

Quantitative Determinants of Successful Turnaround Maintenance Project Implementation in South African Processing Plants

Enos Kwena Mashitisho, Andre Vermeulen and Jan-Harm C. Pretorius

Department of Engineering Management
University of Johannesburg
South Africa

enosmashitisho@yahoo.com, avermeulen.research@gmail.com, jhcpretorius@uj.ac.za

Abstract

Turnaround Maintenance (TAM) projects are high-risk, complex interventions essential to maintaining asset integrity, regulatory compliance, and operational reliability in processing plants. Despite their strategic significance and the efforts of most organisations to ensure successful implementation, the majority of these projects continue to experience cost overruns, quality-related challenges, and schedule delays. This study employed a quantitative approach to analyse the Critical Success Factors (CSFs) that affect the successful delivery of TAM projects in the South African context. Data were collected through a structured questionnaire distributed to TAM practitioners across South African processing plants in industries such as petrochemical, manufacturing, mining, steel, pulp and paper, food and beverage, oil and gas, refinery, and power generation. The study utilised exploratory factor analysis, reliability testing, Pearson correlations, and multiple regression analysis. Findings substantiate that TAM project success is multidimensional, with Quality Management, the Selection and Competence of the Turnaround Manager, and Budget/Cost Compliance identified as the primary predictors of success. Although factors such as communication, top management support, and time management did not appear to be statistically significant in the regression model, they played a strong associative and facilitative role in enhancing project performance. This research provides significant empirical evidence for the TAM project management literature and offers a validated quantitative foundation for developing an integrated TAM implementation framework.

Keywords

Turnaround Maintenance, Critical Success Factors, Quantitative Analysis, Project Management, Processing Plants

1. Introduction

Turnaround Maintenance (TAM), also known as Shutdown Maintenance (SM), is planned, periodic maintenance carried out during plant shutdowns to enable inspections, repairs, equipment replacement, plant overhauls, and regulatory compliance (Moniri et al., 2021). Tight timelines, substantial capital expenditure, complex stakeholder involvement, and heightened operational and safety risks are common in processing plants undertaking TAM projects (Al-Turki et al., 2019). Ineffective TAM implementation in South African processing facilities can lead to significant financial losses, extended production downtime, safety concerns, impaired asset integrity, and regulatory non-compliance.

This study is informed by Critical Success Factor (CSF) Theory, first introduced by Rubin and Sealing in 1979, which holds that organisational and project success depends on a limited number of critical areas that require continuous managerial attention and effective performance (Ayat et al., 2021). A widely used list of CSFs was developed in 1988 (Pinto & Slevin, 1988). The CSF approach has been widely applied in project management research to identify the factors most closely associated with successful project outcomes. In the context of TAM projects, factors such as

leadership competence, communication effectiveness, top management support, quality management, and budgetary control are deemed critical given the complexity and high risk of shutdown maintenance activities. Furthermore, TAM projects may be viewed from a socio-technical systems perspective, which recognises that project success depends on the effective interaction among technical systems, organisational processes, management practices, and human factors (Lenahan, 2011). Despite the expanding corpus of knowledge on determinants of project success, relatively few empirical studies have quantitatively investigated TAM-specific success factors in processing plant environments (Masubelele & Mnkandla, 2021). While project management literature provides extensive insights into generic project success factors, many studies are based in construction, infrastructure, or general project management contexts. These studies may not adequately reflect the technical complexity, operational interdependencies, and elevated risk profile of turnaround maintenance projects (Obiajunwa, 2012).

To facilitate successful TAM implementation, prior research has emphasised the importance of leadership capacity, efficient quality management systems, safety culture, organisational support, and effective project controls (Masubelele & Mnkandla, 2021). For example, Sahoo (2013) highlighted the role of quality management in reducing rework, maintaining asset integrity, and ensuring regulatory compliance during shutdown operations. In a similar vein, decision-making in high-pressure turnaround situations, multidisciplinary coordination, and risk minimisation all require managerial and leadership skills. Budgeting and cost control also remain important considerations given the substantial expenditures associated with turnaround projects and the significant consequences of cost overruns (Lenahan, 2011). Although previous studies have identified numerous factors associated with TAM project success, important gaps remain in the literature. First, limited empirical research has quantitatively assessed the relative importance of CSFs in processing plant environments. Second, few studies have quantitatively examined the strength and statistical significance of relationships between CSFs and successful TAM project implementation using multivariate analytical techniques. Third, there is limited context-specific evidence from South African processing plants despite their unique operational, regulatory, and economic challenges. Consequently, this study seeks to address these gaps by investigating the relationships between selected CSFs and successful TAM project implementation in South African processing plants. Accordingly, this study contributes to the existing body of knowledge by quantitatively evaluating the relative importance of selected CSFs and examining their statistical relationships with successful TAM project implementation within the South African processing plant context.

1.1 Objectives

The overall aim of this study is to examine the CSFs that influence the successful implementation of TAM projects in South African processing plants. The specific objectives of the study are as follows:

1. To identify and evaluate stakeholder perceptions of the critical success factors that impact the successful implementation of TAM projects.
2. To examine the relationships between the identified critical success factors and successful TAM project outcomes to determine the extent to which these factors contribute to overall project success.

2. Literature Review

Processing plants are among the most advanced and complex facilities worldwide, responsible for continuous production and the maintenance of highly sophisticated assets (Elwerfalli et al., 2018). In complex processing industries such as steel, aluminium, pulp and paper, food and beverage, oil and gas, refineries, and petrochemicals, equipment operates under harsh conditions. As a result, equipment and plants are vulnerable to deterioration from ageing, corrosion, erosion, fatigue, and wear. Minor failures can sometimes be managed with minimal effort. However, severe failures may lead to unplanned shutdowns, environmental hazards, production losses, and increased costs (Moradi & Shadrokh, 2019). TAM / Shutdown Maintenance (SM), as defined by Lenahan (2011), is a plant-level project encompassing a wide range of activities, including inspection, repair, upgrading, and overhaul of processing equipment. TAM projects are typically initiated to address plant deterioration and asset degradation. Subsequently, multidisciplinary teams comprising technicians, engineers, specialists, quality control personnel, and maintenance managers are quickly mobilised to execute designated work scopes aimed at restoring and improving plant reliability. Despite being among the costliest types of maintenance, TAM is an indispensable, cost-effective intervention, particularly in industries with continuous production operations, such as steel processing, paper and pulp, food and beverage, food processing, oil and gas, refineries, and petrochemical plants. TAM projects are crucial for ensuring system safety and maintaining plant reliability (Zhu & van Jaarsveld, 2022).

