in reliability engineering for automotive parts manufacturing (Bujna & Prístavka, 2014; Case et al., 2010; Pantazopoulos & Tsinopoulos, 2005; Sham et al., 2008; K. D. Sharma & Srivastava, 2018). The FMEA standard documentation is expected to deliver risk mitigation, defect prevention, conformance of products and processes, product safety, contingency and preventive plans. It is so structured to also satisfy the procedures of PPAP, APQP, MSA and SPC, leading to compliance with IATF 16949:2016 (Rewilak, 2014). A typical FMEA process is formulated by the author as in Algorithm 2.1.

Algorithm 2.1

Failure Mode and Effect Analysis (FMEA)

Step 1.	Perform causal Ichikawa diagram and corresponding FMEA visualisation to identify quality indices and map out key steps in risk assessment in a quality-by-design based process development.
Step 2.	Engineering teams across whole parts and individual units within manufacturing process and operations perform SPC (Elg et al., 2008; Rohani et al., 2009) to reduce/eliminate process variability and FMEA to investigate and assess effects of identified failure modes on the manufacturing system (internal stakeholder) and the customer (external stakeholder) satisfaction.
Step 3.	Perform risk analysis using FMEA for manufacturing process and propose measures to mitigate the risks.
Step 4.	Deploy FMEA process protocol to meet the customer requirements by satisfying: ▪ PPAP: conduct risk identification and mitigation process necessary for risk reduction prior to product/service release (Hempleman, 1998; Lafayette et al., 2017), ▪ APQP: take a communication-intensive structured team approach to define and execute measures to ensure conformance to customer specifications (Stamatis, 2019), ▪ MSA: conduct system capability for risk-based metrology to determine the amount of variation (Rewilak, 2014; Simion, 2019).

FMEA is both time-consuming and physically a very tedious process as it requires expert-based thoroughness and systematic examination of the operation of all aspects of the design with respect to the individual quality parameters. This follows that only engineers with an appreciable working knowledge in FMEA will find this rather painstaking process easy to deploy. Thus, a lack of extensive experience can lead to a compromised engineering design judgment. Nonetheless, Ramly and Atan (2018) reported inconsistencies in the development of FMEA, which exposes the process to potential failure in delivering the intended results required to prevent propagation of product defects from the manufacturing process. It is on this basis that Hunt et al. (1993), and Ramly and Atan (2018) proposed auxiliary open-ended architectures to optimise FMEA in order to meet the IATF 16949:2016 standard.

Although FMEA lacks technical veracity and has over the years been considered as the preferred methodology to perform quality assessment and mitigate risk at both the design and manufacturing stages, its documentation is in principle static (Tiuc & Draghici, 2015). The registrar audit findings reveal that the risk mitigation and defect prevention elements of FMEA are often non-executed (Kluse, 2017). This implies that automotive manufacturing organisations cannot rely on FMEA to satisfy the requirements of PPAP, APQP, MSA and SPC. As these tools are essential tools within the automotive manufacturing system, it follows that reliance on FMEA will trigger shortcomings in an attempt to fulfil the overall IATF 16949:2016 standard.

2.4.2 Barriers to QMS and TQM implementation

Surviving today's competitive and constantly changing demand pattern pressures automotive manufacturing organisations to seek rapid but robust responses to address issues that threaten the existing myriad of quality systems (Flowers & Cheng, 2008, 2009, 2011). The sheer scale of auto recalls is among the demands that continue to subject automotive manufacturing processes to quality scrutiny. However, an automotive manufacturing organisation's attempt to incorporate standard quality practices such as QMS based on the ISO 9000 series of standards and Total Quality Management (TQM), for example, usually faces both internal and external barriers (Karaszewski, 2004; Lambert & Ouedraogo, 2008; Prasad & Tata, 2003).

Although Ab Rahman and Tannock (2005) identified top management, policy and planning management committee and skills-based personnel involvement as contributing factors that cause quality deployment to trip over, the researchers (Ab Rahman et al., 2005) failed to identify the specific barriers created by the social (human) factors to the implementation of TQM methods. In another report, Nandurkar et al.'s (2014) empirical study of how the combination of TQM with manufacturing methods such as just-in-time (JIT), Total Productive Maintenance (TPM) and Supply Chain Management (SCM) is expected to optimise performance of an automotive component manufacturing plant rather resulted in a sub-optimal performance. On a critical note, Nandurkar et al.'s (2014) work failed to pinpoint the specific quality control and document maintenance policies required to integrate the TQM-based automotive manufacturing system.

With a stipulated deadline of December 2006 for automotive manufacturing organisations to switch from ISO 9000 to ISO/TS 16949 (incorporated in IATF 16949:2016), the mission to adequately deploy core quality tools such as TQM and other popular complementary quality techniques remain widespread in practice within the industry (Mohd Rohani et al., 2006). The progress of TQM in automotive manufacturing SMEs, particularly in developing countries, is seen as a present-day significant subject of interest. Ab Rahman et al. (2005) carried out case studies of three Malaysian medium-scale automotive parts manufacturers in order to (1) identify both the quality implementation challenges the SMEs are encountering and (2) to gain insights into the companies' desire to develop more advanced quality management methodologies. Using the Malaysian national Quality Management Excellence Award (QMEA) standard as the reference material, the authors (Ab Rahman et al., 2005) conducted structured interviews with top management at each of the three SMEs to analyse how the companies have adopted distinct approaches to the implementation of TQM.

As the findings in this review are integral to the development of the proposed QX Engineering framework, a multiple search protocol as featured in Algorithm 2.2 was adopted to help identify a wide range of primary studies on relevant quality barriers to QMS and TQM implementation across manufacturing, service organisation and business management online databases (Fink, 2022; Higgins & Green, 2008; Kitchenham, 2004). In order to identify and index the potential types of barrier construct ($T_{(B)}$) to quality system implementation in the personnel construct ($T_{(B)}$I), organisational strategy construct ($T_{(B)}$II), organisational behaviour construct ($T_{(B)}$III), performance construct ($T_{(B)}$IV), and technical construct ($T_{(B)}$V), Algorithm 2.2 is designed to help achieve this segment.

Algorithm 2.2

Identifying barriers to QMS-ISO 9000 series and TQM implementation

Step 1.	Conduct multiple search protocol (Feak, 2009; Fink, 2022; Higgins & Green, 2008; Jesson et al., 2022; Kitchenham, 2004)
Step 2.	Set and consolidate research questions (RQs): ▪ RQ_1: What barriers challenge organisations that want to implement ISO 9000 series standard? ▪ RQ_2: What internal force-induced opposing parameters do organisations have to overcome in order to become TQM-based? ▪ RQ_3: What are the boundary conditions organisations must satisfy for the implementation of QMS? ▪ RQ_4: What are the underlying external factors that impede the implementation of QMS (ISO 9001)–TQM at the organisational level in both developed and developing countries? ▪ $RQ_{(consolidated)}$: Is overcoming the factors that impede the implementation of TQM, QMS (ISO 9000 family) in organisations a recipe towards developing a quality concept for automotive manufacturing SMEs?
Step 3.	Perform Boolean inclusion-exclusion criteria scheme to guide selection of 25 relevant studies (SS1–SS25) out of 88 citations.
Step 4.	Extract data that directly address RQ_1–RQ_4 and $RQ_{(consolidated)}$ from SS1–SS25 (Cooper, 1998; Cooper & Hedges, 1994; Khan et al., 2003; Kitchenham, 2004).
Step 5.	Evaluate and synthesise SS1–SS25 to index potential barriers to QMS and TQM implementation particularly across manufacturing organisations in Africa, Asia, Europe and the Middle East.
Step 6.	Perform ranking by frequency of occurrence of contributor $T_{(B)s}$.

To guide the search (Step 1) for relevant studies as related to the barriers to QMS and TQM, an initial PICOC (Population, Intervention, Comparison, Outcome and Context) criteria (see Table 2.1) is adopted.

Table 2.1: PICOC used to guide the formulation of RQ_1—RQ_4 for the review

Population Specific population or domain of interest for investigation	Organisations employing QMS, TQM and or are ISO 9000 series certified
Intervention Intervention being appraised	Taxonomies of quality schemes used by various organisations
Comparison Comparison or control within domain of investigation	*Beyond the scope of this systematic literature review*
Outcomes Outcome measures of interest	The detrimental consequences of the barriers
Context Research protocol to provide the most valid evidence	Small to medium to large organisations in general

Structuring the research question

In order to clearly define the search terms as well as map out the inclusion and exclusion criteria for relevant literature identification, appraisal or evaluation, selection and synthesis, the research questions are explicitly formatted into a structured research question. The structured format of the consolidated research question focuses strictly on "overcoming the barriers" as related to the outcomes, leading to refining the PICOC (Table 2.2). This was a necessary step to clearly define the search terms and use the *inclusion* and *exclusion* criteria (Table 2.3).

Table 2.2: Structured research question

Population	Organisations employing QMS, TQM and or are ISO 9000 series certified AND organisations seeking QMS, TQM and ISO 9000 series standard implementation
Intervention	QMS, TQM, ISO 9000 family used by organisations
Comparison	*It is not within the scope of this systematic review to conduct comparative studies*
Outcomes	Compromised total quality implementation is the core outcome of interest
Context	Devastating outcomes in at least three population (geographic) groups; QMS, TQM and ISO 9000 practising organisations

Table 2.3: Boolean-based quality selection protocol via Inclusion (*I*) and Exclusion (*E*) criteria

No.	Indices of quality query	Decision
1	Is the study consistent with the research aim(s) and objective(s)?	If ***yes*** then ***I***, otherwise ***E***
2	Is the study consistent with the research methodology?	If ***yes*** then ***I***, otherwise ***E***
3	Are the research aim(s) and objective(s) clearly stated, without any ambiguity?	If ***yes*** then ***I***, otherwise ***E***
4	Did the author(s) do a thorough literature search on the subject area to avoid compromising data integrity of their own study?	If ***yes*** then ***I***, otherwise ***E***
5	Did the author(s) present to have full knowledge in QMS/TQM/ISO 9000 standard?	If ***yes*** then ***I***, otherwise ***E***
6	Did author(s) appear to have either individual knowledge of a geographic location of interest or covered extensive literature search on the geographic area(s) of interest to RQ?	If ***yes*** then ***I***, otherwise ***E***
7	Did the author(s) identify as well as segregate the barriers into categories (for statistical or mathematical inferences)?	If ***yes*** then ***I***
8	Did the author(s) provide references to identified barriers for trackability to source?	If ***yes*** then ***I***

Table 2.4: Search protocol designed to select relevant literature

Domain	Search Terms
RQ_1 – RQ_4	ISO 9000 organisations, barriers and ISO 9000, TQM implementation, QMS implementation and barriers
$RQ_{(consolidated)}$	TQM, QMS, ISO 9000, quality systems and assurance, quality organisations
Populations	TQM/QMS/ISO 9000 organisations
Interventions	TQM/QMS/ISO 9000 implementation quality systems AND manufacturing organisations/organisations
Outcomes	TQM/QMS/ISO 9000 implementation success, effects of barriers
Context	Manufacturing industry, practitioner organisations
Similar Terms	QMS impact organisations, TQM process performance, hybrid methodology, continuous performance improvement, continuous quality improvement, performance improvement processes, hybrid remanufacturing, quality heterogeneity, QCD research, ISO 9001 implementation, TQM implementation, ISO 9000:2000 requirements, QMS/TQM/ISO 9000 implementation barriers, ISO 9000-QMS, ISO 9001 QMS impact
Boolean Operators	(([ISO 9000] AND [barriers]) OR [ISO 9000 implementation]) AND [process] (([QMS] AND [barriers]) OR [QMS]) AND [process] (([TQM] AND [barriers]) OR [TQM]) AND [process]

Employing the quality assessment procedure for the inclusion and exclusion criteria and based on the Boolean-based search protocol (Table 2.4), resulted in the 25 studies (SS1–SS25) out of 88 citations. The rigorous relevance screening of publications focused mainly on the taxonomies of quality systems implementation, geographic locations of interest to the study's aim and objective, mechanisms or methodology used to identify barriers to implementation of QMS–TQM–ISO 9000 series standard in organisations. The 25 selected studies (SS) from 2000–2014 are presented in Table 2.5.

Table 2.5: Selected primary and secondary studies

Coded*	Title	Journal	Authors	Year	Source	Type	Label
	Empirical investigation of ISO 9001 quality management systems' impact on organisational learning and process performances	Total Quality Management	Lambert and Ouedraogo	2008	Journal paper	Empirical investigation	QMS
SS1	ISO 9000 implementation barriers and misconceptions: an empirical study	International Journal of Business Administration	Al-Najjar and Kamel	2011	Journal Paper	Empirical investigation	ISO 9000
SS2	Quality Management Systems within the Public Sector: the Case of ISO 9000 Implementation Barriers in Malaysian Local Government	IOSR Journal of Business and Management (IOSR-JBM). ISSN: 2278-487X	Abdullah	2012	Journal paper	Survey	QMS and ISO 9000
	HY-CHANGE: a hybrid methodology for continuous performance improvement of manufacturing processes	International Journal of Production Research	Dassisti	2010	Journal paper	Hybrid methodology	CPI[1]
	Hybrid (re)manufacturing: manufacturing and operational implications	International Journal of Production Research	Mahapatra et al.	2012	Journal paper	Hybrid (re)manu-facturing	HR[2]
	Multiple case-study analysis of quality management practices within UK Six Sigma and non-Six Sigma manufacturing small- and medium-sized enterprises	Proc. IMechE Vol. 223 Part B: J. Engineering Manufacture	Kumar and Antony	2009	Journal paper	Case study (multiple)	QM ISO
SS3	Quantifying barriers to implementing Total Quality Management (TQM)	European Journal for Industrial Engineering	Raj and Attri	2010	Journal paper	Mathematical modelling	TQM

	An improved self-starting cumulative count of conforming chart for monitoring high-quality processes under group inspection	International Journal of Production Research	C. W. Zhang et al.	2012	Journal paper	Control charting technique	HQP[3]
SS4	The Barriers Affecting the Implementation of Quality Management System-ISO 9000 in Libyan Manufacturing Public Sector Organisations	Management Research Institute, School of Management, Faculty of Business and Informatics, University of Salford, UK	Sharif	2005	PhD thesis	Case study (multiple)	QMS-ISO 9000
	How supply quality management improves an organization's quality performance: a study of Chinese manufacturing firms	International Journal of Production Research	Lo et al.	2007	Journal paper	Empirical research	SQM[4] TQ[5]
SS5	Preparing to overcome the Barriers of Implementing a Quality Management System: a case study of EDB Card Services AS	UMEÅ School of Business	Sandström and Svanberg	2011	PhD thesis	Case study	QMS
	Integrated total quality management: Beyond zero defects theory and towards innovation	Total Quality Management	Matias and Coelho	2011	Journal paper	Integration	TQM, QMS, ISO 9000
SS6	Hurdles and barriers in implementing ISO 9000 Certification in small and	Indian Journals	Bhat[2]ti et al.	2013	Journal	Case Study	ISO 9000

[2] http://www.indianjournals.com/glogift2k6/glogift2k6-1-1/theme_2/Article%202.htm

	medium enterprises (SME) in Punjab state (India)[1]						
SS7	Enablers and barriers of implementing ISO 9001 – quality management system (QMS) in the service sector in Sir Lanka	International Research Sessions, Sri Lanka	Jayasundara and Rajini	2014	Journal paper	Survey	ISO 9001 QMS
	Methodology for quality management of projects in manufacturing industries	Total Quality Management	Milunovic and Filipovic	2013	Journal paper	Modelling	QM[6]
	Successful implementations of MES in Korean manufacturing SMEs: an empirical study	International Journal of Production Research	Lee et al.	2012	Journal paper	Empirical study	MES[7]
SS8	Critical Factors to Quality Management System Implementation: relevant literature review 1992-2012	Industrial and Systems Engineering	Almeida et al.	2014	Conference	Literature Review	ISO 9001 QMS
	An on-time delivery improvement model for manufacturing organisations	International Journal of Production Research	Karim et al.	2010	Journal paper	Case study	OTD[8]
	Coordinating quality, production and sales in manufacturing systems	International Journal of Production Research	Ioannidis et al.	2004	Journal paper	Modelling	QC[9]
SS9	Critical factors affecting the implementation decisions and processes of ISO quality management systems in Taiwanese public sectors	Institute of Public Affairs Management, National Sun, Taiwan	Chu and Wang	2000	Article	Empirical Study	ISO QMS

[1] http://www.indianjournals.com/glogift2k6/glogift2k6-1-1/theme_2/Article%202.htm

SS10	Factors Affecting Successful Implementation of ISO 9001: 2000	In proceedings	Sharp et al.	2005	Article	Case Study	ISO 9000
	The barriers to realising sustainable process improvement: A root cause analysis of paradigms for manufacturing systems improvement	International Journal of Computer Integrated Manufacturing	Hicks and Matthews	2010	Journal paper	Review	MI[10]
	An integrated model for optimisation of production and quality costs	International Journal of Production Research	Abdul-Kader et al.	2010	Journal paper	Modelling	QO[11]
	Quality improvement supported by the 5S, an empirical case study of Mexican organisations	International Journal of Production Research	Ablanedo-Rosas et al.	2010	Journal paper	Empirical study	QI[12]
SS11	Benefits, barriers and pitfalls coming from the ISO 9000 implementation: the impact on business performances	WSEAS Transactions on Business and Economics	Cagnazzo et al.	2010	Journal paper	Survey	ISO 9000
	Diagnosing and prognosticating the quality movement – a review on the 25 years quality literature (1987–2011)	Total Quality Management	Dahlgaard-Park et al.	2013	Journal paper	Review	TQM
SS12	Overcoming barriers to sustainable implementation of the ISO 9001 system	Managerial Auditing Journal	Zeng et al.	2007	Journal paper	Survey	ISO 9000
SS13	Organizational behaviour barriers in implementing ISO 9000 within the Malaysian local governments	Elixir International Journal	Abdullah et al.	2012	Journal paper	Survey	ISO 9000

SS14	ISO 9000: Motivations and Difficulties do they relate?	University of Twente	Jansen	2008	PhD Thesis	Literature and Empirical Studies	ISO 9000
SS15	An Evaluation of Obstacles Preventing Implementation of TQM in Libyan Organisations	Business and Management Research Journal	Saïdani & Shibani	2012	Journal paper	Literature Review and Survey	TQM
SS16	Analysis of interaction among the barriers to total quality management implementation using interpretive structural modeling approach	Benchmarking: An International Journal	Talib et al.	2011	Journal paper	Modelling	TQM
SS17	An Empirical Study of Barriers in Implementing Total Quality Management in Service Organizations in Pakistan	Asian Journal of Business Management Studies	Khan	2012	Journal paper	Empirical	TQM
SS18	Barriers to Implement TQM in Japanese Way: A Study on Companies in Malaysia	International Review of Business Research Papers	Shaari	2010	Journal paper	Mixed method	TQM
	Quality prediction for reconfigurable manufacturing systems via human error modelling	International Journal of Computer Integrated Manufacturing	Elmaraghy et al.	2008	Journal paper	Modelling	QP[13] RMS[14]
SS19	The existing barriers in implementing Total Quality Management	UBBCLUJ, Romania	Catalin et al.	2014	Research paper	Literature study	TQM
SS20	Barriers and benefits of Total Quality Management in the construction industry: evidence from Turkish contractors	Research/Expert Conference with International Participations	Polat et al.	2011	Conference paper	Survey	TQM
SS21	Barriers in the implementation of Total	Jurnal Teknik Industri	Amar and Zain	2002	Journal paper	Survey	TQM

	Quality Management in Indonesian manufacturing organizations						
	The practices of integrating manufacturing execution systems and Six Sigma methodology	International Journal for Advanced Manufacturing Technology	Hwang	2006	Journal paper	Integration	MES[7]
	Evaluating the Relationship and Influence of Critical Success Factors of TQM on Business Performance: Evidence from SMEs of Manufacturing Sector	The IUP Journal of Operations Management	Kaur and Sharma	2014	Journal paper	Empirical study	TQM
SS22	Barriers to TQM Implementation within a Private Medical Services Organizations in Saudi Arabia	International Journal of Business Administration	Alsughayir	2014	Journal paper	Survey	TQM
SS23	Impact of organization culture on TQM implementation barriers	Brunel Business School, Brunel University	Al-Jalahma	2012	PhD Thesis	Survey	TQM
SS24	Breaking Through Barriers to TQM Effectiveness: Lack of Commitment of Upper-Level Management	Total Quality Management	Soltani et al.	2005	Journal paper	Literature survey	TQM
	Simulation study of coordinating layout change and quality improvement for adapting job shop manufacturing to CONWIP control	International Journal of Production Research	Li	2010	Journal paper	Simulation modelling	QI[12]
SS25	Exploring the Barriers and the Level of TQM Implementation in	Research Journal of Applied Sciences, Engineering and Technology	Tey and Loon	2014	Journal paper	Survey	TQM

	Malaysian Construction Industry						

Coded*: Selected studies (SS) for synthesising

CPI[1]: Continuous performance improvement
HR[2]: Hybrid remanufacturing
HQP[3]: High-quality processes
SQM[4]: Supply quality management
TQ[5]: Total quality
QM[6]: Quality management
MES[7]: Manufacturing execution systems
OTD[8]: On-time-delivery
QC[9]: Quality control
MI[10]: Manufacturing improvement
QO[11]: Quality optimisation
QI[12]: Quality improvement
QP[13]: Quality prediction
RMS[14]: Reconfigurable manufacturing systems

In seeking to profile the potential factors that inhibit the implementation of QMS, TQM and or ISO 9000 series standard across manufacturing organisations in Africa, Asia, Europe, and the Middle East, the selected studies (SS1–SS25) were reviewed. The types of barriers to the implementation of QMS-TQM-ISO 9000 series standard, are indexed in the matrix (see Table 2.6).

Table 2.6: Barriers to QMS-ISO 9000 standard & TQM implementation

Types of barriers ($T_{(B)}$) inhibiting QMS-TQM-ISO 9000 series standard implementation				
$T_{(B)}$ I	**$T_{(B)}$ II**	**$T_{(B)}$ III**	**$T_{(B)}$ IV**	**$T_{(B)}$ V**
Personnel Culture	**Organisational Strategy**	**Organisational Behaviour**	**Performance Measurement**	**Technical**
Personnel resistance; Limited or no knowledge in quality systems; QMS, TQM and ISO 9000 series requirements deemed unrealistic; Inability to change organisational culture; Unmotivated; Lack of learning and development training programme; Lack of team-building and team orientation; Lack experience to perform internal audits; Lack of leadership; Lack of qualified personnel; Negative perception or attitude towards quality among employees; Lack of involvement, cooperation and commitment; Absenteeism; Employees not interested in organisation's future; Lack of adequate time; Weak personnel participation; Lack of leadership for quality; Weak labour strength.	Rigid towards technological change; Poorly defined organisational objectives; Complacency; Absence of mechanisms for continuous improvement and advancing strategies; Appropriateness of financial resources; Lack of long-term developmental policies; Short-sightedness; Lack of implementation planning; Lack of communication; Difficulty in allocation of personnel responsibilities and authority; Lack of guidance for registration; Lack of financial resources for quality; Difficulty in fulfilling quality requirements; Lack of motivation system; Conflicting policies; Inadequate resources; No benchmarking; Strategic plan excludes quality.	Lack of top management commitment; Inadequate appreciation of quality tools; Non-ductile culture; Resistance; Apathy of staff and top management; Weak interdepartmental relations; Instability of senior managers; Lack of personnel with know-how to perform internal audits; Top administration complexity; Absence of consulting boards; Lack of employee training programmes; Opposition to external auditing; TQM, QMS standard misconceptions; Lack of effective communication; Lack of recognition or rewards system; Difficulty in allocation of personnel responsibilities and authority; Problems regarding role of quality auditors; Difficulty in developing documentation; Improper control of documents and data; Lacking organisational structure;	Lack of mechanisms for performance appraisal; No access to data and results; Lack of quality monitoring systems; Lack of attention to the indices of performance; No customer feedback platform; Lack of attention to the needs of internal and external stakeholders; Difficult to perform internal audits; Lack of related information; Lack of customer's voice; Lack of documentation; Lack of supplier control and cooperation; Scarcity of resources; Lack of benchmarking; Difficulty to quantify cost of poor quality.	Culture of unscheduled and non-conformance to international standards; QMS, TQM and ISO 9000 series standard tools deemed too technically challenging; Non-utilisation of TQM, QMS and ISO 9000 series standard methodologies; Lack of tools and equipment; Absence of facilities for quality systems; Problems related to instruments, equipment and tools; Missing benefits of obtaining certification; Difficult of calibration; Inadequate technology; Nonconformities and lead time; Infrastructure; No benchmarking; Lack of quality measurement.

		Lack of awareness; Bureaucratic; Wrong people in wrong positions; Time and resource consumption; Conflicting policies; Lack of customer satisfaction.		

Although Amar and Zain (2002), Awan and Bhatti (2003), Curry and Kadasah (2002) found a strong correlation between ISO 9001:2000 standard and TQM, and Goetsch and Davis (2000) reported a compatibility between QMS–ISO 9000 and TQM, QMS-based SS5 failed to adequately respond to TQM-oriented RQ_2 without resorting to making assumptions. In analysing the study, the ranking of the dependence power in Table 2.7 shows that lack of top management ($T_{(B)}$III), personnel ($T_{(B)}$I), and organisational ($T_{(B)}$II) commitments are evidently the most dominant human-driven barriers to QMS-TQM implementation.

Table 2.7: Ranking by Frequency of Occurrence of $T_{(B)}$

Source	Barriers inhibiting QMS-TQM-ISO 9000 series standard implementation						
SS	**$T_{(B)}$I**	**$T_{(B)}$II**	**$T_{(B)}$III**	**$T_{(B)}$IV**	**$T_{(B)}$V**	**Driving Power**	**Rank**
SS1	1	1	1	1	1	5	I
SS2	1	1	1	1	1	5	I
SS3	1	1	1	1	1	5	I
SS4	1	0	1	0	1	3	III
SS5	1	1	1	0	1	4	II
SS6	0	1	1	1	0	2	IV
SS7	1	0	1	0	1	3	III
SS8	1	0	1	0	1	3	III
SS9	1	0	1	0	1	3	III
SS10	1	1	1	1	1	5	1
SS11	1	1	1	0	1	4	II
SS12	0	1	0	0	1	2	IV
SS13	1	1	1	0	0	3	III
SS14	1	1	1	0	0	3	III
SS15	0	1	1	1	1	4	II
SS16	1	1	1	0	1	4	II
SS17	1	1	1	1	1	5	I
SS18	1	1	0	1	0	3	III
SS19	1	1	1	1	0	4	II
SS20	1	0	1	1	0	3	III
SS21	1	1	1	0	0	3	III
SS22	1	1	1	1	0	4	II
SS23	1	1	1	1	1	5	I
SS24	1	0	1	1	1	4	II
SS25	1	1	1	1	1	5	I
Dependence Power	22	19	23	14	17		
Rank	II	III	I	V	IV		

The appraisal of the studies revealed a total dependence power of 95 barriers, dominated by the top ranked three ($T_{(B)}$III, $T_{(B)}$I and $T_{(B)}$II respectively) contributors, within which are embedded 59 common barriers that hinder the execution of QMS-ISO 9000 in Africa, Asia and the Middle East. Twenty-four (24) and nineteen (19) internally- and externally-induced impediments are potential barriers to TQM and QMS respectively; and at least fifteen (15) significant misconceptions are reported about the ISO 9000 certification, equalling the same number of opposing quality indices particularly in the Middle East. With respect to the factors that are deterrents to the implementation of QMS-TQM-ISO 9000 series standard, the ranking of the dependence power shows that lack of top management commitment (featured in $T_{(B)}$III), employees' apathetic approach (which is an element of $T_{(B)}$I) to change, and uncompromising organisational culture (which is descriptive of $T_{(B)}$II), are evidently the most dominant behavioural barriers.

Table 2.7 further reveals that $T_{(B)}$III, $T_{(B)}$I and $T_{(B)}$II present the most significant systemic human factors that potentially dictate the dynamics of the organisation's approach to quality, implying that there is a need to require top management to stimulate personnel to champion the quality cause as the first layer initiative of a quality framework implementation. This suggests the need for the latter to seek to identify the relational characteristics that coordinate top management's influence on driving quality systems and the strength of interdepartmental relations. Measuring the relationships between the fundamentally social factors (human-based variables) can lead to determining the correlation between the dependent variables (internal and external stakeholders, and the manufacturing environment) and independent variables (organisation-wide interconnected quality process) to characterise the regression paths between the 2-class variables. These assertions, coupled with the variations in the matrix of Table 2.6, which cause a deviation from the nominal quality value, informed the process mapping for the development of the proposed QX Framework in Chapter 3. The need to feature a mitigation solution against the human activity-induced barriers to quality system implementation in automotive manufacturing SMEs.

2.4.3 Quality deployment function (QFD)

Quality Function Deployment (QFD) is a customer-centric decision-driven comprehensive product development matrix that maps out product manufacturing parameters against customer specifications. It follows from Aswad (1989), Gentili E. et al. (2008), Lewis and Samuel (1991), Qattawi et al. (2013), and van de Poel (2007) that the layout of the QFD matrix is designed to identify and quantify the voice of the customer (VOC) and translate them into key critical input data or engineering characteristics (EC) for the manufacturing process, leading to product output parameters that satisfy the product target characteristics at a minimum manufacturing cost.

The manufacturing objective of the QFD methodology is to enhance quality, reduce lead time in both the automotive manufacturing and delivery at minimum cost, and most essentially achieve product conformance to customer specifications, as meeting such satisfaction can lead to a guaranteed market share and profitability (Davis, 1988; Lamers et al., 2008). In translating the VOC into a tangible product that falls within the desired target quality characteristic, a QFD matrix typically follows the steps the author has described in Algorithm 2.3.

Algorithm 2.3:

Quality Function Deployment (QFD)

Step 1.	Perform the QFD benchmark that features plausible design parameters (DP) to ensure the consumer automobile product conforms to product quality specifications or engineering outputs, $Y_1,\ldots,Y_q$ that satisfy the customer requirements (CR) or desires such as fast, mile per gallon economy, safety, big in size, reliable, reasonably priced, etc., or inputs, $x_1,\ldots x_m$. This stage essentially translates CR into development/performance metrics that constitute the critical to quality (CTQ) required to set the design/quality characteristics, process parameters and fulfil production planning targets.
Step 2.	Setup the engineering parameters, featuring the components that can be measured and designed. These constitute controllable or physical parameters such as dimensions, weight, engine with respect to power, expected life, manufacturing resources and cost, speed, etc., that are necessary to meet parts deployment targets.
Step 3.	Set values on the engineering parameters necessary for optimisation to meet manufacturing process targets. This activity entails setup of default targets for $Y_1,\ldots,Y_q$, where inputs will have targets.
Step 4.	Gauge process output parameters in relation to process input parameters to estimate the correlations between them in filling roof matrix of the House of Quality (HoQ). The latter does factor in the trade-offs between the various DPs based on the interrelationships between them, leading to meeting the manufacturing requirements targets.
Step 5.	Review the QFD diagram and conduct performance analysis through assessing correlation between manufacturing competitive factors necessary to guide revision and optimisation of manufacturing strategy development.

As *Step 1* of Algorithm 2.3 relies mainly on the VOC of a public transport under consideration, for example, it is worth noting that if the questionnaire for information gathering does not feature an exhaustive list that leads to customer satisfaction, then the reliance on varied statistical survey results will lead to a failed product and a financial loss to the QFD-practicing automotive manufacturing organisation. This approach does also not fully account for the consumer's varying requirements and those of government regulatory bodies, whose observations can lead to recalls (Ruan et al., 2002).

In relating engineering metrics to parts characteristics in *Step 2*, which requires that engineering metrics should be related to parts characteristics, the QFD approach reveals difficulties in using a tool for micro-electro-mechanical systems (MEMS), for example. This is because most MEMS do not have physical 'parts' that are assembled into a final device but rather have product specifications and a manufacturing process designed to create the product (Lamers et al., 2007, 2008). In agreement with Lamers et al. (2008), the knowledge gained will help in identifying process parameters for an integrated QFD in the context of optimising QFD to relate engineering metrics to design and process concepts in the proposed QX Framework in Chapter 3, if found plausible to extract contributory input data.

Once the ECs are optimised in *Step 3* for an enhanced manufacturing process in *Step 4* to meet targets, the QFD process will not be able to adequately accommodate any further customer's eventual variations as per the original requirements or specifications. An attempt to resolve any missed customer requirement adds to an already large complex matrix size and time-intensive QFD process. This alludes to a QFD matrix's failure to satisfy all customer segments, prioritise customer requirements and fulfil engineering characteristics. These lead to a number of constraints in time, finance and operational risks.

The insights gained from the above QFD drawbacks and methodological problematic issues (Kazemzadeh et al., 2008; ReVelle et al., 2019; Tan & Shen, 2000) will help guide the formulation of the input data variables required to integrate the proposed QX Framework with a flexible but optimised QFD component.

2.4.4 Axiomatic design framework

Axiomatic Design (AD) is described as a logical and systematic synthesis quality-oriented tool, process or framework (Suh, 1990). An AD is typically mapped across four design domains (Suh, 1990, 1999, 2001, 2005) consisting of:

- the *value-adding* customer attribute (CA) domain,
- the functional requirement (FR) domain - what it does,
- the design parameter (DP) domain – what it looks like in the physical, and

- the process variable (PV) domain – manufacturing process mapping while taking into consideration the constraints or what needs to be avoided.

Hinged on the Independence Axiom (Axiom 1), which needs FR to maintain independence (i.e. adaptability to change), and the Information Axiom (Axiom 2) which is necessary to minimise the information content of design in order to achieve robustness (Flowers & Cheng, 2012; Goo et al., 2019; Heo et al., 2007; Makarov, 2013; Pallaver, 2005; Suh, 1990, 1999, 2001, 2005), the implementation of an AD process follows the steps the author has described in Algorithm 2.4.

Algorithm 2.4

Axiomatic Design (AD)

Step 1.	Cross-functional engineering design team identifies critical-to-customer (CTC) specifications (CA) and translates them into ECs.
Step 2.	Thoroughly study the CA domain to map out the nFR, which are the attributes to resolve in order to meet the customer's desires.
Step 3.	Use nFR to determine nDP in the physical domain. Perform $FR \rightarrow DP$ mapping by analysing and synthesising the nFR and where necessary decomposing FR_n to FR_{nm} in order to map out the plausible nDP required to satisfy nFR. The decomposition process, which is essentially extracting sub-FRs or $(FR)_{mn}$ and their corresponding how-to-achieve-the-FR sub-DPs or $(DP)_{mn}$ is iterated until a desired manufacturing engineering design level is reached. Ideally, each FR requires a corresponding DP, for $nFR \gg nDP$ is an agent of coupled design and $nDP >> nFR$ leads to a cost-biased redundant design. The latter two are undesirable (Suh, 2003).
Step 4.	Create system architecture by performing $FR \rightarrow DP$ hierarchical upper and lower levels relationship analysis between domains in matrices with respect to associated design matrix $[A]$, required to determine mutual interferences and design evaluation, and governed by the matrix notation or design equation below: $\{FR\}_{m\times 1} = [A]_{m\times n}\{DP\}_{n\times 1}$where the characteristics of the domain $\{FR\}$, and co-domain $\{DP\}$, have their usual meaning, and the $[A]$ may be diagonal or uncoupled design, triangular or decoupled design, or a full matrix denoting a coupled design (Suh, 2003).

Contrary to manufacturing systems designed on the basis of heuristics in which the validation process is generally cost-intensive and stochastic, satisfying the two axioms of AD maximises the probability of success in satisfying the nFR and provide the roadmap required to minimise the validation (Heo et al., 2007). This follows that non-value-added iteration and "unwanted coupling" must be avoided or removed from the DP to satisfy Axiom 1 and subsequently apply directly to Axiom 2 in order to increase the probability, $P_{\{m\}}$, of satisfying all mFR of a system I_{sys} subject to constraints (Suh, 2005) expressed in (2.1).

$$I_{sys} = -\,log_2 P_{\{m\}} \tag{2.1}$$

In the manufacturing scenario (process or production) where it becomes imperative to increase the information content in an attempt to deliver a product that has a large number of features or desirables, the system approaches a dynamic complexity with entropic measurement H as seen in the example equation (2.2) for a manufacturing process (Flowers & Cheng, 2008). This introduces increased constraints with associated maximised risk in the design process (Hintersteiner & Zimmerman, 2000) and subsequently violates Axiom 1. Under such information-intensive content DP manufacturing scenario, the nFR supersedes nDP. This will not only result in a usually undesired coupled design system and cause a departure from achieving a robust design (B. S. El-Haik, 2005), but it will also be difficult to both manage and replicate the process (Fujimoto, 2001a, 2001b; Nakao, 2016; Takeishi et al., 2001).

$$H(S) = -\left\{PlnP + (1-P)ln(1-P) + (1-P)\left[\sum_{M^b}\sum_{N_j^b} p_{ij}^q lnp_{ij}^q + \sum_{M^q}\sum_{N_j^q} p_{ij}^m lnp_{ij}^m + \sum_{M^m}\sum_{N_j^m} p_{ij}^b lnp_{ij}^b\right]\right\} \tag{2.2}$$

where

p^q – probabilities of queues

p^m – probabilities of machine running (non-redundant)

p^b – probabilities of non-programmable states (e.g. rejects, errors, rework, breakdown)

M – number of resources

N_j – number of states at resource j

The above complexity can occur when the probability of success is low for a design, in which case the information content (I_{sys}) required to satisfy the mFR is high (Suh, 2005). From a design standpoint and contrary to (2.2), uncoupled design is usually desired in AD while information is minimised in the DP in order to achieve the ideal design required to satisfy all nFR. This enables poorly configured parts or errors and constraints to be easily identified, modified and implemented, ensuring adjustability or adaptability to change in nFR

(Hintersteiner & Zimmerman, 2000; Suh, 1990, 2001). Although the above engineering merit of AD is expected to translate into optimising both manufacturing resources and business processes in general, Fujimoto's (2001a, 2001b) and Takeishi et al.'s (2001) findings claim that uncoupled design rather exposes Japanese manufacturing organisations to undue disadvantage as their competition renders it easy to imitate their products. The Japanese manufacturing industrial competitive experiential insight with regards to coupled design being preferred, among some of the leaders in manufacturing, over the supposedly merit-driven decoupled design led to the assertion that AD is viewed as misleading among some within Japan's automotive manufacturing sector (Nakao, 2016).

As a key component of this study is to identify application inadequacies in existing quality tools to enable optimisation for their integration within the proposed QX Framework, the information on the triggers of complex process design that leads to the nature of (2.2), Fujimoto's (2001a, 2001b), Takeishi et al's (2001) and Nakao's (2016) findings on the demerit assertions made by the automotive manufacturing sector in Japan, for example, present a necessary opportunity to feature design parameters to address such quality issues within the proposed QX Framework in Chapter 3. Of particular interest to this review is to feature processes that will mitigate the occurrence of the nature of disadvantages identified in the studies of Fujimoto (2001a, 2001b), Takeishi et al. (2001) and Nakao (2016).

2.4.5 Taguchi's robust design method

Taguchi's Robust Design Method (TRDM), which has been applied successfully in optimising the performance of an automotive product (Ibrahim et al., 2019; Luangpaiboon et al., 2010; Samantaraya et al., 2018) and automotive manufacturing process (Mondal et al., 2014; Parker, 2020; Sohal & Howell, 1998), relates primarily to modeling the quality losses within the product or process specification limits (Devor et al., 1992; Zhou et al., 2019).

TRDM seeks to setup a robust design in which the manufacturing process will not only stay within the specifications but also centres on the quality target, in that any time the process deviates from the target, there is a loss to the customer (even if the process remains within the specifications) (Mondal et al. 2014; Zhou et al., 2019). This leads to the deduction that if the processes are reliable, then it will translate into a reliable outcome. To achieve this, TRDM models, featuring the controllable factors (such as CTQ-based FRs) and the performance-biased noise (N) factors (including uncontrollable factors such as humidity, rains, storms, temperatures, customer usage pattern, etc.), should have the objective that the design process does not only satisfy the customer specifications but also the process mean meets the target

(Mitra, 2011; Mondal et al., 2014). This indicates that any time the process mean deviates from the target and there is a process variance, a quality loss is apparent, leading to the formulation that quality loss (L), which is a function of the process output (Y), is proportional to the square of the deviation from the target (t), as expressed in (2.3) (Y. Zhang et al., 2019):

$$L(Y) = \left(\frac{M}{D}\right)(Y - t)^2 \tag{2.3}$$

where M – monetary loss to the manufacturer when the process departs from the specifications

D – customer-defined tolerance, that views product as defect

t – target for the process as a CTQ index

Y – process mean/value or output

and $\left(\frac{M}{D}\right)$ is the proportionality constant.

In Taguchi's view (Zhang et al. 2019), the quality loss is not only described by a deviation from the target value but also due to the variance in signal control factors (for example, an accelerator), leading to the average quality loss, Q_a, per unit of a product sample about the mean, μ, and standard deviation, σ, given by (2.4):

$$Q_a = \frac{M}{D} = [(\mu - t)^2 + (\sigma)^2] \tag{2.4}$$

where $(\mu - t)$ is a deviation of the mean, μ, from the target, t.

Taguchi's concept of robust design follows that as variability is embedded in all operations, it is a desired quality parameter to create automotive products through manufacturing processes that are not too sensitive to controllable factors (Ree et al., 2014). This leads to the formulation of the loss function, influenced by the larger-the-better (LTB), smaller-the-better (STB) or target-the-best (TTB) quality characteristics. In his development of the Quality Loss Function, Taguchi et al. (2004) stated that:

> *"The larger-the-better characteristic should be nonnegative, and its most desirable value is infinity. Even if the larger the better, a maximum of nonnegative heat efficiency, yield, or nondefective product rate is merely 1 (100%); therefore, they are not larger-the-better characteristics. On the other hand, amplification rate, power, strength, and yield amount are larger-the-better characteristics because they do not have target values and their larger values are desirable" (p. 21)*

The above statement implies that:

1. The quality characteristics that have a maximum possible target of 100% are not LTB, and
2. The quality characteristics that do not have target values but desirable larger values are LTB-based.

Depending on the type of quality characteristic (LTB, STB, TTB) under consideration for a manufacturing process, a quality-based performance measure known essentially as signal-to-noise (S/N) ratios is used to determine optimal settings of the controllable factors (Mitra, 2011; Sharma et al., 2007). Although TRDM seeks to alleviate poor quality-stimulated monetary losses, it is practically a Herculean task to both interpret Taguchi's dimensionless S/N ratios, particularly for automotive manufacturing systems with large number of quality characteristics and correlate them to revenue goals. By TRDM concept, the need to maximise S/N ratios or consider more than a single response or quality characteristic can translate into both compromised revenue and ambiguity in decision-making. This presents a controversy in that, although TRDM seeks to address financial losses to the customer each time the process deviates from the target or customer specifications, the cumbersome approach to alleviating the quality indicators or vQDD can actually result in monetary loss to the manufacturing organisation.

TRDM is modelled on both controllable and noise factors, with the desire for the control factors to far exceed the noise factors in order to identify and significantly reduce the latter. This approach is intended to minimise the impact of variation, response, and neutralise noise to ensure the process mean remains at the target. However, Taguchi's inability to exhaustively explore control-by-control factor interactions leads to the deduction that other methods, such as Robust Design based on Profit Maximisation (RDPM), which have the capability to capitalise on control-by-control factor interactions within large systems, can yield far more and reliable robust settings compared to TRDM (Devor et al., 1992).

As TRDM does not entertain randomisation, it therefore requires that the experimenter must have an expert knowledge in the technique to be able to identify the significant factor interactions. However, as Taguchi Methods are not prominently a featured core part of university taught curriculum, automotive manufacturing SME personnel will be required to invest in specialist training in TRDM. Such cost-based investment can cause an additional financial loss in the event of the abrupt departure of the trained personnel from the organisation.

2.4.6 Lean and Six Sigma

One of the major challenges automotive manufacturing SMEs face is how best to improve the manufacturing and delivery process while providing value to the customer. In order to address these challenges, manufacturing organisations incorporate two of the most popular quality management systems called Lean and Six Sigma (6σ). The integration of Lean with 6σ is among the prominently sought quality principles used by Indian multinational manufacturing corporations to not only improve manufacturing processes but to also survive the competition (Krishna et al., 2008). Lean is a concept designed to eliminate non-value added (NVA) activities or waste (defects, overproduction, unnecessary inventory, high cycle times, unnecessary movement of people or equipment, over-processing, etc.) from the manufacturing process (Rahani & Al-Ashraf, 2012; Rose et al., 2014). Six Sigma (6σ) is a data-driven methodology with focus on making a manufacturing process effective with 99.99996% defect-free or producing 3.4 defects or less in one million opportunities (Raju et al., 2014; Sambhe & Dalu, 2011b, 2011a).

In applying the 6σ methodology to reduce the defects or variation in the headlining process of automobile parts manufacturing, for example, Rittichai and Chutima (2016) adopted a cause-and-effect matrix, FMEA and 2^{k-1} fractional factorials design to screen the potential factors that cause quality to fall OOS from the expected values in the headlining. Rittichai and Chutima's (2016) work resulted in the reduction of defects of headline from 12.21% to 6.95%. This is about 50% improvement in quality, suggesting the difficulty in achieving the 3.4 defects in a million opportunities that 6σ targets. Such scenario inspires the need to examine the efficiency, adequacy, objectivity of 6σ practices, and subsequently integrate the method with other quality systems (Cox et al., 2013).

Sambhe and Dalu (2011a) took a quantitative approach to design a research methodology they used to explore the status and imminent factors for evaluating the feasibility of 6σ implementation at a sample population of 30 Indian automotive manufacturing SMEs over the period of 2009 to 2010. Sambhe and Dalu's (2011a) study revealed diversified practices of traditional quality initiatives, featuring ISO 9000, TQM, Kaizen, and many others, interfaced with observable poor implementation schemes of 6σ in the Indian SME automotive sector. In a similar scenario in which the effective implementation of 6σ methodology within UK automotive manufacturing SMEs had been considered as poor, A. Thomas & Lewis, (2007) developed and applied a combination of Total Productive Maintenance (TPM) and 6σ strategy in an SME manufacturing sector as an attempt to mitigate imminent major critical-to-quality (CTQ) issues.

Sambhe and Dalu's (2011a) comparative data analysis identified parameters such as 6σ training programmes, top management key responsibilities, performance metrics and a need for an organisation-wide practical knowledge in existing complementary quality tools as the premise to implement 6σ methodology within automotive manufacturing SMEs. A. Thomas and Lewis's (2007) work mapped out the optimum parameter settings and maintenance activities required to alleviate CTQ problems, leading to achieving significant improvements in product quality. However, both Sambhe and Dalu (2011a), and A. Thomas and Lewis' (2007) studies failed to design a deployment roadmap for a robust implementation of 6σ methodology to adequately address general cases within the industry. In agreement with Kazmierski (2015), the gaps within both studies include a missed opportunity to study group dynamics such as the behavioural differentiation and the integration process of achieving unity of groups toward a common goal, a developed quasi-experimental study for an enriched define-phase of the 6σ methodology, and a qualitative study to better understand the conditions that influence significant differences in respondents from different sectors that operate within the same automotive domain.

To demonstrate how other quality tools can be used within the 6σ framework to optimise objectivity and efficiency in achieving high quality in products, Cox et al. (2013) introduced the Process Variation Diagnosis Tool (PROVADT), which subsequently applies a Gage R&R and Provisional Process Capability to fulfil the *Measure* and early *Analyse* phases of the Design Measure Analyse Improve Control (DMAIC) process improvement cycle. Cox et al.'s (2013) approach makes it possible, for example, for Clue Generation associated quality techniques such as a Shainin Multi-Vari study (S. Sharma & Chetiya, 2009) and Isoplot to be obtained to enable further analysis without requiring additional samples of automobile parts or products. However, although the PROVADT method is effective in improving a manufacturing process, this is limited to small badges or samples particularly in low volume high value manufacturing.

As quality drawbacks or defects in a product are likely to occur during the design phase of the 6σ method, this introduces in-built constraints to the manufacturing process. This suggests that improving a product during the design phase is plausible than attempting improvement during the post-design phase. To alleviate this occurrence, Suresh et al. (2016) proposed a pre-emptive requirement of taking a Design for Six Sigma (DFSS) approach to product development at the early stage of the design phase of 6σ. In applying DFSS for design improvement to an automotive component, for example, Suresh et al. (2016) introduced the use of the Identify, Define, Optimise and Validate (IDOV) phases as an added feature to enhance the automotive manufacturing process. Defining the DFSS concept as a framework to guide the design of an automotive component and get the manufacturing process right the first time, B. Zhang (2007) considers TRDM a critical quality tool as a design optimisation feature in any DFSS-based project. This selection is in line with Park and Sohn's (2005) view of developing an advanced strategy in selecting an optimised product design and manufacturing process that is insensitive to various multivariate variations (such as a Monte Carlo variation-based simulation that integrates Mohalanobis Distance (MD) method). However,

1. B. Zhang's (2007) use of the discriminant analysis technique-based MD method to detect and analyse the manufacturing variation patterns in comparison with
2. Suresh et al's (2016) proposed IDOV phases within the DFSS concept, and that of
3. Gijo and Scaria's (2014) use of TRDM and Beta correction to synergistically optimise 6σ

reveal that there is no one single tool to optimise 6σ as a standalone, thus creating the opportunity to combine lean and 6σ that removes the complexities and failures encountered in the separate deployment of lean and 6σ methodologies.

Lean Six Sigma (LSS)

Lean Six Sigma (LSS), a combined methodology of both lean manufacturing — a concept designed to provide value to the customer by eliminating waste from the manufacturing process, reducing cycle time and focusing on continuous improvement (Salleh et al., 2011; Verma & Sharma, 2015) - and 6σ — a concept to significantly reduce variation in order to optimise the manufacturing processes (Kęsek et al., 2019; Sambhe & Dalu, 2011a; Singh & Rathi, 2019; A. Thomas & Barton, 2006) - is so designed to help reduce product defects, eliminate nonconformance quality characteristics, maintain market share, improve profitability, process performance and bottom-line results of automotive manufacturing organisations (Narottam et al., 2020; Shokri et al., 2016). A typical LSS follows the steps the author has described in Algorithm 2.5.

Algorithm 2.5

Lean Six Sigma (LSS)

Step 1.	Determine the goals of the project and define value as per customer specifications, requirements and expectations.
Step 2.	Categorise process activities into non-value added (NVA), value-added (VA) and enabling value added (EVA).

Step 3.	Perform value stream mapping (VSM) to identify waste and agents of waste in the workflow and subsequently remove NVA activities to improve process and product quality. Continue to improve process performance with respect to what is CTC.
Step 4.	Create a Kaizan, 5S, TPM to ensure a continuous flow system that optimises the process efficiency.
Step 5.	Unless integrated in *Step 4*, introduce a Poke Yoke device to alert defects or failures in the process.
Step 6.	Introduce a just-in-time (JIT) scheme to promote a pull system that mitigates disruption that affects delivery time to customer demand.
Step 7.	Unless featured in *Step 6*, introduce SMED (single minute exchange of dies) to optimise equipment changeover time.
Step 8.	Introduce 5S for facility (cleaning) management while maximising profits and efficiency.
Step 9.	If required by the nature of the manufacturing process, introduce Jidoka as an intelligent automation to halt assembly or production whenever a defect occurs.
Step 10.	If required by the nature of the manufacturing process, introduce a Heijunka to evenly distribute the load by balancing the production lines.
Step 11.	Introduce Gemba for enhanced observation and corrections in real time to make room for EVA.
Step 12.	Introduce Kanban system to ensure continuous management of inventory to prevent compromised working capital at the production stage.
Step 13.	Measure the current unaltered process, identify the existence of any defects and map out the steps required to remove the root causes of the defects.
Step 14.	Perform continuous improvement by continually monitoring existing processes and conducting regular adjustments, where necessary, to control new phases or processes in order to optimise (future) performance and delivery.
Step 15.	If there is need to develop new processes or phases with the goal to achieve 6σ-based results (i.e. DFSS) to improve the overall performance and customer satisfaction, then perform a define-measure-analyse-design-verify (DMADV).

In exploring the integration of both lean and 6σ methodologies as an ideal unified quality and process optimisation tool to complement existing operations in automotive component manufacturing organisations within the Durban Automotive Cluster in the KwaZulu Natal district of South Africa, for example, Rathilall and Singh's (2018) preliminary study concluded that the organisations in the region reported a very low success rate of lean and 6σ methodologies as standalone systems. They cited a difficult-to-transition from theory to practice scenario.

While the combination of lean manufacturing and 6σ promises a complete set of quality tools to improve the efficiency and quality of both the product and associated processes, it is asserted that many UK automotive manufacturing SMEs are either not aware of or conversant with the 6σ methodology, and where they have some appreciable knowledge, they lack the resources required to implement 6σ-based projects (Antony et al., 2005). It can also be drawn from Antony et al. (2005, 2010) that 6σ on its own is not entirely robust since its causality component limits the user from studying and understanding feedback from other factors in the process improvement chain. This translates into the poor understanding of the dynamic behaviour of the quality improvement process. It is within such vein that some automotive manufacturing SMEs resort to reducing their limited practical appreciation of LSS by relying on SPC, a common technique associated with both, as a step to identify pre-production errors, leading to reducing scrap, process variability and customer complaints and thereby preventing nonconformities (Andrew et al., 2008; Mohd Rohani et al., 2006; Pascu et al., 2020).

2.5 Methods used for modeling quality systems

This Section reviews some of the methods used for modeling quality-based operations and identifies the limitations associated with each system's attempt to address potential quality issues. The methods adopted by the authors and associated limitations are presented in Table 2.8.

Table 2.8: Review of methods for modelling and implementation of quality systems

Author (year)	Method	Limitations
Asher (1992)	Developed TQM implementation framework, based on manufacturing and service operational requirements	Limited by existing data collection system for quality/customer feedback metrics
Husband & Mandal (1999)	Developed conceptual model derived wholly from literature review	Lacks data to validate the operational feasibility of the model
Yusof & Aspinwall (2000)	Developed conceptual framework for TQM implementation	Full extent of the demonstrability of the framework has not been ascertained
Tam et al. (2001)	Developed data flow analysis (DFA) modelling as business process modelling (BPM) methodology	Single case-study restricts the model's assessment for full capacity validation
Hansson & Klefsjo (2003)	TQM implementation model developed through multiple case studies	The operational dynamics of the model has not been explored fully in content
Thomas & Webb (2003)	Developed conceptual framework and model, a derivative of survey of manufacturing firms in the UK	The findings are limited to an outcome of a survey that was limited to only the UK population. Limited by one demographic, the framework can be flawed as it does not represent the general manufacturing population
Sharif (2005)	Conceptual framework developed based on four barrier categories derived from literature review	Model is limited to guiding research methodology
Jansen (2008)	An ISO 9000 system implementation model based on singular case study	Categorised into three main organisation-wide motivational and difficulty factors, which is not an isolated case in that the research is limited to a too small population to create an informed generalisation that is representative of the target audience
ISO (2009)	Instrumented a process model of the ISO 9000 family of standards to guide the manufacturing and service domain to deliver quality as promised	The process model approach indicates that organisations can use eight QMS principles to achieve continuous improvement. This will face challenges if an organisational top management decided not to place the model in an environment of continuous improvement
Skiti (2009)	Case-oriented quasi-qualitative and quantitative TQM implementation survey	Validation of the framework is narrow as case was tested in only one healthcare facility
Dassisti (2010)	A hybrid model for continuous performance improvement (CPI) oriented on BPR and continuous quality improvement (CQI) frameworks	Lacks systemic structure to stimulate objectivity
Kim et al. (2010)	Constructed a formal human-machine cooperative model based on the finite state automation (FSA) model	Although tested in a manufacturing system, the model does not exhibit the agility to coevolve with human operator complexities or demand pattern uncertainties
Colledani & Tolio (2011)	Developed performance of production systems evaluating analytical quality blueprint	The system is only an approximation as it does not feature a number of quality taxonomies that assess operational variables during significant changes in manufacturing system
Das (2011)	Proposed a global supply chain (GSC) model oriented on elements critical-to-quality (CTQ)	Although GSC is a novel approach to integrating QMS, a singular case study is not sufficient to surmise its wide applicability

Kumar et al. (2011)	Six sigma implementation framework	The framework has been tested in only three SME environments in a limited number of geographic locations, which limits its validation for robustness in other settings
Talib et al. (2011)	ISM-based model developed to profile hierarchy of TQM barriers	Besides the possibility to understand TQM barriers, the study does not explain how to operationalise the interpretive structural model (ISM) to alleviate TQM implementation challenges.
Al-Jalahma (2012)	Conceptual framework developed based on TQM literature review	Organisational culture constructs mapped onto six TQM implementation barriers exclude environmental or legislation requirements and organisation's inherent characteristics for own QMS
Li et al. (2012)	Constructed a queue network model	The system's ability to cope with solving a multi-dimensional Markov problem — an essential dimension for quality evaluation — has not been established.
Mahapatra et al. (2012)	Proposed mixed integer linear programming (MILP) based approach to determine optimum production plan	The integrated optimisation model processes approximate information. This can be erroneous as it does not have the intelligence to identify what constitutes precise or accurate information
Amin & Karim (2013)	Developed a mathematical model to evaluate and map out manufacturing waste stream	The robustness of the model with respect to the interdependencies relating to the manufacturing strategy (lean) and waste factors have not been investigated

As it is intended for the process mapping for the development of the proposed QX Engineering Framework to employ taxonomies of quality tools, this research draws lessons from the limitations identified in the methods used to model some of the quality frameworks presented in Table 2.8. These will help assist in further identification of agents of quality variations at the early design stage and implementation.

The development of a TQM framework can take a multifaceted approach based on the targeted highest level functional requirements across the manufacturing operations goals (Asher, 1992), implementation requirements as needed along specific manufacturing and supply chain (Yusof & Aspinwall, 2000), derivatives of benchmarking case studies (Hansson & Klefsjö, 2003) and survey data (Thomas & Webb, 2003), mixed-methods research findings (Skiti, 2009) and hierarchical process approach (Talib et al., 2011). As outlined in Section 2.4.2, the core culprits of barriers to TQM implementation are situated within the organisational culture and its interrelated cohorts such as personnel, top management and organisation-wide barrier constructs (Talib et al., 2011). As the behaviours of human actors within a social construction can create the quality culture within a manufacturing environment, the adversarial attitudes of the personnel within the hierarchical barrier construct expose the implementation to variations such as the limitations identified against author's work.

As the implementation procedures of TQM are an essential component for enriching the proposed new quality engineering framework, the research philosophy and research strategy (see Chapter 3) adopted for this research takes a concurrent transformative (multifaceted) approach to quantitative and qualitative data collection by surveying research participants from North America, Central Europe, Africa, Middle East and Asia. Of particular relevance to this research is that data extracted from both expert experiential perception and consumer perspective potentially avoids the customer feedback limitation propagated in Asher's (1992) method.

In developing the proposed QX Engineering framework, which is embedded with elements of TQM implementation, analysing extensive data from research participants of cohorts of experts engaged within automotive manufacturing organisations and of consumers of automobile products and services yielded relevant input parameters that are translated into functional requirements to achieve a more holistic quality engineering framework that:

(1) Presents a wider applicability and devoid of limited demonstrability (Yusof & Aspinwall, 2000)

(2) Offers a content-rich inclusive framework for increased operational dynamics, contrary to the limitations observed within Hansson and Klefsjo's (2003) adopted method.
(3) Selecting to adopt a non-probability sampling technique to survey research participants from across five (5) continents avoids the likelihood of limiting the framework to only a small segment of a UK demographics, for example. This applies to Thomas and Webb's (2003) work in which their conceptual framework may be susceptible to flaw by virtue of its limited applicability to the global automotive audience.
(4) Sharif's (2005) conceptual framework is developed based on four (4) barrier constructs derived from secondary data. This approach potentially limits the model due to the absence of primary data that can be extracted through interactive enquiry from the target group. While this research adopts Sharif's (2005) as an initial step to design the initial concept of the proposed new quality engineering framework, this research also identified additional input parameters from primary data provided by experts and consumers. The latter is used to optimise the initial QX design in Chapter 7, thus answering RQ3 and achieving RO4.

It is imperative that a quality process that is consistently devoid of variation or the limitations such as identified in Table 2.8 will translate into delivering functional quality in manufacturing systems. The highlights presented above as contributions of this research are aimed at seeking optimal but cost-effective quality engineering framework for manufacturing organisations (Ghobadian & Gallear, 1996; Goh & Ridgway, 1994; Mohd Rohani et al., 2006; A. J. Thomas & Webb, 2003).

2.6 Operational research approach to identifying quality issues

This Section examines five (5) out of 150 exemplary case studies of operational research methods used to identify quality issues across manufacturing operations. The methods, listed below, are inevitably somewhat disparate in their nature and impact but collectively can contribute to identifying inadequacies in existing methods for quality performance measures and implementation:

1. Case study analysis
2. Robust design product development methodology
3. Mathematical modelling
4. Conceptual product design
5. Cross-functional integration

2.6.1 Case study analysis

A case study can be described as an empirical inquiry (Yin, 2009) that

1. investigates a contemporary phenomenon within its real-life context, especially when
2. the boundaries between phenomenon and context are not clearly evident.

In seeking to provide an appreciable amount of information on real-life scenarios, a case study can take a multi-method approach by requiring hypotheses, research questions integrated with internal, external and construct validity and reliability to adequately address the research objective(s). Suitable for addressing the *why* and *how* research questions (Yin, 2009), case study is frequently used for qualitative analysis in social science research. However, the pattern of requirements during the past fifty years has forced the social sciences to become more "scientific" and quantitative (Friedman & Sage, 2004). Of particular interest is that a case-based study can reveal the human factor whose behaviour or interaction with the manufacturing system can influence the quality outcome.

> *Case 1: Bhuiyan, N. and Alam, N. (2005). A case study of a quality system implementation in a small manufacturing firm. International Journal of Productivity and Performance Management, 54(3), 172–186.*

This paper reports the use of case study to investigate the challenges, barriers and the outcome of implementing a quality system in a small-sized Canadian manufacturing company, ABC Structures (pseudonym), whose primary market is in North America. Although motivation for the study was derived from ABC's need of a QMS to satisfy the manufacturing company's requirements (internal force) to improve its quality processes, fulfil customer expectations (external force #1), pave the way for business expansion globally (external force #2), and to become ISO 9000 compliant, the case study also aimed to respond to existing research that has suggested that the ISO 9000 standard comes with major associated roadblocks and therefore may not be suitable for manufacturing SMEs.

Within the first nine months, the challenges and specific internal barriers that potentially impede the implementation of the quality system were identified. These findings were compared to an ISO-implementation-related empirical study, leading to the production of new procedures to guide the company to overcome the quality implementation hurdles. In particular, each of ABC's numerous mainly stainless steel-made products has its individual manufacturing process requirements. The most crucial manufacturing activity at ABC is gas metal arc and gas tungsten arc welding of raw materials, steel pipes and assembly accessories. As such, ABC was required to streamline its business processes, control conformances associated with their range of products, process and system, reduce rework, and inculcate a quality culture. In addition to using this information to formulate the quality framework, Bhuiyan and Alam (2005) adopted a multi-method approach to collect data from various sources including informal conversations and interviews with internal stakeholders, documents, plant tours, observations of the manufacturing process, and inspection of product samples.

Based on the data collected, an 8-step quality system implementation plan was developed to engender a systematic approach to the quality procedures. The eight steps comprised of (1) the gap analysis which determined the discrepancies between ABC procedures and the ISO 9000 standard and protocols to address the gaps; (2) in-house training in ISO 9000 to enable ABC personnel to understand the quality standard; (3) a cross-functional quality council (QC) served as the project management team; a management representative (MR) led the change; (4) quality policy and measurable objectives were developed to define and guide the milestones; a documentation of procedures was initiated; training of shopfloor personnel was considered; and (5) an internal audit was conducted to determine the gaps remaining for top management's review in the next QC meeting.

This case study of the systematic development of a quality system and implementation revealed a number of issues that needed to be addressed to comply with the ISO 9000 standard requirements. Prominent among ABC's challenges that were addressed included an optimised welding process; established preventive maintenance for ABC machines; development of a non-conformance-tracking system that leads to a quantitatively analytical conformance report to monitor quality failures and stimulate rework time-effectively; absence of internal inspection leading to recommended independent quality function for future implementation; and redesigned procedure for handling customer complaints. During the initial stages of the quality system implementation, certain organisational barriers, such as decision-makers' adherence to the status quo and reluctance to change, stimulated an all-talk-no-action attitude among many of the top managers, and hindered the implementation exercise.

Practical implication

Although the use of a single case-based multi-method approach to investigate the barriers to the implementation of QMS led to the development of an 8-step quality system implementation protocol, the validity of the method adopted is limited since data is analysed within only one organisation and not across different scenarios or multiple cases. This study would have led to a more enriched outcome if it had extended its data collection to the primary product stakeholders (external customers), indirect stakeholders (the environment within which the SME's products function) and environmental protection agencies. These can potentially reveal additional quality issues and subsequently lead to developing an objective determination of optimised new sets of procedures for an overall company-wide QMS framework that will not only satisfy the requirements of ISO 9000 but also reduce the many steps required for each product's manufacturing process.

2.6.2 Robust design method

Robust design is a subset of the design-and-test product development methodology and is suitable for making products resistant to variations in manufacturing processes and noise factors that potentially compromise product performance (Takeshita & Hosokawa, 2007). In essence, the robust design method provides a systematic approach to designing high quality products at low cost and within the shortest acceptable time.

> *Exemplary Case 2: Acharya, U. H., Gijo, E. V. and Antony, J. (2010). Quality engineering of a traction alternator by robust design. Proc. IMechE Part B: J. Engineering Manufacture, 224(2), 297–304.*

This paper describes the applicability of the robust parameter design method, to reduce sensitivity in hard-to-control variation in a traction alternator and associated manufacturing processes in simultaneity with maximising the performance values of the product in response to customer complaints. A large electrical company involved in the development of traction alternators for hybrid diesel-electrical engine feared losing its market share to the competition as their customers complained about the current efficiency (65% – 74%) of the product. The design department, therefore, needed to come up with the best performance parameter values in order to achieve high efficiency (90% minimum) to satisfy the customer or functional requirements (*nFR*) within the shortest practicable time.

The customer complaints (also known as quality indicators) were characterised and summarised into a representative matrix in the context of values of *nFR*. This gave rise to a series of brainstorming sessions, after which 13 efficiency influencing control factors and three levels corresponding to each factor, and associated noise, were selected in accordance with quality practice and Taguchi's criteria. The 13 control factors were allocated in an orthogonal or inner array and the noise factors of nine combinations in the outer array, leading to the master plan of the experiment.

To achieve the study's aim of improving the efficiency of the traction alternator, the variation in the performance characteristics of each combination of control factors was expressed in terms of the "lower-the-better" signal-to-noise ratio (LB:S/N ratio). The significance of S/N ratio indicates that the higher the ratio (upper limit was 100 within the scope of study), the more the system satisfies the *nFR*. Analysis of variance (ANOVA) was performed on the S/N ratios and the output of analysis based on the TRDM was used to determine the contribution of each of the factors to the variability in performance of the product and associated individual effect on efficiency. The overall expected average efficiency at the best combination was evaluated and found to be 94.33%, falling within the 95% confidence interval.

Following the experimental results, in which no physical trials were initially performed to avoid loss of productive time and costs, five assemblies were carried out and tested in the design laboratory of the company under the standard test conditions. Confirmation from the trials aligned with the experimental expectations, suggesting that the results exceeded the *nFR* and customer maximum requirements. The study did not only demonstrate that the fundamental principle of robust design was appropriate to adequately address the quality issue of the product cost-effectively, but also suggested that TRDM is time-effective as it took two months to achieve the best design for the traction alternator compared to the average 8 to 12 months of cycle time it would have taken to attempt the objectives, if a design-build-test classical approach had been employed.

Practical implication

The reliability of the findings of this study would have been more interesting if the investigators had considered to perform physical trials. This would have considerably exhausted identification and removal of any kinks in the manufacturing process and warranted corrective measures to ground the design method.

2.6.3 Mathematical methods

A range of mathematical methods are playing a significant role in the optimisation and control of manufacturing engineering systems in a number of different contexts (Mirahmadi, 2009; Raj & Attri, 2010), including:

- improving and experimentally validating the accuracy of an individual industrial robot;

- designing manufacturing software using Vudjood algebra;
- enhancing automated process planning system setup;
- using dimensional analysis to predict the material removal rate (MRR) of cryogenic treated grades of titanium alloys during electric discharge machining processes;
- determining tensile instability in hydromechanical deep drawing;
- accurate positioning for inclined drilling of workpiece; and
- identifying quality indicators to help in the implementation of a quality system such as demonstrated.

Exemplary Case 3: Raj, T. and Attri, R. (2010). Quantifying barriers to implementing Total Quality Management (TQM), European J. Industrial Engineering, 4(3), 308–335.

Acknowledging that organisations often experience difficulty in successfully implementing TQM due to unidentified barriers, this study aimed to use the Graph Theoretic Approach (GTA) to quantify the barriers as well as propose an ideal TQM index to evaluate the inhibiting power of these barriers. Based on lessons learned with respect to how TQM is often misunderstood, failure to implement the philosophy across organisations and the drawbacks of models to help identify the inherent barriers to implement TQM, the investigators proposed to use GTA simply because it offers a systematic and logical approach and is useful for mathematical modelling and analysing various kinds of systems and problems. The steps in the research method used were defined by expanding the objectives of the study to include identification and segregation of barriers into different categories through literature survey; development of a mathematical model of the barriers using GTA; proposing a single numerical index to represent the value of the multinomial of the model; and a proposed methodology for comparing different organisations in terms of TQM evaluation.

The literature survey at the initial stage identified 24 barriers, which were too large to compute using GTA. The barriers were therefore grouped into five categories, comprising human and cultural barriers; behavioural barriers; technical barriers; strategic barriers; and performance appraisal barriers. This approach enabled a GTA-based digraph to be used to model and analyse the five grouped barriers and their dependent elements, transitioning them into variable characteristic matrix TQM barriers (VCMTQM). Although VCMTQM is useful to address individual effects of TQM barriers, it is limited in quantitative value. Thus, a variable permanent matrix (VPMTQM) was defined for the organisation to represent the effect of the barriers in creating the TQM domain and interdependencies. This led to a proposed variable permanent function (VPFTQM), which is a multinomial mathematical expression that enabled the researchers to quantify both TQM barrier and associated interdependencies present within the organisation.

In the final stage of this research project, comparisons were made between organisations based on their VPFTQM value. The organisation with the lowest VPFTQM has the best chance of implementing TQM. This activity also led to the findings that organisations are similar if their TQM barrier digraphs are isomorphic at system and subsystem level, otherwise they are dissimilar. In a subsequent case-based comparison between Organisation 1 and Organisation 2, whose individual TQM barriers were a function of four critical barriers, the coefficients of dissimilarity and similarity between the organisations allowed them to perform self-evaluation to identify weaknesses and areas requiring improvement. This grounded the applicability of the theoretical model to determine the VPFTQM, also termed TQM barrier index (TQMBI), that impede the implementation of the TQM philosophy in an organisation.

Practical implication

The inability for GTA-based model to compute 24 barriers, making Raj and Attri (2010) to resort to grouping the identified barriers into five segments, can potentially limit the VCMTQM in quantitative value. As such limitation can translate into latent barriers, the assertions made through VPMTQM as representative of the effects of the barriers and that of the use of VPFTQM to quantity TQM barriers and associated interdependencies within manufacturing organisations are debateable.

2.6.4 Conceptual product design

Conceptual Design in itself is a research method that can take a quantitative, qualitative or mixed method and concurrent engineering approach. It thus culminates in a multi-method in order to adequately address a research objective such as developing a quality system for a manufacturing organisation's shopfloor. While existing literature has presented the extent to which conceptual design is applicable to engineering research, there exists evidence of weaknesses associated with the expert knowledgebase of the researchers. However, a number of researchers (including Tjiparuro & Thompson, 2004) took strategic approaches to address such deficiency by systematically carrying out conceptual design-based engineering research successfully. The exemplar case paper is one example of such an illustrative approach.

> *Exemplary Case 4: Fung, R. Y. K., Chen, Y. and Tang, J. (2007). A quality-engineering-based approach for conceptual product design. Int J Adv Manuf Technol, 32, 1064–1073.*

This study takes a quality engineering approach to develop a conceptual product design that incorporates the customer's voice. To validate the applicability of the proposed quality-engineering-based methodology for conceptual product design, the researchers considered the conceptual design of a new mobile phone for illustrative purposes. The conceptual product design was developed through five phases. In Phase 1, a product was defined in terms of the customer requirements (CRs) and a QFD's HOQ was used to translate the VOC into engineering terminology or engineering characteristics (ECs). Inside the QFD, the relative importance of the *what-based* CRs were listed in order of preference and mapped onto respective *how-based* ECs. In essence, an EC or a number of ECs connected to a CR provided designers information on how to satisfy the CR. In the illustrative example case of the mobile phone, a market survey was conducted and the feedback from users revealed five major CRs which were mapped against eight ECs. The relationships between these attributes were represented in an HOQ of mobile phone.

In Phase 2, alternative concepts were explored to identify alternative technologies (ATs) appropriate to help realise the product. To guide designers to generate a range of ATs, morphological matrix analysis (MMA) was integrated into the methodology. With reference to the new mobile phone, the ATs for realising each of the ECs and the MMA resulted in a total of 1,944 plausible concepts. Following this, the performance attributes of ATs (TPA) for the respective ECs were evaluated in Phase 3. A multi-attribute decision-making technique was used to determine the values of the performance attributes of ATs for each EC, culminating in decision-oriented data and information. As it may be difficult to reduce cost after a product has been conceptually designed, estimation of the product development cost (Phase 4) was duly considered when selecting the alternative concepts in the early design stage. In the case of the new mobile phone, TPA values and development costs of the ATs for each of the eight ECs were tabulated together before the selection (Phase 5) of the ATs. Each of the eight ECs was performed using possibility distribution function and possibility optimisation model (POM).

A significant dimension to this study was its methodical approach to repair the weakness created by existing conceptual design methods that do not only relate concepts generation by a combination of basic features to the feasibility of the concepts, but also isolate the customer preferences in the modeling concept. The application of theoretical models in the conceptual product design method accounted for the uncertainties of technology development cost in early design stages. This also made it possible to incorporate the customer-perceived scale of preference into a POM for design concept selection.

Practical implication

This study would have resulted in a more objective outcome if Fung et al. (2007) had extended the engineering requirements to satisfy the CRs beyond the VOC to identify other stakeholders such as the manufacturing company's own internal manufacturing practices, regulatory authority bodies' standards and environmental requirements. An extended knowledge beyond the initial design requirements and constraints as seen at Phase 1 and Phase 2 of the study can mitigate recalls that often result from quality failures.

2.6.5 Cross-functional integration

Brettel et al. (2011) report that previous research has limited emphasis on the effects of cross-functional integration (CFI) on performance measures, although the method is significantly too complex to allow general conclusions in terms of performance impacts. Considering that manufacturing has often been ignored in prior CFI-based research, Brettel and colleagues (2011) took a multi-functional design approach to assess how integrating research and development (R&D), marketing and manufacturing functions impact the effectiveness and efficiency of product development. Their findings, which revealed that the integration between any two functional systems (R&D and manufacturing, for example) impacts the product differently, agree with Song et al's (1998) assertion that although CFI can increase the quality, manufacturability and the marketing of the final product, arriving at a consensus can be a complex task due to functional differences and goals across the departments in the loop. This challenge, however, presents a window of opportunity for promising alternative approaches to CFI to be sought. These include information technology-based CFI and product management and development (Engelen et al., 2012; Turkulainen & Ketokivi, 2012), and quality management schemes as illustrated by the exemplar study below.

Exemplary Case 5: Pfeifer, T., Reissiger, W. and Canales, C. (2004). Integrating six sigma with quality management systems. The TQM Magazine, 16(4), 241–249.

Considering the inherent limitations in successfully implementing the vital roles Six Sigma (6σ) and QMS individually play to address organisational quality issues, this study aimed to combine 6σ and QMS to achieve optimal improvement potential. In order to map out a step-by-step approach to combine 6σ and QMS, the researchers' first step was to review and document the critical factors of success and limitations of 6σ and QMS through a literature survey. As the requirements of QMS are practically those of the ISO 9000 standard, the reading was extended to the eight quality management principles published as ISO 9000:2000. The information gathered was used to clearly map out the objectives of the proposed LSS–QMS combined framework. A key finding of the literature survey showed that 6σ, which "only" focuses on a determined quality strategy and a continuous improvement process, is integrated in existing management systems to stimulate organisational success in Germany.

In integrating 6σ with QMS, the relevant processes within the two domains were determined and their interactions analysed. Data on the input parameters were derived from the 6σ-based SIPOC (supplier-input-process-output-customer), which is necessary for process modeling before project execution, and previously documented QMS-based business processes. The process analysis outlined how the process maps offer an analytic framework in order to show the interactions of processes. Based on the comparisons between 6σ and QMS, areas requiring improvement were identified. The QMS-based process objectives and the planned 6σ project target objectives are compared, taking into account the impact of modifications in interrelated processes. Once the conformance parameters between the project and process objectives were defined, the researchers provided a "project participants selection" criterion to help elect the "most competent" for specific tasks and decision-making. This precedes the planning of project resources, which has the potential to help allocate adequate productive time to human resources to guarantee a successful project execution.

To ensure consistency between project objectives and their associated protocols, a standardisation of LSS–QMS project evaluation measures was considered. This organisation-based study encompassed evaluating and addressing financial outcomes with respect to all dependent variables (processes) that determined the conditions for 6σ suitability for setting operational project objectives, etc. The final stage of the study provided the basis and foundation for the systematic documentation of results, using QMS well-structured facilities for profiling process-related results. In view of the case study, the need to document results does not only present a clear picture of processes, system procedures, list lessons learned and many others, but also represents the feasibility of integrating 6σ and QMS as well as increasing the acceptability of QMS.

Practical implication

Although the use of CFI to combine 6σ with QMS resulted in optimising system performance to an appreciable degree, the integration-success relationship failed to adequately address all the objectives. This is due to a managerially controlled CFI, depending on the industry's core goals.

An overview of 2.6

The five exemplary case studies provide insights that will be useful to inform the development of the proposed QX Engineering Framework. Fig. 2.3 presents a summary of the lessons derived from the practical implications of the exemplary cases.

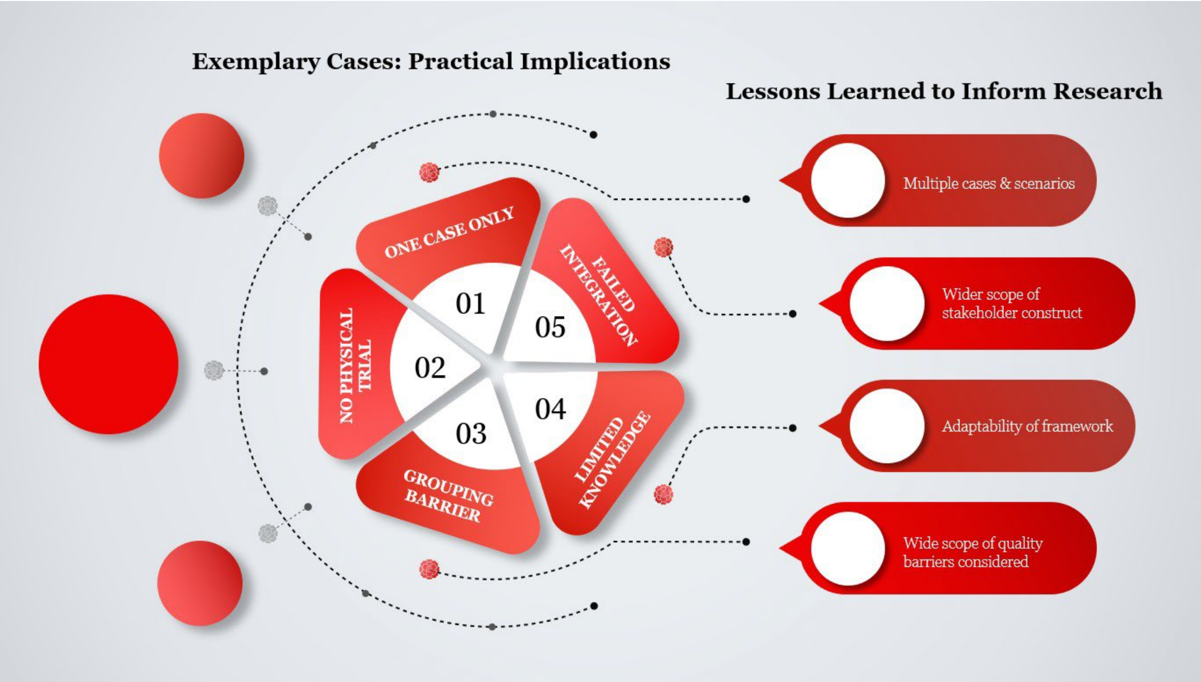


Fig. 2.3: Key lessons learned from practical implications of exemplary cases

Manufacturing organisations attempt to adopt a myriad of quality systems as driven by the goal to exceed customer expectations as well as gain a competitive advantage. However, failure to map out the core quality indicators, including the human factors, can potentially create gaps in many engineering research studies such as illustrated throughout the Exemplary Cases 1–5. As depicted in Fig. 2.3, the five exemplary cases presented that:

1. Exemplary Case 1 considered the use of only a single case-based multi-method to investigate the trajectory of barriers to QMS implementation. This presents potential validity issues due to limited data to inform the case study analysis for a targeted general or wider audience. Contrary to Bhuiyan and Alam's (2005) use of one case only, this research takes a pragmatism approach to multiple cases and scenarios to widen the scope of the findings and development of the proposed design
2. Acharya et al.'s (2010) Exemplary Case 2 features no physical trial. This implies that an exhaustive approach was not taken to ensure reliability of the results. As a

consequence, any potential errors that will have been otherwise exposed if physical trials had been considered, will translate into missed countermeasures against unforeseen inadequacies. In this research, a wider scope of stakeholders, regulatory standards bodies, etc., are considered as independent variables or hierarchical constructs in order to map out a solution to each individual associated quality dimension or barrier construct.

3. Raj and Attri's (2010) Exemplary Case 3 selected to group barrier constructs due to the limitation of the mathematical GTA-based model. Grouping barriers conceals individual barrier indicators, which implies that a solution designed to address a group of barriers cannot adequately address each individual barrier implications. To mitigate any related occurrence, this research designs a framework that is adaptable throughout the manufacturing process.
4. Fung et al.'s (2007) and Pfeifer et al.'s (2004) Exemplary Cases 4 and 5 were collectively limited in information and as such inadequately addressed their individual case objectives. As a lesson drawn from these cases, this research considers a wider scope of barriers in order to ensure a robust approach to creating quality solutions.

The insights gained from the practical implications of the exemplary five case scenarios in this Section are of particular interest to Chapter 3 in that they collectively describe the quality performance trajectory of internal capabilities of manufacturing organisations and the characteristics of the external environment within which they compete. This will map out associated elements towards the responses to RQ1 and RQ2, and essentially inform the modeling agents required to explore the design and implementation trajectories of the select quality tools that will be featured within the proposed RQ3-oriented QX Engineering Framework development process framework.

2.7 Summary and capability gaps

It is evidenced from this review that the inadequacies in existing core quality tools coupled with the influence of social (human) factors continue to cause automotive manufacturing processes and automobile products to deviate from the target quality characteristics. In their quest to respond to satisfying standard quality, manufacturing process and customer requirements, automotive manufacturing SMEs often deploy integrated quality methodologies. However, scenarios such as cost-intensive and brand-damaging auto recalls and rejects, for example, continue to serve as one of the core metrics of poor quality delivery.

Among the integrated quality tools prominently employed within the automotive manufacturing sector are FMEA, PPAP, APQP, MSA, SPC, QMS, TQM, ISO 9000 series, QFD, AD, TRDM, and LSS. The use of these quality techniques has validity to a large extent, but all efforts made to integrate them to optimise production processes have not been fully achieved to date. In order to create a paradigm shift towards optimal quality engineering and achieve zero defects in process and product lifecycles, frequent engineering changes must occur across APDMPMR domains. Thus, this Chapter focused on reviewing and identifying key barriers to quality implementation in order to highlight their associated practical implications in the literature. The review found that a major contributor to vQDD is the human factor in the context of top management and personnel along the process chain. While quality failures of existing quality methods are highlighted in the studies reviewed in this Chapter, ***a holistic or one-fit-all quality engineering framework is missing in each case.***

To address the need for a quality framework, the aim of this Chapter is, firstly, not to contest the existing quality methodologies but rather to seek to identify the implementation challenges that the proposed QX Framework will solve to subsequently add value to them. Secondly, as ***the focus of core quality capability development is critical-to-satisfaction for automotive manufacturing SMEs to remain highly quality based***, the development of the proposed quality framework will also feature a component of ***how to create the ideal process flow to fill the capability gaps***.

