Modeling Critical Success Factors in Flood Control Infrastructure: Toward a Theory of Effective Quality Management Systems

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Modeling Critical Success Factors in Flood Control Infrastructure: Toward a Theory of Effective Quality Management Systems

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Abstract: *Flood control infrastructure is essential for mitigating the increasing risks posed by climate change. However, challenges in implementation often stem from inadequate quality management systems (QMS). This study develops a theoretical model identifying critical success factors (CSFs) for effective QMS implementation in flood control projects. Using a mixed-methods approach including meta-analysis, Pareto analysis, and the Analytic Hierarchy Process (AHP), the research prioritized the most impactful CSFs based on expert input from the Pasig-Marikina River Channel Improvement Project. Key organizational CSFs included top management commitment, employee empowerment, and continuous improvement. The resulting framework provides a standardized guide for enhancing quality, efficiency, and accountability in project execution. The study contributes to both theory and practice by offering a structured model to inform policy, guide construction firms, and support future research on quality management in climate-resilient infrastructure development.*

Keywords: Quality Management System, Sustainable Construction Practices, Organizational Performance, Deming's Theory, PLS-SEM

1. INTRODUCTION

The increasing severity and frequency of flooding events—driven by climate change and rapid urbanization—pose significant challenges to infrastructure resilience in developing regions. In response, flood control projects have become central to disaster mitigation and sustainable urban development. However, despite major public investments, many of these projects face delays, quality issues, and poor coordination, often stemming from inconsistent application of quality management practices.

This study addresses the gap in theory-driven frameworks by proposing a model that identifies and prioritizes critical success factors (CSFs) essential to effective quality management system (QMS) implementation in flood control infrastructure. Using a mixed-methods approach—combining meta-analysis, Pareto analysis, and the Analytic Hierarchy Process (AHP), the research highlights key CSFs derived from both literature and expert validation. The resulting model offers a structured guide for improving project performance, standardizing quality practices, and informing policy in the infrastructure sector.

1.2 Background of the Study

Flood control infrastructure is a critical component of national development strategies, especially in countries prone to climate-induced disasters such as the Philippines. These projects aim to mitigate the risks associated with increasing rainfall intensity, typhoons, and storm surges driven by climate change. In urban areas like Metro Manila, rapid urbanization has outpaced the capacity of existing drainage and flood control systems, exacerbating flood vulnerability and exposing millions to environmental and economic hazards [1], [2].

Despite significant public investment in flood control initiatives under programs such as the "Build, Build, Build" agenda, several issues persist. These include delays in project delivery, poor inter-agency coordination, substandard construction practices, cost overruns, and failure to meet quality expectations [3], [4]. Projects such as the Pasig-Marikina River Channel Improvement Project (PMRCIP) illustrate these challenges, as they encounter technical, environmental, and managerial constraints throughout implementation.

One of the root causes of these persistent problems is the inconsistent application and monitoring of quality management systems (QMS) at the project level. While ISO 9001 and other formal QMS frameworks have been introduced, many contractors operate under informal or inadequately enforced quality practices [5]. Additionally, government agencies lack a unified approach for evaluating and enforcing QMS compliance during flood control infrastructure implementation [6].

Numerous studies have identified critical success factors (CSFs) for construction and infrastructure projects generally, such as leadership commitment, employee training, stakeholder engagement, and effective communication [7],[9]. However, there is a notable research gap in developing a comprehensive, theory-driven model that identifies and prioritizes CSFs specific to flood control infrastructure projects, especially in the context of developing countries like the Philippines. Most existing models are either too generic or focused on corporate-level quality systems, lacking application to public-sector infrastructure projects.

Therefore, this study addresses this gap by developing a theoretical model that identifies and prioritizes the CSFs necessary for effective QMS implementation in flood control projects. By applying methods such as meta-analysis, Pareto analysis, and the Analytic Hierarchy

Process (AHP), the study proposes a framework tailored to the unique operational, environmental, and institutional challenges of flood mitigation projects in Metro Manila.

2. MATERIALS AND METHODOLOGY

2.1 Theoretical Framework

The study is grounded in established theories and principles from quality management and project success frameworks, which inform the identification and evaluation of critical success factors (CSFs) in infrastructure projects.