From a strategic perspective, TAM is regarded not merely as a maintenance task but as a philosophy centred on scheduling plant shutdowns to minimise downtime while boosting operational efficiency and asset performance (Sahoo, 2013). Elwerfalli et al. (2018) further emphasise that effective downtime management during TAM events enhances equipment reliability and increases productivity. One of the primary goals of TAM is to mitigate risks associated with plant deterioration and, as a result, prevent catastrophic failures that could lead to unsafe working conditions, explosions, toxic releases, and environmental harm. These projects represent some of the largest maintenance investments in industrial operations, with major Turnaround (TA) events typically lasting four to five weeks and sometimes consuming an entire annual maintenance budget (Al-Turki et al., 2019). TAM events are not considered routine maintenance but rather full-scale projects. Given the scale and interdependence of activities, TAM requires a formal project management framework from the planning phase to project termination (Moniri et al., 2021). Consequently, if TAM is poorly managed, it can lead to significant operational disturbances, financial losses, and safety risks (Zhu & van Jaarsveld, 2022). Therefore, the successful execution of TAM projects is particularly important for preventing unscheduled breakdowns that could significantly affect financial performance across processing industries such as the petrochemical, oil and gas, and refining sectors, while maintaining operational efficiency, safety, and competitiveness within processing plants.

Drawing on Critical Success Factor Theory, this study focuses on the limited set of managerial, organisational, and operational factors most strongly associated with successful TAM project implementation. The concept of critical success factors was introduced by Rubin and Sealing in 1967 and has since been extensively studied across various industries (Ayat et al., 2021). A widely used list of CSFs was developed in 1988 (Pinto & Slevin, 1988). Critical success factors are essential elements that support the effective implementation of project goals and objectives. In TAM projects, these factors are crucial in determining whether objectives such as schedule adherence, budget management, safety performance, and quality standards are achieved.

TAM initiatives are also inherently complex, dispersed, and resource-intensive. These projects involve strict safety regulations, skilled contractors, and a range of operations. As a result, success largely depends on carefully identified CSFs. When these aspects are appropriately addressed, project coordination improves, risks decrease, and on-time delivery is ensured. However, ignoring important success criteria frequently results in subpar TAM project performance, leading to budget overruns and safety issues (Hadi et al., 2022). Thus, managers must continuously review every decision made during the TAM project implementation stages. This monitoring capability allows management to assess how quickly the project is progressing and where it is in its life cycle. The critical success variables that significantly affect TAM project performance should be given top priority when sequencing steps and considering relevant CSFs during implementation (Datta et al., 2023). Therefore, strategic plans and overall performance may be jeopardised by a poor grasp of how the organisation's objectives relate to critical success elements (Yamin & Sim, 2016).

3. Methods

To achieve the objectives of this study, a quantitative research design and methodology were strategically employed to address the research questions. According to Murshed and Zhang (2016), a research methodology provides a systematic approach to addressing a research problem, including formulating questions, selecting respondents, and adopting methods to extract meaning. Similarly, Wohlin and Runeson (2021) highlighted that research methodology serves as the overarching strategy for conducting a study, based on the assumptions and rationale that guide method selection. This study is grounded in a positivist quantitative approach, which follows a logical, theory-driven process to test relationships among variables (Ghanad, 2023).

Within a positivist framework, researchers rely on quantitative methods to identify relationships among variables and test hypotheses using measurable data (Kellmereit, 2015). In the context of TAM projects in continuous process industries, objective measurement is vital given the complexity, scale, and high-risk nature of shutdown operations. Therefore, quantitative methods are essential from a positivist perspective for testing hypotheses, analysing CSFs, and identifying key predictors of project success using statistical techniques such as regression and correlation analyses. Such approaches support the generalisation of results across similar industrial contexts (Hair Jr. et al., 2019). Consequently, a quantitative methodology was deemed appropriate for achieving the objectives of this study and for empirically assessing the proposed TAM success constructs.

3.1 Sampling Procedure of this Study

This study employed a non-probability purposive sampling technique, also known as judgemental or expert sampling, targeting industry professionals with specialised knowledge of TAM projects (Sallis et al., 2021). This approach was deemed appropriate given the technical and contextual expertise required to evaluate TAM project performance and success factors effectively. The method was selected to include TAM practitioners experienced in continuous processing plants, who contributed to the study. Participants included maintenance managers, project managers, engineers, technicians, planners, safety officers, and other key stakeholders involved in TAM projects. Participants were recruited across sectors such as petrochemical, manufacturing, mining, steel processing, paper and pulp, food and beverage, oil and gas, refineries, and power generation facilities in South Africa. The researcher therefore aimed to recruit 326 participants to cover most process industries and ensure adequate statistical power across processing plants. The sample reflected a broad range of experience levels, roles, and organisational responsibilities. This sampling strategy aimed to strengthen the robustness and credibility of the results. The diverse respondent profile provided comprehensive insights into TAM project execution and enabled reliable analysis of the relationships between critical success factors and project outcomes.

Table 1. Participants information

Job Title	Frequency	Valid Percent
TAM / Shutdown / Maintenance Manager	35	10.7
Maintenance Engineer	16	4.9
Project Manager	12	3.7
Technician	97	29.8
Maintenance Planner	26	8.0
Safety Officer	3	0.9
Quality Control / Quality Assurance	25	7.7
Other	112	34.3
Total	326	100.0

Table 1 summarises respondents' positions in TAM process industries. Of 326 valid responses, the largest share (112, 34.3%) fell into the "Other" category. This group is expected to include artisans, supervisors, contractors, and other plant staff who are directly or indirectly involved in TAM projects, reflecting the multidisciplinary nature of TAM environments. Technicians form the second-largest group, with 97 respondents (29.8%), followed by TAM/Shutdown/Maintenance Managers (35 respondents, 10.7%), Maintenance Planners (26 respondents, 8.0%), and Quality Control/Quality Assurance professionals (25 respondents, 7.7%). Smaller proportions are directly involved in TAM projects, including Maintenance Engineers (16 respondents, 4.9%), Project Managers (12 respondents, 3.7%), and Safety Officers (3 respondents). Overall, the respondent profile shows broad representation across essential functional roles involved in TAM project planning, execution, and oversight.

