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RESEARCH PAPER

The mediating effects of Quality 4.0 on public sector engineering-based projects

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ABSTRACT

Goal: The distress experienced within the capital projects, with delays at the forefront, raises the question of the effect quality has on the progression of these endeavours. It is vital to assess the effect of the quality approach employed currently in conjunction with the imminent fourth industrial revolution (4IR).

Design/Methodology/Approach: The research adopted a positivist philosophy and was deductive in nature, employing a quantitative method with a non-probability survey of public-sector engineering-based SOEs. Partial least squares structural equation modelling (PLS-SEM) path modelling was used to analyse complex interrelationships among observed and latent variables.

Results: The results confirmed the hypotheses with customer focus (CF), staff training (ST), quality process (QP) management, and supplier quality (SQ) management, between project performance (PF) and successful completion (SC), while they were not supported with leadership commitment (LC), employee focus (EF), and quality culture (QC). Highlighting a customer-centric and enabling environment for the adoption of Quality 4.0, and making it conducive to leveraging the advantages of Industry 4.0 technologies.

Practical implication: The contribution of contingency theory to industry, policy makers, and the sector is to guide organisations towards a quality-centric policy to align efforts to leverage the advantages of Quality 4.0 principles and 4IR technologies.

Originality/value: This approach diminishes the silver bullet concept of executing capital projects towards customer satisfaction, as there can be more than one solution to enhance performance and the progress of capital acquisition projects.

Keyword: Quality 4.0; TQM; Quality principles; Project management; Capital acquisition project.

1. INTRODUCTION

Worldwide, there is pressure on governments to meet the needs of the public while also ensuring security with restricted budgets, which calls for decisions that are justifiable and informed about project funding (Chih and Zwikael, 2015). There is a critical element to complete large infrastructure projects quickly and to execute them in a very efficient manner, so that the benefit may be derived from the taxpayer's money. The taxpayers also benefit from the volume of work that can be achieved from efficient usage of scarce resources (Tshidavhu and Khatleli, 2020). There has been an increase in the value from R340 billion in July 2020 to R540 billion in 2024 in the integrated strategic projects (SIP) spent by the Department of public works in the Republic of South Africa (RSA); these are various projects that the department undertakes in commitment to improve infrastructure delivery by completing these projects within schedule and budget (2024). Despite this, there have been delays such as 32 months on the Badger fighting vehicles, which are intended to replace the ageing Ratel as the prime

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fighting vehicle for the SA Army. These delays in the availability of prime mission equipment (PME) add to the difficulties in keeping the landward force operational (Martin, 2019). Ika and Saint-Macary (2014) expressed that cost overruns, delays, and red tape are a common occurrence. The conception of employment opportunities, driving economic growth, and assured benefits permeating to the marginalised and poor are how large-scale projects are promoted in RSA. However, there is an abundance of failure of these endeavours in addressing social concerns (Tshidavhu and Khatleli, 2020). There is definitely a need to explore the nascent field of Quality 4.0 in the context of combating capital project delays (Antony *et al.*, 2024). There is literature on the benefits of Industry 4.0 technologies on quality management, but there is a shortage in research on critical failure factors and success factors.

The delivery of products/product systems has gained more importance over time (Bousdekis *et al.*, 2023, Virmani *et al.*, 2024), which has led to the emergence of many quality concepts and methods (Bousdekis *et al.*, 2023). The engineering-based projects are extremely important within the user environment, either military or infrastructure, and their delivery is required on time to allow usage of prime mission equipment. Therefore, this necessitates the introduction of Quality 4.0, which is a combination of quality management with technology and digitalisation (Bousdekis *et al.*, 2023). Industry 4.0 has a transformational ability to integrate physical and digital systems, with the ability to drive innovation and efficiency throughout industries (Khan and Emon, 2025). Smart quality systems improve business performance and efficiency and are also improved by smart quality systems, and they also increase customer satisfaction (Magodi *et al.*, 2024). The benefits of Quality 4.0 are presented as the promotion of adaptability and flexibility, and companies are empowered to act quickly to the change in market conditions (Virmani *et al.*, 2024). Critical success factors are explained as satisfactory results, and they ensure an organisation's successful competitive performance (Rampini and Berssaneti, 2024). The study endeavours to fill the research gap and contribute by guiding the industry, policy makers, and the sector toward a quality-centric policy that aligns efforts to leverage the advantages of Quality 4.0 principles and 4IR technologies. The purpose of the study is to investigate the mediating effect of Quality 4.0 principles on performance and successful completion of the capital acquisition projects. The project is successfully completed if the predefined project objectives are achieved within the agreed-upon scope, schedule, and budget, and quality output (Karimulla and Gupta, 2024). The subsequent Section 2 of the article encompasses the theoretical and empirical review of the literature, followed by the research methodology in Section 3. Then the results are expressed in Section 4, and Section 5 encompasses the discussion of the study. Then Section 6 covers the conclusion of the study, while Section 7 includes the implications and future research directions.

