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**Implementing PowerBI Reporting for Quality Analysis in Decision
Making Processes: A QFD and FMECA-Based Approach**

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Abstract

This thesis presents the development and pilot implementation of a Power BI-based decision support model to enhance quality analysis and risk management in public procurement. The system aims to enable more transparent, data-driven, and audit traceable decision making processes across the procurement life cycle through the integration of Quality Function Deployment (QFD) and Failure Modes, Effects, and Criticality Analysis (FMECA).

The research addresses the institutional need for mechanisms that go beyond compliance and cost minimization, providing structured approaches for supplier quality evaluation, operational risk prioritization, and stakeholder-aligned decision-making. The system is supported by a PostgreSQL backend and integrates both internal and external data sources (e.g., TED, MEPA). It features modular dashboards tailored to specific institutional roles, including procurement officers, contract managers, and compliance officers.

In the QFD module, stakeholder needs are systematically captured and translated into weighted evaluation criteria, improving objectivity and consistency throughout the supplier selection process. Simultaneously, the FMECA engine calculates Risk Priority Numbers (RPNs), enabling early identification and mitigation of potential procurement failures. These tools are integrated into an interactive Power BI environment, offering real-time alerts, SLA tracking, and role-based analytics.

A pilot study conducted in collaboration with a regional public procurement agency demonstrated that the platform improved evaluation clarity, risk responsiveness, and compliance with procurement policies. Stakeholder feedback highlighted increased confidence in decision making, reduced subjectivity in evaluations, and strong alignment with EU procurement directives and national digital governance goals.

The integration of quality, risk, and data visualization analytics into a unified framework presents a replicable model for the modernization of public procurement. Furthermore, it creates opportunities for future developments, including AI-based forecasting, blockchain enabled audit trails, and ERP interoperability.

Contents

Acknowledgements.....	1
Abstract.....	2
Contents.....	3
List of Figures.....	7
List of Tables.....	8
Chapter 1: Introduction.....	9
1.1 Background and Rationale.....	9
1.1.1 Strategic Importance of Public Procurement.....	10
1.1.2 Challenges in Traditional Procurement Systems.....	11
1.1.3 The Role of Technology and BI in Modern Procurement.....	12
1.1.4 The Necessity for International Governance.....	13
1.1.5 Regulatory Compliance and Institutional Efficiency.....	14
1.1.6 Alignment with the Public Sector's Wider Goals.....	15
1.2 Problem Statement.....	17
1.2.1 Data Inconsistency and Fragmentation Across Procurement Systems.....	18
1.2.2 Lack of Real-Time Decision-Making and Analytical Tools.....	19
1.2.3 Insufficient Quality and Risk Integration in Procurement.....	21
1.2.4 Fragmented Data Ecosystems and Technical Limitations.....	22
1.2.5 Gaps in Risk and Quality Integration.....	24
1.2.6 Data Governance and Security Challenges in Procurement Systems.....	26
1.3 Research Objectives.....	27
1.4 Scope and Limitations.....	30
1.4.1 Scope of the Study.....	30
1.4.2 Limitations of the Study.....	32
1.4.3 Delimitations.....	34
Chapter 2: Literature Review.....	36
2.1 Theoretical and Conceptual Foundations.....	36
2.1.1 Public Procurement in the Modern Public Sector.....	36
2.1.2 Digital Transformation and E-Procurement Systems.....	38
2.1.3 Decision-Support Systems and Power BI.....	40
2.1.4 Data Mining and Its Relevance in Procurement.....	42
2.1.5 Database Management in Public Administration.....	46
2.1.6 Data Governance, Privacy, and Regulatory Frameworks (e.g., GDPR).....	49
2.2 Business Intelligence and Reporting Technologies in Procurement.....	53
2.2.1 Overview of Business Intelligence Platforms.....	54
2.2.2 Microsoft Power BI for Public Sector Applications.....	56
2.2.3 Relational Databases: SQL and PostgreSQL Integration.....	59
2.2.4 ETL Processes for Procurement Data Transformation.....	63
2.2.5 Dashboards and KPI Visualization in Procurement Systems.....	66

2.3 Quality and Risk Management Frameworks in Procurement.....	68
2.3.1 Quality Function Deployment (QFD).....	69
2.3.2 FMECA in Public Procurement.....	70
2.3.3 Integration of QFD and FMECA with Business Intelligence Tools.....	72
2.3.4 Comparative Advantages over Traditional Tools.....	74
2.3.5 Comparative Analysis: QFD–FMECA versus AHP and Hybrid MCDA Methods....	76
2.4 Systemic Gaps and Challenges in Existing Frameworks.....	79
2.4.1 Fragmentation and Redundancy in Procurement Data.....	79
2.4.2 Lack of Real-Time, Integrated Decision-Making.....	79
2.4.3 Inadequate Use of Quality and Risk Methodologies.....	80
2.4.4 Technical Limitations: Data Quality, Empty Fields, and Linkage Errors.....	80
2.4.5 Security and Compliance Gaps in Procurement Data Systems.....	81
Chapter 3: Research Methodology.....	83
3.1 Research Design.....	83
3.1.1 Mixed-Methods Approach.....	83
3.1.2 Case Context: Regional Public Company.....	85
3.2 Data Collection Strategy.....	87
3.2.1 Source Identification.....	87
3.2.2 Stakeholder Engagement.....	88
3.2.3 Flowchart of Collection Process.....	89
3.3: Analytical Framework.....	90
3.3.1 Database Development (SQL/PostgreSQL).....	90
3.3.2 ETL Process and Data Cleaning.....	91
3.3.3 Power BI Dashboard Architecture.....	91
3.3.4 Metrics Selection (KPIs, SLAs).....	92
3.3.5 Integration of Quality Function Deployment (QFD).....	92
3.3.6 Integration of FMECA (Failure Modes, Effects, and Criticality Analysis).....	93
3.4 Implementation Methodology.....	94
3.4.1 Dashboard Development Strategy.....	94
3.4.2 Quality Analysis Workflow.....	98
3.4.3 Risk Mapping Strategy.....	100
3.4.4 User Access and Security Features.....	103
3.4.5 Testing and Validation Steps.....	106
3.4.6 Feedback Collection Methods.....	107
3.4.7 Timeline and Roadmap.....	108
3.4.8 Summary of Quality and Risk Integration.....	110
Chapter 4: System Design and Development.....	112
4.1 System Architecture Overview.....	113
4.1.1 Conceptual Architecture.....	113
4.1.2 Physical Architecture.....	115
4.1.3 System Objectives and Design Principles.....	116

4.2 Data Layer Design.....	117
4.2.1 Table Structures and Entity Relationships.....	117
4.2.2 Indexing Strategy and Query Optimization.....	119
4.2.3 Query Performance Benchmarking.....	119
4.2.4 PostgreSQL Schema and Normalization Strategy.....	123
4.2.5 Governance and Change Management.....	124
4.3 BI Dashboard Structure.....	125
4.3.1 Power BI Interface Layout and Navigation.....	126
4.3.2 Role-Based Segmentation and Security Enforcement.....	127
4.3.3 Integration with Decision-Making and Institutional Workflows.....	128
4.4 QFD Implementation Details.....	129
4.4.1 Stakeholder Input Collection and Translation.....	130
4.4.2 House of Quality Matrix Modeling in BI.....	131
4.4.3 Mapping to Procurement KPIs.....	132
4.5 FMECA Risk Engine Design.....	133
4.5.1 Input Configuration for Severity, Occurrence, and Detectability.....	134
4.5.2 Automated RPN Logic and Alert Rules.....	137
4.5.3 Risk Matrix and Visual Integration in BI.....	139
4.6 System Interoperability and Data Flow.....	141
4.6.1 APIs, Connectors, and Real-Time Data Updates.....	142
4.6.2 Flow of Data from PostgreSQL to Power BI.....	143
4.7 Data Security and Governance Integration.....	145
4.7.1 Encryption, Logging, and GDPR Safeguards.....	145
4.7.2 Audit Trails and Access Governance.....	147
Chapter 5: Results and Evaluation.....	149
5.1 Pilot Implementation Context.....	149
5.1.1 Case Study Setup and Environment.....	149
5.1.2 Data Anonymization and Procurement Scenario.....	150
5.2 Dashboard Use-Case Demonstrations.....	152
5.2.1 Supplier Quality Evaluation During Tender Assessment.....	152
5.2.2 SLA Monitoring and Post-Award Contract Oversight.....	153
5.2.3 Pre-Award Risk Detection Using the FMECA Engine.....	154
5.3 Quality Evaluation (QFD) Results.....	156
5.3.1 Structure and Scoring of the QFD Matrix.....	157
5.3.2 Visualization of QFD Scoring.....	158
5.3.3 Effectiveness in Representing Stakeholder Expectations.....	159
5.3.4 Influence on Procurement Decisions.....	160
5.3.5 Lessons Learned and System Adjustments.....	161
5.4 Risk Prioritization (FMECA) Results.....	162
5.4.1 Key Risk Patterns Based on RPN Analysis.....	162
5.4.2 Example Interventions Supported by System Alerts.....	164

5.4.3 Risk Intelligence as a Decision-Support Mechanism.....	166
5.4.4 Lessons Learned and Opportunities for Refinement.....	167
5.5 User Testing and Usability Feedback.....	167
5.5.1 Structured Survey Outcomes.....	168
5.5.3 Live Demonstrations and Workflow Integration.....	170
5.5.4 Lessons Learned and Design Implications.....	171
5.6 Impact Summary: Pre- vs. Post-Implementation Comparison.....	172
5.7 Policy Alignment and Regulatory Fit.....	173
5.7.1 Compliance with Public Procurement Policy Requirements.....	174
5.7.2 Fit with EU Directives and Transparency Standards.....	176
5.7.3 Alignment with National Policy Objectives.....	178
Chapter 6: Conclusion and Future Scope.....	182
6.1 Summary of Contributions.....	182
6.2 Research Limitations.....	185
6.3 Implications for Public Procurement Governance.....	187
6.4 Recommendations for Future Research.....	189
6.5 Technology Roadmap: AI, NLP, and Blockchain Integration.....	193
6.5.1 Objectives of Integration.....	193
6.5.2 Six-Month Implementation Roadmap.....	194
6.5.3 Technical Alignment and System Architecture.....	194
6.5.4 Legal and Ethical Considerations.....	195
6.5.5 Evaluation Metrics.....	195
6.5.6 Strategic Implications.....	196
6.5 Final Reflection.....	196
Appendix A: QFD Numerical Example and Sensitivity Analysis.....	200
Appendix B: FMECA Risk Flow and Statistical Assumptions.....	203
References.....	207

List of Figures

Figure 2.1: Evolution of Public Procurement Systems	38
Figure 2.2: Workflow and Architecture of Database Management in Public Procurement Systems.....	49
Figure 2.3: GDPR-Compliant Data Governance Framework for Public Procurement Systems.....	53
Figure 2.4: Relational Database Schema Supporting Procurement Reporting and Power BI Integration	63
Figure 2.5: ETL Flow for Procurement Intelligence Architecture	66
Figure 2.6: Conceptual Framework of the Unified BI-QFD-FMECA Reporting System.....	82
Figure 3.1: Procurement Data Collection Lifecycle and Stakeholder Integration	89
Figure 3.2: Entity-Relationship Diagram (ERD).....	95
Figure 3.3: Dashboard Architecture Layer	97
Figure 3.4: RBAC-RLS-GDPR-Based User Access and Data Security Architecture	106
Figure 3.5: Project Timeline and System Rollout Roadmap.....	110
Figure 4.1: Conceptual Bridge Between Objectives and Architecture.....	112
Figure 4.2: Conceptual System Architecture.....	117
Figure 5.1: Stakeholder Evaluation of Dashboard Use-Cases by Functional Criteria	156
Figure 5.2: Supplier QFD Comparison Across Quality Dimensions.....	159
Figure 5.3: RPN distribution chart, risk alert visualization	164
Figure 5.4: Impact of dashboard-informed interventions	166
Figure 5.5: User Interaction Metrics for Dashboard Usage	171
Figure B1: FMECA Risk Propagation.....	203

List of Tables

Table 1.1: Summary of Delimitations	35
Table 2.3: Comparative Summary – AHP/Hybrid Models vs. QFD–FMECA	78
Table 3.1: Categorization of Procurement Risks and Associated Control Mechanism.....	10
Table 4.1 – Query Benchmarking Results (Pre- vs. Post-Tuning).....	120
Table 4.2: Query Performance Benchmarks Before and After Optimization Techniques.....	123
Table 4.3: Risk Categorization Thresholds	138
Table 5.1: Effectiveness in Representing Stakeholder Expectations.....	159
Table 5.2: Key Risk Patterns Based on RPN Analysis.....	162
Table 5.3: Quantitative Results Overview	168
Table 5.4: Role-Fit Satisfaction Ratings Overview	169
Table 5.5: Summary of Key Performance Metrics.....	172
Table 6.1: Summary Table of Key Contributions	184
Table 6.2: Six-Month Roadmap for AI, NLP, and Blockchain Integration	194
Table 6.3: Evaluation Metrics for AI, NLP, and Blockchain Integration.....	195
Table A.1: Mapping of Stakeholder Needs to Technical Features.....	200
Table A.2: Weighted Scores, Normalized Scores, and Final Rankings.....	201
Table A.3: Sensitivity of Rankings Under Weight Variations.....	202

Chapter 1: Introduction

1.1 Background and Rationale

Public procurement is a fundamental means through which government ministries and public organizations acquire the goods, services, and works necessary for the delivery of public services and the attainment of policy objectives. The practice is a significant component of national economies, accounting for approximately 12% to 15% of the Gross Domestic Product (GDP) of OECD countries. Due to its economic importance, public procurement is not only a mere routine administrative function but a strategic tool utilized to spur economic development, social equity, and environmental sustainability. Regional public enterprises, like S.C.R. Piemonte S.p.A., plays a key part in this setting. They are the regional governments, municipalities, and public hospitals centralized contracting authorities, running tenders from multi-million-euro building works to critical medical equipment.

Public procurement within the European Union (EU) is regulated by a comprehensive code of legislation that aims at enhancing transparency, competition, and effective utilization of public resources. The EU public procurement directives call for open competition, non-discrimination, and equal treatment of suppliers, thereby bringing about the establishment of a single market for public contracts.

In spite of the strategic potential of public procurement, a majority of institutions in the public sector face challenges in the actualization of effective and transparent procurement processes. A few of the common pitfalls include fragmented information systems with no real-time monitoring, and misaligned risk and quality management systems. Such problems can lead to inefficiency, excessive expenditure, and loss of public confidence.

Solutions to these issues are provided by technological innovations in digital technology. Business Intelligence (BI) tools such as Microsoft Power BI facilitate integration of data from disparate sources, visualization of procurement activities, and determination of actionable information. Application of BI tools in conjunction with methods such as Quality Function Deployment (QFD) and Failure Modes, Effects, and Criticality Analysis (FMECA) can enhance decision-making by linking procurement activities to stakeholder requirements and by uncovering possible risks in advance.