3.2 Data Analysis Techniques

In this study, quantitative data analysis employed descriptive and inferential statistics, facilitated by IBM SPSS Statistics. SPSS is widely recognised by researchers for its ability to manage large, complex datasets. This capability makes it particularly suitable for research in engineering, business, and the social sciences (Guo et al., 2012). The data analysis process adopted in this study consisted of several steps. The first stage was to conduct descriptive statistics to summarise respondent characteristics and evaluate overall trends in stakeholders' perceptions of the CSFs. In the second stage, the reliability of the survey scales was assessed using Cronbach's alpha to evaluate internal consistency. The third stage involved applying Exploratory Factor Analysis (EFA) with Varimax rotation to reveal the underlying CSF structure and assess construct validity. Lastly, Pearson correlation analysis was utilised to examine inter-constructed relationships, and multiple regression identified the CSFs with the greatest influence on TAM project success.

4. Data Collection

Data collection is a critical component of the research process, as it provides the basis for valid and reliable findings and for grounding the study in a theoretical framework. It systematically gathers relevant information to investigate and address the research problem through a carefully designed methodology (Mazhar et al., 2021). The quantitative data for this study were collected through a structured questionnaire informed by a systematic literature review. The survey instrument assessed various critical success factors and TAM project success outcomes. This study used a five-

point Likert scale in the structured questionnaire. To simplify the quantification of character and personal qualities, this method enabled the quantification of stakeholder perceptions and facilitated statistical analysis of relationships among variables. To maximise accessibility and response rates, the questionnaire was distributed via both electronic and physical means. The electronic survey was delivered to participants from various processing plants in South Africa via Microsoft Forms, allowing them to complete it at their convenience. However, physical distribution of the questionnaire was also employed to ensure that participants with limited digital access were accommodated. Consequently, a structured questionnaire was developed to obtain measurable information on the key constructs, and the survey instrument assessed critical success factors. Before any data collection commenced, participants were informed of the study's purpose, the participation procedures, and the estimated completion time. In this study, participants were assured that their anonymity and confidentiality would be maintained to uphold privacy and to comply with established ethical research standards. Participation was entirely voluntary; no participant was forced to take part.

5. Results and Discussion

5.1 Numerical Results

5.1.1 Reliability and Factor Structure

Table 2 presents the calculated high internal consistency reliability across all constructs, along with the Cronbach's alpha values used in this study. Generally, Cronbach's alpha coefficients are evaluated using thresholds of 0.70, 0.80, and 0.90, indicating acceptable, good, and excellent reliability, respectively (Hair et al., 2019). All constructs in this study demonstrated high levels of internal consistency:

- Budget/Cost Compliance (BCC, $\alpha = 0.875$) and Time/Duration Management (TDM, $\alpha = 0.871$) both demonstrated strong reliability, indicating that the items within these scales consistently measure cost and schedule management aspects of TAM projects.
- Top Management Support (TMS, $\alpha = 0.902$) showed excellent reliability in the test. The results confirm that the items adequately capture leadership involvement and support for TAM initiatives.
- The constructs Communication (CCN, $\alpha = 0.924$), Selection of Turnaround Manager (STM, $\alpha = 0.927$), and Quality Management (QMM, $\alpha = 0.924$) had the highest Cronbach's alpha values, indicating strong reliability. These results suggest that communication effectiveness, leadership competence, and quality management practices are measured with strong internal consistency in TAM projects.
- Lastly, Successful TAM Project Implementation, the dependent construct (STPI, $\alpha = 0.893$), also demonstrated excellent reliability. This result ensures that success indicators such as cost, time, quality, and performance improvements are consistently measured.

The results of the reliability analysis affirm that the measurement instrument demonstrated robustness and internal consistency, providing confidence in the use of these constructs in subsequent inferential testing (Sallis et al., 2021).

Table 2. Reliability measures of the measurement items

Construct ID	Construct	Number of Items	Cronbach's Alpha (α)
BCC	Budget/Cost Compliance	8	0.875
TDM	Time/Duration Management	8	0.871
TMS	Top Management Support	8	0.902
CNN	Communication	8	0.924
STM	Selection of Turnaround Manager	8	0.927
QMM	Quality Management	8	0.924
STPI	Successful TAM Project Implementation	8	0.893

In this study, an exploratory factor analysis was utilised to test the constructs' validity and, as a result, demonstrated a clear factor structure, emphasising the multidimensional nature of TAM success. Table 3 summarises the results of the dataset suitability evaluation using the Kaiser-Meyer-Olkin (KMO) and Bartlett's tests. The KMO value of 0.957 indicates excellent sampling adequacy, within the accepted threshold, validating that the correlations among variables are sufficiently strong to support factor analysis (Naik & Bagodi, 2021). Hence, it was feasible to conduct the exploratory factor analysis. Consequently, Bartlett's Test of Sphericity revealed a highly significant result (Approx. Chi-Square = 11,048.366, $df = 1035$, $p < 0.001$). This result shows a robust correlation structure, since Bartlett's Test is less than 0.05, the proposed upper limit. It is apparent from these findings that the observed inter-item correlations

are appropriate for data reduction (Fuentes-Moraleda et al., 2022), providing robust evidence of the data's factorability. The findings confirm that the constructs (Budget/Cost Compliance, Time/Duration Management, Top Management Support, Communication, Selection of Turnaround Manager, Quality Management, and Successful TAM Implementation) are well-suited for further exploratory factor analysis.

Table 3. Kaiser-Meyer-Olkin (KMO) Measure and Bartlett's Test of Sphericity

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.957
Bartlett's Test of Sphericity	Approx. Chi-Square	11048.366
	df	1035
	Sig.	<.001

5.1.2 Correlation Analysis

The correlation analysis was conducted to establish significant positive relationships between all key CSFs and the successful implementation of TAM projects. Table 4 shows that all seven constructs in the correlation matrix are significantly and positively linked at the 0.01 level (one-tailed), confirming both the internal consistency of the measurement model and the interconnectedness of the TAM project management constructs.