2. THEORETICAL AND EMPIRICAL REVIEW OF THE LITERATURE

The argument made towards the adoption of the contingency theory is that there are no universal strategic choices applicable to every situation in a business, indicating that there is no one-size-fits-all approach in how the strategy of the organisation is organised (Yu *et al.*, 2020). The fit amongst the key variables of the Quality 4.0 principles is proposed by the contingency theory to reach high levels of performance. The contingency theory is intent on identifying an optimal course of action for undertaking capital acquisition projects, taking into consideration the influence of external and internal factors on the organisation. Contingency theory stresses that the optimal results will not be achieved with a single Quality 4.0 principle; it is contingent on relationships amongst Quality 4.0, project performance, and the successful completion of capital acquisition projects. Project performance refers to how well the project is being executed throughout the lifecycle, whether the project was completed on time, within budget, and to specification. This criterion is used to measure project success. Henceforth, a project may be deemed successfully completed even if it is delivered late, over budget, and under delivered against the specification, because it is still delivered to the benefit of the stakeholders' expectations (client/users) (Bannerman, 2008, Vesa, 2023). Contingency theory is consistent with the fact that there is no 'best way' to develop and implement strategies (Darvishmotevali *et al.*, 2020); henceforth, the approach to conducting the study is theoretical with the introduction of a framework. The study guides management in implementing policies that direct efforts toward the successful completion of capital acquisition projects. However, the core tenet of contingency theory is that a project organisation must be cognisant that there is no paramount method or principle to be applied in all circumstances. Further emphasising

that capital acquisition projects may not be managed with a singular superlative way or theory.

2.1 Acquisition process and the evolution of quality with the emerging 4IR

There are four primary phases of the system life cycle: planning, acquisition, operational deployment, and maintenance, culminating in disposal (2016). The primary system life cycle, from planning to disposal, would reveal gaps in the required operational capability (ROC) based on analyses, and the need arises from obsolescence or new technology introduced within the domain. The gap in the ROC refers to replacing an ageing Ratel fleet with a modernised system. The changes within the operational environment, enhanced requirements, obsolescence, or cost effectiveness result in shortcomings in the ROC (Oosthuizen and Roodt, 2008). The requirement will have to be fulfilled through the acquisition process that undergoes phases within the secondary life cycle. The acquisition process includes requirements analysis, options analysis, contracting, design and development, qualification, contract management, handover, and commissioning (2016). The study interrogates the weaknesses from a quality perspective during these phases that have the propensity to exacerbate the cost overruns, schedule delays, and mismatch in offered solutions to close the gap in the ROC. It is important to note that there are two types of capital projects, which are large-scale and are performed for the general public benefit, such as roads and public buildings. While some are carried out for special assessment for private benefit, such as street improvements and sewage (2017, Zeb, 2022). There is a keen interest in those capital projects that are performed for the general benefit of the public; the success of these capital projects requires adopting quality management (QM) to ensure said success. This requires a manner in which both project management and quality management are addressed concurrently to ensure a successful outcome of the endeavour. The organisation may gain both local and global markets' competitive advantage by employing a strategy of improving its capital project system (Nyakala *et al.*, 2020, Scott-Young and Samson, 2008). Alessandri *et al.* (2004) posit that, when assessing capital projects, the focus should be on improving organisational decision-making. Decision-making within an organisation must be structured in a manner that leads to decisions that are beneficial to the organisation. The decisions must be void of ignorance and lead to no detriment to the organisation and society at large, while further considering official constraints and pressure that affect rational decision-making in capital projects. The decision-making within capital acquisition projects must have the intent of reducing risk and eliminating inefficiencies that lead to failures in addressing the gap in the ROC.

To gain a competitive advantage with rivals within global markets, organisations can effectively deploy quality as a strategy to achieve a competitive advantage (Antony *et al.*, 2021). Important developments in any scientific discipline are attributed to changes in conditions such as increased customer demands, globalisation, or competitive pressure that cause changes in paradigms (Weckenmann *et al.*, 2015). Kloppenborg and Petrick (2002) argue that the parallel evolution of QM and project management (PM) has been driven by global competitiveness and the dynamic change within the environment. The company that wants to remain competitive in today's marketplace must view QM as a necessity. QM could be the answer to how the organisation does things more easily, faster, and smarter (Diamond, 2022). Organisations within the capital acquisition domain have to view the external influences and take advantage of the benefits of the parallel evolution of QM and PM as necessities to remain competitive. There are two meanings of quality implemented by Juran, which are products free of deficiencies and having features. While Philip Crosby developed two concepts, which entail that quality is free and zero defects. Quality is free because the savings derived from quality development programmes pay for themselves through savings. While striving to attain zero defects will save costs, culminating in improved profits, taking industrial evolution into account (Alghamdi, 2016). The philosophy provides tangible benefits; however, it may be impractical to realise the absolute elimination of defects in the highly variable environment of complex capital projects, but quality remains as a strategic response to inherent variability and gaining a competitive advantage. The industrial revolution is divided into four stages, the first being dependence on water and steam around 1870, and the second phase is signified by the use of steel, electricity, and mass production. The third phase was characterised by dependence on electronics and the Programmable Logic Controller (PLC) (Maganga and Taifa, 2023, Sader *et al.*, 2019).

The final and current phase, with the advent of the usage of different technologies for automation of manufacturing processes, is identified as Industry 4.0 (Souza *et al.*, 2022). The 4IR converges cyber and physical technologies as opposed to previous industrial revolutions, placing reliance on one dominant technology (Sader *et al.*, 2019, Sony *et al.*, 2020, Dias *et al.*, 2022). There is congruence amongst several authors that human error is reduced by cyber-physical systems (CPS), more so around the stages that are labour-intensive (Chiarini and Kumar, 2022). The digital technologies, like data analytics and cyber-physical systems, must be used to transform QM and TQM as opposed to just extending the TQM principles. The first paradigm shift in quality was with the introduction of mass production, 1900-1940, where the focus was only on the quality inspection of the delivered product without known anomalies. Although the approach avoided customer complaints and recourse, the methodology is mainly based on filtering of waste from final products during inspection (Weckenmann *et al.*, 2015, Dias *et al.*, 2022). Then the focus of progression was from the quality of the product towards the quality of the process, where the manufacturing processes were given due consideration in 1940. This led to the reduction of waste and high losses that result from the inspection concept by establishing control over the production process (Weckenmann *et al.*, 2015).