This thesis will design and deploy a Power BI-based reporting system integrating Quality Function Deployment (QFD) and Failure Mode, Effects, and Criticality Analysis (FMECA) techniques to improve the analysis of quality and decision-making in public procurement. The case study focuses on an Italian public entity owned by Regione Piemonte that is involved in

handling complex tenders and procurement projects. Through improving data integration, visualization, and risk analysis, the suggested system will automate procurement processes, enable compliance with regulatory requirements, and enhance transparency and accountability.

1.1.1 Strategic Importance of Public Procurement

Public procurement is a significant instrument for governments to realize policy objectives, economic growth, and public service provision. Its significance is underpinned by its huge contribution to national economies. For example, public procurement represents around 13% of GDP in OECD countries. Within the European Union, it stands at around 14% of GDP, or over €2 trillion each year.

Aside from its economic significance, public procurement is also a means for advancing social and environmental agendas. By incorporating sustainability into procurement operations, governments can encourage innovation, mitigate environmental impacts, and boost social inclusion. Green public procurement policy, for example, encourages the purchase of environmentally sustainable commodities and services that mitigate the impacts of climate change and ensure resource efficiency.

The regional public authorities, such as Consip S.p.A. in Italy, play a fundamental role in the management of public procurement policy. They serve as central purchasing bodies, aggregating demand across various public sector organizations with the aim of achieving economies of scale as well as simplifying procurement procedures. Through their resources and competencies, the regional public authorities are able to enhance procurement efficiency, reduce costs, and ensure adherence to relevant legal and regulatory structures.

But public procurement's strategic potential is usually hampered by operational intricacy. Inconsistent data systems, protracted processes, and insufficient integration across the various phases of procurement can create inefficiency and lowered effectiveness. Further, complexity in regulatory policy demands robust systems of compliance management and risk mitigation.

To harness the complete potential of public procurement, combined solutions must be used that involve the use of technological tools along with methodical methodologies. The use of BI tools like Power BI can help enable real-time data analysis and visualization, which can enable procurement professionals to make more informed decisions. The use of QFD can enable the perfect integration of procurement activities with the specifications of the stakeholders, while FMECA is a methodical methodology for identifying and reducing risk.

By utilizing these comprehensive systems, public sector agencies can transform procurement into a strategic facilitator for the realization of policy goals, improved service provision, and sustainability.

1.1.2 Challenges in Traditional Procurement Systems

In contrast to its critical significance, conventional procurement practices still experience significant roadblocks that compromise transparency, effectiveness, and alignment with policy goals. These include the data fragmentation, where procurement data becomes dispersed across various platforms and departments, and as a result, creates a complex environment for the integration, access, and analysis of the data. This not only increases the administrative burdens but also diminishes the capacity of public institutions to respond quickly to evolving project demands.

In many public sector organizations, procurement processes often utilize outdated methods of operation, including manual documentation systems and primitive spreadsheet programs. Such tools are not qualified to incorporate data in real-time, conduct predictive analytics, or include risk visualization capacities abilities that are increasingly vital for the strategic handling of complex tenders. Additionally, the use of manual processes entails a high rate of human inaccuracies, lengthy report timelines, and data entry inconsistencies.

The second main challenge is the lack of defined frameworks to enable the integration of stakeholder needs and risk identification as part of procurement decision-making processes. Quality measurement practices are inherently reactive and, therefore, the identification of risks is typically retrospective, with consequent service disruption, overspend, and non-achievement of service level agreements (SLAs).

Conformity with complicated legal frameworks like the EU Procurement Directives and national law relating to transparency is a critical concern. Most organizations do not have adequate systems to monitor contract obligations, keep audit trails, and administer the document lifecycle, and this therefore leaves them open to legal exposures and reputational damage.

In addition, the systems currently in place too often do not possess the scalability and adaptability features that are needed. As innovative digital solutions and emerging regulatory requirements arise, the old systems prove incapable of adjusting and generate huge financial and operational costs. The constraint limits innovation and hinders strategic direction for change through procurement.

Given such constraints, it is imperative that the procurement system adopts a data-driven and technology-enabled methodology. Integrating Business Intelligence systems with advanced quality and risk management techniques offers a way to close such loops. This thesis presents the development of such a system by leveraging Power BI, QFD, and FMECA to optimize procurement processes, improve governance, and facilitate evidence-based decision-making.

1.1.3 The Role of Technology and BI in Modern Procurement

The trend of digitalization has radically altered the face and potential of public procurement. Among the leading technologies driving this change, Business Intelligence (BI) tools particularly Microsoft Power BI have emerged as key facilitators of data-driven decision-making. In the context of procurement, BI solutions integrate data from disparate sources, such as Enterprise Resource Planning (ERP) systems, supplier databases, and contract documents, into a unified analytical framework. This enables procurement authorities to graphically represent trends, generate reports, and establish proactive response mechanisms against anticipated risks.

Modern procurement is not only evaluated on the grounds of cost-effectiveness but also with respect to value creation, timeliness, supplier diversity, and sustainability. Real-time achievement of such complex goals requires the use of real-time analytics, advanced reporting systems, and the secure incorporation of internal as well as external data sources. Power BI, through its inherent ability to generate personalized dashboards and support ETL (Extract, Transform, Load) processes, offers a versatile platform that accommodates these needs.

It allows stakeholders to view real-time dashboards relevant to their respective roles whether it's managing tender status, monitoring supplier compliance, or following budget spending.

In addition, Business Intelligence solutions enable better government through enhanced auditing capabilities. With the deployment of advanced data logging tools and version control mechanisms, government organizations can now trace the individuals who accessed, updated, and authenticated data and enhance transparency and accountability. This is especially relevant in regulatory situations like EU Directives or domestic anti-corruption law.

A second significant aspect involves the handling of risks. The procurement process involves inherent risks like delays, contractor defaults, and legal disputes. Business Intelligence tools enable the incorporation of tools for evaluating risks like Failure Modes, Effects, and Criticality Analysis (FMECA), and the ability to visualize heatmaps, project vulnerability forecasts, and the inclusion of mitigation techniques. By combining historical trends with real-time data inputs, the systems improve anticipatory governance, a critical aspect for procurements with increased risk.

In addition to this, Power BI allows for the integration of Quality Function Deployment (QFD), strengthening the alignment between procurement specifications and stakeholders' expectations. As a result, the procured items effectively cater to the actual end-users' requirements as well as the regulatory bodies and funding organizations.

The integration of Business Intelligence solutions into public procurement is a major leap that reshapes the government's strategy from reactive to proactive. Utilizing data integration, visual analytics, and the dynamic interaction of quality and risk, Business Intelligence solutions make the procurement agencies operate not only as organizations specializing in transactions but as critical strategic catalysts for improvement in the public sector.

1.1.4 The Necessity for International Governance

Public procurement is marked with significant complexity, including regulatory demands and the necessity to improve data use. While many separate tools and applications are being put in place, government bodies still work in fragmented data silos, discrete report systems, and inadequate risk mitigation processes. Fragmentation creates inconsistencies in decision making, redundant efforts, and weak strategic controls.

To counter these limits, it is critical to create an integrated strategy that meshes technical ability with proven quality assurance and risk management processes. The strength of this strategy is in its ability to integrate disparate data streams, extend process visibility, and systematically include stakeholder requirements with risk mitigation strategies in the planning and execution of procurement.

This thesis presents an integrated approach that brings together three key components - **Power BI**, **Quality Function Deployment (QFD)**, and **Failure Modes, Effects, and Criticality Analysis (FMECA)** to improve how public procurement decisions are made, evaluated, and managed.

At the core is **Power BI**, which acts as the system's real-time intelligence layer. It enables dynamic dashboards, personalized views for different user roles, and seamless tracking of procurement activities over time. This allows procurement teams to monitor key indicators as they unfold, respond quickly to emerging issues, and make data-backed decisions with confidence. Everyone involved whether a procurement officer, finance controller, or auditor has access to the same up-to-date, transparent information.

QFD strengthens this foundation by ensuring that procurement decisions are directly informed by stakeholder needs. It provides a structured way to capture the perspectives of end-users, policymakers, and oversight bodies, and convert those expectations into clear technical criteria and evaluation points. This helps ensure that what is procured not only meets functional requirements, but also aligns with broader institutional goals and public values.

To manage uncertainty and reduce risk, **FMECA** is integrated into the process. It offers a systematic method for identifying where things might go wrong before they do. By scoring risks based on severity, likelihood, and detectability, and calculating a Risk Priority Number (RPN), the system helps prioritize areas needing attention. This is especially valuable in high-value or complex public contracts, where failures can have significant legal, financial, or reputational consequences.

What makes this integration powerful is not just the automation it offers, but the shift in mindset it enables. Instead of viewing procurement as a compliance exercise or administrative task, this

framework positions it as a strategic, data-informed function. It encourages early risk mitigation, cross-functional coordination, and better alignment between policy and execution.

In an era where public institutions are expected to deliver more with less and do so transparently this integrated framework supports smarter, more accountable procurement. It helps governments and public agencies move from reactive problem-solving to proactive planning, while also reinforcing public trust through data-driven decision-making. This aligns with Directive 2014/24/EU, Article 18, which establishes the principles of equal treatment, non-discrimination, and transparency as foundational to all procurement procedures across EU member states.

1.1.5 Regulatory Compliance and Institutional Efficiency

Observance of regulations is not only a matter of law regarding public procurement but is indeed a core method of promoting integrity, fairness, and effectiveness in the use of public funds. In the context of the European Union, the sector is governed by the EU Public Procurement Directives 2014/24/EU and 2014/25/EU. Directive 2014/24/EU, Article 18 mandates that contracting authorities treat economic operators equally and without discrimination, ensuring transparency and proportionality. Furthermore, Article 56 specifies the criteria for qualitative selection and award, and Article 67 allows the use of the 'most economically advantageous tender' (MEAT) method, incorporating quality and lifecycle cost into evaluation thus embedding both legal compliance and strategic procurement. These directives are transposed into national legislation by EU member states. For example, in Italy, through the "Codice degli Appalti" (Public Contracts Code), which aligns national procedures with European standards and ensures legal harmonization.

Compliance goes beyond mere conformance with legal texts. It involves the duty to comply with standards of auditing, procurement thresholds, documentary requirements, and codes of ethics. Public administrations must put in place controls that ensure traceability across the various stages of the procurement cycle, from the publication of tender notice to bid examination, contract award, and supervision during execution. The importance of traceability is even greater when audits are performed by institutions like the Corte dei Conti in Italy and the European Court of Auditors because the latter review the use of public resources against legal mandates and the principles of value maximization.

However, many public institutions suffer from fragmented systems that make compliance a manual and time consuming process. The handling of documents, screening of contractors, and bid analysis are often performed using outdated tools, and thus increasing the possibilities of human mistake, lost records, and slow reporting. This not only risks legal compliance but even hampers the performance of institutions through the redirection of human resources toward administrative activities and away from strategic management.

The business intelligence technology, as embodied in applications like Microsoft Power BI, provides new solutions for the integration of regulatory compliance into electronic procurement.

Power BI provides the ability to create dashboards to monitor regulatory KPIs in real time, including tender close dates, diversity of tenderer participants in the tender process, deviation from budgeted expenditure, and contract execution milestones. Moreover, it provides integration with regulatory databases, automated notifications for potential non-compliance like insufficient bid documentation and contract expirations and security controls at the user level to ensure the sensitive information is accessed and dealt with only by the authorized people.

In addition, the use of formalized data models like SQL or PostgreSQL for backend systems ensures the improved consistency of data inputs and allows validation against predetermined rule sets for regulatory compliance. Such processes include automated checking against mandatory fields, timelines, and regulatory levels, reducing the administrative load for procurement officers. The use of Failure Modes, Effects, and Criticality Analysis (FMECA) in the systems also allows for early identification of possible procedural failure modes like delays in approvals and conflict of interests, which lead to possible legal and reputational exposures.

One of the important aspects of regulatory compliance is related to data protection, especially as per regulations like the General Data Protection Regulation (GDPR). Procurement processes deal with sensitive data, including financial data, bidder identities, and confidential contracts. Introducing GDPR-compliant capabilities like encryption, audit trails, and data retention policies into the reporting tools is the way to ensure public trust and strengthen the legitimacy of institutions.

The mutual dependence of compliance and institutional performance is amply reflected in the use of performance audits and benchmarking studies. Tools like the OECD Methodology for Assessing Procurement Systems (MAPS) show that properly governed procurement institutions record better outcomes in the timeliness, quality, and effectiveness of public spending. Digital reporting systems that ensure regulatory compliance thus necessarily improve institutional performance by minimizing delays, removing redundant checks, and promoting forward-looking decision-making. Overall, the regulation through integration with the digital environment entails more than the mere implementation of the law; instead, it requires the establishment of a culture of accountability, effectiveness, and strategic vision. Its system is designed in the thesis to consolidate the above capacities through the alignment of the analytical capabilities of Power BI with formal data practices and established quality-risk assessment tools. Its method allows public procurement institutions to accomplish their statutory mandates while at the same time improving service delivery and strengthening public trust.

1.1.6 Alignment with the Public Sector's Wider Goals

Public procurement is a vital aspect of commercial activity and a tool for the implementation of strategic policy at the national and regional levels. As public agencies seek greater operational effectiveness, they are increasingly faced with the challenge of moving beyond mere compliance with legal requirements and financial probity, and for methodologies to be at the

forefront of achieving more far-reaching socio-economic and environmental policy goals. This chapter analyzes the degree to which the proposed framework is aligned with these ambitious goals and aims to promote reform while maintaining core principles across the public sector.

A. Transparency and Accountability

One of the core goals of public sector modernization is promoting transparency in the decision-making process. This aligns with Article 18(1) of Directive 2014/24/EU, which establishes the principles of equal treatment, non-discrimination, and transparency throughout procurement procedures. A key feature of deploying a reporting solution based on Power BI is that it supports transparency through dashboards with real-time data and traceable performance indicators. These capabilities enable decision-makers, oversight bodies, and the public to monitor procurement workflows, precluding information asymmetry and deterring unethical conduct. Moreover, built-in traceability supports the documentation requirements emphasized in Article 40, strengthening accountability and audit readiness.

B. Strategic and Sustainable Public Spending

At the international and European Union levels, there is growing emphasis on using public procurement as a lever for sustainable development. In accordance with Article 67 of Directive 2014/24/EU, which allows contracting authorities to evaluate tenders based on the most economically advantageous offer (MEAT), incorporating social, environmental, and innovation-related criteria is legally supported. This study uses Quality Function Deployment (QFD) to translate stakeholder expectations including sustainability goals into measurable evaluation criteria. For instance, environmental impact can be tracked through carbon emission indicators or resource efficiency metrics embedded in technical specifications.