Based on the results presented in the Correlation matrix model, Successful TAM Project Implementation (STPI) is strongly and positively associated with all independent constructs, with correlation coefficients ranging from $r = 0.509$ for Time/Duration Management (TDM) to $r = 0.645$ for Quality Management (QMM). These findings suggest that each of the identified critical success factors is meaningfully related to successful TAM project implementation. The model suggests that while effective scheduling plays an important role, quality compliance, managerial competence, and communication significantly influence project success. These findings also indicate that effective cost management is closely associated with leadership capability, organisational support, and quality management within TAM projects. Top Management Support (TMS) is strongly correlated with Communication (CCN, $r = 0.694$) and Selection of the Turnaround Manager (STM, $r = 0.633$). These findings indicate that higher levels of executive support are strongly linked with effective information sharing and the management of turnaround leadership within TAM projects. Based on the coefficient results, communication (CCN) shows the strongest single correlation in the model, with QMM ($r = .727$). The research results demonstrate that quality assurance and the successful completion of TAM projects are positively associated with structured and effective communication. The relationship between communication and the Turnaround Manager (STM) is strong ($r = .660$). These results indicate that effective communication strategies help improve the level of support provided by top management. The data also clearly show the relationship between selecting a Turnaround Manager (STM) and all other components, including Quality Measurement Management (QMM) ($r = .651$) and Quality Measurement Management (QMM) ($r = .636$). Therefore, the research results emphasise the importance of having an experienced manager to ensure quality assurance and successful completion of TAM projects. In addition, QMM showed the strongest correlation with STPI ($r = .645$). Based on the correlation findings of this study, it is suggested that adherence to quality standards and inspection practices is strongly associated with successful TAM outcomes. The strong relationship between Communication and quality management further highlights the importance of effective information sharing and collaboration within TAM projects. Its strong association with communication ($r = .727$) further highlights that quality performance is inseparable from effective information flow and collaboration.

Table 4. Correlations matrix – final model

		STPI	BCC	TDM	TMS	CCN	STM	QMM
Pearson Correlation	STPI	1.000	.610	.509	.576	.591	.636	.645
	BCC	.610	1.000	.550	.622	.584	.625	.592
	TDM	.509	.550	1.000	.542	.549	.531	.521
	TMS	.576	.622	.542	1.000	.694	.633	.618
	CCN	.591	.584	.549	.694	1.000	.660	.727
	STM	.636	.625	.531	.633	.660	1.000	.651
	QMM	.645	.592	.521	.618	.727	.651	1.000
Sig. (1-tailed)	STPI	.	<.001	<.001	<.001	<.001	<.001	<.001
	BCC	.000	.	.000	.000	.000	.000	.000

N	TDM	.000	.000	.	.000	.000	.000	.000
	TMS	.000	.000	.000	.	.000	.000	.000
	CCN	.000	.000	.000	.000	.	.000	.000
	STM	.000	.000	.000	.000	.000	.	.000
	QMM	.000	.000	.000	.000	.000	.000	.
	STPI	326	326	326	326	326	326	326
	BCC	326	326	326	326	326	326	326
	TDM	326	326	326	326	326	326	326
	TMS	326	326	326	326	326	326	326
	CCN	326	326	326	326	326	326	326
	STM	326	326	326	326	326	326	326
	QMM	326	326	326	326	326	326	326

Generally, the conceptual framework of this study is validated by the correlation results. The results confirm that quality management, communication, and managerial competence are the factors most strongly associated with successful TAM project implementation. Meanwhile, cost, time, and leadership support remain key enablers.

5.1.3 Regression Analysis

A multiple regression analysis addressed the second research objective: to examine the relationships between the identified critical success factors and successful TAM project outcomes, and to determine how much these factors contribute to overall project success. This analysis aimed to assess how well the six critical success factor constructs (Budget/Cost Compliance, Time/Duration Management, Top Management Support, Communication, Selection of the Turnaround Manager, and Quality Management) predict the dependent variable, Successful TAM Project Implementation.

Model Summary

The results in Table 5 indicate that six predictors account for approximately 54.2% of the variance in STPI, with an R^2 of 0.542, demonstrating that this model has strong explanatory power. The adjusted R^2 of 0.533 further supports the model's robustness after adjusting for the number of predictors. Therefore, the model also demonstrates strong explanatory power. The independent constructs are positively correlated with STPI at 0.736, and the standard error of 0.44434 indicates acceptable model fit and the ability to predict accurately.

Table 5. Model summary

Model	R	R Square	Adjusted R-Square	Std. Error of the Estimate
1	.736 ^a	.542	.533	.44434
a. Predictors: (Constant), Quality Management, Time/Duration Management, Budget/Cost Compliance, Top Management Support, Selection of Turnaround Manager, Communication				
b. Dependent Variable: Successful Turnaround Project Implementation				

These results demonstrate that the selected constructs collectively explain more than half of the variability in TAM project success. To ensure successful TAM project delivery in processing plants, this finding underscores the utmost importance of integrating financial discipline, time management, managerial leadership, effective communication, project manager competence, and quality management.

ANOVA Analysis

The F-test as part of ANOVA was conducted to assess the statistical significance of the regression model, as shown in Table 6, indicating a highly significant model, $F(6, 319) = 62.849$, $p < .001$ (Table 6; Singh, Kumar, & Sagar, 2021). This suggests that the six independent variables, BCC, TDM, TMS, CCN, STM, and QMM, together provide a strong prediction of STPI. The predictors account for a substantial portion of the variance in STPI, as the regression sum of squares (74.451) exceeds half of the total variance (137.433), yielding an R^2 of 0.542. The relatively low residual sum of squares (62.982) also indicates that the model's unexplained variance is minimal.

Table 6. ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	74.451	6	12.409	62.849	<.001 ^b
	Residual	62.982	319	.197		
	Total	137.433	325			
a. Dependent Variable: Successful Turnaround Project Implementation						
b. Predictors: (Constant), Quality Management, Time/Duration Management, Budget/Cost Compliance, Top Management Support, Selection of Turnaround Manager, Communication						

Overall, the ANOVA tests confirm the regression model's reliability, showing that the six predictors significantly contribute to explaining variance in successful TAM project implementation.