Capability gaps

Based on the literature review, the author identifies the following capability gaps:

- The failures in existing quality tools, the barriers to QMS implementation, the difficulty in deploying quality methodologies such as LSS, and the shortfalls of combinations of a host of quality techniques imply that ***there is a lack of capability to create a one-fit-all quality engineering framework that enables automotive manufacturing SMEs to develop an in-house customised userfriendly and easy-to-deploy efficient quality process***.
- The mode of translating customer specifications, standards requirements, and automotive manufacturing SMEs' needs and expectations into engineering characteristics has not been fully explored. This is evidenced by the ineffective processes that lead to quality failures, resulting in either rejects or recalls. For example, after the design stage in QFD, LSS or TRDM, it is usually a daunting task or impossible

to assess and update key input variables during any significant changes within the customer or standards domain. This suggests that ***there is a lack of capability as to how an integrated quality framework can be designed to mimic xenobiosis to enable (1) continuous assessment of its context as a system to mainly identify vQDD activities, (2) countermeasures to mitigate the occurrences of vQDD as a means to stimulate continuous improvement, and (3) post-design and in-process updates to specifications***. Addressing these capability gaps within the context of the development of the proposed quality framework will provide further information upon which to build to answer the research questions posed in this study. These will be achieved as depicted in Fig. 2.4 below.

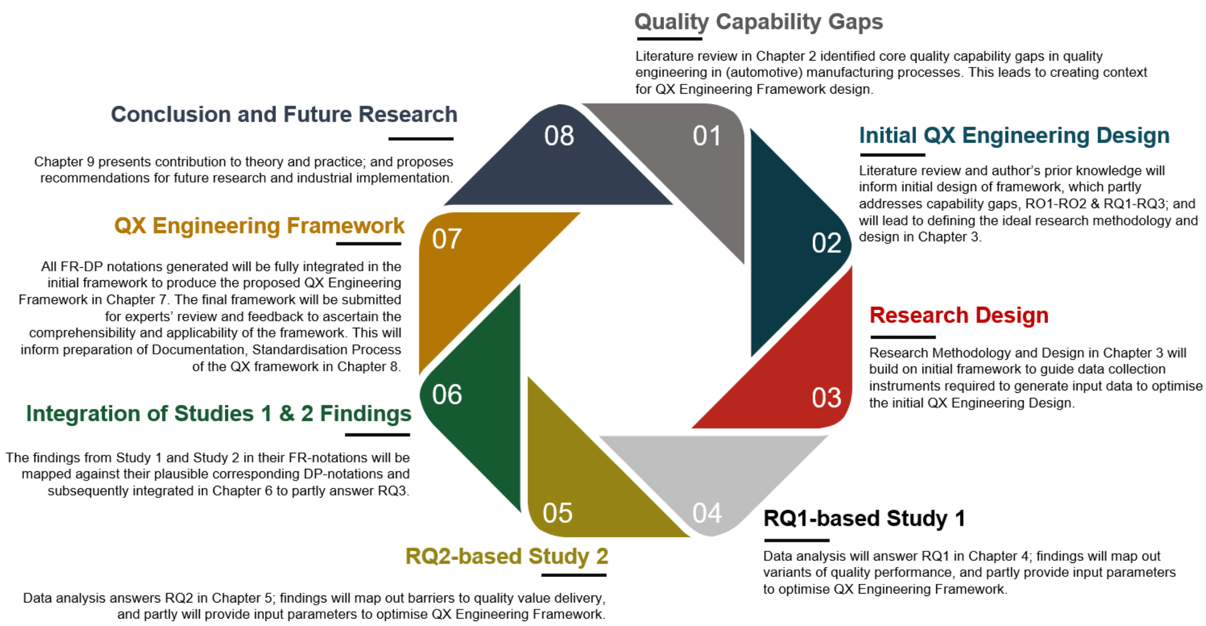


Fig. 2.4: Roadmap to developing proposed QX Engineering Framework

The next Chapter addresses these capability gaps by first identifying the key stakeholders and their organisation-wide goal to attain a quality-focused manufacturing environment. The concept of vQDD that exists within automotive manufacturing organisations in the context of human-based quality issues is presented in Chapter 3 as an integral component required to answer the research problem. The process domain, the derivation of the principal stakeholders' goals that influence the automotive manufacturing critical-to-process and automobile critical-to-product satisfaction domains, and the initial design of the proposed QX Framework that facilitates the integration of IATF 16949:2016-based quality process mapping with core quality capabilities representation will be discussed in the next Chapter. This seeks to adequately satisfy core components of both the research objectives and research questions presented earlier in Chapter 1 (p. 1f). The Chapter will also present the study's Research Methodology and Design.

Chapter 3 Research Methodology and Design

3.1 Introduction

The quality methods and associated failures reviewed in Chapter 2 show that the development of core quality capabilities is critical to achieving a quality-based automotive manufacturing organisation. Although the myriad of quality systems used in the automotive manufacturing industry suggest that many quality tools have been explored to ensure a consistent good degree of quality value delivery, there still remains a lack of holistic quality engineering framework to date. The literature review shows that while there have been several attempts to optimise quality engineering processes within the automotive manufacturing industry, ongoing auto recalls, customer complaints, environmental impact assessments, and automobile product quality failures have continued to expose the inadequacies in the existing quality implementation processes (Cole 2010; Guinot et al., 2017; Liu et al., 2017; Mahdavi et al., 2007; Shin et al., 2014; Topaloglu & Gokalp, 2018). Moreover, although a significant number of multinational automotive manufacturing organisations are QMS-based ISO 9001, IATF 16949:2016 compliant and employ a myriad of quality systems, the findings in Chapter 2 lead to the assertion that a one-fit-all quality engineering framework is currently non-existent. In addition to this, non-ISO/TS 16949 certified companies and those outside the ISO league, in general, face a common challenge in their attempt to transition to the QMS-based IATF 16949:2016 standard (Karaszewski, 2004; Lambert & Ouedraogo, 2008; Prasad & Tata, 2003; Tulus et al., 2018). This is because besides providing a list of quality management items automotive manufacturing SMEs are expected to implement, the IATF 16949:2016 standards document, for example, does not offer a *how-to* process to guide implementation (Silva, 2017).

As evidenced from the secondary data in Chapter 2, the quality implementation shortfalls within automotive manufacturing SMEs are due largely to:

1. Lack of capability to create a one-fit-all quality engineering framework that enables development of an in-house customised, user-friendly and easy-to-deploy quality-focused manufacturing process, effectively and efficiently at minimum cost.
2. Lack of capability to create an integrated systemic quality engineering framework to enable:
    i. continuous assessment of its context as a system to identify and mitigate threats to quality design,

ii. continual improvement, featuring in-process and post-design strategies for changes to specifications.

To address the above quality capability gaps, this Chapter takes a more practical, effective approach to applying Axiomatic Design (AD) methodology to develop the initial design of the proposed quality engineering framework (hereinafter referred to as QX Engineering framework). In this thesis, the term QX Engineering framework (where QX is used for brevity to mean Quality Excellence) is used interchangeably with QX Engineering system, QX Engineering design and QX Engineering in reference to the same meaning. As established earlier in Chapter 2, the core objective for developing the proposed QX Engineering is to equip automotive manufacturing SMEs with the ideal tools they require to create quality-focused or quality excellence (QX) capabilities in automotive manufacturing operations.

3.1.1 Organisation of Chapter

This Chapter is organised into the following segments:

Section 3.2 presents the proposition of QX Engineering and the selection of Axiomatic Design to guide the initial design of the former. Section 3.3 presents how an Axiomatic Design approach is employed for the process mapping of the QX Engineering design goal and decomposition. Section 3.4 outlines the proposed process for QX Engineering system development. This is followed by Section 3.5, proposing a need for deriving a model for vQDD traceability. This relates to building a knowledgebase to enable automotive manufacturing SMEs to identify the critical path they require to track the human agents that vary quality processes within the organisation. In Section 3.6, the above segments conclude with a general summary of the main themes covered.

Section 3.7 discusses the research philosophical stance of the study, featuring how the combination of social constructivism and interpretivism is better suited for this research than the postpositivist paradigm. In Section 3.8 and 3.9, the research design and methods and the facets of mixed-methods research selected for this study are respectively outlined. Section 3.10 describes the research methodological strategy designed for this study, which details the procedures for both deductive and inductive methods for the quantitative (survey) and qualitative (narrative → numeric) data acquisition stages respectively. Sections 3.11 and 3.12 respectively cover the data collection and the methods for the data analysis. This Chapter ends with Sections 3.13 and 3.14, which respectively outline the ethical considerations adopted to guide the research data collection protocols and the summary, highlighting the key coverage of this Chapter.

3.2 Proposition of QX Engineering

To address the quality capability gaps within automotive manufacturing SMEs, this Section presents the process for QX Engineering framework development, as shown in Fig. 3.1. The process features three stages: definition of design goal, development of QX Engineering framework, and derivation of design solutions to identify quality threats.

As automobile product quality requirements are constantly changing within a fierce competitive manufacturing environment, automotive manufacturing SMEs are expected to be highly responsive to optimise their processes in order to cope with the uncertainties in the demand patterns (Acharya et al., 2010; Krishna et al., 2008). It is within this context that QX Engineering is not intended for a specific automotive manufacturing process but designed to enable in-house purpose-driven customisation of the framework to match demand requirements. The QX Engineering framework aims to stimulate cyclic collaborative work that sustains top management commitment across heads of all units to capture any undesired non-value added (NVA) activities. The latter has the tendency to potentially compromise the overall quality design goal.

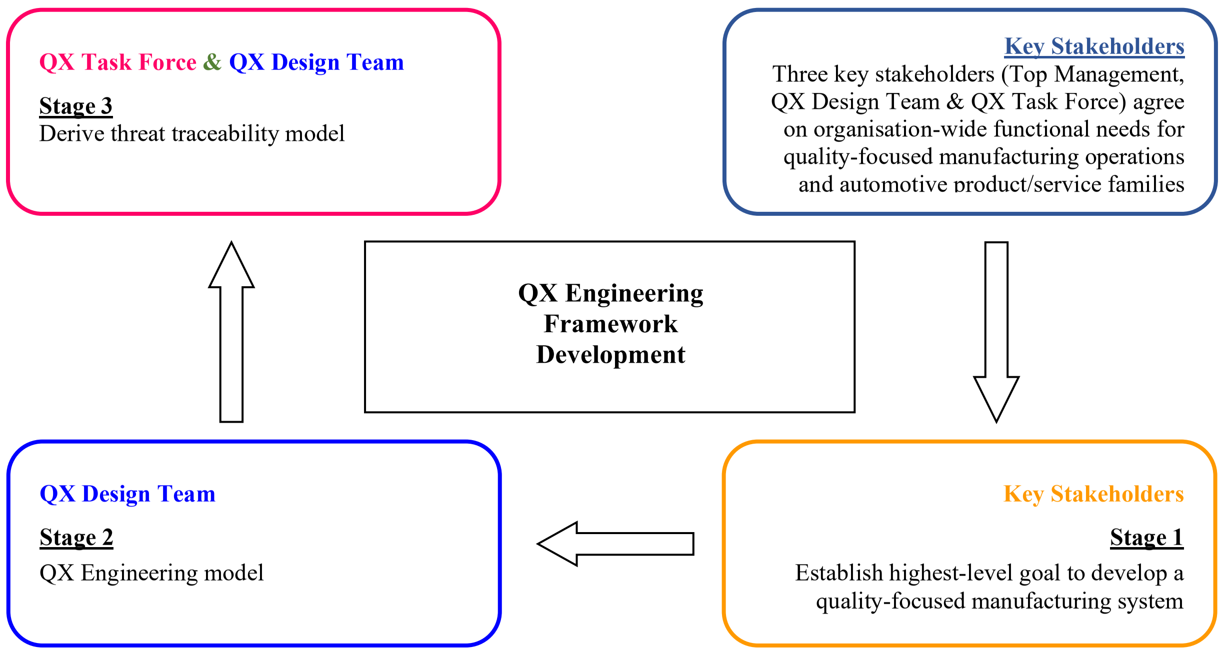


Fig. 3.1 The proposed model for developing a framework for QX Engineering (by author)

The QX Engineering system design process is decomposed into three stages:

1. Defining the design goals – The first stage is to identify the key stakeholders, whose functional needs, expectations, and determination of what defines a quality process value are critical for the success of the proposed quality system (Benabdellah et al., 2020; Lee et al., 2019; Papinniemi et al., 2014). Three key stakeholders: top management, task force, and design team participate in the design process and define threats to the design process, vectors of quality data deviations (vQDD) or non-value added (NVA) activities that can potentially vary the design goals.
2. Developing QX Engineering – In the second stage, the design team redefines the identified design goals into the highest-level functional requirements (FR_0), leading to a model for developing the framework,
3. Deriving design solution for vQDD traceability – Based on the QX Engineering system framework and vQDD model, the third stage engages the task force and design team to identify and derive vQDD or threats to the QX Engineering system components. This features implementation procedures to enable continual improvement of effective countermeasures.

Outlined in detail in Section 3.3, this study takes an Axiomatic Design approach to develop the initial design of QX Engineering. Axiomatic Design will offer a methodical approach to achieve the three core stages identified above by defining guidelines for the design of QX Engineering with a focus on automotive manufacturing SMEs (Goo et al., 2019; Heo et al., 2007; Suh, 1990, 1999, 2003, 2005; Yilmaz et al., 2020). Because of the flexibility or agility nature of Axiomatic Design, it makes room for contributory data to be derived from other methods and then converted into input parameters required to optimise an initial design at both the early stage or at a later stage (Rauch et al., 2019). Beng and Omar (2014) implied that Axiomatic Design principles can guide the designer/engineer in effectively selecting the functional embodiment that facilitates a product or process development. These align with the methodical approach this study seeks to achieve through the development of a new quality engineering framework for automotive manufacturing SMEs.

3.3 QX Engineering design goal decomposition

The first stage of the QX Engineering design process starts with the formation of a team of three key stakeholders, namely, top management, task force (designated QX Task Force), and design team (designated QX Design Team). This study identifies them as core decision-makers who establish the overall organisational functional needs and expectations in the context of delivering high quality target value. They define high-level design goals that must be satisfied for an organisation to achieve a quality-focused manufacturing operation effectively and efficiently. These are translated into the hierarchical level 1 analysis otherwise referred to as highest-level functional requirements (FR_0) of the design decomposition. Thus, these key stakeholders set the high-level QX design goals that must be fulfilled in order to achieve a quality-engineered automotive manufacturing process. Table 3.1 shows the three key stakeholders and their functions and goals within the context of this research.

Table 3.1 Key stakeholders and their functions, goals and requirements

QX Engineering Design Process Key Stakeholders

Key Stakeholder	Function	Goals	Requirements
Top Management	They establish the need for QMS-based IATF 16949:2016 oriented automotive manufacturing operations; to gain organisation-wide quality capabilities; to deliver high-quality automobile products in a short-time and at the lowest cost; and to stay competitive	To achieve QMS-oriented high-quality manufacturing operations excellence that satisfies customer requirements efficiently and effectively and delivers continual improvement	An effective QMS-oriented process
Task Force	They are a multidisciplinary team of engineers, managers, IT specialists, who maintain regular cyclic quality value strategies, monitoring-based interaction with all QX-focused components within the organisation to identify threats, NVA activities; review the state of the manufacturing processes; take in-depth assessment of critical-to-satisfaction processes in the context of target deliverables to organisation, customer, regulatory standard authorities	To achieve an effective quality process monitoring that enables sustainable quality process values by identifying and eliminating threats	An efficient internal quality auditing process
Design Team	The designers are a multidisciplinary team of engineers, project managers, multifunctional experts, who translate the organisational management's functional needs and goals into engineering characteristics	To achieve a QMS quality engineering design that satisfies organisation-wide goals effectively and efficiently at minimum cost	An efficient QMS-oriented process

Table 3.1 shows that top management is committed to driving the organisation towards achieving a high-quality focused manufacturing process and delivering at high-quality levels within all the interconnected components. Embedded within this quality status is a comprehensive design process for optimal quality-focused operations that feature core elements of critical-to-satisfaction capabilities for performance in terms of customer-centric expectations, myriad of quality engineering tools, and continuous improvement. The context of top management will identify and encompass drivers of its functions and needs such as external and internal forces or issues as related to emerging technologies, new market entry

strategies, economy, the environment, innovation that can influence its manufacturing objectives, OEM's parts pricing mechanism, quality goals, ineffective manufacturing project deployment, poor preventive maintenance, and manufacturing sustainability. And although it is often a common practice to setup automobile manufacturing system's requirements based mainly on the customer's (also referred to as primary stakeholder) requirements (Benabdellah et al., 2020; Lee et al., 2019; Papinniemi et al., 2014), this study prioritises the overall organisation's needs as the primary stakeholder or (internal) customer and, therefore, its requirements must precede those of the external customers. This assertion is established on the premise that automotive manufacturing SMEs with an excellent degree of core quality competencies, competitive capabilities and high standard quality-focused manufacturing operations will translate into quality automobile products.

As indicated in Table 3.1, the formed QX Task Force is concerned with conducting regular periodical reviews of the organisation's processes with respect to external standards for quality requirements such as those of the automotive regulatory authorities, environmental regulatory bodies, the triggers of auto recalls, the IATF 16949:2016 standard, etc., and the expectation of the automobile product customers and users. Their task is to regularly conduct auditing and monitoring to identify any agents of quality failures or threats to the design process and taking measures for corrective actions. Their activities stimulate the need to introduce countermeasures to mitigate the occurrence of vQDD. Functioning as a dedicated organisation-wide internal auditor and quality process monitoring team, the QX Task Force maintains a regular review reporting interaction with top management. This leads to formulating steps towards quality policies documentation in conjunction with the designers, who are engaged in translating top management and QX Task Force requirements into measurable process performance and procedures for implementation of good quality practice.

In this research, the stakeholders set and agree on the key automotive manufacturing process needs and automobile product specifications to derive a common goal that is the highest-level functional requirement in order to satisfy the organisational core objectives.

3.3.1 Mapping the highest-level functional requirement $(\boldsymbol{FR_0})$

Following the identification of the functional needs of the key stakeholders and their primary goals in Table 3.1, the next step is to express them as the highest-level functional requirement or FR_0. These are therefore mapped against corresponding plausible highest-level design parameters or DP_0 (Suh, 1990, 1999, 2005). The design relationship between the FR_0 and DP_0 is expressed as in (3.1):

$$\{FR\}_{m\times 1} = [\mathbf{A}]_{m\times p}\{DP\}_{p\times 1} \tag{3.1}$$

where the left-hand array represents the key stakeholders' goal objective domain or vector with m functional requirements, the right-hand array is the corresponding co-domain or vector of the design parameters with p characteristics to satisfy the FR_0, and $\mathbf{A}$ is the design matrix. Central to the key stakeholders' functional needs and goals is to develop an initial design of a QMS-based QX Engineering that satisfies their desires. Thus, the FR_0 that defines the key stakeholders' goal and its corresponding DP_0 is proposed as in Table 3.2 below.

Table 3.2 Key stakeholder FR_0

Definition of FR_0			
Functional Requirements (FR)		Design Parameters (DP)	
FR_0	Develop a quality-focused manufacturing system to satisfy stakeholder needs	DP_0	Quality-engineered automotive manufacturing system design

At this stage, the definition of FR_0 does not present a complete solution but rather a process. Thus, the next step is to decompose the highest (first) level functional requirement (i.e. FR_0) into the second level functional requirements (FR_1 and FR_2). This is described in the next Section.

3.3.2 Mapping the second level functional requirements (FR_1 and FR_2)

In decomposing FR_0 into the second level FR_1 and FR_2, it is essential to note that FR_1 and FR_2 can be applied to realise the highest-level design parameters (DP_0). As such, this recognises that the key stakeholder goal or core objective encompasses effectively and efficiently satisfying the requirements and expectations of external stakeholders such as service/product users, automotive regulatory bodies, environmental standards authorities, etc. Since the highest-level functional requirement seeks to develop an all-inclusive solution for a process of continual improvement, it is also desired by the stakeholders for the design to respond to post-process or post-production quality failures that result in auto recalls, rejects, and the like at the intersections illustrated in Fig. 3.2.

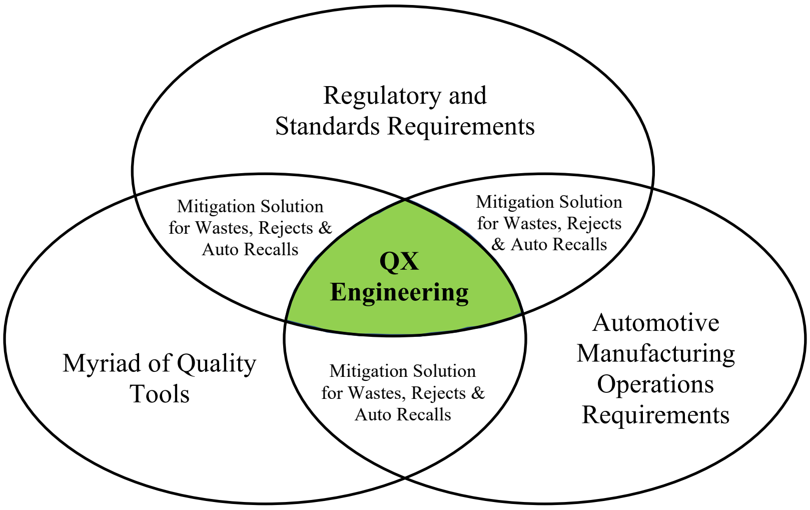


Fig. 3.2 Conceptual intersection of QX Engineering design

After identifying the target segments in Fig. 3.2 that adds details to the highest-level functional requirement that the highest-level design parameter must also satisfy as a core part of the organisation-wide overall objective, two types of quality target values are identified as follows:

- **Type-I Quality Target Value (Type-I QTV):** in the context of achieving a quality design process that effectively satisfies state-of-the-art automotive manufacturing operations for process and automobile products, regulatory and standards, and myriad of quality tools functional objectives efficiently at the minimum possible cost.
- **Type-II Quality Target Value (Type-II QTV):** featuring mitigation solutions to address bottlenecks, constraints, including process/product rejects; auto recalls; quality implementation failures; supply chain and logistics ineffectiveness; OEMs uncertainties; *unfavourable* government legislations; pedestrians, investors, vehicular passengers and users' complaints; regulatory bodies' (automotive – such as NHTSA, DVSA, FCAI, ADR; environmental standards; QMS, IATF 16949:2016, etc.) requirements; user's variation of stakeholders' quality setup, etc.

Based on Type-I QTV and Type-II QTV, the second level functional requirements are defined as follows:

FR_1: Maximise the quality target value-added to the process and product

FR_2: Minimise manufacturing cost

As the lower-level detailed designs have not been established at this level of the design process, the *design intent* is ideally conceptualised as a triangular matrix (3.2).

$$\begin{Bmatrix} FR_1 \\ FR_2 \end{Bmatrix} = \begin{bmatrix} X & 0 \\ X & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \end{Bmatrix} \tag{3.2}$$

The basis for the triangular matrix in (3.2) is to ensure that subsequent lower-level design decisions are consistent with the highest-level, FR_0, design decision (Suh, 1990, 2003). This ensures the independence of FRs and demands for DPs to be determined sequentially.

Table 3.3 Setting the second level FRs

Definition of FR_1 and FR_2

Functional Requirements (FR)		Design Parameters (DP)	
FR_1	Achieve the desired quality value added of the design	DP_1	QX Engineering system for maximising quality value added of the QX design
FR_2	Minimise cost-biased activities in developing the QX design	DP_2	System for minimising systemic cost-associated activities in developing the design

Having defined the second level functional requirements, the next step is to continue the decomposition in order to determine the design details in the third level FRs. As regards the objective of this study, the third level FRs are mapped across the QMS-based IATF 16949:2016 standard, which is the most widely used global standard for quality management in the automotive manufacturing industry (Bacoccini, 2016; Gruszka & Misztal, 2017; Laskurain-Iturbe et al., 2020; Pinto et al., 2019).

3.3.3 Derivation of the third level functional requirements

Decomposing FR_1

The core objective of FR_1 is to satisfy customer requirements effectively with respect to quality reliance in operations and efficiently in terms of delivering quality performance value. Although it is often a general concept that the design setup for a manufacturing system is primarily based on a customer's requirements (Benabdellah et al., 2020; Lee et al., 2019; Papinniemi et al., 2014), this study considers automotive manufacturing SMEs as the primary customer or stakeholder. This is because according to the scope of this study, it is desired for automotive manufacturing SMEs to originate and establish the need to develop a one-fit-all QMS-oriented quality engineering process that enables continual improvement, mitigation of vQDD, reduced cost-biased manufacturing resources and waste, core quality competencies, and competitive capabilities. This asserts that an automotive manufacturing SME is therefore the primary customer and owner of the above *attributes*, including supporting functions such as the process design, and design team. These automotive manufacturing SMEs' attributes are collectively the goal that FR_1 must satisfy in order to deliver quality target value to Top Management, QX Design Team and QX Task Force as well as translate into value-added to QX design.

As the IATF 16949:2016 standard imposes the implementation of key performance indicator as a means to control the overall automotive manufacturing system, which provides a surety to customers (Gruszka & Misztal, 2017; Laskurain-Iturbe et al., 2020; Pinto et al., 2019), the decomposition of the third level functional requirements is derived as quality process value objectives oriented on the IATF 16949:2016 standard. These are shown in Table 3.4.

Table 3.4 QMS-based IATF 16949:2016 – International Standard for Automotive Quality Management Systems oriented objectives

IATF 16949:2016-oriented Quality Process Value Objectives		
Customer support	Supplier performance and control	Product safety and quality
Performance evaluation	Product & service design and development	Regulatory and standards compliance
Customer satisfaction	Failure Mode and Effects Analysis (FMEA)	Manufacturing resources efficiency
Defect mitigation	Reduction of variation and waste	Operating cost efficiency
Measure and report	QMS performance and effectiveness	Increase operational control
Workplace auditing	Equipment maintenance efficiency	Risk assessment & mitigation
Laboratory management	Measurement System Analysis (MSA)	Process efficiency and effectiveness
Design and development	Product Part Approval Process (PPAP)	Automotive regulatory compliance
Production service	Advanced Product Quality Planning (APQP)	Statistical Process Control (SPC)
Continual improvement	Nonconformities and countermeasures	Environmental standards compliance
Supply chain efficiency	Health and safety compliance	

To stay competitive, automotive manufacturing SMEs are expected to deliver at high-quality (effectively) and at the barest minimum manufacturing cost (efficiently). The deployment of good quality process is a function of the amount of information required to develop both the automotive manufacturing system and product. This requires the design team to ensure a set of lowest possible independent functional requirements needed to characterise the highest-level design objective within the specifications of high quality and cost (Type-I QTV) and constraints of compliance (Type-II QTV). This will fall within the definition of the Independence Axiom and enable process iteration.

In reference to Table 3.4, the 32 core objectives derived from the IATF 16949:2016 standard violate the Independence Axiom in that a number of the objectives overlap with others. This assertion is illustrated by the following examples:

- The requirements criteria for the risk assessment and mitigation objective overlaps with those for both the internal and external laboratory management for performance, tests and calibrations. The former also entails organisation-wide approach to internal audit of systems, processes and products which includes performance evaluation, workplace auditing and FMEA.
- The regulatory and standards compliance requirements also encompass those for automotive regulatory compliance, environmental standards compliance, health and safety compliance.
- The quality-oriented continual improvement code extends to the procedures for SPC, MSA, PPAP, APQP, nonconformities and countermeasures, reduction of variation and waste, defect mitigation, customer support, supplier performance and control.

The significant amount of overlapping among the objectives in Table 3.4 suggests that a large number of DPs may be required to satisfy the FRs. This can potentially result in a usually *undesired* coupled or redundant design. In the desired *ideal design* of a system, the number of DPs is equal to the number of FRs and the independence of the FRs is maintained (Suh, 2003).

Based on the above, this study selects the three quality objectives of FR_1 from Table 3.4, whose scopes also take into consideration the 29 other objectives. These are considered as added details of the third level functional requirements or sub-FR_1, whose decompositions drive the design process towards the goals established earlier. They are defined as follows:

- Process Efficiency and Effectiveness: As regards this study, the key stakeholders are interested in developing a quality-based robust process that delivers expected quality value across functional objectives to effectively satisfy all manufacturing operational requirements and efficiently at the lowest possible cost.
- Regulatory and Standards Compliance: This addresses top management's concern about quality failures or unforeseen circumstances that can potentially lead to costly auto recalls, compromised brand reputation, expose organisation's operations to scrutiny over conformance issues. QX Task Force is also concerned with conducting regular reviews of organisation-wide processes with respect to both internal goals and external standards for quality conformities as well as derive countermeasures to respond to the failures.
- Continual Improvement: While a process of ongoing improvement is desired at the heart of top management objectives for organisation's sustainability, the QX Task

Force role is to ensure a constant delivery of quality at all units internally as well as capture agents of constraints in-process and post-process and translate them into expected results.

The next step is to decompose the high-level goals into more detailed Type-I QTV, featuring Continual Improvement, Regulatory and Standards Compliance and Process Efficiency and Effectiveness; and Type-II QTV, featuring responses to cost and quality indicators such as rejects, quality deviations, auto recalls, etc. These are defined so as to satisfy IATF 16949:2016 standard.

As an ideal manufacturing system is expected to satisfy the customer-centric domain or key stakeholder (also the organisation) requirements through efficient processes that create quality target value with zero waste, the three IATF 16949:2016 based objectives are defined for the sub-FR_1 as follows:

- $FR_{1.1}$ Implement QMS-based IATF 16949:2016 for regulatory and standards requirements
- $FR_{1.2}$ Design quality-oriented process efficiency and effectiveness for automotive manufacturing operations and automotive product
- $FR_{1.3}$ Define process strategy to enable continual improvement

Decomposition of FR_2

While FR_1 is defined for a design that enables automotive manufacturing SMEs' system to effectively deliver better quality, FR_2 is focused on enabling the design to deliver high quality efficiently at the lowest feasible manufacturing cost. According to Koren (2010), high-quality products came at the expense of high manufacturing cost in terms of designing manufacturing systems to feature more labour force, extra space and large buffers between machines to smoothen operations. However, Toyota's modification of the automotive manufacturing system into an efficient design that focused on eliminating waste (of time and material resources) in the early 1960s, substantially reduced manufacturing cost. The Toyota Production System or Lean Production approach the company employed gave Toyota a competitive advantage in that carrying out manufacturing operations that tackled costly process errors or wastes at the early stage translated into introducing consistently high-quality but less expensive automobiles into the marketplace.

Although lean production or lean manufacturing systems focus on producing high-quality products at reduced cost by eliminating waste (defects, excess inventory, over-processing, etc.), the trend of auto recalls that affected over 20 million automobiles, including Toyota's 2 million brand vehicles, due to quality issues (Liker, 2010), suggests that it is inadequate to rely solely on the lean principle. This is because it does not encompass a complete set of procedures to satisfy the requirements of automotive regulatory bodies the likes of the U.S. National Highway Traffic Safety Administration (NHTSA), the UK's Driver and Vehicle Standards Agency (DVSA), etc.

Paulose and Kihara (2012) assert that automotive manufacturing organisations are expected to familiarise themselves with guidance on the implementation of safety recalls as prescribed by their target markets. In agreement with Paulose and Kihara (2012), FR_2 is decomposed across the parameters that induce:

- Auto recalls (NHTSA, DVSA, etc.)
- Product rejects (as per customer-centric domain, etc.)
- Environmental data deviations (environmental agencies, government legislation, etc.)
- Departures from IATF 16949:2016 and related QMS
- Regulatory and Standards nonconformities
- Barriers to quality system implementation waste within the context of the lean philosophy and requirements of automotive regulatory bodies.

As any aspect of the above list has high financial implications as well as can expose company's brand image to public scrutiny or damage, this study refers to any activity that contributes to any of the above as a *threat* to the design process or *vector of quality data deviation (vQDD)*. Thus, the goal of FR_2 is to search, envisage, identify and eliminate any threat to the quality design process of vQDD traceability at both in-process and post-process stages. This will enable a quality delivery via a process of an ongoing improvement system. Given the above, the sub-FR_2 are defined in relation to the threats or vQDD as in Table 3.5.

Table 3.5 Threats to the design process or vectors of quality data deviations

Threats or vectors of quality data deviations (vQDD)			
1.	Under-utilised personnel	9.	Inadequate internal auditing
2.	Excess inventories	10.	Quality skills gap
3.	Non-value-added movements	11.	Personnel apathy
4.	Inefficient processing	12.	Top management non-committal
5.	Overproduction	13.	Organisational behaviour
6.	Defects	14.	Automotive standards nonconformities
7.	Non-value-added waiting/downtime	15.	Environmental standards nonconformities
8.	Inefficient transportation		

The cost-associated threats listed in 1 to 8 in Table 3.5 are derived from the constituents of waste as derived from lean manufacturing (Johansson & Osterman, 2017; Koren, 2010; Leksic et al., 2020; Pienkowski, 2014; Suhardi et al., 2019). For example, paying labour fees to the QX Design Team for a phase within a design process that takes (t + 1) hours to complete instead of an expected reasonable completion time of (t – 1) hours, simply because there were extensive non-value-added movements (unnecessary motion = waste), waiting (delay or downtime = waste), excessive drafting and redesigning steps (over-processing = waste), and printing every material (over-production = waste) for internal distribution among team members, is an illustration of an ineffective and inefficient cost-associated process.

The vQDDs listed as 9 to 15 are defined from the analysis of dependence power within the context of most dominant human-based behavioural barriers to QMS-related quality implementation in the literature review in Chapter 2. While addressing threats 1 to 13 favour mostly in-process manufacturing system operations to deliver high quality, any significant departure from items 14 and 15 can potentially lead to auto recalls. On this basis, the intent of the design process is not limited to in-process production but also to feature processes that adequately address eventualities that result in either voluntary or mandatory auto recalls.

3.4 QX Engineering system development

After defining the third level functional requirements ($FR_{1.1}$ to $FR_{1.3}$), the second stage is to develop the QX Engineering system that fulfils the highest-level functional requirement, FR_0. To achieve this, the study proposes two iterations of the design decomposition. This will enable conceptualisation of the corresponding design parameters for each FR until they are exhausted without violating the independence axiom. According to the Axiomatic Design method (Suh, 1990; 1999; 2001; 2003; 2005), this approach transforms the design intent into realisable detailed designs given by the lowest-level design matrices.

3.4.1 First iteration of the design decomposition

As the key stakeholders' goal is to achieve an effective and efficient design process that promises automotive manufacturing operations that satisfy QMS-based IATF 16949:2016 standard as well as the standard requirements of related regulatory authorities, the first iteration focuses on conceptualising the plausible corresponding DPs for FR_1 to fulfil the quality value objectives. This is proposed as in Table 3.6.

Table 3.6 DPs for sub-FR_1 ($FR_{1.1}$, $FR_{1.2}$ and $FR_{1.3}$)

Functional Requirements	Design Parameters
FR_0: Develop a quality-focused manufacturing system to satisfy stakeholder needs	DP_0: Quality-engineered automotive manufacturing system design
FR_1: Achieve the desired value-added quality of the design	DP_1: QX Engineering system for maximising value-added quality of the QX design
$FR_{1.1}$: Implement QMS-based IATF 16949:2016 for regulatory and standards requirements	$DP_{1.1}$: Procedure for implementing regulatory and standards requirements
$FR_{1.2}$: Design quality-oriented process efficiency and effectiveness for automotive manufacturing operations and automobile product	$DP_{1.2}$: Quality-oriented process efficiency and effectiveness system
$FR_{1.3}$: Define process strategy to enable continual improvement	$DP_{1.3}$: Procedure for selecting process strategy

As automotive manufacturing systems and automobile products must satisfy the requirements and expectations of regulatory bodies, in particular, this study selects $DP_{1.1}$ to precede the design parameters for $FR_{1.2}$ and $FR_{1.3}$. This is because it is essential for the manufacturing organisation to familiarise itself first with the requirements of the regulatory bodies of interest and then map its manufacturing processes across the functional requirements of the regulatory authorities. This is a more cost-time-effective approach than a top-down approach that precedes with $FR_{1.2}$. Achieving $FR_{1.1}$ can guide the processes required for designing effective quality-oriented automotive manufacturing operations that deliver $FR_{1.2}$ and enable an ongoing improvement ($FR_{1.3}$). This is because the key output variables of $FR_{1.2}$ and $FR_{1.3}$ must satisfy the standard requirements of the regulatory bodies in the context of FR_1. This proposed iteration posits that, if automotive manufacturing SMEs are able to align their manufacturing processes and output, then they strategically position themselves to easily achieve regulatory and standard compliance.

The relationships between the vectors of sub-FR_1 and sub-DP_1 as established above are described by the design matrix [A] in (3.3), which satisfies the independence axiom.

$$\begin{Bmatrix} FR_{1.1} \\ FR_{1.2} \\ FR_{1.3} \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ X & X & 0 \\ X & X & X \end{bmatrix} \begin{Bmatrix} DP_{1.1} \\ DP_{1.2} \\ DP_{1.3} \end{Bmatrix} \tag{3.3}$$

The X in the design equation (3.3) represents a strong relationship between corresponding FR-DP pair in the above decoupled design. As the set of sub-FR_1 above are expected to satisfy the IATF 16949:2016-based quality objectives in Table 3.4, a further decomposition (zigzagging) of the hierarchical level 3 is continued until the lowest $FR_{1.n}$ can be reached or exhausted to lead to its corresponding $DP_{1.n}$.

FR_2 is defined for a design to enable reduced manufacturing resources cost. This can be achieved by focusing on efficiently identifying and eliminating threats to the design or vQDD, which can consequentially vary the goal towards FR_0. This is because any uncaptured or inadequately addressed vQDD can flaw the design process and result in high financial implications. The third-level functional requirements or sub-FR_2 that must be achieved to address the threats to the design process are defined based on Table 3.5 and are proposed with their corresponding mitigation solution-based sub-DPs as shown in Table 3.7:

Table 3.7 Mitigation solution-based corresponding DPs for sub-FR_2 ($FR_{2.1}$ to $FR_{2.15}$)

Functional Requirements		Design Parameters	
FR_2:	Minimise cost-biased activities in developing the system design	DP_2:	Procedure for minimising cost-associated threats to developing the system design
$FR_{2.1}$:	Restructure under-utilised personnel	$DP_{2.1}$:	Conduct strength/weakness analysis
$FR_{2.2}$:	Eliminate NVA excess production of resources	$DP_{2.2}$:	Production Kanban
$FR_{2.3}$:	Eliminate factors of defects within the system design	$DP_{2.3}$:	Process for zero defect
$FR_{2.4}$:	Eliminate NVA inventory of design resources	$DP_{2.4}$:	Process for resource efficiency
$FR_{2.5}$:	Eliminate NVA movements of human and material resources	$DP_{2.5}$:	Establish Standard Operating Procedures (SOPs) for manufacturing resource processes
$FR_{2.6}$:	Minimise NVA waiting in the system	$DP_{2.6}$:	Continuous flow design
$FR_{2.7}$:	Eliminate inefficient processing within the system	$DP_{2.7}$:	Process Kaizan design
$FR_{2.8}$:	Minimise inefficient transportation of resources in the system	$DP_{2.8}$:	Create flow between processes
$FR_{2.9}$:	Determine and mitigate personnel apathy towards design process	$DP_{2.9}$:	Procedure for determining and mitigating personnel apathy behaviours
$FR_{2.10}$:	Mitigate top management non-committal towards quality implementation process	$DP_{2.10}$:	Mitigation solution against top management non-committal attitudes
$FR_{2.11}$:	Determine quality training needs required for core quality capabilities	$DP_{2.11}$:	Core quality capability training programmes
$FR_{2.12}$:	Mitigate organisational behaviour against quality engineering processes	$DP_{2.12}$:	Mitigation solution for organisational apathetic behaviour against design
$FR_{2.13}$:	Maintain internal audit of quality process	$DP_{2.13}$:	Procedure for conducting internal audit of quality process across all departments
$FR_{2.14}$:	Mitigate automotive regulatory and standards nonconformities within the system elements	$DP_{2.14}$:	Mitigation solution against regulatory and standards nonconformities

$FR_{2.15}$:	Mitigate environmental compliance nonconformities within the design processes	$DP_{2.15}$:	Mitigation solution for environmental compliance nonconformities

It is clear in Table 3.7 that $DP_{2.1}$ to $DP_{2.15}$ present general mitigation solutions for the respective $FR_{2.1}$ to $FR_{2.15}$. As such, a further decomposition of $subFR_2 \rightarrow subDP_2$ is required until an $FR_{2.n}$-$DP_{2.n}$ is reached for exhausted mitigation solutions to address the vQDDs or threats. Within the context of this study, vQDDs are generally described as follows:

1. Under-utilised personnel: indexed by a variety of metrics including skills gap, poor incentives, capability misplacement, disengaged personnel knowledge or skills waste. This type of human potential waste can translate into compromised processes, hidden process problems, excess motion due to lack of personnel input.
2. NVA excess production: this is as a result of extra production of resource *"just-in-case"* instead of as needed in *"just-in-time"* demand. This potentially causes idle or waiting time, hidden quality problems, NVA transportation, etc.
3. Defects: result from scrapping products, reworking, cost-biased NVA process output, undetected abnormalities, transmitted defects along the design process, inconsistent design process, and the like.
4. NVA inventory: more than necessary inventory leads to material damage in transit or storage, increased lead time, hidden problems, producing more resources than the key stakeholders need, prevented production due to accumulated defects, etc.
5. NVA motion or movements: repetitive motion of personnel or resources, multiple data entry, unnecessary rearrangement of resources can be counterproductive and increases health and safety issues.
6. NVA waiting: this can be created by unevenness in the production workstations, delayed communication, delayed reviews, excessive and ineffective meetings, missing instructions, delayed instruction, lack of capacity, etc. The waste of waiting can also lead to NVA excess inventory and over production.
7. Inefficient processing: designing and redesigning without significant changes, generating multiple reports for distribution within key stakeholders, fixing components that need not to be fixed, and the like, constitute overprocessing.
8. NVA transportation: this is as a result of excessive movements of personnel and resources, which can lead to unnecessarily increased labour cost for NVA work, material wear and tear, etc.

9. Personnel apathy: personnel lack of support for quality systems, team building and orientation, involvement, organisation's competitive future, etc., exhibit apathy towards growth (see Chapter 2 on *Barriers to QMS and TQM implementation*).
10. Top management non-committal: inadequate appreciation of quality tools, lack of attention to the needs of internal and external stakeholders, lack of personnel training programmes, weak interdepartmental relations, opposition to quality auditing, etc., are illustrative of lack of top management commitment (see Chapter 2 on *Barriers to QMS and TQM implementation*).
11. Skills gap: lack of learning and capacity-building training programmes, personnel not interested in self-development for organisation's future, etc., are potential barriers to QMS implementation (see Chapter 2 on *Barriers to QMS and TQM implementation*)
12. Organisational behaviour: defined apathy of personnel towards quality implementation, top administration complexity, QMS misconceptions, lack of effective communication, lack of rewards system to keep personnel motivated, difficulty in developing SOP for quality-focused processes, etc. (see Chapter 2 on *Barriers to QMS and TQM implementation*).
13. Inadequate or missing internal audit: difficulty to perform internal audits, opposition to external auditing, lack of quality monitoring systems, lack of experience to conduct quality auditing, etc., inhibit QMS implementation (see Chapter 2 on *Barriers to QMS and TQM implementation*)
14. Regulatory and standards nonconformities: the culture of unscheduled reliability maintenance and non-conformance to international standards, disinterest in ISO series standard requirements, QMS misconceptions, etc., are a recipe for non-compliance and auto recalls (see Chapter 2 on *Barriers to QMS and TQM implementation*)
15. Environmental standards nonconformities: opposition to conformities, resistance to change, lack of SOP for environmental standard compliance, and the like, can be a recipe for non-compliance and auto recalls (*see Chapter 2 on Auto recalls*)

At this stage, the FRs and their corresponding DPs are not exhaustive in detail to produce the highest-level design parameter, DP_0. Thus, a second iteration of the design for the development of QX Engineering system is presented in the next section.

3.4.2 Second iteration of the design decomposition

The second iteration of the design decomposition begins with the decomposition of the hierarchical level 3 analysis, involving $FR_{1.1}$ to $FR_{1.3}$ with respect to the IATF 16949:2016 standard-based quality objectives in Table 3.3. In order to satisfy the stakeholder goal, the hierarchical level 4 analysis or fourth-level decomposition of $FR_{1.1}$ to $FR_{1.3}$ and their associated DPs are defined and presented in Table 3.8.

Table 3.8 Fourth-level decomposition of FR_1

Functional Requirements		Design Parameters	
FR_0:	Develop a quality-focused manufacturing system to satisfy stakeholder needs	DP_0:	Quality-engineered automotive manufacturing system design
FR_1:	Achieve the desired value-added quality of the design	DP_1:	QX Engineering system for maximising the value-added quality of the QX design
$FR_{1.1}$:	Implement QMS-based IATF 16949:2016 for regulatory and standards requirements	$DP_{1.1}$:	Procedure for implementing regulatory and standards requirements
$FR_{1.1.1}$:	Create and define IATF 16949:2016-oriented hierarchy for processes, procedures and work instructions	$DP_{1.1.1}$:	Master IATF 16949:2016-based action level for processes, procedures and work instructions
$FR_{1.1.2}$:	Produce a IATF 16949:2016-based Manual for QMS scope, quality policy, quality objectives, corporate policies	$DP_{1.1.2}$:	IATF 16949:2016-based Manual for QMS scope, quality policy, quality objectives and corporate policies
$FR_{1.1.3}$:	Design implementation protocols for processes, procedures and control, and recording method	$DP_{1.1.3}$:	Implementation protocols for processes, procedures and control, and records of implementation
$FR_{1.1.4}$:	Determine required training needs for QMS	$DP_{1.1.4}$:	Multipurpose QMS training programmes across all units
$FR_{1.1.5}$:	Create procedures for conducting internal audit process, internal audit report generation, and countermeasures	$DP_{1.1.5}$:	Standard Operating Procedures (SOP) for internal audit process, internal audit reporting, and corrective actions
$FR_{1.1.6}$:	Produce QX Task Force — Management protocol for review of internal audit report	$DP_{1.1.6}$:	QX Task Force and Management SOP for review of internal audit
$FR_{1.1.7}$:	Develop Standard Operating Procedures (SOP) for IATF 16949:2016 standard practice	$DP_{1.1.7}$:	SOP for QMS and IATF 16949:2016 standard practice
$FR_{1.1.8}$:	Produce QX Engineering-based documentation based on requirements of QMS IATF 16949:2016 standard	$DP_{1.1.8}$:	QX Engineering-based documentation outline processes in compliance with IATF 16949:2016 statutory and regulatory requirements
$FR_{1.1.9}$:	Achieve quality regulatory and standard compliant status for QX Engineering compliant design	$DP_{1.1.9}$:	Produce QX Engineering quality compliant validation process
$FR_{1.2}$:	Design quality-oriented process efficiency and effectiveness for automotive manufacturing operations and automobile product	$DP_{1.1}$:	Quality-oriented process efficiency and effectiveness system
$FR_{1.2.1}$:	Define and group product families for production	$DP_{1.2.1}$:	Procedure for defining and classifying product families
$FR_{1.2.2}$:	Design manufacturing process and strategy based on automobile product family functional requirements	$DP_{1.2.2}$:	Procedure for selecting QMS-oriented manufacturing process and strategy
$FR_{1.2.3}$:	Determine the QMS-based master process for automobile product design	$DP_{1.2.3}$:	QMS-based master process selection for automobile product design

$FR_{1.2.4}$: Maximise manufacturing resources	$DP_{1.2.4}$: Product-oriented QMS-based manufacturing facility layout to minimise waste
$FR_{1.2.5}$: Determine QX Engineering design for quality control	$DP_{1.2.5}$: QX Engineering system for automobile product families
$FR_{1.3}$: Define process strategy to enable continual improvement	$DP_{1.3}$: Hoshin Kanri for continuous improvement
$FR_{1.3.1}$: Determine Key Performance Indicators (KPI), objectives and quality-based process approach for continual improvement	$DP_{1.3.1}$: Procedure for selecting quality-based process to achieve KPIs and objectives
$FR_{1.3.2}$: Determine scope of environmental and automotive regulatory policy objectives	$DP_{1.3.2}$: Information and report system
$FR_{1.3.3}$: Design internal and external stakeholder feedback to determine gaps in quality of service and automobile product families	$DP_{1.3.3}$: Continuous feedback information flow system
$FR_{1.3.4}$: Determine master process to respond to vectors of quality data deviations or threats	$DP_{1.3.4}$: Standardise Master process selection for addressing vectors of quality data deviations or threats

Table 3.9 Fourth-level decomposition of FR_2

Functional Requirements	Design Parameters
FR_0: Develop a quality-focused manufacturing system to satisfy stakeholder needs	DP_0: Quality-engineered automotive manufacturing system design
FR_2: Minimise cost-biased activities in developing the system design	DP_2: Procedure for minimising cost-associated threats to developing the system design
$FR_{2.1}$: Determine strengths and weaknesses of under-utilised personnel	$DP_{2.1}$: Conduct strength/weakness analysis
$FR_{2.1.1}$: Reposition non-utilised skilled personnel	$DP_{2.1.1}$: Procedure for determining positioning for talent
$FR_{2.1.2}$: Define process for maximising use of skilled personnel	$DP_{2.1.2}$: Procedure for maximising use of skilled personnel
$FR_{2.1.2}$: Determine master process for personnel utilisation	$DP_{2.1.2}$: Master process for maximised human resources
$FR_{2.2}$: Eliminate NVA excess production of resources	$DP_{2.2}$: Production Kanban
$FR_{2.2.1}$: Minimise repetitive design and printed-matter	$DP_{2.2.1}$: Short process setup for design
$FR_{2.2.2}$: Avoid long changeovers	$DP_{2.2.2}$: Standardise stable schedules
$FR_{2.2.3}$: Minimise reliance on forecasted demand	$DP_{2.2.3}$: Just-in-time production
$FR_{2.2.4}$: Determine production volume control	$DP_{2.2.4}$: Production Pareto analysis

	$FR_{2.2.5}$: Determine master process for capturing NVA production activities		$DP_{2.2.5}$: Master process for identifying and mitigating agents of overproduction integrated with Nagara
$FR_{2.3}$: Eliminate factors of defects within the system design		$DP_{2.3}$: Process for zero defects	
	$FR_{2.3.1}$: Eliminate rework		$DP_{2.3.1}$: Procedure for on-line quality inspection
	$FR_{2.3.2}$: Eliminate non-productive time		$DP_{2.3.2}$: Procedure for implementing quality at the source
	$FR_{2.3.3}$: Eliminate agents of variations		$DP_{2.3.3}$: Six Sigma process selection
	$FR_{2.3.4}$: Determine master process for capturing defects		$DP_{2.3.4}$: Master process integrated with Mizusumashi, Andon system and Hanedashi
$FR_{2.4}$: Eliminate NVA inventory of design resources		$DP_{2.4}$: Process for resource efficiency	
	$FR_{2.4.1}$: Define process to control inventory		$DP_{2.4.1}$: Heijunka process
$FR_{2.5}$: Eliminate NVA movements of human and material resources		$DP_{2.5}$: Production resources scheduling procedures	
	$FR_{2.5.1}$: Reduce material movements		$DP_{2.5.1}$: Material flow-oriented layout
	$FR_{2.5.2}$: Reduce human resource unnecessary motion		$DP_{2.5.2}$: SOPs for manufacturing processes
$FR_{2.6}$: Minimise NVA waiting in the system		$DP_{2.6}$: Continuous flow design	
	$FR_{2.6.1}$: Reduce machine operations NVA idle time		$DP_{2.6.1}$: Manufacturing system scheduling
	$FR_{2.6.2}$: Minimise personnel waiting on material or machine operations		$DP_{2.6.2}$: Process continuous flow
$FR_{2.7}$: Eliminate inefficient processing within the system		$DP_{2.7}$: Process Kaizan design	
	$FR_{2.7.1}$: Determine master process		$DP_{2.7.1}$: Standardised master process
$FR_{2.8}$: Eliminate inefficient transportation of resources in the system		$DP_{2.8}$: Procedures for reducing excessive transportation	
	$FR_{2.8.1}$: Define process for minimising NVA transportation		$DP_{2.8.1}$: Single Minute Exchange of Die (SMED) process
	$FR_{2.8.2}$: Minimise transportation of resources within facility		$DP_{2.8.2}$: Production-oriented facility layout
$FR_{2.9}$: Determine and mitigate personnel apathy towards design process		$DP_{2.9}$: Procedures for determining and mitigating personnel apathy behaviours	
	$FR_{2.9.1}$: Define objective monitoring scheme for personnel apathy across all departments and analysis		$DP_{2.9.1}$: Procedures for objective identification of personnel apathy across all departments and analysis
	$FR_{2.9.2}$: Determine risk assessment to minimise personnel apathy		$DP_{2.9.2}$: Procedure for risk assessment based on personnel apathy behaviours
	$FR_{2.9.3}$: Motivate personnel participation in organisational goal		$DP_{2.9.3}$: Reward-sharing programmes

$FR_{2.10}$:	Determine top management non-committal towards quality implementation process and overall organisational goal	$DP_{2.10}$:	Mitigation solution for top management non-committal attitudes
$FR_{2.10.1}$:	Conduct risk assessment to minimise top management non-committal attitudes	$DP_{2.10.1}$:	Procedure for conducting risk assessment based on top management non-committal behaviours
$FR_{2.11.2}$:	Pull top management's commitment to goal	$DP_{2.11.2}$:	Gain-sharing programme
$FR_{2.11}$:	Determine quality training needs required for core capabilities	$DP_{2.11}$:	Core quality capability training programmes
$FR_{2.11.1}$:	Co-evolve with emerging technologies	$DP_{2.11.1}$:	Procedure for regular recurrent training
$FR_{2.12}$:	Mitigate organisational behaviour against quality engineering processes	$DP_{2.12}$:	Mitigation solution for organisational apathetic behaviour against design
$FR_{2.12.1}$:	Determine agents of risks to the design process	$DP_{2.12.1}$:	Procedure for identifying human agent risk factors
$FR_{2.12.2}$:	Determine in-house training and awareness workshop on organisational context and goals	$DP_{2.12.2}$:	In-house training and awareness programme on organisational context and goals
$FR_{2.13}$:	Determine internal audit of quality procedures	$DP_{2.13}$:	Implement internal audit of quality processes across all departments
$FR_{2.13.1}$:	Determine process for conducting internal audit	$DP_{2.13.1}$:	Procedures for conducting internal audit
$FR_{2.13.2}$:	Determine internal audit team	$DP_{2.13.1}$:	Internal audit team selection process
$FR_{2.14}$:	Mitigate automotive regulatory and standards nonconformities within the design processes	$DP_{2.14}$:	Mitigation solution for regulatory and standards nonconformities
$FR_{2.14.1}$:	Determine in-house training and awareness on regulatory and standards compliance requirements	$DP_{2.14.1}$:	Training and awareness programme on regulatory and standards compliance requirements
$FR_{2.14.2}$:	Provide procedure to enable consistency of conforming with regulatory and standards requirements	$DP_{2.14.2}$:	Standard Operating Procedures (SOP) based on requirements for conforming with regulatory authority standard
$FR_{2.15}$:	Mitigate environmental compliance nonconformities within the design processes	$DP_{2.15}$:	Mitigation solution for environmental compliance nonconformities
$FR_{2.15.1}$:	Provide in-house training and awareness on environmental standards compliance requirements	$DP_{2.15.1}$:	Training and awareness programme on environmental standards compliance requirements
$FR_{2.15.2}$:	Provide procedure to enable consistency of conforming with environmental standards requirements	$DP_{2.15.2}$:	Standard Operating Procedures (SOP) based on environmental standards requirement compliance

The above sections partly satisfy Research Objective 1 (RO1 in terms of proposing a novel derivation for a quality engineering framework that is designed to optimise quality processes within automotive manufacturing systems (see also p. 2 for RO1). However, in order to ascertain the integrity and optimise the initial QX Engineering design, further exhaust decomposition of the FRs, establish a validated interaction between FRs and DPs, and conduct a reliable evaluation matrix, mixed-methods research will be carried out in Sections 3.7 to 3.12 for input data extraction and analysis based on multi-stakeholder (automotive manufacturing SMEs, automobile product owners, passengers, automotive engineers, users) responses. The analysis results will lead to an updated edition of the design to produce a conceptual design and analysis of QX Engineering in Chapter 7. As part of the design goal is to cater for post-process quality delivery, the next stage in Section 3.5 proposes a model for tracking social (human) actor-based threats to the quality design process which outcome will be integrated in the conceptual design for an optimised design solution.

3.5 Deriving a model for vQDD traceability

Having identified and defined FR_1 and FR_2, which characteristic vectors are exhaustively decomposed through iterations to result in the highest-level design parameters, DP_0, which defines the QX Engineering system, the third stage engages the QX Design Team and QX Task Force to derive a model for threat or vQDD traceability. The proposed model is a scheme for tracking human adversarial behaviours or attitudes that pose as potential threats to the design process or vectors that cause the key input variables for the expected quality function to deviate from the expected data. As QX Engineering is desired for an all-inclusive design, the model for threats/vQDD traceability is proposed for Type-I QTV and Type-II QTV. For threats to Type-I QTV, this will include personnel within the organisation, who seek and gain an unauthorised access to engineering trade secrets or sensitive data, can deliberately falsify or manipulate data for selfish or malicious reasons, conceal errors or discover cost-based quality issues but intentionally do not report any issues to warrant a counter action, can be a threat or a vQDD to the quality design. This is because such concealed error, for example, can extend false quality data throughout the manufacturing process and manifest at a costly scale in a delivered automobile product.

For Type-II QTV threats, if for an example a customer procures an automobile product X from Q Automotive Engineering and takes the vehicle to Z Motors to carry out significant mechanical alterations simply to achieve certain custom features, then such a customer or car owner can be a threat to the design process that produced X. This is because the action of the car owner can cause some of the inherent mechanical properties of the originally engineered work to be varied. The latter can occur through welding, hammering and other mechanical activities. If such a hypothetical scenario occurred to 25N vehicles and 10 fall out of specification in terms of quality safety issues and consequently triggered an auto recall of the range of Ns in the market, then a QX Engineering practising SME must be able to use the proposed traceability model to trace the possible human or social actor factors that caused the safety quality problem. This can be used in comparison with the findings of regulatory and standards bodies to ascertain the fault analysis with respect to an auto recall. This provides an advantage to automotive manufacturing SMEs to provide safeguarding procedures such as:

- Terms of Use of automobile products: this can ideally mandate customers and their associates to seek consent of the original manufacturer before they carry out intensive alterations of their vehicle. Such a consent application will ascertain whether intended customisation will preserve the product quality (then *Yes*, to customisation) of the product or cause a quality deviation (then *No*, to customisation). If *Yes*, then the original manufacturer recommends the vehicle is taken to its garage or to affiliated ones simply to preserve design integrity. However, if the customer takes the vehicle to any other garage other than the one the original manufacturer recommends, then that automatically forfeits any warranties and breaches the Terms of Use. If *No*, and the preceding hypothetical case applies, then the original manufacturer is indemnified against any mishappening to the unauthorised altered vehicle.
- Derive auto recall contingencies and formulate response capability.
- Enable reconfigurability of existing systems to address on-demand quality issues.

In order to derive a realistic vQDD traceability model, a data collection procedure is adopted in Sections 3.7 to 3.12 to index the threats the behaviours of automobile manufacturing personnel and automobile product external stakeholders (customers, users, etc.) pose. The research is carried out across the following domains:

Type-I QTV-related identifiers: —

- Conduct risk assessment to detect specific threats or vQDDs based on manufacturing organisational needs and behaviours
- Conduct risk assessment to detect specific threats or vQDDs based on regulatory standards authorities' needs and behaviours

Type-II QTV-related identifiers: —

- Conduct risk assessment of specific threats/vQDDs based on customer (car owner) needs and behaviours.
- Conduct risk assessment of specific threats/vQDDs based on secondary user (pedestrian, user, etc.) needs and behaviours.
- Conduct risk assessment of specific threats/vQDD based on identified multistakeholder (OEM, investors, etc.) needs and behaviours.

The analysis results of vQDDs derived from Chapters 4 and 5 will inform the structuring of the threat/vQDD traceability model as established between high-level goals and hierarchical level 4 analysis. This will then be integrated in the conceptual design of QX Engineering in Chapter 7.

3.6 Overview

The aforementioned Sections outlined the use of Axiomatic Design to guide the development of the proposed new quality engineering system for automotive manufacturing SMEs. The definition of design goal, development of QX Engineering framework, and a pathway to deriving design solutions to identify human-induced quality threats have been presented. The process mapping for the stages required to decompose the QX Engineering design goal has been explained through mapping of the first and second level functional requirements. These were followed by the derivation of the third level functional requirements. The latter features 32 key IATF 16949:2016-based quality process value objectives, from which three quality objectives of FR_1 are identified to satisfy all the principal quality objectives without violating the Independence Axiom. Following the initial design of the proposed QX Engineering framework, this study proposes a mixed-methods research to enable the identifications and acquisition of the ideal input data or parameters required to optimise the initial design as well as ascertain its credibility, validity, reliability and viability. The philosophical position taken to guide the selection of the appropriate research methodology and design to enable acquisition of the input parameters are described from Section 3.7 to Section 3.12.

3.7 Research Philosophy

This Section outlines the philosophical worldview that shapes the approach to this study and guides the methodological strategies of enquiry and research methods appropriate to address the (1) variants of quality performance, (2) the factors that compromise quality value delivery, and (3) the mitigation solutions against quality implementation barriers.

The research onion (Fig. 3.3) described by Saunders et al. (2012) is adapted to guide the structuring of the research process presented in Sections 3.7 to 3.12, where each Section presents the selected option from each ring of the onion.

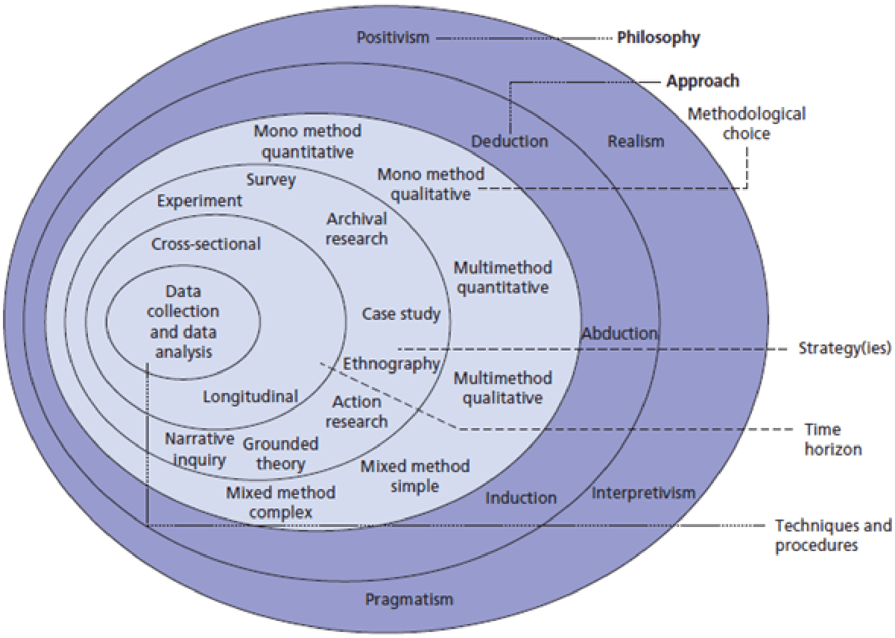


Fig. 3.3 Methodological choices adapted from Saunders et al's. (2012) research onion

3.7.1 Philosophical stance

This Section explains the philosophical assumptions of this research and how the researcher develops knowledge (Saunders et al., 2012). The Section also discusses the choice of the umbrella pragmatic worldview under which social constructivism and interpretivism are synergised in preference against the postpositivist paradigm. As the pragmatic worldview is not committed to any one system of philosophy and reality (Cherryholmes, 1992; Creswell, 2013; Creswell & Creswell, 2018; Morgan, 2007) but rather an enabler of the freedom to choose the research methods, techniques and procedures that can best satisfy the study objectives and adequately address the research questions, I chose the combination of social constructivism and interpretivism as the ideal paradigm to better shape this study. Unlike the case of the postpositivists' position in which causes probably determine effects or outcomes (Cherryholmes, 1992; Creswell, 2013; Creswell & Creswell, 2018; Morgan, 2007; Phillips & Burbules, 2000) via empirical investigation, my own view is that the occurrence of quality engineering or quality design process failures at an implementation, in-process or and operational phase within automotive manufacturing organisations (context) arises as a result of social (human) actors' adversarial or apathetic attitudes. This aligns with Creswell (2013, p. 10) in that the pragmatic worldview:

> *"arises out of actions, situations, and consequences rather than antecedent conditions (as in postpositivism). There is a concern with applications – what works – and solutions to problems. Instead of focusing on methods, researchers emphasise the research problem and use all approaches available to understand the problem."*

It is based on the experience-driven interpretation of such human-induced adverse consequences within the context that the study leans towards the social constructivist and interpretivist lens. The use of the terms *worldview* (Guba, 1990, p. 17) and *paradigm* (Lincoln et al., 2017; Mertens, 1998) are used interchangeably throughout this study as the same in meaning.

Social constructivism and interpretivism

The philosophical worldview proposed for this study is pragmatism in that the research takes an eclectic approach to address the research questions and identify the appropriate methodological choices and strategies for data collection and analysis, and derivation of the needed contributory input data required to optimise the initial design of the proposed new quality engineering framework (Cherryholmes, 1992; Creswell, 2013; Creswell & Creswell, 2018; Morgan, 2007; Patton, 1990; Saunders et al., 2012; Tashakkori & Teddlie, 1998, 2010; Wilson, 2010; Yilmaz, 2013). This resulted in selecting to draw from mixed-methods research and interpretivism assumptions to guide this study.

The context for the proposed QX Engineering is *quality excellence engineering within automotive manufacturing organisations.* As automotive manufacturing SMEs are expected to deliver good quality at minimum manufacturing cost in order to stay competitive and survive in the ever-changing manufacturing environment (Acharya et al., 2010; Krishna et al., 2008), this study aims at developing a novel quality engineering framework to guide against human adversarial behaviours towards quality design, implementation, and process activities. Due to the inherent limitations associated with any individual method (quantitative or qualitative), the study will explore a synergy of multiple methods in order to adequately address the research problem. It is in the direction of seeking a multifaceted approach to facilitating the perspective of this study that the research leans towards the pragmatic worldview. The philosophical underpinning of pragmatism for mixed-methods studies enables multiple methods, different worldviews, different assumptions, and different strategies for data collection and analysis (Creswell, 2013; Morgan, 2007; Patton, 1990; Tashakkori & Teddlie, 1998). The combination of social constructivism and interpretivism paradigms aligns with the intent of this study with respect to (1) understanding how social (human) actors' adversarial interactions vary quality deployment goals, (2) characterising the adversarial behaviours of social (human) actors as vectors of quality data deviation or vQDD (see Section 3.3 on *Decomposition of* FR_2), (3) seeking deep understanding from focus group's experiential perspectives on quality engineering design, and (4) providing analytical generalisation of the mixed-methods study findings (Creswell, 2013; Creswell & Creswell, 2018; Crotty, 1998; Lincoln & Guba, 1985).

This research considers the role of structures in influencing human behaviour in Studies 1 and 2

> Study 1:
> *Why do automotive manufacturing organisations vary systematically in quality performance over time? (RQ1)*
>
> *and*
>
> Study 2:
> *Why do manufacturing organisations, whose primary objective is to maximise the value of quality-oriented processes and automobile products, deliver significantly less than those organisations that have attained quality management system (QMS) certification? (RQ2)*

and thereby does not follow a 'pure' social constructivist stance in acknowledging both actors (human behaviour) and structures (context) in the creation of reality. Actors are, however, responsible for creating the very structures that aspire to monitor and control human behaviour, and human behaviour needs to be assessed for an in-depth analysis of organisations' quality management. Through the postpositivist lens, a claim of knowledge about how human adversarial behaviours can potentially cause quality data deviations within an automotive manufacturing process and organisation as well as automobile products cannot be ascertained (Creswell, 2013). This, therefore, appeals to a "pluralistic approach to derive knowledge about the problem" (Creswell, 2013, p. 11).

It is established earlier that social (human) actors (such as top management and subordinates), whose apathetic behavioural patterns tend to pose as barriers to quality process implementation, are referenced in this research as vectors of quality data deviations (vQDD) or threats to quality design process (see Chapter 2 on *Barriers to QMS and TQM Implementation)*. Such human-induced vQDD activities within an automotive manufacturing organisation constitute a social phenomenon. This leads to the inference that the paradigm of interpretivism posits that an automotive manufacturing organisation constitutes a social phenomenon. In this respect, access to reality is only through social constructions such as personnel apathetic characteristics as driven by an interactional level to quality implementation within an automotive organisation (Grix, 2004, p. 83f.). Within such confines, the ontology of

> Study 3:
> *How can automotive manufacturing organisations overcome the variables that impede the hybridisation and implementation of engineering quality management system (QMS)? (RQ3)*

perceives reality as intersubjectivity, factored by understandings and experiential insights (Abu-Alhaija, 2019). In relation to this, the subjectivist epistemological stance theorises that the researcher's background knowledge cannot be separated from the subject researched (Abu-Alhaija, 2019). This, therefore, assumes that the researcher's own biases will play a role in the inference formation.

Given the limitations in the structures-oriented quantitative technique to addressing Study 1 and Study 2, qualitative method for answering Study 3, and the biases inherent in any of the two individual methods (Creswell, 2013), this study gravitates to mixed-methods strategy and shaped by pragmatic assumptions. The latter is based on the ground that pragmatists do not

> *"commit to any one system of philosophy and reality. This applies to mixed-methods research in that enquirers draw liberally from both quantitative and qualitative assumptions when they engage in their research"* (Creswell, 2013, p. 11).

While the enquiry strategies to address the research problem will employ different techniques due to the divergent orientations (structures-oriented (Study 1 – Study 3) and actors-oriented (Study 3)), the findings from both will be analysed within the social constructivist and interpretivist domain (Creswell, 2013, 2018). This is because, on the bases that the barriers or social phenomenon that contribute to quality data deviations are created by the actions of social (human) actors and fundamentally not entirely by non-human objects, the ontological claims about quality systems implementation within automotive manufacturing organisations will draw on social constructivism. This is in respect to the nature of reality the social actors construct (Bryman & Bell, 2011; Crotty, 1998; Grix, 2004; Saunders et al., 2012). This assessment prompted a need to understand the underpinning factors that cause social actors to act in the way that stimulate an automotive manufacturing organisation to deviate from its highest-level goal (FR_0).

The position or hierarchy personnel occupy is a socially constructed concept or invention. For instance, the characteristics of a top manager in an India-based automotive manufacturing environment will differ from that of his British counterpart, at a different geographic location. Thus, the concept of "top manager" is not real. In contrast to objectivism, constructivism acknowledges both the role of social actors and the context they are embedded in due to the interplay between humans and their manufacturing organisation (Creswell, 2013; Crotty, 1998). Thus, within the constructivist paradigm, my own assertion is that there is a need to develop an engineering system that creates a control over human adversarial attitudes towards quality processes while at the same time acknowledging that human actors design, implement and monitor the QX engineering system. In this regard, human interactional activities with the context (QX Engineering system within an automotive manufacturing organisation) will require mitigation solutions to be put in place as control or countermeasures against human-induced quality issues.

Applying mixed-methods research will yield a validated claim for generalisation (Gibson, 2017). This is presented in detail in Section 3.8. The findings from the three studies, RQ1 – RQ3, were situated and interpreted or merged within the constructivist paradigm, leading to a constructed or created knowledge within a social context (Andrews, 2012; Creswell, 2009). Rather than offer statistical generalisations, the findings of this research are intended to offer a process mapping for quality design that automotive manufacturing SMEs can use to create a customised framework to guide in-house quality-focused manufacturing operations and automobile production.

3.8 Research design and methods

3.8.1 Definition, merits and demerits of mixed-methods research through debates

The limitations of the research methods associated with quantitative and qualitative studies prompted debates among researchers, suggesting the plausibility of combining the two strategies in that the strength in any one method could offset the inherent biases of the other (Bryman & Bell, 2007, p. 642; Creswell & Creswell, 2018; Driscoll et al., 2007; Fetters et al., 2013; Tashakkori & Teddlie, 1998). Although "by the early 1990s, the idea of mixing moved from seeking convergence to actually integrating or connecting the quantitative and qualitative methods strategies of inquiry" (Creswell, 2009, p. 31), Smith (1983, p. 12-23) argues that "each of the two research strategies sponsors different procedures and has different epistemological implications" contrary to the "unfounded assumption that the methods are complementary". While such debates criticise the integration of research strategies on the basis that it ignores the assumptions underlying research methods (Smith & Heshusius, 1986, p. 8), Bryman (1988), J. W. Creswell and Creswell (2018), Johnson and Onwuegbuzie (2004), Tashakkori and Creswell (2007), and Tashakkori and Teddlie (2010) agree that mixed-methods research is gaining far more popularity and is becoming

> *"increasingly articulated, attached to research practice, and recognised as the third major research approach or research paradigm, along with qualitative research and quantitative research"* (Johnson et al., 2007, p. 112).

As the term mixed-methods research presents a broad description of multiple methods or strategies for data collection and analysis, for which a universal definition does not exist, Johnson et al. (2007, p. 119) carried out a study involving leading researchers in the field. This led to 19 definitions of mixed-methods research. While at least 13 of the definitions suggest mixed-methods research is a combination of qualitative and quantitative methods, Johnson et al. (2007, p. 121) defined it as

> *"the combination of, e.g., purposeful & probability sampling, open-ended and closed-ended data collection techniques, and narrative and multivariable analyses - i.e., in which anything can be used together (linked or assimilated into each other) - or it can be defined at a larger theoretical/paradigmatic level as using divergent approaches to inquiry together".*

Following the analysis of their study, Johnson et al. (2007, p. 123) define mixed-methods research as

> *"the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g. use of*

> *qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purposes of breadth and depth of understanding and corroboration".*

The above coupled with Creswell et al.'s (2003, p. 212) definition that it

> *"involves the collection or analysis of both quantitative and/or qualitative data in a single study in which the data are collected concurrently, or sequentially, are given a priority, and involve the integration of data at one or more stages in the process of research,"*

and the generic definition that mixed-methods research is a

> *"[r]esearch in which the investigator collects and analyses data, integrates the findings, and draws inferences using both qualitative and quantitative approaches in a single study or program of inquiry"* (Tashakkori & Creswell, 2007, p. 4)

lacks a reference to philosophical assumptions required to guide a study. As such, J. W. Creswell and Plano Clark (2007, p. 5) offer a more enriched definition of mixed-methods research as a

> *"research design with philosophical assumptions as well as methods of inquiry. As a methodology, it involves philosophical assumptions that guide the direction of the collection and analysis and the mixture of qualitative and quantitative approaches in many phases of the research process. As a method, it focuses on collecting, analysing, and mixing both quantitative and qualitative data in a single study or series of studies. Its central premise is that the use of quantitative and qualitative approaches, in combination, provides a better understanding of research problems than either approach alone".*

The Creswell and Plano Clark (2007) definition of mixed-methods research stated above aligns with the central foundation of this study in taking a philosophical stance to guide the design of multiple methodologies for data collection, analysis and interpretation in a single study.

Although methodological ideologists as Grafton et al. (2011), Malina et al. (2011) and Mingers (2006) argue that mixed-methods research by definition provides the best opportunity for combining the strengths of the two dominant research genres to generate an integrated set of evidence to address a single or set of research questions in one study, Bryman (2011), J. W. Creswell et al. (2003), J. W. Creswell and Plano Clark (2011), Johnson and Onwuegbuzie (2004) and Lisle (2011) assert that this does not necessarily follow that mixed-methods research is without any disadvantages. The enquiry into *how* or *whether* quantitative and qualitative methods can be mixed (or integrated) in a single study sparked theoretical debates or paradigm wars (Denzin, 2012).

Regnault et al. (2018) argue that the paradigm wars are premised by the differences in the underlying ontological and epistemological positions of positivism by which a single objective reality exists and constructivism that is based on a subjective construct for which multiple realities exist. This is exacerbated by the epistemological juxtaposition of both quantitative and qualitative methods in one study (Antwi & Hamza, 2015; Bryman, 2011; Darlaston-Jones, 2007). Their ground is that constructivists, who are qualitative research genre biased, consider reality as subjective and must, therefore, not be mixed with contrasting worldviews. With respect to such methodological purists' philosophical stance, positivists, who are quantitative research methods oriented, view reality as objectively quantifiable and therefore do not share such belief with constructivists or non-positivists.

Contrary to the methodological purists' advocacy, J. W. Creswell (2013) argues that the single use of either quantitative or qualitative method in research cannot produce findings that are representative of the overall population of a study. Table 3.10 presents a summary of the debated merits and demerits associated with the core approaches within mixed-methods research.

Table 3.10 Merits and demerits of mixed-methods research

Sources: Adapted from F. Almeida (2018), J. W. Creswell (2014), Hafsa (2019), Hughes (2016), Johnson and Onwuegbuzie (2004), Koskey and Stewart (2013), Onwuegbuzie and Collins (2007), and Zou et al. (2014).

Mixed-methods Research		
Research Design	**Merits**	**Demerits**
Sequential explanatory	Enables preliminary quantitative findings to inform the design of the secondary qualitative research.	Detecting the quantitative results for further examination and levelling sample size for each stage of the study can be cumbersome. Time and resource demanding.

Sequential exploratory	Suitable for exploring a new phenomenon. Enables pulling qualitative data required to inform quantitative research.	Ascertaining the precise qualitative findings to employ and selection of sample for both stages of study can be difficult. Susceptible to complexity if sample population is very large. Time and resource demanding.
Sequential transformative	Data collection is unrestrictive as it is a function of the theoretical perspective of the researcher. Offers in-depth understanding of a process.	It is susceptible to the researcher's own biases, exposing the validity and credibility of the findings to scrutiny. Time and resource demanding.
Concurrent triangulation	Useful in reducing implementation time via analysing quantitative and qualitative data separately. Enables cross-validation of findings in a single study.	Low flexibility. Irreconcilable discrepancies may exist between quantitative and qualitative findings.
Concurrent embedded or nested	One minor (quantitative or qualitative) data is nested within the dominant (quantitative or qualitative) method. Shortened time required for data collection.	Integrating both quantitative and qualitative data can present challenges. Reconciling findings from two conflicting paradigms in one study can present difficulties.
Concurrent transformative or Parallel transformative	Both methodological choices executed concurrently. Enables representation of diverse views of participants. Shortened time required for data collection.	Integrating both data can be difficult. Reconciling findings from two conflicting paradigms can be difficult.
Concurrent convergence or Parallel convergence	Takes a two-way parallel (objective and subjective) approach to study a problem in its entirety and dimension.	Time-intensive. Requires expertise background.
Sequential complementary	Similar to concurrent embedded design, one approach is used to counter the deficiencies of the other method.	Time-consuming. Mixing both data can be difficult.
Multiphase	Can be used to address complex problems. Stimulates emergent research-relevant enquiries at any stage of a study. Sequential and concurrent designs can be combined in a study, enabling interconnected enquiries.	Background experience in large scale research is required. Time and resource demanding. Cost-biased.
Multilevel	Can be used to address complex problems. Useful in addressing a multi-dimensional problem, hence offers a robust approach to research.	Requires the use of different samples and approaches to decrypt it, hence cumbersome in process mapping. Background experience in large scale research is required. Time and resource demanding. Cost-biased.

Table 3.10 shows that the prevalent demerits within the prominent methodological approaches used in mixed-methods research remain (1) time and resource demands, (2) the scale of preference of the methodological choices, and (3) the difficulty in integrating findings from two conflicting paradigms (Bryman, 2006; Hughes, 2016). Table 3.10 also shows that apart from the issues associated with sequential explanatory or sequential exploratory designs, for example, the standard procedure of obtaining preliminary findings (as input parameters) via either quantitative or qualitative method to inform the design of the second method, presumes that any inherent shortcomings in the first method can influence the credibility and validity of the secondary findings. In this regard, the credibility and validity of the final findings cannot be generalised or ascertained for the greater population without a caution to compromise. Thus, adopting any of the sequential-based strategies will not only be time-intensive but can also potentially transfer any inherently undetected errors from the preliminary study to the second study at the interface of integrating or merging/mixing the databases. These insights inform a multifaceted approach to designing the methodological choice that is suitable for this study (Creswell, 2009; Creswell, 2014).

3.9 Facets of mixed-methods research

In planning a design of mixed-methods research, Creswell et al. (2003) identify four key facets as *timing*, *weighting*, *mixing* and *theorising*. Following my own inclination, these factors guide the design of this study.

Depending on the research objectives of this project, the *timing* of whether to conduct the qualitative and quantitative aspects of a study sequentially or concurrently is an essential step in the initial stage of planning a mixed-methods research (Creswell, 2014). In this study, a convergent strategy will be adopted in that both qualitative and quantitative data will be collected concurrently and analysed simultaneously to address the three research questions. Contrary to a sequential strategy, concurrent design offers both time-effective and resource-effective advantages to this study.

According to Creswell et al. (2003) and Creswell (2014), the second facet for a mixed-methods research is the *weight* assigned to either the quantitative or qualitative research component of a study. This regards which of the two methods is prioritised, made dominant and or emphasised first in a study. In this study, both quantitative and qualitative databases will be collected concurrently but have an unequal *weighting* (Creswell et al., 2003; Creswell, 2014; Tashakkori & Teddlie, 1998). As the philosophical stance underpinning this research does not see one worldview to predominate another (Tashakkori & Teddlie, 1998), the approach to both quantitative and qualitative data collection followed no sequence. Hence, the *implementation* in this study is concurrent (Creswell et al., 2003; Creswell, 2009). That is, quantitative method will be used for data collection and analysis in Study 1 to Study 3 to address RQ1 to RQ3, and additionally qualitative method will be used for data collection and analysis in Study 3 to further enrich the answer for RQ3 at the same time.

This study is purposely situated within the social environment of automotive manufacturing organisations via which contribution to knowledge is constructed through social (human) actors' activities. As this results in creating reality jointly by the research participants, both the quantitative and qualitative research strategies selected were appropriate for this study. This is because the technique used for data collection aligns with the deductive approach required for *mixing* the dababases for analysis within the social constructivist and interpretivist domain (Crotty, 1998; Grix, 2004; Bryman & Bell, 2007; Saunders et al., 2012).

Mixing the quantitative and qualitative databases can occur at multiple stages (i.e. data collection, data analysis or interpretation stage, etc.) of a mixed-methods research (Creswell et al., 2003; Creswell, 2009; Creswell & Plano Clark, 2007). In this study, the quantitative and qualitative findings or databases were merged or *mixed* at the combined data analysis and interpretation stage in Study 3. To achieve this, relevant parts of the textual components of the quantitative survey were transformed into numerical data and merged with the descriptive quantitative data (Creswell, 2009). This is intended to ensure a generation of credible, validated and generalised conclusion on how the proposed new quality engineering framework further addresses RQ1, RQ2 and RQ3.

In reference to Creswell et al. (2003), which presents that a research design that is oriented on either sequential explanatory or exploratory strategy is guided mainly by implicit theoretical perspective, the design for this study is shaped by explicit ideological perspective as premised by its consideration of a concurrent approach to data collection, unequal weighting of the research methods and mixing the findings at the interpretation phases.

3.10 Research design

This study examines whether the ideological perspective of vectors of quality data deviations (vQDD) as defined earlier in Section 3.7 apply to social (human) actors within automotive manufacturing SMEs. As concentrating the literature review in Chapter 2 on (1) examining the key barriers to quality process implementation and (2) the role of social (human) actors' apathetic attitudes towards quality processes reveal human factors as quality indicators (i.e. agents of quality failures), this study assumes that such social phenomenon that stimulate quality deviations exist within automotive manufacturing organisations. This perspective, which is not only reflected in the research questions but also guided the initial design of the proposed quality engineering framework in Chapter 3 to address the quality capability gaps identified in Chapter 2, gauged the direction of the design of the mixed-methods research procedures for this study. This encompassed the methodological choices appropriate to facilitate the data collection, analysis, merging of the databases, interpretation procedures, and the format of reporting the findings (Tashakkori & Teddlie, 1998; Creswell & Plano Clark, 2007; Creswell, 2009). Section 4.5.1 outlines the details of how a transformative lens will be used in a concurrent transformative strategy mixed-methods design to facilitate the perspective of this study (Creswell et al., 2003; Creswell, 2009; Creswell, 2014; Creswell & Plano Clark, 2007; Tashakkori & Teddlie, 1998).