C. Data-Driven Public Administration

In alignment with the EU's vision of digital transformation and smart public administration, this framework provides secure, structured, and scalable data infrastructure to enable evidence-based governance. Through business intelligence techniques, the system supports predictive planning, outcome-based evaluations, and policy responsiveness all consistent with the EU's open data and e-Government initiatives.

D. Risk-Responsive Procurement

Managing procurement risk has become a critical mandate, especially under complex, multi-vendor scenarios. By incorporating Failure Modes, Effects, and Criticality Analysis (FMECA), the system proactively identifies and visualizes procurement vulnerabilities. This reflects the EU's broader strategic intent—as outlined in Recital 89 of Directive 2014/24/EU to improve procurement outcomes through innovation and risk-responsive design.

E. Scalability and Interoperability

Modern public administration requires system interoperability at national and transnational levels. This framework is designed to integrate with platforms such as MEPA (Italy), TED (EU), and GeM (India). The use of open standards (e.g., SQL/PostgreSQL) ensures compatibility with EU-wide procurement reporting, in line with Articles 44 and 56 of Directive 2014/24/EU, which allow for digital tools and structured procedures in the selection and award process.

F. Ethical and Legal Compliance

The framework embeds legal and ethical safeguards throughout the system. It implements role-based access control, data encryption, and audit trails to ensure alignment with the General Data Protection Regulation (GDPR) and with EU public contracting standards. This supports the transparency requirements set out in Articles 18 and 40 of Directive 2014/24/EU, reinforcing legal compliance and minimizing reputational risk.

1.2 Problem Statement

Public procurement is a core element of public administration, impacting the provision of public services, legal compliance, and the effective use of public resources. Despite its vital significance, procurement processes in many government organizations still remain inefficient, information is not well managed, and decisions tend to be reactive. Regional public organizations, with complex tender processes, often lag in sustaining transparency, ensuring quality, and reducing the threat of risks, mainly because of outdated systems and fragmented reportage frameworks.

A major hurdle is the lack of standardized and cohesive data management frameworks. As an example, information related to procurement, from tender advertisement to pre-qualification of the suppliers, performance data, contract-related KPIs, and payment processes, is siloed across different departments and databases. As a result, there is redundancy, manual effort waste, and reduced transparency in the procurement process. And with no single authority overseeing processes, decision-makers lack the capacity to monitor processes in near-real-time, as well as extract valuable insights from historical data.

Also compounding the situation is the use of traditional tools, including spreadsheets and written documents. These tools are typified by high labor requirements and a high rate of errors, along with their inability to provide real-time status and predictive analytics. Inability to adaptively model the factors of risk, monitor stakeholder priorities, and assess the performance of the suppliers hampers strategic management and exposes organizations to legal, financial, and operational exposures.

In addition to technological and organizational barriers, public institutions often lack standardised approaches to quality and risk analysis. Existing processes used to identify procurement breakdowns characterised by delays in delivery, budget overruns, or noncompliance on the part of suppliers are largely reactive in nature. Frameworks like Quality Function Deployment (QFD) and Failure Modes, Effects, and Criticality Analysis (FMECA), although widely applied in manufacturing and engineering domains, still remain underutilised in the public procurement context. The absence of systematised alignment with respect to quality and risk erodes both procurement outcome effectiveness and stakeholder confidence.

Finally, effective use of reporting tools, including those provided by Microsoft Power BI, is hindered by the presence of raw data, blank rows and columns, missing entries, and poorly connected tables. The inconsistencies in the data compromise the validity of visual dashboards and analytical outputs, and hence fuel the challenges linked to the automation and optimization of procurement processes.

To address these challenges, this thesis proposes the integration of Business Intelligence reporting (via Power BI) with quality (QFD) and risk (FMECA) methodologies, underpinned by robust database architecture. This integrated system is designed to enhance procurement governance by offering real-time insights, structured quality alignment, proactive risk management, and compliance with regulatory requirements like GDPR.

1.2.1 Data Inconsistency and Fragmentation Across Procurement Systems

One of the major challenges faced in public procurement administration is inconsistency and fragmentation of procurement-relevant data. Many public organizations have procurement data scattered across multiple disparate systems, spreadsheets, electronic correspondence, and third-party vendor websites. Having such standalone data environments hinders the smooth flow of information across departments and restricts centralized access to important information. Therefore, procurement teams often face redundant administrative issues, time-consuming cross-verification processes, and lack of consistency in reporting formats.

A relevant concern here is the incompleteness of the data entry process, where vital information vendor identification numbers, contract conditions, and delivery schedules are left out either through omission or lack of enforcement of data entry conventions. Likewise, the occurrence of blank rows and columns in raw data could bring about inaccurate interpretations, especially when the omissions are not properly remedied in the extraction and transformation steps.

Even after the use of electronic procurement systems, the integration deficiency is still significant. Weakly linked databases with non-existent or poor foreign keys like tender IDs or supplier IDs lead to fragmented relational data models that create inaccuracies in report

generation, incomplete data visualization, and finally, decisions based on inadequate information.

The data challenges have implications that affect all aspects of the procurement process, from tender design through bidder qualification, contract administration, and compliance monitoring. Without reliable data, procurement professionals cannot properly evaluate the performance of their suppliers, compare actual performance with defined benchmark standards, or detect early warning signs for the possible failure of a project.

In addition, this discrepancy presents serious challenges to transparency and regulation compliance. National procurement codes and the EU Procurement Directives prioritize the requirement for traceable and auditable procurement records. Fragmented and partial data undermines the capacity of an organisation to account for itself in auditing, answer regulatory bodies' questions, or comply with open data publication requirements.

Without a formalized data governance process, data quality is subject to human errors, duplication, version differences, and a lack of accountability. For mitigating the above, it is important that a formalized and systematic data governance process is defined. The use of relational database management systems like SQL or PostgreSQL allows the alignment of procurement records against a predefined schema, maintaining data quality, enabling traceability, and improving readiness for immediate analysis using tools like Power BI.

In conclusion, tackling data fragmentation and inconsistency is foundational to any effort aiming to modernize procurement. It sets the stage for implementing advanced analytics, quality alignment, and risk assessment methodologies thereby enabling public organizations to shift from reactive procurement management to strategic, data-driven decision-making.

1.2.2 Lack of Real-Time Decision-Making and Analytical Tools

In situations where procurement decisions call for a careful balancing of cost savings, regulatory compliance, quality assurance, and stakeholder priorities, swift and effective decision-making is a must. Yet, government agencies tend to resist implementing more dynamic tools that facilitate this kind of agility. The ongoing use of static tools like Excel, PDFs, or manually prepared summaries hinders procurement departments from being sufficiently nimble and strategic in their operation during project execution.

Real-time decision-making is not only needed for strategic decisions such as choosing the compliant bid winner or accepting change orders but for strategic tracking of procurement KPIs including delivery lead times, performance indices for the supplies, budget usage, and exposure to risk as well. Yet, with the constraints of available systems, procurement professionals tend to work with stale or lagged data. By the time differences or variances are detected, corrective action is more costly and less efficient.

The lag in responsiveness poses significant problems in critical or time-sensitive procurement situations, such as the procurement of medical equipment for hospitals, infrastructure maintenance contracts, and emergency service procurement. In such cases, delays can lead to significant business disruption, financial losses, or even jeopardize public well-being. Without analytic insight, procurement organizations take a reactive stance on firefighting problems as they crop up instead of anticipating and mitigating them in advance.

In addition, traditional tools lack advanced functionalities like automated alerts, flexible data filters, predictive analytics, and visual performance dashboards. These functionalities typically exist in higher-end Business Intelligence (BI) platforms, for which Microsoft Power BI is an example, but are not fully leveraged and holistically integrated across the public sector. Even where BI tools are utilized, they are typically detached from real-time data feeds or limited to static financial reporting; in addition, they tend to overlook the integration of non-financial data like supplier risk, contract non-compliance, and inefficiencies across the procurement process lifecycle.

Another important concern is related to the poor use of predictive analytics and data mining of historical information. Lack of use of the tools discourages organizations from drawing lessons from previous procurement stages, identifying failure patterns (repeated delivery delays and contractual disputes with contractors), or predicting possible disruptions ahead of time. Lack of machine learning and statistical forecasting approaches translates to the failure to capture important information that could be used to formulate anticipatory steps.

The difficulty goes beyond the technological realm to include institutional competencies. Procurement personnel may lack sufficient training in analytic interpretation, and organizational structures may be unable to integrate or act on real-time intelligence effectively. Without proper change management and system integration, even the best tools will be used suboptimally.

Therefore, to enable real-time, data-driven decision-making, public procurement systems must incorporate the following:

- A centralized database with live data connectivity;
- BI dashboards that are updated automatically and customized per user role;
- Embedded risk visualization tools such as heatmaps and alert mechanisms;
- Scenario-based forecasting models for procurement planning;
- Integration with quality (QFD) and risk (FMECA) frameworks for comprehensive oversight.

The deployment of these capabilities can significantly reduce response times, enhance transparency, and allow procurement professionals to take proactive actions. It also facilitates

the measurement of performance benchmarks, the reporting of results to stakeholders, and the preparation for regulatory audits making procurement a responsive and accountable public service rather than a procedural roadblock.

1.2.3 Insufficient Quality and Risk Integration in Procurement

Modern assessments of government procurement processes include not just financial and compliance aspects but a more comprehensive range of quality and risk factors relating to operational resilience, stakeholder satisfaction, and the achievement of policy objectives like transparency and sustainability. Nevertheless, for the vast majority of government institutions, quality assurance and risk management frameworks are still underdeveloped and indeed are not yet in place.

One serious constraint involves the lack of systematic and rational methods for converting stakeholder requirements into buying specifications. Often, the contract documents and the related assessment parameters are prepared in the absence of careful critical analysis of the requirements, and the ensuing outcomes either end up being too vague or do not represent the actual end-users' legitimate requirements. What this indicates is that the requirement-specification discontinuity translates into the fact that while the project deliverable is technically appropriate, the end goal is neither achieved with respect to the expected benefits regardless of adherence to delivery schedules, quality of service, and environmental compatibility.

Quality Function Deployment is a common methodology in the field of engineering and project design that allows the transformation of stakeholders' inputs into technical requirements directly related to procurement processes. Its use in the procurement process is, however, limited because of a lack of appropriate levels of knowledge, understanding, and technical know-how. Consequently, procurement efforts tend to ignore strategic performance considerations, such as sustainability aspects, quality of service delivery, and the significance of innovation factors important in determining the long-term effectiveness of the procurement outcomes.

In contrast, the public procurement processes that relate to the management of risk typically exhibit a reactive approach. Organizations address shortages and failure to comply only after they occur, rather than proactively including the former as inputs in the bidding and planning processes. No extensive study of the Failure Modes, Effects, and Criticality Analysis (FMECA), a method known to be effective in past usage in the context of industrial and systems engineering, has been conducted for this particular context. The procedure provides a formalized process for establishing probable failure modes, assessing their effects and chances of occurrence, and applying related countermeasures.

The situation is complicated further by the lack of universally standardized platforms for the visualization and handling of quality and risk metrics. Procurement teams are at a loss in the

absence of centralized dashboards or matrix-based report systems, and they run into challenges while tracking probable failure risks, quality deviation, and open corrective actions. Additionally, this situation impedes the process of internal auditing because the quality and risk-related documents are fragmented and not easily accessible in standard formats.

Furthermore, the existence of fragmented data systems and separate frameworks of reporting lessens the utility of oversight. Lack of a unified system designed to bring together supplier assessments, monitor performance, and initiate compliance records hinders the capacity to assess vendor trustworthiness or conduct required procurement performance reviews.

The consequences of these limitations are far-reaching:

- Frequent contract amendments due to vague specifications.
- Supplier disputes over unclear performance expectations.
- Inability to forecast or mitigate disruptions.
- Non-alignment with EU regulatory priorities on value-for-money and lifecycle costing.

To overcome the above inadequacies, the integration of QFD and FMECA with a Power BI-based procurement system is suggested in this thesis. QFD will be utilized to map stakeholders' requirements across the procurement process to achieve quality alignment at every stage. Early identification and prioritization of the resultant risks will be facilitated using FMECA and incorporated into dashboards as visual indicators or as heatmaps.

The integration of the tools into a Business Intelligence system will facilitate the tracking of quality objectives, evaluation of supplier-associated risks, and the establishment of continuous improvement processes. The transition from a reactive to proactive style of management will guarantee heightened accountability within the public sector, enhance the implementation of contracts, and promote greater public confidence in public procurement processes.

1.2.4 Fragmented Data Ecosystems and Technical Limitations

A major impediment to the evolution of public procurement systems is the fragmented nature of data ecosystems that are separate across different departments, stages of the procurement process, and electronic systems. Even with efforts for the digitalization of public administration, procurement information is often found in separate departmental silos in the form of sets of spreadsheets, standalone databases, and even occasionally in paper form. Such a lack of integration drastically hampers the handling, analysis, and use of information that is related to the procurement process.

Procurement data is a wide-ranging term, covering tender notices, bid postings, vendor information, contract terms, delivery schedules, compliance data, and performance metrics. Yet

with the presence of differing database schemas and a lack of interoperability, the datasets often do not come with commonly identifiable names or consistent taxonomies. As a result, cross-matching is practically impossible except through manual intervention, and the problems of duplication, inconsistencies in versions, and poor reporting arise.

There are many government agencies using outdated tools like Excel spreadsheets for crucial procurement tasks including bid analysis and the monitoring of performance. These manual tools are prone to several technical issues:

- **Incomplete Data Entry:** Missing fields, skipped forms, and incorrectly recorded entries are commonplace.
- **Empty Rows and Columns:** Due to non-standardized templates and inconsistent form usage, essential data often goes unfilled or is recorded outside the intended format.
- **Improper Linking of Databases:** Data such as supplier profiles and contract performance metrics often reside in unlinked tables or systems, impeding comprehensive analysis.

The challenges in handling the technical aspects are further compounded by inadequate information technology infrastructure and ineffective governance related to procurement data. The limited access to systems with the critical features, including role-based access controls, encryption, or audit trails, greatly increases concern for the confidentiality of data as per the General Data Protection Regulation (GDPR). Bid pricing and assessments of the performance of vendors are often vulnerable to unauthorized access because of the lack of proper access controls.

Further, legacy systems will experience interoperability constraints linked with dynamic data exchange protocols like APIs, which limit their ability to interact with outside platforms like Italy's electronic procurement system, known as MEPA, and with the European Union's Tenders Electronic Daily, known as TED. The lack of interoperability drastically lowers the chances for automating, benchmarking, and comparative procurement analysis across regions. The fragmented nature of procurement data hinders the use of powerful data analytics and visualization tools. Instruments like Power BI are hampered in the ability to make effective dashboards and perform the analysis of trends because of the lack of harmonized, normalized, and consolidated data sets. Subsequently, procurement decisions are often based upon intuition or human judgment, or even from erroneous data visualizations, with significant gaps in operational effectiveness and strategic insight.