Finding causal activities that lead to errors was much more effective than filtering and subsequent correction. Quality control came into effect, where it was no longer just a mere reaction after inspection, but was used to control quality (Weckenmann *et al.*, 2015). The focus shifted around the 1960s from only quality control to quality assurance priori. This is achieved by taking into consideration the possible problems and risks and preventing them before they occur, instead of controlling and reacting posteriori (Weckenmann *et al.*, 2015). The complexity of the product and the rising demands of the customers due to competition around 1980 prompted the consideration of the interdependencies with the suppliers. It is done through the development of the concept that is focused on the customer as opposed to the one-directional push-strategy enterprise-focused view (Weckenmann *et al.*, 2015, Adebiyi *et al.*, 2021). However, the complexity introduces challenges that come with the integration, and the risks that ensue due to dependency and the cost of coordination with suppliers. The fourth and current paradigm shift is due to the evolution of QM toward the significance of delivering high-quality results, instead of being compelled by the high pressure from the market (Weckenmann *et al.*, 2015, Hanum, 2022). The Quality 4.0 paradigm is novel and emerges in the context of Industry 4.0 through a combination of quality management and improvement models (Bousdekis *et al.*, 2023, Rogala *et al.*, 2024), and technology approaches that foster factors and competencies that are critical for organisational success (Bousdekis *et al.*, 2023). Even though there is a link between digitalisation and improvement, the adoption presents new complexity, such as skillset requirements and dependency on data.

Weckenmann *et al.* (2015) assert that the use of knowledge discovery and data mining technologies in TQM is the foremost task of research within engineering and QM. The impact of technology on TQM has been associated with studies of Quality 4.0 (Mtotywa, 2022). Henceforth, Antony *et al.* (2021) profess that managing quality in the modern era is, in simple terms, Quality 4.0. Quality 4.0 is a branch of Industry 4.0 using intelligent solutions and algorithms emerging from technology (Souza *et al.*, 2022, Ramezani and Jassbi, 2020). Quality 4.0 tools are Artificial Intelligence (AI), big data, enabling technologies such as Internet of Things (IoT), Industrial Internet of Things (IIoT), Virtual Reality (VR), integrated systems, cloud computing, and Augmented Reality (AR), manufacturing advancements such as three-dimensional (3D) printing (Antony *et al.*, 2021, Maganga and Taifa, 2023, Carvalho *et al.*, 2021). The Quality 4.0 journey transitioned to being a consumer-centric and digitally enabled migration from being compliance-centric and process-enabled (Chiarini and Kumar, 2022). The intention of Quality 4.0 is not to replace existing norms but to improve established methodologies that incorporate quality practices, principles, and resources within a modern digital setting (Antony *et al.*, 2024, Rogala *et al.*, 2024). The realisation of the benefits may be obstructed by organisational constraints, requiring critical engagement within the organisation in terms of adaptability towards being a data-intensive environment.

Mengistie (2019) highlights these elements amongst the many elements of TQM, like focus on the customer, commitment of top management, continuous improvement, empowerment of employees, process approach, and QM of the supplier. The digitalisation of TQM is characterised as Quality 4.0 and the resultant effect on quality technology, individuals, and processes. Henceforth, it may be defined as the application of technologies related to Industry 4.0 to quality (Carvalho *et al.*, 2021, Jokovic *et al.*, 2023, Khourshed and Gohar, 2023). However,

Ali *et al.* (2022) highlight various factors from the existing literature that are responsible for implementing Industry 4.0 technologies, such as top management, focus on customer, learning and training, teamwork/Human resource management (HRM), process, management, and quality information and analysis. There are critical implementation challenges of the mediating principles; the principles have been proven to have a positive effect, but were proven without considering the component of digitalisation. The required skill-set, availability of a reliable network, infrastructure, cybersecurity, and general resistance to change may hinder implementation. The hypotheses of the study are henceforth generated using the literature, with the consistent Quality 4.0 principles among the authors being used as relevant data and their mediating effects between performance and successful completion of capital projects. The principles include leadership and management commitment (LC), customer focus (CF), employee focus/engagement (EF), quality culture (QC), staff training (ST), quality process (QP) management, and supplier quality (SQ) management (Akanmu *et al.*, 2020, Sim *et al.*, 2022, Carnerud, 2020).

2.2. Conceptual Model and Hypotheses

Higher operational excellence, optimal innovation, and superior performance are achieved through the use of Quality 4.0. Used in conjunction with a combination of new technologies, methods, and standard quality tools. Therefore, the hypotheses are presented in the conceptual model in Figure 1, and the first hypothesis is the assessment of the effect of the iron triangle on the successful completion of acquisition projects.

H1: The performance of projects within the set cost, schedule, and quality will have a significant effect on the successful completion.

The leadership style required for Quality 4.0 is knowledge-oriented leadership, since innovation and learning are required in Quality 4.0 (Sony *et al.*, 2020, Dias *et al.*, 2022). The second hypothesis is to assess the effect of leadership commitment on the iron triangle (cost, schedule, and quality).

H2: Leadership and management commitment has a significant mediation effect between project progression and successful completion.

The retention, development, and acquisition of customers is influenced by Artificial Intelligence-based customer relationship management (AI-CRM) because products are personalised using real-time data to improve CRM through the implementation of Quality 4.0 (Antony *et al.*, 2021, Chiarini and Kumar, 2022). Thus, the third hypothesis may be formulated to assess the effect of the focus on the customer on the achievement of the iron triangle.

H3: Focus on the customer has a mediation effect between project progression and successful completion.

The traditional usage of robots with the intent for higher productivity and product or service quality is not adopted. The collaborative robotics (COBOTS) is instead elected, where tasks are completed with robots and people working together (Maganga and Taifa, 2023, Dias *et al.*, 2022, Chiarini and Kumar, 2022). The fourth hypothesis involves the evaluation of the effect of the focus of the employees on the achievement of the iron triangle.