3.10.1 Methods for data collection

Mapping out the identifiers of the factors that stimulate quality design and process failures within automotive manufacturing organisations, irrespective of the myriad of quality systems within the industry, is the motivation for the proposed initial conceptual framework design in Chapter 3. In addressing the three (3) main research questions stated in Chapter 1, this study takes a transformative lens approach to (1) examine why automotive manufacturing organisations vary in quality performance over time (Study 1/RQ1) and non-QMS league members deliver less than QMS-certified organisations (Study 2/RQ2), (2) examine and provide understanding of the underpinning factors that produce human adversarial behavioural patterns against quality processes, (3) develop a system to control social (human) actors' apathetic attitudes towards quality implementation, (4) develop mitigating solutions against human-induced quality data deviations, (5) create a knowledgebase to guide how automotive manufacturing SMEs can overcome the variables that impede hybridised quality systems (Study 3/RQ3), and (6) map out the parameters required to optimise the initial QX engineering design (Study 3/RQ3). As drawn from the literature review (Chapter 2), the above will help automotive manufacturing organisations within the SME domain to develop core quality capabilities that are critical to deriving an in-house, customised holistic quality engineering framework. This would help automotive manufacturing SMEs to develop countermeasures to mitigate against eminent barriers and associated threats to quality implementation and processes. Concurrent transformative strategy mixed-methods research is selected for this study purposely to better address the research questions and map out the parameters required to optimise the initial QX Engineering framework by merging both quantitative and qualitative databases (Creswell, 2009; Creswell, 2014; Creswell & Plano Clark, 2007; Tashakkori & Teddlie, 1998).

Fig. 3.4 illustrates the generic approach to a concurrent transformative design in which both quantitative and qualitative data are collected simultaneously and analysed approximately about the same time. As shown in Fig. 3.4, the data collection stage in each method entails the individual procedures for the quantitative strand (survey) and qualitative components and associated products or data (non-numeric data from survey; focus group transcripts, etc.). As the integration stage requires a juxtaposition of both databases, the qualitative data at its independent analysis phase is quantified for use with or against the quantitative results at the integration phase. This enables drawing meta-inferences from both databases.

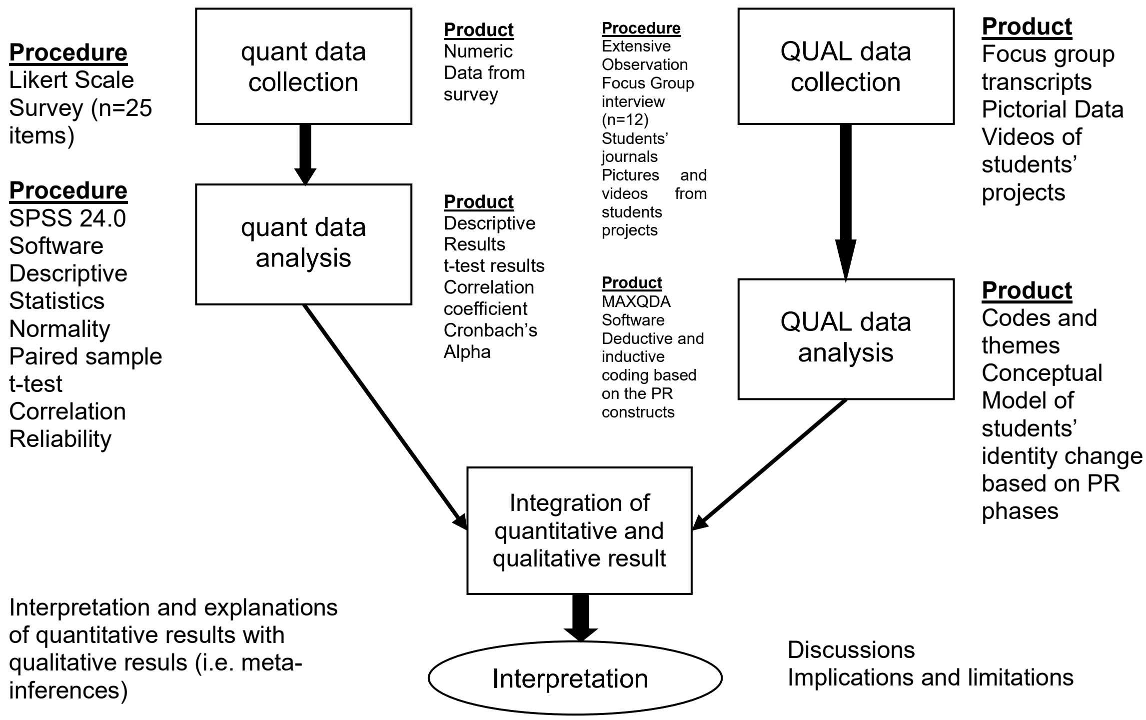


Fig. 3.4 Concurrent transformative mixed-methods research design (Talafian et al., 2019)

The QUAL + quan notation in Fig. 3.4 shows an unequal *weighting* in that the (dominant) qualitative strand is emphasised or prioritised to explain the (minor) quantitative results at the interpretation phase (Creswell, 2003; Creswell, 2014; Talafian et al., 2019). While Talafian et al. (2019) assert that concurrent transformative mixed-methods research design lends itself as a good benchmark, the methodological choice for this study adopts a three-way quantitative strand for Studies 1 to 3 as described in detail in Section 3.10.2, a qualitative component for Study 3, and a proposed review of the new quality engineering system for Study 3. Based on this approach to data collection, the notation is a QUAN + qual to indicate that the quantitative

(QUAN) aspect of the research is the dominant instrument for data collection in comparison to the qualitative (qual) instrument.

Study 1 to Study 3 entail the use of both closed-ended and open-ended online and printed-paper questionnaire surveys to seek the identifiers of human-biased vQDDs and quality dimensions driven enquiries mapped against the research questions and objectives stated in Chapter 1. In simultaneity to the explanatory (quantitative) component, the instrument for additional data extraction for Study 3 involves the use of semi-structured open-ended interview to conduct the exploratory (qualitative) enquiries which scheme is mapped against the overarching *how-based* RQ3. The qualitative part of the study will also *examine how automotive manufacturing organisations derive mitigation solutions* to address quality issues. This is of particular interest in identifying the parameters surrounding the central or social phenomenon as well as present the perspectives or experiential insights of the research participants (Abu-Alhaji, 2019; Creswell, 2014). The design of the concurrent transformative mixed-methods research for this study is depicted in Fig. 3.5.

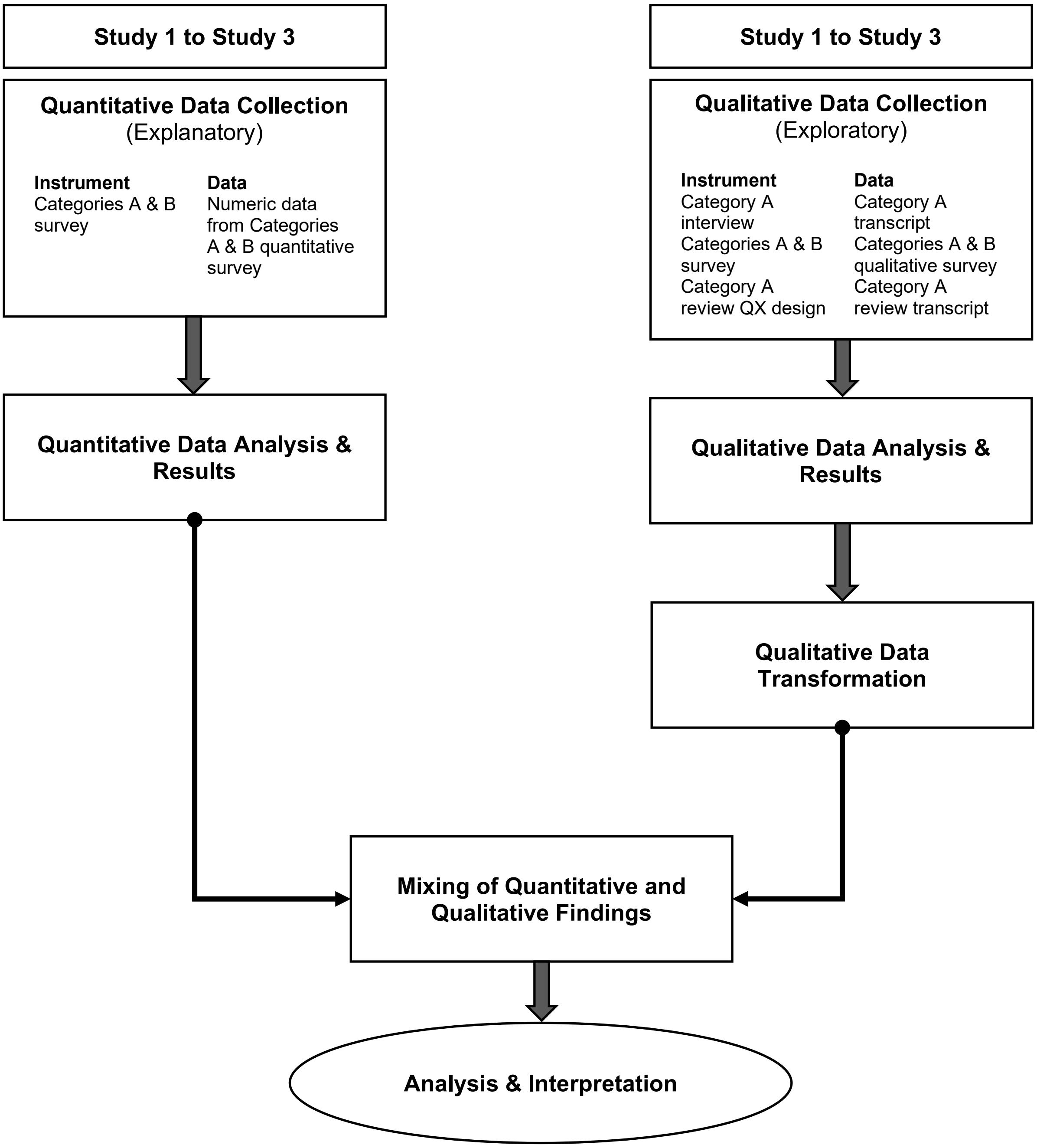


Fig. 3.5 Concurrent transformative mixed-methods research for this study (by author)

Two types of focus groups of research participants exist:

1. The *traditional focus group*: which "presumes a group setting in which members have direct interaction with each other and participate in a generative process in which one participant's input might be built upon another" (Loxton, 2021) and
2. The *nominal focus group*: which follows the "nominal group technique" concept (Gallagher et al., 1993) in that it "reduces the risk of undue influence from other participants or observers" (Loxton, 2021).

As a traditional focus group presents a significant level of biases associated with research participants' tendency to freely share others' experiences or observations as their own in response to an enquiry (Bennekom, 2002) and coupled with logistical complexities associated with creating a suitable location for a functional group, this study selects the concept of nominal focus group which does not require the congregation of or interaction amongst the research participants (Gallagher et al., 1993; Loxton, 2021).

Although random sampling of the population enables equal probability in selecting individual research participants (Bernstein, 2016, p. 897; Schacter et al., 2020, p. 747), this study leans towards quota or nonprobability sampling. Quota sampling is a "nonprobability convenience sampling technique in which the proportion of identified groups is predetermined by the researchers" (Gray et al., 2016, p. 344). As the intent of this study was to seek in-depth understanding to describe the social phenomenon that underlies social (human) actors' role in varying quality processes, this research purposefully selects pre-defined focus groups of research participants as opposed to seeking generalisation of the findings from a randomly selected population (Charmaz, 2014; Gray et al., 2016; Marshall & Rossman, 2011; Munhall, 2012). Thus, nonprobability sampling is appropriate for this mixed-methods research in that the selected focus group of research participants "can provide extensive information about the experience" of the social phenomenon being studied (Gray et al., 2016, p. 344).

The focus group of research participants in Category A and Category B for the quantitative strand and Category A for the qualitative strand of the enquiries are described in Table 3.11. In order to ensure the integrity of the data collected and the quality of the research participants, the selection of the participants was streamlined to invite only individuals who are conversant with standard quality dimensions, at least 18 years of age, and hold a minimum undergraduate academic degree qualification or its equivalent. Out of the total number of ten (10) in the expert Category A group invited to participate, a total of 8 responded, resulting in a response rate of 80%. In the consumer Category B group, 25 out of 30 invited research participants responded, yielding a response rate of 83.3%. The merit offered by invitation to online based surveys include rapid response, ease of sending out an online invitation directly from the survey instrument, ease on the part of the research participant to fill the online questionnaires, and the ease of importing the data into excel and furthermore into the analysis database application tool (Cobanoglu & Çobanoğlu, 2003; Karakoyun & Kurt, 2010). In inviting the research participants to complete the two sets of web-based survey instruments in both categories, no incentives of any kind were either promised or offered.

Table 3.11 Category of research participants

Category A	Category B
Engineers in the automotive manufacturing industry	Automobile product owners
Experts in quality process design within automotive manufacturing firms	Investors in automotive manufacturing
Design engineers in the automotive manufacturing sector	Automobile product users (drivers, etc.)
Decision-makers or managers within the automotive manufacturing industry	Automotive mechanics, OEMs, etc.

Quality of cohort of expert research participants in Category A

The cohort of experts in Category A of the research participants from China (50%), Germany (25%), India (12.5%) and USA (12.5%), who are engaged within either QMS/ISO-certified or non-ISO league member large (>250 employees) automotive manufacturing organisations (62.5%) and SME (<250 employees) automotive manufacturing firms (37.5%), function within the environment of IATF 16949:2016 (62.5%), ISO 9001 (62.5%), ISO 14004 (50%), AEC-Q100/AEC-Q200 (12.5%), and ISO 17025 (12.5%). Although a large sample size is generally thought of falling within precision in outcome than small sample sizes as per the population of this cohort,

> *"a survey strategy should give you more control over the research process and when sampling is used, it is possible to generate findings that are representative of the whole population at a lower cost than collecting the data for the whole population"*(Saunders et al., 2007, p. 138)

and if a proper selection scheme is adopted to ascertain the non-probabilistic small sample is of good quality, then this will yield a reliable outcome that is representative of the total population of the research domain (Zikmund, 2003). As this study was not intended to produce an outcome of statistical generalisation but rather a critical and analytical assessment of the data collected to deduce the outcome situated within social construct of the automotive manufacturing domain, the non-probability sample size used in both categories were not only of relevance by qualification but also appropriate and adequate for this research and essentially representative of the automotive manufacturing population (Zikmund, 2003).

The research participants in Category A, who have been in their current positions at their employment for at least three (3) years (Table 3.12), occupy key positions including Engineering Design Lead (25%), Vehicle Auditor (12.5), Quality Manager (25%), Project

Manager (12.5%) and Product Compliance Operations Manager (25%). With regards to the additional qualitative data collection, 50% of the research participants in Category A accepted the invitation to participate in the interview component of the study and 37.5% offered to review the optimised QX Engineering design (see also Section 3.10.3 Data Collection Instrument).

Table 3.12: Length of time (in months) at research participants' position in organisation

Months in current position at employment

	N	%
36.00	1	12.5%
38.00	1	12.5%
48.00	3	37.5%
54.00	1	12.5%
72.00	1	12.5%
180.00	1	12.5%

The target research participants within the cohort of experts were acquired through my global professional engineering networks in the automotive manufacturing sector, academic institutions and professional engineering affiliated institutions including the Institution of Mechanical Engineers. This avoided random invitations to participate, which has the potential to spam-index the unsuspecting research participants and breach their privacy protocols. Randomised sampling can also easily be ignored by the target group members as such mode of invitation is general, lead to unwanted multiple submissions, and does not appeal to the often-preferred personalised invite.

Quality of cohort of consumer research participants in Category B

The cohort of consumers in Category B (N=25) from nine (9) countries (see Table 3.13) were individuals from diverse professional backgrounds but had appreciable knowledge of the characteristics of quality dimensions for automobile products and associated consumer services. The backgrounds of this cohort included automotive standard regulator (4%); conversancy with IATF 16949:2016 (16%), ISO 9001 (48%), ISO 14001 (24%), ISO 26262 (4%), ISO 14001 (12%), and AEC-Q100/AEC-Q200 (4%); and awareness of automotive manufacturing organisations that are compliant with IATF 16949:2016 (12%), ISO 9001 (52%), ISO 14001 (20%), ISO 26242 (4%), ISO 45001 (8%), and AEC-Q100/AEC-Q200

(4%). With 96% as automobile product owners, 72% as automobile drivers and 4% engaged within logistics and supply chain management, the experiences and knowledgebase of this focus group in Category B of consumers was an essential ingredient to the data collected. This template ensured only very relevant experience-based and quality-oriented knowledge-biased responses were collected.

Table 3.13: Research participants by country

Research participants by country

	N	%
China	4	16.0%
Germany	4	16.0%
Ghana	7	28.0%
India	1	4.0%
Israel	1	4.0%
Malawi	4	16.0%
Norway	1	4.0%
UK	1	4.0%
USA	2	8.0%

3.10.2 Design of survey questionnaire

Taking into consideration the differences in backgrounds of both Category A and Category B research participants, the construction of the research enquiries was designed to feature realistic questions that were devoid of technical and incomprehensible terms. In particular, the questions were constructed in non-jargonistic fashion and where necessary, they were enriched with additional or extended information and definitions that further described as well as decomposed the enquiry such that the research participant was able to comprehend it. This ensured the questions appeared unambiguously simple, grammatically sound, concise but content-rich, and without any confusing terminologies. Sentence structures that may be misconstrued as judgmental and prejudiced were avoided throughout the construction of the questionnaires. This helped to frame the questions such that they were, in the actual sense of the word, relevant, significant, useful, and meaningful to the research participants of both categories, automotive manufacturing industry, interest groups in academia, and most importantly this study.

In a very few cases, open-ended questions were constructed to purposely seek the direct written responses (qualitative data) of research participants. This enabled the research participants to provide additional individual opinions about the quality indicators that directly concerned them. The surveys were mostly composed of close-ended questions, featuring checklist response formats, which offered the research participants an easy-to-complete template for immediate data gathering; and semantic differential scale, which provided the research participants with the opportunity to rate a statement regarding quality dimensions and dynamics within the frames of a multi-point rating option. In order to properly align the responses that were relevant to answer the research questions first stated in Chapter 1, the questionnaires were structured into three studies as described in the next subsections. The complete questionnaire sets for the cohorts of experts and of consumers are presented in Appendix 1 and Appendix 2 respectively.

In drawing from extant literature and theoretical background of both expert and consumer-biased expectations of the quality dimensions automotive manufacturing organisations should deliver, the questionnaire for each of the three (3) studies was constructed to gather relevant data in order to form deductions as to how a departure from those expectations can (1) compromise quality performance (RQ1), (2) cause less quality delivery (RQ2), and (3) create quality barriers (RQ3). Identifiers of relevant input parameters from the findings in each Study were translated into functional requirements, and their associated design parameters were defined to further optimise the initial QX engineering design in Study 3 as part of a solution-driven holistic approach to further address the RQs and achieve the research objectives (see Chapter 1). The structures, based on Appendices 1 and 2, of the surveys for RQ1-based Study 1 and RQ2-based Study 2 are presented in Chapters 4 and 5 respectively. The roadmapping RQ3-oriented Study 3 is outlined in Chapter 6.

3.10.3 Data collection instrument

In order to ensure the quality integrity of the data collection instruments used and the richness of the questionnaire content, a pilot Word and online editions of the survey for both Category A and Category B were conducted. This was to pull feedback, comments and or recommendations to help identify any flaws, incomprehensible questions, areas requiring further clarity, and the like, and to ensure that each question was relevant to soliciting the data required to contribute to the findings each of the three studies are structured to produce (Saunders et al., 2012). The feedback provided by the experienced academic researchers and engineering professionals, who participated in the pilot survey, led to streamlining a number of questions, enriching the comprehensiveness of a set of questions, providing further clarity to avoid any ambiguity, and substantially reducing the open-ended questions while increasing the close-ended sets of questions. Ensuring the integrity of the survey instruments led to thorough revisions and formalising 173 relevant survey questions for the cohort of experts in Category A and 68 questions for Category B research participants.

The semi-structured interview questions were constructed based on the collective key stakeholder functions, goals and requirements first established in Table 3.1. The purpose is to give the research participants the room to express their individual perspective as to how automotive manufacturing organisations could identify barriers to quality implementation induced by social (human) actor's adversarial behaviours and counteract them. Following the same protocol required to ensure unbiased, non-confusing, misleading types of questioning styles, 17 questions were mapped out against RQ3 to seek experts' perception. Although four (4) research participants initially accepted the invitation to do the Interview, only one responded to the reminder. Sensing that 75% of the research participants were reluctant to go through with the Interview, the author quickly created an alternative or option to the Interview by reformatting the interview questions into a Word version of a Qualitative Data Collection questionnaire (see Appendix 4). The author dispatched the Word edition of the intended interview questionnaire, asking the four (4) research participants to answer the Interview questions in the qualitative questionnaire just as they would in a real interview. It was after adopting this strategy that one of the research participants in the SME sector responded to confirm his availability for the interview. The interview protocol and format is presented in Appendix 3.

Within the qualitative segment, a cohort of three (3) experts accepted the invitation to review the new QX Engineering Framework. However, on following up on them, only one research participant in Category A responded to review the optimised QX Engineering Framework. The review protocol and format is presented in Appendix 5.

3.11 Data collection

Bryman and Bell (2007, p. 305f.) assert that *"there are several phases in the selection of a sample for content analysis"*. As this aligns with the pragmatic approach this research adopts, the selection of the research participants was strictly limited to the domains defined in Table 3.12, simply to ensure the sample is representative of quality-based perspectives of both experts and consumers as relates to the dimensions and associated variations of quality value delivery within automotive manufacturing organisations. This research is not a part of an ongoing research and is not undertaken in cooperation with any interest group, organisation or consortium. As such, the research participants, particularly of Category A, are not engaged in companies with whom the author/researcher has any affiliation or collaboration with. This, therefore, excludes any potential element or agent of biasness. Of significance in the non-probabilistic selection of Category A was that the research participants are engaged strictly within automotive manufacturing firms that are an SME or large organisation, QMS/ISO family compliant or non-compliant, public or private. The research participants in both categories were not required to supply the names and addresses of their companies. They were anonymised in consistency with the ethical considerations (Section 3.13) of this research.

Irrespective of whether the automotive manufacturing firms in which the research participants within the cohort of experts (Category A) are compliant with any QMS-based standard or not, the survey questionnaire was administered to both QMS standard certified and non-certified. The need to include non-QMS certified SMEs in the survey was to assess Horváth and Szabó's (2019) assertion in the literature review that suggests that SMEs find incorporation of quality standards very expensive, time-consuming and very difficult to implement (see Chapter 2).

The method for data acquisition used in this study was a single web-based quantitative data collection instrument that featured a survey questionnaire, followed by quantitative data analysis procedures using SPSS. As the research participants in China could not access the online version of the survey built on Google Forms due to cyber restrictions, the Microsoft Windows Word Doc version was emailed to the invited research participants (N=8) in China to manually complete and return it to the author by webmail. This approach, which did not involve printing the questionnaire of several papers and then snail-mailing back and forth, was cost-time-resource-effective (Cobanoglu et al., 2001). To ensure consistency, the completed data were input into the online edition of the survey platform for collective analysis. Taking a deductive-based study approach, the use of quantitative data technique satisfied the objective of gaining insights into the perspectives of the two focus groups and to translate the quality indices into optimal QX process parameter identifiers.

The data collection phases as depicted in Fig. 3.5 take a phenomenological approach to capture the expertise knowledge and experiences of the focus groups through an in-depth, open-ended semi-structured interview survey and close-ended questionnaire survey situated within the research questions, research objectives, key stakeholders' construct, and quality process value objectives as established earlier in this Chapter (Creswell, 2014; Miles et al., 2014).

The qualitative interview aspect is best suitable to further address RQ3 as a sole quantitative method does not offer the research participant the flexibility to justify their responses, decisions, opinions or choices. Data from the interview component is used to map out the transformative context required to develop the ideal parameters required to put control over human adversarial behaviours towards quality process design within automotive manufacturing SMEs. The data from the interview and expert feedback from the review of the new quality engineering design will lead to a further enhancement of the QX engineering design, where appropriate, and position the final product and its applicability for acceptability within the automotive manufacturing SME sector.

As parts of the three studies sought input parameter identifiers for the optimisation of the proposed initial QX engineering design, segments of the enquiries were focused on barrier constructs that impede quality implementation and the potential human-induced factors that stimulate deviations in expected quality data. This yielded relevant key input parameters that were ideally required to design and embed the quality problem traceability model within the proposed new quality engineering design. It also resulted in refining the content of the hierarchical level analysis presented in this Chapter. This segment further considered the role of human adversarial attitudes that potentially vary quality design processes along the *in-process*, *post-process*, *in-service*, and *post-delivery* manufacturing and supply chains. Table 3.14 shows the 22 themes for Category A and 5 themes for Category B research participants across which the enquiries were set to seek the required data.

Table 3.14: Questionnaire structure in relation to dimensions of quality and overall organisation-wide performance

Cohort of Experts		Cohort of Consumers
Awareness and compliance	Core quality tools implementation	Quality standards awareness
Quality knowledge	Quality performance	Auto recalls handling
Quality design documentation	Company's QMS	Automobile dealership factor
Manufacturing equipment standardisation	Process efficiency and effectiveness	Automobile choice influencing factors
Managing safety recalls	Standard Operating Procedure	Emerging technologies
Dealer responsibility	Process monitoring	Other quality dimensions
Personnel effectiveness	Continuous improvement	
Defect traceability	Rating departments	
Manufacturing facility	Management support	
Risk assessment	Nonconformance products	
Software validation	Management mindset	
Other quality dimensions		

As the notation for the strategy designed for this study is a QUAN + qual, indicating an unequal weighting in which the quantitative data dominates the qualitative data, the mixed-methods research findings could be susceptible to an unequal evidence (Creswell, 2009, 2014). In order to mitigate any discrepancies that might occur between the two distinct databases at the various integration and interpretation stages, this study did not seek to compare the quantitative and qualitative results but rather mix them for a mixed-methods study analysis and interpretation. This approach enriched the answers to the RQs and built a knowledgebase to provide an insightful understanding of the perspective of the study and research participants' views within the context of quality process design and implementation. It further developed an understanding needed to stimulate personnel (social actors') attitudes for constructive transformation within automotive manufacturing SMEs.

As the data collection aspect of the study selected to invite a focus group of 10 research participants defined by Category A, a cohort of 30 consumers or Category B to participate in the survey, and 4 from the participating cohort of experts to participate in the qualitative interview and review of the proposed new quality framework (QX Engineering), 8 (80%) of the targeted experts, 25 (83.3%) within Category B accepted the invitation to participate in the survey, and 3 (75%) and 4 (100%) from Category A accepted the invitation to the interview and review of QX Engineering respectively (see also Section 3.10.3 Data Collection Instrument). Although the research participants were purposely defined and selected by qualification and suitability for the acquisition of credible and relevant data, the invitation to participate in the survey was voluntary and not spurred by any rewards or promises. Aside from the high standard criteria set for the invitation of the research participants, the selective approach also prevented multiple submissions by the same person. The test or pilot submissions were not included in the final data. It can be inferred from Dillman et al. (2009) that achieving a 75% to 100% response-to-participate rate in a survey can be seen as excellent, relevant and acceptable. As shown in Appendix 1 and Appendix 2 for both surveys, information on the Research Background, Purpose of the Research, Funding, Confidentiality and Data Storage, and Research Outcome were featured at the opening of the survey questionnaires.

3.12 Methods for data analysis

This Section outlines the steps taken to ensure the integrity of the data collected, featuring data management, screening and the selected data analysis tool.

3.12.1 Management of data integrity

Quantitative web-based survey data was collected from a total of 33 research participants via Google Forms. The data was downloaded from Google Forms in CSV format, exported in MS

Excel (XLS) format and scanned for any discrepancies before being uploaded in SPSS for subsequent analysis. With the exception of the email addresses of research participants in Category A, who volunteered their electronic contact details in order to be reached for the qualitative interview and quality framework review components of the research, the research participants' names, email addresses and names of their affiliated companies were not required. This was to maintain the anonymity of the research participants and the organisations they work for.

Where applicable and appealed to voluntarily enter information regarding research participants' position in their employ, the information provided in response to the open-ended enquiry was not renamed, coded or categorised into groups. This was because the dataset was not too large to warrant such an approach. Besides that, the study was not designed to seek statistical generalisation which would have necessitated the need to categorise the positions into groups to reduce high volume data complexity. The positions or job titles recorded of the cohort of experts were Engineering Design (25%), Vehicle Auditor (12.5%), Quality Manager (25%), Project Manager (12.5%), Product Compliance Operations Manager (12.5%) and Quality Engineer (12.5%).

3.12.2 Data management in SPSS database

The datasets for both Category A and Category B in SPSS database were first thoroughly and individually screened in the Data View in order to map out lengthy variable descriptions and entries that may have contained unintended personally identifiable data about the research participants and the names of their organisations. This exercise also enabled a thorough check of all data entries to ensure the entries were representative of what the respondent had intended as appropriate to answer a research question as well as correct errors that resulted from importing the Google Form file into SPSS. Where missing data were identified in a few cases, it was mainly because the question did not apply to the research participants, or they preferred not to answer a particular question. In order to clean the datasets for both categories, all the entries were viewed in Variable View and each was reset mainly into proper Variable Name, Data Type as String or Numeric, Width, Decimals, Label in terms of concise description of variables, Values which were numeric codes assigned to non-numeric elements (in this study, the value labels were 1=Yes; 2=No; 3=Don't know or Preferred not to answer, for example), and Measure which denoted whether a variable was Nominal, Ordinal or Scale. All missing data were initially coded 99999 as a place holder before any analysis. A few more thorough line-by-line screenings of both Category A and Category B databases were conducted against both questionnaire sets to ensure all the entries were in the correct places to answer the associated questions. After the accuracy of the datasets had been ascertained, the placeholder code 99999 was deleted in all the missing data fields to avoid discrepancies or errors in any descriptive statistical measures to run the frequencies of all the individual questions. In cases of the few missing data, the researcher intentionally did not contact the research participants. This was to prevent the temptation of establishing or triggering a personal communication with the research participant that could potentially construe as an intention to delve into the research participant's position on its company's quality culture and consequently compromise the anonymity position assured at the beginning.

Although the nature of the Google Forms allows the use of a feature to mandate research participants to respond to any question the research deems fit to make compulsory to be answered, such mandatory feature was only applied to the **Q1 Consent to Participate Form** at the beginning of each questionnaire. While Q171 and Q173 request research participants in Category A to enter their email addresses if they agreed to honour the invitation to the qualitative interview and review of the new quality engineering framework, both questions did not make the entries mandatory. One disadvantage mandatory designated questions present is that research participants may choose to answer a question they otherwise would not answer simply to move on to the next section. If the research participants encounter more mandatory questions they cannot skip, they may be deterred to stop their attempt to complete the questionnaire. This study considered to purposely leave the questions open to allow the research participants to make an independent and non-mandated decision to volunteer their personally identifiable email addresses. In this study, four (4) research participants in Category A accepted the invitation to the interview and three (3) offered to review the new quality design. The addresses of the research participants in these categories were removed from the submitted questionnaire and therefore not reported in the analysis and discussion phases in order to preserve their privacy. Following this, a final line-by-line thorough screening ensured that no errors, duplications or oversights were present and as such the two databases were confirmed refined enough for analysis. This approach to edit the database for analysis, construction of codes with related meaning, general refining of the codes and construction of categories for analysis was inspired by Faria-Schützer et al. (2021).

3.12.3 Data analysis

The analysis of all the datasets was set into three categories of indexing (1) variants of quality performance delivery, (2) less quality value causes and (3) quality barrier solutions. These are relevant to addressing RQ1, RQ2 and RQ3 in Study 1 (see Chapter 4), Study 2 (see Chapter 5) and *Study 3* (see Chapter 6) respectively. Study 1 and Study 2 are bridged in Chapter 6 to outline the overlap between the two studies as a necessary step to identify the most relevant contributory input parameters for Study 3. The relevant FR_{1s} and FR_{2s} findings extracted from Study 1 and Study 2 are synthesised in Chapter 6 and their corresponding DPs are mapped out to both enrich the content for RQ3 and optimise the initial QX Engineering design in Chapter 7. Descriptive statistics in SPSS was used to find common patterns by focusing mainly on the frequency of all the Study-relevant quality index data in each category.

Based on the concurrent transformative strategy designed in Fig. 3.5 for this research, the data analysis entails three stages (Caracelli & Greene, 1993; Creswell, 2014; Creswell & Plano Clark, 2007; Tashakkori & Teddlie, 1998, 2010):

1. Quantitative Data Analysis
2. Qualitative Data Analysis, descriptive and thematic textual analysis
3. Mixed-methods Data Analysis, featuring the mixing of the transformed or quantified qualitative data with the quantitative data, where required. It is beyond the scope of this study to compare the dominant quantitative (QUAN) databases with the minor qualitative (qual) data simply because the weighting is unequal and comparing such distinct studies can present discrepancies throughout the interpretations. Thematic mixing of the data also yielded input parameters required to further optimise the proposed QX framework in Study 3.

This study used SPSS to conduct the data analysis of all the quantitative and qualitative enquiries within one platform (Loxton, 2017; Raediker & Kuckartz, 2019, 2020a, 2020b). SPSS is an industrial standard software for data analysis that enables analysis of quantitative and qualitative databases within its mixed-methods window, allowing the integration, merging or mixing and or comparison of the quantitative and qualitative results for an entire analysis and interpretation in comparison to similar other platforms such as MAXQDA Analytics Pro 2020 (Kuckartz & Rädiker, 2020; Loxton, 2021).

In identifying and analysing the role of human agents or human behaviours that induce quality failures within automotive manufacturing organisations (context), the human adversarial attitudes and the context were coded as measurable variables. As such, the three studies provided insights into the following segments:

1. Human adversarial behaviours as vectors of quality data deviations (vQDD)

2. Correlation between vQDD and quality engineering solution-oriented behaviours
3. Relational characteristics that stimulate top management's influence on coordination of quality systems and strength of interdepartmental relations

Measuring the relationships between the fundamentally human-biased core variables characteristic of these quality vectors or indices helped to further determine and develop the relationship between the key stakeholders' construct or independent variables (Top Management, Design and Task Force) and dependent variables (myriad of quality dimensions). The analysis also addressed a set of secondary or sub-RQs as children/daughters derived from the parent or anchor RQs. Coding and labelling the questionnaire sets was done after carrying out the survey in order to maximise data cleaning through line-by-line and entry-by-entry review of all the datasets. Segment responses from Category A and Category B relating to implementation of quality design processes were analysed to characterise the quality dimensional paths and impacts between the associated variables.

Based on the lessons learnt from the literature review in Chapter 2, the analysis of the three studies was used to map out barrier constructs (such as top management barriers, personnel barriers, organisational quality culture barriers, quality authority body barriers, manufacturing process barriers, quality capability barriers) within the context (i.e. the organisation with quality systems), and types of organisational overall interconnected culture or independent variables (key stakeholders' construct). This approach led to the derivation of the:

1. Parameters associated with human adversarial behaviours as potential vectors that impact quality delivery across the domains of Type-I & Type-II QTVs (see Section 3.3.2), QMS implementation, quality procedures regulatory compliance, manufacturing process efficiency and effectiveness, manufacturing costs, and continual improvement.
2. Underlying factors of *why automotive manufacturing organisations vary systematically in quality performance over time (RQ1)* and *why automotive manufacturing organisations whose primary objective is to maximise the value of quality-oriented processes and automobile products deliver significantly less than those organisations that have attained QMS certification (RQ2).* The findings also identified the indices of human adversarial attitudes that were appropriate to guide the modelling of a vQDD traceability design to enrich the proposed *quality barrier solution development (RQ3)*.
3. Parameters that are characteristic of the adverse impact of human adversarial attitudes on an automotive manufacturing organisational quality deployment goal and or context.

> This aligns with my philosophical position within the social constructivist paradigm to develop a new quality engineering system that will control social (human) actors' adversarial behaviours to stimulate the transformative change an organisation requires to both create a quality-focused manufacturing operations environment and sustain its highest-level functional requirement (FR_0).

While it is time-effective to first use SPSS to design a coding scheme generated from an anchor code that is based on the parent research question in advance of a qualitative interview (Crabtree & Miller, 1999; Fereday & Muir-Cochrane, 2006; Leydens et al., 2004; Patton, 2002), this approach was not necessary for the interview aspect of the study. As it was established earlier in this Chapter that the outcome of this study is not dependent on statistical generalisation but rather takes a critical approach to examine the perception of the research participants as situated within the enquiries and context, there was no need to design a coding scheme in SPSS from the parent RQ1-3 pre-interview and to create its daughters in NVivo pre/post-interview (Marshall, 1996). This is because it was intended that the expert research participants' perception in response to enquiries will be transcribed and critically reviewed against the context of each RQ-based question in relationship to the key stakeholders' construct/barrier (independent variable) and quality dimensions (dependent variable).

While Study 1, Study 2 and Study 3 databases were analysed independently and their results used to contribute answers to their respective RQs, satisfy the research objectives (ROs) and produce the input parameters required to enrich the initial QX Engineering design, the quantitative and qualitative results were mixed or connected and situated within each of the three studies to enable collective interpretation and validation of the findings in each study. This aspect is further presented in the next Section below.

3.12.4 Data transformation, interpretation and validation

Following the independent data analysis and results of Study 1, Study 2 and Study 3 to address RQ1, RQ2 and RQ3 respectively, parts of the qualitative data were transformed to numeric data to enable mixing with the databases of Study 1 to Study 3 at the interpretation phases of the mixed-methods design. The intent of the interpretation of the mixed-methods study is not to generalise from a traditional statistical standpoint, but rather to use a transformative lens to offer deeper insights into the research problem for a more analytical generalisation.

The findings from the mixed method instrumentation were ideally grounded in literature and evaluation-based case study to validate the integrity of the selected methodology and findings, and the integrated QX Engineering framework. This also led to content validation and reliability of the data collection instrument (Borrego et al., 2009; Crabtree & Miller, 1999; Fereday & Muir-Cochrane, 2006; Frankel & Devers, 2000; Leydens et al., 2004; Patton, 2002).

3.13 Ethical considerations

As the methodological choices for this research entail the involvement of human participants within a social construct (automotive manufacturing organisations), the ethical protocols set forth by the University of Gloucestershire were observed. In addition to considering the research ethics prescribed and approved by the University of Gloucestershire Research Degrees Committee (2008), the following, not to be construed as an exhaustive list, were duly observed throughout the study and data collection phases:

- Drafted and sent out formal letters of invitation to invite suitably qualified individuals within Category A and Category B as research participants.
- Designed survey questionnaire, used Google Forms to collect data online and where necessitated by China's position on limitation on all things Google, a Word Doc edition was provided. Both instruments were done in such a way so as not to solicit the research participants' personally identifiable information.
- Designed open-ended in-depth, semi-structured interview-based questions or questionnaire in a way that did not solicit the research participants' identifiable, personal information.
- In-depth, semi-structured interview protocol did not seek interviewees to introduce themselves in a way that would record their personally identifiable information. However, professional background, qualifications, position, etc., were sought for correct placement into Category A or Category B.
- Designed data collection methods in such a way so as to not index respondents' personally identifiable information and
- Duly observed and respected the norms and internal culture of the research participants' manufacturing organisations to avoid coming out as intrusive or invasive. This also included adhering to the organisation's health and safety procedures and code of ethics. Furthermore, the research participants' organisations and employees were assured of confidentiality of provided information and the right to withdrawing from the research project at any point in time without any consequences, via an informed consent clause on online and offline data collection means, respectively.

3.14 Summary

This Chapter outlined the extension of Axiomatic Design to guide the development of the proposed quality engineering framework. The Chapter has shown that the methodological choice for this study is the most appropriate strategy to adequately address Study 1 (RQ1), Study 2 (RQ2) and Study 3 (RQ3) and derive the key input contributory data required to optimise the RQ3-oriented initial QX Engineering design. Driven by the research objectives (see Chapter 1), the research methodology and design choice selected to address the research questions and perspectives of the study are presented in Fig. 3.5 and summarised in Table 3.15 below. Aside from the comprehensive quantitative data pulled from the survey questionnaire, the qualitative data component enabled content validation by giving the research participants the opportunity to provide their own expert and experiential opinion on the causative agents of the variants of quality process implementation, quality sustainability and the impact on quality-biased construct within automotive manufacturing organisations. The qualitative interview data was transcribed, refined where necessary, critically analysed and situated within the quality barrier solution construct (RQ3) as a necessary step to achieve RO3 (see Chapter 1 on *Research objectives*).

One of the key components of the research strategy adopted for this Chapter was based on the philosophical worldview (pragmatism) proposed for this study, which enabled taking various approaches to seek the various parameters required to address the RQs, process mapping for the development of the proposed vQDD traceability model required to enable automotive manufacturing SMEs to track human-induced quality failures *in-process* and *post-process*, and an optimised QX Engineering framework.

Table 3.15: Summary of research methodology and design

Research Component	Selected Type	Justification for Selection
Methods	Quantitative Qualitative	Use of multiple instruments to measure the relationships between key stakeholder construct and associated hierarchical constructs, and quality dimensions
Philosophy	Social constructivism & interpretivism	Philosophy adopted enables use of transformative lens to analyse responses situated within a social construct without statistical generalisation
Approach	Deductive	Prior knowledge enables initial theoretical generalisation, leading to conceptual design of framework
Strategies	Survey Interview Review	Multiple data from different instruments enables data integration or mixing at various stages to enrich findings
	Concurrent transformative	Multiple data collection

Sampling	Non-probability	Data from a focused group, cohort of experts and consumers ensures capture of relevant and credible data, etc.
Data collection	Survey questionnaires Interviews Review	Web-based survey of cohort of experts and consumers of automobile products; Semi-structured interview; Review of proposed quality design
Data analysis	Interpretive/deductive	Avoids a generally statistical generalisation

The development of QX Engineering design for automotive manufacturing SMEs is motivated by my own philosophical stance that while human actors socially construct their reality (e.g., Putnam & Banghart, 2017), human adversarial behaviours should be monitored and controlled by the context they inadvertently vary. Thus, a QX Engineering design within the context (automotive manufacturing SMEs), that the social (human) actors interact with, will need to put a monitoring and control mechanism in place as countermeasures to mitigate against human adversarial behaviours towards organisational quality goals or objectives. The details from the data analysis, findings, interpretation and integration are presented and discussed in Chapters 4 to 7.

Chapter 4: Study 1 Findings — Time-Dependent Variants of Quality Performance

4.1 Introduction

Chapter 4 analyses and examines the relationships between the constructs of emerging technologies, quality of service, management culture and continuous (operations) monitoring and quality performance variants. The research methodology and design for the data analysis of the results and findings is outlined in detail in Chapter 3 — Sections 3.7 to 3.12. In seeking to address

> *Why do automotive manufacturing organisations vary systematically in quality performance over time? (RQ1)*

a transformative concurrent strategy was adopted to collect the quantitative (closed-ended survey) and qualitative data (open-ended interview and survey) from expert knowledgebase and experience of professionals (Category A of research participants) within the employ of automotive manufacturing organisations and the perception of consumers (Category B research participants) of automobile products and services. Throughout this Chapter, research participants in Category A and Category B are also referred to as cohort of experts and cohort of consumers, respectively. The quantitative data from web-based survey questionnaire and the qualitative data from both the open-ended survey and interview are analysed and the results are discussed throughout this Chapter. As established earlier in Chapter 3 — Sections 3.7 to 3.12, this study is not designed to deduce a statistical generalisation but rather to offer a critical examination of the activities that are causative agents of quality performance variation. In this regard, the data analysis is pivoted on the outcome of descriptive statistics, featuring the frequencies of the research participants' responses in relation to the identifiers of quality variants in the context of the RQ1-based statements.

As it is within the frame of interpretivism that the author's worldview to determine an understanding into the variants of quality performance (RQ1) is embedded with the researcher's own biases, it suffices to add validity and credibility to the findings of this Study by seeking the situational perception of each research participant. This premised the use of descriptive statistics as the main statistical component of analysis for this Study. While the frequencies of occurrence of the quality indicators (i.e. identifiers of quality variants) required to understand the quality perception and observations of the cohort of experts and consumers as situated within the context of RQ1, open-ended interview and qualitative survey enabled research participants to explain their opinion about the statements in their own words.

4.1.1 Study 1: survey questions regarding variants of quality performance

The main goal of this RQ1-based Study of the survey was to identify the factors that cause automotive manufacturing organisations to vary in their delivery of quality performance. The first set of questions of the Category A survey instrument was composed of questions in relation to the size of the automotive manufacturing organisation the research participants' work for, and their firm's compliance with any of the quality industry standards. The survey instrument for the cohorts of consumers featured questions that gathered data on research participants' automobile ownerships, level of their satisfaction with the vehicular systems they own, and quality standards awareness. In both cases, a common question, which related to whether both sets of research participants are aware of automotive manufacturing organisations that conform to any of the quality industry standards, was also featured in the first Section of the survey questionnaires.

As the goal of Study 1 was to seek the identifiers of compromised quality performance delivery (RQ1) within automotive manufacturing firms and the quality value stream (such as the auto dealership, etc.), relevant questions for this Study were constructed based on the quality dimensions or themes described in Table 4.1 below. These quality dimensions were derived from the QMS-based core quality objectives in Table 3.4 (see Chapter 3) and in relationship to the three (3) key stakeholder construct defined in Chapter 3.

Table 4.1: List of themes to guide structured survey for RQ1-oriented Study 1

Study 1 Questionnaire Overview of Themes & Questions	
Themes:	**Questions related to:**
Standard awareness	Whether the cohort of consumers are familiar with the automotive industry standard as well as are aware of quality standards compliant firms; Whether the cohort of experts' automotive manufacturing firms are quality standard compliant.
Automobile choice influencing factors	What factors influence Category B research participants' decision for choosing automobile products to purchase or lease.
Automobile dealership factor	Quality of service experiences encountered at automobile dealership.
Quality knowledge	Whether myriad of industry standard quality systems is integrated across the manufacturing operations at Category A research participants' organisations.
Manufacturing equipment standardisation	The significance of manufacturing equipment standardisation with respect to quality performance.

Dealer responsibilities	How automobile dealership responsibilities can impact performance with respect to safety auto recalls.
Manufacturing facility	How manufacturing facilities enable operations maintenance and efficiency.
Process efficiency and effectiveness	How expert participants rank their firms’ manufacturing process efficiency and effectiveness and how these can impact quality value.
Standard operating procedures (SOP)	Whether expert participants’ firms develop an in-house documentation featuring its manufacturing processes to guide task execution.
Management support	How expert participants rank their firms’ top management responsibilities.
Management mindset	The significance of variants of quality performance as revealed through experts’ ranking and evaluation of their individual firm’s Top Management mindset or beliefs towards ISO family of quality standard
Process monitoring	Whether expert participants’ firms have a dedicated process monitoring team that monitors various departments to capture variants of quality performance
Continuous improvement	How expert participants rank their Top Management responsibilities regarding factors that impede quality performance
Rating departments	How expert participants rank the effectiveness/ineffectiveness of core departments in identifying variants of performance
Quality performance	How expert participants rank their firms’ quality performance with respect to achieving success metrics
Risk assessment	Whether expert participants’ firms conduct risk assessments to detect human adversarial behaviours

The questions within the above segments were designed to help map out the variants of quality performance as pertains to automotive manufacturing organisations’ delivery of automobile products and services. These solicited responses based on the cohort of consumers’ experiences and experts’ knowledge. This is because the perspective or opinions of the individual research participants are their entitlement, and their worldview of the quality variation causes within the context of this research.

The data extracted from the responses to the questions, based on the variants of quality performance, provided information on quality variation causes as well as identifiers of the related core functional requirements (FR) required to optimise the initial QX engineering design in Chapter 3 (see Tables 3.8 and 3.9). The sets of questionnaires related to the themes in Table 4.1 are presented in detail in Appendix 1 and Appendix 2.

While this Study is designed to answer RQ1, it is also worth noting that analysis of the findings will take a roadmapping approach to identify or derive relevant input parameters (as key input variables or KIVs) required to help modify or optimise the initial design of the proposed new quality engineering framework (also known as QX Engineering Framework) first conceptualised in Chapter 3. The derived input parameters or KIVs from the analysis of the findings in this Study are translated into functional needs and subsequently into functional requirements (FRs) for integration in Chapter 6 in order to process-map out their plausible design parameters (DPs). This is to ensure their applicability and incorporation in the optimisation phase of the QX Engineering design in Chapter 7. Thus, RQ1-relevant FRs and DPs are required as input data or KIVs to optimise the proposed initial QX Engineering design in Study 3 (Chapter 7). Achieving these is a function of answering RQ1, following the structure of this Chapter as illustrated in Fig. 4.1.

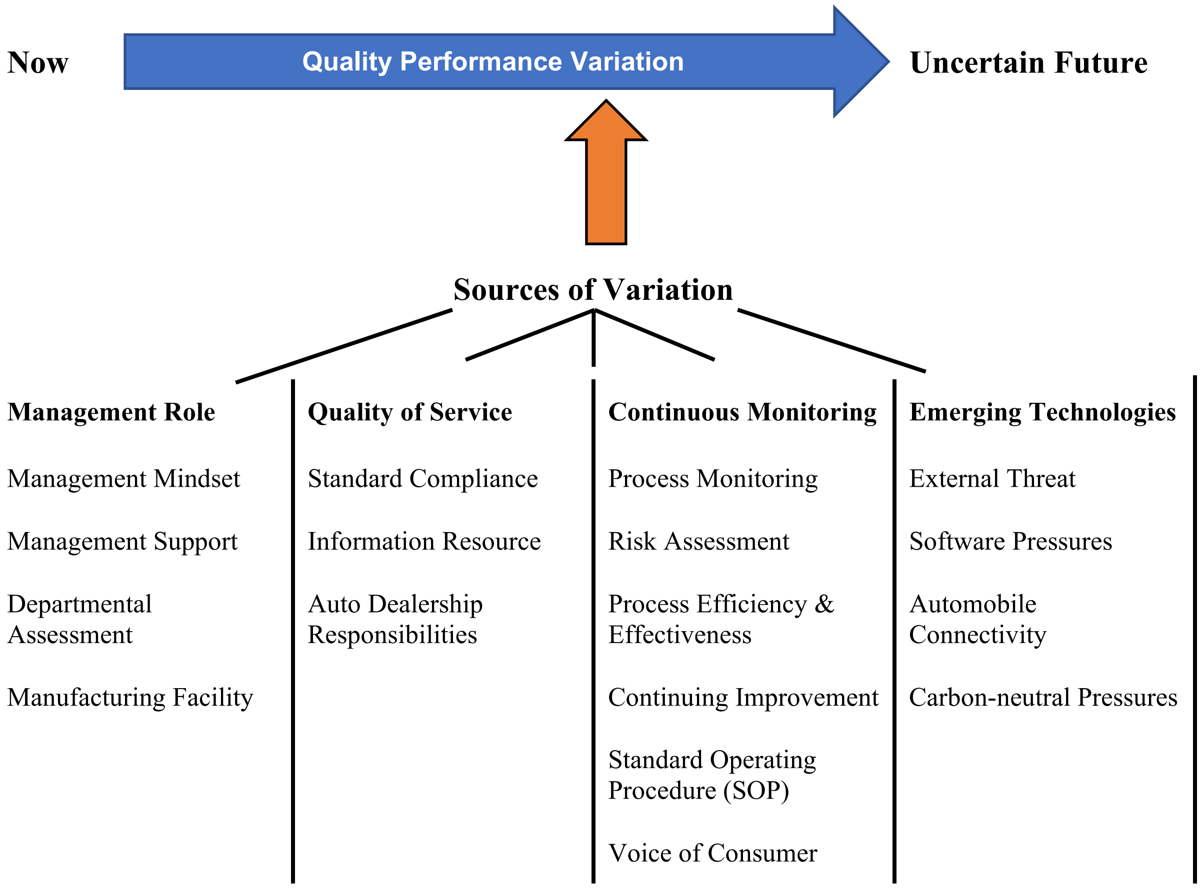


Fig. 4.1: Structure of data analysis process (source: author)

4.1.2 Defining the themes for the investigation

The quantitative (close-ended) and qualitative (open-ended) survey results provide valuable insights into the perception of both experts with significant years of experience at their employ (see Table 3.12 in Chapter 3) and consumers (see Table 3.13 in Chapter 3) as related to the constituent vectors or sources of variants of quality performance. The survey questions related to the *variants of quality performance* (RQ1) were typically mapped against the themes defined in Table 4.1, which are grouped into the categories shown in Fig. 4.1.

Within the context of this research, where relevant, the quality problem statements embedded within the defined themes for this Chapter subject-matter are viewed as functional needs. These functional needs are then coded with functional requirements or FR notations in the form of $FR_{i.j.k}$ or $FR_{n.m}$.

Time

In the context of this research, ***time,*** as stated in

> *Why do automotive manufacturing organisations vary systematically in quality performance over* ***time****? (RQ1)*

is defined as:

> *the space between the existence (or survival) of the earlier established or conventional approach to automotive manufacturing organisation's quality engineering design goals (as at their yesterday) and both the uncertainties in the demand patterns of the consumer and that of automotive standard regulatory bodies* (Source: author).

Thus, throughout this research and where stated, the terms *traditional* and *conventional* will be used interchangeably to reference either yesterday (past), today (present) and or emerging technologies (tomorrow/future) automotive technology. The *future* is viewed in this Study as the ***time*** space between the *past* or *today* and the *future*. This notion is premised by the motivation derived from the literature review (see Chapter 2), resulting in establishing the objective to take a holistic approach to developing a new quality framework that can coevolve with the requirements of the uncertain future.

On the other hand, where we consider the quality reliability of an automobile product or service as a function of time, then we revoke Ramakumar's (1993) time-dependent quality reliability as "the probability that a system will perform its intended function for a specified interval of time under stated conditions." Within this context, El-Haik (2010), asserts that

> *"the probability of quality failure is a monotone-increasing time function which implies that there is a threshold beyond which the design entity is considered failed and not functioning."*

Management Role

As Top Management or Management in general is at the helm of the hierarchy and as such is expected to not only set organisational functional goals but to also offer support as well as coordinate the automotive manufacturing organisation's various departments, the research participants of experts were asked to rate their company's Management Support with respect to functional departmental processes, operations and or goals. The research participants were also asked to respond to questions regarding:

1. The mindset or beliefs of the company's Top Management as related to the automotive industry standard procedures, training, certifications, etc. The codes generated for the statements or construct for the results are defined as in Table 4.2 below.

Table 4.2: Statements as related to Top Management mindset and codes

Statement	Code
Top Management believes that ISO standard procedures and associated standards are not adequate enough for the constantly changing automotive manufacturing environment.	topman_isoenv
Top Management believes that implementation of ISO standards is very difficult, too expensive and time-consuming.	topman_isoexp
Top Management pays very little attention to the adoption and implementation of ISO standards.	topman_isoattn
Top Management believes that not all the personnel across the departments need to necessarily attain ISO standards certifications.	topman_isodept
Top Management offers very little support for staff training in ISO standard procedures.	topman_isosupp

*Other: 1 x Product Compliance Operations Manager; 1 x missing data

2. The extent of the involvement of the Facility Director or Manager, if applicable, within the many facets of quality-based activities. Situated within the context of this study, the objective of an automotive manufacturing facility layout is expected to be designed to enable efficiency in the facility's operations and maintenance such that it supports the smooth activities of all the manufacturing processes. This can enhance adequate technical supervision and shopfloor communication, information dissemination, energy sustainability, reduced complexity, optimised scheduling, quality monitoring and implementation.

3. Standard Operating Procedures (SOP), if applicable, as related to in-house company documentation that provides a guide that breaks down individual manufacturing processes into clearly defined steps to enable personnel to execute tasks accordingly.

The data extracted from this enquiry are presented in Section 4.2 for analysis.

Quality of Service

The global automotive industry standard practice, to a large extent, expects all within the sector to be familiar with the QMS-based ISO families of quality management procedures. In order to instil consumer confidence and trust, a number of automotive manufacturing companies have applied to gain the relevant certification. In order to gain insights into the perception of the consumer as to whether an automotive manufacturing firm's quality standard compliance construes as delivering good quality performance, the research participants of consumers were asked questions as to which quality dimension influences their decision to either purchase or lease an automobile product or service. The enquiries also sought their experiences at the auto dealership in terms of the attitudes or handling of service at the dealership (i.e. auto dealer responsibility) and other related influencing factors. As established earlier in Chapter 3, the role social (human) actors play along the quality delivery chain is an essential component of this research in that the study seeks to identify human adversarial behaviours that vary quality performance dimensions over time.

As part of the research protocol was to accord the research participants with as much information as possible in order to help eliminate any element of confusion, ambiguities and misunderstandings, the following standards were described in the early section of the survey in order to ascertain the research participants in Categories A and B understand them in their universal global definitions in the context of the automotive industry:

- ***IATF 16949:2016*** *or simply IATF 16949 is the global technical standard that governs the quality management systems within the automotive manufacturing industry, encompassing standards for manufactured automotive products, assembly and testing processes and associated services*
- ***AEC-Q100*** *essentially defines the automotive manufacturing industry standard tests for active components (such as switches, power amplifiers, etc.)*

- ***AEC-Q200*** *defines the standard tests for passive devices (such as radio-frequency (RF) filters, etc.)*
- ***ISO 9001*** *focuses on customer satisfaction, operating costs effectiveness, risk management, legal compliance, stakeholder satisfaction, brand credibility, and the like*
- ***ISO 14001*** *focuses on environmental and economic sustainability.*
- ***ISO 26262*** *regards functional safety standard*
- ***ISO 45001*** *focuses on product and service reliability within health and safety business environment*

Questions in relation to Auto Dealer Responsibility were directed at research participants in the expert cohort. This research asserts that gaining access to a company's product or service end-user or consumer is easily achieved through the company's Dealership Network. This is because the latter is expected to maintain the contact details of the consumer. The Auto Dealer, who is an integral part of the supply chain and quality value stream, may also have the opportunity of marketing or acquiring information on consumer's used vehicles or customer-requested modified vehicles originally produced by the research participants' company or as related. In view of this research, the role of an Auto Dealer, if applicable to the research participant's company, is to be a part of the shared responsibility in the matter of safety recalls, quality reliability delivery, for example, as they may hold important information in helping to trace the origins of quality problems. As such, the experts were asked about:

- The steps their companies employ to ensure that their Dealership Network takes a responsible approach to helping to address product safety recalls or defects/rejects
- Who is responsible for monitoring and managing Dealership Responsibilities
- Whether the organisation uses any special software or tool to monitor and manage Dealership Responsibilities

The findings extracted from this Section are presented in Section 4.2 for analysis.

Continuous Monitoring

Automotive manufacturing organisations striving to acquire and retain consumers are expected to engage in continuous monitoring activities of their interrelated business and engineering processes. Situated within the context of this research, monitoring manufacturing and delivery processes, conducting risk assessment, evaluating quality capabilities, assessing process efficiency/effectiveness, etc., are among the facets that stimulate a good degree of quality performance. However, achieving a sustainably reliable continuous monitoring programme can be challenging due to the unpredictive nature of the behaviours of social (human) actors and the constantly changing automotive manufacturing environment. This research views personnel misbehaviours or bad attitudes towards quality as a threat or adversarial behaviour to quality. In order to better understand the dynamics of the barriers or threats to quality performance, the cohort of experts (i.e. professionals within the automotive manufacturing sector, Category A) were asked to rank their company's Management Priorities with respect to Continuous Improvement processes. The data from this survey is presented and analysed in Section 4.2.

Emerging Technologies

The uncertainty in consumer's increasing demand for new and digital technologies are believed to be presenting a myriad of business-oriented risk factors for the automotive industry. Original Equipment Manufacturers (OEMs), for example, are under constant pressure to optimise their existing business and manufacturing models in order to respond to the constantly customer-centric changing environment. In the context of Study 1, these scenarios expose automotive manufacturing organisations to an uncertain future.

With respect to Automobile Connectivity also known as Connected Automobile, for example, today's drivers are increasingly seeking to be connected to their automobiles just as they would with their smartphones, tablets, tech wearables, digital watches, etc. This requirement challenges traditional or conventional automotive manufacturers to integrate their existing processes with digital technologies in order to survive the fierce competition the new (future) digital technology-oriented companies present.

While Connected Automobiles are expected to be equipped with advanced communication technology that enables direct flow of data to and from the vehicle without a need for mobile device, the automobile product is also expected to have Automated Functions that offer convenience, efficiency and safe-driving experience. Examples of such requirements include putting the vehicle in autopilot mode while on highways or self-parking, etc. New and increasing consumer requirements also include Electric Mobility, Driverless Automobile (Autonomous Automobiles), Automobile Sharing, Carbon-neutral vehicular systems, hybrid automobiles, solar-powered vehicles, and the like. Regardless of the economic facts that these demand patterns are expensive for both consumers and the automotive manufacturing companies, the emerging technologies are gaining attention through advocacy groups for a sustainably green or clean environment. These demands have also given birth to the so-called Industry 4.0 digital technology, requiring heavy investment in order to optimise artificial intelligence for an enhanced connected vehicle. This is seen as a means to also address traffic or motorists' hazards such as had been reported of the fatal accidents the Tesla driverless vehicle, for example, had caused over time (The New York Times, 2021; Tech Crunch, 2022). In 2021, the U.S. NBC affiliate KPRC 2 reported that a driverless Tesla 2019 Model S crashed into a tree and burst into flames, killing its two passengers in Texas (Kolodny, 2021). As seen in the related Fig. 4.2, the intensity of the blaze that required 32,000 gallons of water to subdue the flames prompted the KPRC 2 reporter to also add that the Firefighters had to contact Tesla simply to seek information on how best to put off the fire.

Fig. 4.2: A 2019 Tesla Model S crash that killed 2 in Spring, Texas (Source: CNBC)

At the same time CNBC had claimed that *"Tesla sells automated driving systems under the brand monikers Autopilot and Full Self-Driving (FSD) software to some customers who have premium FSD option"* and Tesla CEO Elon Musk said on a popular social media that: *"I think Autopilot's getting good enough that you won't need to drive most of the time unless you really want to"*, (Kolodny, 2021). In the same article (Kolodny, 2021), Tesla lawyers said on record that *"neither Autopilot nor FSD Capability is an autonomous system."*. In a similar misleading promotional video online, The Drive carried the caption *"Mom of the Year Films Kid's Stupid and Dangerous Sleeping Tesla Driver Stunt for TikTok,"* in which the article (The Drive, 2021) claims that Tesla's *"marketing of its Autopilot Advanced Driver Assistance System (ADAS) has led many to misunderstand its capabilities and often overestimate them, sometimes with serious consequences"* such as the case of a Tesla Driver Watching Movie on Autopilot Crashes into

Cop Cars: Police (The Drive, 2020). Following a number of high-impact similar motor accidents such as depicted in Fig. 4.3, the National Highway Traffic Safety Administration (NHTSA) in March 2021 *"opened 27 investigations into crashes of Tesla vehicles"* (CNBC, 2021).


NHTSA probes Tesla Autopilot crash that killed three people

Rebecca Bellan @rebeccabellan / 12:53 AM GMT+2 • May 19, 2022 Comment

Image Credits: NTSB

Fig. 4.3: A 2022 Tesla Model S crash killed 3 in California (Source: Bellan, 2022)

Within the context of this research, all misleading information designed to promote the advent of emerging technologies are classified as human adversarial behaviours or vectors of quality data deviation (vQDD). As depicted in the fatal accidents above, misleading promotional materials had made the victims to buy-in without questioning what could potentially happen if a digitally enhanced vehicle did not adhere to basic traffic regulations human drivers can otherwise respond to.

Under the theme, *Emerging Technologies*, the cohort of consumers (research participants in Category B) were required to describe how they think *emerging and digital technologies* can potentially vary or disrupt the quality performance of automotive manufacturing organisations.

The data, which thematic statements are presented in Table 4.3, from this enquiry are presented in Section 4.2 for analysis and discussion.

Table 4.3: Statements related to emerging technologies and themes/keywords

Statement	Theme
Consumer demand for Automobile Connectivity (i.e. Connected Automobile/Vehicles) and Automobile Automation can disrupt the quality performance of an automotive manufacturer due to the need to change their existing business models in order to satisfy digital-oriented requirements.	**Disruption**
New and well-established digital technology companies in the field of Automobile Connectivity (i.e. Connected Automobile/Vehicle) and Automation will threaten the quality performance of existing (traditional) automotive organisations that are yet to make the transition to incorporate digital technology.	**Threat**
The new trend of Automobile Sharing (i.e. Shared Cars, Shared Rides or Shared Mobility), particularly in highly populated urban settings, will stimulate a decline of private automobile sales.	**Sales decline**
As Automobile Sharing is expected to grow by 2030, there is a high likelihood that a large number of the shared vehicles will be exposed to rapid wear and tear due to excessive use.	**Rapid wear and tear**
The growing demand for Electric or Solar-powered or Hybrid automobiles will place enormous pressure on manufacturers of diesel-powered internal combustion engine driven automobiles, forcing them to make a transition in order to survive the competition.	**Forced transition**
Electric automobiles generate a huge amount of data during the course of driving them. While manufacturers can analyse this data to help optimise their manufacturing process and business models, this is likely to increase manufacturing complexity due to such continuous data collection.	**Increased complexity**
As Driverless Automobile (also known as Autonomous Vehicle) is steadily pushing its way into becoming mainstream, automotive manufacturers in the field are expected to incorporate extensively advanced smart software that will address safety concerns.	**Capital-intensive software**
Consumer’s interest in experiencing a Driverless Automobile (also known as Autonomous Vehicle) demands automotive manufacturers to couple software with hardware. Coupling software and hardware in the manufacturing process model may pose challenges to a manufacturer’s quality performance.	**Software-hardware coupling**
In the event that the software of a digitised automobile is struck with a computer virus or hacked, this can potentially alter the functionality of a driverless vehicle. Such a scenario can compromise the safety of passengers, pedestrians and or other motorists as a virus hit or hacked software could take an autonomous or driverless automobile off its course, for example.	**Software virus risk**
A Driverless Automobile is practically a vehicular robot that will have to cope with the unpredictive behaviours of human drivers' ability to break traffic regulations. This is a safety concern that indicates that Autonomous or Driverless Automobiles may be prone to motor accidents.	**Human adversarial attitudes**

4.2 Data Presentation, Analysis and Discussion of Findings

In this Section, relevant data as related to the themes in Fig. 4.1 are presented. These feature the perception of both cohort of experts and consumers as related to the identifiers of the potential variants of quality performance within automotive manufacturing organisations. Data on the demographic of the research participants of experts, featuring the population of responders, the sizes of the automotive manufacturing firms they work for, length of time at their employ, and countries of origin are presented in Chapter 3. The data on the demographic of the cohort of consumers, featuring their population and countries of origin have been presented in Chapter 3.

4.2.1 Results: Data collection from cohorts of experts and consumers

In this Study, a cohort of experts (N=8), who are engaged professionally within automotive organisations in the Germany, USA, India and China (see Fig. 4.4) and function within key positions in their organisations, were invited to participate in a survey and interview in order to identify variants of quality performance that are embedded within the themes and sub-themes in Fig. 4.1. In order to ensure the credibility of the findings, a cohort of consumers (N=25) of automobile products and services, from nine (9) countries (see Fig. 4.5), who are from various professional backgrounds, industries and academia and are essentially holders of a first university academic degree, were surveyed to deduce from their perception of what the trajectories of quality performance variation entail. All the research participants are above 18 years of age, and the research participants of experts have a minimum of 36 months in their position (middle to top level) at their employ (see Table 4.4). Of particular significance is that the research participants are conversant with at least one of the QMS-based family of quality standards used in the automotive industry.

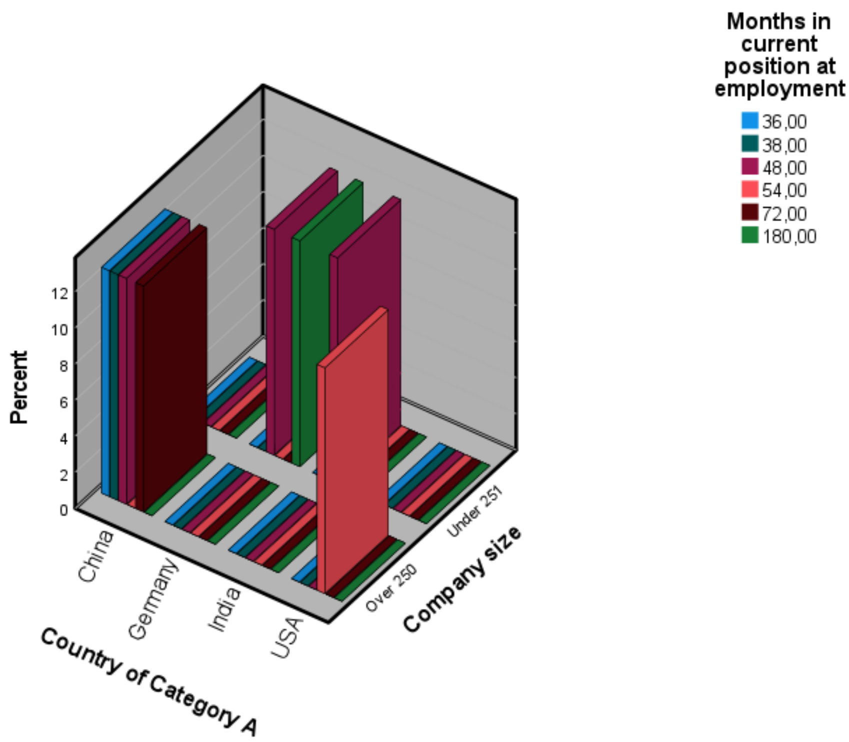


Fig. 4.4: Demographic of Candidate A research participants of experts

Table 4.4: Positions of research participants of experts

Research Participants of Cohort of Experts' Positions			Company size		
			Under 251	**Over 250**	**Total**
	Engineering design team	Count	1	1	**2**
		% within $PositionCA	50%	50%	
	Vehicle auditor	Count	1	0	**1**
		% within $PositionCA	100%	0%	
	Quality manager	Count	0	2	**2**
		% within $PositionCA	0%	100%	
	Project manager	Count	1	0	**1**
		% within $PositionCA	100%	0%	
	Other position in company	Count	0	2	**2**
		% within $PositionCA	0%	100%	
Total			**3**	**5**	**8**

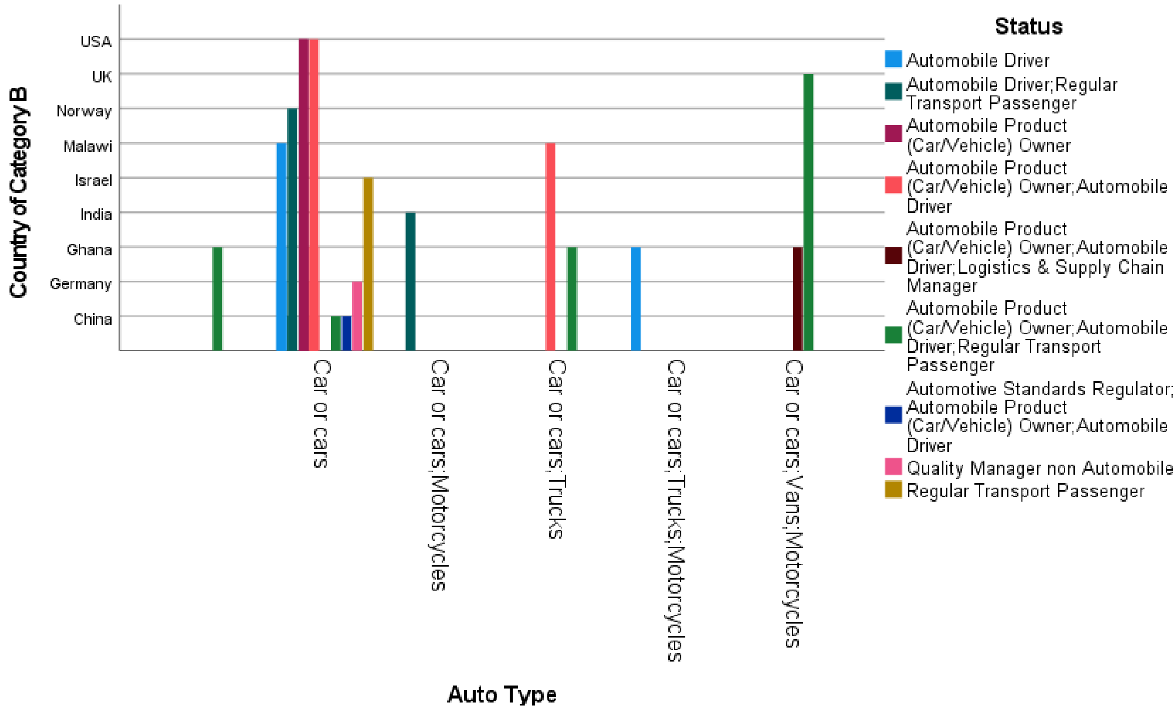


Fig. 4.5: Demographics of Candidate B research participants

Apart from using web applications to conduct the survey component of the data collection protocol, the interview aspect was done via Skype. Definitions and descriptions regarding each theme or quality dimensions were provided in the first section of each survey questionnaire. The same protocol followed in the interview stage to ensure any confusion or ambiguity was cleared in advance of the interview.

4.2.2 Management role

Management Mindset

The mindset of the Top Management of an organisation occupies the top of the hierarchy and its significance is evidenced by the success of the organisation. As such, the mindset or mental orientation with which the top management operates is key to determining the successful future of the organisation. Apart from being expected to set the organisation's core goals, the functionality of each department depends wholly on the Top Management's decision-making mechanism. This study therefore finds it imperative to enquire about the mindset of the Top Management in the companies the research participants of experts work for. The cohort of experts were requested to describe the mindset or beliefs of their company's Top Management in the context of the automotive industry standard procedures, training, certifications, etc. The research participants were required to conduct the description of their assessment using a seven-point Likert scale* of 1 (strongly disagree) and 7 (strongly agree). With reference to the statements presented in Table 4.2 above, Table 4.5 below shows that an accumulated majority (62.5%) of the cohort of experts agree that

> *Top Management believes that ISO standard procedures and associated standards are not adequate enough for the constantly changing automotive manufacturing environment*

Table 4.5: Management's Mindset regarding Standard Compliance

	topman_isoenv	topman_isoexp	topman_isoattn	topman_isodept	topman_isosupp
Strongly disagree	0%	25%	37.5%	0%	12.5%
Disagree	0%	25%	37.5%	37.5%	50%
Somewhat disagree	12.5%	25%	25%	12.5%	12.5%
Somewhat agree	12.5%	0%	0%	25%	12.5%
Agree	50%	12.5%	0%	12.5%	12.5%
Strongly agree	0%	0%	0%	0%	0%
Accumulated agreement	62.5%	12.5%	0%	37.5%	25%
Unknown	37.5%	0%	0%	12.5%	0%

Likert scale: 1 (Strongly Disagree), 2 (Disagree); 3 (Somewhat Disagree), 4 (Neutral/Unknown), 5 (Somewhat Agree), 6 (Agree), 7 (Strongly Agree).

In that same vein, a significant 37.5% of the experts are not certain about the mindset of Top Management as regards their position on a promising future with QMS-based ISO procedures implementation or its agility and versatility for their organisations.

Of particular observed interest is that, while an accumulated disagreement (75%) of the experts do not think that

> *Top Management believes that implementation of ISO standards is very difficult, too expensive and time-consuming*

and an overwhelming 100% of the experts think the contrary applies to the statement:

> *Top Management pays very little attention to the adoption and implementation of ISO standards*

a significant number of the experts (accumulated agreement of 25%) think that

> *Top Management offers very little support for staff training in ISO standard procedures.*

The above observation also resonates with the 37.5% accumulated agreement of experts who think that

> *Top Management believes that not all the personnel across the departments need to necessarily attain ISO certifications.*

As automotive organisations' *time* of existence (in the context of process efficiency or quality performance delivery reliability) practically spans from the mindset of the top in hierarchy, that is the management construct, this subsection analyses and discusses the responses from the cohort of experts regarding how they describe the mindset of the Top Management within their organisations. As this research seeks to take a holistic approach to design a new quality engineering framework, detail attention is given to any relevant quality indicator without discarding a minute entry due to its statistical size. This means an entry of 12.5% is considered as significantly important just as with a higher entry for the same variable. This is because the responses are not restricted to the size of the population of the research participants as a dependent factor to form a statistical analysis, but rather to situate the analysis within the perception of either an individual's perspective or a number of individuals representing a cohort.

In reference to Table 4.5 regarding experts' perception of Top Management's mindset or beliefs in relation to the statements in Table 4.2, the most RQ1-relevant statement is as follows:

> *Top Management believes that ISO standard procedures and associated standards are not adequate enough for the constantly changing automotive manufacturing environment*

The cohort of experts' majority 62.5% accumulated agreement with the statement (topman_isoenv) suggests that Top Management believes there are gaps or deficiencies within the QMS-based ISO family of quality implementation procedures that cannot adequately equip automotive manufacturing organisations with the quality tools they need to implement in order to respond to the uncertainties the changing manufacturing environment presents. The factors that stimulate a constantly changing automotive manufacturing environment include, but are not limited to the following:

1. Unexpected auto recalls by untimely legislation
2. Automotive regulatory bodies' relatively short notice mandated requirements due to unexpected hazards associated with the automotive industry
3. Consumer changing demand patterns
4. Dynamic market dictates
5. Environmental activists' advocacies that pressure lawmakers to demand changes to design, that abruptly disrupt the quality engineering process of automotive manufacturing organisations
6. Emerging technologies or Industry 4.0 pressures on conventional firms
7. And the like

The research participants' observation of the Top Management's mindset towards the inadequacies in the ISO-family of procedures implies that organisations that rely heavily on the guidance provided by the relevant ISO procedures will be exposed to uncontrollable factors of variations in their quality performance if they are confronted with the unpredictive future of constantly changing requirements in the manufacturing environment. This is because in the view of the perceived position of Top Management within the cohorts' organisations, reliance on ISO procedures does not promise mitigation solutions against the adverse impact of the constantly changing automotive manufacturing environment.

In view of the 12.5% cohort of experts who somewhat disagree with the statement and the 37.5% who may not be certain about the mindset of their Top Management regarding the above statement (topman_isoenv), the gap between the agreement and disagreement and abstention presents a need for automotive organisations to develop mitigation solutions against compromised quality performance as may be presented by the uncertain changing requirements patterns of the future. This requires Top Management within automotive manufacturing organisations to map out highest-level functional requirements to develop design solution that mitigate against quality performance variants as precipitated by the changing environment and without relying solely on ISO family of standards.

Translating Top Management biased quality performance variant causes into functional needs

As regards the research participant of experts' perception of their Top Management's beliefs over the other four statements, that is topman_isoexp (75% accumulated disagreement), topman_isoattn (100% accumulated disagreement), topman_isodept (50% accumulated disagreement) and topman_isosupp (75% accumulated disagreement), the collective percentage of majority accumulated disagreement in each case denotes that these cannot adequately answer RQ1 without a resolution to the statement topman_isoenv. Within the frame of reference of the research participants on topman_isoenv as regards Top Management's mindset, a failure to address the gaps in the said statement (topman_isoenv) will vary the other statements with time. The occurrence of this will result in a violation of an automotive manufacturing organisation's quality performance goals. This is because if Top Management believes that the implementation of ISO standard procedures and associated standards are not adequate enough to enable an organisation to coevolve with the constantly changing automotive manufacturing environment, then it implies that the reliability on the existing quality performance processes will fail with time. This also follows that, in due course, existing processes will become non-conforming procedures in the face of future or changing requirements or challenges.

As established earlier in Chapter 3, the second level functional requirement, FR_1, is associated with all functional requirements that must be achieved to maximise the probability of success in the delivery of FR_0. In the same respect, FR_2 is associated with all FRs that must be satisfied to achieve FR_0 cost-resource-process-effectively-and-efficiently. In this regard, the functional needs derived from the findings associated with the statements in Table 4.2 are assigned to either a relevant FR_1 level in Table 3.8 or FR_2 level in Table 3.9. It is worth noting that where fourth-level decompositions of FR_n is not available in the initial QX Engineering Framework in Tables 3.8 and 3.9, these will be introduced at the integration stage in Chapter 6 as well as in the optimisation phase in Chapter 6. These protocols are applied throughout RQ1-oriented Chapter 4 and RQ2-based Chapter 5, where necessary.

In the context of this research, the gaps between the quality performance problem statement {topman_isoenv} and the statements {topman_isoexp, topman_isoattn, topman_isodept, topman_isosupp} are mapped out into the following functional needs with corresponding $FR_{1.1}$ and $FR_{2.1}$ codes as related in domain to Table 3.8 and Table 3.9 respectively:

1. To achieve high-level core quality competent engineers and staff (coded $FR_{1.1.1}$) – relevant to topman_isosupp
2. To develop company-wide familiarity with relevant quality standardised procedures for the automotive manufacturing industry (coded $FR_{1.1.2}$) – relevant to topman_isoenv
3. To achieve company-wide familiarity with relevant international regulatory bodies for the automotive manufacturing industry (coded $FR_{1.1.4}$) – relevant to topman_isodept
4. To achieve familiarity with manufacturing equipment standardisation (coded $FR_{1.1.5}$)

5. To achieve Top Management buy-in (coded $FR_{2.1.2}$) – relevant to topman_isoenv and topman_isoattn
6. To achieve Mid-level Management buy-in (coded $FR_{2.1.3}$) – relevant to topman_isodept
7. To create a process policing or monitoring unit to ensure all departmental adherence (coded $FR_{2.1.1}$) relevant to topman_isodept and topman_isoexp

Situated within this research, the cohort of experts' responses to the statements in Table 4.2 follows that, until an organisation is able to properly translate the above functional needs into functional requirements and identify the corresponding plausible design parameters (DPs) to address each FR to enable the organisation remain up-to-date with its processes, time-dependent variation of quality performance will remain inevitable. The process mapping for defining the plausible DPs for the coded functional needs or associated FRs is presented at the integration phase in Chapter 6.

Manufacturing Facility Director/Manager

As depicted in the queries in Table 4.6, it is observed that although a majority, as much as 62.5%, of the cohort of experts indicate that their firms have a Facility Director or Manager, who is conversant with the ISO procedures, a significant 37.5% indicated that the Facility Director or Manager is not involved in the early design stage. As this research focuses on developing a new quality engineering system with the intension of providing automotive manufacturing SMEs with a tool to help them focus attention to every detail along the quality performance value stream, the 37.5% indication that the Facility Director/Manager is not involved at the early design stage is significant. Their responses are captured in Table 4.6 below.

Table 4.6: Experts' responses regarding Manufacturing Facility Director or Manager

Manufacturing Facility Director or Manager	Yes	No	Unknown
Does your company have a manufacturing Facility Director/Manager?	62.5%	25%	12.5%
If your company has a manufacturing Facility Director/Manager, is the Facility Director/Manager involved in early design stage?	37.5%	12.5%	25%
If your company has a manufacturing Facility Director/Manager, is the Facility Director/Manager conversant with the relevant ISO standards for automotive manufacturing quality procedures?	62.5%	12.5%	25%
Do you use any special software, system or special tool for the review of the Manufacturing Facility with respect to the quality requirements of a working environment?	62.5%	25%	12.5%

The context of this research seeks the functional requirements of a manufacturing facility to feature as an integral component of the quality value stream creation for automotive manufacturing organisations. This is because any variation along the functional processes and materials or resources coordinated or transitioning between the design engineering domain and the manufacturing facility management ripples along the quality performance value chain and can potentially propagate in other associated manufacturing system or activities. In agreement with Allen (2010, p.35-37), the design engineering stage essentially creates a manufacturing blueprint, which features the definition of quality performance or quality characteristics or quality-biased KIVs for all the departments including the Manufacturing Facility. This follows that the functional requirements, as defined at the design stage, for the Manufacturing Facility Director or Manager are time-dependent functional requirements to satisfy a target manufacturing or production goal. In recalling Table 4.6, the cohort of experts' automotive manufacturing organisations that do not involve their Facility Director/Managers at the early design stage are likely to make the latter susceptible to varying the quality performance expectation. This is simply because the manufacturing Facility Director/Managers are not involved at the design stage to ensure their involvement correlates to taking ownership of the expectations in the functional requirements defined in absentia. This position of the study premised the need to ask the cohort of experts as to ***who is responsible for managing the Manufacturing Facility***. Their responses are captured as in Table 4.7 below.