To address these issues, this thesis proposes the design of a centralized relational database using SQL/PostgreSQL, integrated with ETL (Extract, Transform, Load) pipelines to clean, standardize, and consolidate procurement data. This structure will:

- Facilitate accurate linking of supplier, tender, and contract records.

- Eliminate duplication through normalization and enforced data integrity.
- Provide the necessary foundation for real-time Power BI dashboards.

By reducing technical fragmentation, the new framework has the ability to leverage procurement data as a strategic asset of paramount significance, rather than a possible threat. This is believed to facilitate greater transparency and efficiency, with public sector agencies gaining the ability to attain regulatory compliance, efficient proactive threat mitigation, and enhanced delivery outcomes.

1.2.5 Gaps in Risk and Quality Integration

A persistent challenge in public procurement systems is the insufficient integration of quality assurance and risk management mechanisms within the procurement lifecycle. Although the regulatory framework across the European Union transposed into national legislation, including Italy's "Codice degli Appalti" mandates compliance with principles of transparency, equal treatment, and non-discrimination as enshrined in Directive 2014/24/EU, Article 18, the actual operationalization of systematic risk and quality methodologies remains limited.

In conventional procurement settings, quality assurance is predominantly reactive. It is often restricted to basic compliance checklists or preliminary supplier qualification procedures, which do not adequately capture the complex, multidimensional quality expectations of modern public contracts. These expectations encompass not only compliance with technical specifications but also stakeholder satisfaction, adherence to service-level agreements (SLAs), and environmental performance metrics. Directive 2014/24/EU, Article 67, which governs contract award criteria, encourages the consideration of qualitative aspects such as life-cycle costing and sustainability but these dimensions are frequently underutilized in practical evaluation frameworks.

Similarly, risk assessment in procurement tends to be post facto and fragmented. Common failure modes such as delivery delays, material defects, or deficiencies in contract oversight are typically identified only after they manifest operationally. This reactive posture precludes early mitigation efforts and amplifies institutional exposure to preventable risks. The directive provides avenues for proactive planning; Article 40 permits preliminary market consultations to anticipate risks and gather intelligence, while Article 44 outlines the formulation of technical specifications that may embed performance and risk parameters. However, these provisions are not yet mainstreamed in many procurement routines.

Moreover, a structural gap exists between data management systems and the application of quality risk methodologies. Procurement databases are often not designed to capture and link stakeholder requirements to final outcomes, nor to track the evolution of risk factors across procurement cycles. This disconnect impairs visibility and inhibits strategic oversight. In the absence of structured tools such as Quality Function Deployment (QFD) for aligning stakeholder priorities, and Failure Modes, Effects, and Criticality Analysis (FMECA) for quantifying and

ranking procurement risks, public agencies struggle to embed preventive quality and risk practices into procurement workflows.

Additional problems arise due to:

- Absence of real-time risk dashboards that track procurement performance against key risk indicators.
- Inability to prioritize risks based on severity, probability, and detectability, which results in misallocated resources.
- No linkage between end-user feedback and procurement redesign, preventing continuous improvement loops.

QFD allows for translating stakeholder needs into procurement specifications and technical metrics, thereby ensuring alignment between procurement actions and end-user expectations. FMECA complements this by identifying critical failure points and assigning risk priority numbers (RPNs), which help in prioritizing responses and allocating resources for mitigation.

Without these tools, public procurement systems lack the precision and foresights needed to effectively deal with complex tender situations. This creates a lack of alignment with strategies, less stakeholder satisfaction, and recurring operational interruptions.

This thesis addresses these deficiencies by proposing an integrated framework that incorporates QFD and FMECA methodologies directly into the procurement reporting structure using Power BI. By doing so, it enables:

- Visual mapping of stakeholder priorities.
- Continuous monitoring of procurement quality.
- Dynamic identification and prioritization of procurement risks.

The goal is to move public procurement away from being mainly a compliance device into being a strategic tool of government, something that delivers quality while promoting resilience to future dangers.

Without structured methodologies such as Quality Function Deployment (QFD) and Failure Modes, Effects, and Criticality Analysis (FMECA), there is little assurance that quality standards are being systematically embedded or that risk factors are being prioritized effectively.

These integration gaps are methodically addressed through the BI–QFD–FMECA framework presented in Chapter 4.

1.2.6 Data Governance and Security Challenges in Procurement Systems

There is a growing use of web-based platforms to monitor the procurement process in modern public administration, and data security and governance become critical considerations as a result. Procurement systems operate with vital and sensitive information, including financial proposals, contractor evaluations, legal contracts, regulatory compliance records, and strategic confidential material. Failure to secure such information leaves it open to alteration, breaches, and loss and opens public bodies up to legal, financial, and reputational hazards.

Despite this challenge, various public procurement frameworks suffer from gaps in data governance standards. A common weakness is the occurrence of incomplete data entries and discrepancies. Tender documents often come with blank columns and rows, and assessments of the suppliers might include blank rows and columns in the performance matrices. The occurrence of erroneous and incomplete data creates analytical gaps and lowers the precision of the report systems, especially in situations demanding timely decision-making.

Aside from data inaccuracies, the lack of cohesive database integration across different departments is responsible for the development of disparate information silos. Often, departments like procurement, legal, finance, and project management use different tools with different schemas that are not synchronized. Lack of database interoperability lessens overall transparency and results in redundant efforts. Additionally, this increases the chances that decisions will be based on dated or incomplete information.

In addition to this, significant hurdles are faced in data access administration. Most legacy systems do not incorporate role-based authorization capabilities; therefore, sensitive data is accessible to unauthorized staff or not accessible to critical decision-makers and stakeholders requiring immediate access. This lack of sufficient access controls is directly counter to the requirements of the GDPR (General Data Protection Regulation) and similar data protection law, which requires robust controls over people's permissions to access and change sensitive and confidential data.

Another aspect of the risk is related to the absence of data backups and encryption mechanisms. Most important is that public procurement data is protected from unauthorized access as much as from accidental loss through system crashes, power cuts, or cyber-attacks. If encrypted storage mechanisms, secure network communications, and adequately backed-up data are not available, procurement process integrity is constantly under threat.

Furthermore, the traceability and auditability dimensions are often underdeveloped. Perhaps there is too little documentation showing evidence of access to certain data, sanction of certain decisions, or the time when procurement documents were changed. Such circumstances hamper public sector procurement accountability and make the process of internal auditing and outside investigations more complicated.

The existence of security weaknesses impedes innovation. Advanced tools like Power BI operate based on data that is dependable and high quality. Fragmentation databases lead to inconsistencies that negatively affect the precision and functionality of dashboards, predictive analysis, and visual representations used in the assessment of risks.

Given these challenges, strengthening data governance must be a strategic priority. A robust procurement system should include:

- Standardized data entry protocols with mandatory fields and validation checks.
- Integration of relational databases using structured schemas and referential integrity rules.
- Implementation of role-based access controls (RBAC) to limit data exposure.
- Encryption of both data-at-rest and data-in-transit.
- Audit trails to track user activity and ensure traceability.
- Automated backups and disaster recovery protocols.

This study explores the intricacies involved in data governance through the development of a secure and controlled data management system that employs PostgreSQL in the management of relational databases, in addition to Power BI for data visualization and reporting. The system ensures data security, traceability, and integrity to improve organizational decision-making while also meeting the institution's data protection requirements.

1.3 Research Objectives

In the current landscape of public procurement, organizations are increasingly required to operate with greater transparency, efficiency, and accountability. However, most public entities still rely on fragmented systems and manual reporting tools that are ill-equipped to meet the demands of complex procurement environments. Issues such as incomplete data entries, disjointed databases, and the absence of structured quality and risk evaluation frameworks have rendered many procurement systems reactive rather than proactive.

This thesis seeks to overcome these systemic challenges by designing and implementing an intelligent reporting system built on Microsoft Power BI, supported by robust backend data management and enriched through the integration of Quality Function Deployment (QFD) and Failure Modes, Effects, and Criticality Analysis (FMECA). The research aims to deliver a

comprehensive solution that not only streamlines data reporting but also strengthens strategic decision making, compliance, and risk governance across the procurement lifecycle.

To achieve this overarching vision, the following detailed objectives guide the course of this study:

Object 1: Assess the Current Procurement Data Ecosystem

- Investigate how procurement data is generated, collected, and stored across departments.
- Identify inefficiencies including:
 - Fragmented datasets.
 - Incomplete or inconsistent entries (e.g., empty cells, missing supplier names).
 - Improper or missing database links across tables.
 - Manual reporting dependencies (e.g., Excel).
- Evaluate how these inefficiencies impact reporting speed, data accuracy, and decision-making.
- Conduct interviews with procurement personnel to understand real-world bottlenecks and workflows.

Objective 2: Develop a Centralized and Secure Relational Database

- Build a scalable, normalized relational database (using SQL/PostgreSQL) to house procurement data.
- Implement role-based access control and data encryption for privacy and regulatory compliance (e.g., GDPR).
- Design schema structures to capture tender details, supplier records, KPIs, timelines, and audit logs.
- Enable smooth integration with Power BI via ETL pipelines.

Objective 3: Design and Build Real-Time Power BI Dashboards

- Create tailored dashboards for different roles (e.g., managers, auditors, finance).

- Present critical procurement insights: bid timelines, cost metrics, supplier performance, and compliance status.
- Integrate real-time refresh, interactive filtering, and drill-down capabilities.
- Enhance usability through intuitive layouts and custom KPIs.

Objective 4: Integrate Quality Function Deployment (QFD) into Procurement Evaluation

- Use QFD to convert stakeholder needs into quantifiable procurement metrics.
- Map technical specifications to stakeholder expectations using the House of Quality (HoQ).
- Embed QFD matrices in Power BI to support transparent decision-making during evaluations.

Objective 5: Apply FMECA for Structured Risk Analysis

- Identify procurement-specific failure modes such as:
 - Miscommunication in tender specs.
 - Supplier underperformance.
 - Legal disputes over contract clauses.
- Score risks by severity, occurrence, and detectability.
- Visualize risks via Power BI dashboards using heatmaps, trend lines, and status indicators.

Objective 6: Evaluate the System's Effectiveness through Case-Based Testing

- Use historical and simulated data to validate the reporting system.
- Measure improvements in:
 - Decision-making speed.
 - Risk identification accuracy.

- Reduction in manual workload.
- Collect feedback from users and stakeholders to assess practicality and usability.

Objective 7: Assess System Scalability, Adaptability, and Future Potential

- Evaluate how the system can be expanded to other public enterprises or regions.
- Investigate interoperability with MEPA (Italy) and TED (EU).
- Explore future enhancements including:
 - AI-based risk forecasting.
 - Natural Language Processing for automated document parsing.
 - Blockchain for audit trails or digital contracts.

1.4 Scope and Limitations

Public procurement systems are essential for ensuring the responsible and efficient allocation of public funds. However, achieving transparency, strategic oversight, and risk-resilient operations in procurement requires more than regulatory compliance—it necessitates the integration of digital solutions, structured data systems, and analytical methodologies. This research project is framed within this challenge.

The present thesis is aimed at designing and testing a Power BI-based decision-support system integrated with a secure SQL/PostgreSQL relational database, enhanced by two analytical quality frameworks - Quality Function Deployment (QFD) and Failure Modes, Effects, and Criticality Analysis (FMECA). The system targets the key needs of real-time procurement reporting, quality alignment, risk detection, and data security within the context of public sector tenders.

This section outlines the boundaries of the research (scope), the constraints encountered (limitations), and the strategic exclusions (delimitations) chosen to maintain focus.

1.4.1 Scope of the Study

The scope of this study is defined by the technological and managerial challenges associated with procurement reporting and decision-making in public organizations. It focuses on the design, development, and testing of an intelligent procurement dashboard system using Power BI, supported by a structured, secure, and centralized data management architecture.

The main focus is a public company owned by Regione Piemonte, which handles complex procurement processes ranging from infrastructure tenders to hospital material acquisition and service outsourcing. Given the operational scale and diversity of stakeholders involved, the organization presents a suitable context for exploring technology-enhanced procurement governance.

This study includes the following core elements:

1. Centralized Database Design

Creation of a normalized, relational database using SQL/PostgreSQL to consolidate procurement information—such as supplier data, tender timelines, contract terms, and performance metrics. The system is developed with role-based access control, encryption protocols, and compliance with GDPR standards to protect sensitive procurement information.

2. Power BI Dashboard Development

Implementation of **interactive dashboards** customized for various stakeholders (procurement officers, legal teams, auditors, financial controllers) to monitor procurement KPIs. The dashboards include:

- Supplier performance tracking
- Budget vs. actual spend comparisons
- Timeliness of deliveries and milestones
- Contract compliance indicators
- Real-time alerts for anomalies or delays

3. Integration of QFD (Quality Function Deployment)

Use of QFD to map stakeholder requirements such as delivery reliability, sustainability goals, or service quality into procurement evaluation criteria. This allows for alignment between project specifications and actual needs.

4. Application of FMECA (Failure Modes, Effects, and Criticality Analysis)

Introduction of FMECA within the reporting system to proactively identify potential procurement failures such as bid errors, supplier underperformance, or delivery delays and prioritize them based on severity and detectability.

5. Real-Time Decision Support

Provision of **live analytics**, alerts, and visualizations that allow decision-makers to intervene early in procurement cycles, ensuring compliance, risk control, and effective

resource allocation.

6. Security and Governance Compliance

Implementation of structured data governance protocols, ensuring traceability, auditability, and compliance with data protection laws such as the GDPR.

7. Scalability and Replicability

Although the study focuses on a specific regional public organization, the system is designed to be scalable and adaptable to:

- Other regional procurement authorities in Italy
- National procurement systems such as MEPA
- Supranational platforms like TED (Tenders Electronic Daily)

By focusing on these dimensions, the research addresses a pressing gap in public procurement: the need for integrated, secure, and quality-aligned reporting systems that support real-time decision-making and long-term accountability.

1.4.2 Limitations of the Study

While this research proposes an advanced reporting and analytical framework for public procurement, it is important to recognize the boundaries and practical constraints that shape its implementation and generalizability. These limitations reflect the operational, technical, institutional, and methodological challenges encountered during the development and testing of the proposed Power BI-based system.

1. Data Availability and Confidentiality Constraints

The quality and completeness of procurement data are pivotal to the accuracy of reporting systems. However, due to legal, institutional, and ethical concerns, access to sensitive procurement records including financial bids, supplier evaluations, and contract audit trails was limited during the study. Several records had to be anonymized or substituted with simulated datasets, reducing the authenticity and complexity of certain analytical tests. Additionally, GDPR compliance restrictions prevented unrestricted integration of personally identifiable or financial data into Power BI dashboards.