H4: Focus on employees and employee empowerment has a significant mediation effect between project progression and successful completion.

The organisation must cultivate a culture that prioritises learning, quality, and ethics to operate in accordance with the Quality 4.0 approach (Maganga and Taifa, 2023). Therefore, the fifth hypothesis is the assessment of the effect of quality culture on the achievement of the iron triangle.

H5: Improvement in quality culture has a significant mediation effect between project progression and successful completion.

The technical skills required for Quality 4.0 include IT installation, analysis of big data and radio frequency identification (RFID) tags, and transformational skills such as critical thinking, adaptability, creativity, teamwork, and transfer of knowledge (Sony *et al.*, 2020, Dias *et al.*, 2022). The sixth hypothesis is the assessment of the effect of staff training on the achievement of the iron triangle.

H6: Staff training has a significant mediation effect between project progression and successful completion.

Industry 4.0 has a striking feature of end-to-end integration throughout the product life cycle (Sony *et al.*, 2020). The implementation of Industry 4.0 includes horizontal, vertical, and

end-to-end integration (Jokovic *et al.*, 2023, Chiarini and Kumar, 2022, Khourshed and Gohar, 2023). Therefore, the seventh hypothesis is to assess the effect of effective quality process management on the achievement of the iron triangle.

H7: Quality process management has a significant mediation effect between project progression and successful completion.

A common focus on quality of the product by horizontal integration is realised through a fully bidirectional customer-oriented exchange of quality data; the exchange of feedback and quality information must be between the customer and the supplier (Brandenburger *et al.*, 2021). The eighth hypothesis is the assessment of the effect of supplier quality management on the iron triangle.

H8: Supplier quality management has a significant mediation effect between project progression and successful completion.

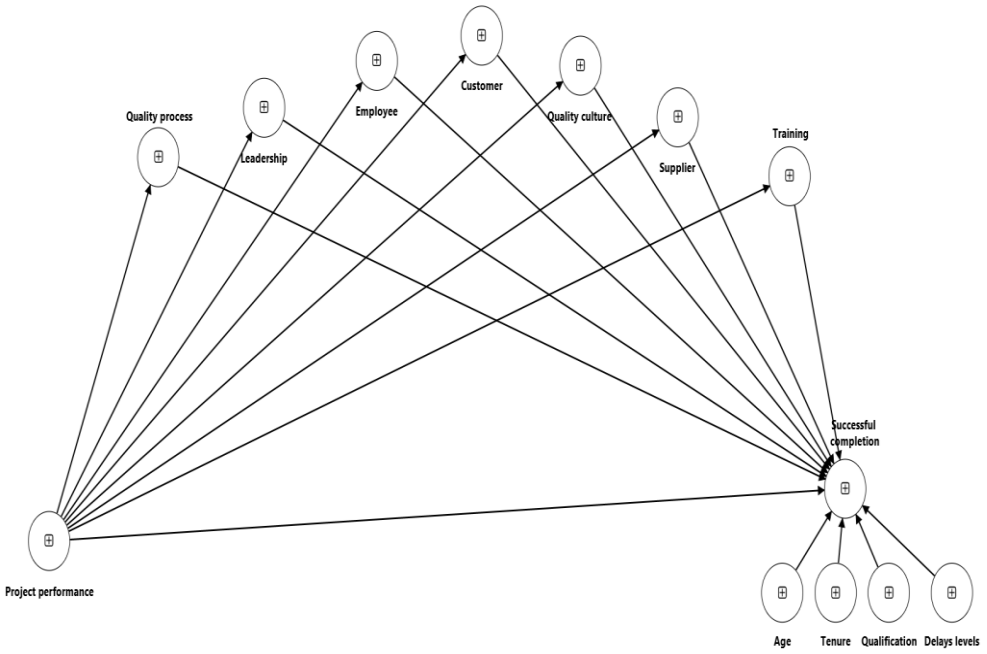

Figure 1 - Conceptual model of the study

3. RESEARCH METHODOLOGY

The study is part of doctoral research investigating the effect of Quality 4.0 on the progression of capital projects. There is a consensus that the quantitative research approach is equated with positivism employing surveys and without any philosophical commitments (Nayak and Singh, 2021). The study was cross-sectional in nature (Seoke *et al.*, 2023), and the population was 1805. The respondents were drawn from the public sector engineering-based organisations. Slovin's equation was used to obtain a sample size of 327 due to its ease of use and minimal input (Adebiyi *et al.*, 2021), and the research considered participants within the non-probability purposive sample who have been exposed to capital acquisition projects (Sudirman *et al.*, 2021). There are limitations of generalisability with using a purposive sample. The sample intentionally included participants who performed administrative functions, engineering, project management, quality management functions, and senior management performing managerial functions during the execution of capital projects. Despite these limitations, the work can be transferred to a similar setting. Participants were not novices, and there was wealth in experience within the engineering sector, with 47,3% of the respondents having a minimum of six years or more of experience in undertaking capital acquisition projects. Data was collected from participants using self-administered questionnaires. The questionnaire was fashioned from literature since the study is novel, and was sent to participants through an online platform such as SurveyMonkey (Al-Ababneh, 2020).

Before full-scale collection of relevant data, the questionnaire was pilot tested in manufacturing industries (Maganga and Taifa, 2023, Antony *et al.*, 2023). The set associated

with a construct is explored, and subsequent refinement is made using exploratory factor analysis (EFA) (Goretzko *et al.*, 2024). The confirmatory factor analysis (CFA) was used to test if the relationship between the latent variable and the manifest indicators. Furthermore, it was assessed if it is congruent with empirical data by testing if the structure implemented by the covariance model reproduces the empirical covariance matrix (Goretzko *et al.*, 2024). Convergence validity is provided when the values of average variance extracted (AVE) are less than composite reliability (CR) (Hair *et al.*, 2019). Indicator variables and structural paths lacking the imposition of distributional assumptions were estimated using partial least squares structural equation modelling (PLS-SEM) (Hair *et al.*, 2019). The study was deductive in nature; henceforth, the adoption of the quantitative method was appropriate to enable hypothesis testing and generalisation of findings. The summary of the methodology is given in Table 1.