Table 4.7: Experts' responses regarding responsibility for managing the Manufacturing Facility

Who is responsible for managing the Manufacturing Facility?	Yes	No	Unknown
Top Management	12.5%	62.5%	25%
Engineering Design Team	25%	50%	25%
Task Force	0%	75%	25%
Internal/Vehicle Auditor	75%	25%	0%
Quality Manager/Director	25%	50%	25%
Project Manager	0%	75%	25%
Human Resource Manager/Director	0%	75%	25%
Purchasing/Procurement and Supply Chain Lead	0%	75%	25%
Owner or Owner Representative	0%	75%	25%
Software Engineer	0%	75%	25%
Risk Analyst	0%	75%	25%
Manufacturing Engineering Lead	50%	25%	25%
IT Infrastructure Assessor	0%	75%	25%
Business Process Engineer	0%	75%	25%
Production Manager	0%	62.5%	25%
Shopfloor Supervisor	25%	50%	25%

Facility Maintenance Lead	50%	25%	25%
Line Manager	25%	50%	25%
Other	0%	0%	0%

As seen in Table 4.7, Internal/Vehicle Auditor generated the majority (75%) as the sector responsible for managing the Manufacturing Facility. The second highest frequency (50%) is the experts' indication that the Facility Maintenance Lead is responsible for managing the Manufacturing Facility. While 62.5% of the experts indicated that there is a Facility Director/Manager at their firms (Table 4.6), it can be observed from Table 4.7 that none of the cohort of experts added the position in the field marked *Other* and left it blank. With reference to the research participants of experts, who overwhelmingly indicated by 75% that their organisations' manufacturing facility is managed by an Internal/Vehicle Auditor, this indicates that the latter is not dedicated to monitoring and auditing processes related to the automobile products in production and associated value stream. In concurring with Khalil & Darwish (2019), companies within such domain are likely to experience variation in their quality performance delivery due to the absence of a dedicated Facility Director/Manager, who can ensure that measures such as implementation of flexibility dimensions can be put in place to achieve quality-based operational performance in response to time-dependent rapidly changing automotive manufacturing environment.

As to whether ***any special software, system or special tool*** is used to ***review the Manufacturing Facility with respect to the quality requirements of a working environment***, 62.5% of the cohort of experts indicated that their organisations have a mechanism for reviewing the manufacturing facility, while 25% of the experts indicated the contrary. The companies within the 25% of not employing any tool or software to review their manufacturing facilities are likely to deviate from the expected quality performance value chain from time to time. This is because, apart from ensuring that a manufacturing facility is reviewed periodically to ensure that operational and interconnected issues such as technology integration, supporting management decisions, workplace-friendliness, process efficiency and productivity, etc. are guaranteed, it is worth noting from El-Khalil (2015) that it required facility management to review and agree on a model simulation (tool/software) that mimicked actual facility outputs in producing three different vehicles as stimulated by a manager from the Big Three (GM, Ford and Chrysler LLC).

Translating Facility Manager-based quality performance variant causes into functional needs

Within the context of this research, a manufacturing facility is considered a part of manufacturing resources. Thus a manufacturing functional need as related the findings associated with the manufacturing Facility Director/Manager is to *maximise the manufacturing resources*. This is associated with $FR_{1.2.4}$ in Table 3.8, requiring a review of the initial $DP_{1.2.4}$ in order to design a mitigation solution against any time-dependent manufacturing waste generation (i.e. any potential deviation from expected quality performance dimension).

Management support

It was deduced from the literature review (see Chapter 2) that none of the researchers delved deeper into investigating to extract critical data from how experts working within the automotive industry evaluate their Top Management Support based on enquiries relevant to the various departmental processes or operations. In this study, the cohort of experts were asked to evaluate by rating their Top Management Support based on RQ1-relevant statements as presented in Table 4.8.

Table 4.8: RQ1-based statements regarding Top Management Support activities

Statement	Code
Top Management defines company main goals and clearly communicates them across all departments	topman_goal
Top Management's standard practice is to assign responsibilities to persons (that is, professionals by their individual names) and NOT to the specific titles (by roles such as Quality Director, Project Manager, Operations Manager, etc.)	topman_arp
Top Management puts in place an existing functional programme or system for monitoring automotive safety-related parts or components and accessories	topman_safparts
Top Management ensures documentation of processes for the management of automotive product safety	topman_docproc
Top Management ensures the company transfers standard product-safety requirements to sub-tier suppliers. (A sub-tier Supplier is any supplier who is a third party who provides components, parts, materials or related products directly or indirectly to your company).	Topman_tpsr
Top Management ensures the company has an existing and effective continual Risk Analysis and Preventive programme	topman_crapp
Top Management ensures the company's continual risk analysis scheme includes a minimum of potential auto recalls, actual recalls, product defects, scrap, rework and rejects	topman_craqd
Top Management ensures the company's manufacturing processes and infrastructure contingency plans are regularly assessed for effectiveness, reviews and updates	topman_mpicpa
Top Management ensures the company has standard requirements for its suppliers to ensure they comply with the industry standard quality management system procedures.	Topman_supp
Top Management ensures the company has standard requirements for its supply chain (or delivery/distribution) channel to comply with the industry standard quality management system procedures	topman_srsc

Top Management ensures the company regularly reviews its audit results of suppliers to ensure the supplier process is robust and assures compliance with the latest applicable statutory, regulatory and other automotive industry standard requirements	topman_rrars
Top Management ensures the company has an effective Internal Audit Team that regularly monitors all key manufacturing processes and reports to Top Management for regular reviews	topman_audit
Top Management ensures the company has a robust framework for designing highly responsive corrective measures to counter quality issues.	Topman_fdrcm
Top Management ensures it builds knowledge as well as remains updated with the quality management standards implementation processes, procedures, records of implementation and controls with respect to the automotive industry standard requirements. The standard requirements in this section refer to the ISO family of standards as related to the automotive industry	topman_qmsip
Top Management ensures optimal communication with all interested parties (stakeholders, both external and internal) exists at all times	topman_cip
Top Management mandates the existence of a system or programme for the Monitoring and Measurement of Quality Performance with related Records of Results	topman_mmqp
Regarding building core quality capabilities, Top Management offers regular staff training and awareness schemes.	Topman_rsta
Top Management significantly invests in personnel training and knowledge development in quality standards, quality tools, and or ISO standard procedures	topman_iptkd

Provided a seven-point Likert scale of 1 (strongly disagree) to 7 (strongly agree), the research participants in Category A were asked to rate the level of their firm's Top Management Support for the various departmental processes or operations. The experts' responses to the statements are presented in Table 4.9.

As shown in Table 4.9, topman_goal generated the majority accumulated agreement (87.5%) indicating that

> *Top Management defines company's main goals and clearly communicates them across all departments.*

Other statements that had the experts' above 60% accumulated agreement include topman_arp, topman_safparts, topman_docpr, topman_craq, topman_cip and topman_iptkd. An important data in Table 4.9 is that the experts' accumulated agreement (37%) that invalidates the statement that:

> *Top Management ensures the company has an existing and effective Continual Risk Analysis and Preventive programme*

is incongruent to the risk-related accumulated agreement (62.5%) that

> *Top Management ensures the company's continual risk analysis scheme includes a minimum of potential auto recalls, actual recalls, product defects, scrap, rework and rejects*

Although an accumulated agreement 87.5% presents a majority indication that *Top Management defines company main goals and clearly communicates them across all departments*, such accumulated agreement 25% topman_fdrcm contrasts with the former statement. In Table 4.9, an 87.5% accumulated agreement with no element of disagreement suggests that the cohort of experts affirm that their organisational management coordinate and support the various departmental processes. This establishes from the statement topman_goal that Top Management both defines the company's target goals and clearly communicates them across all the various departments. While an above 60% accumulated agreement of experts also validate the above in each of topman_crapp, topman_craq, topman_mpicp, topman_rsta, topman_srsc, and topman_mmq case, fractional elements of accumulated disagreement are registered in 10 statements (namely, topman_arp, topman_safparts, topman_docpr, topman_tpsr, topman_supp, topman_audit, topman_fdrcm, topman_qmsi, topman_cip and topman_iptkd). As this research does not rely wholly on statistical findings to form a generalisation but rather to examine individual responses critically in order to generate knowledge from the findings, the RQ1-relevant statements that present disagreements from a section of the research participants are also presented in the following segments.

Table 4.9: Experts' responses to the statements in Table 4.8

	topman_goal	topman_arp	topman_safparts	topman_docproc	topman_tpsr	topman_crapp	topman_craqd	topman_mpicpa	topman_rsta
Strongly disagree	0%	12.5%	12.5%	0%	0%	0%	0%	0%	0%
Disagree	0%	0%	0%	12.5%	12.5%	0%	0%	0%	0%
Somewhat disagree	0%	0%	0%	25%	12.5%	0%	0%	0%	0%
Somewhat agree	12.5%	25%	0%	0	12.5%	37.5%	25%	25%	25%
Agree	37.5%	25%	0%	25%	12.5%	12.5%	0%	12.5%	12.5%
Strongly agree	37.5%%	25%	62.5%	37.5%	25%	25%	37.5%	25%	25%
Accumulated agreement	87.5%	75%	62.5%	62.5%	50%	75%	62.5%	62.5%	62.5%
Neutral/unknown	12.5%	12.5%	25%	0%	25%	12.5%	25%	25%	25%
	topman_supp	topman_srsc	topman_rrars	topman_audit	topman_fdrcm	topman_qmsip	topman_cip	topman_mmqp	topman_iptkd
Strongly disagree	0%	0%	0%	0%	0%	0%	0%	0%	0%
Disagree	0%	0%	0%	0%	0%	0%	0%	0%	0%
Somewhat disagree	12.5%	0%	0%	12.5%	12.5%	12.5%	12.5%	0%	25%
Somewhat agree	0%	12.5%	12.5%	25%	0%	12.5%	25%	0%	25%
Agree	0%	25%	25%	12.5%	0%	0%	37.5%	12.5%	25%
Strongly agree	37.5%	25%	37.5%	25%	25%	37.5%	12.5%	37.5%	12.5%
Accumulated agreement	37.5%	62.5%	75%	62.5%	25%	50%	75%	50%	62.5%
Neutral/unknown	37.5%	25%	12.5%	0%	0%	25%	0%	37.5%	0%

Likert scale: 1 (Strongly Disagree), 2 (Disagree); 3 (Somewhat Disagree), 4 (Neutral/Unknown), 5 (Somewhat Agree), 6 (Agree), 7 (Strongly Agree).

While a majority of 62.5% accumulated agreement by the experts informs that Top Management has in place an existing functional programme or system for monitoring automotive safety-related parts or components and accessories (topman_safparts), 12.5% strongly disagrees with this assertion. By virtue of the philosophical position of this research, a 12.5% *strongly disagreement* against a majority of 62.5% is not considered insignificant. From the viewpoint of this research, a statistical minority of 12.5% signals that the research participants within the 12.5% domain have likely observed activities that invalidate the assertion in topman_safparts. This observation implies that there are activities that vary topman_safparts, which potentially construes as variation in quality performance due to the lapse observed by the 12.5% strongly disagreement. This scenario implies that there is inadequacy in topman_safparts, regardless of a majority claiming the statement is entirely true. Monitoring automotive safety-related parts, as regards topman_safparts, is an integral part of quality performance. The majority of auto recalls had been attributed to failures in auto parts. Thus, a 12.5% *strongly disagreement* in topman_safparts is not negligible.

The above is also established and applied to topman_docpr (37.5% accumulated disagreement), topman_tpsr (25% accumulated disagreement), topman_supp (12.5% somewhat disagreement), topman_audit (12.5% somewhat disagreement), topman_fdrcm (12.5% somewhat disagreement), topman_qmsi (12.5% somewhat disagreement), topman_cip (12.5% somewhat disagreement), and topman_iptkd (25% somewhat disagreement). Associated with the relatively small percentages of disagreements to those quality-oriented statements, an automotive manufacturing organisation will vary in the delivery of the quality performance that the related statements had been intended to validate.

Translating Top Management Support-associated quality performance variants into functional needs

Since this research positions the Top Management concept as a key stakeholder, as established in Chapter 3, the significance of findings associated with the quality-biased statements in Table 4.8 are viewed in terms of functional needs and are therefore assigned FRs as follows (related to Table 3.8 and Table 3.9):

1. $FR_{1.1.1}$ – relevant to topman_goal
2. Achieve/develop company-wide familiarity with relevant quality standardised procedures for the automotive manufacturing industry (coded $FR_{1.1.2}$) – relevant to topman_arp, topman_qmsip, topman_iptkd
3. $FR_{2.1.1}$ & $FR_{2.3}$ – relevant to topman_safparts, topman_crapp

4. $FR_{2.1.2}$ – relevant to topman_arp, topman_tpsr
5. Achieve/Develop QX buy-in across all departments (coded $FR_{2.1.4}$) – relevant to topman_cip
6. $FR_{2.1.3}$ – relevant to topman_goal, topman_cip
7. $FR_{1.1.4}$ – relevant to topman_arp
8. $FR_{1.1.5}$ – relevant to topman_rsta, topman_iptkd
9. Create a reward system to stimulate recurrent training in quality skillset across all departments or units (coded $FR_{1.1.7}$) – relevant to topman_fdrcm, topman_qmsip, topman_rsta
10. Achieve/Develop indigenous knowledge system (IKS)-based quality framework (code $FR_{1.1.6}$) – relevant to topman_qmsip
11. Create standard operating procedures (SOP) for departmental processes (coded $FR_{1.1.12}$) – relevant to topman_docproc
12. Design risk assessment scheme to identify human adversarial behaviours within the quality-of-service units/departments (coded $FR_{1.3.5}$) – relevant to topman_craqd
13. Develop continuous quality performance monitoring scheme (coded $FR_{1.2.6}$) – relevant to topman_mpicpa and also partially addressed by existing $FR_{1.3}$
14. Define key performance indicators (KPI), objectives and quality-based process approach for continual improvement (coded $FR_{1.3.1}$) – relevant to topman_supp
15. Design internal and external stakeholder feedback to determine gaps in quality of service and automobile product families (coded $FR_{1.3.3}$) – relevant to topman_supp, topman_srsc, topman_rrars
16. Develop sustainable optimal customer-centric quality of service delivery scheme (coded $FR_{1.3.6}$) – relevant to topman_srsc
17. Create master process to respond to personnel attitudes that vary quality design targets (coded $FR_{1.3.4}$) – relevant to topman_rrars
18. Produce procedures for skills audit (coded $FR_{1.1.8}$) – relevant to topman_audit
19. Produce/Design procedure for internal auditing quality capacity-building training programmes (coded $FR_{1.1.9}$) – relevant to topman_audit
20. Develop procedure for internal audit of QX practice (coded $FR_{2.1.5}$) – relevant to topman_audit
21. Determine master process for identifying/capturing defects (coded $FR_{2.4.4}$) – relevant to topman_audit
22. Design/Develop process monitoring scheme (coded $FR_{2.4.5}$) – relevant to topman_audit

23. Determine need for in-house training for staff development knowledge in automobile safety regulations (coded $FR_{2.17.1}$) – relevant to topman_safparts, topman_tpsr
24. Develop a system for early detection of potential product safety defect (coded $FR_{2.17.2}$) – relevant to topman_safparts, topman_tpsr
25. Develop a system to notify automotive regulatory bodies of late detection of a product safety defect (coded $FR_{2.17.3}$) – relevant to topman_safparts, topman_tpsr
26. Develop standardised procedure for rendering nonconforming products unusable prior to final disposal (coded $FR_{2.17.4}$) – relevant to topman_safparts, topman_tpsr
27. Create QX Task Force protocol for internal auto recall process monitoring (coded $FR_{2.17.5}$) – relevant to topman_safparts, topman_tpsr

The above FRs are further treated in Chapter 6 at the integration stage.

Reviewing Top Management's operational activities

The critical review approach adopted to review the quality barriers to QMS and TQM (see Chapter 2 on *Barriers to QMS and TQM implementation*) shows that none of the researchers and subject-related reports cited in the literature review identified a need to seek data from automotive manufacturing organisations' personnel's perspective of *who is responsible for reviewing Top Management with respect to their operational activities*.

As Top Management is a key internal stakeholder in an organisation and among the top hierarchy that defines the organisation's highest-level functional requirement, a significant component of this research is to seek insights into *who reviews Top Management*. It is believed within the context of this research that such review can ensure Top Management Support is directed at achieving the company's highest goals. Table 4.10 shows the research participants' responses to the question regarding *who is responsible for reviewing Top Management's operational activities*.

Table 4.10: Key stakeholders for reviewing Top Management's operational activities

Who is responsible for reviewing Top Management operational activities and to ensure Management Support is directed at achieving the company's highest goals?	**Yes**	**No**	**Unknown**
Top Management	25%	50%	12.5%
Engineering Design Team	25%	50%	12.5%
Task Force	12.5%	62.5%	12.5%
Internal/Vehicle Auditor	37.5%	37.5%	12.5%
Quality Manager/Director	37.5%	37.5%	12.5%
Project Manager	12.5%	62.5%	12.5%

Human Resource Manager/Director	12.5%	62.5%	12.5%
Purchasing/Procurement and Supply Chain Leader	12.5%	62.5%	12.5%
Owners or Owner/Representative	75%	0%	12.5%
Software Engineer	12.5%	62.5%	12.5%
Risk Analysis	12.5%	62.5%	12.5%
Manufacturing Engineering Lead	12.5%	62.5%	12.5%
IT Infrastructure Lead	12.5%	62.5%	12.5%
Business Process Engineer	12.5%	62.5%	12.5%
Production Manager	12.5%	62.5%	12.5%
Shopfloor Supervisor	12.5%	62.5%	12.5%
Facility Maintenance Lead	12.5%	62.5%	12.5%
Line Manager	12.5%	62.5%	12.5%
External Auditors	0%	75%	12.5%

As seen in Table 4.10, the entry for Owners or Owner/Representative indicates the highest frequency (75%) compared to all the other entries. An observation of interest is that none of the research participants suggested an entry for External Auditors or a use of a software or tool to evaluate Top Management Support. In organisations where the Owners or Owner/Representative are in charge for reviewing Top Management's operational activities, this is tantamount to asking the Owners or Owner/Representative to review themselves. This is based on the assumption that most company owners are likely to take the Top Management position. Under such hypothetical scenario, there is a limited chance that the Owner-based Top Management can conduct a fair assessment of its operational activities to stimulate a collective business strategic decision-making. Given such a premise, organisations exposed to such a scenario are likely to experience variation in their quality performance value chain from time to time. A contingency scheme against such a bias event is to invite External Auditors to review Top Management's operational activities, whether the position is occupied by the Owner or not. This could lead to an independently uninfluenced objective assessment. However, it can be seen in Table 4.10 that none of the cohort of experts answered *Yes* against External Auditors, with an overwhelming majority of 75% answering *No* and 12.5% as Unknown or Preferred not to answer.

Asked *Do you use a special software or tool for monitoring all manufacturing processes from design to supply or delivery?* the experts' responses are indicated in Fig. 4.6.

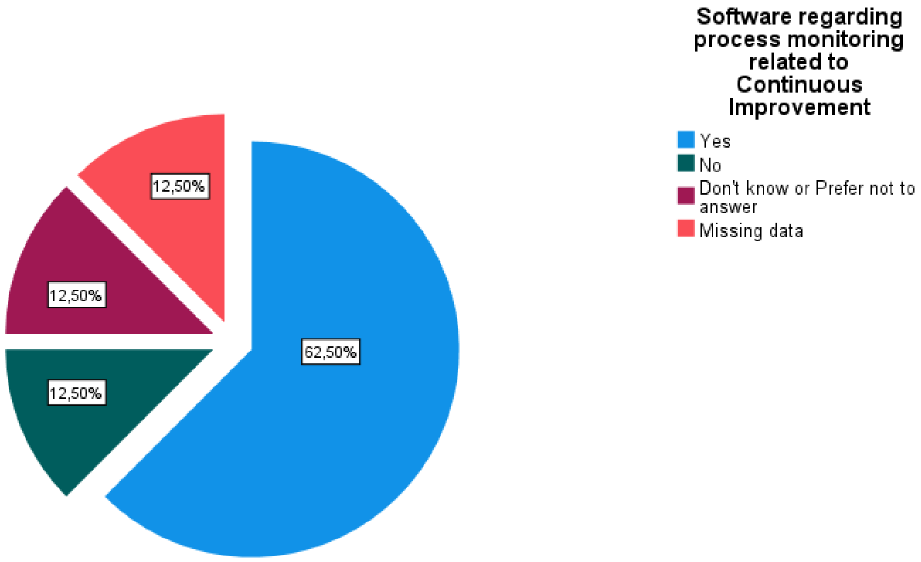


Fig. 4.6: Experts' responses to whether their organisations use a process monitoring tool

Fig. 4.6 shows that a majority of 62.5% indicated that their company's employ either a special software or tool for monitoring all manufacturing processes from design to supply or delivery. 12.5% of the experts answered *No* to affirm that their firms do not use any system to monitor all manufacturing processes from design to supply or delivery. Another 12.5% of the research participants are either unaware of the existence of any software or tool as defined above or they preferred not to respond to the enquiry. Of particular significance of the absence of any tool or software to function as descriptive of the question related to Fig. 4.6 is that variants of quality performance can exist undetected. Undetected or unmonitored activities within a quality value stream implies absence of countermeasures to address any deviations in the expected quality performance.

Translating Top Management operational activities based quality performance variants into functional needs

Translating *reviewing and monitoring Top Management's operational activities and all manufacturing processes* into functional needs, the following relevant FRs are mapped against the former:

1. $FR_{1.1.6}$ – relevant to topman_qmsip
2. $FR_{1.1.5}$ – relevant to topman_rsta, topman_iptkd
3. Create procedures for conducting internal audit process, internal audit report generation, and countermeasures (coded $FR_{1.1.10}$)

4. Produce QX Task Force & Top Management protocol for review of internal audit report (coded $FR_{1.1.11}$)
5. $FR_{2.4.5}$ – relevant to topman_audit
6. Develop objective monitoring sceme to identify personnel apathy towards quality design process (coded $FR_{2.10.1}$)
7. Enable a scheme for reporting observed human adversarial behaviours towards quality design (coded $FR_{2.10.2}$)
8. Determine Top Management non-committal towards quality implementation process and overall organisational goal (coded $FR_{2.11}$)

Based on the findings presented in Table 4.10 and Fig. 4.6, unless an organisation within the range of the responses the research participants provided is able to define corresponding DPs to satisfy each of the coded FRs above, such organisation will experience variations in the expected quality performance delivery channel from time to time. This is because the above FRs are time-dependent functional requirements and a failure to properly map out DPs to address them means a manufacturing system will lack the mechanism to surmise quality performance issues and devise countermeasures to adequately resolve them. The above FRs are further treated in Chapter 6.

Departmental Rating

In the context of this research, automotive manufacturing is a system consisting of various departments, which apart from Production, include Management and Administration, Sales/Marketing, Services and Parts Departments. Coordination and collaboration among these departments must be effective and efficient in order to satisfy both internal and external stakeholder requirements. It is therefore essential to gain an insight into the level of efficiency/effectiveness within the decision-making mechanism and quality-based processes across these four integral departments. On a seven-point Likert scale of 1 (Very Ineffective) and 7 (Very Effective), the cohort of experts were asked to rate their company's departments in the domains stated above. The results presented in Table 4.11 show that half of the experts rate their Parts' Department as effective (50% accumulated agreement) while a 25% of the cohort remain otherwise. Within this window, a 62.5% accumulated agreement of the experts indicates that the Sales Department is effective. The Management and Administration department generated the highest accumulated rating (75%) as an effective department.

Table 4.11: Experts' rating of four departments

Rating management and administration

	N	%
Somewhat Ineffective	2	25.0%
Somewhat Effective	3	37.5%
Effective	1	12.5%
Very Effective	2	25.0%

Rating sales department

	N	%
Somewhat Ineffective	2	25.0%
Somewhat Effective	4	50.0%
Very Effective	1	12.5%

Rating services department

	N	%
Somewhat Ineffective	2	25.0%
Neutral / Unknown	2	25.0%
Somewhat Effective	2	25.0%
Effective	1	12.5%
Very Effective	1	12.5%

Rating parts department

	N	%
Somewhat Ineffective	2	25.0%
Neutral / Unknown	2	25.0%
Somewhat Effective	3	37.5%
Very Effective	1	12.5%

Translating Departmental-oriented quality problem statements into functional needs

In paying attention to the 25% rating of Management and Administration as *somewhat ineffective*, 25% rating of Sales Department as *somewhat ineffective*, 25% rating on Services Department as *somewhat ineffective* and the 25% rating of Parts Department as *somewhat ineffective*, a failure to identify the underlying functional needs that must be addressed to remove these departments from their current functional status as *somewhat ineffective* will potentially translate into compromised quality performance value delivery. The following functional needs are mapped out against the *somewhat ineffective* rating of each of the four departments in Table 4.11:

1. Assigned $FR_{1.1.4}$ – as defined earlier, achieving a company-wide familiarity with automotive regulatory bodies' requirements and expectations can extend the horizon of all the integral departments, leading to improved effectiveness
2. Assigned $FR_{1.1.5}$ – as defined earlier, a familiarity with manufacturing equipment standardisation (MES) across the Parts Department can enhance its functionality and increase its effectiveness
3. Assigned $FR_{1.1.6}$ – building an indigenous knowledge system can stimulate an uncompromising organisation-wide quality culture to mitigate against causes of variation in quality performance delivery

The significance of the research participants' rating of each of the four department as pertains to RQ1 and the identified FRs are presented in Chapter 6 for integration.

4.2.3 Quality of service

As consumer satisfaction is a measure of good quality performance, this component concerns the quality-of-service experiences the research participants in Category B have had at the Auto Dealership. The enquiries also seek data on the factors that influence the research participants of consumers to either purchase or lease an automobile product or service. As seen in Table 4.12, a vast majority of accumulated agreement (90%) indicated that their decision to purchase/lease an automobile was influenced by how the auto dealership handled the order in a professional way. The *level of interaction* they had with the personnel (accumulated agreement 88%) and the *way the automobile product or service was delivered* (accumulated agreement 88%) at the auto dealership also served as influencing factors.

Table 4.12: Research participants' responses to quality of service at auto dealership

	Decision to purchase/lease an automobile as influenced by how the auto dealership handled your order in a professional	Interaction with automobile personnel	The way the automobile or service was delivered
Accumulated agreement	90%	88%	88%
Accumulated disagreement	8%	8%	4%
Neutral/Unknown	8%	4%	4%

Under this segment, the research participants of automobile consumers were asked to describe the factors that help inform their decision when purchasing/leasing an automobile product. Table 4.13 shows that a majority accumulated agreement (76%) of the cohort of consumers based their…

> *…decision to purchase or lease an automobile depends mainly on how much information [you] can access about the range of automobiles in the automotive marketplace*

Table 4.13: Cohort of consumers' responses to statements regarding influencing factors

Auto purchase or lease decision regarding	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	Neutral or unknown
Manufacturer's compliance	24%	16%	8%	4%	12%	12%	24%
purchase or order process	4%	24%	8%	4%	24%	24%	12%
information access	0%	4%	4%	40%	16%	20%	16%
dealership influenced comfort	4%	0%	16%	20%	28%	20%	12%

dealership professionalism	0%	4.2%	8.3%	20.8%	29.2%	20.8%	16.7%
dealership teamwork	4%	8%	8%	28%	20%	8%	24%

The statement that generated the second highest accumulated agreement (70.8%) relates to the consumers' indication that their…

> *…decision to purchase or lease an automobile was influenced by how the automobile dealership handled [your] order in a professional and timely manner*

It is also worth noting that a significant accumulated agreement (68%) shows that the comforting atmosphere the auto dealership created added to the factors that influenced research participants of consumers' inclination to purchase or lease an automobile product or service.

Of particular interest to this research is that the cohort of consumers evidently asserted by a significant accumulated disagreement (48%) in the statement that their…

> *…decision to purchase or lease an automobile depends mainly on the automotive manufacturing company's compliance with any of the automotive industry standards such as IATF 16949:2016, ISO 9001, ISO 14004, ISO 26262*

As the cohort of consumers' response is incongruent to the common belief that consumers are influenced by compliant companies (see Chapter 2 on *Quality tools and methods for manufacturing systems*), it affirms that consumers are the determinants, to a large extent, of what constitutes factors that define quality dimensions via their perception. Thus, in addition to the closed-ended questionnaires, the research participants were also asked the following related open-ended question:

> *In your opinion, what do you think is the most important quality for an automotive dealership or service provider to have or offer?*

As illustrated in Fig. 4.7 below, the themes were generated based on the frequencies of occurrence of the consumer-centric preferential keywords or keyword phrases. The themes were then used to create a mindmap (Fig. 4.7) of the research participants' perspective of the most important quality values for an automotive dealership. Among the dominant keyword or keyword phrases were *knowledge* about the automobile product, *information* regarding safety features, *well-informed* customer care, being *honest* in terms of pricing structure based on trustworthiness, truthfulness and the like, without an element of exploitation.

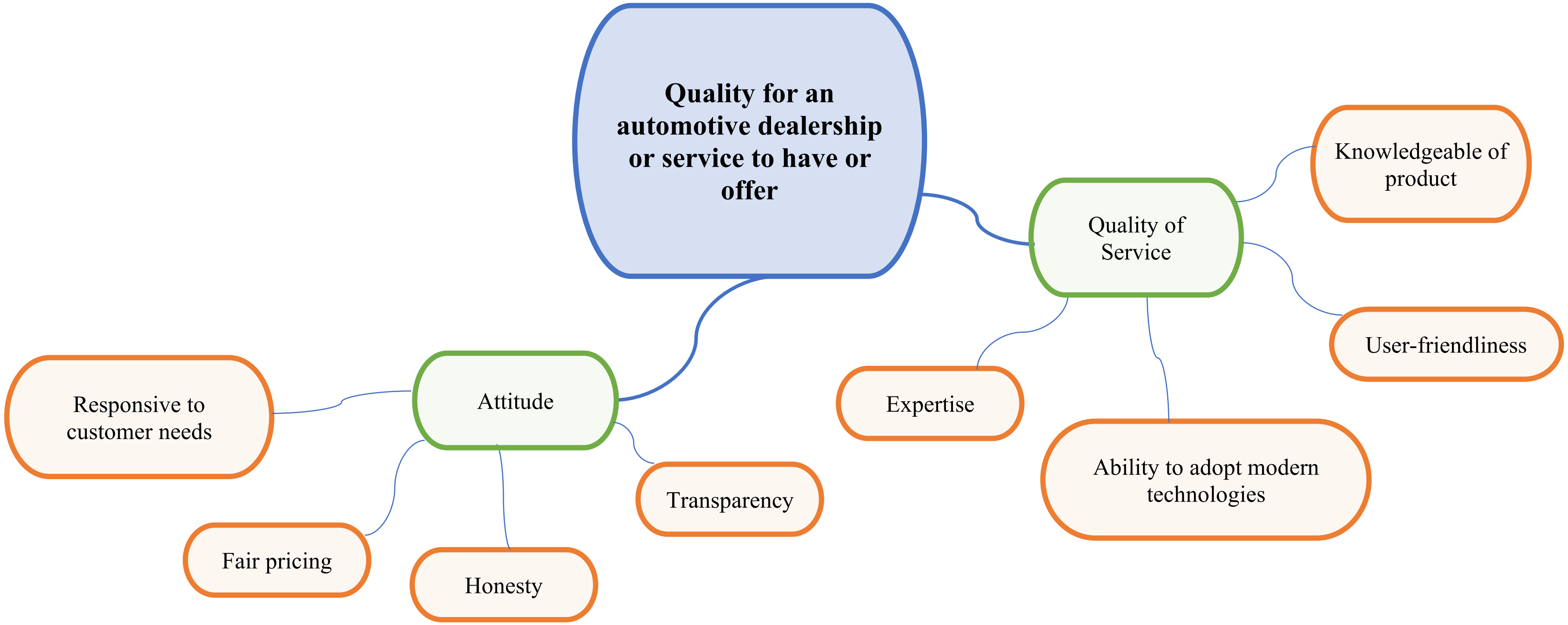


Fig. 4.7: Cohort of consumer responses to the most important quality for an automotive dealership or service provider to offer

The descriptive statistical results associated with Table 4.14 shows the means (5.20, 5.25 and 5.08) of the respective top three statements as embedded with the most influencing factors.

Table 4.14: Statistical means featuring experts' top three scale of preference of decision-influencing statements

Descriptive Statistics

Auto purchase or lease decision regarding	N	Min	Max	Mean	Std. Deviation
manufacturer's compliance	25	1.00	7.00	3.52	2.10396
purchase or order process	25	1.00	7.00	4.56	2.10317
information access	25	2.00	7.00	5.20	1.29099
dealership influenced comfort	25	1.00	7.00	5.08	1.60520
dealership professionalism	24	2.00	7.00	5.25	1.42188
dealership teamwork	25	1.00	7.00	4.56	1.52971

As evidenced in Table 4.14, the research participants of consumers imply that access to information (Std. deviation of 1.29) is vital to the consumer market as it is required to inform decision. Of relevance to this study is that the consumers collectively agree (92%) that they consider it very important for automotive companies to share information about their quality standard status. The research participants of consumers also believe (80% accumulated agreement) that automotive organisations that provide adequate information about the features of their automobile products and auto services (Table 4.15) through multiple sources such as those listed in Table 4.16 perform better in business compared to others in the same industry who do not. It can be seen in Table 4.16 that Google search provides 84% as the most preferred source of automobile product related information, with the second ranked highest (72%) being Internet searches. It is important to note that *Printed Magazines and Documents* (scoring as low as 8%) is no longer a thing of the future. This follows that automotive organisations that have remained to preserve the conventional approach to information dissemination using *Printed Magazines and Documents* will likely experience a very poor rating in their quality performance delivery in terms of a compromised market share.

Table 4.15: Business performance metrics

Business performance metrics	**Yes**	**No**	**Maybe**
Information shared on quality standard status	92%	0%	8%
Better performance due to adequate information provision	80%	8%	12%

Table 4.16: Research participants' sources of information when deciding on auto purchasing or leasing

Source of information	Yes	No
Google search	84.0%	16.0%
Manufacturer's website	52.0%	48.0%
Printed magazines or documents	8.0%	92.0%
Online magazines or documents	36.0%	64.0%
Consultation with dealership	52.0%	48.0%
Consultation with manufacturer	20.0%	80.0%
Word of mouth	52.0%	48.0%
Other internet search engines	20.0%	80.0%
Vehicle information app	20.0%	80.0%
Internet	72.0%	28.0%
Auto forums	24.0%	76.0%
Auto selling platforms	28.0%	72.0%

*Other: YouTube auto reviews (1 case)

Asked as to whether the auto dealership checked, in their presence, the essential quality properties of the functional parts of the automobile at the time of purchase, Table 4.17 shows the responses of the research participants of consumers.

Table 4.17: Consumers' responses on checks of functional parts of automobile product

	Yes	**No**	**Missing data**
Vehicle air conditioning, heater and or defroster system check	64.0%	36.0%	0.0%
Vehicle brakes check	64.0%	32.0%	4.0%
Autobody check	64.0%	32.0%	4.0%
Electrical system and associated accessories check	56.0%	36.0%	8.0%
Exterior paint work check	64.0%	32.0%	4.0%
Fluid level or leaks check	44.0%	52.0%	4.0%
Interior fit and finish check	56.0%	36.0%	8.0%
Exterior and interior lights check	64.0%	28.0%	8.0%
Radio and other audio player systems check	52.0%	44.0%	4.0%
Seatbelts check	52.0%	44.0%	4.0%
Tyres and wheels check	44.0%	52.0%	4.0%
Wind noise control check	20.0%	76.0%	4.0%
Steering and handling check	48.0%	48.0%	4.0%
Water leaks check	20.0%	76.0%	4.0%
Transmission and clutch check	24.0%	72.0%	4.0%

Pre-purchase or pre-test test drive	72.0%	24.0%	4.0%
Test drive	80.0%	20.0%	0.0%

The enquiries that yielded the findings in Table 4.17 were premised by the assertion that consumers of automobile products determine the measures for quality of service through their evaluation or feedback.

Table 4.18 depicts the research participants of consumers' identified quality performance dimensions that influence their decision to buy or lease an automobile product. The dominant dimensions are the organisation's reputation (92%), driving performance of the automobile product (92%) and economical vehicular system in terms of energy consumption rate (80%).

Table 4.18: Research participants of consumers' quality performance dimensions

Quality performance dimensions from research participants' perspective	Yes	No
Manufacturer's reputation	92.0%	8.0%
Dealership reputation	28.0%	72.0%
Automobile aesthetics or design	48.0%	52.0%
Driving performance	92.0%	8.0%
Energy consumption rate	80.0%	20.0%
Use of biodiesel	8.0%	92.0%
Solar-powered	4.0%	96.0%
Electric-powered	24.0%	76.0%
Hybrid	20.0%	80.0%
Brand reputation	56.0%	44.0%
Financing options	44.0%	56.0%
Preferred model availability	32.0%	68.0%
User-friendly	56.0%	44.0%
Environmentally-friendly	36.0%	64.0%

As part of determining the metrics of quality performance through the lens of the research participants of the consumer cohort, the latter were asked to describe the level of the satisfaction they derived at the automobile dealership at the time of purchasing or leasing an automobile. Their responses are captured in Table 4.19. The results show that

1. *Interaction with automobile salesperson or service provider (88% accumulated satisfaction)*
2. *The way the automobile or service was delivered (88% accumulated satisfaction)* and

3. *The overall purchase or lease experience at the automobile dealership (80% accumulated satisfaction)*

are among the majority of the research participants' top four selection of the metrics for satisfaction. Of particular interest to this study is what the research participants also considered as one of top dimensions of good quality of service performance labelled as *post-deliverance experience* (84% accumulated satisfaction; statistical mean of 5.67 shown in Table 4.20) otherwise known also as "after sales service/support".

Table 4.19: Level of cohorts' satisfaction at auto dealership

	Very dissatisfied	Dissatisfied	Somewhat dissatisfied	Somewhat satisfied	Satisfied	Very satisfied	Accumulated Satisfaction	Neutral / Unknown
Interaction	4.0%	4.0%	0.0%	32.0%	52.0%	4.0%	88.0%	4.0%
Service	0.0%	4.0%	0.0%	24.0%	60.0%	4.0%	88.0%	4.0%
Overall purchase or lease experience	0.0%	4.0%	4.0%	20.0%	52.0%	8.0%	80.0%	8.0%
Test drive experience	4.0%	0.0%	0.0%	12.0%	44.0%	20.0%	76.0%	12.0%
Post deliverance experience	0.0%	0.0%	0.0%	20.0%	52.0%	12.0%	84.0%	12.0%
Overall satisfaction with purchase or lease	4.0%	4.0%	0.0%	24.0%	44.0%	8.0%	76.0%	12.0%

Table 4.20: Statistical means featuring quality dimensions via the lens of consumers

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Interaction regarding dealership factor	25	1.00	7.00	5.28	1.30767
Service regarding dealership factor	24	2.00	7.00	5.54	.97709
Overall purchase or lease experience regarding dealership factor	24	2.00	7.00	5.42	1.17646
Test drive experience regarding dealership factor	23	1.00	7.00	5.61	1.37309
Post-deliverance experience regarding dealership factor	24	4.00	7.00	5.67	.86811
Overall satisfaction with purchase or lease regarding dealership factor	24	1.00	7.00	5.21	1.41357

Translating quality-of-service quality dimensions into functional needs

Of particular relevance to this research is the research participants' 48% accumulated disagreement that a manufacturing compliance with the automotive quality standards did influence their decision to either purchase or lease an automobile product or service. With the majority being influenced by the professional way the auto dealership handled their order, the level of interaction they had at the auto dealership, the comfort or friendly atmosphere they were accorded at the dealership, the amount of information they had access to, and other similar factors played a major role in their decision-making and served as a derivative of satisfaction of the degree of quality performance. This follows that if automobile manufacturing organisations pride themselves of being standard compliant and rely solely on the brand reputation they derive from being simply standards compliant, then they are likely to experience compromised quality performance in various facets of quality dimensions. The above findings indicate that irrespective of being standards compliants, automotive manufacturing organisations and their affiliated/associated auto dealership must maximise customercare towards the consumer, including post-delivery or after-sales customer support.

The research participants of consumers also suggested that companies that shared information about their quality status fare well in business. Due to competitiveness, a number of automotive manufacturing organisations may be tempted to withhold certain quality issues from the public domain. Such excludes the customer's voice or observation and can lead to creating an unsatisfied customer, whose behaviour can change with time. A customer develops a different mindset and such can propagate in a disrupted supply or value chain, if the customer leans towards a competitor. It holds true that if a customer falls in love with an automobile product, they are also interested in seeing the manufacturer acknowledge an obvious quality issue and share information with the clientelebase on how the issue is being addressed. In Table 4.16, the cohort of consumers overwhelmingly (92%) suggested that automotive manufacturing organisations that share information on their quality standard status and those that provided adequate information about themselves (80%) perform much better business-wise. Within the context of this research, the above are metrics of quality performance, without which automotive organisations depreciate in their delivery expectation. Within this space, another dimension of quality performance consumers look to access information about automobile products and services is those that are internet-based compared to those that are mainly through printed matter and the like. As per Table 4.16, organisations that maximise search engine optimisation (SEO) inform consumers' (84% according to cohort of consumers regarding

Google search and 72% Internet search) decision-making compared to 92% that responded *No* to *Printed Magazines and Documents* as medium of information dissemination.

Within the context of this research, a core functional need as derived from the responses of the cohort of consumers is to enable automotive organisations to develop an in-house indigenous knowledge system (IKS) that is designed to exceed both the requirements or procedures of the ISO-based QMS families. Such IKS-based quality system can be developed based on expertise knowledge and available information in the public domain. It is a core foundation of this research to develop a quality system that stimulates quality knowledge development based on automotive organisations' expertise knowledge rather than adopt procedures that had been developed remotely. The following functional needs are mapped against the most relevant findings for this research:

1. $FR_{1.1.6}$ – achieve in-house indigenous knowledge system (IKS)-based quality system
2. $FR_{1.1.1}$ – a need to achieve high-level core quality competent engineers and staff
3. $FR_{1.1.3}$ – a need to create a process map for identifying lapses in QMS-based standardised procedures, will enable organisations to design solutions to fill such gaps, thereby exceeding the standards with IKS
4. $FR_{1.2.6}$ – a need to design a continuous quality performance monitoring scheme will enable organisations to capture any changes in customer behaviours towards automobile products or services and create mitigation solutions along the way
5. $FR_{1.3.5}$ – a need to design a sustainably optimal customer-centric quality of service delivery
6. $FR_{2.10.2}$ – design a scheme for reporting observed human adversarial behaviours towards quality design. This can also empower customers to report adversarial behaviours they observe at the auto dealership and post-delivery or after-sales support, if they are considered important external stakeholders
7. $FR_{2.10.3}$ – a need for a risk assessment procedure to identify and eliminate personnel apathetical behaviours

The above functional needs, coded as FRs, are further treated in Chapter 6 at the integration stage.

4.2.4 Continuous monitoring

The context of this research considers the structure of automotive manufacturing organisations' *Continuous Monitoring* scheme as a determinant of the degree of quality performance. As established by the research participants' responses in the questionnaire related to quality-of-service, it can be inferred that the cohort of consumers focused on *sustainable satisfaction*. The latter is evidenced by the highly selected choice of post-delivery service experience (84%), for example. As such, this research positions the *voice of the consumer (VOC)* within the constituents of continuous monitoring schemes. The other relevant dimensions that concern organisations' external stakeholders (consumers, suppliers) include risk assessment, process efficiency and effectiveness, and standard operating procedures (SOP).

Risk assessment

The worldview of this research asserts that the automotive manufacturing sector is constantly confronted with critical risks across the product manufacturing, service and supply chains. Strategic management of critical risks (such as supply chain uncertainties, material failures, personnel sudden departures, manufacturing process disruptions, natural disasters such as related to geomorphologic-related, unexpected disease outbreak or pandemic protocols, economic turbulence, civil unrest, etc.) are key early identifiers for assessment of potential threats to automotive manufacturing organisations' business operations and marketshare.

As established earlier in Chapter 3, one of the core basis for this research is to identify the potential adversarial behaviours of social (human) actors that vary organisation's quality performance goals. Within this stance, the cohort of experts were asked risk assessment related questions that were embedded in the dominant theme as human adversarial attitudes. These questions with respective responses from the cohort of experts are presented in Fig. 4.8a to Fig. 4.8f.

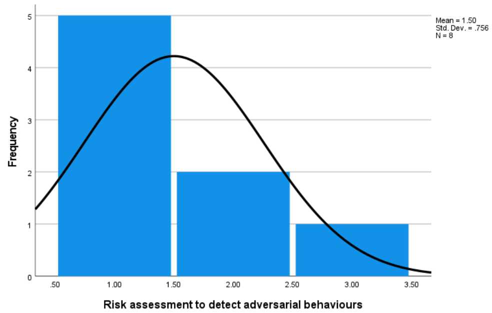


Fig. 4.8a: Does the company conduct Risk Assessment to detect or identify specific staff or personnel adversarial or counter-productive behaviours against the management goals?

Yes: 62.5%

No: 25%

Don’t know / Prefer not to answer: 12.5%

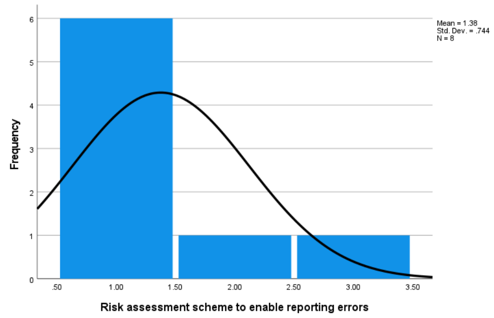


Fig. 4.8b: Does the company have a Risk Assessment scheme that encourages personnel to report any quality-based mistakes they make along the manufacturing operations chain?

Yes: 75%

No: 12.5%

Don’t know / Prefer not to answer: 12.5%

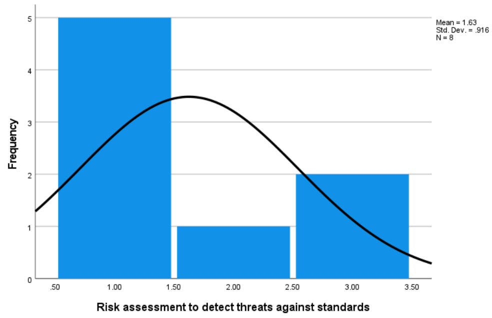


Fig. 4.8c: Does the company conduct a Risk Assessment to detect threats within the company that is potentially against regulatory standards authorities' requirements?

Yes: 62.5%

No: 12.5%

Don’t know / Prefer not to answer: 25%

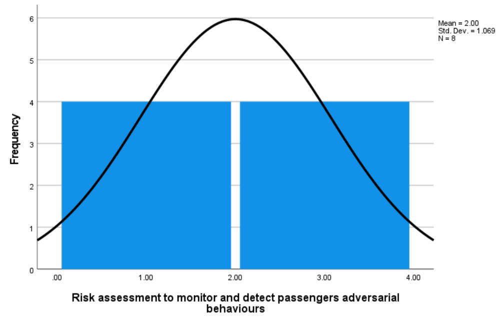


Fig. 4.8d: Does the company conduct a Risk Assessment to monitor and detect specific adversarial behaviours of automobile passengers or drivers or users of their automotive products?

Adversarial behaviour may be defined in this context as any human behaviour that is likely to cause a damage to the intended functional quality of the company’s product in use. An example is deliberately replacing an original part with a non-compliant secondhand part.

Yes: 50%

No: 0%

Don’t know / Prefer not to answer: 12.5%

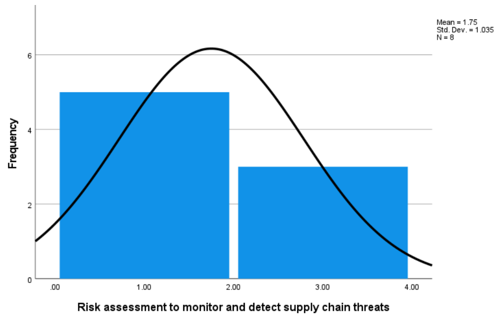


Fig. 4.8e: Does the company have a Risk Assessment scheme to monitor and detect specific potential threats against the smooth operation of the product supply (distribution or delivery) chain?

Yes: 62.5%

No: 0%

Don't know / Prefer not to answer: 37.5%

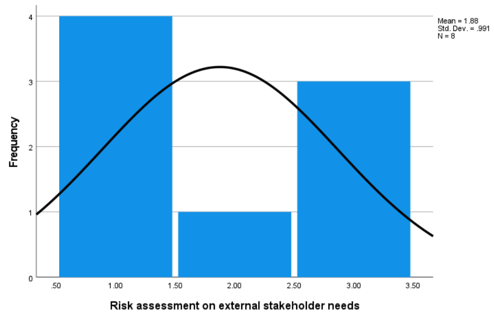


Fig. 4.8f: Does the company conduct a Risk Assessment based on external stakeholder needs? An external stakeholder includes Original Equipment Manufacturer (OEM), investors, owner, etc.

Yes: 50%

No: 12.5%

Don't know / Prefer not to answer: 37.5%

With respect to whether their organisations conduct risk assessments to help extract data on staff/personnel's adversarial or counterproductive behaviours against management goals, 25% of the research participants of the expert cohort answered *No*, while a 12.5% either preferred not to answer or have no information as to whether the automotive manufacturing organisations they work for have such a practice within their operations (see Fig. 4.8a).

While a third of the cohort of experts indicated that their organisations have a risk assessment programme to stimulate self-reporting based on human errors towards quality processes, a quarter were split between *No* and *Don't know or Prefer not to answer* (see Fig. 4.8b). Fig. 4.8c – 4.8f capture the experts' responses (in %) with respect to the other associated questions.

Derived functional needs oriented on risk assessment-based findings

Based on the above human behaviour-oriented quality indicator findings, the following functional needs are mapped out as ideal to mitigate against social (human) actor-induced quality performance variants:

1. Create risk assessment scheme to identify human adversarial behaviours within the quality-of-service units (coded $FR_{1.3.5}$)
2. Enable a scheme for reporting observed human adversarial behaviours towards quality design ($FR_{2.10.2}$)

3. Create risk assessment procedure to eliminate personnel apathetical behaviours ($FR_{2.10.3}$)

Standard Operating Procedures (SOP)

As pertaining to Standard Operating Procedures (SOP) guide for manufacturing operations or processes, 87.5% accumulated of the experts indicated their firms do have SOP documentation while the rest (12.5%) responded as to not having a SOP. On a seven-point Likert scale defined over 1 (Very Ineffective) and 7 (Very Effective), the research participants' responses as to how they rank their organisations' SOP are shown in Table 4.21 below.

Table 4.21: Research participants' rank their companies' SOP

Very Inefficient/Ineffective	0%
Inefficient/Ineffective	0%
Somewhat Inefficient/Ineffective	12.5%
Somewhat Efficient/Effective	12.5%
Efficient/Effective	37.5%
Very Efficient/Effective	12.5%
Accumulated Efficient/Effective	62.5%
Neutral/unknown	25%

Although a majority of the cohort of experts (62.5% accumulated agreement) ranked their firms' SOP as effective, this research draws attention to the 12.5% segment of the experts who relegated their organisations' SOP to *ineffectiveness* and the 25% cohort who chose to be either neutral to ranking their firms' SOP or are simply not in the know as to whether a SOP documentation exists in their employ.

The research participants of experts were also asked as to whether their organisations use any special software or tool to develop their SOP. A majority (75%) indicated that their firms use either a special software or tool to develop their SOP, while a 12.5% of the experts' organisations do not and the other 12.5% did not respond to the enquiry.

Derived functional needs based on SOP-related quality problem findings

Based on the findings within this segment, automotive manufacturing organisations that do not inculcate a culture of developing and adhering to SOP documentation that are designed for each departmental or unit's operations are susceptible to functional gaps in their quality performance delivery. The functional operations within automotive manufacturing departments are time-dependent in that as the demand patterns change with time, departments or units are expected to coevolve with those requirements by designing or optimising existing quality implementation methodologies. A regularly updated SOP, if implemented, can enable process optimisation with time, otherwise organisations can face compromised quality performance delivery issues as the demand patterns change in the future. To mitigate against the lapses in SOP, the following functional needs are derived:

1. Develop SOP for departmental or unit processes (coded $FR_{1.1.12}$)
2. Create procedures for conducting internal audit process, internal audit report generation and countermeasures (coded $FR_{1.1.10}$)
3. Produce QX Task Force and Top Management protocol for review of internal audit report (coded $FR_{1.1.11}$)
4. Provide procedure to enable consistency of conforming with regulatory and standards requirements (coded $FR_{2.15.2}$)

Process monitoring

This research situates *Process Monitoring* as an important tool required to effectively monitor various departmental activities and manufacturing processes in order to expose any lapses that potentially create variants of quality performance and to make room for corrective measures that translate into enhancing process efficiency. On this premise, the cohort of experts were asked:

> *Does your company have a dedicated Process Monitoring Team that monitors the various departmental processes and activities to ensure any identified quality-related issues are promptly identified and adequately addressed?*

With respect to the above enquiry, 62.5% of the research participants indicated the automotive organisations they work for have a Process Monitor Team, while 25% answered they do not have (Fig. 4.9). The experts were also asked as to whether their organisations…

> *…use a special software or tool for monitoring departmental activities and manufacturing processes from design to supply chain management or delivery channels*

of which 50% responded their use of a special software or tool to monitor departmental activities and 25% presented that they do not have anything of the kind or preferred not to respond to the question.

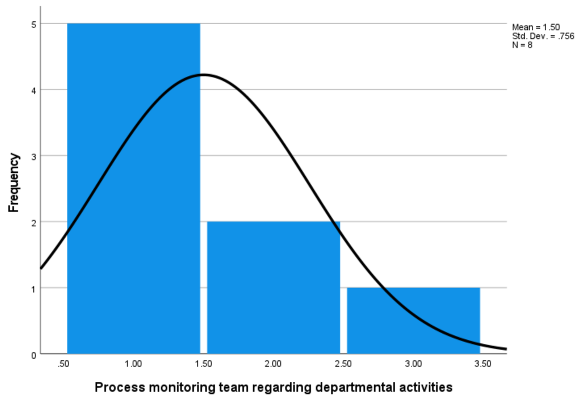


Fig. 4.9: Experts' responses to question related to Process Monitoring Team

Process efficiency and effectiveness

This study considers the cohort of experts' experiential insights into automotive manufacturing organisations' process efficiency and effectiveness as a metric for quality performance. As such, the experts were asked to rank the levels, on a Likert scale of 1 (Very Inefficient/Ineffective) to 7 (Very Efficient/Effective), of their firms' process efficiency and effectiveness in relation to the quality performance dimensions listed in Table 4.22.

Table 4.22: Statements related to process efficiency and effectiveness (peff_)

Statement	Code
The company's manufacturing process efficiency and effectiveness has enabled reduced manufacturing costs	peff_costs
The company's manufacturing process efficiency and effectiveness has enabled increased customer retention	peff_custrtn
The company's manufacturing process efficiency and effectiveness has enabled return on investment (ROI)	peff_roi
The company's manufacturing process efficiency and effectiveness has enabled increased market share	peff_mktshare
The company's manufacturing process efficiency and effectiveness has given the company a competitive edge	peff_compedge
The company's manufacturing process efficiency and effectiveness has enabled growth in sales	peff_sales
The company's manufacturing process efficiency and effectiveness has improved its brand reputation	peff_brand
The company's manufacturing process efficiency and effectiveness has increased customer satisfaction	peff_custsat
The company's manufacturing process efficiency and effectiveness has enabled effective supply chain and logistics management system	peff_sclo
The company's manufacturing process efficiency and effectiveness has enabled an improved overall business performance	peff_busperf

The cohort of experts' responses as presented in Table 4.23 shows that over 60% accumulated agreement suggested a success rate in the process efficiency and effectiveness in relation to each manufacturing sector within their organisations. However, this research draws attention rather to the actual entries for *somewhat efficient/effective, efficient/effective* and *very efficient/effective* in each case. For instance, although peff_costs and peff_custsat each had an accumulated 87.5% and a majority of the other units scored 75% accumulated efficient/effectiveness, all the units scored 12.5% each for *Very Efficient/Effective*. The same was true for all the units but peff_sales, which scored a ranking of 25% for *Very Efficient/Effective*. In comparison with *Somewhat Efficient/Effective*, all the units scored relatively high with peff_custsat as the highest with 62.5% and the majority of the rest at 25%. While these findings add credibility to the significance of this research not relying on statistical generalisation as an accumulated 87.5%, for example, will have otherwise misconstrued as a good degree of *Efficient/Effective* of a unit, this research translates the significant high rankings of the *Somewhat Efficient/Effective* response (min. 25% and max. 62.5%) for each unit into a functional need that cohort of experts' organisations must address in order to prevent any inevitable associated quality performance lapses.

Table 4.23: Experts' rating their firms' process efficiency and effectiveness

	peff_costs	peff_custrtn	peff_roi	peff_mktshare	peff_compedge
Very Inefficient/Ineffective	0%	0%	0%	0%	0%
Inefficient/Ineffective	0%	0%	0%	0%	0%
Somewhat Inefficient/Ineffective	0%	12.5%	12.5%	12.5%	0%
Somewhat Efficient/Effective	25%	37.5%	37.5%	37.5%	37.5%
Efficient/Effective	50%	25%	25%	25%	25%
Very Efficient/Effective	12.5%%	12.5%	12.5%	12.5%	12.5%
Accumulated Efficient/Effective	87.5%	75%	75%	75%	75%
Neutral/unknown	0%	0%	0%	0%	12.5%
	peff_sales	peff_brand	peff_ custsat	peff_sclo	peff_busperf
Very inefficient/Ineffective	0%	0%	0%	0%	0%
Inefficient/Ineffective	0%	12.5%	0%	0%	0%
Somewhat Inefficient/Ineffective	0%	0%	0%	0%	0%
Somewhat Efficient/Effective	37.5%	50%	62.5%	50%	25%
Efficient/Effective	12.5%	12.5%	12.5%	0%	37.5%
Very Efficient/Effective	25%	12.5%	12.5%	12.5%	12.5%
Accumulated Efficient/Effective	75%	75%	87.5%	62.5%	75%
Neutral/unknown	12.5%	0%	0%	25%	12.5%

Likert scale: 1 (Very Inefficient/Ineffective), 2 (Inefficient/Ineffective), 3 (Somewhat Inefficient/Ineffective), 4 (Neutral/Unknown), 5 (Somewhat Efficient/Effective), 6 (Efficient/Effective), 7 (Very Efficient/Effective)

Whether the companies of the research participants *have an effective coordination between the various manufacturing departments during the design stage to ensure efficient and effective manufacturing process*, 62.5% of the experts answered that their organisations have effective coordination between the departments during the design stage, while 12.5% indicated that such does not happen in their organisation.

Another element of interest to this research is whether automotive manufacturing organisations use a special software or tool to optimise the company's manufacturing *Process Efficiency and Effectiveness*. Only 37% of the experts indicated that the automotive manufacturing organisations they work for use a special software or tool (model, framework, etc.) to improve their process efficiencies/effectiveness. With respect to *who is responsible for ensuring the company achieve optimal process efficiency and effectiveness*, the experts' responses are shown in Table 4.24 below.

Table 4.24: Experts' responses regarding process efficiency and effectiveness

	Yes	**No**
Top Management	62.5%	25%
Engineering Design Team	25%	62.5%
Task Force	0%	87.5%
Internal/Vehicle Auditor	0%	87.5%
Quality Manager/Director	37.5%	50%
Project Manager	25%	62.5%
Human Resource Manager/Director	12.5%	75%
Purchasing/Procurement and Supply Chain Leader	12.5%	75%
Owners or Owner/Representative	12.5%	75%
Software Engineer	0%	87.5%
Risk Analysis	0%	87.5%
Manufacturing Engineering Lead	25%	62.5%
IT Infrastructure Lead	0%	87.5%
Business Process Engineer	0%	87.5%
Production Manager	25%	62.5%
Shopfloor Supervisor	0%	87.5%
Facility Maintenance Lead	0%	87.5%
Line Manager	0%	87.5%%

Based on the findings related to *Process Efficiency & Effectiveness* and *Process Monitoring*, the following functional needs are identified:

1. A need to develop SOP for departmental or unit process (coded $FR_{1.1.12}$)

2. Develop a master process or scheme to respond to personnel bad attitudes towards quality design targets (coded $FR_{1.3.4}$)
3. Achieve QX buy-in across all departments or units (coded $FR_{2.1.4}$)
4. Optimise design to identify and eliminate non-value added (NVA) activities (coded $FR_{2.3}$)
5. Design a process monitoring scheme (coded $FR_{2.4.5}$)
6. A scheme for early detection of potential product safety defect (coded $FR_{2.17.2}$)
7. A QX Engineering-based procedure for documentation (coded $FR_{1.1.13}$)
8. A reward system to encourage recurrent training in quality skillset across all departments or units (coded $FR_{1.1.7}$)
9. Create a QX Task Force protocol for internal auto recall process monitoring ($FR_{2.17.5}$)

The above FRs are further treated in Chapter 6 for integration.

Voice of consumer (VOC)

Apart from the human factor towards quality performance delivery as situated within the context of this research, another domain of interest is the quality desires or expectations of the automobile product or service consumer. Of relevance to mapping out identifiable parameters of the continuous monitoring dimensions of quality performance, the cohort of consumers in this research were asked the following open-ended questions:

$Q_{quality\_product}$: In your opinion, what do you think is the most important quality for an automobile product (vehicle, part) to have?

$Q_{quality\_expect}$: In your opinion, what do you think is the core quality performance dimension or parameter most consumers expect from automotive organisations?

Q_{vary_causes}: From your perception, what do you think are some of the underlying factors that vary (i.e. cause changes in) the quality performance of automotive organisations?

Q_{future_change}: If you could change one thing about your vehicle, what would that be?

Based on the responses the research participants of consumer cohort provided, themes were generated from the frequency of their preferential quality performance dimensions. The qualitative data the cohort of consumers provided were purposely not quantified into numeric data as required for inferential statistical analysis to inform concluding remarks. However, attention was directed at the most frequently occurring quality-based keywords or keyword phrase. Themes were then generated out of the frequently occurring quality dimensions or indicators to create the respective mindmaps as shown in $Q_{quality\_product}$-based Fig. 4.10, $Q_{quality\_expect}$-based Fig. 4.11, Q_{vary_causes}-based Fig. 4.12 and Q_{future_change}-based Fig. 4.13.

Fig. 4.10: Mindmap for experts' responses to $Q_{quality\_product}$

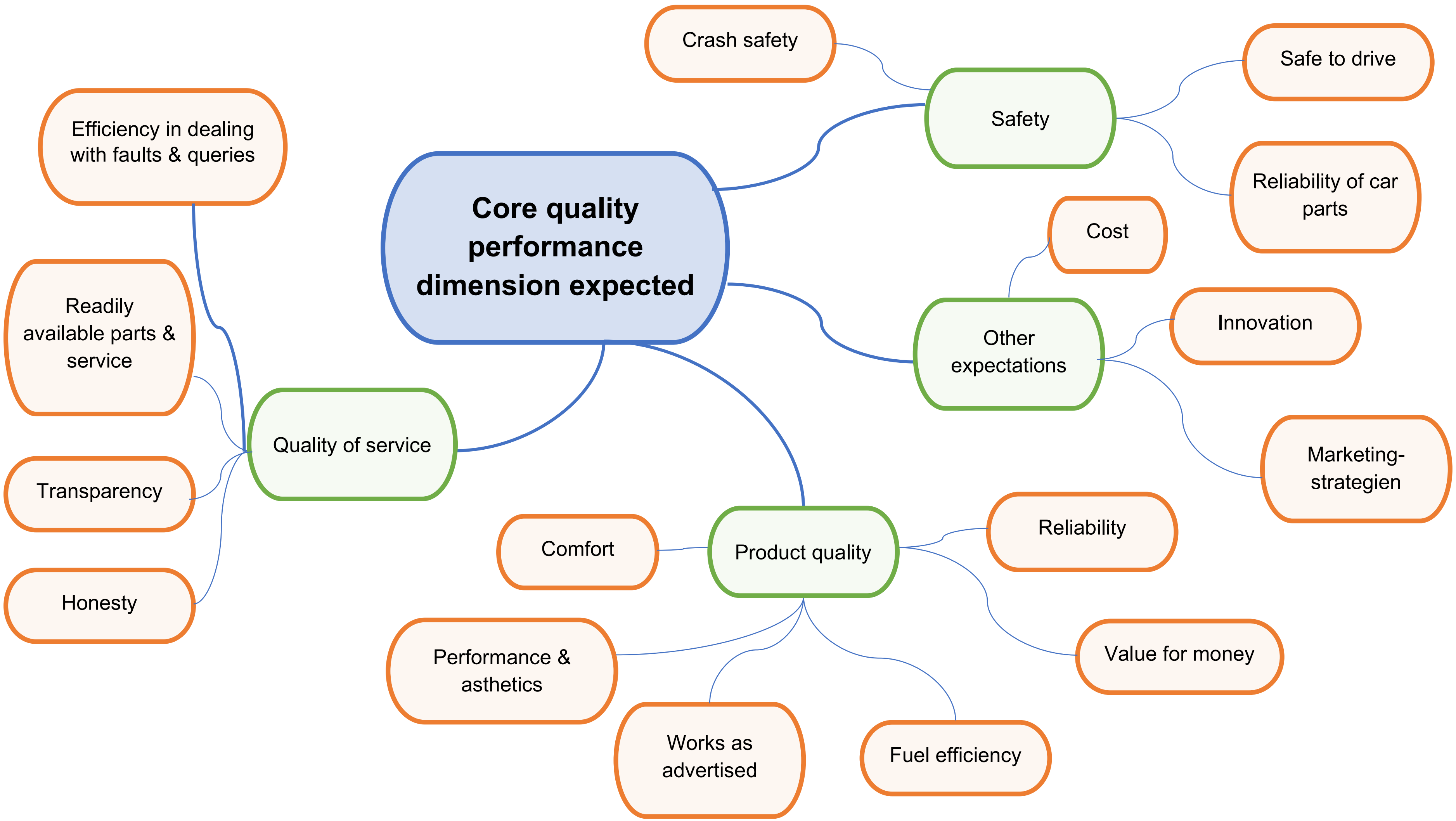


Fig. 4.11: Mindmap for experts' responses to $Q_{quality\_expect}$

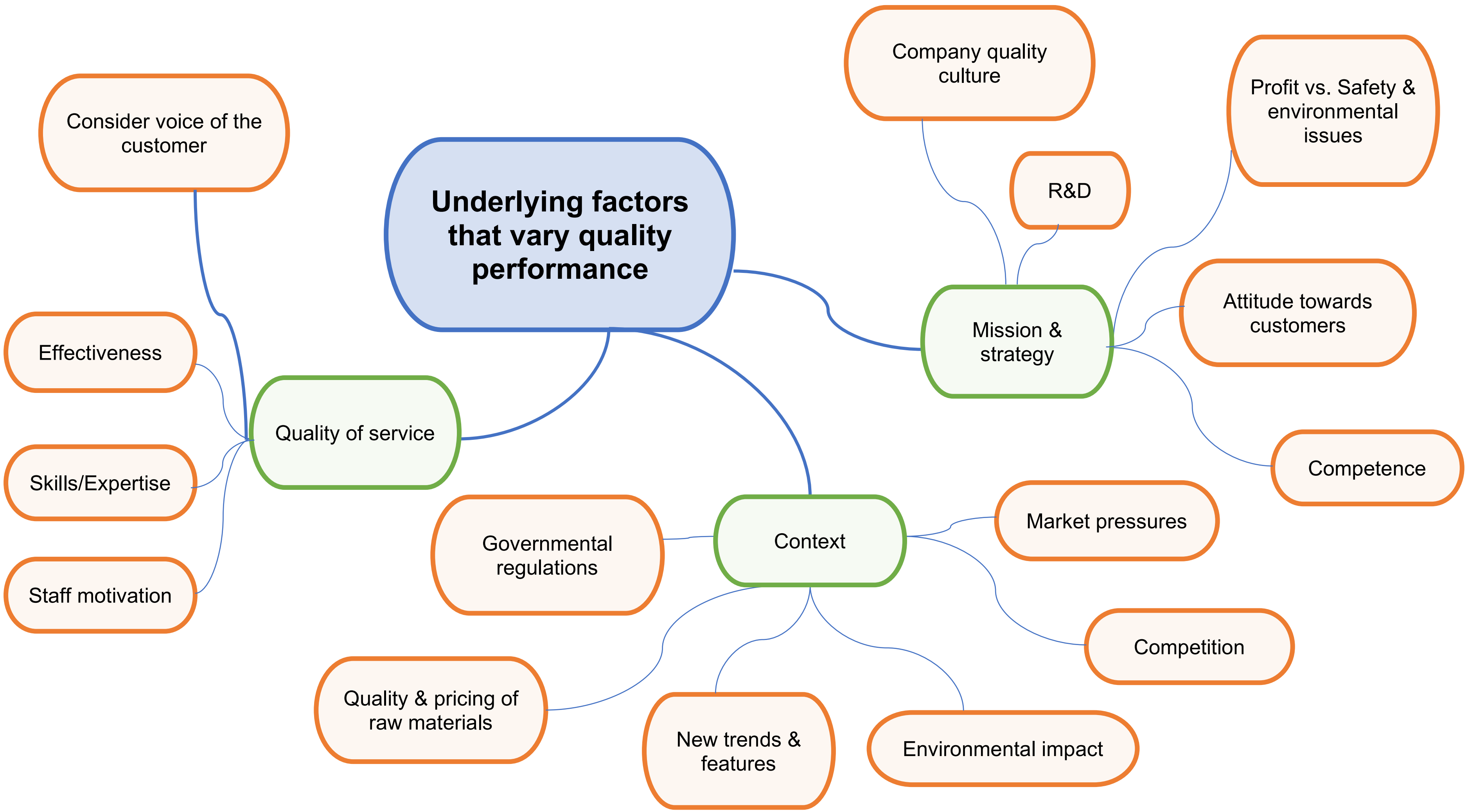


Fig. 4.12: Mindmap for experts' responses to Q_{vary_causes}

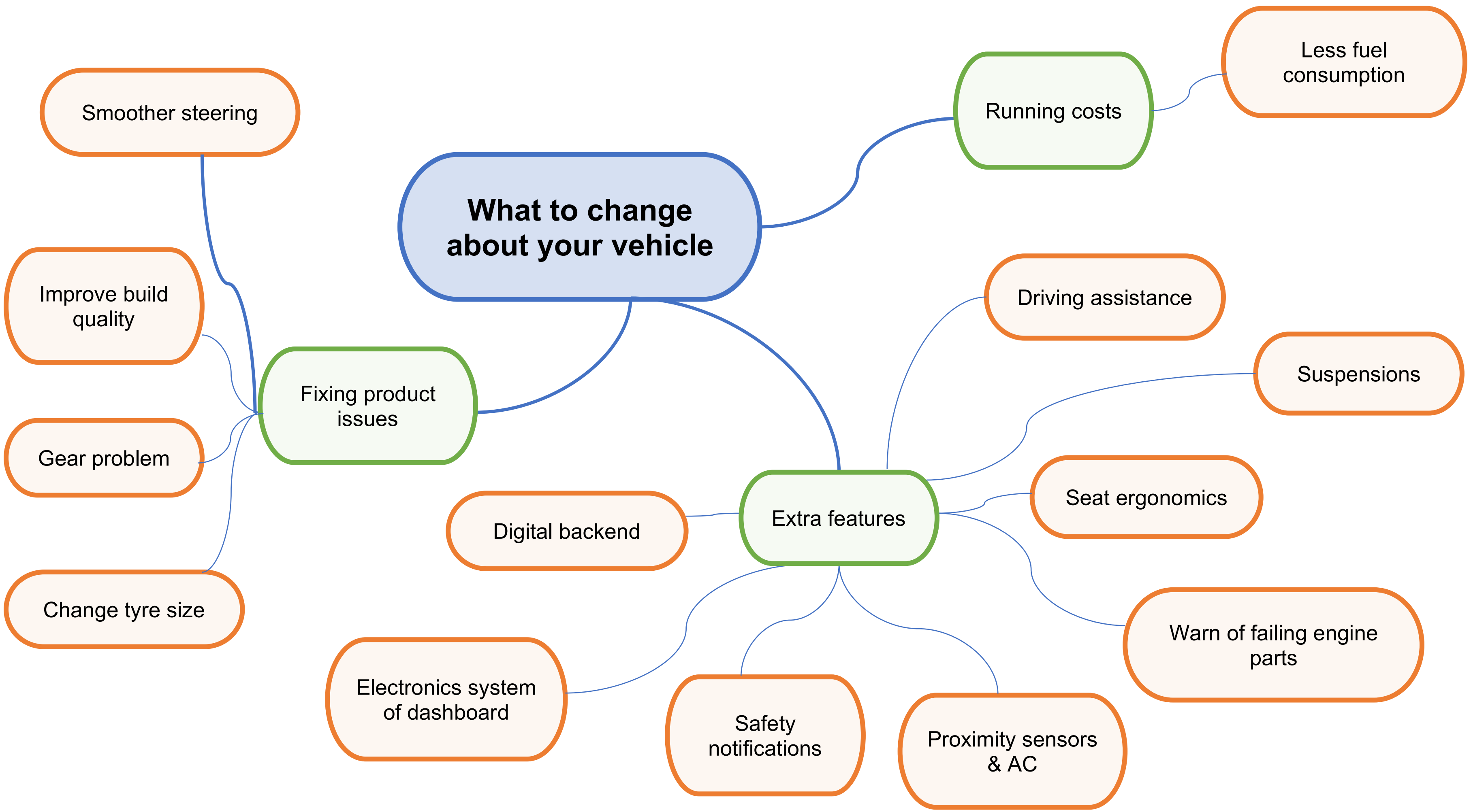


Fig. 4.13: Mindmap for experts' responses to Q_{future_change}

Translating VOC-based findings into functional needs

The research participants' responses to the four questions above provide insights into their perception of what constitutes as key quality performance indicators, without which the latter is compromised. Based on the VOC as provided by the research participants, the following functional needs are derived:

1. Derive sustainably optimised customer-centric quality of service delivery (coded $FR_{1.3.6}$) – this will require a design parameter that optimises auto dealership operations, such as ensuring the dealership carries out an exhaustive checklist to guide checking all functional parts of the automobile product including the themes featured in the mindmaps in Fig. 4.10 and Fig. 4.11
2. Risk assessment scheme to identify human adversarial behaviours within the quality-of-service delivery (coded $FR_{1.3.5}$), continuous quality performance monitoring system (coded $FR_{1.2.6}$) and develop system to mitigate quality performance disruptions presented by emerging technologies ($FR_{2.18}$) – addressing these time-dependent functional requirements will essentially produce design parameters that are mapped against the agents of quality performance variation. $FR_{2.18}$ is particularly focused on time-dependent changing requirements such as enhanced systems for safety notifications, proximity sensors, fuel economy, and other smart-based vehicular systems.

Continuous Improvement (CI)

Integral to the context of this research is a need for automotive manufacturing organisations to inculcate a quality culture of implementing a *Continuous Improvement (CI)* scheme. Relevant to RQ1, the research participants were asked to describe their organisations' Top Management priorities with respect to their *continuous improvement* process. On a Likert scale of 1 (Strongly Disagree) to 7 (Strongly Agree), the experts' responses to the strings of questions as regards their Top Management priorities are presented in Table 4.25.

Table 4.25: Experts' responses with regard to Top Management priorities

Top Management regarding	Strongly Disagree	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Strongly Agree	Accumulated Agreement	Neutral / Unknown
standard set of CI objectives	0.0%	12.5%	12.5%	25.0%	25.0%	25.0%	75%	0.0%
feedback-based corrective measures for CI	0.0%	0.0%	12.5%	12.5%	12.5%	37.5%	62.5%	25.0%

examined risk-based corrective measures for CI	0.0%	12.5%	12.5%	0.0%	37.5%	25.0%	62.5%	12.5%
market research-based corrective measures for CI	0.0%	0.0%	12.5%	37.5%	0.0%	37.5%	75%	12.5%
input-based corrective measures for CI	0.0%	0.0%	37.5%	12.5%	37.5%	12.5%	62.5%	0.0%
auditor-based CI	0.0%	0.0%	0.0%	25.0%	12.5%	12.5%	50%	0.0%
CI-driven performance	0.0%	0.0%	12.5%	12.5%	0.0%	12.5%	25%	12.5%
training-driven CI	0.0%	12.5%	12.5%	0.0%	0.0%	12.5%	12.5%	12.5%
addressing non-conformance issues for CI	0.0%	12.5%	12.5%	12.5%	0.0%	12.5%	25%	0.0%
monitoring NVA for CI	0.0%	0.0%	14.3%	85.7%	0.0%	0.0%	85.7%	0.0%
review of quality policy to enable CI	0.0%	0.0%	37.5%	0.0%	50.0%	12.5%	62.5%	0.0%
standardised training for CI	12.5%	0.0%	12.5%	0.0%	37.5%	12.5%	50%	25.0%
skillset rewards for CI	0.0%	12.5%	12.5%	25.0%	37.5%	0.0%	62.5%	12.5%
Tracking root cause of disruption	0.0%	12.5%	0.0%	37.5%	37.5%	12.5%	87.5%	0.0%
Standard procedure to address disruptions at any operational level	0.0%	12.5%	12.5%	12.5%	50.0%	12.5%	75%	0.0%
Documenting disruptions for corrective measures regarding CI	0.0%	12.5%	12.5%	12.5%	37.5%	12.5%	62.5%	12.5%

Likert scale: 1 (Strongly Disagree), 2 (Disagree), 3 (Somewhat Disagree), 4 (Neutral or Unknown), 5 (Somewhat Agree), 6 (Agree), 7 (Strongly Agree)

As seen in Table 4.25, the objective of this research is to draw attention to the significance of the disgreements in response to the *Continuous Improvement (CI)* dimensions or themes. This is because drawing a conclusion solely based on the higher statistical frequency of occurrence or total accumulated agreement of one quality dimension to determine its degree of goodness can potentially mask the need to address other aspects of compromised quality dimensions. As the core objective of this research is to design a new quality framework, attention is given to every facet of metrics of quality indicators. Within the context of this research, the implications of these disagreement responses are presented within the respective occurrence in Fig. 4.14a to Fig. 4.14j.

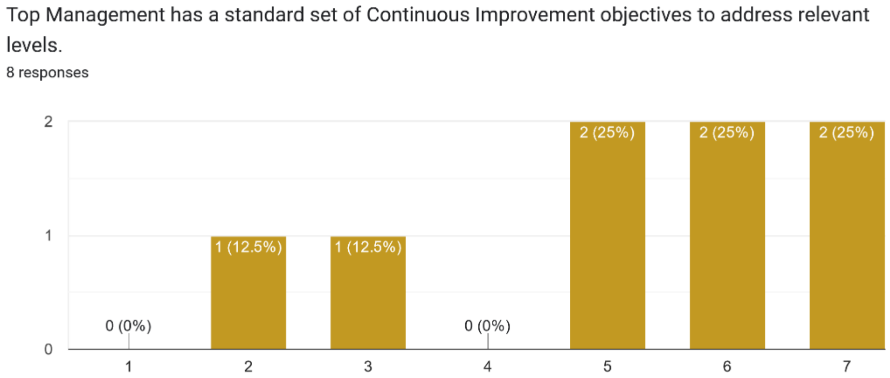


Fig. 4.14a: Experts' responses regarding standard set of CI objectives

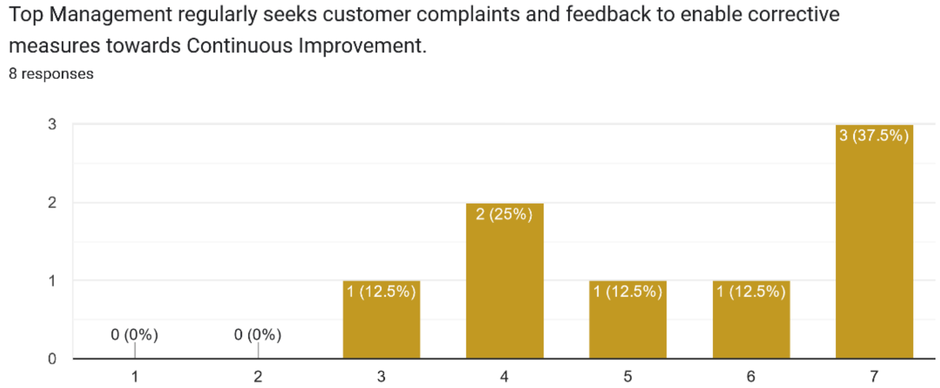


Fig. 4.14b: Experts' responses regarding feedback-based countermeasures

The research participants' 25% accumulated disagreement implied their organisations do not have a CI scheme to address quality issues at the relevant levels. Without a guided standard, quality issues that emerge at various units or departmental levels can go undetected and as such escalate due to missing countermeasures. Automotive organisations within such category are susceptible to ineffective delivery of quality performance due to a compromised or missing continuous improvement scheme. In the context of this research, the above situation is translated into a functional need defined as follows:

1. Continuous quality performance monitoring (coded $FR_{1.2.6}$)

Although 62.5% accumulated agreement shows that the experts' organisations encourage VOC as an added scheme to developing countermeasures towards CI, the significance of the 12.5% that disagrees with the above statement follows that their organisation's CI process, if any, will be void of VOC such as those depicted in Fig. 5.10 to Fig. 5.13. Translating this aspect into a functional need leads to:

1. Design internal and external stakeholder feedback to determine gaps in quality of service and automobile product families (coded $FR_{1.1.3}$)

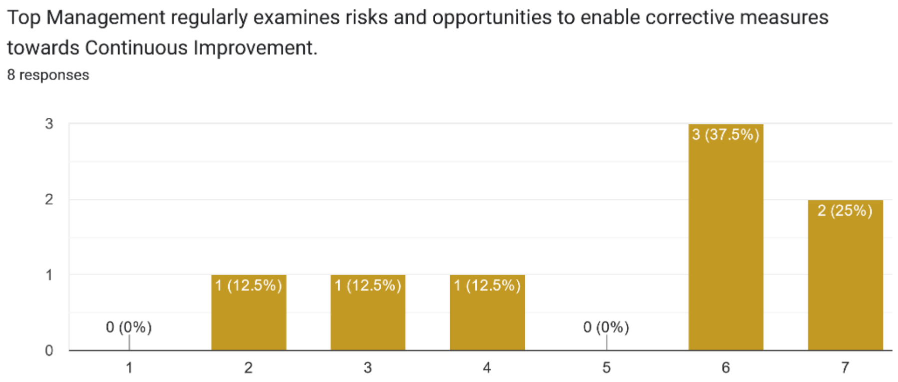


Fig. 4.14c: Experts' responses on examined risk-based countermeasures

In this segment, 25% accumulated disagreement with the above statement by the cohort of experts is indicative of their organisations designing countermeasures against other quality performance issues but devoid of unknown latent risks. This leads to a functional need defined as follows:

1. Risk assessment scheme to identify human adversarial attitudes against quality performance (coded $FR_{1.3.5}$)
2. Risk assessment procedure against personnel apathetical behaviours ($FR_{2.10.3}$)
3. Determine risk factors against quality design process (coded $FR_{2.13.1}$)

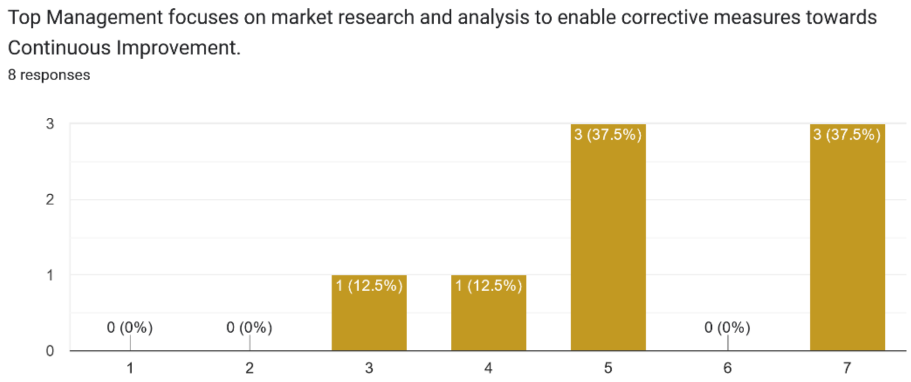


Fig. 4.14d: Experts' responses on market research-based countermeasures

12.5% of the research participants *somewhat disagree* that their organisations' Top Management focuses on market research and associated analysis in order to factor the findings in the corrective measures they design to mitigate any quality performance issues. Without enabling an information flow from the consumer market and automotive regulatory policy objectives, organisations in such category can experience depreciated quality performance in the value chain. This proposes a need to *determine a scope of environmental and local automotive regulatory policy objectives (coded $FR_{1.3.2}$)* as a functional need.