2. Scope Limited to Reporting and Visualization

This study is strictly focused on reporting, data visualization, and analytical alignment with quality and risk parameters. It does not cover other critical procurement activities such as:

- Contract negotiation and legal drafting
 - Post-award contract execution and monitoring
 - Supplier onboarding and market analysis
- While these are vital to overall procurement efficiency, their integration lies outside the scope of the current reporting system and remains a subject for future research.

3. Exclusion of Advanced Predictive Analytics and AI Models

The system does not incorporate AI-driven predictive analytics, machine learning algorithms, or natural language processing tools, which could further enrich risk forecasting and document analysis. While these technologies are recognized as valuable for long-term development, their inclusion was limited by time, skill, and infrastructure constraints. The thesis focuses on structured logic based analytics (QFD and FMECA), with the possibility of AI integration flagged for future enhancement.

4. Technical Constraints Related to Legacy Systems

The proposed system assumes the availability of digital data and basic infrastructure (e.g., structured databases, Power BI licenses). In reality, many public institutions still operate legacy systems with poor interoperability, inconsistent data schemas, and outdated software. As a result, the deployment of the system in some government bodies may require significant upfront data cleansing, infrastructure modernization, and staff training, which was beyond the direct control of this study.

5. Limited Geographic and Institutional Focus

This research is based on the procurement ecosystem of a public enterprise under Regione Piemonte, and while the system is designed to be scalable, institutional variations in legal interpretation, stakeholder roles, digital maturity, and cultural practices may limit direct adoption elsewhere without customization. Comparative testing across multiple government agencies or in different national contexts was not feasible within this project's timeframe.

6. Time-Bound Testing on Limited Case Studies

Due to project duration constraints, the system was tested on a limited number of historical and hypothetical procurement cases. Large-scale longitudinal evaluations or real-time piloting over multiple procurement cycles were not conducted. This affects the ability to generalize findings or quantify long-term performance impacts such as cost savings, risk reduction, or supplier responsiveness.

7. Organizational Change Management Not Addressed

Successful implementation of the system depends not only on technology but also on organizational buy-in, training, and change management frameworks. These aspects, including user resistance, policy realignment, or incentives for adoption, were acknowledged but not addressed in this thesis, as the focus was primarily on technical system development and functionality testing.

1.4.3 Delimitations

Delimitations refer to the boundaries intentionally set by the researcher to narrow the scope of the study and maintain focus on the core research problem. These are not limitations imposed by external constraints, but rather strategic decisions taken to ensure manageability, feasibility, and depth of analysis within the allocated time, institutional support, and research resources.

1. Focus on Reporting, Not Full Procurement Lifecycle

This thesis exclusively concentrates on the data reporting and analytical components of public procurement. The full procurement lifecycle—including market research, supplier engagement, contract negotiation, and post-award contract management—is not within the scope of this study. These stages, although critical, fall outside the purview of a reporting and decision-support framework and would require separate process reengineering and domain expertise.

2. Exclusion of ERP and Automation Systems

Enterprise Resource Planning (ERP) systems and Robotic Process Automation (RPA) platforms are increasingly used to manage procurement workflows. However, this study deliberately excludes automation tools and ERP modules such as SAP Ariba, Oracle Procurement Cloud, or Microsoft Dynamics. Instead, it focuses on open and widely accessible technologies, such as Power BI and PostgreSQL, to maximize applicability in low-resource public sector environments.

3. Geographic and Jurisdictional Scope

The study centers on a government-owned enterprise operating in the Piemonte region of Italy, reflecting the legal, regulatory, and procedural context of Italian and EU public procurement frameworks. While the system is built to be scalable and adaptable, no claims are made about its direct applicability in non-EU legal jurisdictions or under procurement systems based on different legislative models, such as the U.S. FAR (Federal Acquisition Regulation) or UK's Public Contracts Regulations.

4. Use of Predefined Analytical Methodologies

This research employs Quality Function Deployment (QFD) and Failure Modes, Effects, and Criticality Analysis (FMECA) as the primary methods for embedding quality and risk assessment into the reporting framework. Other quality or risk assessment frameworks—such as Six Sigma

DMAIC, Monte Carlo simulations, or ISO 31000 risk standards—are not explored within this study. This delimitation is based on methodological consistency and the compatibility of QFD/FMECA with dashboard-based visualization tools.

5. Tools Chosen for Accessibility and Scalability

Only non-proprietary, widely used technologies were chosen for system development: Microsoft Power BI for visualization and PostgreSQL for back-end data handling. Other commercial Business Intelligence platforms (e.g., Tableau, QlikView, IBM Cognos) or cloud-based data warehouses (e.g., AWS Redshift, Snowflake) were intentionally excluded to maintain accessibility, reduce deployment cost, and ensure long-term sustainability of the system in public sector institutions.

6. Simulated and Historical Data Use

Due to confidentiality and GDPR compliance, the study utilizes historical procurement records (where permissible) and simulated datasets created based on realistic procurement scenarios. No live tenders or ongoing contracts were directly embedded into the study to avoid data breaches and conflicts of interest. As a result, system performance was tested in a controlled environment, which may differ slightly from real-time implementation dynamics.

7. Exclusion of Ethical Audits and Supplier Due Diligence

Although regulatory compliance and transparency are part of the dashboard KPIs, ethical audits, anti-fraud mechanisms, and in-depth supplier background checks were not included as modules within the reporting system. These require specialized investigative frameworks and legal processes beyond the capabilities of the BI system proposed.

Summary of Delimitations:

Area	Delimitations
Procurement Scope	Focus on reporting, not full procurement lifecycle
Tools	Power BI & PostgreSQL only; ERP and automation tools excluded
Jurisdiction	Focused on Italy and EU legal context
Methods	QFD and FMECA used exclusively
Data	Simulated and anonymized data only
Ethics	Ethical auditing and due diligence not included

Table 1.1 - Summary of Delimitations

Chapter 2: Literature Review

2.1 Theoretical and Conceptual Foundations

The theoretical foundations of public procurement have been subject to paradigm shifts from transactional to those involving strategic planning, digitalization, and governance reforms. The traditional view of procurement as being compliance-oriented and bureaucratic has increasingly been replaced with more innovative and results-oriented approaches. This has been influenced by calls for greater accountability, the need to deliver greater value for money, and recognition of the impact of procurement on social, environmental, and economic ends.

In addition, the conceptual frameworks used to understand and manage procurement have shown increased development. The use of Business Intelligence (BI), Quality Management Systems, and diverse risk analysis methodologies has turned procurement from an isolated departmental function to an intrinsic part of overall institutional performance. The concepts such as Total Quality Management (TQM), Strategic Procurement Planning (SPP), and Integrated Risk Management (IRM) have now enriched conventional procurement cycles, hence assisting to bring procurement closer to organizational aims, stakeholder needs, and external regulatory requirements.

Additionally, the digitalization of procurements indicates not only technological growth but also structural change. The change includes integration of the handling of data, automation of processes, and analytical and visualization technologies with a decision-support system. Technologies such as Microsoft Power BI, relational databases, and algorithms for data mining play a key role with respect to such integration. Coupled with structured methods such as Quality Function Deployment (QFD) and Failure Modes, Effects, and Criticality Analysis (FMECA), such technologies enable greater transparency, strategic congruence, and procurement risk mitigations.

The theoretical underpinnings of this thesis therefore lie at the crossroads where classical procurement governance meets developing practices, underpinned by data science, stakeholder management, and risk-informed planning. The theoretical underpinnings of each element are further clarified in the following sections, starting with the changing role of procurement in the contemporary public sector.

2.1.1 Public Procurement in the Modern Public Sector

Public procurement has become an important instrument through which governments deliver public services and meet their economic, environmental, and social policy aims. The Organisation for Economic Co-operation and Development has reported that, on average, public procurement represents between 12% and 15% of the member state's Gross Domestic Product

and is, therefore, among the largest areas of public spending. At the EU level, procurement is estimated to reach more than €2 trillion per year and, therefore, has an even stronger influence on domestic markets and the overall economic context.

Procurement systems have traditionally been designed to ensure strict compliance with procedures and to deliver cost-effectiveness following relevant rules and legislation. These principles remain valid; yet, the modern vision of procurement is much larger. Modern procurement systems are not only expected to deliver goods and services economically but to drive innovation, sustainability, and inclusive growth at the public sector level.

The changing role of procurement is best seen through such policy approaches such as Green Public Procurement (GPP), Socially Responsible Public Procurement (SRPP), and Innovation-Oriented Procurement. These approaches help public organizations consider life-cycle costing, environmental performance, and diversity of suppliers, along with the conventional aspects of price and terms of delivery. For instance, GPP promotes the procurement of ecologically sustainable products and services, while SRPP supports the engagement of small and medium-sized enterprises, social cooperatives, and firms employing vulnerable groups.

At the organizational level, procurement organizations, including the Italian Consip S.p.A., and framework agreements through platforms such as MEPA (Mercato Elettronico della Pubblica Amministrazione) help public authorities achieve economies of scale, reduce administrative burdens, and increase competition. Additionally, these agencies are key hubs for procurement modernization programs through the provision of e-procurement platforms, pre-formatted templates, and electronic contract management solutions.

In spite of these innovations, many public organizations continue to suffer from inefficiency in their operations. Aligned but disparate information systems, limited interoperability, and the lack of quality assurance controls slow down the attainment of procurement's potential. Additionally, procurement mechanisms in the public sector often fail to incorporate real-time analysis, cross-departmental linkage of data, and predictive modeling capability all of which are critical to the enablement of smooth governance of complex procurement processes.

Scholarly work emphasizes the need for adding procurement reform through the use of data-informed practices and performance-outcome assessments. Thai (2001) identifies organizational capability, transparency, and accountability as key drivers of efficient procurement, while Knight et al. (2007) support an overarching strategy where procurement performance is linked to the overall efficacy of institutions.

In this regard, the utility of digital decision-support technologies is of utmost significance. Tools like Power BI enable procurement teams to track the position of tenders, monitor suppliers' compliance, and review key indicators in the moment. These technologies enable organizations to move away from the traditional reactive information-gathering response to the proactive decision-making framework, where they can predict interruptions, review the performance of suppliers, and detect irregularities.

Furthermore, when coupled with structured methodologies like QFD and FMECA, BI tools allow public organizations to move from procedural procurement to stakeholder-oriented, risk-sensitive procurement systems. This integration ensures that public spending not only meets legal requirements but also delivers measurable public value.

Public procurement now goes beyond the acquisition of products and services. It means managing the intricacies, maximizing the effects, and ensuring that public funds are wisely expended, distributed evenly, and used in ways strategically supportive of long-term institutional needs and of the desires of the people.

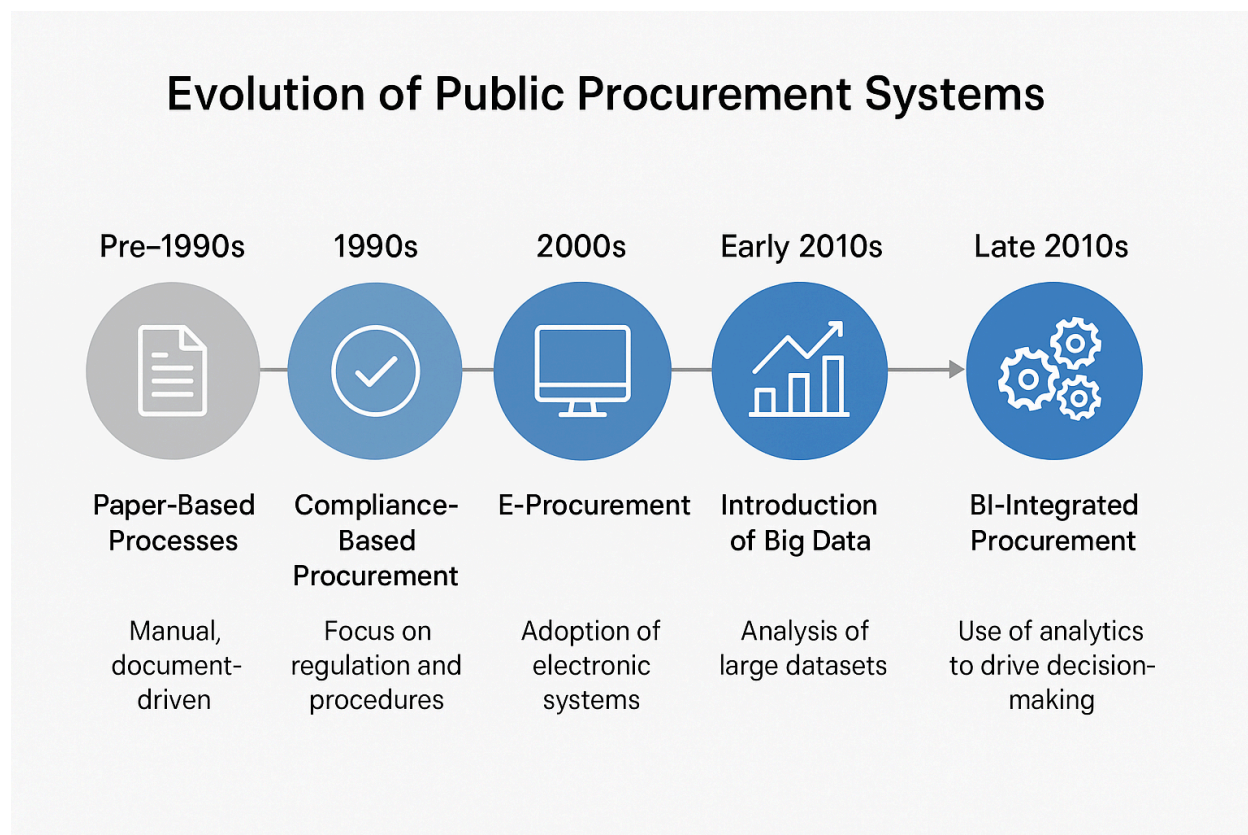


Figure 2.1 – Evolution of Public Procurement Systems

2.1.2 Digital Transformation and E-Procurement Systems

The modern hallmark of governance is marked by the digitalization of public administration, with public procurement serving as a key arena for this development. Governmental authorities increasingly recognize the efficiency, transparency, and accountability gains offered by electronic procurement (e-procurement) platforms. This transformation extends beyond the mere digitization of documents it entails the re-engineering of the entire procurement process, from planning and sourcing through to contracting and contract implementation, using integrated technological solutions.

E-procurement refers to the use of internet-based and digital technologies to execute procurement activities. The expansion of e-procurement systems across EU member states is strongly supported by Directive 2014/24/EU, Article 22, which mandates the use of electronic means of communication in procurement procedures. This policy aims to lower transaction costs, broaden access to tender opportunities, and improve procedural transparency.