Table 1 - Summary of the methodology (Al-Ababneh, 2020)

The research process	Current study
Philosophy	Positivism
Approach	Deductive
Strategies	Survey
Choices	Mono-method
Time horizon	Cross-sectional
Techniques and procedures	Data collection and analysis

4. RESULTS

The average response rate for online surveys is given as 44,1%, and there were 306 respondents when considering the expected sample of 327 respondents, totalling to 94% (Mtotywa and Dube, 2023). The decision rule for evaluating the coefficients and statistical significance was based on a confidence level of 95% ($p < 0.05$) (Seoke *et al.*, 2023, Hair *et al.*, 2019, Chiarini and Kumar, 2022). The respondents were predominantly within 31 to 50 years, and attributed for 33,7% and those over 50 years, attributed for 25,5%. The level of education of the respondents was predominantly those with a Bachelor's degree/Advanced Diploma/B Tech - NQF Level 7, attributed to 32%. While there were those with an Honours Post Graduate Diploma - NQF Level 8 and more, attributed to 40,5% of the respondents. Although most of the respondents experienced delays in 1 year and less, it attributed to 52,6%. While 27,5% of the respondents experienced delays within 2 to 3 years, and 19,9% of respondents experienced delays within 4 years or more of undertaking capital acquisition projects.

Then the results were assessed for errors, and erroneous data points within the set may be kept and treated like any data point. They may be winsorised, where a lesser weight is assigned to them, reducing their effect (Ghosh and Vogt, 2012, Jacobs, 2001). They may also be removed from the sample, which might produce poor estimates of parameters (Ghosh and Vogt, 2012, Leys *et al.*, 2019). The data for the investigation had no issues with missing values, as the missing values were below the 5% threshold. Extreme outliers were detected from the data based on the interquartile range method, with four data sets outside the three times the interquartile range. Skewness and kurtosis of the data are preferred instead of z-values when the responses are greater than 300. The skewness of the data set ranged from -0,194 to 1,497, while kurtosis ranged from -0,974 to 3,199 for the study variables. The variables were within ±2 and ±7 range, indicating that the data are normally or near normally distributed (Sekhula and Mtotywa, 2025).

4.1. Measurement model

The model fit is among the indices of confirmatory factor analysis indices (CFA) using the root mean square residual (SRMR). The model fit is confirmed if the value is less than 0.08, and the value of SRMR = 0,064 indicates that it was well developed. The value of the NFI was 0.724, indicating an acceptable fit; however, a good fit is indicated by values of NFI > 0.9. However, the measurement is treated with caution, as it does not consider all complexities of the

principles (Mtotywa and Kekana, 2023).

4.1.1. Outer loadings, reliability, and convergence

The recommended factor loadings are above 0.708, as the constructs can explain more than 50% of the indicator variance, exhibiting acceptable reliability (Hair *et al.*, 2019, Hair *et al.*, 2017, Sarstedt *et al.*, 2021). Factor loadings (λ) were higher than 0.708 except for those between 0.5 and 0.7, as identified in the independent variables. Which were CF2, CF7, EF5, ST5, and SC5, were considered for further analysis. However, QP5 was removed from the model because it was lower than 0.3, attributable to weak factor loading. This includes the omission of the overlapped observations on QC1 and QP1 due to the identical observed values, which artificially restricts the variability of the data (McNeish, 2017).

The convergence validity is determined using the extracted average variance (AVE), the composite reliability with composite_rho_a and rho_c, and the Cronbach alpha. The internal consistency of the instrument was verified with a reliability test using Cronbach's α. The internal consistency of the construct had an acceptable Cronbach's α since they were all greater than 0,7 as shown in Table 2. The AVE values were between 0.522 and 0.753 for the structural equation model. There is congruence that an AVE of 0.50 or higher provides adequate convergent validity and explains 50% of the variance of the elements of the construct (Hair *et al.*, 2017, Sarstedt *et al.*, 2021, Hair *et al.*, 2019).

Table 2 - Complete loadings of the model, factors, reliability, and convergence validity, adapted from

	(λ)	**α**	**CR (rho_a)**	**CR (rho_c)**	**AVE**
Customer Focus		0.847	0.849	0.884	0.522
CF1	0,752				
CF2	0,662				
CF3	0,716				
CF4	0,722				
CF5	0,788				
CF6	0,713				
CF7	0,694				
Employee Focus		0.861	0.867	0.897	0.594
EF1	0,841				
EF2	0,770				
EF3	0,838				
EF4	0,753				
EF5	0,650				
EF6	0,755				
Leadership Commitment		0.920	0.922	0.936	0.676
LC1	0,770				
LC2	0,798				
LC3	0,839				
LC4	0,848				
LC5	0,861				
LC6	0,846				
LC7	0,789				
Project Performance		0.836	0.856	0.901	0.753
PF2	0.895				
PF4	0,801				
PF5	0,905				
Quality Culture		0,820	0,820	0,893	0,735