Model Coefficients Analysis

Table 7 presents the regression coefficients for the STPI predictors. According to the results, only three of the six predictors were statistically significant contributors to the implementation of the TAM project. As such, BCC ($\beta = 0.200$, $p < .001$), STM ($\beta = 0.222$, $p < .001$), and QMM ($\beta = 0.265$, $p < .001$) were identified as statistically significant predictors of project success. Thus, effective cost management, TAM manager's competency, and strong quality management practices are the most important factors for achieving successful project outcomes in TAM projects. By contrast, predictors TDM ($\beta = 0.081$, $p = .102$), TMS ($\beta = 0.078$, $p = .187$), and CCN ($\beta = 0.037$, $p = .565$) showed no statistically significant effects on project success, even though they were positively correlated with STPI in the previous analysis conducted with the data. This implies that, although they are essential in the broader context of TAM projects, their unique contribution to project success is less significant when other predictors are taken into account. The standardised beta coefficients indicate the relative strength of each predictor: QMM ($\beta = .265$), STM ($\beta = .222$), and BCC ($\beta = .200$). Hence, the three predictors constitute the main drivers of successful implementation of TAM projects. Finally, multicollinearity diagnostics indicated that all predictors had tolerance values above 0.3 and VIF values below 3. Hence, the model was not affected by multicollinearity.

Table 7. Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	.129	.203		.633	.527	-.272	.529		
	Budget Cost Compliance	.200	.055	.200	3.645	<.001	.092	.309	.478	2.091
	Time Duration Management	.088	.054	.081	1.639	.102	-.018	.194	.589	1.698
	Top Management Support	.081	.061	.078	1.323	.187	-.040	.202	.418	2.395
	Communication	.038	.066	.037	.576	.565	-.092	.168	.349	2.861
	Selection of Turnaround Manager	.224	.058	.222	3.835	<.001	.109	.339	.428	2.334
	Quality Management	.269	.061	.265	4.411	<.001	.149	.388	.398	2.513
a. Dependent Variable: Successful Turnaround Project Implementation										

Mahalanobis Distance Rule on Outliers / Residuals Statistics

Table 8 presents the regression diagnostics for the STPI model. According to the model, the expected range is 1.03 to 4.63. These results are consistent with the observed scale of the dependent variable, which has a mean of 3.79 (SD = 0.48). Residual analysis indicates that errors are symmetrically distributed around the regression line, with unstandardised residuals ranging from -2.43 to 1.35, a mean near zero, and a standard deviation of 0.44. Only a small number of cases deviated from the usual ± 3 criterion, according to the standardised residuals (range = -5.46 to 3.04) and studentised residuals (range = -5.58 to 3.16). Hence, while there may be a few outliers, they are unlikely to alter the data or the regression results, indicating that the hypothesis is robust. As a result, a few probable outliers are unlikely to have a major impact on the regression estimates. Cook's Distance readings ranged from 0.000 to 0.203, well below the 1.0 criterion. Based on these results, no single example had a substantial impact on the regression

results. However, leverage values (range = .001 to 0.120, mean = 0.018) are within the allowed range (<0.2), indicating that the data were evenly distributed and the model was not severely strained.

Table 8. Residuals statistics

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.0289	4.6295	3.7868	.47862	326
Std. Predicted Value	-5.762	1.761	.000	1.000	326
Standard Error of Predicted Value	.027	.156	.060	.025	326
Adjusted Predicted Value	1.0330	4.6381	3.7879	.47870	326
Residual	-2.42616	1.35088	.00000	.44022	326
Std. Residual	-5.460	3.040	.000	.991	326
Stud. Residual	-5.583	3.164	-.001	1.006	326
Deleted Residual	-2.53699	1.46310	-.00105	.45446	326
Stud. Deleted Residual	-5.869	3.210	-.003	1.015	326
Mahal. Distance	.216	38.951	5.982	6.214	326
Cook's Distance	.000	.203	.005	.017	326
Centered Leverage Value	.001	.120	.018	.019	326

a. Dependent Variable: Successful Turnaround Project Implementation

Lastly, the Mahalanobis distance had a mean of 5.98 and a range of 0.216 to 38.95. Given the sample size (N = 326) and the number of predictors, these values remain within acceptable bounds, although the maximum suggests that a small number of instances may require additional research to assess multivariate outliers. Overall, these diagnostics verify that the regression model is statistically sound, with normally distributed residuals, no impact from outliers, and no notable violations of the regression assumptions.

5.2 Graphical Results

5.2.1 Model Histogram of Regression Residual Analysis

Figure 1 displays the standardised residuals for the regression model predicting STPI, with the histogram and superimposed normal curve indicating an approximately normal distribution. The residuals have a mean effectively equal to zero (Mean = 6.80×10^{-15}), and the standard deviation is approximately 0.991, both of which indicate that the residuals are centred and scaled appropriately.

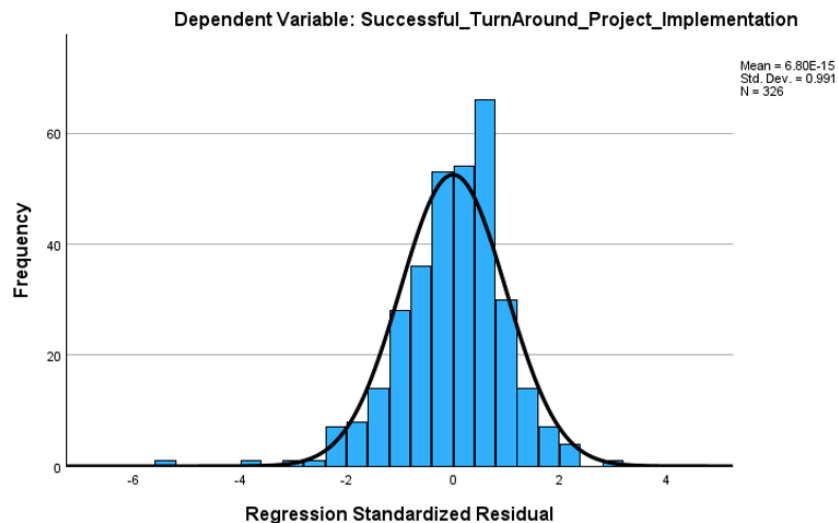


Figure 1. Histogram analysis

Extreme residual values lying well outside ± 3 are very few relative to the total number of data points (N=326). Therefore, the assumption of normally distributed errors holds, with only minor deviations at each tail. This is evidenced by the symmetrical shape of the residual plot and the absence of significant skewness and kurtosis in the

residuals, which would otherwise have the potential to impact the regression results. Overall, the histogram shows that most residuals from the model are normally distributed. Therefore, there is strong evidence of the reliability and validity of the regression analysis results.