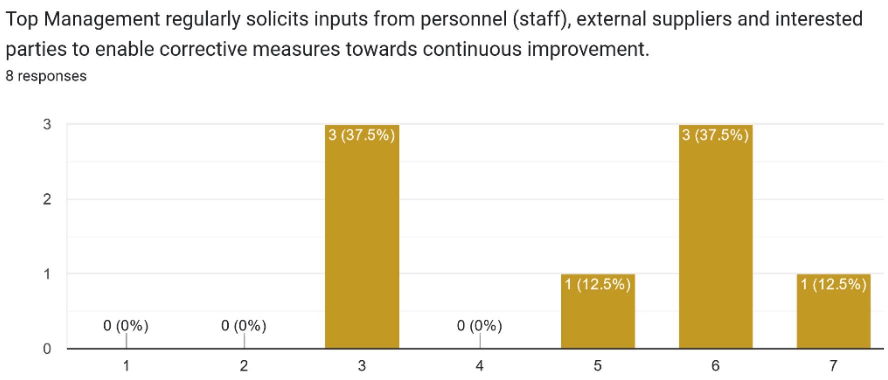


Fig. 4.14e: Experts' responses regarding input-based corrective measures

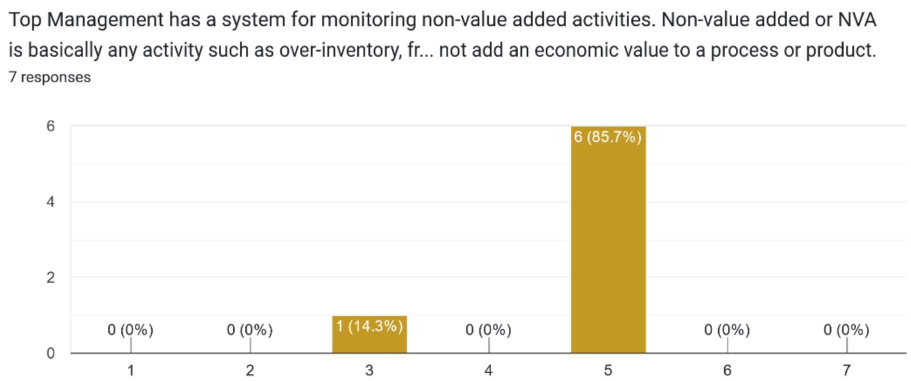


Fig. 4.14f: Experts' response regarding monitoring NVA activities

37.5% of the research participants responded that their organisations do not seek input from internal and external stakeholders in order to develop countermeasures against quality variants along the continuous improvement chain. This can potentially result in creating mitigation solutions that can be devoid of significant indigenous knowledge from personnel or input from OEMs, auto dealerships, etc. As such a gap can compromise an organisation's quality performance, a functional requirement such as $FR_{1.1.6}$, as defined earlier, can seek a design of IKS-based quality standard and implementation procedures that mandatorily solicit contributory input parameters from both internal and external stakeholders (including OEMs, customers, etc.)

14.3% of the cohort of experts indicated that the Top Management within their organisations do not have a system for monitoring non-value added (NVA) activities. As established earlier in Chapter 3 towards the initial design of QX Engineering Framework, NVAs are collectively a waste that can dampen the quality performance process. Without a mechanism to monitor NVA activities, quality wastes such as over inventory, excessive movements, over-production, unnoticed product defects, quality process variation, etc., an organisation within such scenario will experience poor quality performance and financial losses. A mitigation solution is to address the functional needs:

1. Identify and eliminate production-based NVAs (coded $FR_{2.3}$)

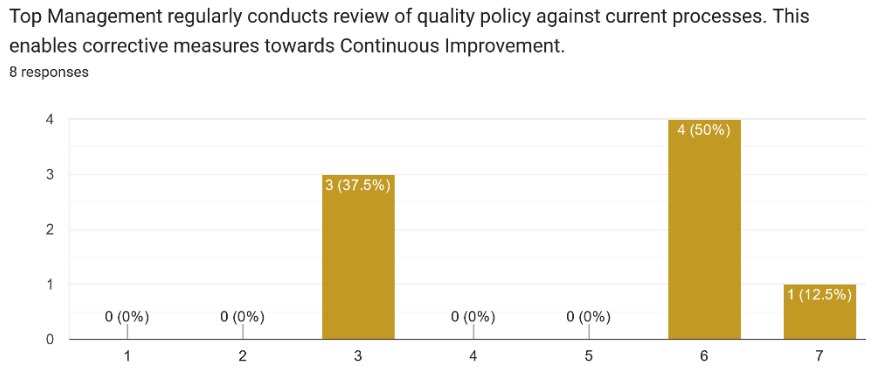


Fig. 4.14g: Experts' responses regarding review of quality policy

As seen in this response, 37.5% of the cohort of experts indicated that the Top Management within their organisations do not regularly review quality policy mapped against current processes. This will consequentially create gaps in any countermeasures required to optimise CI processes, leading to poor quality performance with time. With respect to the context of this research, the functional needs are derived:

1. Documentation on procedure to enable consistency of conforming with regulatory and standards requirements ($FR_{2.15.2}$) will yield a production of subject-related SOP based

2. Eliminate NVA movements of human and material resources (coded $FR_{2.6}$)

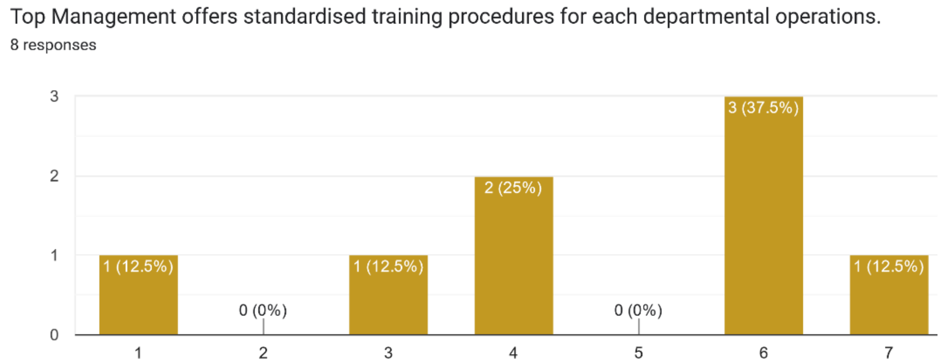


Fig. 4.14h: Experts' responses regarding departmental training procedures

With 25% of the experts' accumulated disagreement with the above statement at their organisations, which is in principle a recipe for compromised quality performance delivery, earlier defined functional needs across $FR_{1.1}$ and associated sub-$FR_{1.1s}$ will address the quality competency skills gaps created by the lack of standardised training procedures at the departmental levels.

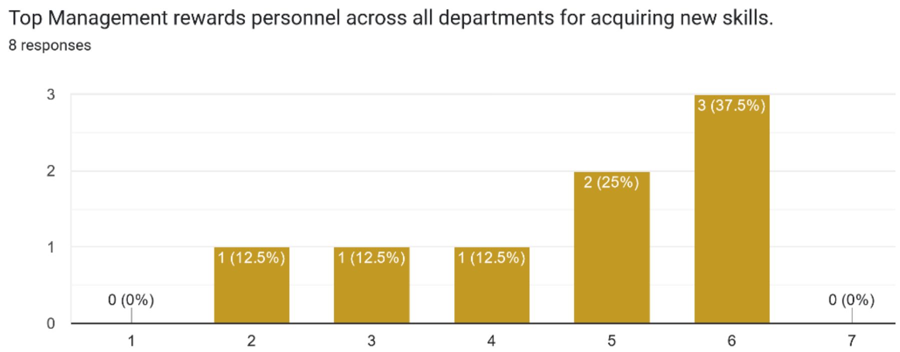


Fig. 4.14i: Experts' responses regarding stimulants for personnel

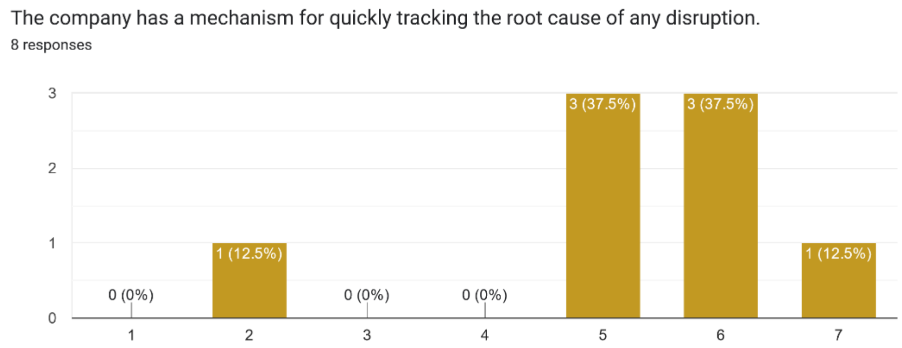


Fig. 4.14j: Experts' responses regarding tracing disruption

As regards whether the Top Management within their organisations do provide rewards or stimulants to encourage acquisition of new skillset, 25% of the cohort of experts responded that no stimulants are offered to staff for acquiring new knowledge. *Creating a reward system to encourage recurrent training in quality skillset across all departments or units (coded* $FR_{1.1.7}$*)*, is considered by this study as a functional need that if not addressed via appropriate design parameters can potentially dent organisations' quality performance delivery. Staying recurrent across the core quality skills set can serve as a quality valued added to the organisation as required for designing mitigating solutions against quality performance variants.

12.5% of the research participants' responded that their companies do not have any mechanism as such. The context of this research posits that without the ability to track root causes of disruptions, quality performance can be compromised to a large extent. This is because untraceable cause of disruption can propagate largely with time, creating a myriad of unresolved quality issues with the consequences of adversely affecting the quality performance index with time. Situated within this research, a functional need in relation to risk assessment is derived from this scenario as a need to design a *system for determining agents of risks to the design process (coded* $FR_{2.13.1}$*)* and *risk assessment scheme to identify adversarial activities (coded* $FR_{1.3.5}$*)*.

With respect to core activities that are a part of common practices for ensuring *Continuous Improvement* at their firms, the research participants responded as respresented in Table 4.26. The results show 50% of the experts indicated that the personnel at their organisations are encouraged to learn the quality and corporate responsibility policy. The same scale of agreement applies to the institution of in-house training schemes that help staff to gain understanding into the quality objectives and how to contribute towards achieving them through related practices. While the majority of the research participants (62.5%) responded that their organisations have effective internal audit regularly and a 62.5% also indicated that it is common practice for individuals to share ideas and feedback, it is worth noting that a majority of the experts responded that personnel are not mandated to report any non-conformity activities within any department.

Table 4.26: Experts' responses to core CI-related activities

	Yes	No	Don't know or Prefer not to answer	Missing Data
Quality and corporate responsibility policy regarding CI	50.0%	25.0%	12.5%	12.5%
In-house training schemes regarding CI	50.0%	25.0%	12.5%	12.5%
Reported departmental non-conformance activities regarding CI	12.5%	62.5%	12.5%	12.5%
Shared ideas and feedback regarding CI	62.5%	12.5%	12.5%	12.5%
Departmental participation regarding CI	25.0%	50.0%	12.5%	12.5%
Documented quality process implementation plan regarding CI	37.5%	37.5%	12.5%	12.5%
Internal auditing regarding CI	62.5%	12.5%	12.5%	12.5%

In order to gain an insight into whether the cohort of experts' companies do employ any means for monitoring their manufacturing processes from design to supply or delivery, majority (62.5%) of the research participants answered *Yes* to using a special software or tool while a 12.5% answered they do not use any tool for monitoring their manufacturing processes. Table 4.27 depicts the full responses.

Table 4.27: Experts' on using a special software or tool for monitoring all manufacturing processes

Software regarding process monitoring related to CI

	N	%
Yes	5	62.5%
No	1	12.5%
Don't know or Prefer not to answer	1	12.5%
Missing Data	1	12.5%

Of particular significance to this research context is that, in automotive manufacturing organisations where there is no system to enable personnel to report any non-conformity activities, such organisations are susceptible to varying quality performance. This is based on the premise that hidden non-conformity behaviours, otherwise known as adversarial behaviours, can propogate along the quality performance value chain and go undetected or untrackable over a long period of time. This research proposes a mitigation solution against nonconformities ($FR_{2.15}$). The FRs defined within this segment are further treated in Chapter 6.

4.2.5 Quality performance variants: emerging technologies focused

Within the context of this research, *Emerging Technologies* are viewed as the uncertainties in the demand pattern that is expected to challenge or disrupt the existing and or conventional operations or processes of automotive manufacturing organisations. It is based on the function of uncertainties and changing demand patterns that position *emerging technologies* as time-dependent functional requirements. This assertion challenges automotive manufacturing organisations to be highly responsive in order to cope with the uncertainties. However, in order to be highly responsive and have the capacity to cope with the uncertainties in manufacturing requirements, manufacturing systems must co-evolve with the changing environment. Organisations seen as outside the domain of digital technology, for example, may be pressured to either respond to the changing requirements organically like complex adaptive systems in order to coevolve with the dynamics of the changes or risk pseudo-extinction due to the associated disruptions. This study posits that emerging technologies such as automobile connectivity (also known as connected automobile), hybrid automobile, auto sharing, driverless automobile and digitised automobile present multifaceted risk factors that potentially vary the automobile manufacturing organisations' goal to deliver good degree of quality performance.

As this research considers automobile product and services consumers to be the drivers of the demand patterns that dictate the dynamics of the manufacturing environment, this segment of the study asked cohort of consumers to describe how they think emerging and digital technologies can potentially vary or disrupt the quality performance of automotive manufacturing organisations. On a Likert scale of 1 (Strongly disagree) to 7 (Strongly agree), the consumers' responses to the statements presented earlier in Table 4.3 are depicted in Table 4.28 and 4.29 (descriptive statistics).

Table 4.28: Research participants' responses to key emerging technologies quality dimensions

Emerging technologies causes to quality performance	Accumulated agreement	Accumulated disagreement	Neutral/Unknown
Disruption	40%	32%	28%
Threat	68%	16%	16%
Sales decline	56%	20%	24%
Rapid wear and tear	72%	12%	16%
Forced transition	84%	4%	12%
Increased complexity	72%	16%	12%
Capital-intensive software	100%	0	0
Software-hardware coupling	68%	24%%	8%
Software virus risk	84%	8%	8%
Adversarial behaviours	76%	12%	12%

Table 4.29: Statistical mean of each statement based on experts' responses

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Disruption of quality performance regarding emerging technologies	25	1.00	7.00	4.28	1.97
Threat to quality performance regarding emerging technologies	25	1.00	7.00	4.76	1.61
Decline of sales regarding emerging technologies	25	1.00	7.00	4.44	1.58
Exposure to wear and tear regarding emerging technologies	25	1.00	7.00	5.20	1.53
Transition regarding emerging technologies	25	3.00	7.00	5.96	1.17
Manufacturing complexity regarding emerging technologies	25	1.00	7.00	4.88	1.54
Incorporation of advanced smart software regarding emerging technologies	25	5.00	7.00	6.20	.76
Coupling software and hardware regarding emerging technologies	25	1.00	7.00	4.84	1.75
Virus hit or hacked software regarding emerging technologies	25	1.00	7.00	5.72	1.70

Unpredictive human drivers' behaviour regarding emerging technologies	25	1.00	7.00	5.36	1.47

The vast majority of the research participants in the consumer cohort (100% accumulated agreement, validated by the standard deviation of 0.76 clustering around the mean 6.20 in Table 4.29), believe that it is essential that automotive manufacturing companies in the field incorporate extensively advanced capital-intensive smart software that will address safety concerns. For example, the failure of the driverless Tesla 2019 Model S to yield to an approaching curve violated the quality performance of an expected negotiation around a bend (see Fig. 4.2). This resulted in a fatal accident that killed the two passengers (Kolodny, 2021) and brought to scrutiny the promise of the capability of the Full Self-Driving (FSD) software.

A significant number of the research participants of the cohort of consumers (84% accumulated agreement) think that Driverless Automobile (also known as Autonomous Vehicle) is steadily becoming mainstream and will present pressures that will induce variations in quality performance over time. Part of the threat to the existing quality performance of conventional automotive manufacturing organisations are engrained in the unpredictive behaviours of human drivers' ability to act in adversarial manner that break traffic regulations. While digital automakers expend at the high end to create the vehicle of the future within the emerging technologies domain, social (human) actors' adversarial attitudes can expose driverless automobile products to motor accidents. Such a scenario can expose digital automakers claim of creating digitally smart vehicles that have advanced predictive software to sense and avoid motor accidents to scrutiny by both the public and automotive regulatory bodies. Where the complexity to ascertain who is in the right may linger on, the human victim and public opinion may split between rating of the quality performance index of digital automakers. As such, unless a mitigation solution is proposed, the unpredictive misbehaviour of human beings towards new technologies can potentially vary quality performance of digital automakers. To cite a few cases of human adversarial behaviours (76% accumulated agreement) that can potentially lead to grave accidents, permanent injuries, fatal incidents and or devastating consequences:

1. In an undated YouTube video, a Hollywood A-List actor Jamie F can be seen physically taking his hands off the steering wheel for a few seconds to demonstrate that the Tesla Model 3 he was driving had the capability to self-drive (source: https://www.youtube.com/watch?v=tB15Da2TRWw). As a personality with over 800,000 subscribers on his YouTube channel, his influence in such promotional video

can easily mislead others into believing that the FSD software has the full capability to enable a driverless vehicle. Within the context of this research, such a human action constitutes an adversarial behaviour. This is because taking the hands off the steering wheel is a violation and a misuse of the Autopilot feature. Although Elon Musk has denounced such violations, he does not rebuke high-profile violators (The Drive, 2021).

2. In another scenario, The Drive (2021) reported that a teenager and his mother made a video in which the teenage boy feigned sleep at the steering wheel of a Tesla. He then retires to the backseat to stimulate taking a nap while the vehicle self-drove. In the context of this research, such an irresponsible stunt or unpredictive human behaviour potentially varies the Autopilot's operating instructions that drivers should not take their hands and eyes off the steering wheel. Fig. 4.15 and Fig. 4.16 show apathetical human behaviours that vary the quality performance of automotive manufacturing organisations within the digital domain.

Fig. 4.15: Screenshot of teenager violating the autopilot's safety instruction (The Drive, 2021)

Fig. 4.16: Teenager, filmed by his mother, pretending to sleep in the backseat while vehicle self drives, presumably (The Drive, 2021)

3. The caption in Fig. 4.3, which highlights the Tesla Autopilot crash that killed three people (TechCrunch, 2022), illustrates the fatalities associated with social (human) actors' unpredictive and adversarial attitudes that from time to time vary quality performance indices.

In reference to the findings in Table 4.28, it is imperative to state that the cohort of consumers believe that the overreliance on artificial intelligence for enhanced digital applications to enable automobile manufacturing organisations to cope with the demand patterns within the emerging technologies' sector will threaten (76% accumulated agreement) or vary quality performance based on the following accumulated agreements:

1. Exposure of automobile system software to *virus attacks* (84%)
2. Excessive use of an expectedly increased number of shared vehicles in 2030 will expose the latter to *rapid wear and tear* (72%)
3. Electric vehicles generate large amounts of data over time (72%), resulting in increased manufacturing complexity. This requires for optimisation of manufacturing process and business models, otherwise variation in existing quality performance will propagate. An excessive increment in the information content (data) will result in low probability of success in addressing the *manufacturing complexity* over a period of time. A complex system may be defined as *any system that features a large number of interacting*

components (FRs) whose aggregate activity is not derivable from the summations of the activity of individual entities and typically exhibits hierarchical self-organisation under selective pressures (Suh, 2005; Swarz et al., 2006). El-Haik (2005), Flowers & Cheng (2008) and Hintersteiner & Zimmerman (2000) infer that the functional requirements under such scenario will supersede the design parameters, forcing the manufacturing system to depart from its quality performance delivery goal. According to axiomatic design (as established earlier in Chapter 3), it is undesirable for FRs to supersede the corresponding DPs. Thus, under such time-dependent FR where there is information increment with time, the DPs cannot satisfy the FRs.

4. Automobile Connectivity can disrupt quality performance of automotive manufacturing firms due to external pressures (or threats) to optimise their existing business models (40%). This is because the slightest variation in quality can result in a serious reputation damage control, such as a variation in one quality issue resulted in a recall of millions of vehicles (recall Chapter 2 on *Auto recalls*).
5. 56% believe that quality performance of sales of non-Automobile Sharing companies will decline. This may be due to the fact that the growing demand for auto sharing in the urban areas can, for example, translate into scenarios such as 20 people who share one vehicle in turns will not have the established need to individually own an automobile.
6. As agreed by 68% of the research participants, consumers' experimental or experiential interest in Driverless Automobile or Autonomous Vehicle will pose an adverse challenge to automotive manufacturer's quality performance as the demand patterns will dictate a need to couple software and hardware at the manufacturing process modeling stage. Such predicted coupling of software and hardware can pressure automotive manufacturing organisations to vary in their key quality performance indicators.
7. An 84% of the research participants of consumers believe that the growing demand for electric- and solar-powered or hybrid automobiles will place enormous pressures on automotive manufacturers of diesel-powered internal combustion engine-driven automobiles. Such pressures can potentially vary the quality performance of non-digital automotive manufacturing organisations if they do not have evolvable systems to enable them cope with the dynamics of the changing environment.

Translating emerging technologies-based quality performance variants to functional needs

In the context of improving consumer satisfaction, product conformance to specification and beyond, process model refinement for both process components and interrelationships between complex systems, and deriving a general consensus on a robust approach to confronting the core quality performance issues, manufacturing organisations must ideally reorganise in order to become transformative, adaptive systems and *evolvable* to satisfy the constantly changing environment as determined by time-dependent functional needs of emerging technologies.

Evolvable manufacturing systems may be described in terms of those systems that proceed or yield not under the sole direction of centralised designed protocols but adaptive in response to uncertainties (Frei et al., 2007), adaptable in the face of complexity, and extendable to produce ideal solutions to address constantly changing manufacturing FRs and constraints. These may be expected to improve exponentially with time. This follows that, unless conventional automotive manufacturing processes are reprogrammed or augmented to cope with the constantly changing or ever-increasing demand patterns (i.e. increasing FRs), there will be lapses in the delivery of quality performance with time. It is worth noting that the more the FRs increase, the more the manufacturing environment changes with a consequential effect of increased manufacturing complexity (Hasselblatt & Katok, 2003).

Thus, developing systems to automatically design and optimise or model complex manufacturing phenomena without being explicitly reprogrammed can lead to increased system responsiveness to optimised system agility, reconfigurability (Wiendahl et al., 2007) and versatility, and thereby increasing competitiveness. It is within this scope and the context of this research that findings in Table 4.28 are translated into functional needs and coded in terms of FR-notation. The latter is presented in the right hand column of the matrix below (see Table 4.30). In mapping the functional needs against the findings, this research purposely assigns them to FR_2 as the study considers them as cost-associated components, whose processes must be achieved cost-effectively. Some of the financial implications or cost indices associated with the desire to satisfy the plausible corresponding DPs, are based on the following but not to be construed as an exhaustive list:

1. Exhaustive list of objectives of automotive manufacturing organisation expressed as functional requirements to mitigate against quality performance variants as *external threats* (including disruption by auto connectivity, human adversarial behaviours, forced transition), *software pressures* (including demand for smart software, hardware-software coupling, uncertain virus attacks), *auto-sharing* (including sales decline due

to market pressures, increased wear and tear) and *carbon-neutral pressures* (due to ever-increasing demands for environmentally-friendly, zero-carbon emission automobile products, manufacturing complexity due to ever-increasing data produced by electric automobiles)

2. Identification of predicted indices of customer satisfaction
3. Predicting as well as collecting data on customer definitions of quality performance
4. Predetermine customer satisfaction needs through high volume survey (including associated research costs)
5. Map out manufacturing systems for improved efficiencies in the mitigation solution
6. Engage high-end digital solutions to interface with existing manufacturing system
7. Upgrade existing manufacturing infrastructure to cope with digitalised automotive manufacturing emerging unpredictive future
8. Project financial implications for contingencies against uncertain design failures, rework, rejects, disrupted operations, inadequate competent human resources, outsourcing manufacturing, etc
9. Mapping out the objectives for satisfying the requirements of automotive standard authorities
10. Applied selected quality systems such as lean management to reduce cost-based waste
11. Overall supply chain and logistics requirements
12. Etc.

This is to enable identification of mitigation solutions or design parameters mapped against each statement. These are further treated in Chapter 6.

Table 4.30: Derived functional needs based on quality challenges oriented on emerging technologies-based statements

Problem Statement	Functional Needs
Consumer demand for Automobile Connectivity (i.e. Connected Automobile / Vehicles) and Automobile Automation can disrupt the quality performance of an automotive manufacturer due to the need to change their existing business models in order to satisfy digital-oriented requirements. New and well-established digital technology companies in the field of Automobile Connectivity (i.e. Connected Automobile/Vehicle) and Automation will threaten the quality performance of existing (traditional) automotive organisations that are yet to make the transition to incorporate digital technology.	*Merge* Develop survival mechanism against disruption posed by Connected Automobile *and* Develop mitigation solution against **threat** posed by Connected Automobile *into* Develop survival and mitigation solution against disruptions posed by Connected Automobile (coded $FR_{2.18.1}$)
The new trend of Automobile Sharing (i.e. Shared Cars, Shared Rides or Shared Mobility), particularly in highly populated urban settings, will stimulate a decline of private automobile sales.	Develop business strategies against threats to market share posed by Automobile Sharing (coded $FR_{2.18.2}$)
As Automobile Sharing is expected to grow by 2030, there is a high likelihood that a large number of the shared vehicles will be exposed to rapid wear and tear due to excessive use.	Develop manufacturing strategies against rapid wear and tear due to predicted growth of Automobile Sharing in 2030 (coded $FR_{2.18.3}$)
The growing demand for Electric or Solar-powered or Hybrid automobiles will place enormous pressure on manufacturers of diesel-powered internal combustion engine driven automobiles, forcing them to make a transition in order to survive the competition.	Develop mitigation solution against unprepared forced transition pressures presented by growing demand for hybrid-powered automobiles (coded $FR_{2.18.4}$)
Electric automobiles generate a huge amount of data during the course of driving them. While manufacturers can analyse this data to help optimise their manufacturing process and business models, this is likely to increase manufacturing complexity due to such continuous data collection.	Develop manufacturing system to address increased manufacturing complexity due to continuous generation of data (coded $FR_{2.18.5}$)
As Driverless Automobile (also known as Autonomous Vehicle) is steadily pushing its way into becoming mainstream, automotive manufacturers in the field are expected to incorporate extensively advanced smart software that will address safety concerns.	Develop alternative solution to address capital-intensive software regarding safety concerns due to Driverless Automobile (coded $FR_{2.18.6}$)

Consumer's interest in experiencing a Driverless Automobile (also known as Autonomous Vehicle) demands automotive manufacturers to couple software with hardware. Coupling software and hardware in the manufacturing process model may pose challenges to a manufacturer's quality performance.	Develop alternative solution to software-hardware coupling due to consumer's uncertain demand patterns in the use of Driverless Automobile (coded $FR_{2.18.7}$)
In the event that the software of a digitised automobile is struck with a computer virus or hacked, this can potentially alter the functionality of a driverless vehicle. Such a scenario can compromise the safety of passengers, pedestrians and or other motorists as a virus hit or hacked software could take an autonomous or driverless automobile off its course, for example.	Develop mitigation solution against software virus risk due to computer virus attack or hack (coded $FR_{2.18.8}$)
A Driverless Automobile is practically a vehicular robot that will have to cope with the unpredictive behaviours of human drivers' ability to break traffic regulations. This is a safety concern that indicates that Autonomous or Driverless Automobiles may be prone to motor accidents.	Develop a system for identifiers of social (human) adversarial behaviours against safety concern (coded $FR_{2.18.9}$)

4.3 Summary

In this Chapter, the survey data as related to Study 1 was screened with SPSS. The findings were presented and discussed. Through the perception of the research participants of experts and consumers, the sources of quality performance variation causes were identified across the four main themes: management role, quality-of-service, continuous monitoring and emerging technologies. Based on the nature of the variants and the respective quality problem statements, functional needs were derived in order to guide the development of plausible corresponding design parameters required to address the functional requirements as mitigation solutions.

This component of the research also revealed a significant number of quality factors that are potentially stimulated by human adversarial behaviours or vQDDs. Overall, the underlying variables that cause automotive manufacturing organisations to vary in quality performance were outlined across the various quality dimensions as defined by the core themes. The derived functional needs which are coded as FRs are further treated in Chapter 6 at the FR-DP integration stage.

Chapter 5: Study 2 Findings — QMS-Compliant and non-Compliant Firms on Quality Value Delivery

5.1 Introduction

Chapter 5 examines which factors are responsible for less quality value deliveries. The constructs of *QMS knowledgebase*; *quality design*; *standards implementation*; and *responses to threats* are assessed with regards to organisations' quality value delivered (independent variable) and their level of departure from compliance, expectations or indices of quality requirements (dependent variables). In seeking to address

> *Why do automotive manufacturing organisations, whose primary objective is to maximise the* ***value*** *of quality-oriented* ***processes*** *and automobile* ***products,*** *deliver significantly less than those organisations that have attained quality management system (QMS) certification? (RQ2)*

the threats and barriers to quality value delivery were established from the collected quantitative (closed-ended survey) and qualitative data (open-ended interview and survey). The research strategy adopted for the data collection is detailed in Chapter 3. Whereas the consumers' responses provided information on their awareness of quality standards and which automotive manufacturers, according to their knowledge, comply with certain quality standards, the experts gave insights on the quality management system of their respective organisations. Based on the enquiries and responses, the quality management systems were assessed with regard to design and implementation stages, the level of involvement of different internal stakeholders, and their response to threats such as auto recalls. The combined responses help to answer RQ2 which can be stated in summary form as follows:

> *Do automotive manufacturing organisations that are QMS-compliant deliver quality value better than non-compliant firms?*

This Chapter, firstly, defines the generated themes as depicted in Fig. 5.1 and presents the data of both cohorts (experts and consumers). Secondly, the findings are analysed and discussed with regard to differences of quality value delivery. Reasons for these differences are drawn from the respondents' answers on the basis of the four generated themes and set into context with the findings of RQ1 and other quality management studies reviewed in Chapter 2.

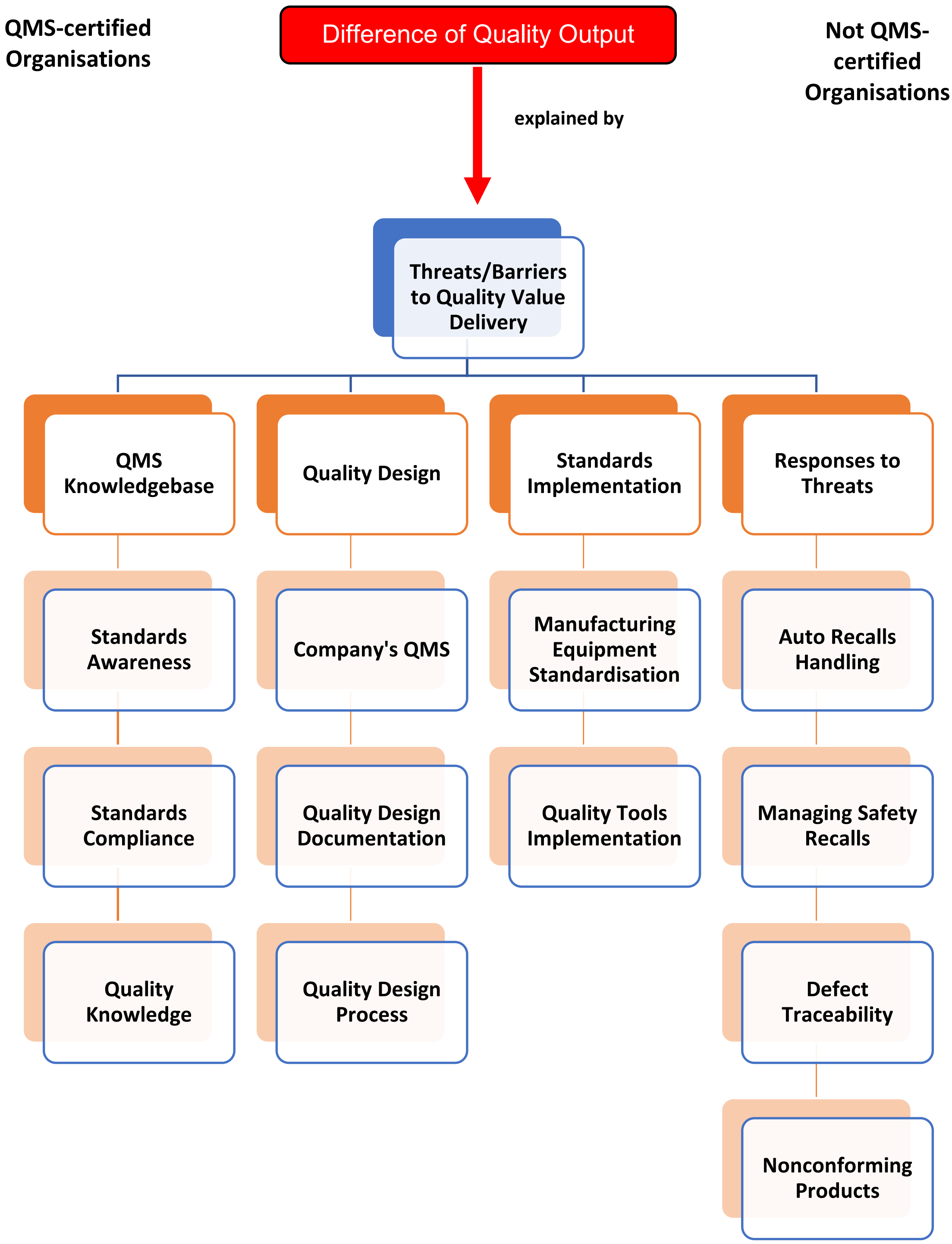


Fig. 5.1: Structure of data analysis process (Source: author)

5.1.1 Defining the themes for the investigation

The collected data from both quantitative (closed-ended) and qualitative (open-ended) survey questions provided insights into the *causes of less quality delivery* (RQ2) of automotive organisations. The findings were mapped against the IATF 16949:2016-oriented quality process value objectives defined in Table 3.4 in Chapter 3 and categorised with corresponding sub-themes as illustrated in Fig. 5.1. Themes and sub-themes that were already extensively covered in Chapter 4 are referred to in this Chapter, where relevant to answering RQ2.

Within the context of this research, where relevant, the quality problem statements embedded within the themes and defined for this Chapter's subject-matter will be viewed as functional needs. These functional needs will be coded with functional requirement notations such as $FR_{i.j.k}$ or $FR_{n.m}$. This will enable identifying plausible design parameters to address the quality statements, and result in mapping out contributory input data to optimise the initial QX Engineering.

QMS knowledgebase

Awareness and Compliance are, according to this research, defined as *standards [that] are collectively a system that defines how automotive manufacturing organisations can satisfy customer requirements and associated stakeholders' goals.* The research participants were asked to respond to questions regarding familiarity with automotive industry quality standards (cohort of consumers), compliance to automotive quality standards in general (both cohorts) and company-specific conformance (cohort of experts). The key automotive industry quality standards and their definitions that were specified in these questions were already provided in Chapter 4.

Additionally, engineering quality knowledge *is related to the integration of quality design and implementation throughout the manufacturing process, from design through to the delivery of product or service to the customer*. In this research, it includes the procedures outlined in key quality standards such as IATF 16949:2016, ISO 9001, ISO 14004, among others. Questions with regard to engineering quality knowledge covered companies' quality engineering knowledge, utilised quality methods, quality policy and involved stakeholders. The data extracted from this enquiry are presented in 5.2 for analysis.

Quality design

The theme *quality design* combines the aspects that utilise quality management system (QMS), quality design documentation and related processes. The enquiry with regard to QMS relates to *in-house developed quality management system (QMS) and personnel's practical knowledge of the relevant ISO standard procedures for the automotive sector* with regards to the elements of ISO QMS certification audit for both the organisation and personnel. Questions for the research participants of experts addressed the compliance of the company's QMS with ISO standards, the inclusion of ISO management system standards' certifications in staff development training programmes, and the internal stakeholders responsible for QMS development and training.

In order to understand the barriers to quality performance and customer satisfaction, the cohort of experts were further asked questions with regard to their companies' quality design documentation and inclusion of customer-specific requirements. Documenting the manufacturing, quality and design specification *communicates the quality design intent to ensure customer satisfaction*. It, moreover, *takes into account the key components of the intended quality delivery in a way that staff across the associated departments can clearly understand what the expectations are with respect to the company's goals*. This *enables early identification of errors, omissions and any quality compromises in the automotive manufacturing documentation and can make room for changes and or change requests*. The findings extracted from this Section are presented and analysed in Section 5.2.

Standards implementation

The quality tools implementation segment relates to *the company's core quality capabilities as found necessary in the optimisation of existing manufacturing processes*. In order to map out the barriers with regard to standards implementation, the expert professionals were asked to rate their companies' use of core quality tools to enhance manufacturing processes and personnel's skillset knowledge in the core quality tools.

Standardisation of manufacturing equipment and systems, furthermore, are *essential in supporting shopfloor staff to minimise or avoid disruption of operation or quality losses*. Using the relevant quality management system-based ISO-standards can *help in aligning in-house manufacturing equipment standardisation to be in tune with the international automotive manufacturing industry standard requirements or procedures*. In order to minimise disruptions or losses, research participants of experts were asked to rate their companies' standardisation of manufacturing equipment and name the internal stakeholder responsible for manufacturing equipment and systems standardisation. The data from this enquiry are presented in Section 5.2 for analysis.

Responses to threats

In the context of this research, *a best practice process for managing auto recalls or addressing product rejects or defects in the automotive industry can help automotive manufacturing organisations to achieve high success when conducting a safety recall or addressing product reject or defect issues*. Some of the key triggers of auto recalls had been defects in the seatbelts, air bags, electronic systems and electrical wiring (see Chapter 2 on *Auto recalls*). Auto recalls are carried out when it becomes evident that a defect is identified within the definition of safety issues that can potentially result in serious injuries or death. This enquiry sought to draw contributory data from vehicle owners or users in asking the cohort of consumers about automotive manufacturing organisations' auto recalls handling from their perspective.

Although best practice is about improving quality, it is also about *examining the existing process and reaffirming that it produces the best results as expected by the industry standard and the customer*. In order to map out the safety practice processes in the respondents' companies, the cohort of experts were asked to specify the safety systems in place in the case of arising safety issues.

This research *considers product, process, and or service defect traceability a significant element for reducing complexities associated with product recall, reject or manufacturing system/service failures*. This is often the case when automotive products are, for example, not properly registered, making it difficult to identify any faulty products through registration with the relevant regulatory bodies. Defects can also be present in manufacturing equipment or systems. In order to establish defects' handling at their companies, respondents of the expert cohort were asked to relate their companies' mechanism with regard to defects' handling, methods and system for tracing defect components or parts, and personnel responsible for managing the defects traceability process.

In essence, *a product conformance evaluation requirement applies to a product that has gone through the parts' approval process and is ready to ship to the customer*. The context of this research asserts that *a nonconforming product should not find its way into the hands of the roadside mechanic workshop, unofficial auto marketplace, or is accidentally distributed to an unsuspecting customer*. A nonconforming product is practically a product that is unusable and unrepairable. As regards *nonconforming products*, the cohort of experts were required to describe their companies' intent or standard practice and requirements for rendering nonconforming products unusable prior to final disposable. The codes generated for the statements or construct for the results are defined in Table 5.1 below.

Table 5.1: Statements as related to nonconforming products and Codes

Statement	Code
The company has developed an effective process for the identification and disposition of nonconforming products.	id_nonconf
The company uses an external firm to evaluate and render its nonconforming products unusable.	eval_nonconf

The *continuous improvement* enquiry regards *the elements that are necessary to help map out the ideal processes required to enable continual improvement of automotive manufacturing processes*. Chapter 4 in-depth analysed and discussed how the cohort of experts described their companies' management priorities with regard to *continuous improvement* processes. Apart from the other sub-themes in this Section, the sub-theme *continuous improvement* is addressed and discussed in Section 5.2, where relevant for threats and barriers to quality value delivery.

5.2 Data presentation, analysis and discussion of findings

In this Section, relevant data as related to the themes in Fig. 5.1 are presented. Whereas the themes *QMS knowledgebase* and *Responses to Threats* feature the perception of both cohorts of experts and consumers, the themes *Quality Design* and *Standards Implementation* solely rely on the descriptions and ratings of the expert professionals of their own companies' QMS.

5.2.1 QMS knowledgebase

Awareness and compliance

The cohort of consumers were asked about their *familiarity with automotive industry quality standards*. The results are displayed in Fig. 5.2 below. Whereas half of the research participants (52%) in the consumers' cohort were not familiar with any automotive industry quality standards, ISO 9001 (with a percentage of 48%) was the only quality standard all other research participants were knowledgeable of. All the other standards had lesser knowledge representation: ISO 14001 (20%), IATF 16949:2016 (16%), ISO 45001 (12%), ISO 26262 (4%) and AEC-Q100 & AEC-Q200 (4%). It is of interest which quality standards automotive organisations are compliant with, when compared with the quality standards that are general knowledge. This formed the second segment of questions.

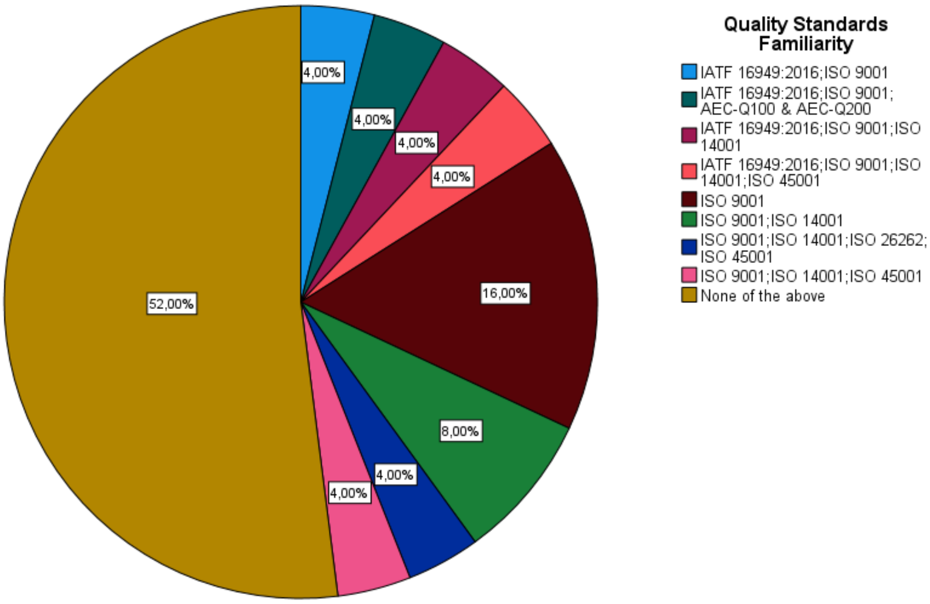


Fig. 5.2: Quality standards familiarity (consumers)

Both groups of research participants were asked to relate whether they know any automotive manufacturing firm that is compliant with specified quality standards such as ISO 9001 and IATF 16949:2016. The responses of the cohort of consumers and those of the research participants in the expert cohort are presented in Tables 5.2 and 5.3 respectively. The responses show that ISO 9001 compliant companies are common in both cases. It can also be seen that the cohort of experts in the large automotive manufacturing sector are aware of more compliant companies than the research participants in the SME domain. Tables 5.2 and 5.3 also show that the number of AEC-Q100 and AEC-Q200 compliant companies, by virtue of the research participants' collective responses, are extremely low.

Table 5.2: Cohort of consumers' responses to familiarity with compliant firms

Do you know any…	**Yes**	**No**	**Not familiar**	**Missing data**
IATF 16949:2016 compliant firm	12.0%	16.0%	68.0%	4.0%
ISO 9001 compliant firm	52.0%	16.0%	32.0%	0.0%
ISO 14001 compliant firm	20.0%	24.0%	56.0%	0.0%
ISO 26262 compliant firm	4.0%	16.0%	80.0%	0.0%
ISO 45001 compliant firm	8.0%	20.0%	72.0%	0.0%
AEC-Q100 & AEC-Q200 compliant firm	4.0%	16.0%	76.0%	4.0%

Table 5.3: Cohort of experts' responses to familiarity with compliant firms

Do you know any…			**Company size**		
			Under 251	**Over 250**	**Total**
Quality Standards Compliance	IATF 16949:2012 compliant	Count	1	5	6
	ISO 9001 compliant	Count	3	5	8
	ISO 14001 compliant	Count	1	5	6
	ISO 26262 compliant	Count	0	5	5
	ISO 45001 compliant	Count	0	4	4
	AEC-Q100 and Q200 compliant	Count	0	1	1
Total		Count	3	5	8

Asked ***which of the automotive industry quality standards does [your] company conform to***, the cohort of experts' responses in specifying their respective companies' standard conformance are depicted in Table 5.4. The results show that the large automotive manufacturing organisations (over 250 employees) the cohort of experts represent conform to the industry standards listed, including ISO 17025*. Apart from conforming to ISO 9001 and ISO 14001 standards, the research participants of experts from the SME sector responded that their organisations do not conform to any other standards.

Table 5.4: Cohort of experts' responses to their companies' conformance

Which of the following industry quality standards does your company conform to?			**Company size**		
			Under 251	**Over 250**	**Total**
Quality Standards Conformance	IATF 16949-2016	Count	0	5	5
	ISO 9001	Count	1	4	5
	ISO 14001	Count	3	5	8
	ISO 26262	Count	0	4	4
	ISO 45001	Count	0	4	4
	AEC-Q100 and Q200	Count	0	1	1
Total		Count	**3**	**5**	**8**

*Other: ISO 17025 – 1 Company over 250

As outlined in the literature review in Chapter 2, it is common knowledge among researchers (Braun et al., 2020; Horváth & Szabo, 2019; Mcmahon, 2001; Mittal et al., 2018; Smit et al., 2016) that large manufacturing organisations often demonstrate high-level goal-setting manufacturing spirit to gain a competitive edge, which translate into stimulating a need to widen the scope of their operations in comparison to the seemingly narrowed approach most SMEs take. As shown in Table 5.3, the research participants representing large organisations

(>250 employees) responded to knowing more companies that are quality standard compliant than the cohort in the SME domain do. This follows that the former may be more aware of their competitors and the competitiveness the changing manufacturing environment presents than those within the SME sector. AEC-Q100 and AEC-Q200, for example, are a couple of the dedicated automotive standards. As depicted in Table 5.3, not a single research participant from the SME sector indicated any knowledge or awareness about this integral element of quality standard. These, among other lapses, lead to the deduction that organisations, such as large companies, that are more aware of QMS-based organisations within their sector are in a much better position to deliver better quality value than those companies that have limited knowledge about the quality standard status about their competition or environment. It is imperative, therefore, for organisations to widen the horizon of their companies and their compliance. Otherwise, this can translate into less quality value delivery due to implications associated with the lack of knowledge and awareness.

It is also reasonable to assert that one of the key quality value indicators is with automotive industry standards such as IATF 16949:2016 as detailed in the literature review in Chapter 2. As a QMS-based standard, IATF 16949:2016 is essentially globally recognised as an enabler of quality process engineering for the automotive manufacturing sector (Bacoccini, 2016). The findings in Table 5.4 show that while all five of the research participants from the large automotive manufacturing organisations indicated their companies are IATF 16949:2016 compliant, none of the cohort of experts from the SME sector responded to indicate that their companies conform to the said standard. It can also be seen from Table 5.4 that unlike the large organisations that are associated with ISO 26262, ISO 45001 and AEC-Q100 & AEC-Q200 as indicated by their representative cohort of experts, none from the SME sector selected any one of these QMS-oriented standards. Lack of relevant and standardised QMS-based procedures is also indicative of limited management commitment. This, among many other factors, can give rise to delivering less quality value compared to organisations that are QMS-oriented and are equipped with documented relevant procedures as demonstrated by the cohort of experts from large companies (see the responses in Table 5.4).

It is also worth noting that organisations that are not governed by standard QMS procedure-based documentation, such as seen in the outcomes in Table 5.4, are more susceptible to quality value delivery process inadequacies (Kehr & Proctor, 2017) and vehicular occupational hazards (Beraldi & Kaminski, 2016) than those organisations that are QMS-oriented.

Derived functional needs based on the findings in awareness and compliance

This research is to develop a new quality engineering framework that enables SMEs to develop their in-house core quality competencies oriented on indigenous knowledge system (IKS). The essence of creating an IKS-based quality design is to empower personnel to tap into their expert knowledge to create a custom quality management system that is designed to deliver to exceed expectation while not departing from the requirements of the industry standard procedures. Based on the responses provided mainly by the cohort of experts from the SME backgrounds, the following functional needs are identified:

1. Develop company-wide familiarity with relevant quality standardised procedures for the automotive manufacturing industry (coded $FR_{1.1.2}$)
2. Achieve company-wide familiarity with relevant international regulatory bodies for the automotive manufacturing industry (coded $FR_{1.1.4}$)
3. Achieve customised, in-house, indigenous knowledge system (IKS)-based hierarchy quality system (coded $FR_{1.1.6}$)

These FRs are treated in Chapter 6.

Quality knowledge

Of particular significance to this study in the metric for quality value delivery is automotive manufacturing organisations' experiential knowledge in the quality tools that complement the implementation of QMS-based standard procedures (see Chapter 2 on *Quality tools and methods for manufacturing systems*). With regard to *quality engineering knowledge*, the experts were asked as to which industry standard quality engineering knowledge is included at the early design stage at their companies (with reference to IATF 16949:2016, ISO 9001 – ISO 45001, amongst others). Their responses are captured in Fig. 5.3 below. A majority 62.5% of the cohort of experts indicated that their organisations include quality engineering knowledge at the early design stage, while 25% of the experts indicated the contrary and 12.5% did not know or preferred not to answer this question.

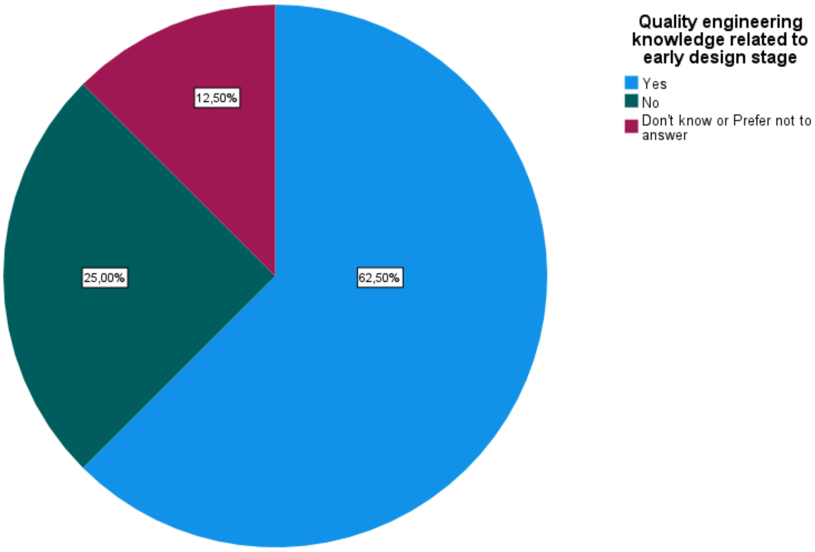


Fig. 5.3: Quality standards familiarity (consumers)

With regard to the *quality methods*, experts of large organisations indicated for all nine (9) specified quality methods, apart from the Taguchi Robust Design Method, that they are utilised at their respective companies (see Table 5.5). In comparison, the three (3) SME representatives' responses showed a partial inclusion of the quality methods in their companies, as depicted in Table 5.5. In the field designated as *Other*, further quality methods were entered: 8D (1 large org.), 5S (1 SME), and Shainin RedX (2 large organisations). It is of interest to this research that overall, SMEs utilise core quality methods to a lesser extent than large organisations which aligns with other studies' findings (see literature review in Chapter 2).

Table 5.5: Quality methods utilisation (experts)

Which of the following quality methods are used within your company?		**Company size**		
		Under 251	**Over 250**	**Total**
Six Sigma	Count	1	5	6
Total Quality Management (TQM)	Count	1	5	6
Product Part Approval Process (PPAP)	Count	1	5	6
Lean Management System	Count	0	5	5
Failure Mode and Effects Analysis (FMEA)	Count	2	5	7
Statistical Process Control (SPC)	Count	1	5	6
Quality Function Deployment (QFD)	Count	0	5	5
Advanced Product Quality Planning (APQP)	Count	1	5	6
Taguchi Robust Design Method (TRDM)	Count	0	2	2
Total	**Count**	**2**	**5**	**7**

*Other: 8D; 5S; Shainin RedX

While the majority of experts (85.5%) indicated that their companies have *a standardised quality policy*, the respective quality policies differ with regard to *the activities featured*, as depicted in Table 5.6. Experts from large organisations predominantly entered 'Yes' towards all five (5) specified activities. With regard to SMEs, one (1) expert did select 'Unknown' for all quality policy activities and one (1) expert predominantly indicated 'No', which contrasted with one (1) expert entering 'Yes' to the majority of activities. This confirms above findings in Table 5.5 with regards to SMEs and demonstrates that in contrast to large organisations, SMEs generally lag behind in quality policy as well as quality methods utilisation.

Table 5.6: Activities featured in company's Quality Policy (experts)

			Company size		
			Under 251	**Over 250**	**Total**
The company's Quality Policy is...	Always appropriate to the overall company goal	Count	2	4	6
		% within $QP	33.3%	66.7%	-
	Consistent with the quality objectives of the company	Count	1	5	6
		% within $QP	16.7%	83.3%	-
	Well-communicated and well-understood within the company	Count	1	4	5
		% within $QP	20.0%	80.0%	-
	Regularly reviewed by top management	Count	1	5	6
		% within $QP	16.7%	83.3%	-
	Kept as a Standard Reference Document	Count	0	5	5
		% within $QP	0.0%	100.0%	-
Total		Count	2	5	7

The essence of employing the use of a standardised quality policy is to enable automotive manufacturing organisations to inculcate a culture of adopting acceptable procedures along the quality value process. This is because such a practice can stimulate search-and-track quality flaws or failures at various levels and drive the design of countermeasures required for improved systems. Thus, it is in the interest of automotive manufacturing organisations to adopt standardised quality policies. With reference to Table 5.6, the cohort of experts from large organisations responded in the majority to all the statements while those from the SME sector show a large separation from their counterparts.

While standardised quality policies are a template for automotive manufacturing organisations to satisfy the functional requirements of consumers and regulatory bodies, their existence is an enabler of periodical auditing or review. An ISO quality policy, for instance, expects organisations to build their quality policy on their objectives and values. These stimulate continuous improvement. Non-QMS-based automotive organisations that are limited in the use of quality policy in their operations, as depicted by the representation of the cohort of experts from the SME domain, will deliver less quality value compared to the QMS-based large organisations presented in Table 5.6.

The research participants of experts were asked as to *which of the automotive manufacturing (internal) parties is involved as key stakeholders or decision-makers of quality performance in the early product or service design process*. Their responses are captured in Table 5.7 below.

Table 5.7: Key Stakeholders in the early product or service design process (experts)

	Yes	No
Top management	62.5%	37.5%
Engineering design team	87.5%	12.5%
Task force	0.0%	100.0%
Vehicle auditor	50.0%	50.0%
Quality manager	75.0%	25.0%
Project manager	87.5%	12.5%
Human resource manager	12.5%	87.5%
Purchase and supply chain leader	50.0%	50.0%
Owner representative	25.0%	75.0%
Software engineer	25.0%	75.0%
Risk analyst	25.0%	75.0%
Manufacturing engineering lead	62.5%	37.5%
IT infrastructure assessor	0.0%	100.0%
Business process engineer	37.5%	62.5%
Production manager	50.0%	50.0%
Shopfloor supervisor	25.0%	75.0%
Facility maintenance lead	12.5%	87.5%
Line manager	25.0%	75.0%

The key stakeholders, as per the responses from the research participants representing both SMEs and large companies, were mainly Engineering Design Team (87.5%), Project Manager (87.5%) and Quality Manager (75%). Comparing the entries for large organisations and SMEs, however, revealed differences: key stakeholders mentioned for SMEs were Top Management (2), Engineering Design Team (2) and Project Manager (2) (see Table 5.8), while large organisations depend on a more diverse set of stakeholders, including Engineering Design

Team (5), Vehicle Auditor (4), Quality Manager (5), Project Manager (5), Purchase and Supply Chain Leader (4) and Manufacturing Engineering Lead (4). It is of interest here that Top Management did not feature prominently among the key stakeholders for large organisations, in comparison to its role for SMEs.

Table 5.8: SME Stakeholders in the early product or service design process (experts)

Stakeholders at Early Design Process		**Company size**	
		Under 251	**Total**
Top management	Count	2	2
Engineering design team	Count	2	2
Quality manager	Count	1	1
Project manager	Count	2	2
Human resource manager	Count	1	1
Owner representative	Count	1	1
Risk analyst	Count	1	1
Manufacturing engineering lead	Count	1	1
Business process engineer	Count	1	1
Production manager	Count	1	1
Shopfloor supervisor	Count	1	1
Line manager	Count	1	1
Total	Count	**3**	**3**

As to whether *any special software or tool* is used to *assess the company's core quality capabilities*, 62.5% of the research participants of experts indicated that their organisations have a software/tool that is used to assess quality capabilities, while 37.5% of the experts indicated the contrary.

Manufacturing quality knowledge in the context of this research study is related to the integration of quality design and implementation throughout the manufacturing process, from early design stage through to the delivery of automobile products and service to the consumer. Industry-standard quality engineering knowledge includes the procedures outlined in QMS-based IATF 16949:2016 and the ISO families applicable to the automotive industry. When asked as to whether

> *…industry-standard quality engineering knowledge (e.g. IATF 16949:2016, ISO 9001, ISO 14004; ISO 26262, ISO 45001, etc.) [is] included at the early design stage at your company?*

more than half (62.5%) of the research participants in the expert category that responded in the affirmative are engaged in large automotive organisations (>250 employees). A common pattern is observed in the data as 25% of the research participants of the SME domain indicated that their organisations do not include QMS-based procedures at the early design stage and the remainder 12.5% either preferred not to answer or had no knowledge about their firm's position on the subject-matter. This agrees with the deduction that SMEs do not implement QMS-based ISO family procedures due to a number of constraints (see Chaper 2). Since the vast array of the interconnectivity within the manufacturing system, including supply chain and logistics, OEM (original equipment manufacturer) requirements, and the many associated components in the manufacturing operations, adhere to the various QMS-standard procedures, SMEs that do not inculcate the culture of implementing any one or a combination of the QMS families are susceptible to quality performance variants. This is because lack of knowledge and experience to implement such industry standard quality tools can result in compromised quality performance delivery. The absence of such quality practice is an indication of a quality capability gap as identified in the literature review (see Chapter 2). Furthermore, without referring to any of the internationally recognised or acceptable industry-standard as a benchmark, automotive manufacturing SMEs such as those represented by the research participants are likely to deviate from the core dimensions of quality.

Besides the enquiry of the use of QMS-based families of quality implementation systems at the early design stage, a myriad of core quality techniques also exists (see Chapter 2 on *Quality Tools and Methods for Manufacturing Systems*; see Chapter 3 on *Derivation of the Third Level Functional Requirements*). Apart from the 25% of the research participants that confirmed that their organisations (>250 employees) use Taguchi Robust Design Method (TRDM) throughout the manufacturing process, the majority of the cohort of experts also indicated that the large organisations they work for use Six Sigma methodology (75%), Total Quality Management, TQM, (75%), Product Part Approval Process, PPAP, (75%), Lean Management System (62.5%), FMEA (87.5%), SPC (75%), QFD (62.5%) and Advanced Product Quality Planning, APQP, (75%). However, the research participants in the SME domain registered extremely very low to zero (Lean Management System and QFD) use of the industry known quality systems, suggesting that their organisations do not employ the core quality tools. While all the cohort of experts from the large organisations selected Lean Management System and QFD, none of the experts from the SMEs responded in selecting either of these two quality systems. The lack of experiential or practical background knowledge of such quality methods, among others, follows categorically that organisations within such domain will deliver less quality value compared to those that are QMS-oriented and employ such quality methods as listed in Table 5.5. Lean Management System, for example, is significant in helping to identify waste and reduce them via appropriate mitigation solutions or countermeasures. As such, the absence of such method from an organisation's process means non-value added (NVA) activities that constitute waste will potentially distant such organisations far from QMS-oriented companies in terms of delivering quality value.

Quality systems such as PPAP and APQP are prominently situated within the quality system in automotive manufacturing (see Chapter 2). As such, SMEs and other sectors of the automotive manufacturing organisations that do not use a myriad of the core quality tools are thought of being susceptible to departing from the foundational blueprint that roadmaps the implementation of enhanced quality performance. Thus, unless SMEs in particular are able to translate such quality knowledge gap or limited knowledgebase in the core quality tools into functional needs, they will fail to deliver a good degree of quality value in the face of their time-dependent competition.

Translating quality engineering knowledge problem statement findings into functional needs

With respect to the context of this research, functional needs as related to this segment is the need to *Maximise core quality capabilities across personnel*. In order to satisfy this functional need, the following FRs statements are mapped out as follows:

1. Develop high-level core quality competent engineers and staff (coded $FR_{1.1.1}$)
2. Create a reward system to encourage recurrent training in quality skillset across all departments or units (coded $FR_{1.1.7}$)

These are further treated in Chapter 6 at the integration phase.

5.2.2 Quality design

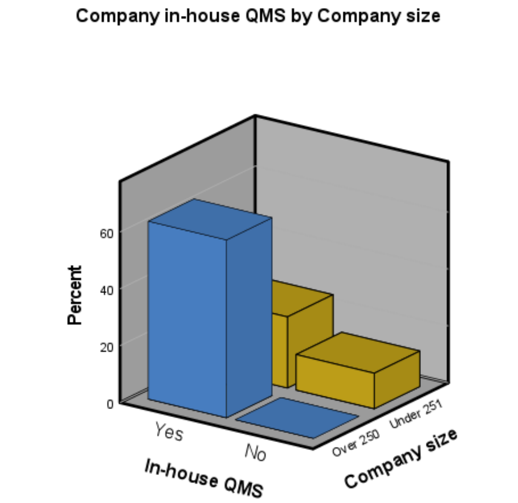
Company's QMS

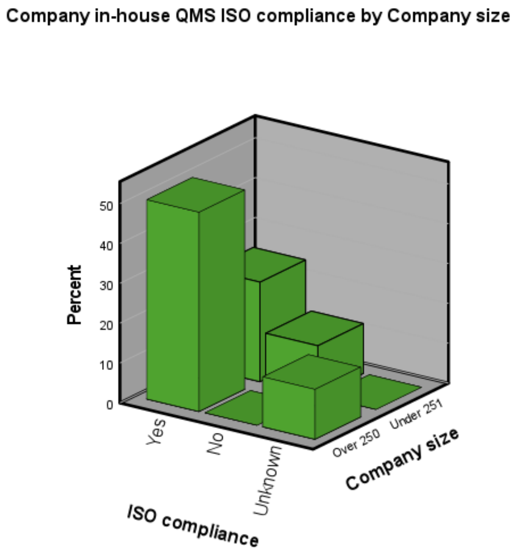
This component concerns the in-house developed quality management system (QMS) and seeks data on personnel's knowledge of the relevant ISO standard procedures. As seen in Table 5.9, a vast majority (87.5%) of the cohort of experts indicated that their respective companies had developed their own quality management system (QMS) which consists of policies, procedures, human resources and technology. The level of compliance with the ISO standard applicable to the automotive sector (75%) and inclusion of certification courses in ISO management system standards in their companies' staff development training programmes (75%) was also significant.

Table 5.9: Company's in-house QMS (experts)

	Regarding company in-house QMS	Regarding company in-house QMS ISO compliance	Regarding company staff ISO certification
Yes	87.5%	75.0%	75.0%
No	12.5%	12.5%	12.5%
Don't know or Prefer not to answer	0%	12.5%	12.5%

In comparing, company's in-house QMS for both company sizes in Table 5.9 with the individual size percentages for SMEs and large organisations shown in Fig. 5.4, it is of significance to this research that the responses for the SMEs show lower percentages for all three categories: In-house developed QMS, ISO compliance and Staff ISO certification.





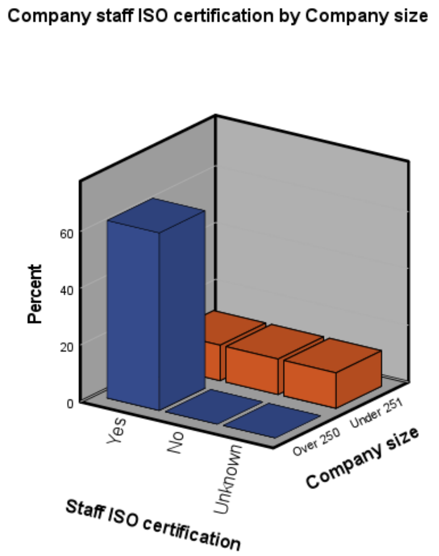


Fig. 5.4: Company's in-house QMS by Company size (experts)

The experts were asked as to *who is responsible for developing the company's own quality management system (QMS) and personnel training programme to prepare both the company and personnel for ISO certification*. Their responses are captured in Table 5.10 below.

Table 5.10: Key Stakeholders in developing company's own QMS and personnel training programme (experts)

Who is responsible for developing firm's own QMS and personnel training programme to prepare for ISO certification?	**Yes**	**No**
Top Management	25.0%	75.0%
Engineering Design Team	37.5%	62.5%
Task Force	0%	100%
Internal/Vehicle Auditor	0%	100%
Quality Manager/Director	87.5%	12.5%
Project Manager	12.5%	87.5%
Human Resource Manager/Director	25.0%	75.0%
Purchasing/Procurement and Supply Chain Leader	12.5%	87.5%
Owners or Owner/Representative	0%	100%
Software Engineer	0%	100%
Risk Analysis	0%	100%
Manufacturing Engineering Lead	12.5%	87.5%
IT Infrastructure Lead	0%	100%
Business Process Engineer	12.5%	87.5%
Production Manager	37.5%	62.5%
Shopfloor Supervisor	0%	100%
Facility Maintenance Lead	25.0%	75.0%
Line Manager	0%	100%

As can be seen in Table 5.10, Quality Manager generated the highest frequency (87.5%) for developing company's own QMS and personnel training programme. On whether a *special software or tool is used to develop the company's own QMS in conformance with the ISO standards as well as developing the schemes for ISO certification for both the company and staff*, 62.5% answered 'Yes' and 37.5% answered 'No'.

Quality design documentation

In the context of this study, documentation of the manufacturing, quality and design specification assists staff to know what is expected of them with respect to the company's goals and enables early identification of any quality compromises for any necessary amendments or countermeasures. With regard to its impact on customers, the experts were asked whether their companies *have an in-house developed Quality Design Documentation that features how design specifications can take into account the key components or parameters required to maximise customer satisfaction*. They were further asked *whether adequate information is incorporated into the Quality Design Documentation to ensure manufacturing equipment resources are easily accessible in a timely manner*, and *whether the documentation includes and evaluates customer specific requirements*. The responses to these three questions are presented in Table 5.11.

Table 5.11: Quality Design Documentation (experts)

	Quality design documentation regarding featured design specifications	Quality design documentation regarding incorporated information	Quality design documentation regarding featured customer requirements
Yes	75.0%	50.0%	75.0%
No	25.0%	37.5%	12.5%
Company has no Quality Design Documentation	0%	12.5%	12.5%

The results show that 75% of the experts indicated that their organisations do have in place a *quality design documentation* that features *design specifications* with regard to *maximising customer satisfaction* and addressing customer specific requirements. A 50% of the cohort entered 'Yes' with regard to the inclusion of manufacturing equipment resources accessibility in the documentation.

The experts were asked as to *who is usually involved in the preparation of the Quality Design Documentation*. As depicted in Table 5.12, the Engineering Design Team (75%), Project Manager (75%), Quality Manager (62.5%) and Manufacturing Engineering Lead (62.5%) had the highest percentages of specified key stakeholders, which aligns with the findings of Table 5.7 relating to the early product or service design process. It is of interest here, however, that only 25% indicated that Top Management is involved during the preparation stage.

Table 5.12: Key Stakeholders for preparing the Quality Design Documentation (experts)

Who is usually involved in the preparation of the Quality Design Documentation?	Yes	No	Unknown
Top Management	25.0%	62.5%	12.5%
Engineering Design Team	75.0%	12.5%	12.5%
Task Force	0%	87.5%	12.5%
Internal/Vehicle Auditor	25.0%	62.5%	12.5%
Quality Manager/Director	62.5%	25.0%	12.5%
Project Manager	75.0%	12.5%	12.5%
Human Resource Manager/Director	0%	87.5%	12.5%
Purchasing/Procurement and Supply Chain Lead	50.0%	37.5%	12.5%
Owners or Owner/Representative	0%	87.5%	12.5%
Software Engineer	12.5%	75.0%	12.5%
Risk Analysis	12.5%	75.0%	12.5%
Manufacturing Engineering Lead	62.5%	25.0%	12.5%
IT Infrastructure Lead	0%	87.5%	12.5%
Business Process Engineer	12.5%	62.5%	12.5%
Production Manager	37.5%	50.0%	12.5%
Shopfloor Supervisor	12.5%	75.0%	12.5%
Facility Maintenance Lead	12.5%	75.0%	12.5%
Line Manager	37.5%	50.0%	12.5%

*Other: Regulation Engineer: 12.5%

On *whether a special software or tool is used to review quality-based procedures and documenting them*, 37.5% answered ‘Yes’, 50.0% entered ‘No’ and 12.5% did not know or preferred not to answer the question.

Translating quality design problem identifiers into functional needs

Similar to the outcomes and implications associated with the previous Section, i.e. quality policy, the cohort of experts from SME organisations show very low responses towards the quality design documentation statements with respect to Table 5.9, Fig. 5.3 and Table 5.11. Organisations such as those represented by the cohort of experts from large organisations that have an in-house QMS, are ISO-family compliant and promote staff training in ISO-related programmes have a competitive advantage in quality value delivery compared to other organisations such as those represented by the research participants from the SMEs companies. These lapses can be addressed by translating them into the earlier functional needs as follows:

1. $FR_{1.1.1}$ – related to staff development training
2. $FR_{1.1.2}$ – related to in-house QMS design and quality design documentation
3. $FR_{1.1.3}$ – related to personnel's knowledge of ISO family of standards
4. $FR_{1.1.4}$ – related to familiarity with compliance with ISO-families and quality design documentation

5.2.3 Standards implementation

Manufacturing Equipment Standardisation

As standardisation of manufacturing equipment and systems is essential for supporting shopfloor staff to minimise or avoid disruption of operation or quality losses, the cohort of experts were asked as to what extent their *organisations standardise [their] manufacturing equipment before or during the design stage.*

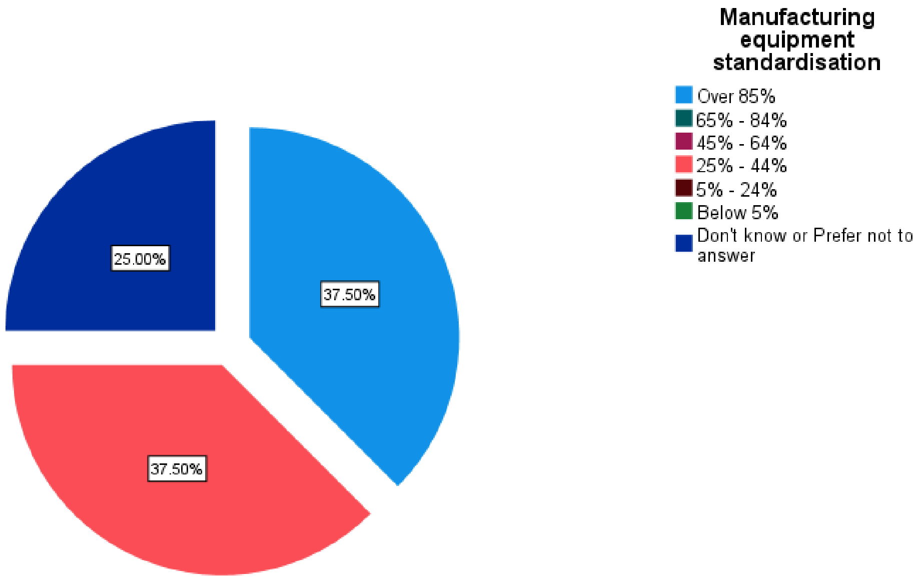


Fig. 5.5: Manufacturing equipment standardisation before or during design stage (experts)

Provided with seven (7) possible entry fields from over 85% to below 5% (see Fig. 5.5 for their responses), 37.5% of the experts selected 'Over 85%', while another 37.5% opted for the range '25%-44%'. A significant 25.0% of the research participants of experts were not certain about the inclusion of manufacturing equipment standardisation at their companies.

On a general note, QMS-oriented organisations incorporate a number of documented procedures that make room for the standardisation of manufacturing equipment. Unless an automotive manufacturing organisation employs similar practice within their corporate processes, they will likely encounter discrepancies in their processes to conform to the industry standard requirements in either the product or delivery process. As seen in Fig. 5.5, a significant 37.5% of the experts indicated their organisation is below 50% with regards to standardising their equipment while a 25% responded as either not knowing whether manufacturing equipment standardisation is embedded within their processes or they simply elected not to respond to the statement. In either cases, automotive manufacturing organisations within the segment as described by the research participants will deliver less quality value due to inherent inefficiencies in equipment standardisation that can potentially give rise to nonconformities compared to QMS-based organisations that institute the practice of standardising manufacturing equipment.

With regards to *who is responsible for ensuring manufacturing equipment and systems standardisation* at their organisations, Table 5.13 depicts that Engineering Design Team (87.5%), Manufacturing Engineering Lead (62.5%) and Production Manager (62.5%) generated the highest frequencies.

Table 5.13: Manufacturing equipment standardisation before or during design stage (experts)

Who is responsible for ensuring manufacturing equipment and systems standardisation?	**Yes**	**No**	**Unknown**
Top Management	0%	87.5%	12.5%
Engineering Design Team	87.5%	0%	12.5%
Task Force	0%	87.5%	12.5%
Internal/Vehicle Auditor	0%	87.5%	12.5%
Quality Manager/Director	50.0%	37.5%	12.5%
Project Manager	37.5%	50.0%	12.5%
Human Resource Manager/Director	0%	87.5%	12.5%
Purchasing/Procurement and Supply Chain Lead	37.5%	50.0%	12.5%
Owners or Owner/Representative	12.5%	75.0%	12.5%
Software Engineer	0%	87.5%	12.5%
Risk Analyst	0%	87.5%	12.5%
Manufacturing Engineering Lead	62.5%	25.0%	12.5%
IT Infrastructure Lead	0%	87.5%	12.5%
Business Process Engineer	0%	87.5%	12.5%
Production Manager	62.5%	25.0%	12.5%
Shopfloor Supervisor	12.5%	75.0%	12.5%
Facility Maintenance Lead	37.5%	50.0%	12.5%
Line Manager	25.0%	62.5%	12.5%

Quality Tools Implementation

This component concerns a company's core quality capabilities and its use of core quality tools to optimise existing manufacturing processes. The research participants of experts were requested to describe their companies' use of the specified core quality tools such as Six Sigma, Failure Mode and Effects Analysis (FMEA), etc., to enhance their manufacturing processes. Their responses, based on a seven-point Likert scale from 1 (Very Poorly) to 7 (Very Well), are presented in Table 5.14. The results show that an accumulated majority of the cohort of experts rated their companies' use of core quality tools positively (from 'somewhat well' to 'very well'), with Failure Mode and Effects Analysis (FMEA) ranking the highest percentage (87.5%). This was followed by Six Sigma Methodology (75%), Production Part Approval Process (75%), Measurement System Analysis (75%), Statistical Process Control (75%) and Quality Function Deployment (75%). The outlier was one (1) SME case that marked three (3) fields with 'Very Poorly'.

Table 5.14: Experts' responses regarding quality tools used to enhance existing manufacturing processes

Capability and Implementation	Very Poorly	Poorly	Somewhat Poor	Somewhat Well	Well	Very Well	Accumulated Agreement	Unknown / Not at all
Six Sigma	0.0%	0.0%	12.5%	12.5%	50.0%	12.5%	75.0%	0.0%
Lean management system	12.5%	0.0%	12.5%	12.5%	50.0%	0.0%	62.5%	0.0%
Production Part Approval Process (PPAP)	0.0%	0.0%	0.0%	12.5%	50.0%	25.0%	75.0%	0.0%
Advanced Product Quality Planning (APQP)	0.0%	0.0%	0.0%	0.0%	37.5%	25.0%	62.5%	25.0%
Measurements System Analysis (MSA)	0.0%	0.0%	0.0%	0.0%	75.0%	0.0%	75.0%	12.5%
Statistical Process Control (SPC)	0.0%	0.0%	0.0%	12.5%	62.5%	0.0%	75.0%	12.5%
Quality Function Deployment (QFD)	12.5%	0.0%	0.0%	0.0%	50.0%	25.0%	75.0%	0.0%
Failure Mode and Effects Analysis (FMEA)	0.0%	0.0%	0.0%	12.5%	62.5%	12.5%	87.5%	0.0%
Total Quality Management (TQM)	0.0%	12.5%	12.5%	0.0%	50.0%	12.5%	62.5%	0.0%
Taguchi Robust Design Methods (TRDM)	12.5%	12.5%	0.0%	12.5%	25.0%	0.0%	37.5%	25.0%

*Missing data was removed

Of further interest is that the research participants of experts were asked to rate the overall personnel skillset knowedge in the core quality tools at percentage levels between less than 5% and 85%–100%. As depicted in the outcome in Fig. 5.6, there is a pronounced discrepancy between SMEs and large organisations with regards to *personnel skillset knowledge*: While experts of large organisations rated the level between 65% and 100%, the cohort from the SME domain lies significantly in the low ranges (between 5% and 24%; 45% and 64%).

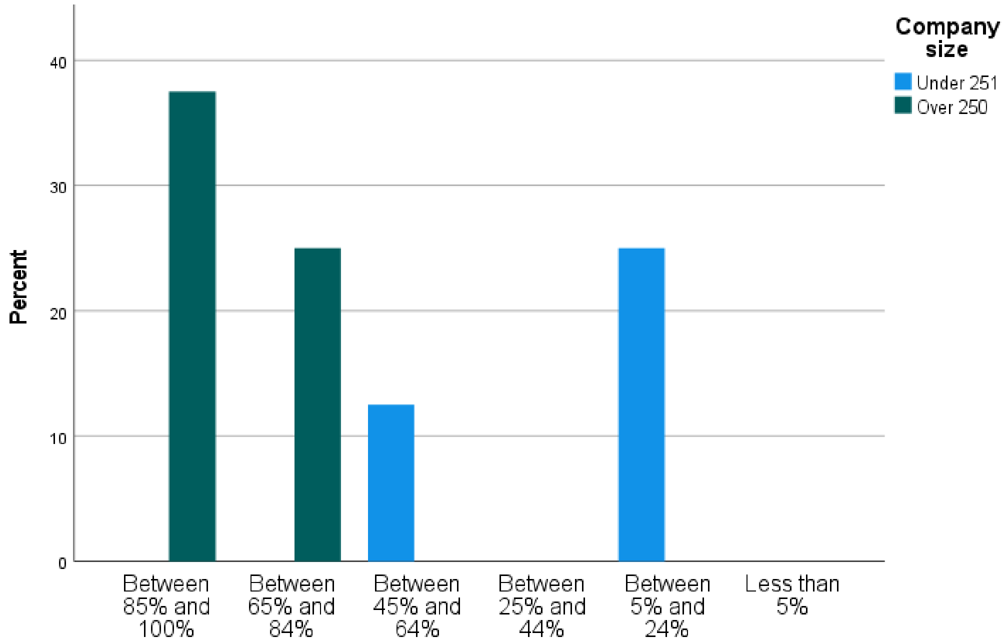


Fig. 5.6: Personnel skillset knowledge in the core quality tools (experts)

The experts were also asked as to *who is responsible for the implementation of core quality systems, methods or tools across the overall manufacturing process, from product design to delivery*. Their responses are captured in Table 5.15.

Table 5.15: Key stakeholders for implementing core quality systems, methods or tools (experts)

Core quality tools implementation lead	Yes	No	Don't know or Prefer not to answer
Top management	37.5%	37.5%	12.5%
Engineering design team	62.5%	12.5%	12.5%
Task force	0%	75%	12.5%
Vehicle auditor	25%	50%	12.5%
Quality manager	62.5%	12.5%	12.5%
Project manager	12.5%	62.5%	12.5%
Human resource manager	37.5%	37.5%	12.5%
Purchasing and supply chain lead	50.0%	25%	12.5%

Owner representative	0%	75%	12.5%
Software engineering	12.5%	62.5%	12.5%
Risk analyst	12.5%	62.5%	12.5%
Manufacturing engineer lead	12.5%	62.5%	12.5%
IT infrastructure assessor	12.5%	62.5%	12.5%
Business process engineering lead	12.5%	62.5%	12.5%
Production manager	50.0%	25.0%	12.5%
Shopfloor supervisor	12.5%	62.5%	12.5%
Facility maintenance lead	12.5%	62.5%	12.5%
Line manager	25.0%	50.0%	12.5%

As captured in Table 5.15 above, the responses reflect the key stakeholders for both company sizes collectively are Engineering Design Team (62.5%), Quality Manager (62.5%) and Purchasing Supply Chain Lead (50%) and Production Manager (50%). One (1) respondent (from a large organisation) entered into the field 'Other' *Customer Service, Product Compliance Lead* as further key stakeholders. In comparison, Table 5.16 displays the results for experts from SMEs which highlights the role of Top Management for one (1) SME.

Table 5.16: SME key stakeholders for implementing core quality systems, methods or tools (experts)

			Company size	
			Under 251	**Total**
Stakeholders Quality Tools Implementation	Top management	Count	1	1
	Engineering design team	Count	1	1
	Quality manager	Count	1	1
Total		Count	2	2

*Percentages and totals are based on respondents. Missing data was removed (1 respondent).

a. Dichotomy group tabulated at value 1 (Yes).

With regard to the employment of *any special software or tool used to assess personnel level of competency in the core quality tools*, 50% of the cohort of experts answered 'Yes'; 37.5% opted for 'No' and 12.5% did not know or preferred not to answer this question.

Translating quality indicators associated with standards implementation into functional needs

As depicted in the above outcomes, in all cases the research participants from the SME sector lag behind in responses as compared to those of the cohort of experts from large organisations. The following are worth noting:

1. A need to *achieve company-wide familiarity with relevant quality standardised procedures for the automotive manufacturing industry (coded $FR_{1.1.2}$)* and *build familiarity with manufacturing equipment standardisation (coded $FR_{1.1.5}$)* will address the gaps associated with the lapses pronounced through the experts' responses depicted in Fig. 5.5.
2. As it requires conversance and competency in the core quality methods in order to harness their implementation to enhance existing processes, a need to translate such into a functional need in the context of *developing high-level core quality competent engineers and personnel (coded $FR_{1.1.1}$)* and *create a process map for identifying flaws in quality implementation in QMS-based standardised procedures (coded $FR_{1.1.3}$)* can help organisations to deliver good quality value without necessarily being mainstream QMS-certified
3. As regards whether the organisations the cohort of experts work for use any special tool or software to assess personnel level of skillset competency in the core quality methods, a *standard procedure for skillset auditing (coded $FR_{1.1.8}$)* will address the issue

The above mapped out functional needs are further treated in Chapter 6 at the integration stage.

5.2.4 Responses to threats

Auto Recalls Handling

This component sought to draw contributory data from the cohort of consumers with regard to their perception on how automotive manufacturing organisations handle auto recalls (see Table 5.17). As shown in Table 5.17, 48% of the cohort of consumers responded 'Yes' to indicate that *they believe that most automotive manufacturing companies make it mandatory for their staff to develop knowledge in or become conversant with the general automobile Safety Regulations*. 24% of the research participants of consumers, however, do not share the belief, another 24% of the cohort indicated lack of information about the enquiry, while the remainder 4% answered *No*.