	(λ)	α	CR (rho_a)	CR (rho_c)	AVE
QC3	0,864				
QC4	0,860				
QC5	0,847				
QC6	0.807				
Quality Process Management		0.771	0.771	0.868	0.686
QP2	0,830				
QP3	0,855				
QP4	0,799				
Successful Completion		0,785	0,837	0,862	0,619
SC2	0,849				
SC3	0,884				
SC4	0,836				
SC5	0,523				
Supplier Quality Management		0.828	0.830	0.879	0.593
SQ1	0.787				
SQ2	0.810				
SQ3	0.746				
SQ4	0.770				
SQ5	0.733				
Staff Training		0.902	0.903	0.923	0.633
ST1	0,838				
ST2	0,864				
ST3	0,797				
ST4	0,819				
ST5	0,681				
ST6	0,775				
ST7	0,784				
Demographic					
Age (AG)	1,000				
Delays (DL)	1,000				
Qualifications (DL)	1,000				
Tenure (TN)	1,000				

The model fit: SRMR = 0,064, NFI = 0,724
Source: Seoke *et al.* (2023)**.**

4.1.2 The discriminant validity (HTMT)

Discriminant validity was determined using cross-loading and Heterotrait-Monotrait ratio (HTMT) (Seoke *et al.*, 2023, Mtotywa and Kekana, 2023, Hair *et al.*, 2019). Heterotrait-Monotrait (HTMT) and Cross loadings were used for the analysis of the discriminant validity of the full measurement model, as shown in Tables 2 and 3. The relevant dimension loading was achieved, and the values were higher than 0.708. The other dimensions ranged within 0.2 of the primary dimensions. HTMT was used to confirm discriminant validity, and the loadings were less than 0,878. Which is within the 0.90 (HTMT.90) threshold, indicating that the discriminant validity is met (Mtotywa and Dube, 2023, Mtotywa and Kekana, 2023, Hair *et al.*, 2019).

Table 3 - Discriminant validity results – Heterotrait-Monotrait Ratio (HTMT)

Discriminant validity		**AG**	**CF**	**DL**	**EF**	**LC**	**PF**	**QF**	**QC**	**QP**	**SC**	**SQ**	**TN**	**ST**
HTMT Ratio	AG													
	CF	0,133												
	DL	0,296	0,189											
	EF	0,145	0,874	0,111										
	LC	0,066	0,805	0,140	0,804									
	PF	0,024	0,513	0,053	0,493	0,366								
	QF	0,057	0,273	0,092	0,188	0,244	0,061							
	QC	0,077	0,833	0,129	0,875	0,734	0,614	0,074						
	QP	0,101	0,838	0,152	0,892	0,764	0,493	0,196	0,859					
	SC	0,153	0,843	0,104	0,764	0,656	0,704	0,168	0,830	0,827				
	SQ	0,138	0,778	0,073	0,799	0,621	0,534	0,125	0,811	0,732	0,753			
	TN	0,564	0,121	0,329	0,137	0,108	0,022	0,097	0,099	0,143	0,133	0,121		
	ST	0,133	0,767	0,144	0,837	0,744	0,535	0,197	0,866	0,854	0,774	0,662	0,178	

4.1.3 Explanatory power of the complete measurement model

The R^2 values for small, medium and large are stipulated as 0.0196 (0.02), 0.1304 (0.13), and 0.2592 (0.26), respectively (Cohen, 2016, Sarstedt *et al.*, 2021). R^2 is used to analyse the explanatory power of the model, providing the variance explained. The results were medium to substantial, indicated by R^2 values ranging from 0,107 to 0,269 for Quality 4.0 principles. R^2 = 0.313 for project performance (PF), and R^2 = 0.643 for successful completion (SC) in Table 4. Although the effect sizes, f^2 for small, medium, and large are indicated respectively by 0.02, 0.15, and 0.35. The sizes were 0.120 to 0.296 between Quality 4.0 variables, performance, indicating a moderate effect (Hair *et al.*, 2019, Cohen, 2016). There was a negligible effect between Quality 4.0 variables and SC based on sizes of 0.000-0.075 (Seoke *et al.*, 2023, Cohen, 2016). Predictive precision and relevance are indicated by Q^2 values higher than 0, 0.25, and 0.50 (Hair *et al.*, 2019). The Q^2 values obtained were 0.269 and 0.592 for PF and SC, respectively, confirming the fit of the structural model (Mtotywa and Kekana, 2023).

Table 4 - The explanatory power of the complete measurement model, adapted from

	R^2	Q^2	f^2 PF	f^2 SC
Project Performance (PF)	0.313	0.269		0.075
Project Success (SC)	0.643	0.592		
CF	0,194		0.240	0.067
EF	0,179		0.217	0.001
LC	0,107		0.120	0.000
QC	0,262		0.354	0.006
QP	0,163		0.195	0.034
SQ	0,207		0.261	0.017
ST	0,229		0.296	0.023
Age (AG)				0.000
Delays (DL)				0.000
Qualification (QF)				0,001
Tenure (TN)				0.000

source: Seoke *et al.* (2023).

4.2 The structural model

The mediation analysis places emphasis on causal interactions and the mediating effects of the Quality 4.0 principles, between project performance (PF) and successful completion (SC) of capital acquisition projects (Mtotywa and Kekana, 2023). The latent variables of the study are project performance (predictor), Quality 4.0 principles (mediator) and the successful completion of capital acquisition projects (outcome) and are included in the model. Demographic variables were included within the study as control variables to investigate the possible influence on project progression (Sekhula and Mtotywa, 2025). The most generic formulation of a mediation hypothesis is the recognition of an active organism that acts as an intervention between a stimulus and a response, the role of Quality 4.0 principles was tested for mediation (Baron and Kenny, 1986).