2.1.1 Total Quality Management (TQM) Principles

Total Quality Management (TQM) forms a foundational principle in this research, promoting continuous improvement, customer focus, and organization-wide commitment to quality. In the construction industry, TQM has been recognized as a strategy that improves project performance through collaborative practices, feedback mechanisms, and consistent adherence to quality goals [10]. Successful TQM implementation emphasizes leadership commitment, employee involvement, and process-based approaches, which align closely with CSFs identified in this study [11].

Fig. 1.0 Total Quality Management framework.
Source: aprica.com

2.2.2 ISO 9001 Quality Management System

The study also draws on the ISO 9001:2015 Quality Management System (QMS) framework, which provides a structured approach to achieving consistency, customer satisfaction, and process efficiency in project execution. ISO 9001 principles, such as evidence-based decision making and risk-based thinking, guide the formalization of QMS in construction projects and are widely adopted across sectors to ensure accountability and improve service delivery [12]. In infrastructure projects, ISO-based QMS helps align project outcomes with quality standards, although implementation at the project level remains a challenge [13].

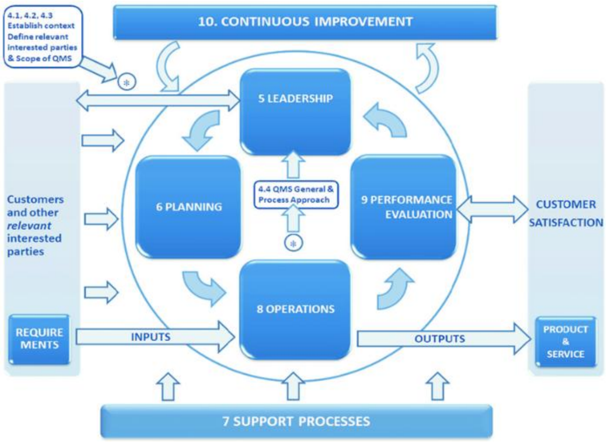

Fig. 2.0 ISO 9001:2015 QMS Framewrk

2.2.3 Critical Success Factors (CSFs) Theory

The CSF theory, originally proposed by Rockart, has been widely applied in construction and project management to identify the key elements that must be managed well to ensure project success. In infrastructure projects, CSFs encompass organizational, technical, and stakeholder-related factors that have a direct impact on performance outcomes [14]. Studies emphasize the need to assess CSFs within specific project contexts, as general models often fail to capture the dynamic variables of public infrastructure development [15].

A conceptual framework has been developed from the determination of CSFs of project management practice [16]. The author assessed the relation of the identified CSFs to project objectives, implementation, and performance which resulted in a conceptual framework, as shown in Fig. 5, that have identified five (5) variables for project success namely human factors, project procedures, project management action, external issues, and project-related factors. Based on these variables, the context of CSFs is easier to determine as well as the project outcome of different project management phases – from initiation to close-out.

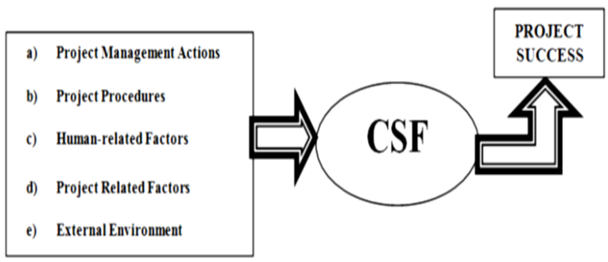

Fig. 3.0 Conceptual Framework for Project Management Practice Critical Success Factors

2.2.4 Analytical Hierarchy Process (AHP)

To prioritize CSFs, the study employs the Analytic Hierarchy Process (AHP), a multi-criteria decision-making (MCDM) tool developed by Saaty. AHP enables complex decision problems to be structured hierarchically, allowing qualitative and quantitative judgments to be integrated in a consistent and traceable manner [17]. This approach is particularly suited for infrastructure projects, where competing priorities must be balanced, and subjective judgments by experts can be systematically quantified [18].

2.2.5 Project Success Frameworks
Frameworks such as the Project Implementation Profile (PIP) and the Project Excellence Model have also informed the study's structure. These models highlight how factors like top management support, stakeholder engagement, and technical competence influence project outcomes [19], [20]. Integrating such frameworks enables a comprehensive understanding of the interactions between quality systems and project-level success.