Consistent with this evolution, centralized e-procurement platforms have emerged as pivotal enablers. A prime example is Italy's MEPA (Mercato Elettronico della Pubblica Amministrazione), a national-level online marketplace facilitating public procurement operations. These platforms support a full range of activities including tender publication, supplier registration, bid submission, proposal evaluation, and contract awarding—all conducted electronically. As emphasized in Article 5 of Directive 2014/24/EU, which outlines general principles of transparency and equal treatment, such platforms enhance the accessibility of opportunities for small and medium-sized enterprises (SMEs), while increasing competition and reducing entry barriers.

From a systems architecture perspective, e-procurement platforms integrate multiple procedural modules, each supported by independent databases. These may include vendor registries, contract lifecycle management tools, financial accounting systems, and administrative portals. However, interoperability remains a key challenge, as many modules are hosted on heterogeneous systems lacking real-time data exchange capabilities.

Achieving seamless communication across these systems requires the adoption of interoperability standards, well-defined API (Application Programming Interface) structures, and shared data normalization protocols. Such integration is crucial for connecting e-procurement platforms to external databases, including fiscal registries, supplier compliance databases, and EU-wide notice boards such as Tenders Electronic Daily (TED). Integration with Business Intelligence (BI) platforms such as Microsoft Power BI significantly enhances analytical capacity, enabling real-time reporting, strategic planning, and risk management.

Digitally mature e-procurement systems offer a range of documented benefits:

- **Speed and Efficiency:** Automated workflows reduce the administrative burden associated with tendering and evaluation.
- **Auditability:** Electronic records provide end-to-end traceability, aligning with Article 84 of the Directive, which requires thorough documentation of procurement decisions.
- **Data Quality and Validation:** Digital interfaces support input validation, ensuring accuracy and completeness in submitted documentation.
- **Real-Time Monitoring:** BI integration supports tracking of key procurement performance indicators (KPIs) such as delivery lead times, cost adherence, and contract modifications.

- **Supplier Accessibility:** Online systems facilitate broader participation, particularly among SMEs, thereby promoting diversity and innovation in procurement markets.

Nonetheless, the deployment of digital procurement systems is not without its challenges. Common barriers include legacy IT infrastructure, limited staff capacity, and institutional resistance to change. Moreover, the handling of procurement data must comply with privacy and cybersecurity regulations such as the General Data Protection Regulation (GDPR), necessitating the incorporation of encryption, role-based access controls, and comprehensive audit logs.

Furthermore, the success of digital procurement platforms depends on their ability to serve as enablers of strategic policy, rather than mere transactional tools. This entails robust governance arrangements, the implementation of measurable performance indicators, and alignment with broader public-sector agendas related to sustainability, innovation, and fiscal prudence.

In summary, digital transformation in procurement represents a shift from static, compliance-based operations to dynamic, data-informed governance. The role of procurement is being redefined as an integrative, strategic function. The incorporation of Power BI dashboards, Quality Function Deployment (QFD), and Failure Modes, Effects, and Criticality Analysis (FMECA) exemplifies this new paradigm where real-time data, stakeholder alignment, and proactive risk management become foundational to effective public procurement.

2.1.3 Decision-Support Systems and Power BI

Decision-support systems are a cutting-edge technology solution to increase the transparency, efficiency, and overall quality of decision-making practices applicable to the public and private sectors. The complexity of public procurement, involving the presence of numerous proposals, many stakeholders, and the need to wisely spend public funds, requires the introduction of strong and transparent decision-support systems.

Decision-support system is generally defined as an automated system used to collect, analyze, and disseminate information with the specific purpose of aiding decision makers to make informed and wise decisions. Decision-support systems generally integrate several components, such as database management systems, analytical structures, user interfaces, and knowledge bases, to support semi-structured and unstructured decision-making processes. Decision-support systems in the context of public procurement enable authorities to aggregate information from a wide range of heterogeneous bases, such as fiscal records, suppliers' performance indicators, past agreements, and key indicators; such integration further generates actionable intelligence to guide the development of policies, operational strategies, and tactical decision-making.

Role of DSS in Public Procurement -

In public procurement, DSS provide value at multiple stages:

- **Pre-Tender Phase:** DSS help evaluate procurement needs, forecast budgets, and align acquisition strategies with policy goals.
- **Tender Evaluation:** These systems offer structured frameworks to score supplier bids against predefined criteria, ensuring objectivity and transparency.
- **Post-Award Monitoring:** DSS facilitate real-time tracking of contract execution, including delivery timelines, performance metrics, and compliance issues.

Despite the many benefits, traditional Decision Support Systems used in public procurement have been subjected to substantial limitations due to outdated platforms, limited integration functionalities, and being dependent on rigidly structured data such as spreadsheets. The growing complexity of procurement requires greater flexibility, interaction, and decision support through visualization; therefore, the integration of Business Intelligence technology becomes inevitable in this scenario.

Introduction to Microsoft Power BI

An initial review of Microsoft Power BI Microsoft Power BI is an advanced business intelligence solution intended to transform raw information to form meaningful reports and engaging visuals. The application supports the gathering of information from disparate locations such as Excel spreadsheets, SQL databases, SharePoint, web APIs, and cloud platforms, and it allows the user to edit the information using Power Query and Data Analysis Expressions (DAX). The information is then visualized using dynamic dashboards specific to the needs of the individual user depending upon the organizational role and expected result.

In the procurement domain, Power BI functions as a powerful DSS engine, offering several key capabilities:

1. **Real-Time Data Visualization:** Live dashboards allow stakeholders to track tender timelines, supplier performance, and financial spend in real-time.
2. **Customizable Metrics:** Procurement KPIs such as bid-to-award ratios, cost overruns, and compliance deviations can be tailored to organizational needs.
3. **Drill-Down Analysis:** Users can explore trends across time, contracts, vendors, or procurement categories to uncover root causes or anomalies.

4. **Role-Based Access:** Sensitive information can be protected through security layers, ensuring that only authorized personnel view critical metrics.

Integration with Public Sector Systems

The integration of Power BI with relational database management systems, such as SQL and PostgreSQL, and procurement platforms such as MEPA and TED enables organizations to significantly improve their capacity to monitor, report, and regulate their operational functions. For example, procurement units are able to analyze the continual performance of suppliers against Service Level Agreements (SLAs) using Power BI dashboards, and compliance officials can monitor compliance with contractual terms across all departments.

In addition, the integration of Power BI with conventional methods like the use of Quality Function Deployment (QFD) and Failure Modes, Effects, and Criticality Analysis (FMECA) takes it beyond the role of being only a visualisation tool. The application has the capability to represent the needs of the stakeholders visually, map quantitative assessments against technical requirements, and track risk prioritization levels through the procurement process, all of which are supported by an integrated analytical framework.

Advantages Over Traditional Decision Tools

Unlike traditional spreadsheet-based tools, Power BI enables:

- **Automation:** Dashboards are updated automatically, eliminating the need for manual data entry and reducing errors.
- **Scalability:** The system can accommodate datasets from multiple departments, tenders, and years.
- **Interactivity:** Filters, slicers, and drill-downs provide users with dynamic control over data views.
- **Audit Trails:** Version histories and user activity logs support transparency and traceability in high-stakes procurement environments.

These capabilities make Power BI not just an analytical tool, but a strategic enabler of evidence-based governance, ensuring that procurement decisions are aligned with performance outcomes, budget goals, and regulatory compliance.

2.1.4 Data Mining and Its Relevance in Procurement

In the evolving domain of public sector procurement, data mining has emerged as a transformative analytical approach, particularly in response to the growing complexity, volume, and strategic relevance of procurement data. Governments and public institutions are

increasingly recognizing that beyond regulatory compliance and transactional oversight, procurement data when systematically analyzed can yield insights critical to achieving cost-efficiency, transparency, risk reduction, and quality assurance. The discipline of data mining provides the theoretical and practical tools to enable this shift from reactive reporting to anticipatory governance.

Defining Data Mining in the Context of Procurement

Data mining is broadly defined as the computational process of identifying hidden patterns, correlations, anomalies, and trends in large datasets using a blend of statistical methods, machine learning algorithms, and database management techniques (Han, Pei, & Kamber, 2011). In the context of public procurement, these datasets may include supplier profiles, tender submissions, contract performance logs, financial disbursements, audit findings, and stakeholder feedback. The application of data mining in procurement allows public agencies to move beyond surface-level reporting and engage in deeper diagnostic and predictive analysis.

Data mining techniques commonly applicable in procurement include:

- Classification algorithms (e.g., decision trees, support vector machines) to predict the likelihood of supplier default or risk-prone contracts;
- Clustering to identify common characteristics among tenders or vendor groups, assisting in segmentation and policy targeting;
- Association rule mining to detect frequent patterns or co-occurrences in procurement behaviors (e.g., delayed deliveries linked with specific product categories);
- Anomaly detection to flag outliers in cost estimates, bid values, or timelines that may suggest fraud, inefficiency, or data entry errors;
- Regression analysis to forecast procurement performance metrics such as delivery delays, budget deviations, or contract modification frequencies.

These methods enable the conversion of raw, fragmented procurement data into actionable intelligence enhancing both operational oversight and strategic planning capabilities.

Strategic Applications in Public Procurement

The application of data mining in public procurement serves multiple strategic functions, contributing to enhanced performance, integrity, and accountability:

1. **Supplier Evaluation and Benchmarking:** By analyzing historical records on delivery punctuality, quality non-conformities, and contract penalties, data mining supports quantitative vendor performance evaluations. This information can inform tender scoring

models and qualification criteria, reducing the subjectivity of supplier selection.

2. **Fraud Detection and Compliance Monitoring:** Public procurement is vulnerable to irregularities such as bid rigging, collusion, and artificial price inflation. Anomaly detection and rule-based mining help detect deviations from normative patterns, triggering early warnings and facilitating forensic audits.
3. **Cost and Demand Forecasting:** Historical procurement data can be used to predict future demand trends, cost fluctuations, or budget requirements, enabling better financial planning and bulk negotiation strategies.
4. **Contract Risk Identification:** Mining contract data across multiple cycles reveals patterns of risk factors such as project types with high amendment rates or specific suppliers frequently involved in litigation thus improving risk classification and mitigation protocols.
5. **Policy Impact Assessment:** Data mining enables public bodies to evaluate the impact of procurement policies (e.g., green procurement mandates or SME participation incentives) by analyzing participation trends, pricing differentials, or outcome metrics over time.

Integration with Business Intelligence Tools

The real value of data mining is realized when its outputs are seamlessly integrated into decision-support systems that enable real-time access, visualization, and interaction. Business Intelligence (BI) platforms such as Microsoft Power BI serve as the interface through which mined insights become operationally relevant.

Power BI allows for:

- The visualization of clustered supplier groups or risk categories through interactive charts and heatmaps;
- The integration of predictive regression models into dashboard forecasts;
- Automated alerts generated from anomaly detection algorithms;
- Drill-down analysis from institutional-level KPIs to transaction-level details.

Through this integration, procurement managers are not only informed of past behaviors but also equipped to forecast risks, prioritize contracts, and allocate resources dynamically. This fusion of data mining and BI redefines procurement reporting from being reactive and descriptive to being predictive and prescriptive.

Challenges and Considerations in Public Sector Contexts

Despite its potential, the application of data mining in public procurement presents several institutional and technical challenges:

- **Data Quality and Availability:** Inconsistent data entry, missing values, unstructured formats, and legacy systems hinder the accuracy and reliability of mining outputs. These deficiencies often originate from decentralized data management practices and a lack of standardized data governance frameworks.
- **System Integration Barriers:** Many public agencies operate in siloed IT environments where procurement, finance, and compliance systems lack interoperability. This fragmentation limits access to comprehensive datasets needed for effective mining.
- **Skill and Capacity Gaps:** Public procurement departments often lack personnel with data science expertise or the resources to maintain mining infrastructures, making capacity-building and cross-functional training essential prerequisites.
- **Ethical and Legal Constraints:** The use of sensitive personal and financial data in data mining must comply with legal frameworks such as the General Data Protection Regulation (GDPR). This requires rigorous anonymization protocols, secure access controls, and auditability of data usage.
- **Trust and Organizational Resistance:** The transition to data-driven procurement is often met with skepticism or resistance from stakeholders unfamiliar with analytical tools, necessitating change management strategies and stakeholder engagement.

Relevance to the Thesis Framework

Within this thesis, data mining is not an isolated technical solution but a foundational layer that supports the integration of Power BI with QFD and FMECA methodologies. Specifically:

- Mined supplier data will inform QFD matrices by quantitatively aligning procurement requirements with stakeholder expectations.
- Failure trend patterns will feed into FMECA assessments, allowing procurement teams to prioritize risks based on historical evidence.
- Cleaned and structured data from mining processes will ensure high-precision, real-time Power BI dashboards.

This architecture promotes a virtuous cycle: data mining improves data quality and insight depth, BI platforms deliver the insights effectively, and QFD/FMECA frameworks ensure

alignment with quality and risk objectives. Together, they enhance procurement governance and enable strategic decision-making grounded in empirical evidence.

2.1.5 Database Management in Public Administration

Efficient database management lies at the heart of effective digital governance. In the context of public administration, where operations span multiple departments, regulatory frameworks, and stakeholder engagements, the ability to store, manage, and retrieve data securely and consistently is critical. Procurement, as one of the most data-intensive functions within public administration, demands a high degree of database organization to support decision-making, regulatory compliance, performance monitoring, and transparency.

The Role of Databases in Public Sector Operations

Public administration generates and processes vast quantities of data across a range of functions: human resources, budgeting, contracts, compliance, project management, and procurement. As such, relational databases act as foundational infrastructure that ensures the systematic recording, organization, and retrieval of this data. The role of a well-structured database system in public procurement includes:

- Maintaining a single source of truth for all procurement records (e.g., supplier details, tender documents, bid submissions);
- Enabling linkages across processes (e.g., pre-qualification to contract award to post-award performance monitoring);
- Ensuring referential integrity across interdependent tables (e.g., linking contract IDs to supplier IDs);
- Facilitating standardized reporting, audit trails, and regulatory submissions;
- Supporting integration with analytical platforms like Power BI for real-time visual dashboards.

Unlike private enterprises that may enjoy flexible tools and fewer compliance obligations, public institutions must manage data under stricter regulations, limited technical expertise, and multi-level scrutiny. Hence, the design and operation of their databases demand specific architectural choices to ensure stability, interoperability, and legal compliance.

Structured Database Models in Public Procurement

Relational Database Management Systems (RDBMS), such as PostgreSQL, MySQL, and SQL Server, remain the preferred technologies in public administration due to their ability to enforce

data normalization, relational integrity, and structured query execution. In procurement applications, a typical relational schema may include:

- **Supplier Table:** Contains tax IDs, contact information, qualification scores;
- **Tender Table:** Stores information on bidding deadlines, technical criteria, budgets;
- **Bid Table:** Links suppliers to tenders, stores offer values, delivery timelines;
- **Contract Table:** Captures award decisions, implementation schedules, amendments;
- **Performance Table:** Tracks compliance with timelines, quality scores, penalties.