4.2.1 Hypothesis testing

The basis of the analysis of the structural relationship is the size and significance of the beta coefficients (Hair *et al.*, 2017). Once a criterion is adopted for the study, then reject the null hypothesis if the p-value is sufficiently small, or else do not reject the null hypothesis (Hair *et al.*, 2017). The first hypothesis tested the significance of the relationship between project performance and successful completion, and the results of the path PF -> SC (β = 0,553, p < .05) as indicated in Table 5. The third hypothesis tested customer mediation effect of the focus on project performance and successful completion. Customer focus had a positive statistically significant mediation effect between the project performance and successful completion, using the specific indirect effects, PF -> CF -> SC; (β = 0,123, p < .05). The sixth hypothesis states

that the staff training had a significant mediation effect between project performance and the successful completion. Staff training had a statistically positive significant mediation effect between project performance and successful completion, based on the specific indirect effect, PF -> ST -> SC; (β = 0,078, p < .05).

The seventh hypothesis indicated that quality process management had a significant mediation effect between project performance and successful completion. The specific path of indirect effect indicated that quality process management had a statistically positive significant mediation effect between project performance and successful completion, PF -> QP -> SC; (β = 0,073, p < .05). The eighth hypothesis states that supplier quality management has a significant mediation effect between project performance and successful completion. The effect of supplier quality management had a positive statistically significant mediation effect between project performance and successful completion, based on specific indirect effects, PF -> SQ -> SC; (β = 0,054, p < .05). However, there were no statistically significant positive mediation effects for leadership commitment (LC) H2, employee focus (CF) H4 and quality culture (QC) H5, between project performance and successful completion. There was also no significant positive relationship between age, delays, qualification, and tenure after successful completion.

Table 5 - Structural Equation Model Path Coefficients

Effects	Paths	*β*	T statistics (|O/STDEV|)	P values	Hypothesis	Decision
Total effects	AG -> SC	-0,002	0,053	0,957		
	CF -> SC	0,279	3,991	0,000		
	DL -> SC	-0,013	0,340	0,734		
	EF -> SC	-0,036	0,495	0,620		
	LC -> SC	-0,017	0,245	0,806		
	PF -> CF	0,440	8,538	0,000		
	PF -> EF	0,423	7,771	0,000		
	PF -> LC	0,328	6,203	0,000		
	PF -> QC	0,511	10,987	0,000		
	PF -> QP	0,404	7,588	0,000		
	PF -> SC	0,553	12,841	0,000		
	PF -> SQ	0,455	9,712	0,000		
	PF -> ST	0,478	10,198	0,000		
	QF -> SC	0,020	0,552	0,581		
	QC -> SC	0,088	1,285	0,199		
	QP -> SC	0,181	2,626	0,009		
	SQ -> SC	0,119	2,218	0,027		
	TN -> SC	0,014	0,293	0,770		
	ST -> SC	0,164	2,439	0,015		
Total direct effects	AG -> SC	-0,002	0,053	0,957		
	CF -> SC	0,279	3,991	0,000		
	DL -> SC	-0,013	0,340	0,734		
	EF -> SC	-0,036	0,495	0,620		
	LC -> SC	-0,017	0,245	0,806		
	PF -> CF	0,440	8,538	0,000		
	PF -> EF	0,423	7,771	0,000		
	PF -> LC	0,328	6,203	0,000		
	PF -> QC	0,511	10,987	0,000		
	PF -> QP	0,404	7,588	0,000		

	PF -> SC	0,201	4,480	0,000	Hypothesis 1	Supported
	PF -> SQ	0,455	9,712	0,000		
	PF -> ST	0,478	10,198	0,000		
	QF -> SC	0,020	0,552	0,581		
	QC -> SC	0,088	1,285	0,199		
	QP -> SC	0,181	2,626	0,009		
	SQ -> SC	0,119	2,218	0,027		
	TN -> SC	0,014	0,293	0,770		
	ST -> SC	0,164	2,439	0,015		
Specific indirect effects	PF -> ST -> SC	0,078	2,414	0,016	Hypothesis 8	Supported
	PF -> SQ -> SC	0,054	2,063	0,039	Hypothesis 6	Supported
	PF -> QP -> SC	0,073	2,466	0,014	Hypothesis 7	Supported
	PF -> QC -> SC	0,045	1,255	0,210	Hypothesis 5	Not supported
	PF -> LC -> SC	-0,005	0,242	0,809	Hypothesis 2	Not supported
	PF -> EF -> SC	-0,015	0,484	0,628	Hypothesis 4	Not supported
	PF -> CF -> SC	0,123	3,654	0,000	Hypothesis 3	Supported

5. DISCUSSION

The findings do attest to the existence of the phenomenon of delays within capital acquisition projects, with at least 80,1% of the respondents experiencing delays within three years when undertaking capital acquisition projects. Research concludes that delays were evident based on the findings, which means that cost and schedule overruns that arise from delays have a significant detriment in not realising the benefits of the projects. There was congruence within the literature with the results that indicated statistical significance of the mediation effects of Quality 4.0 principles, and there were results that were not in congruence with the literature. The results indicated that management must invest in the successful implementation of the TQM and Quality 4.0 programs, by allocating resources to the endeavour so that they can be incorporated throughout the organisation (Dias *et al.*, 2022). Although the results of (EF) in the current study indicate that employees are not empowered to control their work environments (Eriksson and Westerberg, 2011), nor are they provided the autonomy to direct efforts within their respective domains. However, the results of the study indicate that the culture within the organisations was not positive and supportive towards the implementation of TQM and Quality 4.0 (Alghamdi, 2016). This does not translate into a conducive environment that enables the usage of expedient principles, which aid in the transformation of input into output within the set iron triangle. The usage of radical approaches that come with TQM and Quality 4.0 to enable purposeful decision-making expediently was not evident; henceforth, there will be delays in projects (Tshidavhu and Khatleli, 2020).