As per the responses of the consumers, in automotive manufacturing organisations where management does not mandate a need for staff to develop knowledge in *safety regulations*, then there is a likelihood that staff may be engaged in "unintended" adversarial behaviours that may result in poor handling of auto recall issues. QMS-certified organisations or organisations that have developed an in-house QMS that is mapped across the expectations or procedures of the standard QMS template are more likely to have a collective collaborative and cooperative staff when it comes to handling or responding to auto recalls than non-QMS-based companies. Under such a hypothetical case, a QMS-based company will be better positioned in handling auto recalls in a more economic and productive way than the non-QMS driven companies.

Table 5.17: Consumers' responses regarding auto recall handling

Do you believe that most automotive manufacturing companies make it mandatory for their staff to develop knowledge in or become conversant with the general automobile Safety Regulations?	Yes	48.0%
	No	4.0%
	Don't think so	24.0%
	Don't know	24.0%
Do you believe most automotive manufacturing organisations are open about their weaknesses?	Yes	8.0%
	No	44.0%
	Don't think so	40.0%
	Don't know	8.0%
Do you believe most automotive manufacturing organisations have a special system in place to notify automotive regulatory bodies of any late detection of a safety defect that could potentially affect vehicles or products that have already been supplied for use?	Yes	40.0%
	No	4.0%
	Don't think so	24.0%
	Don't know	32.0%
Do you believe most automotive companies have a special system in place via which they are able to notify automotive regulatory bodies about any late detection of a safety defect that could potentially affect vehicles that have NOT yet been supplied for use?	Yes	28.0%
	No	16.0%
	Don't think so	20.0%
	Don't know	36.0%
As a consumer, do you think it is better for automotive companies to share information on how they respond to auto recall or automobile defect/reject issues?	Yes	96.0%
	No	4.0%

The research participants of consumers were also asked as to whether they believe that *most automotive manufacturing organisations are open about their weaknesses*. A majority of 44% of the cohort of consumers responded that they do not believe companies share information about their weaknesses while a 40% indicated they do not think organisations can be open about their weaknesses. Against the 8% of the research participants that answered that they believe that most automotive manufacturing organisations are open about their weaknesses, the implication derived from the majority that responded to the contrary can lead the assertion that when companies are open to acknowledging their weaknesses, they in turn affirm their clientelebase in terms of respecting their sense of judgment. Within the context of this research, being open about weaknesses is tantamount to exposing the areas requiring corrections. For instance, if VW's engineers had been open about the weaknesses in their emissions levels in 2005, then they would have sought voluntary recall rather than resort to installing an illegal software into diesel engines that compromised their brand reputation (see Chapter 2 on *Auto recalls*; Goodman, 2015; Gorzelany, 2014). One of the core values with QMS-oriented automotive manufacturing organisations is to enable auditing of internal process procedures. Such exercises help identify process gaps that can be addressed to stimulate operational excellence. This is also a function of how open the organisation is about their weaknesses. On the other hand, non-QMS-based organisations to some extent lack in-depth insights into non-conformities that can propagate through unidentified weaknesses. This can lead to poorly addressed flawed processes due to missing QMS procedures or guidance, resulting in less delivery of quality value.

With respect to whether *automotive manufacturing organisations have a special system in place to notify automotive regulatory bodies of any late detection of a safety defect* that could potentially affect vehicles or products post-delivery, 40% of the research participants of consumers believe they do while a minority 4% believe otherwise. However, 24% of the cohort of consumers do not think the statement holds for automotive manufacturing organisations and a significant 32% do not know about the position of companies within the frame of the statement.

Regarding whether the research participants believe that most automotive companies have a mechanism or procedure in place via which they are able to notify automotive regulatory bodies about any late detection of a safety defect before an affected product enters the supply chain, 28% of the research consumers believe the statement holds for automotive organisations while a 16% do not share such belief. A 20% of the consumer cohort indicated they do not think so. Organisations with an established QMS can create a protocol that enables voluntary recall due to either early or late detection of safety defect compared to non-QMS-oriented organisations. In terms of the context of this research, the setup of an in-house quality management system (QMS), which is not necessarily ISO-biased but features an exhaustive list, can enable internal and external audits, leading to identifying key practices that align with the expectations of international regulators including the Environmental Protection Agency (EPA) requirements. The absence of such mechanism can potentially render non-QMS-oriented organisations diminishing returns via poor quality value delivery.

Central to the above is the question of whether *it is better for automotive manufacturing companies to share information on how they respond to auto recall or automobile defect/reject issues* or not. An overwhelming 96% agreed that it is better for automotive companies to do so. The responses of consumers, therefore, indicated the importance of automotive manufacturing organisations to be transparent and responsive to auto defects pre- and post-delivery.

Managing Safety Recalls

While the section on Auto Recalls Handling presented the consumers' voice with regard to recalls, this Section focuses on Managing Safety Recalls from the perspective of the cohort of experts working in the automotive sector (see Table 5.18). With regard to whether the experts' companies make it mandatory for their *staff to develop knowledge in or become conversant with the General Product Safety Regulations*, 62.5% of the cohort of experts responded that they do while 37.5% answered that their companies do not mandate such practice. As depicted also in Table 5.18, an overwhelming 100% of the experts indicated that their organisations do have a Code of Practice on Safety that staff must adhere to. Situated within the context of this research, a *Code of Practice on Safety* in the automotive sector mainly refers to action taken when a defect is identified within the definition of safety issues that can potentially result in serious injuries or death (see Chapter 2 on *Auto recalls*).

The experts were further asked as to whether their companies are aware of the potential safety recall Early Warning System, which they significantly answered with 'Yes' (87.5%) and with a 12.5% responded as not knowing or rather preferred not to answer. 62.5% of the experts indicated that their companies have a system for locating information quickly at the request of automotive industry governing bodies. However, 37.5% of the experts responded that their companies lack a system that enables them to quickly locate information at the request of governing bodies. Similarly to the questions for the consumers in the previous Section, the experts were further asked as to whether their companies have a *special system in place to notify automotive regulatory bodies of any late detection of a safety defect* that could potentially affect vehicles or products post-delivery, and whether *they have such notification system in place for identified pre-delivery safety detections*. Whereby the reported 62.5% for the post-delivery notification were significant with 25% on a contrary response note, only 37.5% entered 'Yes' to having a pre-delivery safety detection notification respectively.

With reference to Table 5.18, it is reasonable to submit that automotive organisations that are inadequate with product safety regulations, Early Warning System required for safety recalls, system for locating requested data promptly, template for post-delivery late detection and pre-delivery safety detection notification, are mostly situated within non-QMS-based domain. By standard, a QMS template is expected to offer an extensive array of procedures across the various manufacturing value delivery stream or processes. It can be seen throughout the above sections that the research participants in the SME bracket lag behind those in the large organisation sector. The latter, as per the responses from the respective cohort, are from large organisations that have employed most of the ISO-series QMS standards.

Table 5.18: Experts' responses on safety recalls protocols

Safety Recalls	Yes	No	Unknown
General product safety regulations	62.5%	37.5%	0%
Code of practice	100%	0%	0%
Early warning system	87.5%	0%	12.5%
Locating information upon authorities' request	62.5%	37.5%	0%
Post-delivery late detection of safety defect	62.5%	25.0%	12.5%
Pre-delivery late detection of safety defect	37.5%	37.5%	25.0%

Provided with 10 questions in relation to *which key items their companies have or put in place in the event of an automotive product safety recall or manufacturing defect*, the majority of the experts answered 'Yes' for all the statements listed in Table 5.19, including, amongst others, *description of the identified defect and its effect* (75%), *an ideal solution to address the defect* (75%) and *a traceability mechanism to track the product with defect* (75%).

Table 5.19: Experts' responses to Conducting a safety recall

In conducting an automotive product safety recall or manufacturing defect or reject, which of the following key items does your organisation have or put in place?	**Yes**	**No**	**Unknown**
Description of the identified defect and its effect	75.0%	12.5%	12.5%
An ideal solution to address the defect	75.0%	12.5%	12.5%
A robust process for product recall/reject	75.0%	12.5%	12.5%
A traceability mechanism to track the product with defect	75.0%	12.5%	12.5%
Robust internal procedures to isolate the problem	62.5%	25.0%	12.5%
A communication and media protocol	62.5%	25.0%	12.5%
Documentation of lessons learnt	62.5%	25.0%	12.5%
Quality improvement action plan	75.0%	12.5%	12.5%
Service improvement action plan	75.0%	12.5%	12.5%
Technical upgrade action plan	62.5%	25.0%	12.5%

Comparing the percentages by company size, however, Fig. 5.7 shows that the experts from the SME sector indicated three (3) key items that are missing from their companies' product safety recall procedures: (1) robust internal procedures to isolate the problem; (2) a communication and media protocol; and (3) documentation of lessons learnt. Furthermore, one of the SME research participants answered ‘Don’t know or Prefer not to answer or *Unknown*’ for all 10 statements. As asserted in the literature review in Chapter 2 and in agreement with Braun et al. (2020), Horváth and Szabó (2019) and Smit et al. (2016) , it can be drawn from the missing steps in the SME procedures regarding management of safety recalls as indicative of a less preparedness of SMEs in the event of product safety recalls or manufacturing defects which makes an ad-hoc reaction more likely than standardised reaction. It also suggests that non-QMS-based organisations are likely to have such quality value gaps in their processes due to missing documentation on handling such procedures. As such, such companies will deliver less quality value in comparison to QMS-based organisations that appear to be rich in documented procedures across the value chain.

Nonetheless, a collective 87.5% of the experts from both company sizes (SMEs and large) indicated that their companies *document product safety-related issues* (with 1 ‘Unknown’ exception), as depicted in Table 5.20.

Table 5.20: Experts’ responses to Documenting product safety-related issues

Do you document product safety related issues?	**Yes**	**No**	**Unknown**
Documenting product safety issues	87.5%	0%	12.5%

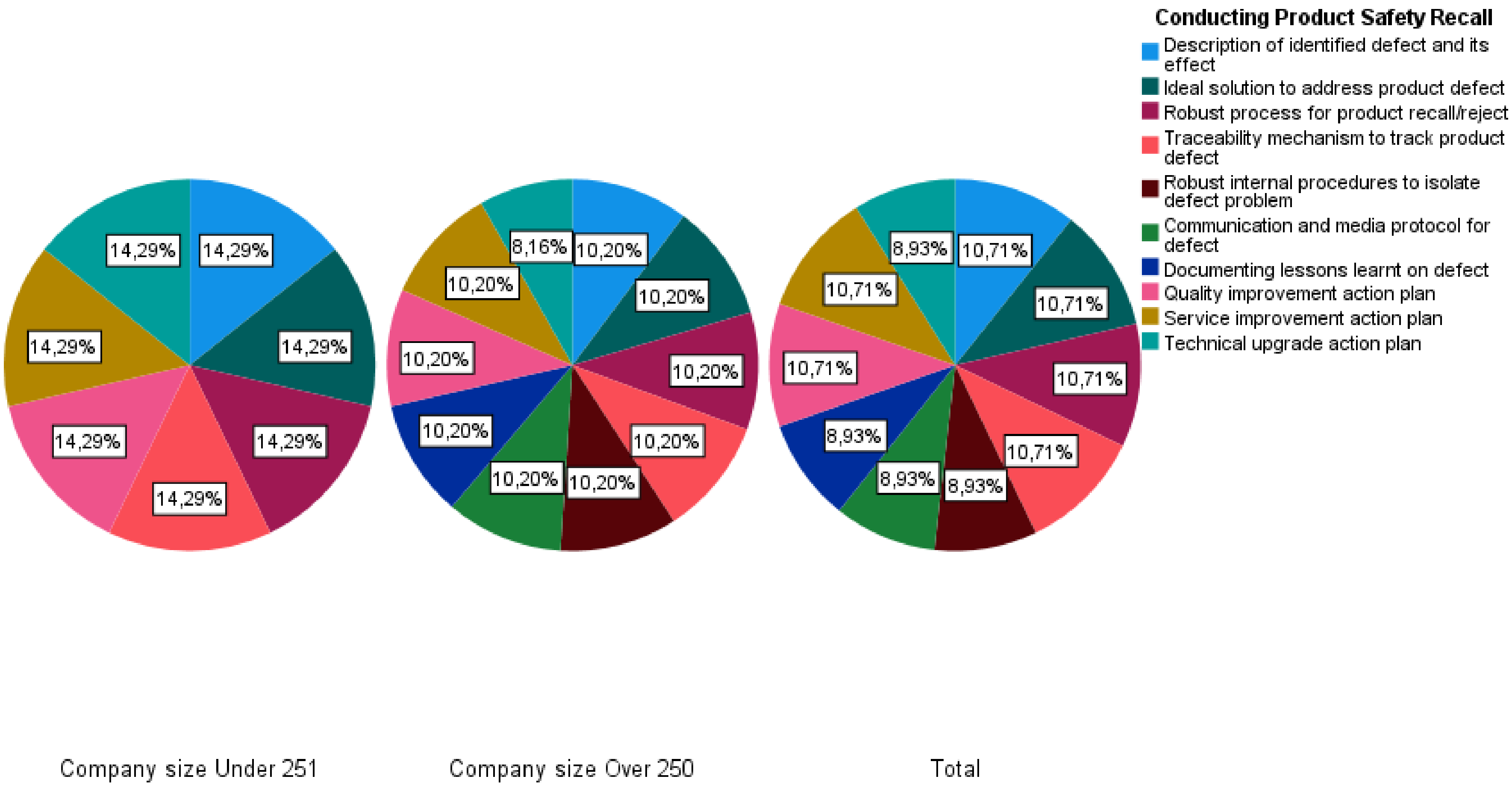


Fig. 5.7: Conducting product safety recall by company size (experts)

The cohort of experts were, furthermore, asked as to *who is responsible for managing safety recall or product defect/reject issues* at their organisations. As evidenced in Table 5.21, the Quality Manager (75%) and Engineering Design Team (50%) are predominantly in charge for handling safety recalls or product defects.

Table 5.21: Key stakeholders for managing safety recalls (experts)

Who is responsible for managing safety recall or product defect/reject issues?	**Yes**	**No**	**Unknown**
Top Management	37.5%	50.0%	12.5%
Engineering Design Team	50.0%	37.5%	12.5%
Task Force	25.0%	62.5%	12.5%
Internal/Vehicle Auditor	0%	87.5%	12.5%
Quality Manager/Director	75.0%	12.5%	12.5%
Project Manager	12.5%	75.0%	12.5%
Human Resource Manager/Director	0%	87.5%	12.5%
Purchasing/Procurement and Supply Chain Lead	0%	87.5%	12.5%
Owners or Owner/Representative	12.5%	75.0%	12.5%
Software Engineer	0%	87.5%	12.5%
Risk Analysis	12.5%	75.0%	12.5%
Manufacturing Engineering Lead	25.0%	62.5%	12.5%
IT Infrastructure Lead	0%	87.5%	12.5%
Business Process Engineer	0%	87.5%	12.5%
Production Manager	25.0%	62.5%	12.5%
Shopfloor Supervisor	12.5%	75.0%	12.5%
Facility Maintenance Lead	0%	87.5%	12.5%
Line Manager	12.5%	75.0%	12.5%

As to whether *any special software or tool* is used to *manage product safety recall or defect/reject issues* at their employ, more than 60% of the research participants of experts from large organisations indicated their organisation has a software or tool to manage safety recalls or defects, while the experts from SMEs were split evenly among the three columns (1 'Yes', 1 'No', 1 'Don't know/Prefer not to answer' or 'Unknown'). The responses of the cohort are depicted in Fig. 5.8.

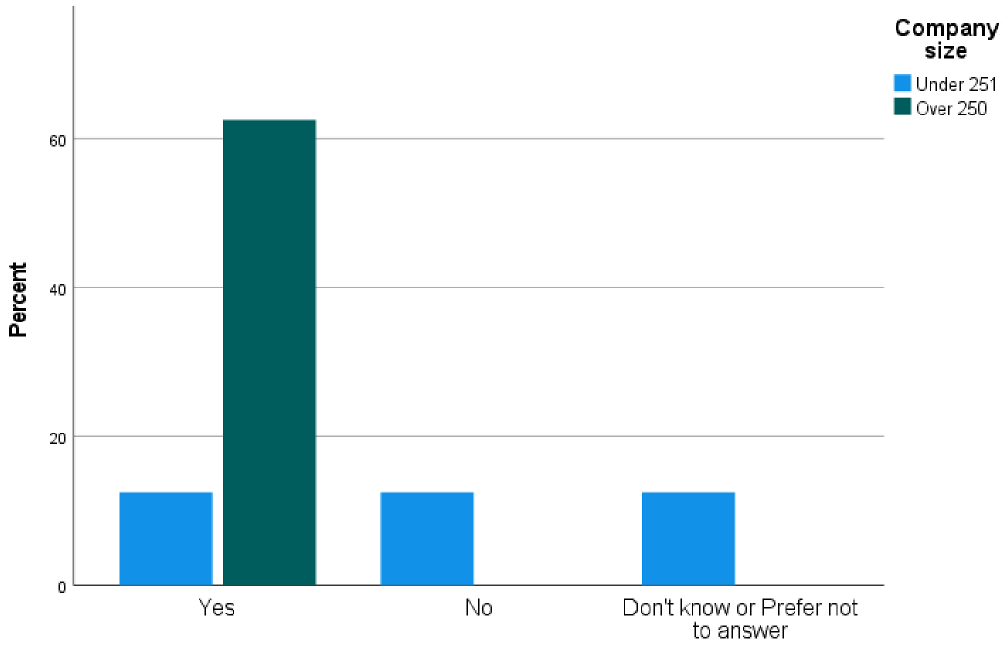


Fig. 5.8: Experts' responses on software or tool used to manage product safety recalls

As seen in the outcome shown in Fig. 5.8, the depiction of over 60% in the case of the research participants of experts indicating that their organisations (large) do have a special tool or software that is used to manage product safety recall or defect or reject issues, as opposed to the level of responses by the cohort from the SME sector, confirms the assertion that QMS-oriented large organisations are likely to have extended procedures for managing safety recalls than their counterparts that are non-QMS-oriented.

Defect Traceability

As this research considers product, process and or service defect traceability a significant element for reducing complexities with regard to product recall/reject or manufacturing system/service failures, this Section identifies the defect traceability mechanisms and methods in place at experts' companies. This Section, thus, takes a different outlook on product defect issues to the previous Section in focusing on tracing than handling the defect.

With regard to whether there exists an established *mechanism along the manufacturing operations, processes or value chain to enable identification or tracking of defect products once they are delivered into service or use*, the majority of the cohort of experts indicated that their companies have such mechanism in place. The experts' responses are depicted in Table 5.22 below. On a general note, all the research participants from the large automotive manufacturing organisations responded that their organisations do have system in place for tracking defect products post-delivery, compared with the limited response shown by the SME sector.

Table 5.22: Mechanism for tracking defect products post-delivery (experts)

			Company size		
			Under 251	Over 250	Total
Tracking post-delivery product defect	Yes	Count	1	5	**6**
	No	Count	1	0	**1**
	Don't know or Prefer not to answer	Count	1	0	**1**
Total		Count	**3**	**5**	**8**

Percentages and totals are based on respondents.

Provided with eleven (11) fields of specified methods, the cohort of experts were asked *which of the methods their companies use to enable traceability once a defect component or part enters the market*. The results in Fig. 5.9 show that only *bar coding* and *batch coding* are methods utilised by SME experts' companies, while large organisations use a variety of methods as shown in the legend.

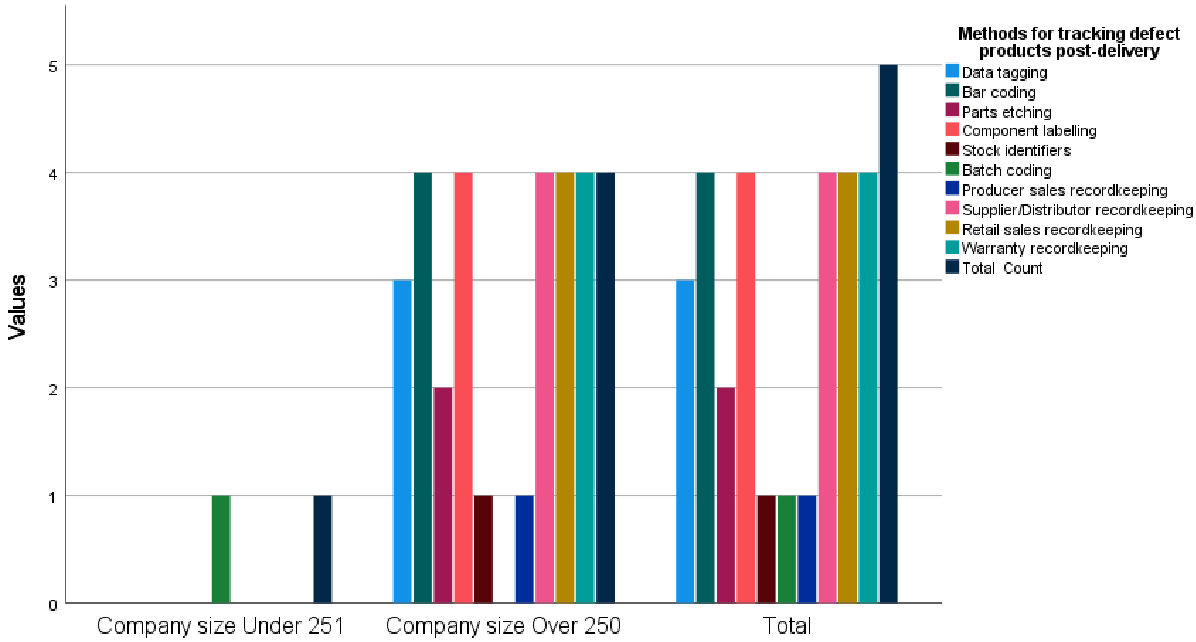


Fig. 5.9: Methods used to trace a defect component or part post-delivery by Company size (experts)

The outcome in similarity between Table 5.22 and Fig. 5.9 is that the large organisations are QMS-based, which offers them a competitive advantage in quality value delivery compared with the non-QMS-based organisations (such as the SME-based companies represented in this research) that are limited with standardised documented procedures.

With regard to procedures and systems for tracking defect products once they are delivered into service, the majority of experts entered 'Yes' for the five (5) provided questions presented in Table 5.23. In particular, the questions entailed *whether their companies monitor their product defect traceability process through a quality auditing process* and *document the* *process for the management of automotive production service, accessory parts or components safety*. The third question that was rated 'Yes' at 87.5% indicated that the experts' companies *have a quality auditor or director who is dedicated to all quality-related processes and issues*. With respect to the last two related questions:

- *(1) Does your company have a system that has been designed to enable personnel to report any errors (or adversarial behaviours) they commit along the manufacturing line or processes? In the context of this research, an Adversarial Behaviour may be defined as any deliberate action or behaviour by a staff or personnel that is likely to cause a quality issue within the manufacturing operation*, the majority of 75% answered that their organisations employ such a system, the majority of experts in the SMEs split between 'Don't know or Prefer not to answer' and 'No'. The results of the responses are depicted in Fig. 5.10a as well as in Table 5.23.

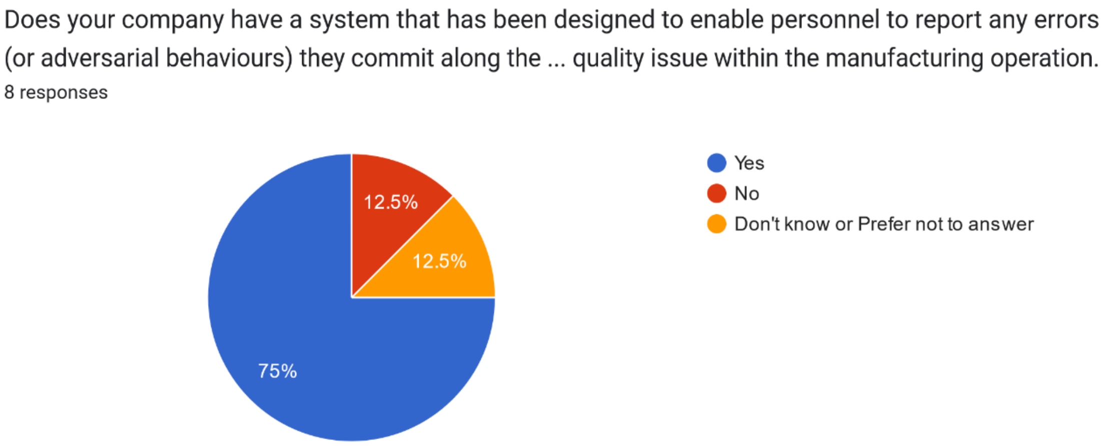


Fig. 5.10a: Experts' responses on a system for personnel self-reporting errors

- *(2) Does your company have a system that has been designed to enable personnel to report any errors (or adversarial behaviours) committed by other staff or personnel along the manufacturing line or processes? In the context of this research, an Adversarial Behaviour may be defined as any deliberate action or behaviour by a staff or personnel that is likely to cause a quality issue within the manufacturing operation*, outside the large organisation in the majority (75%) responding that their organisations do have a structure in place to enable personnel to report one another on observed adversarial behaviours, the majority of the SMEs represented by the associated experts fall outside the scheme (see Fig. 5.10b).

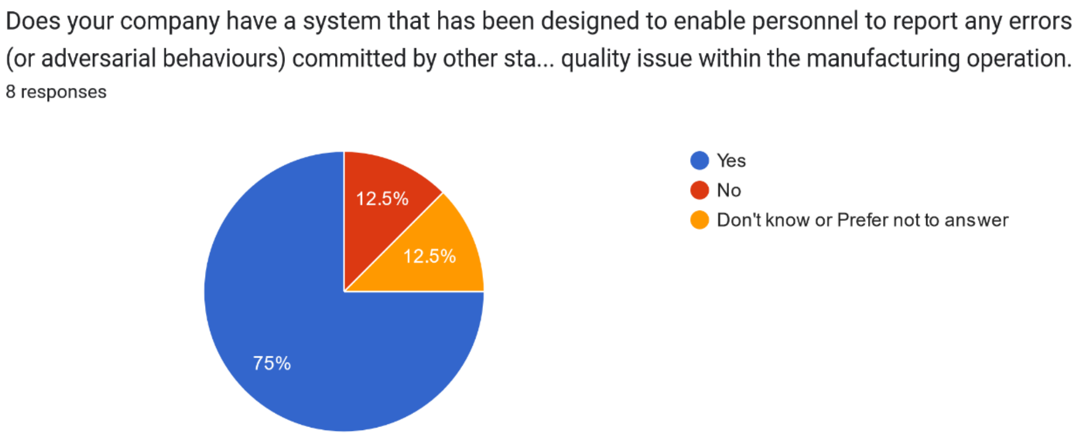


Fig. 5.10b: Experts' responses to system availability to enable reporting errors

Table 5.23: Procedures and Systems for tracking defect products post-delivery (experts)

	Yes	No	Don't know or Prefer not to answer
Product defect traceability process monitoring via quality auditing process	75.0%	12.5%	12.5%
Documenting process of automotive production service	75.0%	0.0%	25.0%
Quality auditor or quality director dedicated to all quality issues	87.5%	12.5%	0.0%
Self-reporting adversarial behaviours	75.0%	12.5%	12.5%
Personnel reporting adversarial behaviours of others	75.0%	12.5%	12.5%

In the context of this research, an adversarial behaviour may be defined as any deliberate action or behaviour by a staff or personnel that is likely to cause a quality issue within the manufacturing operation. While companies that have a system in place to enable defect tracing through process monitoring as well as auditing have a competitive advantage in delivery quality value than those organisations who do not, it is of particular interest to this research for organisations to consider having both a system that encourages self-reporting of adversarial behaviours, whether intentional or unintentional, that result or can potentially cause quality data deviations and a structure that empowers personnel to report the bad attitudes they observe about others that can adversely compromise the quality value delivery.

The experts were also asked as to *who is in charge of managing the product/service defect traceability process*. The responses captured in Table 5.24 below depict that Quality Manager (62.5%) and Production Manager (50%) received the highest frequencies among the key stakeholders for managing the product/service defect traceability process. In the field 'Other', one (1) respondent further specified key stakeholders that had not been listed: 'Customer Service' and 'Product Compliance'.

Table 5.24: Experts' responses on Key stakeholders responsible for managing the product/service defect traceability process

	Yes	No	Don't know or Prefer not to answer
Top management	12.5%	75.0%	12.5%
Engineering design team	12.5%	75.0%	12.5%
Task force	0.0%	87.5%	12.5%
Vehicle auditor	25.0%	62.5%	12.5%
Quality manager	62.5%	25.0%	12.5%
Project manager	12.5%	75.0%	12.5%
Human resource manager	0.0%	87.5%	12.5%
Purchasing and supply chain lead	25.0%	62.5%	12.5%
Owner representative	0.0%	87.5%	12.5%
Software engineering	0.0%	87.5%	12.5%
Risk analyst	0.0%	87.5%	12.5%
Manufacturing engineering	12.5%	75.0%	12.5%
IT infrastructure assessor	0.0%	87.5%	12.5%
Business process engineering	0.0%	87.5%	12.5%
Production manager	50.0%	37,5%	12.5%
Shopfloor supervisor	25.0%	62.5%	12.5%
Facility maintenance lead	12.5%	75.0%	12.5%
Line manager	25.0%	62.5%	12.5%

As depicted in Fig. 5.11 below, a *special software or tool for the defect traceability process* is mostly utilised by large companies (60%), contrasted by less than 20% of SMEs.

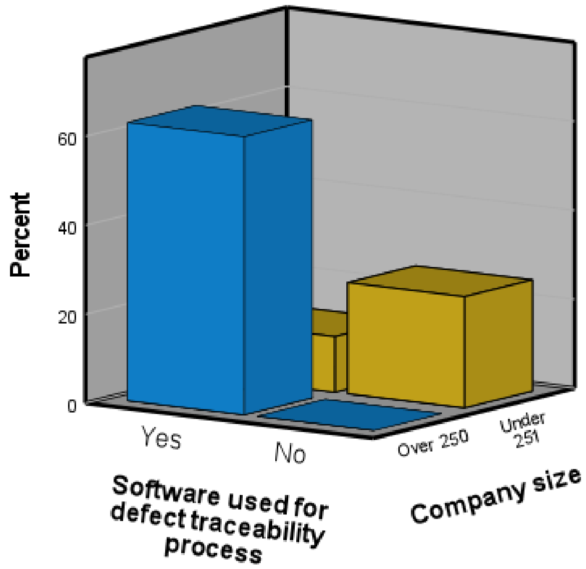


Fig. 5.11: Software or tool for the defect traceability process by Company size (experts)

Nonconforming Products

It is this research's position that a nonconforming product should not be distributed to a customer as it is practically a product that is unusable and unrepairable. On a Likert scale of 1 (Strongly Disagree) to 7 (Strongly Agree), the research cohort of experts were requested to *describe their companies' intent or standard practice and requirements for rendering nonconforming products unusable prior to final disposal*. The results are described through the following segments.

As shown in Fig. 5.12, the cohort of experts' accumulated agreement (75%) validates the following statement in each individual component case:

> *The company has developed an effective process for the identification and disposal of nonconforming products*

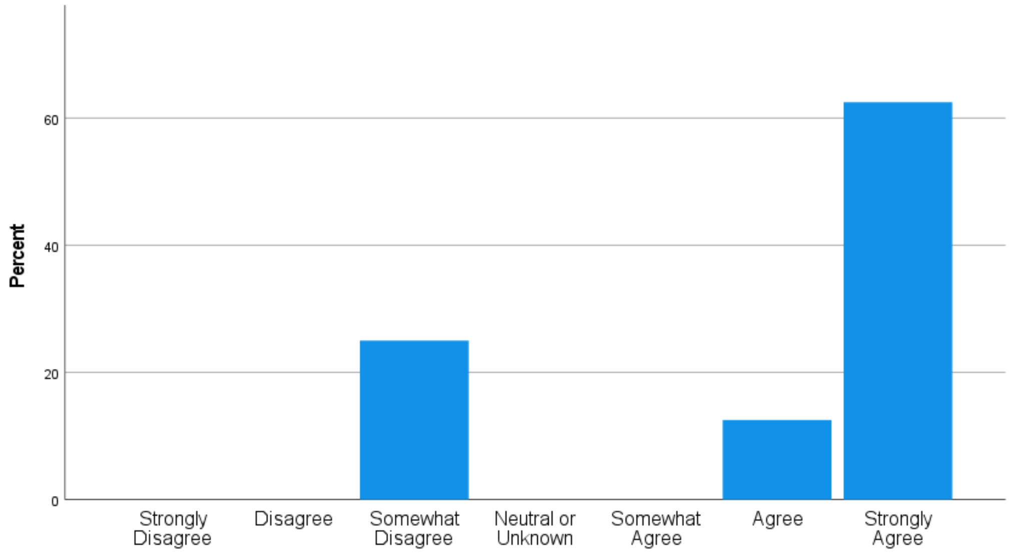


Fig. 5.12: Identification and disposition of nonconforming products (experts)

The second statement

> *The company uses an external firm to evaluate and render its nonconforming products unusable*

had a split response as the experts' accumulated agreement (37.5%) was at the same percentage level as 'Disagree' (37.5%), with 12.5% 'Unknown' and '12.5%' Missing Data (as presented in Fig. 5.13).

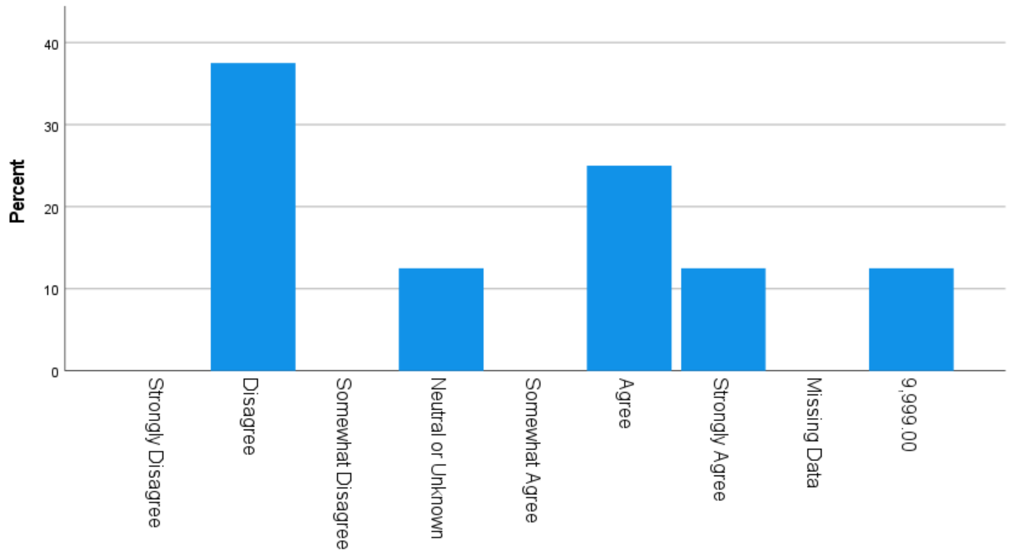


Fig. 5.13: External firm on evaluating nonconforming products (experts)

The experts were asked as to *who is responsible for ensuring nonconforming products are identified and properly disposed of*. Their responses are captured in Table 5.25 below, indicating Engineering Design Team (50%) and Quality Manager (50%) to be the key stakeholders in the cohort of experts' companies.

Table 5.25: Key stakeholders for ensuring identification and proper disposing of nonconforming products (experts)

	Yes	No	Missing Data
Top management	12.5%	75.0%	12.5%
Engineering design team	50.0%	37.5%	12.5%
Task force	0.0%	87.5%	12.5%
Vehicle auditor	0.0%	87.5%	12.5%
Quality manager	50.0%	37.5%	12.5%
Project manager	0.0%	87.5%	12.5%
Human resource manager	0.0%	87.5%	12.5%
Purchasing and supply chain lead	12.5%	75.0%	12.5%
Owner representative	0.0%	87.5%	12.5%
Software engineer	0.0%	87.5%	12.5%
Risk analyst	0.0%	87.5%	12.5%
Manufacturing engineering lead	12.5%	75,0%	12.5%
IT infrastructure assessor	0.0%	87.5%	12.5%
Business process engineering lead	12.5%	75.0%	12.5%
Production manager	25.0%	62.5%	12.5%
Shopfloor supervisor	25.0%	62.5%	12.5%
Facility maintenance manager	0.0%	87.5%	12.5%
Line manager	0.0%	87.5%	12.5%

As to whether *any special software or tool* is used to *manage the process of identifying and disposing of nonconforming products*, half of the cohort of experts (50%) entered 'Yes', while the other half (50%) negated it (see Table 5.26 for the results).

Table 5.26: Software or tool used to identify and dispose of nonconforming products (experts)

	Yes	No
Software used to identify and dispose of nonconforming products	50%	50%

On a general note, organisations that do not implement or lack QMS that aligns with standard practice are susceptible to delivering less quality value due to the following observable reasons:

- Lack of effective process for identification and proper disposal of nonconforming products (recall Fig. 5.12)

- Objective or dedicated external assessment to evaluate and properly render nonconforming products unusable (recall Fig. 5.13)
- Absence of standard monitoring or auditing activities for regular search-and-track to identify and dispose of nonconforming products (recall Table 5.26)

The next sub-section translates these lapses into functional needs.

Translating response-to-threats into functional needs

Having mapped out the factors that potentially cause automotive manufacturing organisations to deviate from the expected quality value delivery, the threats are translated into functional needs in order to help drive design parameters that can address them as functional requirements to enable SME automotive manufacturing companies to deliver more quality value just as their QMS-oriented counterparts. The following functional needs are defined against the dimensions within this Section:

1. Produce a master process to respond to personnel attitudes that vary quality design targets (coded $FR_{1.3.4}$) – relevant to responses depicted in Fig. 5.10a and Fig. 5.10b
2. Develop risk assessment scheme to identify human adversarial behaviours within the quality-of-service departments (coded $FR_{1.3.5}$) – relevant to responses depicted in Fig. 5.10a and Fig. 5.10b
3. Identify monitoring system for identifying personnel apathy towards quality design process (coded $FR_{2.10.1}$) – relevant to responses depicted in Fig. 5.10a, Fig. 5.10b, Table 5.22
4. A scheme for reporting observed human adversarial behaviours towards quality design (coded $FR_{2.10.2}$) – relevant to responses depicted in Fig. 5.10a, Fig. 5.10b, Table 5.23
5. Develop a scheme to stimulate self-reporting of adversarial behaviours against company goals (coded $FR_{2.10.4}$) – relevant to responses depicted in Fig. 5.10a, Fig. 5.10b, Table 5.23
6. Motivate/encourage personnel participation in organisational goal (coded $FR_{2.10.5}$) – relevant to responses depicted in Fig. 5.10a, Fig. 5.10b, Table 5.23
7. Determine need for in-house training of staff/personnel development knowledge in automobile safety regulations (coded $FR_{2.17.1}$) – relevant to the responses in Tables 5.17 to 5.20, Fig. 5.7
8. Develop a system for early detection of potential product safety defect (coded $FR_{2.17.2}$) – relevant to responses in Fig. 5.8, Table 5.22, Fig. 5.9

9. Develop a system to notify automotive regulatory bodies of late detection of a product safety defect (coded $FR_{2.17.3}$) – relevant to responses in Fig. 5.13
10. Standardised procedure for rendering nonconforming products unusable prior to final disposal (coded $FR_{2.17.4}$) – relevant to the responses in Fig. 5.12 and Fig. 5.13
11. Create a protocol for internal auto recall process monitoring (coded $FR_{2.17.5}$) – relevant to the responses depicted in Fig. 5.11

The above functional needs in terms of their respective FRs are treated in Chapter 6 at the integration phase.

5.3 Summary

This Chapter identifies the factors that cause non-QMS-oriented automotive organisations to deliver less quality value than those organisations in the QMS league. Based on the survey data that was screened using the statistical tool SPSS, the findings reveal that the automotive manufacturing SMEs represented by a segment of the cohort of experts are not compliant with most of the ISO-family of standards or at the least have an in-house QMS. This is evidenced by how the non-QMS-based SMEs lagged behind their counterparts who are from large organisations that are QMS-focused.

The nature of the findings were translated into functional needs and assigned with functional requirement (FR) notations. In Chapter 6, the identified FR notations will be treated in terms of identifying and defining their corresponding plausible design parameters (DPs).

Chapter 6: Synthesising Studies 1 and 2 Findings

6.1 Introduction

The objective of this Chapter is to synthesise the research findings in Study 1 (Chapter 4) and Study 2 (Chapter 5) in terms of their FR-notations and plausible corresponding DP-notations. The purpose of the latter is to integrate existing knowledge, the author's industrial experience and the research findings towards addressing RQ3. The outcome is used as input contributory data to produce the RQ3-oriented novel quality engineering framework that can be replicated and customised by automotive manufacturing SMEs irrespective of their geographic locations and cultural backgrounds. Section 6.2 focuses on identifying and defining corresponding plausible design parameters (DP_{1s}) to address the FR_1-related functional requirements in both RQ1-based Chapter 4 and RQ2-oriented Chapter 5. In Section 6.3, the corresponding design parameters (DP_{2s}) for the FR_2-related functional requirements derived from RQ1-based Study 1 and RQ2-focused Study 2 are outlined. The integration of the RQ1- and RQ2-based FRs is used to optimise the initial QX Engineering framework, leading to addressing RQ3 in Chapter 7. Section 6.4 presents a chapter summary.

6.2 Defining and mapping corresponding DP_{1s} to RQ1- and RQ2-based FR_{1s}

Based on the axiomatic design approach adopted in Chapter 3 in designing the initial QX Engineering system in Table 3.8 and Table 3.9, the plausible corresponding DP_{1s} to address each of the associated quality problem statement or functional needs, which are coded in terms of functional requirements as FR_{1s} in Study 1 and Study 2, are defined in the following segments.

6.2.1 Quality competent-rich manufacturing system/environment ($FR_{1.1}$)

In order to achieve a high-level quality competent personnel/staff across all units/departments ($FR_{1.1}$) as well as to map out a blueprint for quality assurance manufacturing organisation ($DP_{1.1}$), the corresponding DP_{1s} against the earlier defined FR_{1s} that are relevant to standards awareness and compliance, quality knowledge, quality design documentation, ISO standards, QMS, standards implementation, management mindset, management support, Top Management's operational activities, quality of service, core quality competence development, and continuous improvement, are identified and defined in the matrix below.

Table 6.1: Identifying and defining corresponding DP1s to satisfy RQ1- and RQ2-based FR_{1s}

RQ1-RQ2-FR_{1s}	Corresponding Design Parameters (DP_{1s})	
$FR_{1.1.1}$	$DP_{1.1.1}$	Design a career enrichment and continuing professional qualification development training programme in core quality tools (including FMEA, SPC, QFD, Six Sigma, Lean Management, PPAP, APQP, MSA, Heijunka, Mizusumashi, etc.)
$FR_{1.1.2}$	$DP_{1.1.2}$	Design multipurpose quality standards training programmes (including ISO 9001, ISO 14001, ISO 26262, ISO 45001, AEC-Q100 & AEC-Q200, IATF 16949:2016) across all relevant units or departments
$FR_{1.1.3}$	$DP_{1.1.3}$	Design a roadmap for identifying weaknesses, gaps and noise in ISO 9001, ISO 14001, ISO 26262, ISO 45001, AEC-Q100 & AEC-Q200, IATF 16949:2016 and associated procedures
$FR_{1.1.4}$	$DP_{1.1.4}$	Design introductory training programme for developing familiarity with all the major internationally known automotive manufacturing sector regulators (including Automotive Council UK, NHTSA US, TÜV Germany)
$FR_{1.1.5}$	$DP_{1.1.5}$	Design training programme in manufacturing equipment standarisation (MES) across shopfloor and relevant units

In recalling Table 3.8 (Chapter 3), the initial definitions of $FR_{1.1.1}$ to $FR_{1.1.5}$ and their corresponding $DP_{1.1.1}$ ro $DP_{1.1.5}$ were modified to specifically target the derived RQ1- and RQ2-based FRs. $FR_{1.1.5}$ and $DP_{1.1.5}$ are introduced.

6.2.2 Create in-house quality implementation procedure documentation

The research context is pivoted on stimulating SMEs in the automotive manufacturing industry to tap into their indigenous knowledge system to design engineering solutions to develop their own indigenous knowledge system (IKS)-based quality management system (QMS) to design quality implementation into their existing process. This resulted in defining the functional requirement as expressed in $FR_{1.1.6}$ below. The corresponding design parameter required to achieve $FR_{1.1.6}$ is defined by the notation $DP_{1.1.6}$. This will also satisfy the functional requirement of continuous improvement, management support, Top Management's operational activities, departmental support, quality of service, standards awareness and compliance.

$FR_{1.1.6}$: Develop customised, in-house, indigenous knowledge system (IKS)-based hierarchy for quality implementation processes, procedures and work instructions

$DP_{1.1.6}$: Design company's IKS-based quality standard and implementation procedures that exceeds the expectations of QMS-based ISO family of procedures

With reference to Table 3.8 (Chapter 3), $FR_{1.1.6}$ and $DP_{1.1.6}$ are a new introduction.

6.2.3 Developing a sustainable core quality capability

Having observed a need for a sustainable quality capability skillset development, the matrix below defines the associated design parameters. These will satisfy the functional requirements of quality knowledge development, core quality competence building, process monitoring, standards implementation, and management support.

$FR_{1.1.7}$	$DP_{1.1.7}$	Design a reward system to stimulate capacity-building in core quality systems, continuing professional enrichment and mastery of firm's IKS-based quality
$FR_{1.1.8}$	$DP_{1.1.8}$	Design internal skills audit procedures
$FR_{1.1.9}$	$DP_{1.1.9}$	Design procedures for auditing quality capacity-building training programmes

In recalling Table 3.8 (Chapter 3), the definitions of the previous $FR_{1.1.7}$ to $FR_{1.1.9}$ and their corresponding $DP_{1.1.7}$ to $DP_{1.1.9}$ were substantially modified to reflect on the findings in RQ1-based Study 1 (Chapter 4) and RQ2-based Study 2 (Chapter 5).

6.2.4 Documentation for procedures and internal audits process

In order to address the functional need of creating a Standard Operating Procedures (SOP) across all departments or units within automotive manufacturing SMEs, internal auditing and template for company-wide procedures, $DP_{1.1.10}$ to $DP_{1.1.13}$ are introduced as mapped against the earlier defined $FR_{1.1.10}$ to $FR_{1.1.13}$. The DPs in the matrix below will also satisfy requirements for process monitoring, management support, and Top Management's operational activities.

$FR_{1.1.10}$	$DP_{1.1.10}$	Standard Operating Procedures (SOP) for internal audit process, internal audit reporting, and corrective actions
$FR_{1.1.11}$	$DP_{1.1.11}$	Design QX Task Force & Top Management SOP's for review of internal audit
$FR_{1.1.12}$	$DP_{1.1.12}$	Design individual QX-oriented SOP for departments or unit
$FR_{1.1.13}$	$DP_{1.1.13}$	Design QX Engineering-based reference documentation, outlining processes that satisfy compliance with automotive body standard requirements (including IATF 16949:2016 statutory and regulatory requirements, etc.)

6.2.5 Enhance continuous quality performance monitoring

Based on the research participants' collective responses oriented on the voice of the consumer, management support, continuous improvement, manufacturing Facility Director/Manager and quality of service, the originally defined $DP_{1.2.4}$ in Table 3.8 (Chapter 3) is modified as shown in the matrix below, in order to adequately satisfy $FR_{1.2.4}$.

$FR_{1.2.4}$	$DP_{1.2.4}$	Product-oriented and or service-based QX-oriented manufacturing facility layout to minimise waste
$FR_{1.2.6}$	$DP_{1.2.6}$	Design quality performance monitoring protocol at internal departmental level and the value chain

Apart from modifying the previous $DP_{1.2.4}$, $DP_{1.2.6}$ is introduced as mapped against $FR_{1.2.6}$ in order to satisfy the requirements for stimulated *continuous quality performance monitoring* across all departments/units.

6.2.6 Enabling continual improvement

Based on the findings in Chapter 4 and Chapter 5, the initially defined process strategy to enable continual improvement ($FR_{1.3}$) in Table 3.8 (Chapter 3) is substantially modified. Mapped across $FR_{1.3.1}$ to $FR_{1.3.4}$, the corresponding $DP_{1.3.1}$ to $DP_{1.3.4}$ were significantly modified as shown in the matrix below. In order to also partially satisfy the requirements for auto recall handling, management support, VOC, quality of service, risk assessment, process monitoring, continuous monitoring, and continuous improvement, $DP_{1.3.5}$ and $DP_{1.3.6}$ were introduced to address $FR_{1.3.5}$ and $FR_{1.3.6}$ respectively.

$FR_{1.3.1}$	$DP_{1.3.1}$	Design procedure for selecting quality-based process to achieve KPIs and objectives
$FR_{1.3.2}$	$DP_{1.3.2}$	Design information pool and report system of domestic environmental and automotive regulatory policy objectives
$FR_{1.3.3}$	$DP_{1.3.3}$	Design a continuous feedback information flow system to map out customer-determined quality dimensions
$FR_{1.3.4}$	$DP_{1.3.4}$	Standardise master process selection for addressing human behaviours that vary quality design process
$FR_{1.3.5}$	$DP_{1.3.5}$	Design risk assessment scheme to monitor human adversarial behaviours, focused on quality of service
$FR_{1.3.6}$	$DP_{1.3.6}$	Design optimised customer-centric quality of service for the supply chain, including affiliated auto dealerships

6.3 Defining and mapping corresponding DP_{2s} to RQ1- and RQ2-based FR_{2s}

As established earlier in Table 3.9 (see Chapter 3), FR_2 is defined for minimising cost for deriving the design solution to satisfy all the FRs required to achieve the high-level functional requirement, FR_0. Based on the FRs derived from the functional needs with respect to the findings in RQ1-focused Chapter 4 and RQ2-oriented Chapter 5, the corresponding DPs are defined as presented in the following segments.

6.3.1 Achieving organisation-wide QX Engineering Design buy-in ($FR_{2.1}$)

Based on the lessons derived from the responses the cohort of experts presented about their opinions regarding management mindset and support for departmental operational activities, including process monitoring, it suffices to propose a QX buy-in across Top Management and shopfloor. This necessitated the need to revamp the previously defined $FR_{2.1}$ and associated decompositions in Table 3.9 (Chapter 3). This resulted in the earlier defined $FR_{2.1.1}$ to $FR_{2.1.4}$. The corresponding DPs are defined as shown in the matrix below.

RQ1-RQ2-FR_{2s}		**Corresponding Design Parameters (DP_{2s})**
$FR_{2.1.1}$	$DP_{2.1.1}$	Design QX Task Force
$FR_{2.1.2}$	$DP_{2.1.2}$	Procedure for Top Management buy-in
$FR_{2.1.3}$	$DP_{2.1.3}$	Procedure for Mid-level Management buy-in
$FR_{2.1.4}$	$DP_{2.1.4}$	Procedure for QX buy-in across all departments
$FR_{2.1.5}$	$DP_{2.1.5}$	Design procedure for internal audit of QX practice

6.3.2 Eliminating non-valued added resources ($FR_{2.3}$)

In order to eliminate manufacturing waste associated with process monitoring, continuous improvement, and management support activities, the previously defined corresponding $DP_{2.2}$ in Table 3.9 (Chapter 3) is modified as shown in the matrix below.

$FR_{2.3}$	$DP_{2.3}$	QX Task Force procedures

6.3.3 Capturing quality defects

In order to process and map-out manufacturing quality defects and related quality issues, the initially defined $DP_{2.4.4}$ in Table 3.9 (Chapter 3) is modified as depicted in the matrix below. A second parameter, $DP_{2.4.5}$, mapped against $FR_{2.4.5}$ is introduced to further address quality issues relevant to process monitoring, Top Management operational activities, and management support.

$FR_{2.4.4}$	$DP_{2.4.4}$	QX quality process integrated with select relevant quality tool
$FR_{2.4.5}$	$DP_{2.4.5}$	QX Task Force process monitoring procedure

6.3.4 Mitigating against adversarial behaviours towards QX Engineering Design ($FR_{2.10}$)

To address the need to design a system for tracking social (human) actors' adversarial behaviours against QX Engineering Design process ($DP_{2.10}$), new design parameters are introduced as shown in the matrix below. These will partly address the functional requirements for continuous monitoring, risk assessment, Top Management operational activities, auto recall handling, and quality of service.

$FR_{2.10.1}$	$DP_{2.10.1}$	Procedure for objective identification of personnel apathy across all departments and analysis
$FR_{2.10.2}$	$DP_{2.10.2}$	Design solution-oriented system to address adversarial behaviours through transformational lens
$FR_{2.10.3}$	$DP_{2.10.3}$	Procedure for risk assessment based on personnel apathy behaviours
$FR_{2.10.4}$	$DP_{2.10.4}$	Design conflict resolution and personnel support system in the event of departure from company goals
$FR_{2.10.5}$	$DP_{2.10.5}$	Reward-sharing programmes

6.3.5 Mitigation against top management non-committal attitudes ($FR_{2.11}$)

Based on the responses as related to Top Management's operational activities, $FR_{2.11}$ is introduced purposely to help *determine top management non-committal towards quality implementation process and overall organisational goal*. The corresponding $DP_{2.11}$ is defined as in the matrix below.

$FR_{2.11}$	$DP_{2.11}$	Mitigation solution for top management non-committal attitudes

During the interview phase, the research participant of the expert cohort (RP00004) from an automotive manufacturing and design engineering SME sector was asked as to how much management within automotive manufacturing organisations care about auto recalls and if there are consequences due to human adversarial behaviours. RP00004 responded (AS IS) as follows:

> *"I think many people don't care. Once you are at a big car company, you don't have to take care; it is almost impossible to be fired because of that in [country name withheld]. And if they have followed the procedure like they are taught, there is no way to be fired. I have a friend who is a manager at [large and top brand automotive manufacturing organisation name withheld]. He said he doesn't care about money because it is not his own money. It is the money of the stock holder. And who has to pay? The customer. And they pay. That is his mind. Once the image is there, everybody is going to buy the [brand name withheld] cars. It is quite easy to exploit the value of an image. The clue is to set up an image. It is not any discussion about ISO 9001 or something like that but about the buying customer.*

The deduction from the above response is that top management or top internal stakeholders, particularly, within large automotive manufacturing organisations are not held accountable to face individual consequences. While it is common or general public knowledge that any affected automotive manufaturing organisation loses substantially due to auto recalls, such an assertion or claim as made by a Manager of a large automotive organisation implies that there is an element of belief that follows that the financial implication in the aftermath of a recall is distributed over the stock holders and the consumers. To address this component, the following decompositions of $FR_{2.11}$ are proposed and their corresponding DPs defined.

$FR_{2.11.1}$:	Conduct risk assessment to minimise top management non-committal attitudes
$FR_{2.11.2}$:	Pull top management's commitment to goal
$DP_{2.11.1}$:	Produce for conducting risk assessment based on top management non-committal behaviours
$DP_{2.11.2}$:	Gain-sharing programmes

6.3.6 Reducing factors of risks to the design process

To ensure a sustainable quality design process and enhance continuous improvement, the previously defined $FR_{2.13}$ in Table 3.9 (Chapter 3) is revamped and a new parameter necessary to help *determine agents of risks to the design process ($FR_{2.13.1}$)* is introduced. The corresponding plausible design parameter ($DP_{2.13.1}$) is defined as presented in the matrix below.

$FR_{2.13.1}$	$DP_{2.13.1}$	Procedure for identifying human agent risk factors

6.3.7 Enabling consistency with standards requirements

In order to enable automotive manufacturing SMEs to achieve consistency with regulatory and standards requirements, the previously defined $FR_{2.15.2}$ in Table 3.9 (Chapter 3) is modified in order to better address the related responses from the cohort of expert within the dimensions of continuous improvement and SOP. This also led to the modification of the previously defined $DP_{2.15.2}$. The updated version of the latter is presented in the matrix below.

$FR_{2.15.2}$	$DP_{2.15.2}$	Standard Operating Procedures (SOP) based on requirements for confirming with regulatory authority standard

6.3.8 Developing highly responsive system to address auto recall issues ($FR_{2.17}$)

The research participants' responses as related to auto recalls, safety recalls, auto recall handling, safety regulations, defect traceability and other related dimensions reveal a plethora of safety and recall management issues that require automotive manufacturing organisations to be very responsive. As the research findings suggest that SMEs that are outside the QMS-league are at disadvantage considering the number of protocols or procedures involved in addressing auto recall related issues. It is in this direction and in addition to this research interest in defect traceability, among similar others, that a new segment that is dedicated to auto recall issues is introduced towards the optimisation of the proposed QX Engineering System. The DPs defined for $FR_{2.17.1}$ to $FR_{2.17.4}$ are presented in the matrix below.

$FR_{2.17}$	$DP_{2.17}$	Design highly responsive system to address auto recall issues
$FR_{2.17.1}$	$DP_{2.17.1}$	Design training programme in automobile safety regulations, featuring adherence to code of practice of safety
$FR_{2.17.2}$	$DP_{2.17.2}$	Effective system for early safety defect detection and documented procedures in the event of a recall
$FR_{2.17.3}$	$DP_{2.17.3}$	System for notifying automotive regulatory bodies of late (or early) detection of a product safety defect pre-delivery (or post-delivery) or both
$FR_{2.17.4}$	$DP_{2.17.4}$	Design and document standardised procedure for rendering nonconforming products unusable prior to final disposal

As set forth earlier in Chapter 3, one of the important key stakeholder functionalities is to maintain a continuous monitoring of processes to ensure any variants are promptly identified and addressed along the quality value stream. As auto recall ($FR_{2.17}$) is associated with very high financial implications apart from the reputation damaging effect in the aftermath of bad publicity (see Chapter 2 on *Auto recalls*), it is sometimes difficult to ascertain industry survival solutions. In maximising mitigation solutions, the following related functional requirement ($FR_{2.17.5}$) was identified to optimise the initial design into having the internal quality process vigilante (QX Task Force) develop systems to enable continuous monitoring processes as well as developing a rapid response mechanism to address any recall or product defect issues.

$FR_{2.17.5}$: Create QX Task Force protocol for internal auto recall process monitoring

$DP_{2.17.5}$: Develop internal auto recall response process monitoring

6.3.9: Developing a system to mitigate quality performance disruptions presented by emerging technologies

Within the context of this research, *emerging technologies* (prominently featured in RQ1-based Chapter 4) will challenge existing manufacturing systems to either adapt or coevolve with the changing environment. The disruptions the advent of emerging technologies create can also make conventional manufacturing organisations to be susceptible to pseudo-extinction. The focus of this research is to enable SMEs to achieve high-level quality engineering culture or status, irrespective of the market uncertainties the myriad of problems emerging technologies create. Recognising the need to optimise the initial QX Engineering design, regardless of whether the target SME user is engaged in emerging technologies or not, the new quality engineering framework is intended to enable organic customisation. The latter will enable the design to adapt to changing requirements. With reference to the problem statements associated with *emerging technologies* as presented in the findings in RQ1-based Study 1, the quality associated problem statements that were translated into functional needs and assigned FR notations, are treated with their corresponding design parameters in the matrix below.

$FR_{2.18.n}$	Corresponding Design Parameters ($DP_{2.18.n}$)	
$FR_{2.18.1}$	$DP_{2.18.1}$	Contingency design against disruption by Connected Automobile
$FR_{2.18.2}$	$DP_{2.18.2}$	Design market entry schemes against sales decline caused by increased Connected Automobile demand
$FR_{2.18.3}$	$DP_{2.18.3}$	Manufacturing strategies for optimised engineered tyres
$FR_{2.18.4}$	$DP_{2.18.4}$	Mitigation solution against threat to business existence
$FR_{2.18.5}$	$DP_{2.18.5}$	Integrate existing manufacturing processes complex adaptive system (CAS) response mechanism cost-resource-effectively
$FR_{2.18.6}$	$DP_{2.18.6}$	Optimise mitigation solutions against human adversarial behaviours against quality designs
$FR_{2.18.7}$	$DP_{2.18.7}$	Develop adaptive design, without need to couple software-hardware, to satisfy customer-centric uncertain demand patterns
$FR_{2.18.8}$	$DP_{2.18.8}$	Minimise dependency on extensive software integrated systems and design mitigation solution against cyber attacks
$FR_{2.18.9}$	$DP_{2.18.9}$	Optimise safety information dissemination and disrupt misleading information in public domain

6.4 Summary

In this Chapter, the FRs derived from the findings in RQ1-based Chapter 4 (Study 1) and RQ2-based Chapter 5 (Study 2) were integrated together along with their corresponding design parameters (DPs). Mapped against the initial QX Engineering Framework design in Table 3.8 and Table 3.9 in Chapter 3, the new parameters will be used as contributory input data to optimise the initial QX Engineering Framework. This further integration of the input data from the integrated findings in Chapter 4 and Chapter 5 will address RQ3 in Chapter 7.

Chapter 7: A Novel Strategy for the Development of QX Engineering Design

7.1 Introduction

Situated within the context of this research, the objective of this Chapter is to take the findings from RQ1-based Study 1 in Chapter 4 and RQ2-based Study 2 in Chapter 5, which were integrated in Chapter 6 in FR—DP notation terms, and use them as input contributory parameters to optimise the initial QX Engineering Design. This will answer the research question (RQ3) below:

> *How can automotive manufacturing organisations overcome the variables that impede the hybridisation and implementation of engineering quality management system (QMS)? Study 3*

Based on the findings in Study 1 and Study 2, this Chapter will address RQ3 via the following outline:

1. Refine aspects of the initial QX Engineering Design (see Table 3.8 and Table 3.9 in Chapter 3)
2. Modify key stakeholders' functions, goals and requirements (first proposed in Table 3.1 in Chapter 3)
3. Enrich the highest-level functional requirement (FR_0) and its corresponding DP_0 as well as their associated decomposed FR_1 and FR_2
4. Integrate RQ1-based and RQ2-based FR-DP into initial QX Engineering Design
5. Chapter summary, proposing submission of optimised QX Engineering Design for review

7.2 Remodifying initial model for developing QX Engineering Design

Validating formation of key stakeholders

Based on the lessons derived from the literature review in Chapter 2, three key stakeholders were defined in Chapter 3 as integral to the development of the proposed QX Engineering Design. However, to ascertain the key stakeholders defined earlier within the context of this research, the research participants of experts were asked to identify *"who is responsible for the…"* in relation to all the departmental functional operations and activities. The findings, as depicted in Fig. 7.1a – Fig. 7.1r, show that the stakeholders prominently mapped across the various responsibilities are as follows:

1. Engineering Design Team (Fig. 7.1b)
2. Quality Manager/Director (Fig. 7.1e)
3. Top Management (Fig. 7.1a)
4. Internal/Vehicle Auditor (Fig. 7.1d)

One key observation is that the research participants of experts from the large organisation domain featured mostly different personnel positions throughout this segment. The cohort of the SME category, however, were very low in terms of numbers and, in some cases, registered no personnel to any position with regards to Internal/Vehicle Auditor (Fig. 7.1e), Purchasing Supply Chain Lead (Fig. 7.1h), Software Engineer (Fig. 7.1j), and IT Infrastructure (Fig. 7.1m). This cohort also registered very low for Human Resource Manager (Fig. 7.1g) and Risk Analyst (Fig. 7.1k). However, one of the core personnel positions that featured prominently in the SME cohort responses was Top Management.

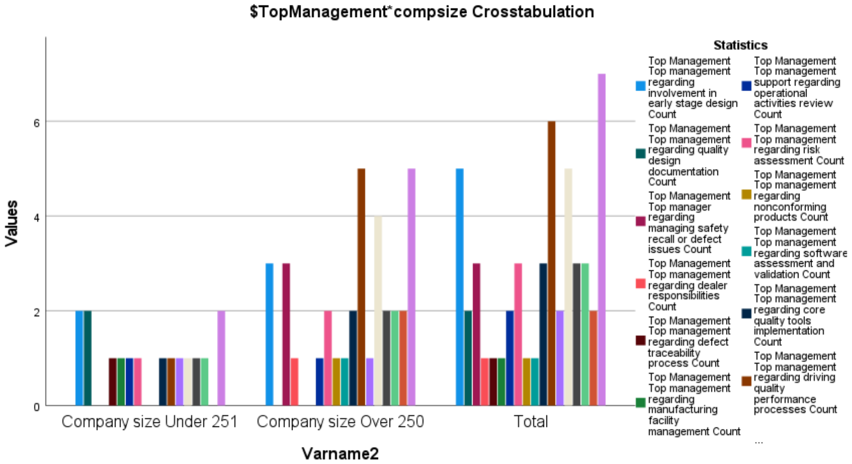


Fig. 7.1a: Top Management responsibilities

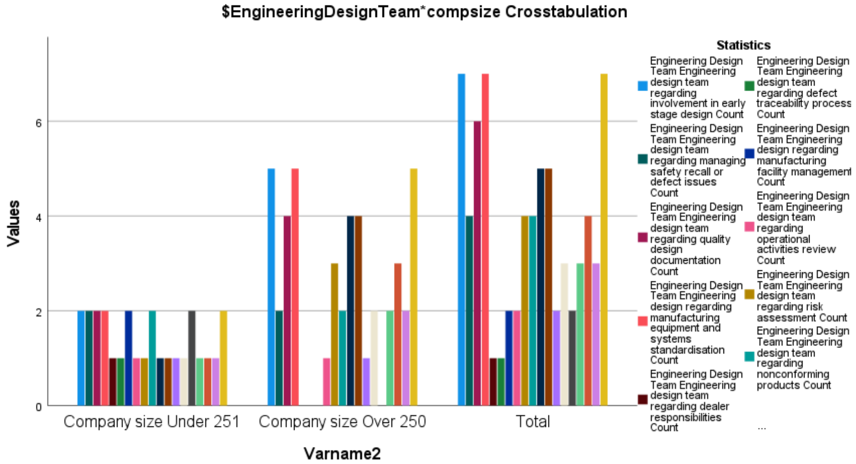


Fig. 7.1b: Engineering Design Team responsibilities

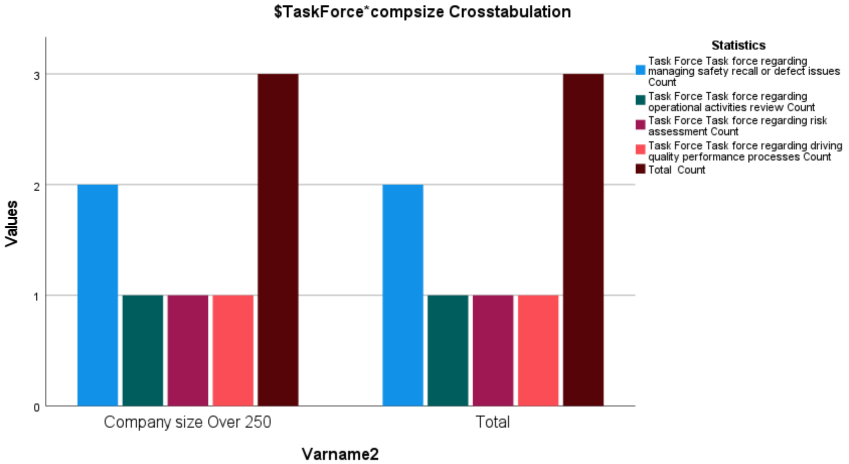


Fig. 7.1c: Task Force responsibilities

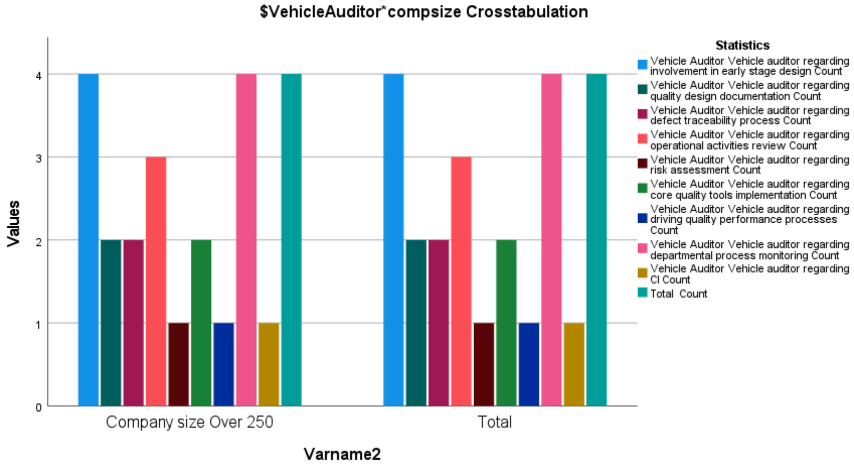


Fig. 7.1d: Internal/Vehicle Auditor responsibilities

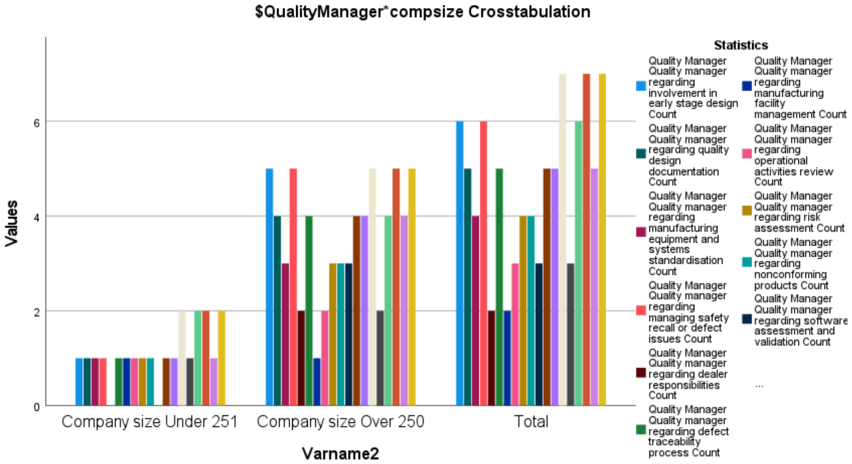


Fig. 7.1e: Quality Manager/Director responsibilities

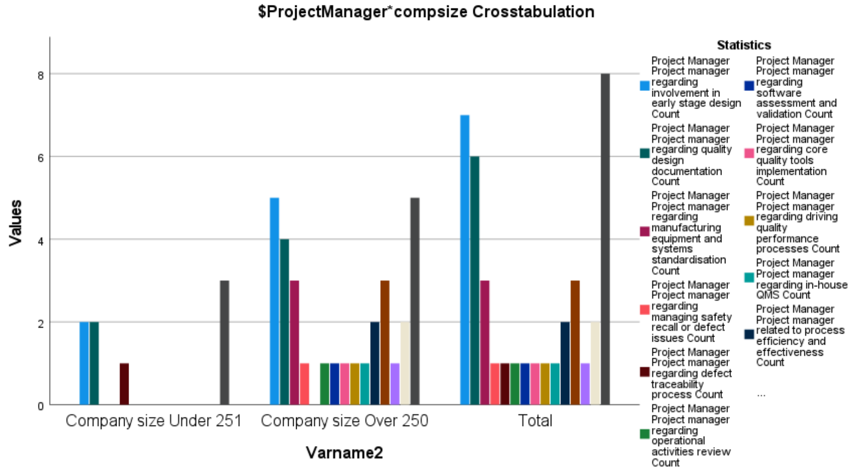


Fig. 7.1f: Project Manager responsibilities

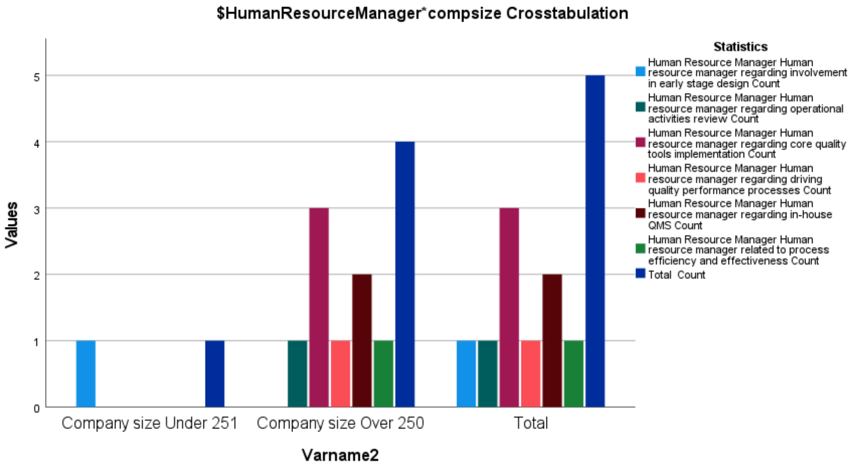


Fig. 7.1g: Human Resource Manager responsibilities

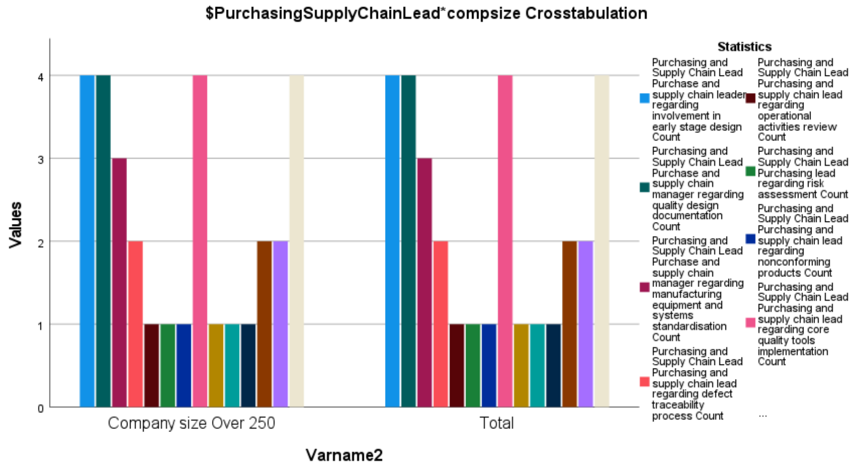
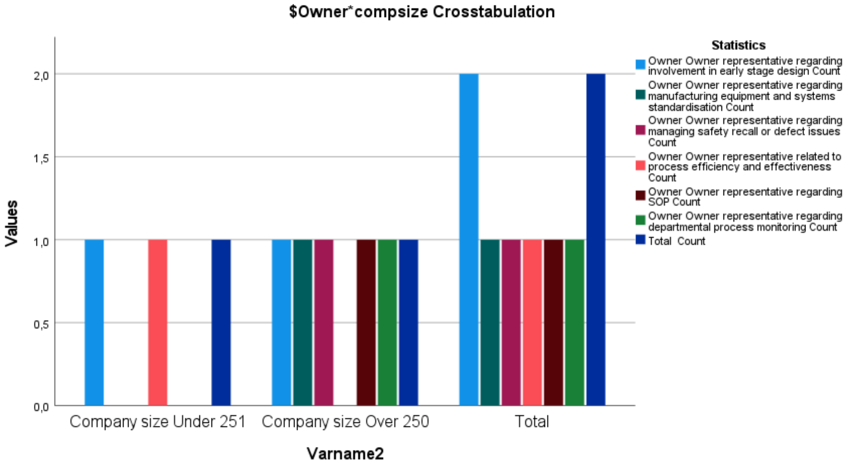


Fig. 7.1h: Purchasing and Supply Chain Lead responsibilities



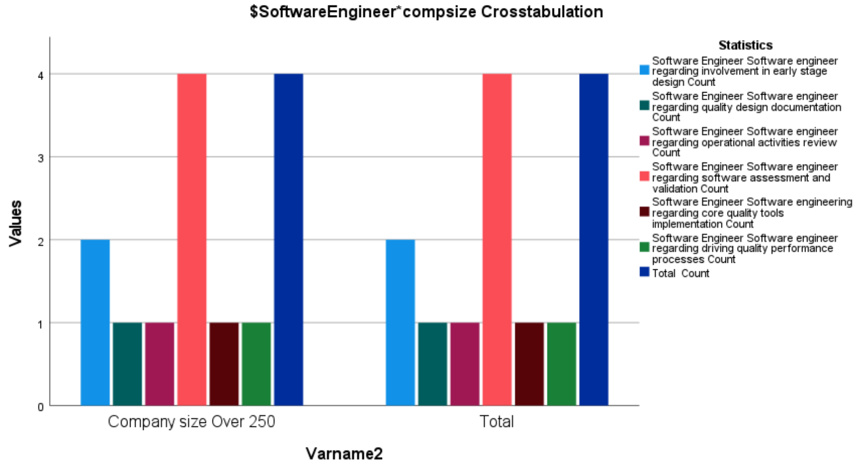
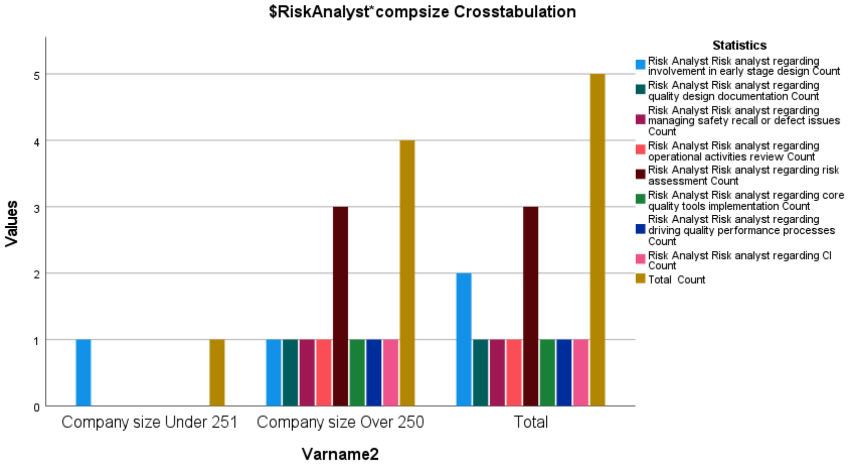


Fig. 7.1i: Owner or Owner Representative responsibilities

Fig. 7.1j: Software Engineer responsibilities



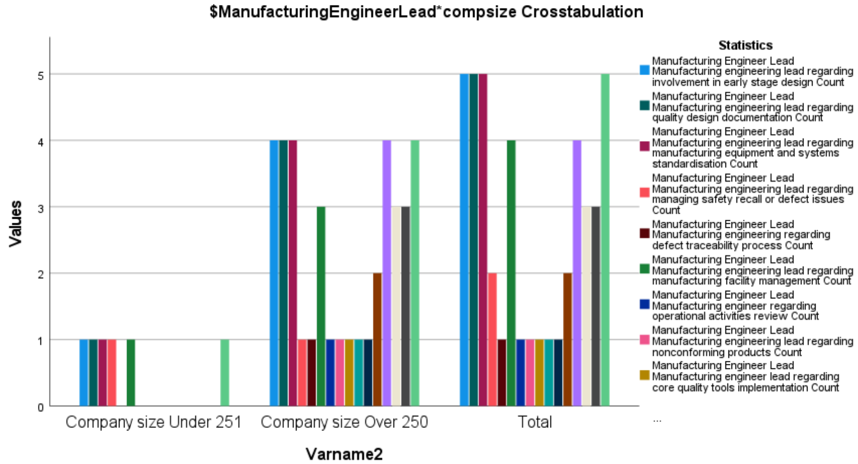


Fig. 7.1k: Risk Analyst responsibilities

Fig. 7.1l: Manufacturing Engineer Lead responsibilities

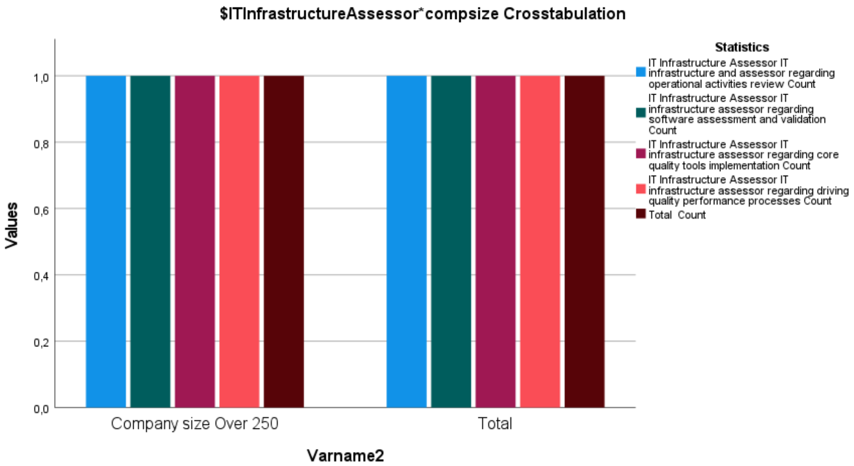


Fig. 7.1m: IT Infrastructure Assessor responsibilities

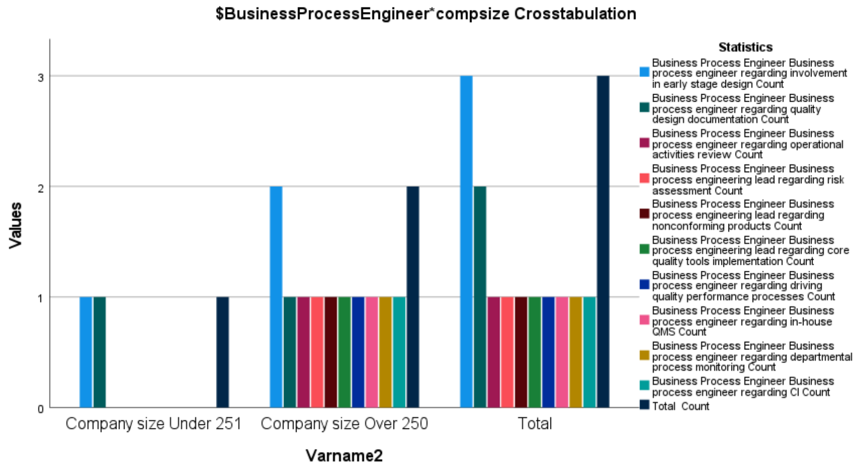


Fig. 7.1n: Business Process Engineer responsibilities

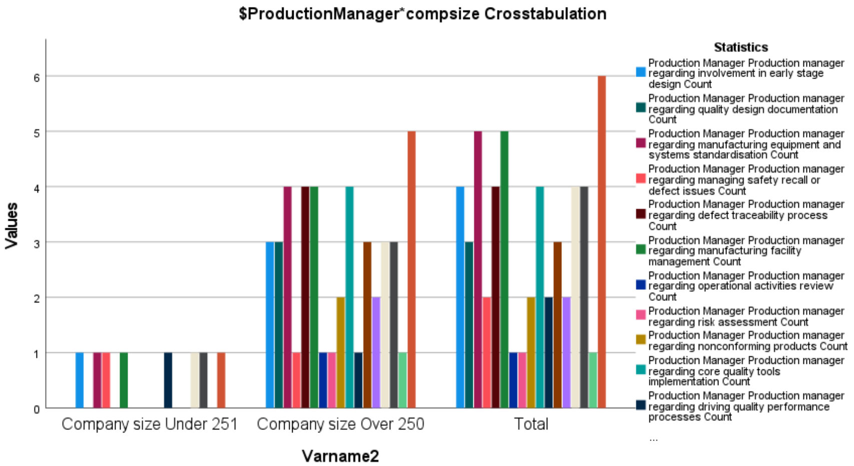


Fig. 7.1o: Production Manager responsibilities

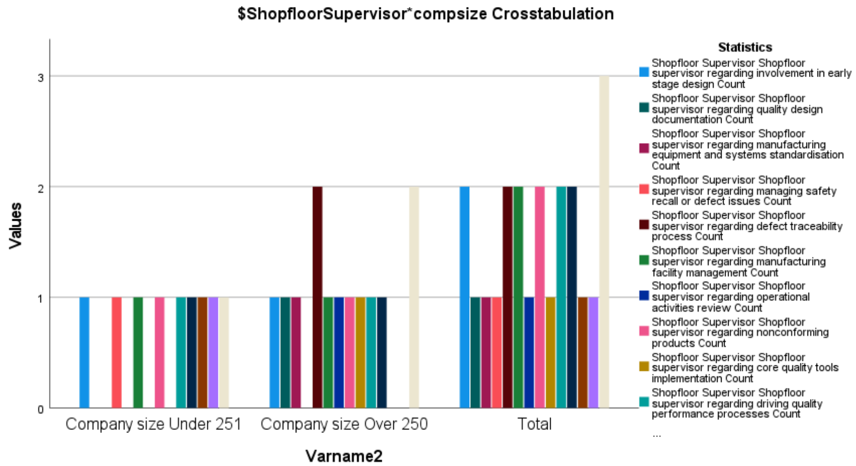
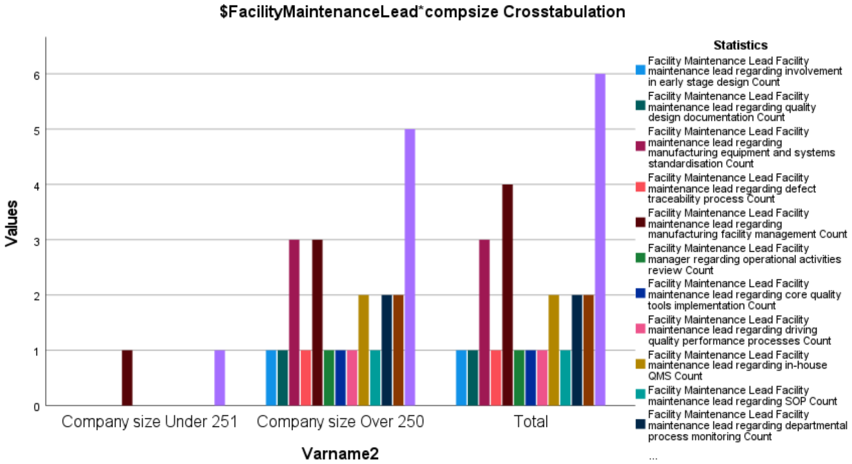


Fig. 7.1p: Shopfloor Supervisor responsibilities



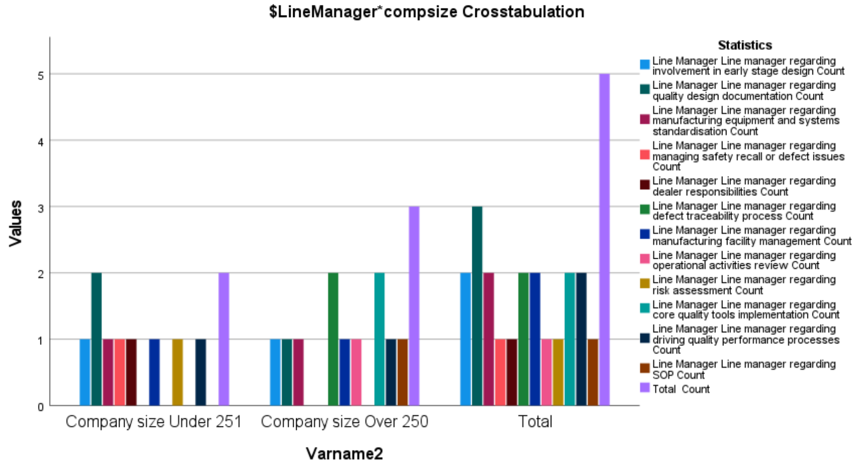


Fig. 7.1q: Facility Maintenance Lead responsibilities

Fig. 7.1r: Line Manager responsibilities

Fig. 7.1: Research participants' responses to person responsible for operational activities

Given the above findings, the initial model for developing QX Engineering Design, which was first established in Chapter 3, is modified to feature the following significant elements:

- To mitigate against the adverse effect in the aftermath of overreliance on Top Management within SMEs for every major strategic decision-making from the start of company's goals statement to the end of delivery, the following are proposed to modify the Key Stakeholder setup.
    - ✓ Top Management (whether they are company owners or next of kin or are the originator of the company's goals and related targets) selects two core stakeholder groups, namely a QX Design Team and a QX Task Force.
    - ✓ Top Management shares ownership of its goals and desires for the company with QX Design Team and QX Task Force, purposely to stimulate a debate in order to exhaust the pros and cons. This can potentially lead to a total buy-in (such as established by $FR_{2.1}$, $FR_{2.1.2}$–$FR_{2.1.4}$) by QX Design Team and QX Task Force, leading to balanced or shared responsibilities and mutual ownership of the organisational goals.