The normalization of such tables ensures that each piece of data resides in one logical place, thereby reducing duplication, enhancing consistency, and improving update performance. In contrast, spreadsheet-based systems or flat-file databases—still used in some public offices lack these advantages and often suffer from version control issues, missing data, and redundancy.

Challenges in Public Sector Database Management

Despite growing awareness, many public institutions face chronic weaknesses in their database infrastructures:

1. **Legacy Systems and Fragmentation:** Data is often housed in outdated systems that do not interconnect, creating information silos. Procurement data might be stored in separate systems for tendering, contracting, and payments, with no common identifiers or automated synchronization.
2. **Inadequate Data Validation:** Public agencies frequently suffer from blank fields, misclassified entries, and inconsistent formats due to weak enforcement of input validation rules. This compromises the integrity of the entire procurement process.
3. **Lack of Role-Based Access Controls (RBAC):** Many public systems lack user-level security, exposing sensitive procurement data to unauthorized access or accidental alteration issues especially problematic under GDPR and national data protection laws.
4. **Poor Integration with Business Intelligence Tools:** Incompatible database schemas, missing foreign keys, and unstructured entries make it difficult to integrate with tools like Power BI. This limits the effectiveness of dashboards, slows report generation, and undermines real-time decision-making.
5. **Limited Disaster Recovery and Backup Mechanisms:** Some systems operate without reliable data backup or recovery protocols, making them vulnerable to data loss from

cyberattacks, hardware failures, or system errors.

6. **Lack of Meta-Data and Data Dictionaries:** Without well-defined metadata or schema documentation, procurement databases become opaque to users and developers alike, complicating updates, queries, and external audits.

Best Practices and Standards

To address these shortcomings, global organizations have developed frameworks for enhancing public sector database management:

- The OECD's e-Government Recommendation emphasizes interoperability, scalability, and data integrity;
- UN/CEFACT Standards support common procurement data models for international interoperability;
- EU's eProcurement Technical Standards define standardized fields and formats for electronic tenders.

Adopting these standards in local systems ensures consistency, comparability, and cross-border operability of procurement data critical in the context of transnational initiatives and funding (e.g., EU cohesion funds).

Moreover, leveraging PostgreSQL's powerful open-source RDBMS used in this thesis offers strong support for JSON/BLOB storage, foreign key enforcement, indexing, and ACID compliant transactions. These features make it ideal for public systems that require flexibility and robustness without commercial licensing constraints.

Relevance to This Thesis

Within this research, structured database design plays a critical role in bridging procurement reporting gaps. The proposed architecture includes:

- A centralized relational database built using PostgreSQL to serve as the backbone for all procurement data;
- Standardized schemas and primary/foreign key linkages for seamless data relationships;
- ETL (Extract, Transform, Load) processes to clean, validate, and migrate raw data into usable formats;

- RBAC models to ensure that dashboards in Power BI are tailored by user type (auditor, procurement officer, regulator);
- Referential constraints and validations to avoid missing fields and enforce regulatory logic.

These improvements directly address the fragmentation, inconsistency, and inefficiency challenges identified in current procurement environments. More importantly, they create the foundation for applying advanced analytics and risk-quality methodologies (QFD and FMECA), which require clean, structured, and accessible data to be effective.

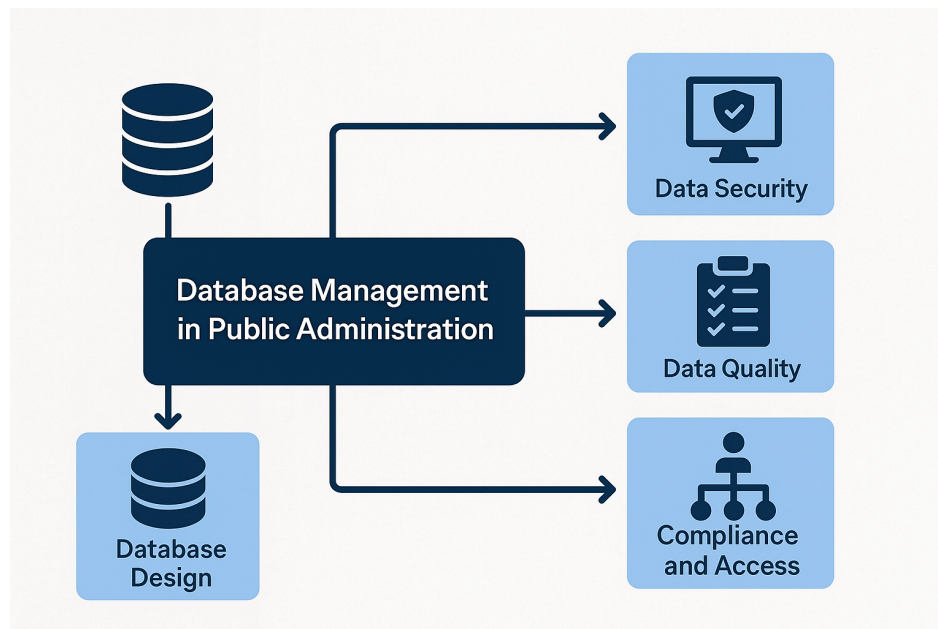


Figure 2.2: Workflow and Architecture of Database Management in Public Procurement Systems

2.1.6 Data Governance, Privacy, and Regulatory Frameworks (e.g., GDPR)

Contemporary public procurement systems are based more on information technologies and integrated information systems in order to improve transparency, efficiency of processes, and management controls. With the trend to move to evidence-based policy-making, it is essential that there is a strong emphasis on overseeing the appropriateness and accuracy of the data while safeguarding privacy and respecting the law. For business intelligence-enabled procurement reporting systems like Microsoft Power BI and back-end databases like

PostgreSQL, proper information governance architecture and stringent adherence to legal protection of information, i.e., the General Data Protection Regulation (GDPR), must be ensured to avoid loss of reputation and continuity of business.

Procurement functions commonly comprise buying, storage, and securely maintaining sensitive information of various types. These encompass information regarding supplier finances, bid information, contracts, performance records, and stakeholder information. All of these are exposed to threats such as misuse, errors, unauthorized disclosure, or failure to adhere to legislations obligatory in their absence without adequate controls. As such, it is critical that governance and privacy be embedded from the beginning in any reporting solution for the government industry.

The present dissertation suggests a data governance model, which is a component of system design. The model emphasizes the necessity of role-based controls, auditing, encryption techniques, normalized database design, and compliance with the General Data Protection Regulation (GDPR).

Through the inclusion of compliance features and moral checks within Power BI dashboards, as well as in the SQL/PostgreSQL backend, this architecture enhances institutional effectiveness and accountability to citizens. Furthermore, it aligns with evolving international standards presented by institutions such as the Organisation for Economic Co-operation and Development (OECD) and the European Commission, both of which advocate for transparency, equity, and digital probity within public administration.

Key Components of Data Governance in Public Procurement

Data governance refers to the policies, processes, and organizational roles that ensure accurate, secure, and complaint handling of institutional data. In public procurement, key governance areas include:

- **Data Integrity and Standardization:** Ensuring consistency across procurement records, from supplier databases to contract terms and budget tracking.
- **Access Controls and Role Management:** Limiting who can view, edit, or export sensitive data such as supplier identities, pricing, or bid scores.
- **Data Ownership and Stewardship:** Assigning accountability for maintaining procurement data quality and updating records in a timely manner.
- **Metadata and Documentation:** Defining naming conventions, data dictionaries, and traceability standards to support transparency and auditability.

These governance mechanisms are vital to aligning the reporting system with public sector mandates on accountability, performance tracking, and stakeholder confidence.

Privacy Protection and Regulatory Compliance

The handling of procurement data must also adhere to strict privacy principles, particularly under the GDPR. The regulation establishes seven foundational requirements that apply to public institutions managing personal and sensitive data:

1. **Lawfulness, Fairness, and Transparency** - Data collection and usage must have a legal basis and be communicated transparently to the data subjects (e.g., bidders, contractors).
2. **Purpose Limitation** - Data must be collected only for specified, explicit purposes such as contract evaluation or regulatory auditing and not used beyond these.
3. **Data Minimization** - Only data that is directly relevant to procurement activities should be collected and stored.
4. **Accuracy** - Information must be kept current and accurate, especially in supplier scoring or legal contract data.
5. **Storage Limitation** - Data should be archived or deleted after the retention period expires, reducing legal and operational risk.
6. **Integrity and Confidentiality** - Appropriate encryption, access restriction, and cybersecurity measures must be employed to protect procurement data.
7. **Accountability and Record Keeping** - Institutions must maintain records of all data processing activities, including who accessed or modified data, and for what purpose.

These principles directly influence how data is handled in Power BI dashboards, PostgreSQL schemas, and ETL (Extract, Transform, Load) pipelines throughout the system.

System-Level Safeguards in Power BI and PostgreSQL

The proposed system includes multiple technical safeguards to uphold data privacy and governance, embedded across both frontend and backend layers:

- **Role-Based Access Control (RBAC):** Custom access policies for procurement officers, legal teams, auditors, and executives.
- **Encryption and Secure Storage:** Implementation of AES-256 encryption protocols for sensitive procurement data.

- **Audit Trails:** System-generated logs capturing who accessed or altered data, ensuring full traceability during audits.
- **Data Masking in Dashboards:** Sensitive fields (e.g., bid amounts, vendor names) can be anonymized when data is shared with oversight bodies or published online.
- **Retention and Deletion Automation:** Backend workflows to automatically archive or purge records after a defined period, aligned with national and EU regulations.

Institutional Governance Frameworks and Best Practices

Beyond the technology, successful data governance in public procurement also requires institutional support. This involves:

- **Governance Committees:** Cross-functional groups overseeing data policy enforcement.
- **Training and Capacity Building:** Educating staff on data ethics, cybersecurity, and compliance roles.
- **Policy Documentation:** Codifying governance protocols for procurement workflows, including vendor data entry, contract monitoring, and KPI evaluation.

Public procurement organizations are increasingly expected to adopt a “data stewardship” model where data is treated as a valuable public asset, subject to ethical management, institutional oversight, and legal compliance.

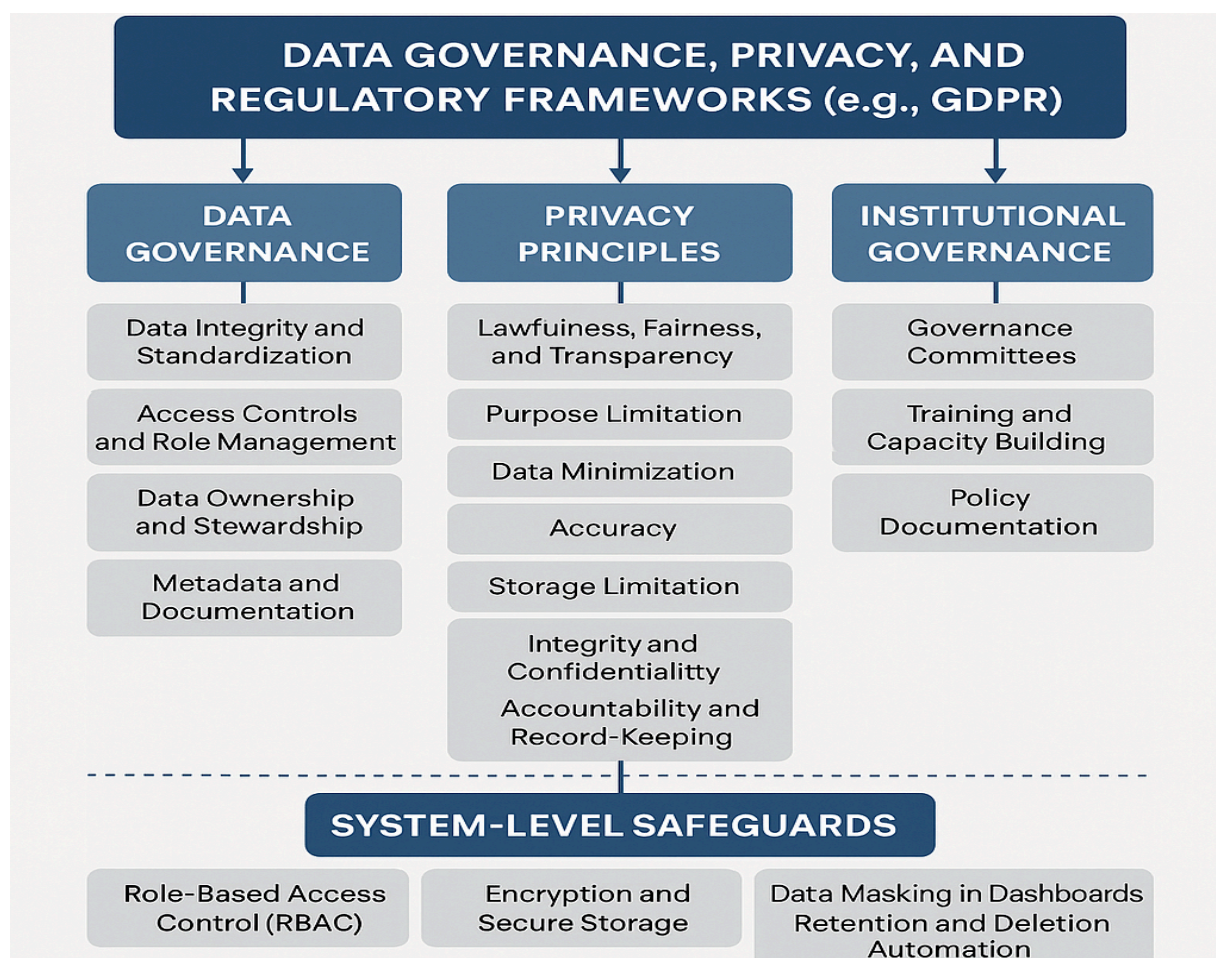


Figure 2.3: GDPR-Compliant Data Governance Framework for Public Procurement Systems

2.2 Business Intelligence and Reporting Technologies in Procurement

The application of Business Intelligence (BI) technology for government procurement is a major step towards improving operational efficiency, transparency, and governance based on fact. Traditionally, government procurement has been based on disparate systems, ad hoc spreadsheet manipulation, and different reporting structures. These are not adequate for modern public institutions facing diverse regulatory environments, tight budgets, and increased accountability in the delivery of services and in the administration of funds.

Business Intelligence solutions make it possible for the procurement information gathered from various internal and external sources to be processed and analyzed, thus providing timely insights and supporting proactive planning. To procurement professionals, this is not about just

reporting; it provides the ability to track critical procurement metrics, forecast potential threats, measure supplier performance, and spot trends at various procurement stages. In the government sector, where both social and monetary factors are involved in taking decisions, the role of intelligence plays a pivotal role.