5.2.2 Normal P-P Plot of Regression Residual Analysis

A normal P-P plot, which assesses how closely the actual cumulative probabilities match those predicted under a normal distribution, is used in Figure 2 to display the distribution of standardised residuals. The residuals can be considered approximately normal because the points mostly follow the diagonal reference line, with only slight deviations at the tails. This alignment supports the normality assumption of multiple regression, indicating that the residuals closely resemble a normal distribution. The P-P plot more clearly shows that the errors are evenly distributed around the line of normality, indicating the model's accuracy, whereas the histogram provides a frequency-based view. When the conclusion that the regression residuals satisfy the normality assumption is supported by both the P-P plot and the histogram, the validity and reliability of the regression analysis results are reinforced.

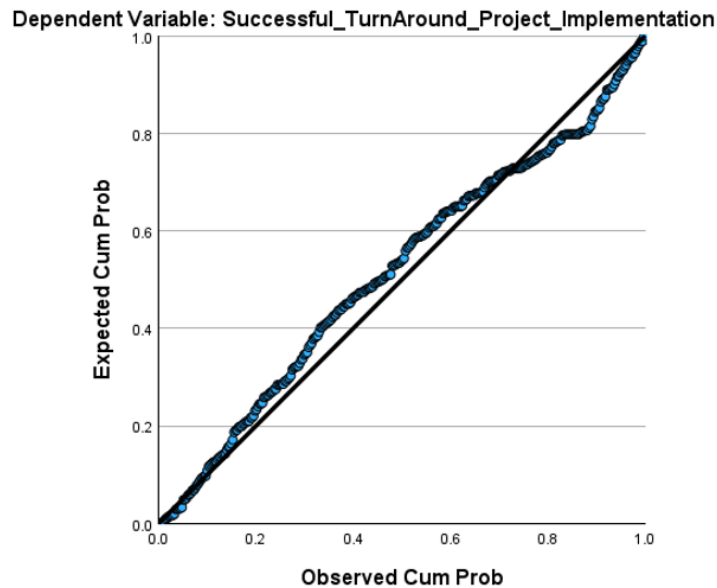


Figure 2. Normal P-P Plot of Regression Residual Analysis

5.2.3 Scatterplot of Regression Residual Analysis

The relationship between standardised residuals and standardised predicted values in the STPI regression model is shown in Figure 3. There are no discernible patterns, such as curves, clusters, or funnel shapes, and the residuals are scattered randomly around zero. The scatterplot indicates that the assumptions of homoscedasticity and linearity, that is, a constant residual variance and a linear relationship between the predictors and the dependent variable, are satisfied. Although there are a few outliers, particularly in the lower-left area near -6 standard residuals, their small number has little effect on the overall residual distribution. The model's robustness is confirmed by the majority of points falling within the permitted range (± 3 standard residuals).

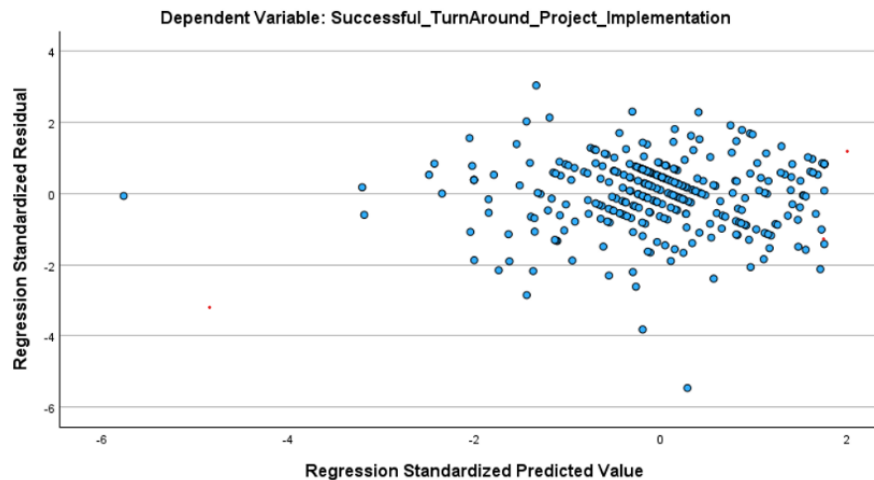


Figure 3. Scatterplot of Regression Residual Analysis

5.3 Proposed Improvements

Cronbach's alpha was selected to evaluate construct reliability because it is widely accepted as the most suitable measure. Values above 0.70 are considered satisfactory for internal consistency (Hair et al., 2019). The results supported the robustness of the measurement tool used in this study for assessing construct reliability, as all constructs demonstrated satisfactory reliability. The survey instrument's underlying factor structure was substantially validated using EFA. With a KMO sample adequacy rating of 0.957, the dataset showed an outstanding fit for factor analysis. The correlation matrix was not a principal diagonal matrix, as indicated by the statistically significant Bartlett's Test of Sphericity ($\chi^2 = 11,048.366$, $df = 1,035$, $p < 0.001$). In general, these findings support construct validity by suggesting that significant inter-item correlations call for factor extraction and dimensional reduction. To assess the predictive relationship between the identified critical success factors and the successful implementation of TAM projects in South African processing plants, multiple regression analysis was used. The model exhibited strong explanatory power ($R^2 = 0.542$), showing that the six independent variables explained about 54.2% of the variation in TAM project success: BCC, TDM, TMS, CCN, STM, and QMM. According to Hair et al. (2019), this level of explanation is significant in social science and engineering management research, demonstrating that the chosen constructs, taken together, offer a strong empirical foundation for understanding TAM performance. At the individual predictor level, QMM ($\beta = 0.265$, $p < 0.001$) was the most influential predictor of TAM project success. The findings demonstrated that the descriptive analysis of stakeholder viewpoints often emphasised the importance of non-conformance management, quality inspections, and continuous improvement initiatives, all of which strongly support this conclusion.

The finding supports existing literature, which states that strict quality assurance is vital for reducing rework, ensuring compliance with regulatory and industry standards, and maintaining long-term asset reliability in high-risk projects (Denicol, Davies, & Krystallis, 2020). Similarly, STM ($\beta = 0.222$, $p < 0.001$) was identified as a strong and substantial predictor, underscoring the importance of decision-making skills and leadership competency, and highlighting the capacity to manage interdisciplinary teams under operational pressure and time constraints. This aligns with previous studies that emphasise leadership effectiveness as a key driver of success in complex industrial and shutdown projects (Salman & Hassan, 2020). BCC ($\beta = 0.200$, $p < 0.001$). The results also demonstrated a significant positive impact, confirming the continued significance of financial discipline in controlling overruns, preserving stakeholder trust, and maintaining organisational viability. Therefore, the findings suggest that effective cost-control measures are closely linked to successful TAM outcomes and must be regarded as crucial components of TAM project planning and implementation.