With reference to the originally developed stages required for developing the initial QX Engineering Design in Fig. 3.1, the following modifications are made and depicted in Fig. 7.2 below:

1. Key Stakeholders: Top Management, QX Design Team and QX Task Force
    a. Top Management, QX Design Team and QX Task Force are Key Stakeholders to champion quality-focused organisational-wide manufacturing operations and product and service families
2. Stage 1: Stakeholders define organisational QX Engineering Design goals
3. Stage 2: QX Design Team develops framework for QX Engineering Design
4. Stage 3: QX Task Force researches and documents potential quality performance variants (external and internal), based on the changing requirements, market uncertainties, regulatory requirements, customer-centric demand patterns, etc., and documents them periodically. This aspect is necessary to identify human adversarial behaviours to enable countermeasures throughout the span of the quality design
5. Stage 4: QX Design Team and QX Task Force create QX Engineering Design to mimic a complex adaptive system (CAS) in terms of being able to adapt to the changing requirements (as coevolving)

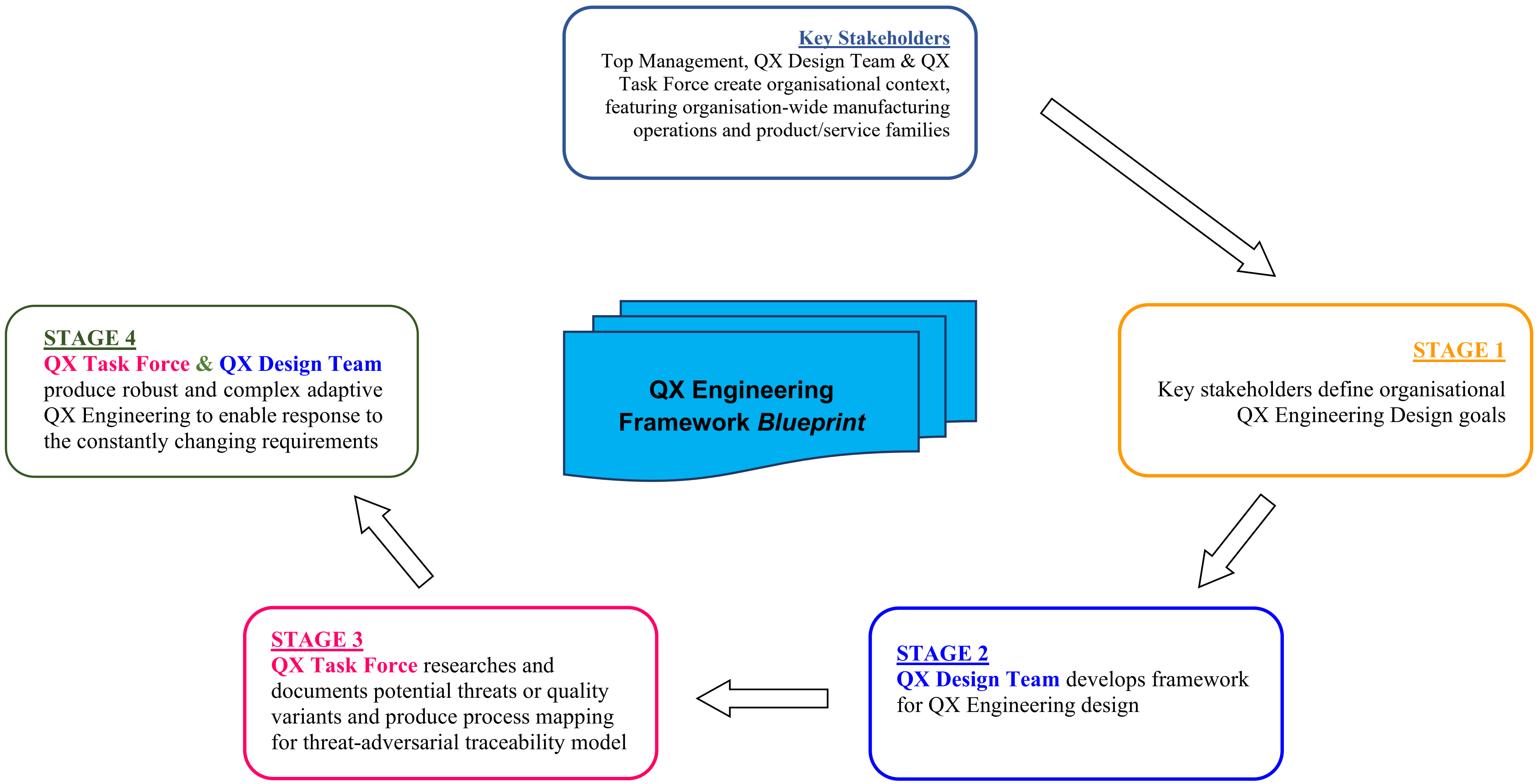


Fig. 7.2: Modified stages for developing QX Engineering design (by author)

While the first two process stages defined earlier in Chapter 3 hold, the previously defined third stage in Chapter 3 is absorbed into new third and fourth stages as follows:

3. QX Task Force – In the third stage, the QX Task Force takes a cost-effective approach to conduct periodical process reviews, focusing attention on the potential variants of quality performance based on the constantly changing requirements, market uncertainties, human adversarial behaviours (externally and internally), automotive/environmental regulatory bodies' requirements, customer-centric demand patterns, etc. The QX Task Force documents the findings and occasionally holds Key Stakeholder meetings to inform design decisions.
4. QX Design Team and QX Task Force – In the fourth stage, QX Design Team and QX Task Force optimise QX Engineering Design to mimic a Complex Adaptive System (CAS) to enable the design to coevolve with the dynamics of the constantly changing automotive manufacturing environment. This is to ensure the design will be highly responsive. The modified or optimised QX Engineering Design will offer the benefit of responding to social (human) actors' adversarial behaviours by having countermeasures in place timeously.

7.3 Modifying key stakeholder functional goals and requirements

As it had been established earlier in Chapter 1, regarding the need to design a novel quality engineering system for SMEs in the automotive industry, the research takes into account the need to identify contributory input parameters from the research participants. This was a necessary step to reduce or prevent the author's own biases in wholly deciding the functional goals and requirements for the target sector without a voice of the consumer (VOC) and experts within the automotive manufacturing industry. In this regard, and as part of exploring the applicability of the proposed QX Engineering Design, the research participants of a cohort of experts were asked to …

> *…provide information on what [you] think are the main underlying factors that make it difficult for automotive manufacturing companies to successfully implement a quality system for a combination of more than one quality system to enhance the quality performance of their manufacturing operations.*

The majority (75%) of the experts (RP00003 to RP00008) that answered the above RQ3-related qualitative survey question provided their experiential opinions in the following context:

1. RP00003, from an SME firm, responded that *"We should know well about our company's product and process and we should adopt what quality management system is best for them"*

   Based on RP00003's response, the following functional requirements are derived:

   a. $FR_{RP00003.1}$: Develop extensive knowledge in organisation's product and manufacturing processes
   b. $FR_{RP00003.2}$: Adopt QMS that is best to satisfy $FR_{RP00003.1}$

2. RP00004, from an SME, responded that: *"The free mind of thinking is getting lost by modern education system"*

   Based on RP00004's response, the following FR is derived:

   a. $FR_{RP00004.1}$: Develop a system to enable project/solution-based knowledge development, creativity and innovation

3. RP00005, from a large organisation, responded that: *"Quality management need[s] to balance the managements from the major functions including PE, ME, Supply Chain, Sales, Customer Service, etc. This involves strategic works and also operational level works, the complexity of products and noise, competition from the market also make it a major concern for automotive business"*

   Based on RP00005's response, the following FRs are derived:

   $FR_{RP00005.1}$: Design QMS implementation to accommodate company-wide functional operations

4. RP00006, from a large organisation, responded as follows:

   a. (1) *"Management support. A strong quality mindset of management team must promote and continuously drive quality improvement"*
   b. (2) *"Cost pressure. In many cases quality activities are deemed as additional activities that result in cost increase. It requires holistic view and long-term mindset to invest in preventive activities, and learn from failure"*
   c. (3) *"Quality culture and mindset. At operational level it takes [a] long time and effort to train or change the behavior of operator"*

   Based on RP00006's response, the following FRs are derived:

   i. $FR_{RP00006.1}$: Develop a system to stimulate management support for quality culture
   ii. $FR_{RP00006.2}$: Develop a system to minimise quality implementation costs
   iii. $FR_{RP00006.3}$: Develop a system that takes a holistic approach to reset management's mindset

iv. $FR_{RP00006.4}$: Design a system to stimulate a quality culture

v. $FR_{RP00006.5}$: Develop a system to reset organisation's staff mindset

5. RP00007, from a large organisation, responded that: *"QMS should provide the evidence to top management that could add the value to company not just add the cost"*

   Given the above response, the following FR is mapped:

   i. $FR_{RP00007.1}$: Develop a system to prove that QMS can add value to company and not just cost-biased

6. RP00008, from a large organisation, responded that: the *"Process is too long"*

   Based on the above response, the FR below was deduced:

   a. $FR_{RP00008.1}$: Develop a system to minimise the [quality] implementation process

From the perspective of the research participants of experts, this study makes the deductions that implementation of QMS-based ISO family of standards:

- Does not provide an exhaustive, if any, solution as regards a company's own processes ($FR_{RP00003.1}$, $FR_{RP00005.1}$, $FR_{RP00007.1}$)
- Does not enable creativity due to reliance on QMS structured procedures ($FR_{RP00004.1}$)
- Has financial implications associated with the implementation ($FR_{RP00006.2}$, $FR_{RP00007.1}$)
- Does not imply value-added ($FR_{RP00007.1}$)
- Is time-consuming and cumbersome with long process ($FR_{RP00008.1}$)

In addition to the above data, an open-ended qualitative interview was held with RP00004, who has combined decades of experience both in Top Management and Engineering Design Lead in an automotive manufacturing SME in Germany. RP00004's reaction regarding QMS-based procedure implementation protocol was as follows:

> *"Because it is a big [overhead], costing money, development time and then finally, it is not worth to follow this up. So then what you see is that many big, big companies, supplier companies, they move to Eastern countries like in Eastern Europe where you can maintain it because in Germany, it is getting too complicated to follow this up. It is really difficult.*
>
> *"Because you have an overhead, you have quality people to organise, to live to force on that because it is just a cover of a structure and it is just… I know many development engineers say, it is nice for serial production, procedures to follow up, to control about quality. In respect of development, it is a no-go. Because it*

> *is always, if you want to follow up the 9001 procedure in a development process, you will never get a product."*

When asked as to what SMEs could do to be QMS-compliant or follow the QMS standard, RP00004 responded that:

> *"I don't know all the details about it [ISO 9001]. But you have to follow a strict – about safety, about the use of tools, about the used electricity. OK this is really good to follow this up, to make a safety background of everything you do. But if you want to be creative, you have to leave this structure. OK, let's do an experiment. And then if someone comes up, it is not working according to ISO 9001, then you will never do the experiment which is going to bring you a next step in the production, which is the problem in your product. Mainly, I have to deal with development engineers which is completely different. Once you know what you want to produce, then ISO 9001 is a useful tool. But it is just for the production, and not for development."*

The above responses generally agree with the assertions of the other cohort, $FR_{RP00003.1}$ – $FR_{RP00008.1}$, in that the research participants agree jointly on what they deem as inadequacies in QMS-oriented ISO standards. They collectively believe the standards are external to their own indigenous knowledge adaptation and that it limits exploring their own internal processes, forcing them to adopt procedures that may not necessarily address their own internal quality issues.

Based on the above data, the key stakeholders' initially defined functions, goals and requirements, that were first established in Table 3.1 (Chapter 3), are refined as in Table 7.1 to feature the perspective of the cohort of experts. In this context, the richness of the objectives is to enable the target audience, automotive manufacturing SMEs, to develop an in-house or indigenous knowledge system (IKS)-based customised quality design with the QX Engineering Design as the ideal blueprint or roadmap.

Table 7.1 Key stakeholders' functions, goals and requirements

QX Engineering Design Process

Key Stakeholder	Function	Goals	Requirements
Top Management	They establish the need to achieve quality-focused automotive manufacturing operations; organisation-wide core quality capabilities; standard and consistent quality automobile products and services at the lowest manufacturing costs; competitiveness	To develop quality-oriented manufacturing environment, which efficiently and effectively satisfies the requirements of the internal stakeholders, consumers, regulatory authorities, etc., and delivers continuous improvement	An efficient and effective quality excellence-oriented process
QX Task Force	They are a highly competent multidisciplinary team of engineers, project managers, quality managers, IT specialists, who maintain regular cyclic quality value strategies, monitoring-based interaction with all departments within the organisation to identify internal threats to quality, non-value added activities, adversarial behaviours, review of the state of the manufacturing processes, in-depth assessment of critical-to-satisfaction processes in the context of quality target value deliverables to the organisation, customer, updates on regulatory standard authorities, assessments to identify internal & external barriers to quality implementation processes, etc. Additionally, while they report to Top Management, they also evaluate and review Top Management operational activities	To design an effective quality monitoring process, which enables sustainable quality implementation by identifying and eliminating threats to the quality value chain	An efficient internal and external quality auditing process
QX Design Team	The design engineers are a multidisciplinary team of engineers, project managers, multifunctional experts, who translate the organisational Top Management's functional needs and goals into engineering characteristics	To develop QX engineering design that satisfies organisation-wide goals effectively and efficiently at minimum cost	An efficient QX-Engineering process

7.4 Optimisation process mapping for initial QX Engineering Design

7.4.1 Refining the highest-level functional requirement (FR_0)

As in Table 3.8 in Chapter 3, the key stakeholders' highest-level functional requirement (FR_0) and its corresponding highest-level design parameter (DP_0) were initially defined as follows:

FR_0: Develop a quality-focused manufacturing system to satisfy stakeholder needs

DP_0: Quality-engineered automotive manufacturing system design

However, based on the updated key stakeholders' functions, goals and core requirement to create *an efficient and effective quality excellence (QX)-oriented process* as detailed in Table 7.1, the initial FR_0 and DP_0 were redefined as follows:

FR_0: Develop a QX Engineering Design for automotive manufacturing system
DP_0: Produce a roadmap for QX Engineering Design

It is intended for the refined DP_0 to design a roadmap that satisfies FR_0, translating into producing key stakeholders' desired development of an efficient but cost-resource-effective QX-focused process.

7.4.2 Refining second level functional requirements (FR_1 and FR_2)

Having modified the highest-level functional requirement, FR_0, in sub-section 7.4.1 above, it is necessary to refine the initial second level functional requirements (FR_1 and FR_2) in order to map out and exhaust FR_1 and FR_2 associated decompositions. As set in Chapter 3, FR_1 and FR_2 are necessary to enable the organisation to achieve its highest-level functional requirement at a minimal cost. Thus, recalling the initial second level FRs below

FR_1: Develop the desired value-added quality of the design
FR_2: Minimise cost-biased activities in developing the system design

And their respective DPs below

DP_1: QX Engineering system for maximising the value-added quality of the QX design
DP_2: Procedure for minimising cost-associated threats to developing the system design

We refined them to as follows

FR_1: Develop the desired high-level quality value-added design
FR_2: Minimise cost-biased activities in developing QX Engineering Design

and their respective corresponding

DP_1: QX Engineering Design for maximising the quality value-added
DP_2: System for minimising cost-associated activities in developing QX Engineering Design

7.4.3 Introducing a compliant validation for QX Engineering Design

In order to achieve a long term and evolvable quality system, this study proposes a need to *achieve quality regulatory and standard compliant status for QX Engineering compliant design (coded $FR_{1.1.14}$)*. This will subsequently translate into standardisation of QX Engineering Framework for a long term use. The plausible corresponding DP to satisfy $FR_{1.1.14}$ is defined as follows:

> *$DP_{1.1.14}$: Produce QX Engineering quality compliant validation process*

$FR_{1.1.14}$ and $DP_{1.1.14}$ will complement the input data derived in Section 6.2.4 in Chapter 6.

7.4.4 Modifying $FR_{1.2.3}$

As the proposed QX Engineering Framework is meant to produce a roadmap that is hinged on indigenous knowledge system (IKS), this aspect of the research modifies the previously defined $FR_{1.2.3}$, which proposes the determination of a QMS-based master process. The revised $FR_{1.2.3}$ and corresponding $DP_{1.2.3}$ are defined as follows.

> *$FR_{1.2.3}$: Determine QX-based master process for automobile product and or service design*
>
> *$DP_{1.2.3}$: QX-based master process selection for automobile product or service design*

7.5 QX Engineering Framework

The production of the proposed QX Engineering Framework entails the optimisation of the initial QX Engineering Framework or Design. We recall the matrices in Table 3.8 and Table 3.9 in Chapter 3 and for the purpose of this Chapter rename these matrices as Table 7.2 and Table 7.3 respectively. Table 7.2 features the hierarchies or fourth-level decomposition of FR_1 and Table 7.3 entails the hierarchies or fourth-level decomposition of FR_2. Thus, the optimisation begins by first updating the definitions of FR_0 and DP_0 in both Table 7.2 and Table 7.3 (recall revisions in Section 7.4.1). The revised FR_1 with its corresponding DP_1 is used to update Table 7.2 and that of FR_2 with its plausible DP_2 is used to update Table 7.3 based on the modifications established in Sections 7.4.2.

Secondly, the FR_{1s} and their decompositions along with their corresponding DP_{1s} in Sections 6.2.1, 6.2.2, 6.2.3, 6.2.4, 6.2.5, and 6.2.6 are integrated into Table 7.2 according to their subject-matter description domain. The FR_1-related notations and their corresponding

DP_{1s} defined in Sections 7.4.3 and 7.4.4 are recalled and incorporated into Table 7.2 according to their decomposition level in the hierarchy.

Thirdly, all the FR_{2s} and their decompositions along with their plausible corresponding DP_{2s} in Sections 6.3.1, 6.3.2, 6.3.3, 6.3.4, 6.3.5, 6.3.6, 6.3.7, 6.3.8, and 6.3.9 are integrated into FR_2-based Table 7.3 according to their hierarchies within their subject treatment domains.

It is worth noting that auto recall-oriented $FR_{2.17}$ and emerging technologies issues-focused $FR_{2.18}$ and their decompositions are new parameters and are introduced to the optimised QX Engineering Framework for the first time in Table 7.3. Similarly, where new input parameters (FR-DP) are introduced to the initial design, they are linked to their respective subject-related quality dimensions as either standalone parent or parent with daughters. An example is introducing $FR_{2.18.10}$ and its corresponding $DP_{2.18.10}$ and linking them to $FR_{2.18}$ as they share the same common theme of emerging technologies.

Table 7.2 Optimised fourth-level decomposition of FR_1

Functional Requirements		Design Parameters	
FR_0:	Develop a QX Engineering Design for automotive manufacturing system	DP_0:	Produce a roadmap for QX Engineering Design
FR_1:	Create the desired high-level quality value-added	DP_1:	QX Engineering Design for maximising the quality value-added
$FR_{1.1}$:	Develop high-level quality competent-rich manufacturing system	$DP_{1.1}$:	Blueprint for high-level quality assurance manufacturing system
$FR_{1.1.1}$:	Develop high-level core quality competent engineers and staff	$DP_{1.1.1}$:	Design a career enrichment and continuing professional qualification development training programme in core quality tools (including FMEA, SPC, QFD, Six Sigma, Lean Management, PPAP, APQP, MSA, Heijunka, Mizusumashi, etc.)
$FR_{1.1.2}$	Develop company-wide familiarity with relevant quality standardised procedures for the automotive manufacturing industry	$DP_{1.1.2}$	Design multipurpose quality standards training programmes (including ISO 9001, ISO 14001, ISO 26262, ISO 45001, AEC-Q100 & AEC-Q200, IATF 16949:2016) across all relevant units or departments
$FR_{1.1.3}$	Create a process map for identifying flaws in quality implementation in QMS-based standardised procedures	$DP_{1.1.3}$	Design a roadmap for identifying weaknesses, gaps and noise in ISO 9001, ISO 14001, ISO 26262, ISO 45001, AEC-Q100 & AEC-Q200, IATF 16949:2016 and associated procedures
$FR_{1.1.4}$	Achieve company-wide familiarity with relevant international regulatory bodies for the automotive manufacturing industry	$DP_{1.1.4}$	Design introductory training programme for developing familiarity with all the major internationally known automotive manufacturing sector regulators (including Automotive Council UK, NHTSA US, TÜV Germany)
$FR_{1.1.5}$	Achieve familiarity with manufacturing equipment standardisation (MES)	$DP_{1.1.5}$	Design training programme in MES across shopfloor and relevant units
$FR_{1.1.6}$:	Develop customised, in-house, indigenous knowledge system (IKS)-based hierarchy for quality implementation processes, procedures and work instructions	$DP_{1.1.6}$:	Design company's IKS-based quality standard and implementation procedures that exceed the expectations of QMS-based ISO family of procedures

$FR_{1.1.7}$: Create a reward system to encourage recurrent training in quality skillset across all departments or units

$FR_{1.1.8}$: Produce procedures for skills audit

$FR_{1.1.9}$: Produce procedure for internal auditing quality capacity-building training programmes

$FR_{1.1.10}$: Create procedures for conducting internal audit process, internal audit report generation, and countermeasures

$FR_{1.1.11}$: Produce QX Task Force & Top Management protocol for review of internal audit report

$FR_{1.1.12}$: Develop Standard Operating Procedures (SOP) for departmental or unit processes

$FR_{1.1.13}$: Produce QX Engineering-based procedure documentation

$FR_{1.1.14}$: Achieve quality regulatory and standard compliant status for QX Engineering compliant design

$FR_{1.2}$: Design quality-oriented process efficiency and effectiveness for automotive manufacturing operations and automobile product

$FR_{1.2.1}$: Define and group product families for production

$FR_{1.2.2}$: Design manufacturing process and strategy based on automobile product family functional requirements

$FR_{1.2.3}$: Determine QX-based master process for automobile product and or service design

$FR_{1.2.4}$: Maximise manufacturing resources

$DP_{1.1.7}$: Design a reward system to stimulate capacity-building in core quality systems, continuing professional enrichment and mastery of firm's IKS-based quality

$DP_{1.1.8}$: Design internal skills audit procedures

$DP_{1.1.9}$: Design procedures for auditing quality capacity-building training programmes

$DP_{1.1.10}$: Standard Operating Procedures (SOP) for internal audit process, internal audit reporting, and corrective actions

$DP_{1.1.11}$: Design QX Task Force & Top Management SOP's for review of internal audit

$DP_{1.1.12}$: Design individual QX-oriented SOP for departments or unit

$DP_{1.1.13}$: Design QX Engineering-based reference documentation, outlining processes that satisfy compliance with automotive body standard requirements (including IATF 16949:2016 statutory and regulatory requirements, etc.)

$DP_{1.1.14}$: Produce QX Engineering quality compliant validation process

$DP_{1.2}$: Quality-oriented process efficiency and effectiveness system

$DP_{1.2.1}$: Procedure for defining and classifying product families

$DP_{1.2.2}$: Procedure for selecting QX-oriented manufacturing process and strategy

$DP_{1.2.3}$: QX-based master process selection for automobile product and or design

$DP_{1.2.4}$: Product-oriented and or service-based QX-oriented manufacturing facility layout to minimise waste

$FR_{1.2.5}$: Determine QX Engineering design for quality control	$DP_{1.2.5}$: QX Engineering system for automobile product families
$FR_{1.2.6}$: Continuous quality performance monitoring	$DP_{1.2.6}$: Design quality performance monitoring protocol at internal departmental level and the value chain
$FR_{1.3}$: Define process strategy to enable continual improvement	$DP_{1.3}$: Design optimal system for continuous improvement
$FR_{1.3.1}$: Define Key Performance Indicators (KPI), objectives and quality-based process approach for continual improvement	$DP_{1.3.1}$: Design procedure for selecting quality-based process to achieve KPIs and objectives
$FR_{1.3.2}$: Determine scope of environmental and local (i.e. country of operation and market) automotive regulatory policy objectives	$DP_{1.3.2}$: Design information pool and report system of domestic environmental and automotive regulatory policy objectives
$FR_{1.3.3}$: Design internal and external stakeholder feedback to determine gaps in quality of service and automobile product families	$DP_{1.3.3}$: Design a continuous feedback information flow system to map out customer-determined quality dimensions
$FR_{1.3.4}$: Determine master process to respond to personnel attitudes that vary quality design targets	$DP_{1.3.4}$: Standardise master process selection for addressing human behaviours that vary quality design process
$FR_{1.3.5}$: Create risk assessment scheme to identify human adversarial behaviours within the quality-of-service units	$DP_{1.3.5}$: Design risk assessment scheme to monitor human adversarial behaviours, focused on quality of service
$FR_{1.3.6}$: Develop sustainably optimised customer-centric quality of service delivery	$DP_{1.3.6}$: Design optimised customer-centric quality of service for the supply chain, including affiliated auto dealerships

Table 7.3 Optimised fourth-level decomposition of FR_2

Functional Requirements		Design Parameters	
FR_0:	Develop a QX Engineering Design for automotive manufacturing system	DP_0:	Produce a roadmap for QX Engineering Design
FR_2:	Minimise cost-biased activities in developing QX Engineering Design	DP_2:	System for minimising cost-associated activities in developing QX Engineering Design
$FR_{2.1}$:	Achieve organisation-wide QX Engineering Design buy-in	$DP_{2.1}$:	System for organisation-wide QX Engineering Design buy-in
$FR_{2.1.1}$:	Create QX Task Force	$DP_{2.1.1}$:	Design QX Task Force
$FR_{2.1.2}$:	Achieve Top Management buy-in	$DP_{2.1.2}$:	Procedure for Top Management buy-in
$FR_{2.1.3}$:	Achieve Mid-level Management buy-in	$DP_{2.1.3}$:	Procedure for Mid-level Management buy-in
$FR_{2.1.4}$:	Achieve QX buy-in across all departments	$DP_{2.1.4}$:	Procedure for QX buy-in across all departments
$FR_{2.1.5}$:	Develop procedure for internal audit of QX practice	$DP_{2.1.5}$:	Design procedure for internal audit of QX practice
$FR_{2.2}$:	Determine strengths and weaknesses of under-utilised personnel	$DP_{2.2}$:	Design QX-based strength and weakness analysis
$FR_{2.2.1}$:	Define process for maximising use of skilled personnel	$DP_{2.2.1}$:	Procedure for maximising use of skilled personnel
$FR_{2.2.2}$:	Determine master process for personnel utilisation	$DP_{2.2.2}$:	Master process for maximised human resources
$FR_{2.3}$:	Eliminate non-value added excess production of resources	$DP_{2.3}$:	QX Task Force procedures
$FR_{2.3.1}$:	Minimise repetitive design and printed-matter	$DP_{2.3.1}$:	Short process setup for design
$FR_{2.3.2}$:	Avoid long changeovers	$DP_{2.3.2}$:	Standardise stable schedules
$FR_{2.3.3}$:	Minimise reliance on forecasted demand	$DP_{2.3.3}$:	In-demand production (i.e. production on demand)
$FR_{2.3.4}$:	Determine production volume control	$DP_{2.3.4}$:	Production Pareto analysis
$FR_{2.3.5}$:	Determine master process for capturing non-value added production activities	$DP_{2.3.5}$:	Master process for identifying and mitigating agents of overproduction

$FR_{2.4}$:	Eliminate factors of defects within the value stream design	$DP_{2.4}$:	Process for zero defects
$FR_{2.4.1}$:	Eliminate rework	$DP_{2.4.1}$:	Procedure for on-line quality inspection
$FR_{2.4.2}$:	Eliminate non-productive time	$DP_{2.4.2}$:	Procedure for implementing quality at the source
$FR_{2.4.3}$:	Eliminate agents of variations	$DP_{2.4.3}$:	QX quality process selection
$FR_{2.4.4}$:	Determine master process for capturing defects	$DP_{2.4.4}$:	QX quality process integrated with select relevant quality tool
$FR_{2.4.5}$:	Develop process monitoring scheme	$DP_{2.4.5}$:	QX Task Force process monitoring procedure
$FR_{2.5}$:	Eliminate non-value added inventory of design resources	$DP_{2.5}$:	Optimal process for resource efficiency
$FR_{2.5.1}$:	Define process to control inventory	$DP_{2.5.1}$:	QX quality process for inventory
$FR_{2.6}$:	Eliminate non-value added movements of human and material resources	$DP_{2.6}$:	Optimised production resources scheduling procedures
$FR_{2.6.1}$:	Eliminate unnecessary material movements	$DP_{2.6.1}$:	Design material flow-oriented layout
$FR_{2.6.2}$:	Reduce human resource unnecessary movements	$DP_{2.6.2}$:	Create SOP for manufacturing processes
$FR_{2.7}$:	Minimise non-value added waiting in the system	$DP_{2.7}$:	Continuous flow design
$FR_{2.7.1}$:	Eliminate machine operations non-value added idle time	$DP_{2.7.1}$:	Optimise manufacturing system scheduling
$FR_{2.7.2}$:	Minimise personnel waiting on material or machine operations	$DP_{2.7.2}$:	Optimise process continuous flow
$FR_{2.8}$:	Eliminate inefficient processing within the system	$DP_{2.8}$:	Optimise processing design
$FR_{2.8.1}$:	Determine master process	$DP_{2.8.1}$:	Standardised master process
$FR_{2.9}$:	Eliminate inefficient transportation of resources in the system	$DP_{2.9}$:	Design procedures for reducing excessive transportation
$FR_{2.9.1}$:	Define process for minimising non-value added transportation	$DP_{2.9.1}$:	Single Minute Exchange of Die (SMED) process

$FR_{2.9.2}$:	Minimise transportation of resources within facility	$DP_{2.9.2}$:	Production-oriented facility layout
$FR_{2.10}$:	Identify and mitigate social (human) actors' adversarial behaviours towards QX Engineering Design	$DP_{2.10}$:	Design system for tracking human adversarial behaviours against QX Engineering Design process
$FR_{2.10.1}$:	Develop objective monitoring scheme to identify personnel apathy towards quality design process	$DP_{2.10.1}$:	Procedures for objective identification of personnel apathy across all departments and analysis
$FR_{2.10.2}$:	Enable a scheme for reporting observed human adversarial behaviours towards quality design	$DP_{2.10.2}$:	Design solution-oriented system to address adversarial behaviours through transformational lens
$FR_{2.10.3}$:	Create risk assessment procedure to eliminate personnel apathetical behaviours	$DP_{2.10.3}$:	Procedure for risk assessment based on personnel apathy behaviours
$FR_{2.10.4}$:	Develop a scheme to encourage self-reporting of adversarial behaviours against company goals	$DP_{2.10.4}$:	Design conflict resolution and personnel support system in the event of deviation from company goals
$FR_{2.10.5}$:	Motivate personnel participation in organisational goal	$DP_{2.10.5}$:	Reward-sharing programmes
$FR_{2.11}$:	Determine top management non-committal towards quality implementation process and overall organisational goal	$DP_{2.11}$:	Mitigation solution for top management non-committal attitudes
$FR_{2.11.1}$:	Conduct risk assessment to minimise top management non-committal attitudes	$DP_{2.11.1}$:	Procedure for conducting risk assessment based on top management non-committal behaviours
$FR_{2.11.2}$:	Pull top management's commitment to goal	$DP_{2.11.2}$:	Gain-sharing programme
$FR_{2.12}$:	Determine quality training needs required for core capabilities	$DP_{2.12}$:	Core quality capability training programmes
$FR_{2.12.1}$:	Co-evolve with emerging technologies	$DP_{2.12.1}$:	Procedure for regular recurrent training
$FR_{2.13}$:	Mitigate organisational behaviour against quality engineering processes	$DP_{2.13}$:	Mitigation solution for organisational apathetic behaviour against QX Engineering design
$FR_{2.13.1}$:	Determine agents of risks to the design process	$DP_{2.13.1}$:	Procedure for identifying human agent risk factors
$FR_{2.13.2}$:	Determine in-house training and awareness workshop on organisational context and goals	$DP_{2.13.2}$:	In-house training and awareness programme on organisational context and goals
$FR_{2.14}$:	Determine internal audit of quality procedures	$DP_{2.14}$:	Implement internal audit of quality processes across all departments

$FR_{2.14.1}$: Determine process for conducting internal audit	$DP_{2.14.1}$: Procedures for conducting internal audit
$FR_{2.14.2}$: Determine internal audit team	$DP_{2.14.2}$: Internal audit team selection process
$FR_{2.15}$: Mitigate automotive regulatory and standards nonconformities within the design processes	$DP_{2.15}$: Mitigation solution for regulatory and standards nonconformities
$FR_{2.15.1}$: Determine in-house training and awareness on regulatory and standards compliance requirements	$DP_{2.15.1}$: Training and awareness programme on regulatory and standards compliance requirements
$FR_{2.15.2}$: Provide procedure to enable consistency of conforming with regulatory and standards requirements	$DP_{2.15.2}$: Standard Operating Procedures (SOP) based on requirements for conforming with regulatory authority standard
$FR_{2.16}$: Mitigate environmental compliance nonconformities within the design processes	$DP_{2.16}$: Mitigation solution for environmental compliance nonconformities
$FR_{2.16.1}$: Provide in-house training and awareness on environmental standards compliance requirements	$DP_{2.16.1}$: Training and awareness programme on environmental standards compliance requirements
$FR_{2.16.2}$: Provide procedure to enable consistency of conforming with environmental standards requirements	$DP_{2.16.2}$: Standard Operating Procedures (SOP) based on environmental standards requirement compliance
$FR_{2.17}$: Develop highly responsive system to address auto recall issues	$DP_{2.17}$: Design highly responsive system to address auto recall issues
$FR_{2.17.1}$: Determine need for in-house training for staff development knowledge in automobile safety regulations	$DP_{2.17.1}$: Design training programme in automobile safety regulations, featuring adherence to code of practice of safety
$FR_{2.17.2}$: Develop a system for early detection of potential product safety defect	$DP_{2.17.2}$: Effective system for early safety defect detection and documented procedures in the event of a recall
$FR_{2.17.3}$: Develop a system to notify automotive regulatory bodies of late detection of a product safety defect	$DP_{2.17.3}$: System for notifying automotive regulatory bodies of late (or early) detection of a product safety defect pre-delivery (or post-delivery) or both
$FR_{2.17.4}$: Develop standardised procedure for rendering nonconforming products unusable prior to final disposal	$DP_{2.17.4}$: Design and document standardised procedure for rendering nonconforming products unusable prior to final disposal

$FR_{2.17.5}$: Create QX Task Force protocol for internal auto recall process monitoring	$DP_{2.17.5}$: Develop internal auto recall response process monitoring
$FR_{2.18}$: Develop a system to mitigate quality performance disruptions presented by emerging technologies	$DP_{2.18}$: Design a system to mitigate quality performance disruptions as and when created by emerging technologies
$FR_{2.18.1}$: Develop survival and mitigation solution against disruptions posed by Connected Automobile	$DP_{2.18.1}$: Contingency design against disruption by Connected Automobile
$FR_{2.18.2}$: Develop business strategies against threats to market share posed by Automobile Sharing	$DP_{2.18.2}$: Design market entry schemes against sales decline caused by increased Connected Automobile demand
$FR_{2.18.3}$: Develop manufacturing strategies against rapid wear and tear due to predicted growth of Automobile Sharing in 2030	$DP_{2.18.3}$: Manufacturing strategies for optimised engineered tyres
$FR_{2.18.4}$: Develop mitigation solution against unprepared forced transition pressures presented by growing demand for hybrid-powered automobiles	$DP_{2.18.4}$: Mitigation solution against threat to business existence
$FR_{2.18.5}$: Develop manufacturing system to address increased manufacturing complexity due to continuous generation of data	$DP_{2.18.5}$: Integrate existing manufacturing processes complex adaptive system (CAS) response mechanism cost-resource-effectively
$FR_{2.18.6}$: Develop alternative solution to address capital-intensive software regarding safety concerns due to Driverless Automobile	$DP_{2.18.6}$: Optimise mitigation solutions against human adversarial behaviours against quality designs
$FR_{2.18.7}$: Develop alternative solution to software-hardware coupling due to consumer's uncertain demand patterns in the use of Driverless Automobile	$DP_{2.18.7}$: Develop adaptive design, without need to couple software-hardware, to satisfy customer-centric uncertain demand patterns
$FR_{2.18.8}$: Develop mitigation solution against software virus risk due to computer virus attack or hack	$DP_{2.18.8}$: Minimise dependency on extensive software integrated systems and design mitigation solution against cyber attacks
$FR_{2.18.9}$: Develop a system for identifiers of social (human) adversarial behaviours against safety concern	$DP_{2.18.9}$: Optimise safety information dissemination and disrupt misleading information in public domain

$FR_{2.18.10}$:	Create system for monitoring dynamics of entry strategies of emergency technologies	$DP_{2.18.10}$:	Develop a QX Task Force emergency technologies monitoring system

7.6 Summary

This Chapter answers research question 3 or RQ3 by integrating the functional requirements derived from RQ1-based Study 1 and RQ2-based Study 2 and their corresponding design parameters, which were integrated in Chapter 6, into the initial QX Engineering Framework in order to achieve the desired optimised QX Design. As detailed in Table 7.2 and Table 7.3, the design parameters address each of the functional requirements based on the responses provided by both the cohorts of experts and consumers. In adopting the final QX Engineering framework design, the provisions within the quality design, which includes embedded models for continuous monitoring and auditing, will help automotive manufacturing organisations to overcome the variables that are barriers to the hybridisation (i.e., synergising) and implementation of engineering quality systems. In Chapter 8, the optimised QX Engineering design was submitted to an automotive engineer in the SME automotive engineering sector in Germany, and an academic with a manufacturing quality engineering background in the UK for review.

7.6.1 QX Engineering Design: a mitigation solution against quality barrier causes

Enriched with extended identified functional requirements with corresponding design parameters as derived from the exhaustive sets of research data collection (quantitative and qualitative), the optimised QX Engineering Design is integrated with the plausible design parameters required to equip automotive manufacturing organisations to overcome the variables, quality variants as well as human adversarial behaviours that impede the implementation of quality systems.

Chapter 8: Documentation, Standardisation Process & Applicability of QX Engineering

8.1 Introduction

The purpose of this Chapter is:

1. To validate the integrity of the new quality engineering system design, named QX Engineering Design, via a review by research participants of experts from automotive manufacturing SMEs, cohorts of automobile product and service consumers and academics (Research Objective 3, established earlier in Chapter 1)
2. To propose the need for a Documentation, Standardisation Process and Applicability of QX Engineering as well as to propose a QX Design adoption as a standard quality system for SMEs in automotive manufacturing and related service sector by documenting its process and procedures (Research Objectives 2 & 4, established earlier in Chapter 1)

The above list forms the structure of this Chapter.

8.2 Review method for QX Engineering

As the context of this research takes into account the need to create knowledge from an objective point of view as supported by the worldview of the author, the invited reviewers were sent the optimised QX Engineering Design without a closed-ended questionnaire survey to complete and submit online, on paper and sent through the post or interviewed on phone to give comments. These approaches, in the author's beliefs, may present latent biases and vary the intended objectivity in the assessment sought. To avoid any biases, the following steps were considered:

Step 1. A *synopsis* was provided to the reviewer in the first segment of the invitation

Step 2. A *review request* information was presented in the second segment of the invitation

Steps 1 and 2 were followed through as presented *AS IS* in the segments below. The outcome of the review feedback is presented in Sections 8.2.1 and 8.2.2.

Synopsis to my approach:

The Top Management joins with the Engineering Design Team to form a Quality Monitoring and Implementing Task Force. Their key functional definitions are in Table A1 (see Appendix 5). These are collectively **Key Stakeholders** of the organisation, who set their highest-level goal, defined as the highest-level functional requirement and is denoted by FR_0. The design parameter required to satisfy FR_0 is defined by DP_0. These goals, featuring organisation-wide core objectives, are presented in Table A2 (see Appendix 5) and Table A3 (see Appendix 5). I take an axiomatic design approach to decompose FRs and their respective DPs until exhausted and the iterations stop. However, because I recognise that good quality must be achieved at a minimal cost, otherwise it is no quality, I defined FR_1 as the functional requirement (FR) we need to satisfy to achieve FR_0 and FR_2 as the FR we need to satisfy to achieve FR_1 at a minimum cost. Hence you will notice that FR_2 is in the cost-biased Table A3 (see Appendix 5). For each FR_n there is a corresponding DP_n to satisfy the production of FR_n. Table A1 is the definition by function, goal and requirements of the key stakeholders I select to champion the implementation of QX Engineering Design with their (fictional) organisation.

Review Request:

Thank you very much for agreeing to review the proposed QX Engineering Design, designed for automotive manufacturing SMEs. I would appreciate your honest opinion that would certainly help me to fine-tune the design. Please review the QX Engineering Design (Table A2 (see Appendix 5) and Table A3 (see Appendix 5)) below and give me your review feedback in 3 to 5 statements based on your experiential opinion. The following are key dimensions you could also factor in addition to your review remarks.

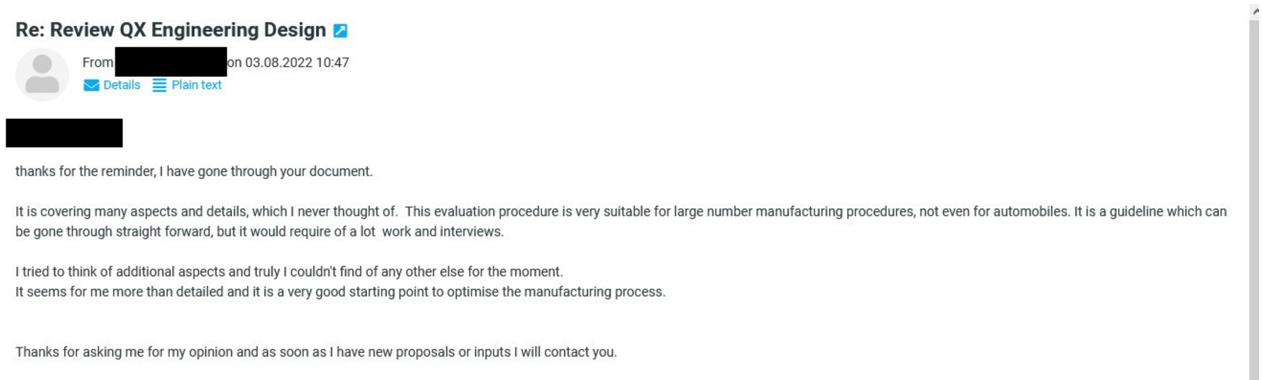
1. *Which features of QX Design resonate with your own approach to engineering quality process?*
2. *In comparing with ISO family of standards procedures, which of the two do you honestly think will appeal to Small and Medium-sized companies? Please explain your answer in a short statement, highlighting key components.*
3. *Do you think QX Engineering Design can easily be adopted in an SME environment within automotive service? Please explain your answer briefly.*
4. *What do you think is missing from the conceptual design that you think if added, it could improve the current QX Engineering Design?*
5. *Please p*rovide any other feedback or review comment as you deem necessary.

When you're done, kindly either email me your review comments by email or via WhatsApp text message.

8.2.1 QX Engineering Design: a review from the perspective of an automotive design engineer and automotive manufacturing SME owner & expert (Germany)

The optimised QX Engineering Design (in Tables 7.2 and 7.3, Chapter 7) was submitted to an automotive manufacturing engineer, whose professional portfolio includes aerospace engineering, mechanical engineering, automotive design engineering, car builder, vehicular refurbishing and combined decades of years of experience as founder of an SME automotive engineering design company with clients in the domain of major brand large (>250) automotive manufacturing companies.

As can be deduced from the review response of the automotive design engineer (see Fig. 8a and Fig. 8b for enhanced readability), whose professional profile includes a production of a limousine truck in Germany, the QX Engineering Design is said to *"covering many aspects and details"*. It is in the expert Reviewer's opinion that it is emphatically *"very suitable for large number manufacturing procedures"* and explained that the design is not limited to the automobile sector.


Re: Review QX Engineering Design

From [redacted] on 03.08.2022 10:47

Details Plain text

[redacted]

thanks for the reminder, I have gone through your document.

It is covering many aspects and details, which I never thought of. This evaluation procedure is very suitable for large number manufacturing procedures, not even for automobiles. It is a guideline which can be gone through straight forward, but it would require of a lot work and interviews.

I tried to think of additional aspects and truly I couldn't find of any other else for the moment.
It seems for me more than detailed and it is a very good starting point to optimise the manufacturing process.

Thanks for asking me for my opinion and as soon as I have new proposals or inputs I will contact you.

Fig. 8a: Review response of automotive design engineer

thanks for the reminder, I have gone through your document.

It is covering many aspects and details, which I never thought of. This evaluation procedure is very suitable for large number manufacturing procedures, not even for automobiles. It is a guideline which can be gone through straight forward, but it would require of a lot work and interviews.

I tried to think of additional aspects and truly I couldn't find of any other else for the moment.
It seems for me more than detailed and it is a very good starting point to optimise the manufacturing process.

Thanks for asking me for my opinion and as soon as I have new proposals or inputs I will contact you.

Fig. 8b: Enhanced readable version of reviewers response as in Fig. 8a

While the reviewer asserts that the QX Engineering Design seems *"more than detailed and it [QX] is a very good starting point to optimise the manufacturing process"* and that it is a straight-forward guideline, the reviewer also implied that a lot of work and interviews would be required to explore additional aspects. The reviewer admitted *"I tried to think of additional aspects and truly I couldn't find any other else for the moment"*.

8.2.2 QX Engineering Design: a review from the perspective of an academic scholar in manufacturing quality engineering systems (United Kingdom)

An academic scholar with academic qualifications in manufacturing engineering in advanced manufacturing systems, analytical mathematics and quality engineering backgrounds, the reviewer responded as depicted in Fig. 8c to Fig. 8f. The enhanced readable edition of Fig. 8c is Fig. 8d.

Re: Review QX Engineering Design

From [redacted] on 03.08.2022 13:57

Details   Plain text

1. All the features of the QX design resonates with my approach to quality engineering process because all the elements mentioned in the QX quality design are all important in any quality engineering process
2. ISO 90001 is a general standard applicable to all industries, IATF 1649 is maintained by the IATF. even though there is a segregation, IATF 16949 IS IN A WAY AN EXTENTION OF iso 90001, BEING BUILT ON THE SAME FOUNDATION. THEREFORE, a company in automotive sector will have to implement both ISO 90001 requirements and IATF 16949 specific requirements.
3. QX ENGINEERING DESIGN CAN BE adopted because it uses ISO 90001 and IATF 16949 which are the two most important ISO for SMEs
4. Nothing is missing because the QX quality engineering design is an innovative design different from the other quality designs which are already overused in the manufacturing domain.

Fig. 8c: Academic scholar's review response

This reviewer referred to the horizons of the relevant quality management system standards, including IATF 16949:2016 (see Figs. 8c–8f), to assert that the features embedded within the QX Engineering Design *"resonates with my [his own] approach to quality engineering process because all the elements mentioned in the QX quality design are all important in any quality engineering process"*.

1. All the features of the QX design resonates with my approach to quality engineering process because all the elements mentioned in the QX quality design are all important in any quality engineering process
2. ISO 90001 is a general standard applicable to all industries, IATF 1649 is maintained by the IATF. even though there is a segregation, IATF 16949 IS IN A WAY AN EXTENTION OF iso 90001, BEING BUILT ON THE SAME FOUNDATION. THEREFORE, a company in automotive sector will have to implement both ISO 90001 requirements and IATF 16949 specific requirements.
3. QX ENGINEERING DESIGN CAN BE adopted because it uses ISO 90001 and IATF 16949 which are the two most important ISO for SMEs
4. Nothing is missing because the QX quality engineering design is an innovative design different from the other quality designs which are already overused in the manufacturing domain.

Fig. 8d: Enhanced readable edition of Fig. 8c

According to ISO.org, the ISO 9000 family is the world's best known quality management standard for companies and organisation of any size. ISO 90001

2. IATF 16949 (2016) will fully respect ISO 90001 (2015) structure and requirements. IATF 16949 (2016) is not a stand alone quality management standard but is implemented as a supplement to and in conjunction with ISO 90001 (2015), (ISO.org).

1. the QX design is good because is an innovative design for new generation of quality designs

3. QX Engineering design can be easily adopted in an SME environment within the automotive service because it is a proponet of ISO 90001 and IATF 16949 which are the two important quality standards for automotive industries.

(4) nothing is missing from the QX Engineering design

Fig. 8e: Reviewer's further comments

The reviewer also added that QX Engineering Design can be adopted and applied across the SME sector because it does not vary ISO 9001 and IATF 16949:2016 procedures.

ISO 90001 is a general standard applicable to all industries or sectors. from agriculture to manufacturing and is maintained by ISO. when talking about IATF 16949 the situation is completely different because this standard is maintained by the international automotive task forces and other contributors being specifically applicable to automotive parts.

Fig. 8f: Reviewer's additional comments

8.3 Documentation, standardisation process & applicability of QX Engineering

The structure of QX Engineering offers a meticulous approach to adoptable and customisable in-house quality engineering design by any SME without the need to resort to very complex, expensive and time-intensive quality management tools. The latter are supported by the responses from the cohort of experts as deduced from the qualitative data about the implementation challenges of "mainstream" quality systems. The expert reviewers' responses above also led to drawing the conclusion that QX Engineering can be easily understood within the shortest feasible time of taking a look into the structure. Based on the expert reviewers' responses, which add credibility to the QX design as well as validate its aplication to the SME domain, these set the premise to propose the production of a QX Engineering Design Documentation, Standardisation and Application Methodology for Automotive Manufacturing SMEs. The structure or algorithms as defined in the QX Engineering design matrix (see Tables 7.2 and 7.3) by their nature make the quality design a standard document or template to guide the production of the proposed documentation. Furthermore, it is worth noting that while the matrics presented in Table 7.2 and Table 7.3 may be adequate for SME's resources and characteristics, large organisations operate with a different business model, within a different environment and are inherently bureaucratic. This requires featuring aspects that align with their functional resources and characteristics. In this regard, it suffices to derive a standardisation matrix from Tables 7.1–7.3 that align with large organisation's operational structures (resources and characteristics). Based on the structures of Tables 7.1–7.3, a standardisation process matrix for the QX Engineering framework is derived and proposed as depicted in Table 8.1 below.

Table 8.1: Proposed QX Engineering standardisation process matrix

	Functional Processes*									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1.0 Context of the Key Stakeholder										
1.1 Establishing the organisation's highest-level goal and content				X	X				X	
1.2 Setting up the key stakeholders and their functions					X					
1.3 Define the scope of the QX engineering framework					X					
1.4 Establish QX engineering-oriented quality objectives					X					
2.0 Stakeholder Leadership										
2.1 Top Management and commitment					X				X	
2.2 QX Task Force and commitment					X				X	
2.3 QX Design Team and commitment					X				X	
2.4 Departmental Leads and commitment		X			X				X	
2.5 Standard policy	X	X	X	X	X	X	X	X	X	X
2.6 Organisation-wide responsibilities		X			X				X	
3.0 Establish High-level Core Quality Competent Environment										
3.1 Actions to develop company-wide familiarity with standards	X	X	X	X	X	X	X	X	X	X
3.2 Actions to develop IKS-based quality standard procedures	X	X	X	X	X	X	X	X	X	X
3.3 Actions to develop recurrent skillset auditing process		X	X		X				X	
3.4 Training programme for core quality competence development	X	X	X			X	X	X	X	X
4.0 Documentation										
4.1 Actions to develop SOPs across all departmental processes	X		X	X	X	X	X	X	X	X
4.2 Actions to document quality-related information	X		X	X	X	X	X	X	X	X
4.3 Record documentation	X		X	X	X	X	X	X	X	X
4.4 Project plan documentation	X		X	X	X	X	X	X	X	X
4.5 QX Engineering manual	X		X	X	X	X	X	X	X	X
5.0 Manufacturing Operations										
5.1 Define product families and services	X		X	X				X	X	X
5.2 Document manufacturing process and strategy for products	X		X	X		X	X	X	X	X
5.3 Design QX-based master process for product families	X		X				X	X	X	
5.4 Document QX-based requirements for products and services	X		X				X	X	X	
5.5 Process mapping for control of nonconformities	X		X				X	X	X	
5.6 SOP for addressing product safety	X		X	X	X	X	X	X	X	X
5.7 SOP for addressing product defects or rejects	X		X	X	X	X	X	X	X	X
5.8 SOP for countermeasures against pre/post-delivery detection	X		X	X	X	X	X	X	X	X
5.9 SOP for addressing auto recalls	X		X	X	X	X	X	X	X	X
5.10 SOP for rendering nonconformities unusable and disposable	X		X	X	X	X	X	X	X	X

(Continued)

6.0 Continual Improvement										
6.1 Risk assessment scheme				X			X	X	X	
6.2 Process monitoring				X			X	X	X	
6.3 QX master process for capturing adversarial behaviours				X			X	X	X	
6.4 QX master process for capturing NVA activities				X			X	X	X	
6.5 QX master process to mitigate standards nonconformities				X			X	X	X	
6.6 QX master system for mitigating disruptions				X			X	X	X	
6.7 QX master process for periodical key stakeholder review				X			X	X	X	
6.8 QX master process for periodical departmental heads review				X			X	X	X	

Functional Processes*: 1 – Support; 2 – Training; 3 – Production; 4 – Continuous Improvement; 5 – Management; 6 – Auditing; 7 – Monitoring; 8 – Product Development; 9 – Quality Performance; 10 – Business Operations

8.4 Summary

This Chapter presents review feedback from two reviewers of automotive design engineering, academic and quality engineering backgrounds. The reviewers' collective feedback follows that the optimised QX Engineering design or framework can be easily understood with steps easy to follow, and that it is close to standard. The possibility of the review of the QX Engineering design also satisfies research objective 3 or RO3 as defined earlier in Chapter 1. Based on the constructive reviewers' feedback, Tables 7.1 and the optimised QX Engineering framework, this Chapter also proposes that Tables 7.2 and 7.3 are in principle a matrix for developing a documentation, standardisation process and application of QX Engineering. This satisfies research objective 4 or RO4 as defined earlier in Chapter 1.

Chapter 9: Conclusions and Recommendations for Future Research

9.1 Challenges in quality design implementation

This research established through the literature review and the research findings that there are three main capability gaps that this research sought to fill:

Firstly, there is a lack of core quality capability to create a one-fit-all quality engineering framework that enables automotive manufacturing SMEs to develop an in-house-customised userfriendly and easy-to-deploy-efficient quality process. Although there have been attempts to optimise quality engineering processes within the automotive manufacturing industry, challenges in quality design implementation such as auto recalls, customer complaints, environmental impact assessments, and automobile product quality failures have continued to persist. They thereby expose the inadequacies in the existing quality implementation processes (Cole 2010; Guinot et al., 2017; Liu et al., 2017; Shin et al., 2014; Topaloglu & Gokalp, 2018).

Secondly, despite the compliance of a significant number of multinational automotive manufacturing organisations to QMS-based ISO 9001 and IATF 16949:2016 industry standards and the utilisation of diverse quality systems, a one-fit-all quality engineering framework is currently non-existent. In particular, SMEs have challenges in implementing QMS-based IATF 16949:2016 standard (Karaszewski, 2004; Lambert & Ouedraogo, 2008; Prasad & Tata, 2003; Tulus et al., 2018). Silva (2017), attributing this to the IATF 16949:2016 standards document as solely consisting of a list of quality management items to implement than offering a *how-to* process to guide implementation.

Thirdly, there is a lack of capability as to how an integrated quality framework can be designed to mimic xenobiosis to enable (1) continuous assessment of its context as a system to mainly identify vQDD activities, (2) countermeasures to mitigate the occurrences of vQDD as a means of stimulating continuous improvement, and (3) post-design and in-process updates to specifications. Evidenced by the ineffective processes that lead to quality failures and the near-impossibility to assess and update key input variables after the design stage in QFD, LSS or TRDM, to name a few examples, customer specifications, standards requirements, and automotive manufacturing SMEs' needs and expectations have not been fully considered and translated into engineering characteristics.

9.2 QX Engineering Design: Contributions

This research contributes to previous research on quality engineering in identifying the sources of quality performance variation (Chapter 4) and providing insights into the barriers and threats to quality value delivery (Chapter 5). The identified quality performance variants and barriers to quality target value (QTV) delivery and quality implementation in Studies 1 and 2 provided the input parameters at the integration stage in Chapter 6 required to optimise the initial framework for the development of the QX Engineering Design.

This research, firstly, contributes to the existing engineering body of knowledge and practice in developing a new quality framework that can coevolve with the changing requirements. In seeking to address *why automotive manufacturing organisations vary systematically in quality performance over time*, four areas were identified as sources of quality performance variants. These areas are management role, quality of service, continuous monitoring, and emerging technologies. In order to depart from the reliance on the earlier established or conventional approach to automotive manufacturing organisation's quality engineering design goals, these four areas of sources of quality performance variation have to be assessed and optimised in order to adapt to the uncertainties in the demand patterns of customers and that of automotive standard regulatory bodies.

Secondly, this research identifies causes of less QTV deliveries that explain why non-QMS compliant organisations deliver significantly less quality value than QMS-certified firms. The primary objective for establishing the causes of less quality deliveries was to map out how to maximise the value of quality-oriented processes and automobile products. The identified threats or barriers to quality value delivery fall into the categories QMS knowledgebase, quality design, standards implementation, and responses to threats. This research thereby extends previous research in not only identifying threats to quality delivery but (1) assessing quality delivery from design stage to post-delivery stage, (2) including the human factor in deviations of quality and (3) providing insights into the different approaches of SMEs and large organisations with regard to the quality process and involved key stakeholders.

Thirdly, this research provides practice with a new QX Engineering Framework that is informed by industry quality standards and optimised through this research's findings on the barriers to quality value delivery, and can be easily adapted in an SME environment within the automotive manufacturing sector. Based on the lessons derived from the literature review and the research participants' responses, three key stakeholders were identified as essential for quality management and delivery from the start of company's goals statement establishment to the end of delivery. In order to curb the overreliance of SMEs on Top Management for every strategic decision, as evidenced by this research's data (see Fig. 7a to Fig. 7r), three core stakeholder groups were proposed, namely Top Management, QX Design Team and QX Task Force. By including QX Design Team and QX Task Force in the overall quality delivery process, they are given shared responsiblities and mutual ownership of the organisational goals. Overall, the QX Engineering Design provides SMEs with a mitigation solution against quality barrier causes.

9.2.1 Adding QX Engineering framework to automotive quality engineering systems

The novel QX Engineering system has addressed the capability gaps in literature by providing a methodical framework that enables SMEs to take a systematic easy-to-implement step-by-step approach from creating the organisational context, management or stakeholder responsibilities to constructing organisational highest-level goal through to creating core quality competencies capability as well as process mapping the satisfaction of compliance with standards and delivering quality value to the end consumer.

The QX Engineering system template also features steps such as risk assessment, standardisation, documentation of processes, performance measurements and auditing, continual improvement and other procedures that usually require automotive manufacturing organisations to adopt additional subject-related ISO standards to address. One unique aspect about the QX Engineering that sets it apart from the other quality systems (such as FMEA, QFD, LSS, Six Sigma, TRDM, etc.) is that it features both monitoring of social (human) actors' adversarial behaviours towards quality design, processes and implementation and creating avenues for deriving mitigation solutions against such human attitudes that can potentially vary quality value data. Examples of such uniqueness are embedded in the matrix described by Table 7.3 in terms of $FR_{2.10}$ and its decompositions, and $FR_{2.11}$—$FR_{2.14}$ and their associated decompositions, which must be satisfied to address top management non-committal attitudes towards quality system implementation, organisation-wide adversarial behaviours towards its own goals and internal audit of quality procedures (see Table 7.3).

9.2.2 Situating QX Engineering system within automotive manufacturing SMEs

While the implementation of industry standard quality procedures such as those in the QMS-based ISO family of standards and mainstream quality techniques such as FMEA, TRDM, LSS, etc., are generally too involving and capital-time-intensive for SMEs' limited resources (Horváth & Szabo, 2019; Smit et al., 2016; Braun et al., 2020; Rewilak, 2014; Brannstrom-Stenberg & Deleryd, 1999; Elg et al., 2008; Rohani et al., 2009; Bujna & Pristavka, 2014; Case et al., 2010; Pantazopoulos & Tsinopoulos, 2005; Sham et al., 2009; Sharma & Srivastava, 2018), the novel QX Engineering system is most suitable for SMEs in the automotive engineering service and manufacturing sector. This is because, oriented on SME characteristics, the methodical steps embedded in the implementation of QX Engineering system are easy-to-follow, have eliminated bureaucracies, devoid of complexity, adaptable/customisable to suit and accommodate the implementing organisation's business environment and model, devoid of uncertainties, self-taught approach, internal auditing stimulated, evolvable or organic, preventive maintenance-based, featured with human-based vQDD monitoring components with easily-createable mitigation solutions, continual improvement enabled, etc.

9.2.3 QX Engineering quality design: a robust system

The automotive manufacturing environment is highly dynamic and too complex for deterministic Physics to predict with a degree of certainty. The constantly changing automotive manufacturing environment expects quality systems to be robust enough to ensure sustainable delivery of quality value as well as withstand disruptions. The novel QX Engineering encompasses the core quality characteristics expected of a robust system, which include but are not limited to:

1. Optimisable, customisable, replicable, timeliness, visible, clear objective, cost-effective (as demonstrated by the optimisation process of the initial framework in Chapter 3 to the final design in Chapter 7 and $FR_{1.2.4}$)
2. Enabled quality control, quality planning, quality improvement, process improvement, standards compliance, continuing improvement (as addressed by $FR_{1.1.3}$; $FR_{1.1.6}$; $FR_{1.2.3}$; $FR_{1.2.5}$; $FR_{1.2.6}$; $FR_{1.2}$ and its decompositions; $FR_{1.3}$ and its decomposistions; $FR_{2.16}$ and its decompositions)
3. Customer-centric support, consistency, highly responsive (as addressed by $FR_{1.3.6}$)
4. Risk mitigation, risk assessment, adaptability, ability to cope with disruptions and noises (internally and externally), disaster recovery, rigorousness (as addressed by $FR_{1.3.3}$; $FR_{2.17}$ and its decompositions; $FR_{1.18}$ and its decompositions)
5. Competence building, learnable (as addressed by $FR_{1.1}$ and its decompositions; $FR_{2.12}$)
6. Standardisation process enabled (as addressed in Table 8.1)
7. Documentation of processes, documentation of identifiable records, process equipment, prevents deviations from quality target value delivery, maintains quality (as addressed by $FR_{1.1.5}$; $FR_{1.1.10}$; $FR_{1.1.11}$; $FR_{1.1.12}$; $FR_{1.1.13}$; $FR_{1.1.14}$; $FR_{2.8.1}$; $FR_{2.15.2}$; $FR_{2.16.2}$)
8. Leadership, management, interested parties, personnel engagement (as addressed by $FR_{2.1}$ and its decompositions; $FR_{2.2}$ and its decompositions; $FR_{2.11}$ and its decompositions)

9. Relationship management to mitigate conflicts (as addressed by $FR_{2.2}$ and its decompositions; $FR_{2.10}$ and its decompositions; $FR_{2.13}$ and its decompositions)
10. Environmental factors, human factors, waste mitigation, agents of variation, mitigation against non-value added activities (as addressed by $FR_{1.3.2}$; $FR_{1.3.4}$; $FR_{1.3.5}$; $FR_{2.3}$ and its decompositions; $FR_{2.4}$ and its decompositions; $FR_{2.6}$ and its decompositions; $FR_{2.7}$ and its decompositions; $FR_{2.10}$ and its decompositions)
11. Easy-to-communicate, simplistic, adoptable, replicable, reduced complexity for increased understandability (as depicted in the outcomes of the reviews in Sections 8.2 and 8.3 in Chapter 8)

The core strength of the novel QX Engineering framework are the benefits it can offer SMEs within the automotive engineering service and manufacturing sector in terms of its easy-to-implement, devoid of complexities, self-taught characteristics and most importantly non-departure from the automotive industry standards and compliance procedures.

9.2.4 Scalability of the framework for large automotive manufacturing organisations

By its nature, the QX Engineering framework enables reconfiguration by changing the FR—DP configurations to satisfy the implementing organisational structural needs. This flexibility can allow for the introduction of new sets of FRs and corresponding plausible DPs to satisfy large organisation-wide requirements. Furthermore, such adaptable characteristic of the QX Engineering framework can stimulate new policies across relevant units or departments within the automotive manufacturing operations environment as and when required. This is a necessary and sufficient condition for maintaining sustainable efficiency (i.e., cost-effectively) of large organisations' manufacturing operations. Thus, the novel framework, which is not only for SMEs, can also be scaled up for implementation within larger automotive manufacturing organisations.

9.3 Recommendations for future research

Further research will essentially only improve and widen the applicability of the QX Engineering framework. As the QX Engineering concept is meant to enable customisation, it suffices to say that research must be ongoing to increase its userfriendliness, adaptability and applicability globally irrespective of the size and culture of the organisation. Although the findings in this research provided deepened insights into the dynamics and variants of quality delivery and implementation within automotive manufacturing organisations, the following segments are worth considering for future research.

QX Engineering Design Research

In order to widen the applications horizon of the QX Engineering Framework and its contribution scope as well as to enrich and situate it properly within the targeted automotive manufacturing SME sector as well as large organisations, the following are recommended:

1. Make room for more iterations until the framework model is exhausted in answering all relevant questions in relation to the characteristics and resources of the organisation (SME or big). In this respect, future research will focus more on reviews, interviews and implementation in selected automotive engineering service and manufacturing SMEs and large organisations for testing, evaluation and or review purposes. This could help to further refine the model and ultimately provide it to SMEs and big organisations as a solution for an in-house quality management system.
2. Widen the scope of the existing analysis by carrying out an empirical study of the implementation of the QX Engineering framework at both SMEs and large automotive manufacturing organisations.
3. Extend the applicability and scalability of the framework by conducting empirical research of the customisation and implementation of the QX Engineering framework at other organisations for quality process improvement.
4. Create specific information modules for each FR and associated sub-FR and their corresponding DPs. This will serve as an online-based knowledge bank and reference resource for SME and big organisations, which can be hosted on a dedicated web platform. This will feature a highly modularised approach to enable a free-flow of information with links to other modules, which are aimed at giving a sense of progression. These will feature:
    i. Knowledge-based assessment tools, leading to creating a training-based platform. This could ease new users' access to QX Engineering standardised workflows and procedures
    ii. Regular updates to the proposed web platform, enriched with evolving procedures, amendments, added new information (new key input variables or new contributory data). Search engine optimisation will help position QX knowledge-bases at the top of the search engine

Generalisability

This research conducted surveys with quantitative and qualitative components of two groups: Candidate A cohort of experts (N=8) and Candidate B cohort of consumers (N=25). One limitation of this research could be whether the number of collected and analysed surveys is adequate to generalise the findings. The focus, however, was not on statistical analysis of the data but an in-depth exploration of the quantitative data that was complemented by qualitative open-ended questions, expert interview and reviews of the developed framework. As presented in the previous segments, future research could involve further refining and testing the framework in real-case company scenarios.

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Appendices

Appendix 1: Category A – Survey: Quality Dimensions

Quality Dimensions Questionnaire

PROJECT INFORMATION SHEET

Researcher: Michael Flowers

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Research Background:

This research focuses on quality engineering dimensions as relates to the automotive manufacturing industry. The context of this research questionnaire concentrates on the key indices of quality that measure quality performance and reveals activities that stimulate departures from the intended stakeholder quality goals in the automotive manufacturing industry. The data derived from this questionnaire will help in developing an understanding of how the competitive dimensions of quality performance can impact quality design and implementation processes within automotive manufacturing organisations. Based on the philosophical worldview (i.e. pragmatism) proposed for this study, this component of the methodological choices for data collection will help in the derivation of the contributory data or input parameters required to develop a new quality engineering system for automotive manufacturing SMEs.

Purpose of the Research:

The key purpose of this research is to develop a novel quality engineering system for the automotive manufacturing SME sector.

Funding:

This research, which is a part of a doctorate thesis, is not funded.

Choice of Participants:

As this research takes an eclectic (diverse) approach to seek different perspectives of quality dimensions from persons who are working within or associated with the automotive product manufacturing/development and automotive service providing sector, you are considered as a suitable participant.

Confidentiality and Data Storage:

This research will not seek to publish your personally identifiable information. The information you provide will be treated as anonymous. Where it is detected that you mentioned your name, another person's name, or name of your company in error or unintentionally, such identifiable data will be stored in strict confidence and treated as anonymous within the data analysis and reporting.

Research Outcome:

The research findings and the expected developed new quality engineering framework will form a part of the composition of the doctoral thesis. Derivatives of the research outcome will also feature in topic-related scholarly articles, academic conference proceedings, and the like, as part of the effort to disseminate the research results. While it is anticipated that the research outcome with its derived product will benefit SMEs within the automotive manufacturing sector as well as individuals within the industry, there is no guarantee that the outcome derived from this study will certainly optimise your current quality implementation processes and translate into high quality performance.

Researcher and Supervisors:

Professor Shujun Zhang (Principal Supervisor) and Dr. Martin Wynn (Second Supervisor), both of the University of Gloucestershire, UK, are the Supervisors for this research. The Researcher is Michael Flowers, who is conducting a doctoral research for his thesis.

Thank you for your interest and agreeing to voluntarily participate in this research questionnaire survey. Please review and submit the Consent to Participate Form in the NEXT section.*Required

Consent to Participate Form

Thank you for you for accepting the invitation to participate in this research survey questionnaire. Please complete the whole Consent Form by ticking all theboxes to confirm that you have read the Project Information presented in the preceding section. *

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Tick all that apply.

- ☐ I acknowledge that the Researcher has explained the purpose of this research questionnaire survey to me.
- ☐ I have read the Project Information and understood the intent of this research.
- ☐ I understand that this questionnaire survey will be used for the sole purpose of the research on quality dimensions in the automotive manufacturing sector.
- ☐ I understand that I am not required to supply my name, name of the company I work for, and any personally identifiable information about me.
- ☐ I understand that my participation in this questionnaire survey is voluntary and that I am at liberty to withdraw without giving any reason.
- ☐ I understand and agree that any details of my participation and responses will be stored anonymously on file and may be used in the analysis of data.
- ☐ I understand that parts or all of my responses, if considered relevant to the study, may be used as part of the overall data collected for analysis, which outcome may also feature in the research findings.
- ☐ In view of my acceptance of the aforementioned, I give permission for my responses to be used as deemed appropriate for this research.
- ☐ I therefore consent to participate in this research questionnaire survey.

Standards Awareness & Compliance

The questions in this section are related to automotive industry quality standards awareness and compliance. In essence, the automotive industry standards are collectively a system that defines how automotive manufacturing organisations can satisfy customer requirements and associated stakeholders' goals.

Definitions of key automotive industry quality standards:
IATF 16949:2016 or simply IATF 16949 is the global technical standard that governs the quality management systems within the automotive manufacturing industry, encompassing standards for manufactured automotive products, assembly and testing processes and associated services.

AEC-Q100 essentially defines the automotive manufacturing industry standard tests for active components (such as switches, power amplifiers, etc.).

AEC-Q200 defines the standard tests for passive devices (such as RF filters, etc.).

ISO 9001 focuses on customer satisfaction, operating costs effectiveness, risk management, legal compliance, stakeholder satisfaction, brand credibility, and the like.

ISO 14001 focuses on environmental and economic sustainability. ISO 26262 regards functional safety standard.

ISO 45001 focuses on product and service reliability within health and safety business environment.

How would you describe the size of your company?

Tick only one box.

☐ Small and medium-sized enterprise (SME) – (fewer than 250 employees)

☐ Large or multinational – (250 employees or more)

Which of the automotive industry quality standards does your company conformto? Select all that apply

Tick all that apply.

- ☐ IATF 16949:2016
- ☐ ISO 9001
- ☐ ISO 14001
- ☐ ISO 26262
- ☐ ISO 45001
- ☐ AEC-Q100 & AEC-Q200
- ☐ None of the above
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ____________________

Do you know any automotive manufacturing firm that is IATF 16949:2016 standard compliant?

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ I am not familiar with IATF 16949:2016 standard

Do you know any automotive manufacturing firm that is ISO 9001 standardcompliant?

Tick only one box.

☐ Yes

☐ No

☐ I am not familiar with IATF 9001 standard

Do you know any automotive manufacturing firm that is ISO 14001 certified?

Tick only one box.

☐ Yes

☐ No

☐ I am not familiar with IATF 14001 standard

Do you know any automotive manufacturing firm that is ISO 26262 certified?

Tick only one box.

☐ Yes

☐ No

☐ I am not familiar with IATF 26262 standard

Do you know any automotive manufacturing firm that is ISO 45001 certified?

Tick only one box.

☐ Yes

☐ No

☐ I am not familiar with ISO 45001 standard

Do you know any automotive manufacturing firm that is either AEC-Q100 or AEC-Q200 or both certified?

Tick only one box.

☐ Yes

☐ No

☐ I am not familiar with AEC-Q100 and or AEC-Q200 standard

Quality Knowledge	Manufacturing quality knowledge in this study is related to the integration of quality design and implementation throughout the manufacturing process, from design through to the delivery of product or service to the customer. In this research, industry-standard Quality Engineering Knowledge includes the procedures outlined in IATF 16949:2016, ISO 9001, ISO 14004, ISO 26262, ISO 45001, etc., that are applicable to the automotive industry.

Is industry-standard quality engineering knowledge included at the early designstage at your company? (e.g. IATF 16949:2016, ISO 9001, ISO 14004, ISO 26262, ISO 45001, etc.)

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Which of the following quality methods are used within your company?

Tick all that apply.

☐ Six Sigma

☐ Total Quality Management (TQM)

☐ Product Part Approval Process (PPAP)

☐ Lean Management System

☐ Failure Made and Effects Analysis (FMEA)

☐ Statistical Process Control (SPC)

☐ Quality Function Deployment (QFD)

☐ Advanced Product Quality Planning (APQP)

☐ Taguchi Robust Design Method (TRDM)

☐ Don't know or Prefer not to answer

☐ Other (Specify): ______________________

Does your company have a standardised Quality Policy?

Tick all that apply.

- ☐ Yes
- ☐ No
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ____________________

Which of the following activities is featured in your company's Quality Policy? The company's Quality Policy is...

Tick all that apply.

- ☐ Always appropriate to the overall company goal
- ☐ Consistent with the quality objectives of the company
- ☐ Well-communicated and well-understood within the company
- ☐ Regularly reviewed by top management
- ☐ Kept as a Standard Reference Document
- ☐ An enablement of Continual Improvement
- ☐ The organization does not have a Quality Policy document
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ____________________

Which of the following automotive manufacturing (internal) parties is involved as key stakeholders or decision-makers of quality performance in the early productor service design process? (Select all that apply).

Tick all that apply.

- ☐ Top Management
- ☐ Engineering Design Team
- ☐ Task Force
- ☐ Internal/Vehicle Auditor
- ☐ Quality Manager/Director
- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer
- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead
- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor
- ☐ Facility Maintenance Lead
- ☐ Line Manager(s)
- ☐ Don't know or Prefer not to answer

☐ Other (Specify): ____________________

Do you use any special software or tool to assess the company's core quality capabilities?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Quality Design Documentation	Documentation of the manufacturing, quality and design specification communicates the quality design intent to ensure Customer Satisfaction. Documenting the quality designs and specifications take into account the key components of the intended quality delivery in a way that staff across the associated departments can clearly understand what the expectations are with respect to the company goals. This enables early identification of errors, omissions, and any quality compromises in the automotive manufacturing quality documentation and can make room for changes and or change requests

Does your company have an in-house developed Quality Design Documentation, featuring how design specifications can take into account the key components or parameters required to maximise customer satisfaction?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

With respect to managing efficiency and operations performance, is adequate information incorporated into the Quality Design Documentation to ensure manufacturing resources (such as equipment, manufacturing systems, etc.) are easily accessible in a timely manner?

Tick only one box.

☐ Yes

☐ No

☐ Company has no Quality Design Document

☐ Don't know or Prefer not to answer

Do you evaluate and include customer specific requirements in the Quality Design Documentation? (Customers in eg. OEMs, tier-1, tier-2 and other automotive customers internal or external or both).

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ Company has no Quality Design Document
- ☐ Don't know or Prefer not to answer

Who is usually involved in the preparation of the Quality Design Documentation?Multiple answers allowed

Tick all that apply.

- ☐ Top Management
- ☐ Engineering Design Team
- ☐ Task Force
- ☐ Internal/Vehicle Auditor
- ☐ Quality Manager/Director
- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer
- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead

- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor
- ☐ Facility Maintenance Lead
- ☐ Line Manager(s)
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ____________________

Do you employ the use of a purpose-built software or a special tool forreviewing quality-based procedures and documenting them?

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ Don't know or Prefer not to answer

Manufacturing Equipment Standardisation	Standardisation of manufacturing equipment and systems are essential in supporting shopfloor staff to minimise or avoid disruption of operation or quality losses, for example. Using the relevant quality management system-based ISO-standards can help in aligning in-house manufacturing equipment standardisation to be in tune with the international automotive manufacturing industry standard requirements or procedures.

To what extent does your organisation standardise its manufacturing equipment before or during the design stage?

Tick only one box.

- ☐ Between 85% and 100%
- ☐ Between 65% and 84%
- ☐ Between 45% and 64%
- ☐ Between 25% and 44%
- ☐ Between 5% and 24%
- ☐ Less than 5%
- ☐ Don't know or Prefer not to answer

Who is responsible for ensuring manufacturing equipment and systems standardisation? (Select all that apply)

Tick all that apply.

- ☐ Top Management
- ☐ Engineering Design Team
- ☐ Task Force
- ☐ Internal/Vehicle Auditor
- ☐ Quality Manager/Director

- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer
- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead
- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor
- ☐ Facility Maintenance Lead
- ☐ Line Manager(s)
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ______________________

Managing Safety Recalls	In the context of this research, a best practice process for managing recalls or addressing rejects in the automotive industry can help automotive manufacturing organisations to achieve high success when conducting a safety recall or addressing product reject or defect issues. Although best practice is about improving quality, it isalso about examining the existing process and reaffirming that it produces the best results as expected by the industry standard and the customer.

Does your company make it mandatory for its staff to develop knowledge in or become conversant with the General Product (automotive) Safety Regulations?

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ Don't know or Prefer not to answer

Do you have a Code of Practice on Safety that every staff must adhere to? A Code of Practice on Safety in the automotive sector mainly refers to action taken when a defect is identified within the definition of safety issues that canpotentially result in serious injuries or death.

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ Don't know or Prefer not to answer

Is your company aware of the potential safety recall Early Warning System?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Does your company have a system for locating information quickly at the request of automotive industry governing bodies?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Does your company have a system in place to notify automotive regulatory bodies of any late detection of a safety defect that could potentially affect vehicles or products that have already been supplied for use?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Does your company have a system in place to notify automotive regulatorybodies of any late detection of a safety defect that could potentially affectvehicles that have NOT yet been supplied for use?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

In conducting an automotive product safety recall or manufacturing defect orreject, which of the following key items does your organisation have or put in place? Multiple answers possible.

Tick all that apply.

☐ Description of the identified defect and its effect
☐ An ideal solution to address the defect
☐ A robust process for product recall/reject
☐ A traceability mechanism to track the product with defect
☐ Robust internal procedures to isolate the problem
☐ A communication and media protocol
☐ Documentation of Lessons Learnt
☐ Quality improvement Action Plan
☐ Service improvement Action Plan
☐ Technical upgrade Action Plan
☐ Don't know or Prefer not to answer
☐ Other (Specify): ____________________

Do you document product safety related issues?

Tick all that apply.

- ☐ Yes
- ☐ No
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify):

Who is responsible for managing safety recall or product defect/reject issues? Multiple answers allowed.

Tick all that apply.

- ☐ Top Management
- ☐ Engineering Design Team
- ☐ Task Force
- ☐ Internal/Vehicle Auditor
- ☐ Quality Manager/Director
- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer
- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead

- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor
- ☐ Facility Maintenance Lead
- ☐ Line Manager(s)
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ____________________

Do you use a special software or tool to manage product safety recall ordefect/reject issues?

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ Don't know or Prefer not to answer

Dealer Responsibility	This research asserts that accessing your company's product end-users or customers is easy through your company's Dealership Network as the latter is expected to maintain the contact details of your customers. Your product Dealer may also have the opportunity of marketing or acquiring information on customerused vehicles or customer-requested modified vehicles originally produced by your company. In view of this research, the role of your Dealer, if any, is to be a part of the shared responsibility in the matter of safety recalls as they may hold important information in helping to trace the origins of quality problems

Select which of the following steps your company employs to ensure that your Dealership Network takes a responsible approach to helping to address productsafety recalls or defects/rejects. (Multiple answers allowed)

Tick all that apply.

- ☐ Provide Dealers with clearly defined all-inclusive instructions regarding your products
- ☐ Include a set of instructions in the Dealership Agreement
- ☐ Use intranet/dealer site effectively
- ☐ Motivate dealers to be proactive
- ☐ Mandate dealers to inspect Customer's vehicles thoroughly in their dealership with respect to looking for customer activities that can potentially compromise the intended functional quality of company's original product or service
- ☐ Train Dealership staff, ensuring they are conversant with the General Product Safety Regulations
- ☐ None of the above
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ______________________

Who is responsible for monitoring and managing Dealership Responsibilities? Multiple answers allowed

Tick all that apply.