2.2 Related Studies

Recent literature underscores the significance of implementing robust Quality Management Systems (QMS) in infrastructure projects to enhance performance and resilience. For instance, Okuno et al. introduced a data-driven flood forecasting method based on dynamical systems theory, demonstrating improved prediction accuracy for river stages in Japan, which is crucial for timely flood control measures [21]. Similarly, Tasseff et al. proposed an optimization framework for structural flood mitigation strategies, emphasizing the need for principled design methodologies over ad hoc approaches to enhance the effectiveness of flood control infrastructures [22].
In the context of urban stormwater management, Li et al. conducted a comprehensive performance evaluation of Low Impact Development (LID) practices for sponge city construction in Guangxi, China. Their study utilized the Analytical Hierarchy Process (AHP) to assess various LID scenarios, highlighting the benefits of micro-scale, decentralized facilities in managing stormwater at the source [23].

Flood control has been a key issue in Japan's policy history due to its unique climatological, meteorological, and hydrological conditions. Japan experienced severe flood damage particularly in a period immediately after World War II. Serious flood disasters claiming more than 1,000 deaths occurred almost every year [24].

After each disaster, new approaches, methods, and design standards were introduced, including improvements to methods for flood frequency analysis, changes in economic assessment procedures, and various structural measures such as dams, embankment, erosion and sediment control, sewage systems, as well as high-level embankment and comprehensive flood control. As a result, the number of victims and flooded areas decreased drastically in the rapid economic growth period during the 1950 and 1960s [25]. The necessity of long-term investment in flood control, instead of projects on a single fiscal year budget, was discussed in the wake of a devastating flood in western Japan in 1953.

The consequences of floods extend across various domains, profoundly affecting human well-being, food stability, economic productivity, physical infrastructure, ecological resources, and the overall environment. The aftermath of floods frequently leaves regions without electricity and access to clean drinking water, setting the stage for waterborne diseases to emerge. Even after the floodwaters recede, the aftermath lingers, causing significant challenges [26]. Addressing the challenges of climate change-induced flooding will require a multifaceted approach, including improving flood risk assessment, implementing adaptive measures, and carefully considering land use planning and management strategies [27].

Development of Flood Mitigation Strategies Toward Sustainable Development explores the integration of structural and non-structural flood mitigation strategies, including dams, levees, watershed management, and increased channel capacity, all aiming to reduce flood damage while promoting sustainable development [28].

Nishino and Obara [29] introduced a framework for integrated water resource management using real-time data assimilation for flood forecasting. Their approach, combining radar-based rainfall estimation with hydrological modeling, supports more adaptive flood control strategies. Another study by Rahman and Kim [30] analyzed the use of GIS-integrated rainfall-runoff models to improve flood prediction accuracy in urban catchments, highlighting their role in risk reduction.

These studies collectively emphasize the growing need to adopt intelligent, integrated systems for more effective and anticipatory flood control management, especially in rapidly urbanizing, climate-vulnerable areas.

2.3 Methodology

This study adopted a mixed-methods research design to develop a theoretical framework identifying critical success factors (CSFs) for effective Quality Management System (QMS) implementation in flood control infrastructure projects. The research was conducted in four phases: meta-analysis of existing literature, Pareto analysis for prioritization, expert consultation through a structured survey, and application of the Analytic Hierarchy Process (AHP) to assign weights and develop the model. The integration of qualitative and quantitative methods allowed for a systematic evaluation of theoretical constructs and empirical data, ensuring the robustness and practical relevance of the proposed framework. The design aimed to capture both the broad insights from literature and the contextualized judgments of practitioners actively involved in flood mitigation projects.

The study was established primarily in the Pasig-Marikina River with a catchment area of 635 km2 flows through the center of Metro Manila and finally pours into the Manila Bay. Flooding due to riverbank overflow of this river has been frequently happening for the past 35 years from 1986 to 2020. Metro Manila and the Laguna Lake area, in particular, suffered enormous damage from the heavy rain caused by Tropical Storm Ondoy on September 26, 2009, which brought 453 mm of daily rainfall as recorded at the Quezon City Science Garden Station of PAGASA, and the areas along the Pasig-Marikina River experienced severe inundation, as shown in Figure 3.0.