However, the regression model did not show that Time/Duration Management ($\beta = 0.081$, $p = 0.102$), Top Management Support ($\beta = 0.078$, $p = 0.187$), and Communication ($\beta = 0.037$, $p = 0.565$) were statistically significant predictors of Successful TAM Project Implementation. The regression analysis did not provide sufficient evidence to support a direct predictive effect in this dataset, despite these criteria being highly valued by respondents and showing

favourable associations with project performance. This result suggests that their contribution to project success may operate through links not investigated in this study or may overlap with other variables included in the model. To learn more about their possible contextual or indirect roles in TAM project implementation, further research is needed.

5.4 Validation

This study provides robust empirical validation of the proposed conceptual framework for implementing TAM projects in South African processing plants. The structured quantitative analysis shows that TAM success is influenced by a combination of managerial, operational, and organisational factors beyond traditional time-and-cost metrics.

This study empirically assesses the critical success factors of the TAM. Through descriptive analysis, the study identified budget and cost control, time and duration management, top management support, effective communication, leadership competence, and quality management, all of which achieved consensus among all stakeholders. Subsequent verification through reliability analysis and exploratory factor analysis confirmed that the internal consistency and factor loadings of all constructs met the required standards, demonstrating that this set of research instruments is applicable.

By identifying QMM, STM, and BCC as the most significant factors influencing the successful implementation of TAM projects, the multiple regression results further clarified this idea. Although TDM, TMS, and CNN showed favourable correlations with the successful execution of TAM projects, none were statistically significant predictors in the regression model. Therefore, this study was unable to confirm the direct implications of these variables on project success within the analysed dataset. To fully understand their involvement in implementing and executing TAM projects, future research using large datasets or alternative analytical techniques may be required. The study conducted a diagnostic analysis to ensure that all regression assumptions were met, thereby increasing the model's robustness and reliability. The model's strength is demonstrated by the regression findings, which show that the essential success determinants explained more than 54% of the variance in TAM project success. These findings provide practitioners with clear direction by highlighting the importance of investing in quality management systems, foremost by carefully choosing and developing competent TA managers, and by implementing disciplined cost-control procedures. Academically, the study adds to the limited empirical research on TAM project management, particularly in continuous processing plants and developing countries. The findings offer empirical support for the second research goal by demonstrating the relationship between crucial success criteria and the effective execution of TAM projects.

6. Conclusion

The findings show a significant discrepancy between statistical predictiveness and stakeholder-perceived relevance with respect to research objective 1. Despite participants rating all identified crucial success factors highly. Only QMM, STM, and BCC were found to be direct predictors of successful TAM project implementation. This result implies that a smaller sample of drivers has a greater, quantifiable impact on project success, even when many elements are considered significant.

Regarding Research Objective 2, the study found that the strongest statistically significant predictors of successful TAM project execution were Quality Management, Turnaround Manager Selection, and Budget/Cost Compliance. These factors explained a substantial share of the regression model's variance and showed strong positive correlations with project performance. By contrast, Communication, Top Management Support, and Time/Duration Management, although positively associated with successful TAM implementation, did not emerge as statistically significant predictors when analysed alongside the other factors. The findings suggest that these factors play important supporting or enabling roles within the broader TAM project environment. They ensure adherence to project objectives, minimise delays, and significantly improve execution efficiency. CCN, TMS, and TDM, on the other hand, did not appear in the regression model as statistically significant predictors. Future research should investigate whether these variables exert indirect, moderating, or context-dependent influences on TAM project outcomes. These elements support and reinforce the core success drivers by facilitating coordination, decision-making, and organisational alignment throughout the TAM lifecycle. The results are particularly relevant in the context of South African processing plants, where frequent, complex TAM operations are required due to ageing infrastructure in refineries, petrochemical facilities, and mining processing plants. Ageing assets make shutdown maintenance more technically complex and uncertain, underscoring the need for strong quality management systems, capable TAM leadership, and stringent budget controls. In addition, the scarcity of highly skilled technical labour in South Africa underscores the need for careful selection of TAM managers and robust quality assurance procedures to ensure that maintenance tasks are

conducted effectively and securely. Furthermore, the substantial financial consequences of plant downtime in continuous-processing businesses underscore the importance of budget and cost compliance. Unplanned delays or cost overruns during TAM execution can lead to significant production losses and operational disruptions. Consequently, the finding that budget/cost compliance is a direct predictor highlights the need for strict financial planning and control systems in South African processing facilities.

This study strengthens the theoretical and empirical foundation of TAM project management by providing quantitative support for the proposed TAM implementation methodology and confirming a structured set of success drivers. The results offer organisations seeking to enhance TAM performance, plant dependability, and operational sustainability in the South African industrial setting both scholarly value and practical insights. However, the study also recognises some limitations. The quantitative research approach may overlook important qualitative factors, such as team dynamics, organisational culture, stakeholder relationships, and leadership effectiveness, even though it is appropriate for identifying statistically significant associations. The conclusions of this study may be less applicable to other industrial or geographical contexts due to its primary focus on South African processing plants. Therefore, future research should consider using qualitative or mixed methods approaches to more thoroughly examine these contextual and behavioural factors. Further research could compare TAM practices across other sectors and geographical areas and examine industry-specific variations to improve the robustness and applicability of the suggested methodology.

In conclusion, this study provides quantitative evidence of the critical factors that affect the successful execution of TAM projects in South African processing facilities. By identifying direct and indirect predictors of success, the research supports improved decision-making, more effective TAM planning, and better project implementation. In South African processing sectors, these findings have significant implications for achieving sustained operational performance, enhanced asset reliability, and reduced operational risk.