- ☐ Top Management
- ☐ Engineering Design Team
- ☐ Task Force
- ☐ Internal/Vehicle Auditor
- ☐ Quality Manager/Director
- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer
- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead
- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor
- ☐ Facility Maintenance Lead
- ☐ Line Manager(s)
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ____________________

Do you use any special software or tool to monitor and manage Dealership Responsibilities?

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ Don't know or Prefer not to answer

Defect Traceability	This research considers product, process and or service defect traceability a significant element for reducing complexities associated with product recall or reject or manufacturing system/service failures. This is often the case when automotive products, for example, are not properly registered, making it difficult to identify any faulty products, for example, through registration with the relevant regulatory bodies. Defects can also be present in manufacturing equipment or systems, etc.

Does your company have a mechanism along the manufacturing operations or processes or chain to enable identification or tracking of defect products oncethey are delivered into service (use)?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Which of the following methods does your company use to enable traceabilityonce a defect component or part enters the market? Multiple answers allowed.

Tick all that apply.

☐ Data tagging

☐ Bar coding

☐ Parts etching

☐ Component labelling

☐ Stock identifiers

☐ Batch coding

☐ Producer sales recordkeeping

☐ Supplier/Distributor recordkeeping

☐ Retail sales recordkeeping

☐ Warranty recordkeeping

☐ Customer loyalty programme

☐ None of the above

☐ Don't know or Prefer not to answer

☐ Other (Specify): ______________________

Is your product defect traceability process monitored through a quality auditing process?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Do you document the process for the management of automotive productionservice, accessory parts or components safety?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Does the company have a Quality Auditor or Quality Director who is dedicatedto all quality-related processes and issues?

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ Don't know or Prefer not to answer

Does your company have a system that has been designed to enable personnelto report any errors (or adversarial behaviours) they commit along the manufacturing line or processes? In the context of this research, an AdversarialBehaviour may be defined as any deliberate action or behaviour by a staff or personnel that is likely to cause a quality issue within the manufacturing operation.

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ Don't know or Prefer not to answer

Does your company have a system that has been designed to enable personnelto report any errors (or adversarial behaviours) committed by other staff or personnel along the manufacturing line or processes? In the context of this research, an Adversarial Behaviour may be defined as any deliberate action or behaviour by a staff or personnel that is likely to cause a quality issue within themanufacturing operation.

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ Don't know or Prefer not to answer

Who is in charge of managing product/service defect traceability process? Multiple answers allowed

Tick all that apply.

- ☐ Top Management
- ☐ Engineering Design Team
- ☐ Task Force
- ☐ Internal/Vehicle Auditor
- ☐ Quality Manager/Director
- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer
- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead
- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor
- ☐ Facility Maintenance Lead
- ☐ Line Manager(s)
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ____________________

Do you use a special software or tool for the defect traceability process?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Manufacturing Facility	In the context of this research, the objective of an automotive Manufacturing Facility layout is so designed to enable efficiency in the facility's operations and maintenance such that it supports the smooth activities of all the manufacturing processes. This can enhance adequate technical supervision and shopfloor communication, information dissemination, energy sustainability, reduced complexity, optimised scheduling, quality monitoring and implementation.

Does your company have a manufacturing Facility Director or Manager?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

If your company has a manufacturing Facility Director or Manager, is theFacility Director or Manager involved in the early design stage?

Tick only one box.

☐ Yes

☐ No

☐ There is no manufacturing Facility Director

☐ Don't know or Prefer not to answer

If your company has a manufacturing Facility Director or Manager, is the Facility Director or Manager conversant with the relevant ISO standards for automotive manufacturing quality procedures?

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ There is no manufacturing Facility Director
- ☐ Don't know or Prefer not to answer

How is information disseminated across the various departments within thecompany?

Tick all that apply.

- ☐ Printed documents
- ☐ Printed and Electronic Editions
- ☐ Onsite Team Training or Seminar
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ____________________

Who is responsible for managing the Manufacturing Facility? Multiple answersallowed

Tick all that apply.

- ☐ Top Management
- ☐ Engineering Design Team
- ☐ Task Force
- ☐ Internal/Vehicle Auditor
- ☐ Quality Manager/Director
- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer
- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead
- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor
- ☐ Facility Maintenance Lead
- ☐ Line Manager(s)
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ____________________

Do you use any special software or system or special tool for the review of the Manufacturing Facility with respect to the quality requirements of a working environment?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Management Support

Within the context of this research, the various departments count on the coordination and support of Top Management to help them achieve excellence in their functional operations. In this enquiry, on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree), rate the level of your company's Management Support for the various departmental processes or operations.

Score Scale:
1 – Strongly Disagree
2 – Disagree
3 – Somewhat Disagree
4 – Neutral or Unknown
5 – Somewhat Agree
6 – Agree
7 – Strongly Agree

Top Management defines company main goals and clearly communicates themacross all departments.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management's standard practice is to assign responsibilities to persons (that is, professionals by their individual names) and NOT to the specific titles(by roles such as Quality Director, Project Manager, Operations Manager, etc.).

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management puts in place an existing functional programme or system for monitoring automotive safety-related parts or components and accessories.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management ensures documentation of processes for the management of automotive product safety.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management ensures the company transfers standard product-safety requirements to sub-tier suppliers. (A sub-tier Supplier is any supplier who is a third party who provides components, parts, materials or related products directly or indirectly to your company).

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management ensures the company has an existing and effective continual Risk Analysis and Preventive programme.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management ensures the company's continual risk analysis scheme includes a minimum of potential auto recalls, actual recalls, product defects, scrap, rework and rejects.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management ensures the company's manufacturing processes and infrastructure contingency plans are regularly assessed for effectiveness,reviews and updates.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management ensures the company has standard requirements for its suppliers to ensure they comply with the industry standard quality managementsystem procedures.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management ensures the company has standard requirements for its supplychain (or delivery/distribution) channel to comply with the industry standard quality management system procedures.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management ensures the company regularly reviews its audit results of suppliers to ensure the supplier process is robust and assures compliance withthe latest applicable statutory, regulatory and other automotive industry standard requirements.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management ensures the company has an effective Internal Audit Team thatregularly monitors all key manufacturing processes and reports to Top Management for regular reviews.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management ensures it builds knowledge as well as remain updated with the quality management standards implementation processes, procedures, records of implementation and controls with respect to the automotive industrystandard requirements. The standard requirements in this section refer to the ISO family of standards as related to the automotive industry.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management ensures optimal communication with all interested parties (stakeholders, both external and internal) exists at all times.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management mandates the existence of a system or programme for theMonitoring and Measurement of Quality Performance with related Records ofResults.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Regarding building core quality capabilities, Top Management offers regular staff training and awareness schemes.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management significantly invests in personnel training and knowledge development in quality standards, quality tools, and or ISO standard procedures.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Who is responsible for reviewing Top Management operational activities and toensure Management Support is directed at achieving the company's highest goals? Select all that are applicable.

Tick all that apply.

☐ Top Management

☐ Engineering Design Team

☐ Task Force

☐ Internal/Vehicle Auditor

- ☐ Quality Manager/Director
- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer
- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead
- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor
- ☐ Facility Maintenance Lead
- ☐ Line Manager(s)
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ____________________

Do you use a special software or tool to evaluate Top Management Support?

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ Don't know or Prefer not to answer

Risk Assessment	The worldview of this research asserts that the automotive sector is constantly confronted with critical risks across the product manufacturing, service and supply chains. Strategic management of critical risks (such as supply chain uncertainties, material failures or shortages, software failures, personnel sudden departures, manufacturing process disruptions, natural disasters, unexpected pandemic protocols, economic turbulence, etc.) can help in early identification and assessment of potential threats to a company's business operations and market share.

Does the company conduct Risk Assessment to detect or identify specific staff or personnel adversarial or counterproductive behaviours against the management goals?

Tick only one box.

☐ Yes

☐ No

☐ Don’t know or Prefer not to answer

Does the company have a Risk Assessment scheme that encourages personnel to report any quality-based mistakes they make along the manufacturing operations chain?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Does the company conduct a Risk Assessment to detect threats within thecompany that is potentially against regulatory standards authorities' requirements?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Does the company conduct a Risk Assessment to monitor and detect specific adversarial behaviours of automobile passengers or drivers or users of their automotive product? Adversarial behaviour may be defined in this context as any human behaviour that is likely to cause a damage to the intended functionalquality of the company's product in use. An example is deliberately replacing anoriginal part with a non-compliant secondhand part.

Tick only one box.

☐ Yes

☐ No

☐ Don’t know or Prefer not to answer

Does the company have a Risk Assessment scheme to monitor and detect specific potential threats against the smooth operation of the product supply(distribution or delivery) chain?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Does the company conduct a Risk Assessment based on external stakeholderneeds? As external stakeholder includes Original Equipment Manufacturer (OEM), investors, owner, etc.

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ Don't know or Prefer not to answer

Who is responsible for conducting Risk Assessment? Select all that apply.

Tick all that apply.

- ☐ Top Management
- ☐ Engineering Design Team
- ☐ Task Force
- ☐ Internal/Vehicle Auditor
- ☐ Quality Manager/Director
- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer
- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead
- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor

☐ Facility Maintenance Lead

☐ Line Manager(s)

☐ Don't know or Prefer not to answer

☐ Other (Specify): ____________________

Does the company use a set of specific tools or special software to conduct Risk Assessment in relation to people's attitudes towards the company's products or manufacturing services?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Non-conforming Products	In essence, a product conformance evaluation requirement applies to a product that has gone through the Part Approval process and is ready to ship to the customer. The context of this research asserts that a nonconforming product should not find its way into the hands of the roadside mechanic workshop, unofficial auto marketplace, or is accidently distributed to an unsuspecting customer. A nonconforming product is practically a product that is unusable and unrepairable. On a scale of 1 (Strongly Disagree) to 7 (StronglyAgree) as defined below, describe your company's intent or standard practice and requirements for rendering nonconforming products unusable prior to final disposal. **Score Scale:** 1 – Strongly Disagree 2 – Disagree 3 – Somewhat Disagree 4 – Neutral or Unknown 5 – Somewhat Agree 6 – Agree 7 – Strongly Agree

The company has developed an effective process for the identification anddisposition of nonconforming products.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

The company uses an external firm to evaluate and render its nonconformingproducts unusable.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Who is responsible for ensuring nonconforming products are identified and areproperly disposed of? Multiple answers allowed

Tick all that apply.

- ☐ Top Management
- ☐ Engineering Design Team
- ☐ Task Force
- ☐ Internal/Vehicle Auditor
- ☐ Quality Manager/Director
- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer
- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead
- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor
- ☐ Facility Maintenance Lead
- ☐ Line Manager(s)
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ____________________

Do you use a special tool or software to manage the process of identifying anddisposing of nonconforming products?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Software Validation	Within this research context, the assessment and validation of any software used in the automotive manufacturing processes and service should follow the same rigorous approach required in the development of software. This segment is to enquire about the level of the valuation of any software used by the company from the design stage through the manufacturing process and supply chain to the customer. On a scale of 1 (Strongly Disagree) to 7 (Strongly Agree) as defined below, describe how your company assesses and validates all software used. **Score Scale:** 1 – Strongly Disagree 2 – Disagree 3 – Somewhat Disagree 4 – Neutral or Unknown 5 – Somewhat Agree 6 – Agree 7 – Strongly Agree

The company has a special and rigorous framework to assess a Supplier Software development capability.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

The company uses the following approach or approaches to assess and validate software it uses. Please select what applies.

Tick all that apply.

☐ Software Supplier self-assessment

☐ Customer/Company onsite assessment

☐ Engages an external software assessor

☐ Engages specialist internal software assessor

☐ None of the above

☐ Don't know or Prefer not to answer

☐ Other (Specify): ____________________

Who is responsible for ensuring software platforms used are rigorouslyassessed and validated? Multiple answers allowed

Tick all that apply.

- ☐ Top Management
- ☐ Engineering Design Team
- ☐ Task Force
- ☐ Internal/Vehicle Auditor
- ☐ Quality Manager/Director
- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer
- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead
- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor
- ☐ Facility Maintenance Lead
- ☐ Line Manager(s)
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ______________________

Management's Mindset	On a scale of 1 (Strongly Disagree) to 7 (Strongly Agree), how would you describe the mindset or beliefs of the company's Top Management with regards to the automotive industry standard procedures, training, certifications, etc.? **Score Scale:** 1 – Strongly Disagree 2 – Disagree 3 – Somewhat Disagree 4 – Neutral or Unknown 5 – Somewhat Agree 6 – Agree 7 – Strongly Agree

Top Management believes that ISO standard procedures and associated standards are not adequate enough for the constantly changing automotive manufacturing environment.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management believes that implementation of ISO standards is very difficult, too expensive and time-consuming.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management pays very little attention to the adoption and implementation of ISO standards.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management believes that not all the personnel across the departments need to necessarily attain ISO standards certifications.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management offers very little support for staff training in ISO standard procedures.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Do you use a special software or tool to review Management's Mindset or beliefsor views about the ISO standard for automotive industries?

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ Don't know or Prefer not to answer

Core Quality Tools Implementation	The enquiries within this segment relate to the company's core quality capabilities as found necessary in the optimisation of existing manufacturing processes. On a scale of 1 (Very Poorly) to 7 (Very Well), how would you describe your company's use of the core quality tools listed below to enhance its manufacturing processes? Score Scale: 1 – Very Poorly 2 – Poorly 3 – Somewhat Poor 4 – Unknown / Not At All 5 – Somewhat Well 6 – Well 7 – Very Well

Six Sigma Methodology

Tick only one box.

	1	2	3	4	5	6	7	
Very Poorly	☐	☐	☐	☐	☐	☐	☐	Very well

Lean Management System

Tick only one box.

	1	2	3	4	5	6	7	
Very Poorly	☐	☐	☐	☐	☐	☐	☐	Very well

Production Part Approval Process (PPAP)

Tick only one box.

	1	2	3	4	5	6	7	
Very Poorly	☐	☐	☐	☐	☐	☐	☐	Very well

Advanced Product Quality Planning (APQP)

Tick only one box.

	1	2	3	4	5	6	7	
Very Poorly	☐	☐	☐	☐	☐	☐	☐	Very well

Measurement System Analysis (MSA)

Tick only one box.

	1	2	3	4	5	6	7	
Very Poorly	☐	☐	☐	☐	☐	☐	☐	Very well

Statistical Process Control (SPC)

Tick only one box.

	1	2	3	4	5	6	7	
Very Poorly	☐	☐	☐	☐	☐	☐	☐	Very well

Quality Function Deployment (QFD)

Tick only one box.

	1	2	3	4	5	6	7	
Very Poorly	☐	☐	☐	☐	☐	☐	☐	Very well

Failure Mode and Effects Analysis (FMEA)

Tick only one box.

	1	2	3	4	5	6	7	
Very Poorly	☐	☐	☐	☐	☐	☐	☐	Very well

Total Quality Management (TQM)

Tick only one box.

	1	2	3	4	5	6	7	
Very Poorly	☐	☐	☐	☐	☐	☐	☐	Very well

Taguchi Robust Design Methods (TRDM)

Tick only one box.

	1	2	3	4	5	6	7	
Very Poorly	☐	☐	☐	☐	☐	☐	☐	Very well

Overall, the company's personnel skillset knowledge in the core quality tools isat the following level.

Tick only one box.

- ☐ Between 85% and 100%
- ☐ Between 65% and 84%
- ☐ Between 45% and 64%
- ☐ Between 25% and 44%
- ☐ Between 5% and 24%
- ☐ Less than 5%
- ☐ Don't know or Prefer not to answer

Who is responsible for the implementation of core quality systems or methodsor tools across the overall manufacturing process, from product design to delivery? Select all that apply.

Tick all that apply.

- ☐ Top Management
- ☐ Engineering Design Team
- ☐ Task Force
- ☐ Internal/Vehicle Auditor
- ☐ Quality Manager/Director
- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer

- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead
- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor
- ☐ Facility Maintenance Lead
- ☐ Line Manager(s)
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ______________________

Do you use a special software or tool to assess personnel level of competencyin the core quality tools? Such assessment tool may feature a SWOT analysis,for example.

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ Don't know or Prefer not to answer

Quality Performance	A good degree of Quality Performance indicates that automotive manufacturing services or products are of the highest quality and are delivered through a good quality supply chain management as well. Please rate the quality performance of your company using a scale of 1 (Strongly Disagree) to 7 (Strongly Agree) in terms of the quality dimensions listed in the following segments. **Score Scale:** 1 - Strongly Disagree 2 - Disagree 3 - Somewhat Disagree 4 - Unknown 5 - Somewhat Agree 6 - Agree 7 - Strongly Agree

Based on the company's quality performance, the company has achieved reduced manufacturing costs

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Based on the company's quality performance, the company has achieved increased customer retention.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Based on the company's quality performance, the company has realised return on investment (ROI).

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Based on the company's quality performance, the company has achieved increased market share.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Based on the company's quality performance, the company has gained a competitive edge.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Based on the company's quality performance, the company has seen growth in sales.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Based on the company's quality performance, the company has achieved improved brand reputation.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Based on the company's quality performance, the company has achieved increased customer satisfaction.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Based on the company's quality performance, the company has achieved an effective supply chain and logistics operations.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Based on the company's quality performance, the company has achieved an improved overall business performance.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top management is more focused on investing in optimising the company's quality performance process.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Who is responsible for managing and driving the company's quality performance processes forward? Select all that apply

Tick all that apply.

- ☐ Top Management
- ☐ Engineering Design Team
- ☐ Task Force
- ☐ Internal/Vehicle Auditor
- ☐ Quality Manager/Director
- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer
- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead
- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor
- ☐ Facility Maintenance Lead
- ☐ Line Manager(s)
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ____________________

Do you use a special software or tool to measure, manage and improve thecompany's quality performance?

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ Don't know or Prefer not to answer

Company's QMS	This enquiry relates to in-house developed quality management system (QMS) and personnel's practical knowledge of the relevant ISO standard procedures for the automotive sector with regards to the elements of ISO QMS certification audit for both the organisation and personnel (i.e. individuals).

Has your company developed its own quality management system (QMS), which consists of policies, procedures, human resources, technology, etc.?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Is your company's quality management system (QMS) compliant with the ISO standard applicable to the automotive sector?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Does your company's staff development training programme include certification courses in ISO management system standards?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Who is responsible for developing your company's own quality management system (QMS) and personnel training programme to prepare both the company and personnel for ISO certification? Select all that apply

Tick all that apply.

- ☐ Top Management
- ☐ Engineering Design Team
- ☐ Task Force
- ☐ Internal/Vehicle Auditor
- ☐ Quality Manager/Director
- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer
- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead
- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor
- ☐ Facility Maintenance Lead
- ☐ Line Manager(s)
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ______________________

Do you use a special software or tool for developing the company's own QMS in conformance with the ISO standards as well as developing the schemes for ISO certification for both the company and staff?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Process Efficiency & Effectiveness	On a scale of 1 (Very Inefficient/Ineffective) to 7 (Very Efficient/Effective), rank the level of your company's manufacturing process efficiency and effectiveness. **Score Scale:** 1 = Very Inefficient/Ineffective 2 = Inefficient/Ineffective 3 = Somewhat Inefficient/Ineffective 4 = Neutral/Unknown 5 = Somewhat Efficient/Effective 6 = Efficient/Effective 7 = Very Efficient/Effective

The company's manufacturing process efficiency and effectiveness has enabled reduced manufacturing costs.

Tick only one box.

	1	2	3	4	5	6	7	
Very Inefficient / Ineffective	☐	☐	☐	☐	☐	☐	☐	Very Efficient / Effective

The company's manufacturing process efficiency and effectiveness has enabled increased customer retention.

Tick only one box.

	1	2	3	4	5	6	7	
Very Inefficient / Ineffective	☐	☐	☐	☐	☐	☐	☐	Very Efficient / Effective

The company's manufacturing process efficiency and effectiveness hasenabled return on investment (ROI).

Tick only one box.

	1	2	3	4	5	6	7	
Very Inefficient / Ineffective	☐	☐	☐	☐	☐	☐	☐	Very Efficient / Effective

The company's manufacturing process efficiency and effectiveness has enabled increased market share.

Tick only one box.

	1	2	3	4	5	6	7	
Very Inefficient / Ineffective	☐	☐	☐	☐	☐	☐	☐	Very Efficient / Effective

The company's manufacturing process efficiency and effectiveness has given the company a competitive edge.

Tick only one box.

	1	2	3	4	5	6	7	
Very Inefficient / Ineffective	☐	☐	☐	☐	☐	☐	☐	Very Efficient / Effective

The company's manufacturing process efficiency and effectiveness hasenabled growth in sales.

Tick only one box.

	1	2	3	4	5	6	7	
Very Inefficient / Ineffective	☐	☐	☐	☐	☐	☐	☐	Very Efficient / Effective

The company's manufacturing process efficiency and effectiveness hasimproved its brand reputation.

Tick only one box.

	1	2	3	4	5	6	7	
Very Inefficient / Ineffective	☐	☐	☐	☐	☐	☐	☐	Very Efficient / Effective

The company's manufacturing process efficiency and effectiveness has increased customer satisfaction.

Tick only one box.

	1	2	3	4	5	6	7	
Very Inefficient / Ineffective	☐	☐	☐	☐	☐	☐	☐	Very Efficient / Effective

The company's manufacturing process efficiency and effectiveness has enabled effective supply chain and logistics management system.

Tick only one box.

	1	2	3	4	5	6	7	
Very Inefficient / Ineffective	☐	☐	☐	☐	☐	☐	☐	Very Efficient / Effective

The company's manufacturing process efficiency and effectiveness has enabled an improved overall business performance.

Tick only one box.

	1	2	3	4	5	6	7	
Very Inefficient / Ineffective	☐	☐	☐	☐	☐	☐	☐	Very Efficient / Effective

Does the company have an effective coordination between the various manufacturing departments during the design stage to ensure efficient and effective manufacturing process?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

What manufacturing process do you personally coordinate or are involved in? Multiple answers allowed

Tick all that apply.

- ☐ Design and Analysis
- ☐ Logistics and Supply Chain
- ☐ Auditing/Quality Inspection
- ☐ Quality Manager/Director
- ☐ Procurement
- ☐ Technical Supervision
- ☐ Assembly
- ☐ Project Manager
- ☐ Sales
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ______________________

Who is responsible for ensuring the company achieve optimal processefficiency and effectiveness? Multiple answers allowed

Tick all that apply.

- ☐ Top Management
- ☐ Engineering Design Team
- ☐ Task Force
- ☐ Internal/Vehicle Auditor
- ☐ Quality Manager/Director
- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer
- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead
- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor
- ☐ Facility Maintenance Lead
- ☐ Line Manager(s)
- ☐ Don't know or Prefer not to answer

☐ Other (Specify): ______________________

Do you employ a special software or tool to optimise the company's manufacturing process efficiency and effectiveness?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Standard Operating Procedure (SOP)	This enquiry is related to an in-house company documentation that provides a guide that breaks down individual manufacturing processes into clearly defined steps to enable personnel execute tasks accordingly.

Does your company have a Standard Operating Procedure (SOP) documentation to guide the various manufacturing processes?

Tick only one box.

- ☐ Yes
- ☐ No
- ☐ I am not familiar with SOP
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): __________

Rank your company's Standard Operating Procedure, using the score scale defined below where 1 = Very Ineffective and 7 = Very Effective.

Score Scale:

1 = Very Ineffective

2 = Ineffective

3 = Somewhat Ineffective

4 = Neutral / Unknown

5 = Somewhat Effective

6 = Effective

7 = Very Effective

How would you rank your company's Standard Operating Procedure?

Tick only one box.

	1	2	3	4	5	6	7	
Very Ineffective	☐	☐	☐	☐	☐	☐	☐	Very Effective

Who is responsible for developing your company's Standard Operating Procedure (SOP)? Select all that apply

Tick all that apply.

- ☐ Top Management
- ☐ Engineering Design Team
- ☐ Task Force
- ☐ Internal/Vehicle Auditor
- ☐ Quality Manager/Director
- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer
- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead
- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor
- ☐ Facility Maintenance Lead
- ☐ Line Manager(s)
- ☐ Don't know or Prefer not to answer

☐ Other (Specify): ____________________

Do you use a special software or tool to develop your company's StandardOperating Procedure (SOP)?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Process Monitoring	This research considers that effective monitoring of the various departmental activities and processes can expose any lapses and make room for corrective measures to enhance process efficiency.

Does your company have a dedicated Process Monitoring Team that monitors the various departmental processes and activities to ensure any identified quality-related issues are promptly identified and adequately addressed?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Who is responsible for monitoring departmental activities and manufacturingprocesses from design to final delivery? Select all that apply

Tick all that apply.

☐ Top Management

☐ Engineering Design Team

☐ Task Force

☐ Internal/Vehicle Auditor

☐ Quality Manager/Director

☐ Project Manager

☐ Human Resource Manager/Director

☐ Purchasing/Procurement and Supply Chain Leader

☐ Owners or Owner/Representative

☐ Software Engineer

☐ Risk Analyst

☐ Manufacturing Engineer Lead

☐ IT Infrastructure Assessor

☐ Business Process Engineer

☐ Production Manager

☐ Shopfloor Supervisor

☐ Facility Maintenance Lead

☐ Line Manager(s)

☐ Don't know or Prefer not to answer

☐ Other (Specify): ____________________

Do you use a special software or tool for monitoring departmental activities and manufacturing processes from design to supply chain management or delivery channels?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Continuous Improvement	This enquiry regards the elements that are necessary to help map out the idealprocesses required to enable continual improvement of automotive manufacturing processes.

On a scale of 1 (Strongly Disagree) to 7 (Strongly Agree), rank your company's management priorities with respect to its Continuous Improvement process.

Score Scale:

1 – Strongly Disagree

2 – Disagree

3 – Somewhat Disagree

4 – Neutral or Unknown

5 – Somewhat Agree

6 – Agree

7 – Strongly Agree

Top Management has a standard set of Continuous Improvement objectives toaddress relevant levels.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management regularly seeks customer complaints and feedback to enable corrective measures towards Continuous Improvement.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management regularly examines risks and opportunities to enable corrective measures towards Continuous Improvement.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management focuses on market research and analysis to enable corrective measures towards Continuous Improvement.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management regularly solicits inputs from personnel (staff), externalsuppliers and interested parties to enable corrective measures towards continuous improvement.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management has a system for monitoring non-value-added activities. Non-value added or NVA is basically any activity such as over-inventory, frequent meetings, over-processing, excess movements, delayed communication, and the like, that does not add an economic value to a process or product.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management regularly conducts review of quality policy against currentprocesses. This enables corrective measures towards Continuous Improvement.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management offers standardised training procedures for each departmental operations.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Top Management rewards personnel across all departments for acquiring newskills.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

The company has a mechanism for quickly tracking the root cause of anydisruption.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

The company has a standard procedure to promptly address any disruptions at any business operational level.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

The company has a standard procedure for documenting disruptions in orderto create an information pool for corrective measures, translating into Continuous Improvement.

Tick only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

With respect to ensuring Continuous Improvement, which of the followingpractices are a core activity within your company?

Tick all that apply.

- ☐ Personnel are encouraged to learn the Quality and Corporate Responsibility Policy
- ☐ In-house training schemes inform staff to gain understanding of the quality objectives and how to contribute towards achieving them through related practices
- ☐ Personnel are mandated to report any non-conformity activities within any department
- ☐ It is common practice to share individual ideas and feedback
- ☐ Management ensures departmental participation at all levels
- ☐ There is a structured and documented quality process implementation plan

☐ Effective internal audit is regular

☐ Don't know or Prefer not to answer

☐ Other (Specify): ______________________________

Who is responsible for designing processes that enable ContinuousImprovement? Select all that apply

Tick all that apply.

☐ Top Management

☐ Engineering Design Team

☐ Task Force

☐ Internal/Vehicle Auditor

☐ Quality Manager/Director

☐ Project Manager

☐ Human Resource Manager/Director

☐ Purchasing/Procurement and Supply Chain Leader

☐ Owners or Owner/Representative

☐ Software Engineer

☐ Risk Analyst

☐ Manufacturing Engineer Lead

☐ IT Infrastructure Assessor

☐ Business Process Engineer

☐ Production Manager

☐ Shopfloor Supervisor

☐ Facility Maintenance Lead

☐ Line Manager(s)

☐ Don't know or Prefer not to answer

☐ Other (Specify): ____________________

Do you use a special software or tool for monitoring all manufacturingprocesses from design to supply or delivery?

Tick only one box.

☐ Yes

☐ No

☐ Don't know or Prefer not to answer

Rating Departments

Automotive manufacturing is a system consisting of various departments which mainly include Management and Administration, Sales, Service and Parts Departments. Coordination and collaboration among these departments must be very effective and efficient in order to satisfy stakeholder requirements. On a scale of 1 (Very Ineffective) to 7 (Very Effective) as defined below, how would you rate the four main departments within your company with respect to their business decision-making mechanism and quality-based processes?

Score Scale:

1 – Very Ineffective
2 – Ineffective
3 – Somewhat Ineffective
4 – Neutral / Unknown
5 – Somewhat Effective
6 – Effective
7 – Very Effective

Rate the level of effectiveness/ineffectiveness of your company's Management and Administration department or unit with respect to its business decision- making mechanism and quality-based processes.

Tick only one box.

	1	2	3	4	5	6	7	
Very Ineffective	☐	☐	☐	☐	☐	☐	☐	Very Effective

Rate the level of effectiveness/ineffectiveness of your company's Sales department or unit with respect to its business decision-making mechanism and quality-based processes.

Tick only one box.

	1	2	3	4	5	6	7	
Very Ineffective	☐	☐	☐	☐	☐	☐	☐	Very Effective

Rate the level of effectiveness/ineffectiveness of your company's Services department or unit with respect to its business decision-making mechanism and quality-based processes.

Tick only one box.

	1	2	3	4	5	6	7	
Very Ineffective	☐	☐	☐	☐	☐	☐	☐	Very Effective

Rate the level of effectiveness/ineffectiveness of your company's Parts department or unit with respect to its business decision-making mechanism and quality-based processes.

Tick only one box.

	1	2	3	4	5	6	7	
Very Ineffective	☐	☐	☐	☐	☐	☐	☐	Very Effective

Additional Information	As part of the data gathering for analysis to extract contributory input data for the development of the proposed novel quality engineering system, your expert knowledge and experience-based additional information will be of significance as a professional within the automotive manufacturing sector.

Which of the following best describes your position in the company? Select all that apply or the closest applicable role/position.

Tick all that apply.

- ☐ Top Management
- ☐ Engineering Design Team
- ☐ Task Force
- ☐ Internal/Vehicle Auditor
- ☐ Quality Manager/Director
- ☐ Project Manager
- ☐ Human Resource Manager/Director
- ☐ Purchasing/Procurement and Supply Chain Leader
- ☐ Owners or Owner/Representative
- ☐ Software Engineer
- ☐ Risk Analyst
- ☐ Manufacturing Engineer Lead
- ☐ IT Infrastructure Assessor
- ☐ Business Process Engineer
- ☐ Production Manager
- ☐ Shopfloor Supervisor
- ☐ Facility Maintenance Lead
- ☐ Line Manager(s)
- ☐ Don't know or Prefer not to answer
- ☐ Other (Specify): ____________________

How long have you held your current position in the company? (In terms ofmonths or years). Please write in the field below:

Please use the space provided below to provide information on what you think are the main underlying factors that make it difficult for automotive manufacturing companies to successfully implement a quality system or a combination more than one quality system to enhance the quality performanceof their manufacturing operations? Please write in the field below:

Would you be available, if invited, for an interview at a later date?

Tick only one box.

☐ Yes

☐ No

If you answered yes to participate in an invited interview at a later date, pleaseprovide your reachable email address or preferred contact details.

Would you be interested in evaluating the new quality engineering system orframework that is in-development through this research?

Tick only one box.

☐ Yes

☐ No

If you answered yes to evaluate the new quality engineering system or framework in-development, please provide your reachable email address orpreferred contact details.

Thank You Very Much for Your Participation

Appendix 2: Candidate B – Survey: Indices of Quality Performance

Indices of Quality Performance

PROJECT INFORMATION SHEET

Researcher: Michael Flowers
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University of Gloucestershire
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UK
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Research Background:

This research component probes why automotive manufacturing organisations vary systematically in quality performance over time? The context of this research questionnaire concentrates on the key indicators of quality performance from the perspective or worldview of the automobile product owner (i.e. vehicle owner), automobile driver, vehicle passenger, automotive component or parts dealer, pedestrian, car dealers, etc. The data derived from this questionnaire will help in developing an understanding of how the competitive dimensions of quality performance can impact quality design and implementation processes within automotive manufacturing organisations. Based on the philosophical worldview (i.e. pragmatism) proposed for this study, this component of the methodological choices for data collection will help in the derivation of the contributory data or input parameters required to develop a new quality engineering system for automotive manufacturing SMEs.

Purpose of the Research:

The key purpose of this research is to develop a novel quality engineering system for the automotive manufacturing SME sector.

Funding:

This research, which is a part of a doctorate thesis, is not funded.

Choice of Participants:

As this research takes an eclectic (diverse) approach to seek different perspectives of the key indicators of quality performance from persons who are automobile product owners (i.e. vehicle owners), automobile drivers, vehicle passengers, automotive component or parts dealers, pedestrians, car dealers, etc., you are considered as a suitable research participant.

Confidentiality and Data Storage:

This research will not seek to publish your personally identifiable information. The information you provide will be treated as anonymous. Where it is detected that you mentioned your name, another person's name, or name of your company in error or unintentionally, such identifiable data will be stored in strict confidence and treated as anonymous within the data analysis and reporting.

Research Outcome:

The research findings and the expected developed new quality engineering framework willform a part of the composition of the doctoral thesis. Derivatives of the research outcome will also feature in topic-related scholarly articles, academic conference proceedings, and the like, as part of the effort to disseminate the research results. While it is anticipated that the research outcome with its derived product will benefit SMEs - Small, Medium-sized Enterprises - within the automotive manufacturing sector as well as individuals within the industry, there is no guarantee that the outcome derived from this study will certainly optimise the existing functional qualities of automotive manufacturing and services and translate into high quality performance you expect to experience with automotive products and services.

Researcher and Supervisors:

Professor Shujun Zhang (Principal Supervisor) and Dr. Martin Wynn (Second Supervisor), both of the University of Gloucestershire, UK, are the Supervisors for this research. The Researcher is Michael Flowers, who is conducting a doctoral research for his thesis.

Thank you for your interest and agreeing to voluntarily participate in this research questionnaire survey. Please review and submit the Consent to Participate Form in the NEXT section.

*Required

Consent to Participate Form

Thank you for accepting the invitation to participate in this research survey questionnaire. Please complete the whole Consent Form by ticking all the boxes to confirm that you have read the Project Information presented in the precedingsection. *

UNIVERSITY OF GLOUCESTERSHIRE

Tick all that apply.

☐ I acknowledge that the Researcher has explained the purpose of this research questionnaire survey to me.

☐ I have read the Project Information and understood the intent of this research.

☐ I understand that this questionnaire survey will be used for the sole purpose of the research on quality dimensions in the automotive manufacturing sector.

☐ I understand that I am not required to supply my name, name of the company I work for, and any personally identifiable information about me.

☐ I understand that my participation in this questionnaire survey is voluntary and that I am at liberty to withdraw without giving any reason.

☐ I understand and agree that any details of my participation and responses will be stored anonymously on file and may be used in the analysis of data.

☐ I understand that parts or all of my responses, if considered relevant to the study, may be used as part of the overall data collected for analysis, which outcome may also feature in the research findings.

☐ In view of my acceptance of the aforementioned, I give permission for my responses to be used as deemed appropriate for this research.

☐ I therefore consent to participate in this research questionnaire survey.

Automobile Ownership

This enquiry regards the type of automobile you own or use and the level ofyour satisfaction.

Which of the following automobile products do you own, use or have leased?Select all that apply.

Tick all that apply.

- ☐ Car or cars
- ☐ Trucks
- ☐ Vans
- ☐ Trailer type campers
- ☐ Motorcycles
- ☐ Coach or Bus
- ☐ Other (specify):

On a scale of 1 to 7, how satisfied are you with your automobile?

Tick only one box.

- ☐ Very Satisfied
- ☐ Satisfied
- ☐ Somewhat Satisfied
- ☐ Slightly Satisfied
- ☐ Moderately Satisfied
- ☐ Unsatisfied
- ☐ Very Unsatisfied

If you could change one thing about your vehicle, what would that be? Pleaseprovide your response in the field below.

Standards Awareness

There are a number of quality regulatory bodies within the automotive industry. These include IATF 16969:2016, AEC-Q100, AEC-Q200, ISO 9001, ISO 14001, ISO 26262, ISO 45001, etc., defined below. This section is to enquire about your familiarity with these standards.

Definitions of key automotive industry quality standards:

IATF 16949:2016 or simply IATF 16949 is the global technical standard that governs the quality management systems within the automotive manufacturing industry, encompassing standards for manufactured automotive products, assembly and testing processes and associated services.

AEC-Q100 essentially defines the automotive manufacturing industry standard tests for active components (such as switches, power amplifiers, etc.).

AEC-Q200 defines the standard tests for passive devices (such as RF filters, etc.).

ISO 9001 focuses on customer satisfaction, operating costs effectiveness, risk management, legal compliance, stakeholder satisfaction, brand credibility, and the like.

ISO 14001 focuses on environmental and economic sustainability. ISO 26262 regards functional safety standard.

ISO 45001 focuses on product and service reliability within health and safety business environment

Which of the following automotive industry quality standards are you familiarwith? Select all that apply:

Tick all that apply.

- ☐ IATF 16949:2016
- ☐ ISO 9001
- ☐ ISO 14001
- ☐ ISO 26262
- ☐ ISO 45001
- ☐ AEC-Q100 & AEC-Q200
- ☐ None of the above
- ☐ Other (specify):

Do you know any automotive manufacturing firm that is IATF 16949:2016 standard compliant?

Mark only one box.

- ☐ Yes
- ☐ No
- ☐ I am not familiar with IATF 16949:2016 standard

Do you know any automotive manufacturing firm that is ISO 9001 standard compliant?

Mark only one box.

- ☐ Yes
- ☐ No
- ☐ I am not familiar with IATF 9001 standard

Do you know any automotive manufacturing firm that is ISO 14001 certified?

Mark only one box.

- ☐ Yes
- ☐ No
- ☐ I am not familiar with IATF 14001 standard

Do you know any automotive manufacturing firm that is ISO 26262 certified?

Mark only one box.

- ☐ Yes
- ☐ No
- ☐ I am not familiar with IATF 26262 standard

Do you know any automotive manufacturing firm that is ISO 45001 certified?

Mark only one box.

- ☐ Yes
- ☐ No
- ☐ I am not familiar with IATF 45001 standard

Do you know any automotive manufacturing firm that is either AEC-Q100 orAEC-Q200 or both certified?

Mark only one box.

- ☐ Yes
- ☐ No
- ☐ I am not familiar with AEC-Q100 or AEC-200

Automobile Choice Influencing Factors

This enquiry regards the factors that influence your decision-making for either purchasing or leasing an automobile product (vehicle or auto parts). On a scale of 1 (Strongly Disagree) and 7 (Strongly Agree), how would you describe the options that help inform your decision when purchasing or leasing (such as vehicle rental, taxi, etc.) an automobile product?

Score Scale:

1 – Strongly Disagree

2 – Disagree

3 – Somewhat Disagree

4 – Neutral or Unknown

5 – Somewhat Agree

6 – Agree

7 – Strongly Agree

Your decision to purchase or lease an automobile depends mainly on the automotive manufacturing company's compliance with any of the automotiveindustry standards such as IATF 16949:2016, ISO 9001, ISO 14004, ISO 26262, ISO 45001, etc.

Mark only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Your decision to purchase an automobile or lease an automobile depends mainly on how personalised, fun and friendly the automobile purchase or order process is.

Mark only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Your decision to purchase or lease an automobile depends mainly on how much information you can access about the range of automobiles in the automotive marketplace.

Mark only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Your decision to purchase or lease an automobile was influenced by the comfortyou felt at the automobile dealership.

Mark only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Your decision to purchase or lease an automobile was influenced by how the automobile dealership handled your order in a professional and timely manner.

Mark only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Your decision to purchase or lease an automobile was influenced by how theautomobile dealership works as a team to best satisfy you.

Mark only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

What is your preferred source of information when deciding on purchasing orleasing an automotive product? Select all that apply.

- ☐ Google Search
- ☐ Automotive Manufacturing company's website
- ☐ Printed Auto Magazines or Documents
- ☐ Online Auto Magazines or Documents
- ☐ In-person Consultation with Auto Dealer
- ☐ In-person Consultation with Automobile Manufacturing Company
- ☐ Word of mouth
- ☐ Other Internet Search Engines
- ☐ Vehicle Information App
- ☐ Internet
- ☐ Auto Forums
- ☐ Auto Selling Platforms
- ☐ Other (Specify):

As a consumer, do you think it is very important for automotive companies toshare information about their quality standard status?

Mark only one box.

- ☐ Yes
- ☐ No
- ☐ Maybe

Do you believe that automotive organisations that provide adequate informationabout the features of their automobile products (vehicles, parts, etc.) and automotive services through multiple sources (Internet, Apps, printed magazines, newspapers, flyers, etc.) perform better in business compared to others who do not?

Mark only one box.

- ☐ Yes
- ☐ No
- ☐ Maybe

Which of the following quality performance dimensions influence your decisionto buy or lease an automobile?

Tick all that apply:

- ☐ Automobile Manufacturer Reputation
- ☐ Automobile Dealership Reputation
- ☐ Aesthetics or design of automobile
- ☐ Driving performance
- ☐ Energy consumption rate
- ☐ Solar-powered
- ☐ Electric-powered
- ☐ Hybrid (combination of more than one power energy type)
- ☐ Automobile brand reputation
- ☐ Financing options
- ☐ Availability of preferred model
- ☐ User-friendly
- ☐ Environmentally-friendly (low or zero carbon emission and the like)
- ☐ Other (Specify):

Automobile Dealership Factor

This enquiry regards the quality-of-service experiences you have had at an Auto Dealership when you visited to purchase or lease an automobile product.

Did the automobile dealership check in your presence the vehicle air conditioning, heater and or defroster system to ensure they were all in goodcondition and are functional?

Mark only one box.

- ☐ Yes
- ☐ No

Did the automobile dealership check the vehicle in your presence to ensure thatthe brakes were functional?

Mark only one box.

- ☐ Yes
- ☐ No

Did the automobile dealership check the autobody (including hood, doors, trunk/booth, sunroof, etc.) in your presence to ensure they were all in excellentcondition?

Mark only one box.

- ☐ Yes
- ☐ No

Did the automobile dealership check in your presence to assure you that theelectrical system and associated accessories were all functional?

Mark only one box.

- ☐ Yes
- ☐ No

Did the automobile dealership invite you to join them in checking the exteriorpaint work to ascertain its condition before purchasing or leasing?

Mark only one box.

☐ Yes

☐ No

Did the automobile dealership check the fluid level or leaks in your presence?

Mark only one box.

☐ Yes

☐ No

Did the automobile dealership check, in your presence, the interior fit and finish(which include seats, carpet and dashboard) were all intact and neat?

Mark only one box.

☐ Yes

☐ No

Did the automobile dealership check, in your presence, the exterior and interiorlights were functional?

Mark only one box.

☐ Yes

☐ No

Did the automobile dealership check, in your presence, the radio and other audio player systems were functional?

Mark only one box.

- ☐ Yes
- ☐ No

Did the automobile dealership check, in your presence, all the seatbelts werefunctional?

Mark only one box.

- ☐ Yes
- ☐ No

Did the automobile dealership check, in your presence, all the tyres and wheelswere in good alignment, balance and inflation conditions?

Mark only one box.

- ☐ Yes
- ☐ No

Did the automobile dealership check, in your presence, the automobile windnoise control?

Mark only one box.

- ☐ Yes
- ☐ No

Did the automobile dealership check, in your presence, the steering andhandling?

Mark only one box.

- ☐ Yes
- ☐ No

Did the automobile dealership check, in your presence, to ensure there were nowater leaks possibilities?

Mark only one box.

☐ Yes
☐ No

Did the automobile dealership check, in your presence, the transmission andclutch were functional?

Mark only one box.

☐ Yes
☐ No

Did the automobile dealership offer you a pre-purchase or pre-lease test drive?

Mark only one box.

☐ Yes
☐ No

Did you take a test drive before purchase or lease?

Mark only one box.

☐ Yes
☐ No

On a scale of 1 (Very Dissatisfied) and 7 (Very Satisfied), describe the level of yoursatisfaction at the automobile dealership at the time of purchasing or leasing an automobile.

Scale Score:

1 - Very Dissatisfied

2 - Dissatisfied

3 - Somewhat Dissatisfied

4 - Neutral

5 - Somewhat Satisfied

6 - Satisfied

7 - Very Satisfied

Interaction with automobile salesperson or service provider.

Mark only one box.

	1	2	3	4	5	6	7	
Very Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Very Satisfied

The way the automobile or service was delivered.

Mark only one box.

	1	2	3	4	5	6	7	
Very Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Very Satisfied

Overall purchase or lease experience at the automobile dealership.

Mark only one box.

	1	2	3	4	5	6	7	
Very Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Very Satisfied

The experience of your test drive.

Mark only one box.

	1	2	3	4	5	6	7	
Very Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Very Satisfied

Overall experience with the automobile after taking delivery.

Mark only one box.

	1	2	3	4	5	6	7	
Very Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Very Satisfied

With respect to the level of your satisfaction, how would you rate your entireautomobile purchasing or leasing experience at the auto dealership?

Mark only one box.

	1	2	3	4	5	6	7	
Very Dissatisfied	☐	☐	☐	☐	☐	☐	☐	Very Satisfied

How important is it for you to test drive an automobile before purchasing orleasing it?

Mark only one box.

- ☐ Extremely important
- ☐ Very important
- ☐ Important
- ☐ Somewhat important
- ☐ Not at all important
- ☐ Unimportant

Who was the primary person at the automobile dealership with whom youdiscussed your automobile financing agreements?

Tick all that apply:

- ☐ Salesperson
- ☐ Sales Agent
- ☐ The Manager
- ☐ The Owner
- ☐ Other (Specify):

Auto Recalls Handling

In the context of this research, a best practice process for managing auto recalls or addressing product rejects or defects in the automotive industry can help automotive manufacturing organisations to achieve high success when conducting a safety recall or addressing product reject or defect issues. Although best practice is about improving quality performance, it is also about examining the existing process and reaffirming that it produces the best results as expected by the industry standard and the customer. Some of the key triggers of auto recalls are defects in the seatbelts, air bags, electronic systems, electrical wiring, etc. Auto recalls are carried out when it becomes evident that a defect is identified within the definition of safety issues that can potentially result in serious injuries or death. As a vehicle owner or user, this enquiry seeks to draw contributory data from your perspective.

Do you believe that most automotive manufacturing companies make it mandatory for their staff to develop knowledge in or become conversant withthe general automobile Safety Regulations?

Mark only one box.

- ☐ Yes
- ☐ No
- ☐ Don’t think so
- ☐ Don’t know

Do you believe most automotive manufacturing organisations are open about their weaknesses?

Mark only one box.

- ☐ Yes
- ☐ No
- ☐ Don’t think so
- ☐ Don’t know

Do you believe most automotive manufacturing organisations have a special system in place to notify automotive regulatory bodies of any late detection of a safety defect that could potentially affect vehicles or products that have already been supplied for use?

Mark only one box.

- ☐ Yes
- ☐ No
- ☐ Don't think so
- ☐ Don't know

Do you believe most automotive companies have a special system in place via which they are able to notify automotive regulatory bodies about any late detection of a safety defect that could potentially affect vehicles that have NOTyet been supplied for use?

Mark only one box.

- ☐ Yes
- ☐ No
- ☐ Don't think so
- ☐ Don't know

As a consumer, do you think it is better for automotive companies to share information on how they respond to auto recall or automobile defect/reject issues?

Mark only one box.

- ☐ Yes
- ☐ No

Emerging Technologies

In the context of this research, the uncertainty in consumer's increasing demand for new and digital technologies are presenting multifaceted risk factors for the automotive industry. Original Equipment Manufacturers (OEMs), for example, are under constant pressure to optimise their existing business and manufacturing models in order to respond to the constantly customer-centric changing environment.

With respect to Automobile Connectivity also known as Connected Automobile, for example, today's drivers are increasingly seeking to be connected to their automobiles just as they would with their smartphones, tablets, tech wearables, digital watches, etc. This requirement challenges traditional automotive manufacturers to integrate their existing process with digital technologies in order to survive the fierce competition the new digital technology-oriented companies are creating.

While Connected Automobiles are expected to be equipped with advanced communication technology that enables direct flow of data to and fro the vehicle without a need for mobile device, the automobile is also expected to have Automated Functions that offer convenience, efficiency and safe-driving experience. Examples of such requirements include putting the vehicle in autopilot mode while on highways or self-parking, etc. New and increasing consumer requirements also include Electric Mobility, Driverless Automobile (Autonomous Automobiles), and Automobile Sharing.

This section regards how consumers' constantly changing requirements can stimulate the need for emerging and digital technologies to respond to the constantly changing automotive environment. On a scale of 1 (Strongly Disagree) to 7 (Strongly Agree) as defined by the score scale below, describe how you think emerging and digital technologies can potentially vary or disrupt the quality performance of automotive manufacturing organisations.

Score Scale:
1 – Strongly Disagree
2 – Disagree
3 – Somewhat Disagree
4 – Neutral or Unknown
5 – Somewhat Agree
6 – Agree
7 – Strongly Agree

Consumer demand for Automobile Connectivity (i.e. Connected Automobile / Vehicles) and Automobile Automation can disrupt the quality performance of an automotive manufacturer due to the need to change theirexisting business models in order to satisfy digital-oriented requirements.

Mark only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

New and well-established digital technology companies in the field of Automobile Connectivity (i.e. Connected Automobile/Vehicle) and Automationwill threaten the quality performance of existing (traditional) automotive organisations that are yet to make the transition to incorporate digital technology.

Mark only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

The new trend of Automobile Sharing (i.e. Shared Cars, Shared Rides or Shared Mobility), particularly in highly populated urban settings, will stimulate a declineof private automobile sales.

Mark only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

As Automobile Sharing is expected to grow by 2030, there is a high likelihoodthat a large number of the shared vehicles will be exposed to rapid wear and tear due to excessive use.

Mark only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

The growing demand for Electric or Solar-powered or Hybrid automobiles will place enormous pressure on manufacturers of diesel-powered internal combustion engine driven automobiles, forcing them to make a transition in order to survive the competition.

Mark only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Electric automobiles generate a huge amount of data during the course of driving them. While manufacturers can analyse this data to help optimise theirmanufacturing process and business models, this is likely to increase manufacturing complexity due to such continuous data collection.

Mark only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

As Driverless Automobile (also known as Autonomous Vehicle) is steadily pushing its way into becoming mainstream, automotive manufacturers in the field are expected to incorporate extensively advanced smart software that willaddress safety concerns.

Mark only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Consumer's interest in experiencing a Driverless Automobile (also known as Autonomous Vehicle) demands automotive manufacturers to couple software with hardware. Coupling software and hardware in the manufacturing processmodel may pose challenges to a manufacturer's quality performance.

Mark only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

In the event that the software of a digitised automobile is struck with a computer virus or hacked, this can potentially alter the functionality of a driverless vehicle. Such a scenario can compromise the safety of passengers, pedestrians and or other motorists as a virus hit or hacked software could takean autonomous or driverless automobile off its course, for example.

Mark only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

A Driverless Automobile is practically a vehicular robot that will have to copewith the unpredictive behaviours of human drivers' ability to break traffic regulations. This is a safety concern that indicates that Autonomous or Driverless Automobiles may be prone to motor accidents.

Mark only one box.

	1	2	3	4	5	6	7	
Strongly Disagree	☐	☐	☐	☐	☐	☐	☐	Strongly Agree

Additional Information

As part of the data collection for analysis to extract contributory input data for the development of the proposed novel quality engineering system, any further relevant information from your perspective as an automobile owner or user will be of significance

Which of the following best describes your status? Please select all that apply. *

Tick all that apply.

- ☐ Automotive Standards Regulator
- ☐ Automobile Product (Car/Vehicle) Owner
- ☐ Automobile Product (Vehicle or Vehicle Parts) Owner
- ☐ Automobile Driver
- ☐ Regular Transport Passenger
- ☐ Automobile Hiring Service Manager
- ☐ Automobile Hiring Service Personnel
- ☐ Automobile Freight Manager
- ☐ Logistics & Supply Chain Manager
- ☐ Other (Specify):

In your opinion, what do you think is the most important quality for an automobile product (vehicle, part) to have? Please provide your response in thefield below.

In your opinion, what do you think is the most important quality for an automotive dealership or service provider to have or offer? Please provide your response in the field below.

In your opinion, what do you think is the core quality performance dimension or parameter most consumers expect from automotive organisations? Please provide your response in the field below.

From your perception, what do you think are some of the underlying factors thatvary (i.e. cause changes in) the quality performance of automotive organisations?

What type of automobile do you own or use?

Tick all that apply.

- ☐ Diesel-powered Automobile
- ☐ Biodiesel-powered Automobile
- ☐ Petrol-powered Automobile
- ☐ Electric-powered Automobile
- ☐ Solar-powered Automobile
- ☐ Hybrid Automobile
- ☐ Heat-powered Automobile
- ☐ Hydrogen-powered Automobile

- ☐ Natural Gas-powered Automobile
- ☐ Steam-powered Automobile
- ☐ Liquid Nitrogen or Gas-powered Automobile
- ☐ Compressed Air-powered Automobile
- ☐ Liquefied Petroleum Gas (LPG) or Propane Autogas Automobile
- ☐ Driverless or Autonomous Automobile
- ☐ Connected Automobile
- ☐ Automated Automobile
- ☐ Shared Automobile
- ☐ Other (Specify):

What changes are you likely to make by 2030? Please select as applicable.

Tick all that apply.

- ☐ I would switch my vehicle brand for automobile connectivity services.
- ☐ I would switch to another automotive organisation if it offers connected services for my vehicle.
- ☐ I would switch to another automobile if it is electric or hybrid integrated.
- ☐ I would switch to another automotive manufacturing organisation if it were the only one offering digitised automobile, including full access to data, media, special apps, etc.
- ☐ I would switch back to diesel-powered internal combustion engines because they are relatively high in efficiency compared to others.
- ☐ I would resort to vehicle sharing.

Thank You Very Much for Your Participation

Appendix 3: Interview Guide

The structure and content of the Interview Alternative in Appendix 4 served as the Interview Guide.

Appendix 4: Interview – Alternative

Qualitative Data Collection Questionnaire

PROJECT INFORMATION SHEET

Researcher: Michael Flowers
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URL: www.glos.ac.uk

Introduction:

The context of this interview-inspired qualitative data collection is identification of barrier solution parameters within automotive manufacturing organisations. The purpose of this research component is concerned with how social (human) actors' behaviours across manufacturing organisational operations can pose as barriers to quality implementation. For simplicity, this study views social (human) actors' negative behaviours against good quality practices can be described as threat to quality. The data derived from this study will help develop further understanding of how the negative role or adversarial behaviours of social (human) actors can adversely impact quality design and implementation processes within automotive manufacturing organisations. The data you provide will contribute towards the development of a mitigation solution against human-induced barriers to quality engineering as well as provide a strategy for internal transformation that will create a quality-focus manufacturing operation. Collectively, the outcome of this study will help in additional identification of key input parameters required frame an ideal solution to help automotive manufacturing organisations capture human factors that impede the hybridisation and implementation of engineering quality management systems. Hybridisation in this context refers to the combination of more than two quality systems or tools intended to increase quality performance. Thus, the contributory input data derived from the information provided in this interview positions the interviewee as a Research Participant. Please do not give any identifiable information as research participants and their organisations are meant to be anonymous. All information will be kept strictly confidential. Any concerns can be directed to Michael Flowers on MichaelFlowers@connect.glos.ac.uk.

Thank you for being generous with your time and cooperation.

Purpose of the Research:

The key purpose of this research is to develop a novel quality engineering system for the automotive manufacturing SME sector.

Confidentiality and Data Storage:

This research will not seek to publish your personally identifiable information. The information you provide will be treated as anonymous. Where it is detected that you mentioned your name, another person's name, or name of your company in error or unintentionally, such identifiable data will be stored in strict confidence and treated as anonymous within the data analysis and reporting.

Thank you for your interest and agreeing to voluntarily participate in this research questionnaire survey. Please review and submit the Consent to Participate Form in the NEXT section.

*Required

Consent to Participate Form

Thank you for accepting the invitation to participate in this qualitative research survey questionnaire, which is designed as an option or alternative to the qualitative interview. Please complete the whole Consent Form by ticking all theboxes to confirm that you have read the Project Information presented in the preceding section.

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Tick all that apply.

- ☐ I acknowledge that the Researcher has explained the purpose of this research questionnaire survey to me.
- ☐ I have read the Introduction and understood the intent of this research.
- ☐ I understand that this qualitative questionnaire survey will be used for the sole purpose of the research on barrier to quality dimensions in the automotive manufacturing sector.
- ☐ I understand that I am not required to supply my name, name of the company I work for, and any personally identifiable information about me.
- ☐ I understand that my participation in this qualitative questionnaire survey is voluntary and that I am at liberty to withdraw without giving any reason.
- ☐ I understand and agree that any details of my participation and responses will be stored anonymously on file and may be used in the analysis of data.
- ☐ I understand that parts or all of my responses, if considered relevant to the study, may be used as part of the overall data collected for analysis, which outcome may also feature in the research findings.
- ☐ In view of my acceptance of the aforementioned, I give permission for my responses to be used as deemed appropriate for this research.
- ☐ I therefore consent to participate in this research qualitative questionnaire survey.

Top Management	For the objective of developing a new quality system, this study defines the functions of Top Management as that they establish the need for quality management system (QMS) for the organization. Their goal is to see to it that organization achieve quality capabilities across its personnel, translating into high quality delivery.

1. **How would you describe the size of your company?**

Tick only one box.

☐ Small and medium-sized enterprise (SME) – (fewer than 250 employees)

☐ Large or multinational – (250 employees or more)

2. **In your opinion, do you think there has been any quality implementation issues that you believe the people in Top Management could have prevented?**

☐ Yes

☐ No

If you answered *<u>Yes</u>* to *Question 2*, please use the fields below to provide up to five (5) example cases and briefly explain each case.

1.
2.
3.
4.
5.

If you find it necessary to write in explaining beyond five (5) scenarios or examples, please do so.

Based on your answer to *Question 2*, please give your opinion on what you think Top Management could have done differently to prevent any of such quality issues.

1.
2.
3.
4.
5.

Is there another department within your organization that is responsible for monitoring Top Management to ensure there are checks and balances in personnel (staff)'s behaviours? In other words, is there an independent department within your organization that monitors to track human negative behaviours within Top Management that can negatively impact the organisation's quality goals?

☐ Yes

☐ No

If you answered *Yes*, please use the space below to explain briefly how such a department operate to evaluate and put checks on Top Management. Otherwise, if you answered *No* to the above question, please explain why you think there is no such department that monitors Top Management.

1.
2.
3.
4.
5.

If you find it necessary to write in explaining beyond five (5) scenarios or examples, please do so.

In your opinion, do you think there is a need for another department within the organization to monitor Top Management people's activities to ensure there are checks and balances that identify negative behaviours against quality implementation within the organisation and work to create countermeasures? Please use the space below to provide your opinion on what you think such a monitoring department could do to track negative behaviours and help to correct them within Top Management?

1.
2.
3.
4.
5.

Quality Monitoring and Enforcement	This research describes Quality Monitoring and Enforcement as a multidisciplinary team of engineers, managers, IT specialists, who act like a Task Force in maintaining regular quality value strategists. They work with Top Management to ensure that there is proper coordination amongst all the various departments, making sure that any human negative behaviour to quality processes can be captured and properly addressed. And where necessary they work with the design team to create countermeasures to address any potential human-based barriers to quality. They also ensure the organization is compliant with regulatory standard authorities' requirements.

3. **Does your organisation have a Quality Monitoring and Enforcement department that acts like a quality Task Force, which is responsible for quality process and implementation monitoring across all the departments and, where required, enforce good quality practice at all levels?**

☐ Yes

☐ No

If you answered *<u>Yes</u>* to *Question 3*, please use the space below to provide up to five (5) example scenarios and briefly explain how this Quality Monitoring and Enforcement activity operate within your organisation. Otherwise, if you answered *<u>No</u>* to *Question 3*, please use the space below to provide up to five (5) example scenarios and briefly provide your opinion on why you think the organization does not have a Quality Monitoring and Enforcement activity as defined above.

1.
2.
3.
4.
5.

If you find it necessary to write in explaining beyond five (5) scenarios or examples, please do so.

4. **If you answered *__Yes__* to *Question 3*, in your opinion, do you think the functions of the Quality Monitoring and Enforcement activities are effective?**

☐ Yes

☐ No

If you answered *__Yes__* to *Question 4*, do you think the Quality Monitoring and Enforcement activity could do things differently to prevent any negative human behaviours against quality practices? Please use the space below to provide your opinion on what you think such Quality Monitoring and Enforcement team could do differently to prevent staff negative behaviours against quality processes.

1.
2.
3.
4.
5.

If you find it necessary to write in explaining beyond five (5) scenarios or examples, please do so.

Quality Design	This study defines Quality Design as an activity that encompasses a team of multidisciplinary engineers, project managers, multifunctional experts, who translate the organisational management's functional needs and goals into engineering characteristics. Their target is to achieve QMS quality design practice organization-wide.

***5*. Are you aware of the occurrence of quality issues that were caused by negative human behaviours within the Quality Design activity in your organisation?**

Tick only one box.

☐ Yes

☐ No

If you answered *Yes* to *Question 5*, please use the space below to provide up to five (5) examples of such negative human behaviours.

1.
2.
3.
4.
5.

If you find it necessary to write in explaining beyond five (5) scenarios or examples, please do so.

If you answered *No* to *Question 5* but have observed other human negative behaviours that in your opinion are threats or barriers to quality processes, please briefly explain your opinion or thoughts or observations in the fields below:

1.
2.
3.
4.
5.

If you find it necessary to write in explaining beyond five (5) scenarios or examples, please do so.

Additional Information

6. Across the entire organization, do you think there have been negative staff behaviours that have caused quality issues?

Tick only one box.

☐ Yes

☐ No

If you answered *Yes* to *Question 6*, please use the space below to provide up to five (5) examples of such negative human behaviours.

1.
2.
3.
4.
5.

If you find it necessary to explain your answers beyond 5 examples, please do so.

If you answered *Yes* to *Question 6*, in your opinion please explain what you think Top Management could do or could have done to prevent the negative impact such negative staff behaviours could have on quality implementation process? In other words, what countermeasures do you think Top Management could put in place to monitor staff negative behaviours and correct them.

1.
2.
3.
4.
5.

Thank You Very Much for Your Participation

Appendix 5: Review QX Engineering Design

Synopsis to my approach:
The Top Management joins with the Engineering Design Team to form a Quality Monitoring and Implementing Task Force. Their definitions are in Table A1 below. These are collectively **Key Stakeholders** of the organisation, who set their highest-level goal, defined as the highest-level functional requirement and is denoted by FR_0. The design parameter required to satisfy FR_0 is defined by DP_0. These goals are seen in Table A2 and Table A3. I take axiomatic design approach to decompose FRs and their respective DPs until exhausted and the iterations stops. However, because I recognise that good quality must be achieved at a minimal cost, otherwise it is no quality, I defined FR_1 as the functional requirement (FR) we need to achieve FR_0 and FR_2 as the FR we need to achieve FR_0 at a minimum cost. Hence you will notice that FR_2 is in the cost-biased Table A3. For each FR_n there is a corresponding DP_n to satisfy the production of FR_n. Table A1 is the definition by function, goal and requirements of the key stakeholders I select to champion the implementation of QX Engineering Design with their (fictional) organisation.

Review Request:
Thank you very much for agreeing to review the proposed QX Engineering Design, designed for automotive manufacturing SMEs. I would appreciate your honest opinion that would certainly help me to fine-tune the design. Please review the QX Engineering Design (Table A2 and Table A3) below and give me your review feedback in 3 to 5 statements based on experiential opinion. The following are key dimensions, if you could also factor them in addition to your review remarks.

1. Which features of QX Design resonates with your own approach to engineering quality process?
2. In comparing with ISO family of standards procedures, which of the two do you honestly think will appeal to Small and Medium-sized companies? Please explain your answer in a short statement, highlighting key components.
3. Do you think QX Engineering Design can easily be adopted in an SME environment within automotive service? Please explain your answer briefly.
4. What do you think is missing from the conceptual design that you think if added, it could improve the current QX Engineering Design?
5. Please provide any other feedback or review comment as you deem necessary.

When you're done, kindly either email me your review comments by email or via WhatsApp text message.

Table A1 Key stakeholders' functions, goals and requirements

QX Engineering Design Process

Key Stakeholder	Function	Goals	Requirements
Top Management	They establish the need for quality-focused automotive manufacturing operations; to gain organisation-wide core quality capabilities; to deliver standard and consistent quality automobile products and services at the lowest manufacturing resource cost; and to stay competitive	To achieve standard quality-oriented manufacturing environment and culture of excellence that satisfies the requirements of internal stakeholders (organisation-wide) and external stakeholders (consumers, regulation authorities, etc.) efficiently and effectively, and delivers continual improvement	An efficient & effective quality excellence (QX)-oriented process
QX Task Force	They are a highly competent multidisciplinary team of engineers, project managers, quality managers, IT specialists, who maintain regular cyclic quality value strategies, monitoring-based interaction with all QX-focused sub-teams within the organisation to identify internal threats, non-value added (NVA) activities, adversarial behaviours, regularly review the state of the manufacturing processes, take in-depth assessment of critical-to-satisfaction processes in the context of target deliverables to organisation, customer, regulatory standard authorities, assess to identify internal & external barriers to quality implementation as well as variants of quality performance of company's deliverables, etc. While they report to Top Management, they also evaluate and review Top Management operational activities as regards coordinating all other departments along the manufacturing chain	To achieve an effective quality process monitoring that enables sustainable quality process values by identifying and eliminating threats to quality value stream	An efficient internal and external QX-based quality auditing process
QX Design Team	The design engineers are a multidisciplinary team of engineers, project managers, multifunctional experts, who translate the organisational Top Management's functional needs and goals into engineering characteristics	To achieve QX engineering design that satisfies organisation-wide goals effectively and efficiently at minimum cost	An efficient QX-oriented process

Table A2: Decomposition Process Mapping to achieve FR_1

Functional Requirements	Design Parameters
FR_0: Develop a QX Engineering Design for automotive manufacturing system	DP_0: Produce a roadmap for QX Engineering Design
FR_1: Create the desired high-level quality value-added	DP_1: QX Engineering Design for maximising the quality value-added
$FR_{1.1}$: Develop high-level quality competent-rich manufacturing system	$DP_{1.1}$: Blueprint for high-level quality assurance manufacturing system
$FR_{1.1.1}$: Develop high-level core quality competent engineers and staff	$DP_{1.1.1}$: Design a career enrichment and continuing professional qualification development training programme in core quality tools (including FMEA, SPC, QFD, Six Sigma, Lean Management, PPAP, APQP, MSA, Heijunka, Mizusumashi, etc.)
$FR_{1.1.2}$ Develop company-wide familiarity with relevant quality standardised procedures for the automotive manufacturing industry	$DP_{1.1.2}$ Design multipurpose quality standards training programmes (including ISO 9001, ISO 14001, ISO 26262, ISO 45001, AEC-Q100 & AEC-Q200, IATF 16949:2016) across all relevant units or departments
$FR_{1.1.3}$ Create a process map for identifying flaws in quality implementation in QMS-based standardised procedures	$DP_{1.1.3}$ Design a roadmap for identifying weaknesses, gaps and noise in ISO 9001, ISO 14001, ISO 26262, ISO 45001, AEC-Q100 & AEC-Q200, IATF 16949:2016 and associated procedures
$FR_{1.1.4}$ Achieve company-wide familiarity with relevant international regulatory bodies for the automotive manufacturing industry	$DP_{1.1.4}$ Design introductory training programme for developing familiarity with all the major internationally known automotive manufacturing sector regulators (including Automotive Council UK, NHTSA US, TÜV Germany)
$FR_{1.1.5}$ Achieve familiarity with manufacturing equipment standardisation (MES)	$DP_{1.1.5}$ Design training programme in MES across shopfloor and relevant units
$FR_{1.1.6}$: Develop customised, in-house, indigenous knowledge system (IKS)-based hierarchy for quality implementation processes, procedures and work instructions	$DP_{1.1.6}$: Design company's IKS-based quality standard and implementation procedures that exceed the expectations of QMS-based ISO family of procedures
$FR_{1.1.7}$: Create a reward system to encourage recurrent training in quality skillset across all departments or units	$DP_{1.1.7}$: Design a reward system to stimulate capacity-building in core quality systems, continuing professional enrichment and mastery of firm's IKS-based quality

FR$_{1.1.8}$: Produce procedures for skills audit

DP$_{1.1.8}$: Design internal skills audit procedures

FR$_{1.1.9}$: Produce procedure for internal auditing quality capacity-building training programmes

DP$_{1.1.9}$: Design procedures for auditing quality capacity-building training programmes

FR$_{1.1.10}$: Create procedures for conducting internal audit process, internal audit report generation, and countermeasures

DP$_{1.1.10}$: Standard Operating Procedures (SOP) for internal audit process, internal audit reporting, and corrective actions

FR$_{1.1.11}$: Produce QX Task Force & Top Management protocol for review of internal audit report

DP$_{1.1.11}$: Design QX Task Force & Top Management SOP's for review of internal audit

FR$_{1.1.12}$: Develop Standard Operating Procedures (SOP) for departmental or unit processes

DP$_{1.1.12}$: Design individual QX-oriented SOP for departments or unit

FR$_{1.1.13}$: Produce QX Engineering-based procedure documentation

DP$_{1.1.13}$: Design QX Engineering-based reference documentation, outlining processes that satisfy compliance with automotive body standard requirements (including IATF 16949:2016 statutory and regulatory requirements, etc.)

FR$_{1.1.14}$: Achieve quality regulatory and standard compliant status for QX Engineering compliant design

DP$_{1.1.14}$: Produce QX Engineering quality compliant validation process

FR$_{1.2}$: Design quality-oriented process efficiency and effectiveness for automotive manufacturing operations and automobile product

DP$_{1.2}$: Quality-oriented process efficiency and effectiveness system

FR$_{1.2.1}$: Define and group product families for production

DP$_{1.2.1}$: Procedure for defining and classifying product families

FR$_{1.2.2}$: Design manufacturing process and strategy based on automobile product family functional requirements

DP$_{1.2.2}$: Procedure for selecting QX-oriented manufacturing process and strategy

FR$_{1.2.3}$: Determine QX-based master process for automobile product and or service design

DP$_{1.2.3}$: QX-based master process selection for automobile product and or design

FR$_{1.2.4}$: Maximise manufacturing resources

DP$_{1.2.4}$: Product-oriented and or service-based QX-oriented manufacturing facility layout to minimise waste

FR$_{1.2.5}$: Determine QX Engineering design for quality control

DP$_{1.2.5}$: QX Engineering system for automobile product families

FR$_{1.2.6}$: Continuous quality performance monitoring

DP$_{1.2.6}$: Design quality performance monitoring protocol at internal departmental level and the value chain

FR$_{1.3}$: Define process strategy to enable continual improvement

DP$_{1.3}$: Design optimal system for continuous improvement

$FR_{1.3.1}$: Define Key Performance Indicators (KPI), objectives and quality-based process approach for continual improvement	$DP_{1.3.1}$: Design procedure for selecting quality-based process to achieve KPIs and objectives
$FR_{1.3.2}$: Determine scope of environmental and local (i.e. country of operation and market) automotive regulatory policy objectives	$DP_{1.3.2}$: Design information pool and report system of domestic environmental and automotive regulatory policy objectives
$FR_{1.3.3}$: Design internal and external stakeholder feedback to determine gaps in quality of service and automobile product families	$DP_{1.3.3}$: Design a continuous feedback information flow system to map out customer-determined quality dimensions
$FR_{1.3.4}$: Determine master process to respond to personnel attitudes that vary quality design targets	$DP_{1.3.4}$: Standardise master process selection for addressing human behaviours that vary quality design process
$FR_{1.3.5}$: Create risk assessment scheme to identify human adversarial behaviours within the quality-of-service units	$DP_{1.3.5}$: Design risk assessment scheme to monitor human adversarial behaviours, focused on quality of service
$FR_{1.3.6}$: Develop sustainably optimised customer-centric quality of service delivery	$DP_{1.3.6}$: Design optimised customer-centric quality of service for the supply chain, including affiliated auto dealerships

Table A3: Decomposition Process Mapping to achieve FR_2

Functional Requirements		Design Parameters	
FR_0:	Develop a QX Engineering Design for automotive manufacturing system	DP_0:	Produce a roadmap for QX Engineering Design
FR_2:	Minimise cost-biased activities in developing QX Engineering Design	DP_2:	System for minimising cost-associated activities in developing QX Engineering Design
$FR_{2.1}$:	Achieve organisation-wide QX Engineering Design buy-in	$DP_{2.1}$:	System for organisation-wide QX Engineering Design buy-in
$FR_{2.1.1}$:	Create QX Task Force	$DP_{2.1.1}$:	Design QX Task Force
$FR_{2.1.2}$:	Achieve Top Management buy-in	$DP_{2.1.2}$:	Procedure for Top Management buy-in
$FR_{2.1.3}$:	Achieve Mid-level Management buy-in	$DP_{2.1.3}$:	Procedure for Mid-level Management buy-in
$FR_{2.1.4}$:	Achieve QX buy-in across all departments	$DP_{2.1.4}$:	Procedure for QX buy-in across all departments
$FR_{2.1.5}$:	Develop procedure for internal audit of QX practice	$DP_{2.1.5}$:	Design procedure for internal audit of QX practice
$FR_{2.2}$:	Determine strengths and weaknesses of under-utilised personnel	$DP_{2.2}$:	Design QX-based strength and weakness analysis
$FR_{2.2.1}$:	Define process for maximising use of skilled personnel	$DP_{2.2.1}$:	Procedure for maximising use of skilled personnel
$FR_{2.2.2}$:	Determine master process for personnel utilisation	$DP_{2.2.2}$:	Master process for maximised human resources
$FR_{2.3}$:	Eliminate non-value added excess production of resources	$DP_{2.3}$:	QX Task Force procedures
$FR_{2.3.1}$:	Minimise repetitive design and printed-matter	$DP_{2.3.1}$:	Short process setup for design
$FR_{2.3.2}$:	Avoid long changeovers	$DP_{2.3.2}$:	Standardise stable schedules
$FR_{2.3.3}$:	Minimise reliance on forecasted demand	$DP_{2.3.3}$:	In-demand production (i.e. production on demand)
$FR_{2.3.4}$:	Determine production volume control	$DP_{2.3.4}$:	Production Pareto analysis
$FR_{2.3.5}$:	Determine master process for capturing non-value added production activities	$DP_{2.3.5}$:	Master process for identifying and mitigating agents of overproduction
$FR_{2.4}$:	Eliminate factors of defects within the value stream design	$DP_{2.4}$:	Process for zero defects

$FR_{2.4.1}$:	Eliminate rework	$DP_{2.4.1}$:	Procedure for on-line quality inspection
$FR_{2.4.2}$:	Eliminate non-productive time	$DP_{2.4.2}$:	Procedure for implementing quality at the source
$FR_{2.4.3}$:	Eliminate agents of variations	$DP_{2.4.3}$:	QX quality process selection
$FR_{2.4.4}$:	Determine master process for capturing defects	$DP_{2.4.4}$:	QX quality process integrated with select relevant quality tool
$FR_{2.4.5}$:	Develop process monitoring scheme	$DP_{2.4.5}$:	QX Task Force process monitoring procedure
$FR_{2.5}$:	Eliminate non-value added inventory of design resources	$DP_{2.5}$:	Optimal process for resource efficiency
$FR_{2.5.1}$:	Define process to control inventory	$DP_{2.5.1}$:	QX quality process for inventory
$FR_{2.6}$:	Eliminate non-value added movements of human and material resources	$DP_{2.6}$:	Optimised production resources scheduling procedures
$FR_{2.6.1}$:	Eliminate unnecessary material movements	$DP_{2.6.1}$:	Design material flow-oriented layout
$FR_{2.6.2}$:	Reduce human resource unnecessary movements	$DP_{2.6.2}$:	Create SOP for manufacturing processes
$FR_{2.7}$:	Minimise non-value added waiting in the system	$DP_{2.7}$:	Continuous flow design
$FR_{2.7.1}$:	Eliminate machine operations non-value added idle time	$DP_{2.7.1}$:	Optimise manufacturing system scheduling
$FR_{2.7.2}$:	Minimise personnel waiting on material or machine operations	$DP_{2.7.2}$:	Optimise process continuous flow
$FR_{2.8}$:	Eliminate inefficient processing within the system	$DP_{2.8}$:	Optimise processing design
$FR_{2.8.1}$:	Determine master process	$DP_{2.8.1}$:	Standardised master process
$FR_{2.9}$:	Eliminate inefficient transportation of resources in the system	$DP_{2.9}$:	Design procedures for reducing excessive transportation
$FR_{2.9.1}$:	Define process for minimising non-value added transportation	$DP_{2.9.1}$:	Single Minute Exchange of Die (SMED) process
$FR_{2.9.2}$:	Minimise transportation of resources within facility	$DP_{2.9.2}$:	Production-oriented facility layout

$FR_{2.10}$: Identify and mitigate social (human) actors' adversarial behaviours towards QX Engineering Design	$DP_{2.10}$: Design system for tracking human adversarial behaviours against QX Engineering Design process
$FR_{2.10.1}$: Develop objective monitoring scheme to identify personnel apathy towards quality design process	$DP_{2.10.1}$: Procedures for objective identification of personnel apathy across all departments and analysis
$FR_{2.10.2}$: Enable a scheme for reporting observed human adversarial behaviours towards quality design	$DP_{2.10.2}$: Design solution-oriented system to address adversarial behaviours through transformational lens
$FR_{2.10.3}$: Create risk assessment procedure to eliminate personnel apathetical behaviours	$DP_{2.10.3}$: Procedure for risk assessment based on personnel apathy behaviours
$FR_{2.10.4}$: Develop a scheme to encourage self-reporting of adversarial behaviours against company goals	$DP_{2.10.4}$: Design conflict resolution and personnel support system in the event of deviation from company goals
$FR_{2.10.5}$: Motivate personnel participation in organisational goal	$DP_{2.10.5}$: Reward-sharing programmes
$FR_{2.11}$: Determine top management non-committal towards quality implementation process and overall organisational goal	$DP_{2.11}$: Mitigation solution for top management non-committal attitudes
$FR_{2.11.1}$: Conduct risk assessment to minimise top management non-committal attitudes	$DP_{2.11.1}$: Procedure for conducting risk assessment based on top management non-committal behaviours
$FR_{2.11.2}$: Pull top management's commitment to goal	$DP_{2.11.2}$: Gain-sharing programme
$FR_{2.12}$: Determine quality training needs required for core capabilities	$DP_{2.12}$: Core quality capability training programmes
$FR_{2.12.1}$: Co-evolve with emerging technologies	$DP_{2.12.1}$: Procedure for regular recurrent training
$FR_{2.13}$: Mitigate organisational behaviour against quality engineering processes	$DP_{2.13}$: Mitigation solution for organisational apathetic behaviour against QX Engineering design
$FR_{2.13.1}$: Determine agents of risks to the design process	$DP_{2.13.1}$: Procedure for identifying human agent risk factors
$FR_{2.13.2}$: Determine in-house training and awareness workshop on organisational context and goals	$DP_{2.13.2}$: In-house training and awareness programme on organisational context and goals
$FR_{2.14}$: Determine internal audit of quality procedures	$DP_{2.14}$: Implement internal audit of quality processes across all departments
$FR_{2.14.1}$: Determine process for conducting internal audit	$DP_{2.14.1}$: Procedures for conducting internal audit

$FR_{2.14.2}$:	Determine internal audit team	$DP_{2.14.2}$:	Internal audit team selection process
$FR_{2.15}$:	Mitigate automotive regulatory and standards nonconformities within the design processes	$DP_{2.15}$:	Mitigation solution for regulatory and standards nonconformities
$FR_{2.15.1}$:	Determine in-house training and awareness on regulatory and standards compliance requirements	$DP_{2.15.1}$:	Training and awareness programme on regulatory and standards compliance requirements
$FR_{2.15.2}$:	Provide procedure to enable consistency of conforming with regulatory and standards requirements	$DP_{2.15.2}$:	Standard Operating Procedures (SOP) based on requirements for conforming with regulatory authority standard
$FR_{2.16}$:	Mitigate environmental compliance nonconformities within the design processes	$DP_{2.16}$:	Mitigation solution for environmental compliance nonconformities
$FR_{2.16.1}$:	Provide in-house training and awareness on environmental standards compliance requirements	$DP_{2.16.1}$:	Training and awareness programme on environmental standards compliance requirements
$FR_{2.16.2}$:	Provide procedure to enable consistency of conforming with environmental standards requirements	$DP_{2.16.2}$:	Standard Operating Procedures (SOP) based on environmental standards requirement compliance
$FR_{2.17}$:	Develop highly responsive system to address auto recall issues	$DP_{2.17}$:	Design highly responsive system to address auto recall issues
$FR_{2.17.1}$:	Determine need for in-house training for staff development knowledge in automobile safety regulations	$DP_{2.17.1}$:	Design training programme in automobile safety regulations, featuring adherence to code of practice of safety
$FR_{2.17.2}$:	Develop a system for early detection of potential product safety defect	$DP_{2.17.2}$:	Effective system for early safety defect detection and documented procedures in the event of a recall
$FR_{2.17.3}$:	Develop a system to notify automotive regulatory bodies of late detection of a product safety defect	$DP_{2.17.3}$:	System for notifying automotive regulatory bodies of late (or early) detection of a product safety defect pre-delivery (or post-delivery) or both
$FR_{2.17.4}$:	Develop standardised procedure for rendering nonconforming products unusable prior to final disposal	$DP_{2.17.4}$:	Design and document standardised procedure for rendering nonconforming products unusable prior to final disposal
$FR_{2.17.5}$:	Create QX Task Force protocol for internal auto recall process monitoring	$DP_{2.17.5}$:	Develop internal auto recall response process monitoring

$FR_{2.18}$:	Develop a system to mitigate quality performance disruptions presented by emerging technologies	$DP_{2.18}$:	Design a system to mitigate quality performance disruptions as and when created by emerging technologies
$FR_{2.18.1}$:	Develop survival and mitigation solution against disruptions posed by Connected Automobile	$DP_{2.18.1}$:	Contingency design against disruption by Connected Automobile
$FR_{2.18.2}$:	Develop business strategies against threats to market share posed by Automobile Sharing	$DP_{2.18.2}$:	Design market entry schemes against sales decline caused by increased Connected Automobile demand
$FR_{2.18.3}$:	Develop manufacturing strategies against rapid wear and tear due to predicted growth of Automobile Sharing in 2030	$DP_{2.18.3}$:	Manufacturing strategies for optimised engineered tyres
$FR_{2.18.4}$:	Develop mitigation solution against unprepared forced transition pressures presented by growing demand for hybrid-powered automobiles	$DP_{2.18.4}$:	Mitigation solution against threat to business existence
$FR_{2.18.5}$:	Develop manufacturing system to address increased manufacturing complexity due to continuous generation of data	$DP_{2.18.5}$:	Integrate existing manufacturing processes complex adaptive system (CAS) response mechanism cost-resource-effectively
$FR_{2.18.6}$:	Develop alternative solution to address capital-intensive software regarding safety concerns due to Driverless Automobile	$DP_{2.18.6}$:	Optimise mitigation solutions against human adversarial behaviours against quality designs
$FR_{2.18.7}$:	Develop alternative solution to software-hardware coupling due to consumer's uncertain demand patterns in the use of Driverless Automobile	$DP_{2.18.7}$:	Develop adaptive design, without need to couple software-hardware, to satisfy customer-centric uncertain demand patterns
$FR_{2.18.8}$:	Develop mitigation solution against software virus risk due to computer virus attack or hack	$DP_{2.18.8}$:	Minimise dependency on extensive software integrated systems and design mitigation solution against cyber attacks
$FR_{2.18.9}$:	Develop a system for identifiers of social (human) adversarial behaviours against safety concern	$DP_{2.18.9}$:	Optimise safety information dissemination and disrupt misleading information in public domain
$FR_{2.18.10}$:	Create system for monitoring dynamics of entry strategies of emergency technologies	$DP_{2.18.10}$:	Develop a QX Task Force emergency technologies monitoring system