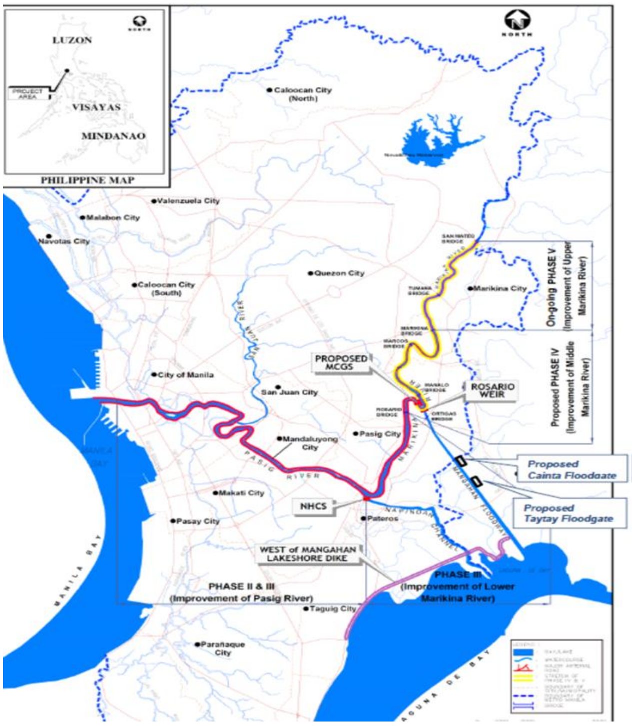

Figure 3.0 Pasig-Marikina River Channel Improvement (PMRCI) Project

The approach to achieving the research's main objective was based on the conceptual framework as shown in Figure 4.0. It is composed of four (4) phases and nine (9) systematical steps to achieve the aim of the study. Furthermore, Table 1 shows the summary of the research instrument, statistical tool, and treatment of data that will be used in the study.

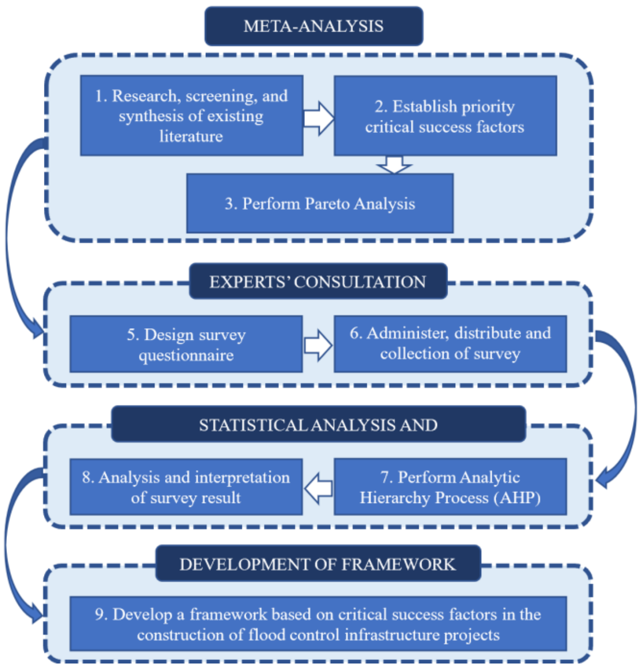

Figure 4.0 Conceptual Framework

The research methodology utilized Meta-Analysis to identify and determine all CSFs and success criteria necessary and appropriate for the Pasig-Marikina River channel Improvement Project. Meta-Analysis is a comprehensive or systematic review and a statistical procedure where data will be collected from different existing studies.

The data analysis process involved three key techniques. First, a meta-analysis synthesized findings from over 40 scholarly articles and institutional reports to identify a comprehensive list of CSFs. Next, a Pareto analysis was used to prioritize the top 20% of these CSFs, following the 80/20 rule, to identify those factors with the most significant influence on project outcomes. Finally, the Analytic Hierarchy Process (AHP) was applied to quantify expert judgments and determine the relative weights of each CSF. A consistency ratio was calculated to ensure logical coherence in the experts' response.
The researcher will only select all the experts from the project team and participants of the PMRCI construction project such as project managers and project heads as the respondents for the survey questionnaires. The experts to be chosen should be competent and reliable in managing the construction project. Moreover, according to Fei & Khan, and Amora & Juanzon [31&32], experts should have the following criteria:

a. At least 30 years old
b. More than 10 years of professional experience

The weighted results were then used to construct the Venn Diagram Model Framework, integrating organizational, project-level, and QMS principles into a unified structure that highlights the dynamic interactions necessary for successful flood control project implementation.