Customer satisfaction in the new era of quality places emphasis on customer demands as a key factor (Dias *et al.*, 2022), and artificial intelligence-based customer relationship management (AI-CRM) will influence retention, development, and acquisition. The results of the study indicate that this was prioritised within the organisations (Antony *et al.*, 2021, Chiarini and Kumar, 2022). Prioritisation of the acquisition of Quality 4.0 skills through staff training will contribute to expediting the completion of projects with the use of the acquired competencies (Antony *et al.*, 2023). Ultimately, the results of (SQ) were consistent with the literature that states that quality problems downstream may be avoided by inspecting the quality and procedures of their suppliers, as opposed to having the main activity of quality as checking the components (Carvalho and Lima, 2022). The results of the study indicated that there was no statistically significant mediation effect of leadership commitment, employee focus, and quality culture between project performance and successful completion. The process is effective if it can have results that meet the customers' needs (Mengistie, 2019). The contradictory results suggest that these aspects are not taken into account when carrying out capital acquisition projects, culminating in the advent of delays in the delivery of prime mission equipment. However, there was a statistically significant positive mediation effect of customer focus, staff training, quality process management, and supplier quality management between project performance and successful completion. There was a statistically significant positive relationship between project performance and the successful completion of capital acquisition projects.

Antony *et al.* (2022) further assert that a combination of new technologies, methods, and standard quality tools, by using Quality 4.0, achieves superior performance, optimal innovation, and higher operational excellence. The soft and hard factors of quality management have a direct and indirect effect on the progression of capital acquisition projects. The soft factors, such as tacit, intangible behavioural factors, or human aspects, such as leadership and people management (Al Shraah *et al.*, 2022, Chen, 2022). The domain is riddled with bureaucracy and red tape that stifles the seamless progression of capital acquisition projects, and these are in the ambit of leadership to address comprehensively. The results indicated that there needs to be more effort from the leadership perspective to provide an enabling environment by reducing the impact of the impediments. Then it may be concluded that there is a relationship between the application of the Quality 4.0 management dimensions and delays within capital projects. This is evidenced by the results that were not statistically significant, emanating as the sources of delays within capital acquisition projects. However, these are important aspects that the organisations must prioritise, so that they are applied effectively and efficiently towards improvement of their performance. There is a need to monitor efficiency of quality culture, employee engagement and leadership commitment,

while taking cognisance of the significant relationships. There was full mediation, as evidenced by the framework that depicts the statistically significant paths. The framework indicates project performance as the independent variable, successful completion as the dependent variable, while the Quality 4.0 principles are indicated as mediator variables. Figure 2 will help identify areas of concern and improvement, and organisations can use the conceptual framework to complete capital acquisition projects within different domains.

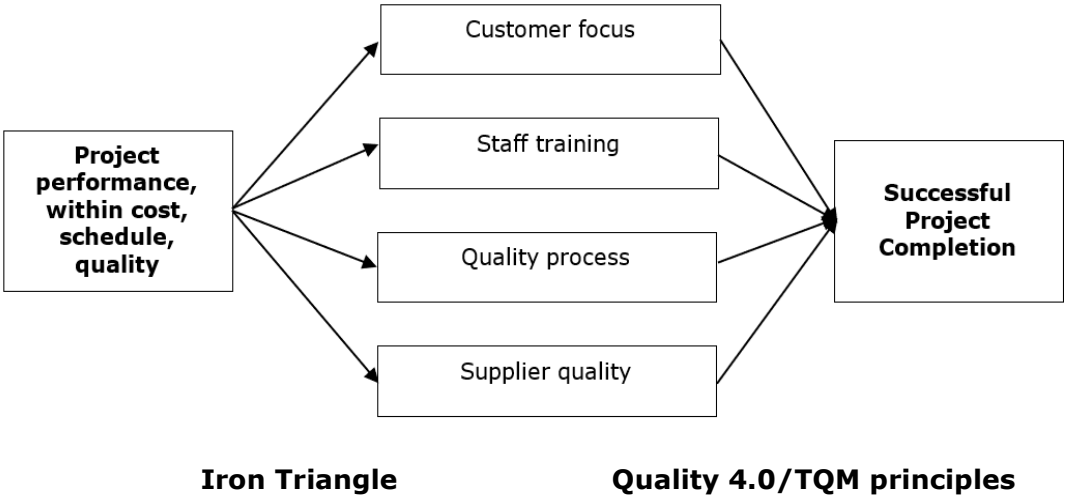

Figure 2 - The Quality 4.0 framework for effective management of capital acquisition projects within public sector engineering-based entities

6. CONCLUSION

Quality 4.0, just like TQM, is an organisational initiative involving everyone in the improvement initiatives. The organisations must adopt a strategy that compels the quality function to operationalise the framework, and test their systems to leverage the benefits of applying the Quality 4.0 principles in their respective industries. The study extends on the quality management theory, and provides a unique application of Quality 4.0 principles within the capital acquisition domain with the aim of combating project delays. The practical implication for management within the sector and government must be one that is knowledge-oriented, and for leadership to provide an enabling environment for innovation and learning for effective implementation of Quality 4.0.

7. IMPLICATIONS AND FUTURE RESEARCH DIRECTIONS

The contingency theory adopted for the research contributes to the body of knowledge by assisting policymakers and organisations within the sector in prioritising their resources. Indicating that there is no optimal Quality 4.0 principle to solve the issues faced by the organisation. The principles may be prioritised according to the framework or a combination of principles, adjudging based on the available resources. The study was quantitative and explanatory rather than including a qualitative component to explore what elements can be embedded in the implementation of the Quality 4.0 principles. The qualitative components of the study could help to explore factors and aspects that were not extracted using a questionnaire. The exploratory element of the study would assist in terms of which principles are relevant above those identified through the literature review. The studies must also consider different mediating variables for successful completion of capital acquisition projects, and not limit the mediation to the variables that were identified within the current study.

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