References

- Al-Turki, U., Duffuaa, S., and Bendaya, M., Trends in turnaround maintenance planning: literature review, *Journal of Quality in Maintenance Engineering*, vol. 25, no. 2, pp. 253–271, 2019.
- Ayat, M., Imran, M., Ullah, A., and Kang, C., Current trends analysis and prioritization of success factors: a systematic literature review of ICT projects, *International Journal of Managing Projects in Business*, vol. 14, no. 3, pp. 652–679, 2021.
- Datta, S., Sobuz, M., Nafe Assafi, M., Sutan, N., Islam, M., Mannan, M., and Hasan, N., Critical project management success factors analysis for the construction industry of Bangladesh, *International Journal of Building Pathology and Adaptation*, 2023.
- Elwerfalli, A., Khan, M., and Munive-Hernandez, J., A new methodology to optimize Turnaround Maintenance (TAM) scheduling for gas plants, *IAENG Transactions on Engineering Sciences: Special Issue for the International Association of Engineers Conferences 2016*, 2018.
- Fuentes-Moraleda, L., Lafuente-Ibáñez, C., Fernandez Alvarez, N., and Villace-Molinero, T., Willingness to accept social robots in museums: an exploratory factor analysis according to visitor profile, *Library Hi Tech*, vol. 40, no. 4, pp. 894–914, 2022.
- Ghanad, A., An overview of quantitative research methods, *International Journal of Multidisciplinary Research and Analysis*, vol. 6, no. 8, pp. 3794–3803, 2023.
- Guo, Q., Wang, G., Gao, J., Yang, R., and Han, J., Reliability analysis of weapon systems based on SPSS, *Proceedings of International Conference on Modelling, Identification and Control*, pp. 1284–1286, Wuhan, China, 2012.
- Hadi, A., Ismail, S., Rani, N., and Bakar, N., Critical success factors of contractors in affordable high-rise public housing in Malaysia, *Sustainability Management Strategies and Impact in Developing Countries*, vol. 26, pp. 179–194, 2022.
- Hair Jr, J., Page, M., and Brunsveld, N., *Essentials of business research methods*, Routledge, 2019.
- Kellmerit, B., Focus groups, *International Journal of Sales, Retailing and Marketing*, vol. 4, no. 9, pp. 42–52, 2015.
- Lenahan, T., *Turnaround, shutdown and outage management: Effective planning and step-by-step execution of planned maintenance operations*, Elsevier, Oxford, UK, 2011.
- Masubelele, F., and Mnkandla, E., The identification of critical success factors for turnaround maintenance projects, *Proceedings of 2021 IEEE AFRICON*, pp. 1–6, 2021.
- Mazhar, S., Anjum, R., Anwar, A., and Khan, A., Methods of data collection: A fundamental tool of research, *Journal of Integrated Community Health*, vol. 10, no. 1, pp. 6–10, 2021.

- Moniri, M., Alem Tabriz, A., Ayough, A., and Zandieh, M., Turnaround project risk assessment using hybrid fuzzy SWARA and EDAS method: the case of upstream oil process industries in Iran, *Journal of Engineering, Design and Technology*, vol. 19, no. 4, pp. 966–988, 2021.
- Moradi, H., and Shadrokhi, S., A robust reliability-based scheduling for the maintenance activities during planned shutdown under uncertainty of activity duration, *Computers & Chemical Engineering*, vol. 130, pp. 1–21, 2019.
- Murshed, F., and Zhang, Y., Thinking orientation and preference for research methodology, *Journal of Consumer Marketing*, vol. 33, no. 6, pp. 437–446, 2016.
- Naik, S., and Bagodi, V., Energy conservation opportunities: evidences from three industrial clusters in India, *International Journal of Energy Sector Management*, vol. 15, no. 3, pp. 600–627, 2021.
- Obiajunwa, C., A framework for the evaluation of turnaround maintenance projects, *Journal of Quality in Maintenance Engineering*, vol. 18, no. 4, pp. 368–383, 2012.
- Pinto, J., and Slevin, D., *Critical success factors across the project life cycle*, Project Management Institute, pp. 1–11, Drexel Hill, PA, USA, 1988.
- Pokharel, S., and Jiao, J., Turn-around maintenance management in a processing industry: a case study, *Journal of Quality in Maintenance Engineering*, vol. 14, no. 2, pp. 109–122, 2008.
- Sahoo, T., *Process plants: shutdown and turnaround management*, 1st ed., CRC Press, Boca Raton, FL, USA, 2013.
- Sallis, J., Gripsrud, G., and Olsson, U. S., *Research methods and data analysis for business decisions*, Springer International Publishing, 2021.
- Singh, R., Kumar, D., and Sagar, B., Valuation of significant difference between various agile methods using one way ANOVA, *Proceedings of 2021 9th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO)*, pp. 1–5, IEEE, 2021.
- Wohlin, C., and Runeson, P., Guiding the selection of research methodology in industry–academia collaboration in software engineering, *Information and Software Technology*, vol. 140, pp. 1–14, 2021.
- Yamin, M., and Sim, A., Critical success factors for international development projects in Maldives: project teams' perspective, *International Journal of Managing Projects in Business*, vol. 9, no. 3, pp. 481–504, 2016.
- Zhu, S., and van Jaarsveld, W. D., Critical project planning and spare parts inventory management in shutdown maintenance, *Reliability Engineering & System Safety*, vol. 219, pp. 1–10, 2022.

Biographies

Enos Kwena Mashitisho holds a Bachelor of Technology degree in Mechanical Engineering from the University of South Africa (UNISA) and a Master of Philosophy in Engineering Management from the University of Johannesburg, South Africa. Mr. Mashitisho has over ten years of professional experience in manufacturing and maintenance engineering environments. He is presently employed as a Maintenance Manager, responsible for the day-to-day management of plant and equipment maintenance operations.

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

Jan Harm Christiaan Pretorius obtained the B.Sc. (Hons.) degree in electrotechnics in 1980, the M.Eng. degree in electrical engineering in 1982, and the D.Eng. degree in electrical and electronic engineering in 1997 from the Rand Afrikaans University, South Africa. He also received the M.Sc. degree in laser engineering and pulse power from the University of St Andrews, Scotland, in 1989, cum laude. He worked for 15 years at the South African Atomic Energy Corporation as a Senior Consulting Engineer. He later served as Technology Manager at the Satellite Applications Centre of the Council for Scientific and Industrial Research (CSIR), South Africa. His research interests include energy systems, engineering management, technology management, and renewable energy applications. He has co-authored more than 300 research papers and has supervised numerous postgraduate students at master's and doctoral levels. He is currently a Professor at the Postgraduate School of Engineering Management in the Faculty of Engineering and the Built Environment at the University of Johannesburg, South Africa, where he has been serving since 1998. He is a registered professional engineer and a professional Measurement and Verification (M&V)

practitioner. He is a Senior Member of the Institute of Electrical and Electronics Engineers (IEEE), a Fellow of the South African Institute of Electrical Engineers (SAIEE), and a Fellow of the South African Academy of Engineering.