3. RESULTS AND DISCUSSION

3.1 Meta Analysis

The study found a total of 40 CSFs with a cumulative of 424 in their frequencies. Most of the factors share the same context, and therefore, they are combined and re-organized to create a more concise and well-comprehensive list of CSFs. Shown in Table 1.0 below are the organized CSFs from the results of the research, screening, and synthesis of the existing literature.

Table 1.0 Comprehensive List of Critical Success Factors

NO.	Critical Success Factors	Frequency
1	Top Management Commitment	51
2	Education and Training	39
3	Effective Project Communication and Coordination	32
4	Employee Empowerment	31
5	Effective leadership	28
6	Teamwork	26
7	Continuous Improvement	26
8	Customer Focus/ Satisfaction	23
9	Structured system procedures and Process Approach	22
10	Allocating appropriate Funding resources	21
11	Project Manager Competence	21
12	An effective quality management plan	20
13	Internal Stakeholders Engagement	10
14	Client Involvement	9
15	Attitude to Change / Change Management	6
16	Contractor Experience	6
17	Evidence based decision making'	6
18	Strong Quality Culture	4
19	Clear Project Goals	4

20	Use of Information and communication technology	3
21	Project personnel motivation and commitment	3
22	Site management and supervision	3
23	Management review / Effective Feedback	3
24	Adopting Digital Technology	3
25	An effective safety management plan	2
26	Planning Effort	2
27	Regular External Audit of QMS	2
28	End-user Involvement	2
29	An effective project performance monitoring	2
30	Construction Site Planning	2
31	Relationship Management	2
32	External Pressure (Govt and competition)	2
33	Adequate knowledge and experience of the project team	1
34	Effective subcontractor selection	1
35	Well defined construction period	1
36	Measurement and Improvement	1
37	Supplier Quality Management	1
38	Industry Relations with Trade Unions	1
39	Reduce the Impact of Non-Standardization	1
40	Non-Standardization	1
	TOTAL	**424**

3.2 Pareto Analysis

The results of the Meta-Analysis were further divided into two main categories under organization and project related attributes of Critical Success Factors. Pareto analysis was then applied to both organizational and project related attributes to come up with the vital few CSFs. The result from the Pareto Analysis was demonstrated through the Pareto chart to evidently indicate the vital few and trivial many of the CSFs. The Pareto analysis shows the ranking of these factors. The Pareto chart is shown in Fig. 5 and 6 in chronological ranking from CSF 1 to CSF 20 of both organization and project attributes. For organization attributes the vital few are Top Management Commitment, Education and Training, Employee Empowerment, Continuous Improvement, and Customer Focus/ Satisfaction.

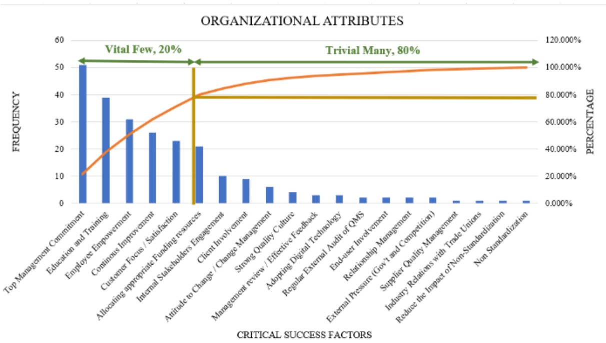

Figure 5.0 Pareto chart of Organization Attributes

For project attributes as shown in Fig. 6, the top attributes are Effective Project Communication and Coordination, Effective Leadership, Teamwork, Structured system procedures and Process Approach, and Project Manager Competence.

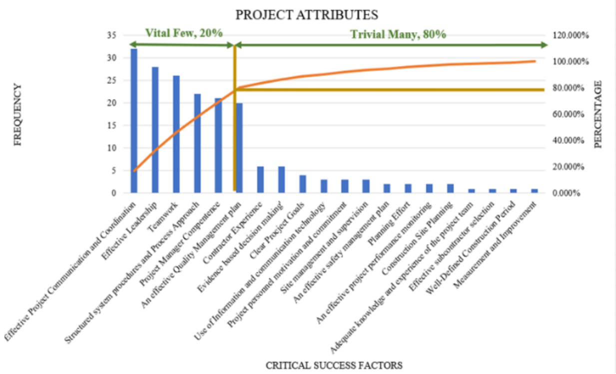

Figure 6.0 Pareto chart for Project Attributes

3.3 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) was utilized as a statistical tool to analyze the ranking of CSFs based on the conducted survey. The AHP Flow Chart showing the goal, criteria, and sub-criteria is shown on Fig. 7. Upon performing the AHP and from the comparison matrix, the weights for each compared element or criterion were calculated. The random consistency index (RI) that has been used is 1.12 corresponding to the size of the matrix. The value of the consistency ratio (CR) was calculated based on the Eigenvalue, CI, and RI.

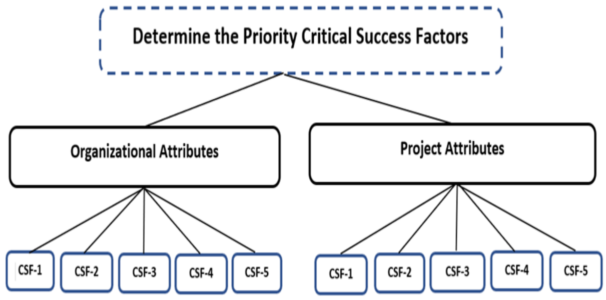

Figure 7.0 AHP Flow Chart

An individual pairwise comparison matrix of sub-criteria was developed for each expert corresponding to each criterion or attribute to compare the results and ranking prior to the consolidation of all completed research surveys. The consolidated pairwise comparison matrix for CSFs with respect to organizational attributes is shown in Table 2.0.

Table 2.0 Consolidated Pairwise Comparison Matrix of CSFs with respect to Organizational Attributes

Project Attributes - Consolidated (Normalized)						**Weights**	**Ranking**
CSF	1	2	3	4	5		
1	1.000	2.005	1.821	1.165	0.509	**21.69%**	**2**
2	0.499	1.000	2.537	1.000	0.422	**16.55%**	**4**
3	0.549	0.394	1.000	0.644	0.321	**9.92%**	**5**
4	0.859	1.000	1.552	1.000	0.612	**17.44%**	**3**
5	1.966	2.371	3.112	1.635	1.000	**34.41%**	**1**
Eigenvalue (γ_{max})			**5.106**				
Random Consistency Index (RI)			**1.120**				
Consistency Index (CI)			**0.087**				
CONSISTENCY RATIO (CR)			**2.35%**				

The result revealed that the priority CSFs with respect to organizational attributes are as follows: CSF 5-Customer Satisfaction, CSF 1-Top Management Commitment, CSF 4 – Continuous Improvement, CSF 2-Training and Education, and CSF 3-Employee Empowerment. Moreover, with the computed eigenvalue and consistency index, the study resulted at the consistency ratio of 2.35% from the pairwise comparison which is less than the maximum allowable consistency ratio of 10% and signifies that the judgment of the expert is consistent.

On the other hand, the consolidated pairwise comparison matrix for CSFs with respect to organizational attributes is shown in Table 3.0.

Table 3.0 Consolidated Pairwise Comparison Matrix of CSFs with respect to Project Attributes

Project Attributes - Consolidated (Normalized)						**Weights**	**Ranking**
CSF	1	2	3	4	5		
1	1.000	1.070	0.931	1.246	0.684	**19.18%**	**3**
2	0.935	1.000	0.725	1.380	1.719	**21.76%**	**2**
3	1.074	1.380	1.000	1.431	1.657	**25.20%**	**1**
4	0.803	0.725	0.699	1.000	0.786	**15.44%**	**5**
5	1.461	0.582	0.603	1.272	1.000	**18.43%**	**4**
Eigenvalue (γ_{max})				**5.098**			
Random Consistency Index (RI)				**1.120**			
Consistency Index (CI)				**0.0807**			
CONSISTENCY RATIO (CR)				**2.18%**			

The result revealed that the priority CSFs with respect to project attributes are as follows: CSF 3-Teamwork, CSF 2-ffective Leadership, CSF 1-Effective Communication and Coordination, CSF 5-Project Manager Competence, and CSF 4-Systematic Procedures and Process. Moreover, with the computed eigenvalue and consistency index, the researcher has arrived at the consistency ratio of 2.18% from the pairwise comparison which is less than the maximum allowable consistency ratio of 10% and signifies that the judgment of the expert is consistent.

The results of this study align strongly with findings from prior research on quality management and infrastructure project success, particularly in the context of flood control and public works. The prioritization of top management commitment as the most influential Critical Success Factor (CSF) echoes the conclusions of Yong and Mustaffa [15], who emphasized leadership support as a core determinant of project performance in the Malaysian construction industry. Similarly, Pheng and Teo [10] highlighted that sustained executive engagement is crucial for the successful implementation of Total Quality Management (TQM) practices.

The study also supports previous work emphasizing the importance of employee empowerment, continuous improvement, and training, which are central themes in ISO 9001-based frameworks [12], [13]. These factors have been consistently associated with improved quality outcomes and operational efficiency in infrastructure settings. For example, Neyestani and Juanzon [11] found that organizations with stronger internal quality cultures, characterized by staff involvement and regular training, outperformed others in meeting both project and regulatory benchmarks.

At the project level, the identification of effective communication, competent project management, and stakeholder engagement as vital CSFs reflects the findings of Westerveld [20] and Slevin and Pinto [19], who noted that coordination and clarity in roles significantly reduce delays and scope creep. These themes were further echoed in IEICES studies such as that of Rahman and Kim [30], where GIS-integrated flood modeling was found to be more effective when coupled with well-coordinated project management and community involvement.

3.4 Framework of Critical Success Factors

The study developed a Venn Diagram Model Framework to conceptualize the interrelationship between key elements influencing the success of flood control infrastructure projects through effective Quality Management System (QMS) implementation. The framework consists of three intersecting domains: organizational attributes, project attributes, and QMS principles. Organizational attributes refer to internal factors such as top management commitment, employee empowerment, continuous improvement, and client satisfaction, which form the foundation of a quality-oriented culture. Project attributes include effective communication, structured procedures, competent management, and stakeholder involvement elements that ensure the practical application of QMS at the project level. The third domain, QMS principles, is grounded in ISO 9001:2015 and includes concepts like risk-based thinking, evidence-based decision-making, and customer focus. The intersections among these domains highlight the synergy required to achieve optimal project performance. At the core, where all three areas converge, lies the ideal project environment—an integrated system where organizational culture, project execution, and quality standards align to ensure the successful delivery of resilient and high-quality flood control infrastructure.

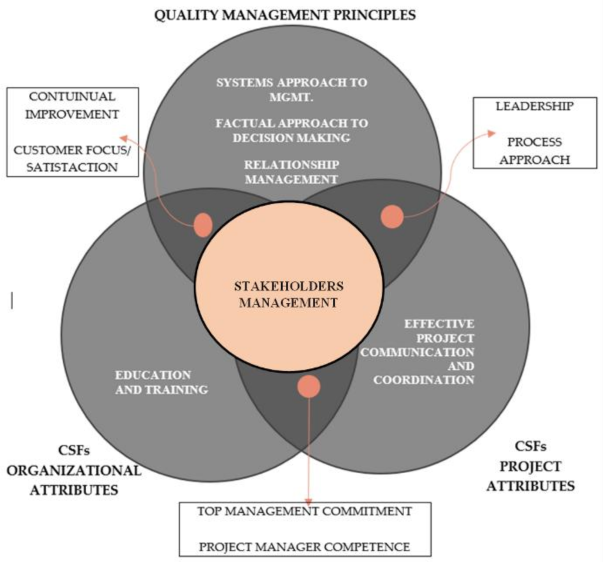

Figure 8.0 Framework of Critical Success Factors and QMS

The framework developed in this study integrating organizational and project-level attributes with QMS principles is consistent with more recent flood control system research emphasizing integrated, real-time decision-making tools [21], [22]. These studies similarly argue that the fusion of institutional capacity, technical systems, and quality standards provides the best foundation for resilient, scalable, and successful flood mitigation infrastructure.

For further studies, its is recommended to increase the number of expert respondents to the studied critical success factors related to flood control project delivery. This research study has only five (5) participants that complied with the requirement of an expert, thus, a large research setting is recommended to expand the number of experts as respondents.

Future researchers are encouraged to apply the framework developed in this study to validate the benefit of determination of critical success factors and quality management systems. The subject matter of this study is limited to analysis and investigation of the Pasig-Marikina River Channel Improvement project, but the framework developed could be applied to various types of construction projects, especially to flood control projects works in different areas or location.

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