Public procurement bodies are tasked with managing a broad set of information, including directories of suppliers, bid notices, payment records, compliance information, shipping schedules, and performance scores. Business Intelligence (BI) systems are integrated platforms that aggregate this information and present it in extensive dashboards consumed by different departments. By enabling in-real-time tracking and visualization of the procurement information, BI elevates day-to-day operational efficiency and transparency in an organization.

Procurement officers, legal advisors, auditors, and fiscal controllers cooperate through Business Intelligence platforms using an integrated information architecture. Such collaboration ensures rectification of inconsistencies, better coordination, and optimization of tracking mechanisms. In addition, Business Intelligence platforms are more and more tailored in accordance with the e-procurement guidelines provided by the European Union and the digital governance concepts promoted in the European Interoperability Framework.

The value of Business Intelligence (BI) systems is most striking when they are integrated into planning structures aimed at managing quality and risks, notably through techniques like Quality Function Deployment (QFD) and Failure Modes, Effects, and Criticality Analysis (FMECA). Integration of the systems enables a greater convergence of the procurement process with stakeholder expectations and greater potential for early detection of risks a consideration of prime importance for government agencies in managing complex and costly procurement projects.

In conclusion, Business Intelligence is the analytical and technical underpinning of the modern procurement governance models. It enables the evolution of procurement functions from administrative cost centers to value-generating, risk-reducing agencies working towards the achievement of broader policy goals.

2.2.1 Overview of Business Intelligence Platforms

Business Intelligence (BI) platforms are software environments that support the capturing, integration, analysis, and visualization of company information, in a way that enhances the ability to make decisions. In the area of government procurement, BI platforms allow government agencies to move away from traditional, rigid, historical reporting models towards more advanced, integrated, real-time, and predictive systems. As applied in the context of government agencies, traceability, compliance, and performance measurement are critical areas.

Some of the leading business intelligence tools on offer in the market today include Microsoft Power BI, Tableau, IBM Cognos, SAP BusinessObjects, and QlikView. These tools offer a range of core functionalities:

1. Data Integration and Connectivity

Business Intelligence (BI) solutions have the potential to connect with a range of different repositories of information, including relational database management systems (SQL Server, PostgreSQL), enterprise resource planning systems (SAP, Oracle), cloud storage solutions (Azure, AWS), and structured spreadsheet formats (Excel, CSV). Public sector agencies are able to bring together different departments' information through this ability, developing an end-to-end view of procurement activities. Where information is compartmentalised, this function is invaluable in achieving maximum visibility and consistency.

2. ETL Capabilities (Extract, Transform, Load)

A fundamental requirement for any Business Intelligence (BI) system is its ability to clean and normalize raw data in the Extract, Transform, and Load (ETL) process. In the context of procurement in particular, this process involves the extraction of supplier-related information, tender schedules, shipment timetables, and payment terms; transformation refers to the removal of redundancy, the normalization of formats, and adherence to predefined schemas; finally, the transformed information is loaded into an analytical model. The ETL process ensures that the resulting dashboards and reports are filled with correct and timely information.

3. Interactive Dashboards and KPI Visualization

One of the important advantages of Business Intelligence (BI) solutions is their ability to present information through interactive graphical presentations, such as charts, gauges, maps, and tables. Procurement professionals are able to track metrics ranging from contract adherence, accuracy of vendor delivery, processing time for invoices, and deviations from estimated expenditures. Visualization of the information allows for early action and enhances communication with stakeholders, authorities, and overseeing organizations.

4. Real-Time Reporting and Alerts

Modern business intelligence platforms enable the design of real-time dashboards, which provide alerts for decision-makers when executing procurement activities. In addition, systems also supply automatic alerts based on set parameters, including late delivery, excessive expenditures, or breaches of set rules with regard to compliance. Such a feature is of particular relevance to government agencies involved in timely tendering exercises or emergency procurements.

5. Role-Based Access and Governance Controls

Public procurement involves a number of stakeholders, including legal advisors, auditors, financial officers, and procurement managers, each requiring a different level of detail. Business Intelligence systems allow administrators to define role-based access, thus ensuring that information, including bid prices and vendor risk scores, is only seen by authorized users. Such a practice not only provides for observance of data protection acts, including the General Data Protection Regulation (GDPR), but also prevents unauthorized changes or breaches.

6. Audit Trails and Versioning

In the public sector, accountability is of fundamental significance. Business Intelligence systems guarantee complete traceability of procurement decisions by providing complete, end-to-end audit logs detailing who accessed a particular piece of information, when, and if, and how, any changes were performed. It ensures traceability from the time a procurement is requested through to the procurement itself and beyond.

7. Support for Advanced Analytics

While operational reporting is the most common use of Business Intelligence (BI) in procurement, many platforms now support predictive analytics, forecasting models, and machine learning integrations. Even though these capabilities are still underutilized in most public agencies, they hold great potential for improving procurement planning and supplier risk management in the years to come.

2.2.2 Microsoft Power BI for Public Sector Applications

In the evolving e-governance scenario, Microsoft Power BI has become an essential tool in facilitating a data-driven governance process in the public sector. Power BI, a self-service enterprise analytics solution, enables users to gather, transform, visualize, and share data insights among different departments in an organization. The speed of its adoption in governments and public organizations is a strategic move to drive real-time reporting, facilitate collaboration between departments, and assure transparency, a guiding principle for modern systems of public procurement.

The issues faced by the government sector are fundamentally different from those faced by the private sector. Budget-related responsibilities, following policy guidelines, governmental oversight, and the need for ethical disclosure require more than just the presentation of information; they require in-depth and timely analyses of large amounts of information. Power BI, with its ease of use and advanced analytical capabilities, is uniquely positioned to meet this need.

1. Centralized Data Integration for Public Procurement

The value proposition of Power BI is based in its ability to bring together disparate systems, a common trait among government agencies. Procurement information often lives in many different systems, including ERP systems (like SAP and Oracle), spreadsheets, legacy databases, and third-party vendor portals. Power BI supports native connectors to a large number of sources, including SQL Server, PostgreSQL, SharePoint, Excel, and web APIs. With this kind of connectivity, procurement organizations are able to bring supplier information, contract expiration dates, report on compliance, and spending trends into a cross-functional analytics workspace.

In the case of public local businesses like S.C.R. Piemonte S.p.A., where different departments cooperate on large tenders, Power BI allows for the combination of the different technical, legal, and finance resources, thus offering an overall picture.

2. Custom Dashboards for Stakeholder-Specific Needs

A hallmark of Power BI is its customizable dashboards tailored to the information needs of different users. In public procurement, these users may include:

- Procurement Managers, who track open tenders, bid evaluations, and vendor performance.
- Auditors, who need traceable logs and contract compliance metrics.
- Regulatory Officers, who monitor adherence to procurement directives.
- Financial Controllers, who oversee budget allocations, commitments, and payment cycles.

Power BI enables all stakeholders to engage with one another through dynamic reporting that is personalized and enables filtering of information by tender status, vendor risk group, or contract type. Such an ability supports a role-sensitive and responsive reporting environment that includes both operational and strategic activities.

3. Real-Time Data Refresh and ETL Integration

Federal agencies often require up-to-date information to meet immediate procurement needs, especially in the areas of healthcare, infrastructure, and emergency response. Power BI enables automatic refresh capabilities by using planned ETL (Extract, Transform, Load) pipelines. For instance, changes in supply delivery schedules or contract milestones are displayed in real-time on a dashboard, thus enabling immediate detection of anomalies and implementation of corrective action in a timely manner.

The in-built Power Query editor in Power BI allows for the transformation of the procurement data sets by cleansing and organizing them, using minimal amounts of technical knowledge. The function is particularly valuable in situations where limited technical resources are involved.

4. Compliance Monitoring and KPI Tracking

Public procurement is governed by a multitude of legal, procedural, and ethical standards. Power BI facilitates compliance by enabling organizations to define and monitor procurement-related Key Performance Indicators (KPIs), such as:

- Percentage of tenders completed within schedule.
- Vendor contract adherence rate.
- Percentage of procurement spend within allocated budget.
- Number of contracts flagged for audit or review.

These metrics are not only necessary for intra-government accountability, they are also necessary to support organizational transparency activities, e.g., open data portals and European Union mandated procurement disclosures. Additionally, interactive displays, e.g., time trend analysis, gauge charts, and compliance heatmaps, can be incorporated into normal governance report upkeep or published through web-based dashboards.

5. Security, Governance, and Role-Based Access

Security is paramount in public procurement, where datasets often include sensitive information such as vendor bids, contract values, and performance ratings. Power BI offers enterprise-grade security features including:

- Role-Based Access Control (RBAC): Ensures users see only what is relevant to their role and clearance level.
- Row-Level Security (RLS): Limits data visibility within datasets, allowing procurement staff to access only the records pertaining to their department or jurisdiction.
- Data Encryption: Power BI supports both data-at-rest and in-transit encryption, in line with GDPR and national data protection regulations.
- Audit Logs: Built-in activity logs track dashboard usage, data refreshes, and report sharing activities for auditability and oversight.

This architecture supports the needs of internal auditors, external regulators, and IT compliance officers.

6. Integration with Advanced Analytical and Quality Tools

A unique strength of Power BI is its compatibility with advanced analytics and external quality/risk management frameworks. In this research, the integration of Quality Function Deployment (QFD) and FMECA (Failure Modes, Effects, and Criticality Analysis) into Power BI is a key innovation.

- QFD matrices, such as the House of Quality, can be visualized within Power BI dashboards, linking stakeholder needs to procurement specifications and evaluation criteria.
- FMECA outputs, including Risk Priority Numbers (RPNs), can be displayed as risk heat maps or severity-probability matrices, allowing proactive identification of procurement vulnerabilities.

These features enhance strategic procurement planning and bring analytical rigor to quality and risk alignment goals that are frequently under-addressed in public tendering systems.

7. Accessibility and Cost Efficiency

Compared to some commercial Business Intelligence solutions that require a huge licensing cost or cloud infrastructure, Power BI is provided under flexible licensing models, including free tiers and government-specific plans through Microsoft 365. Its integration with Microsoft's Azure and Office 365 platforms enables seamless collaboration, especially for departments that are already using Excel, Outlook, or SharePoint. Additionally, the web-based nature of this tool ensures accessibility from any location and any device, thus eliminating the need for local IT infrastructure.

2.2.3 Relational Databases: SQL and PostgreSQL Integration

Efficient public procurement governance increasingly depends on the systematic collection, storage, retrieval, and interpretation of procurement-related data. To support analytical tools such as Microsoft Power BI, the underlying data infrastructure must be both scalable and structurally sound. In this context, relational database management systems (RDBMS) notably SQL-based systems such as PostgreSQL serve as the backbone for structured, secure, and interoperable data environments in the public sector.

1. Rationale for Relational Databases in Procurement

Public procurement operations involve extensive and interdependent datasets: supplier information, tender documents, bid evaluations, compliance indicators, payment milestones, and audit logs. These data elements are best managed using a relational model, which allows complex relationships to be defined through normalized schemas and ensures data referential

integrity across multiple tables. Unlike flat-file databases or isolated spreadsheets, relational databases allow for:

- Enforced consistency through primary and foreign keys.
- Optimized querying through indexing.
- Fine-grained access control.
- Transactional reliability (ACID compliance).
- Scalability across multiple departments and concurrent users.

These characteristics are crucial in the public sector, where transparency, accuracy, and auditability are not optional but statutory mandates.

2. PostgreSQL as a Preferred Platform

Among open-source relational databases, PostgreSQL is widely recognized for its robustness, extensibility, and compliance with SQL standards. Its suitability for public sector applications is evidenced by its adoption across European e-government projects and open-data initiatives. PostgreSQL supports complex data types, full-text search, spatial data (PostGIS), and JSON integration all relevant for large, multidimensional procurement datasets.

In the thesis context, PostgreSQL serves as the central data repository for integrating procurement records from multiple sources, structuring them into a normalized schema that supports analytical processes in Power BI. Tables may include:

- Vendors (vendor_id, legal_name, rating, certifications)
- Tenders (tender_id, project_name, start_date, deadline, estimated_cost)
- Contracts (contract_id, tender_id, supplier_id, execution_status, contract_value)
- KPI_Tracking (contract_id, milestone_id, actual_delivery_date, deviation_score)
- Audit_Log (user_id, action_type, timestamp, record_modified)

Such a structure allows seamless mapping between procurement activities and their respective KPIs, risk scores, or compliance flags.

3. Integration with Microsoft Power BI

Power BI provides native connectors for PostgreSQL, enabling direct query and import mode integrations. These features allow dashboards to reflect either live data or scheduled snapshots, depending on system performance and institutional policy. The integration process follows standard ETL (Extract, Transform, Load) pipelines:

- Extract: Pull data from PostgreSQL views or tables.
- Transform: Cleanse and shape data using Power Query.
- Load: Visualize data within Power BI dashboards.

For example, a procurement officer may use Power BI to analyze vendor performance trends across multiple contracts, pulling real-time data from normalized PostgreSQL tables and presenting them via interactive charts, maps, and drill-down filters.

4. Data Integrity and Validation Mechanisms

One of the key advantages of relational databases is their ability to enforce data quality through schema constraints, triggers, and stored procedures. In PostgreSQL, the following features enhance the validity of procurement data:

- Check constraints ensure that values (e.g., bid amounts, delivery dates) remain within logical boundaries.
- Foreign Key constraints maintain consistency between related tables (e.g., no orphan contracts without a linked tender).
- Unique constraints prevent duplication (e.g., duplicate vendor registrations).
- Triggers can enforce real-time validation rules, such as requiring that all tenders must include at least three submitted bids before being closed.

These controls address recurring issues in public procurement data such as empty fields, mismatched references, or inconsistent units and prepare the dataset for reliable reporting and risk analytics.

5. Security and GDPR Compliance

In the public domain, data security and regulatory compliance especially with respect to the General Data Protection Regulation (GDPR) are paramount. PostgreSQL includes advanced security features such as:

- Role-based access control (RBAC): Limits user access to only necessary tables and fields.
- SSL/TLS encryption: Secures data during transmission.
- Row-level security: Restricts access to specific rows based on user roles.
- Audit extension (pgAudit): Tracks access to sensitive data for internal reviews or external audits.

This security architecture enables public institutions to maintain trust, enforce compliance, and reduce the likelihood of breaches or unauthorized access.

6. Scalability and Interoperability with Public Sector Systems

PostgreSQL's extensibility and standards compliance make it interoperable with national e-procurement systems such as:

- MEPA (Mercato Elettronico della Pubblica Amministrazione) in Italy.
- TED (Tenders Electronic Daily) in the EU.
- Open Government Data portals (e.g., dati.gov.it).

By supporting industry standards such as XML, JSON, and REST APIs, PostgreSQL facilitates the inter-agency exchange of procurement data, ensuring that information on tenders, contractors, and procurement outcomes can be shared or compared across departments, municipalities, or regions.

Additionally, PostgreSQL supports data archiving and historical querying, which are essential for longitudinal studies, internal benchmarking, and regulatory reporting.

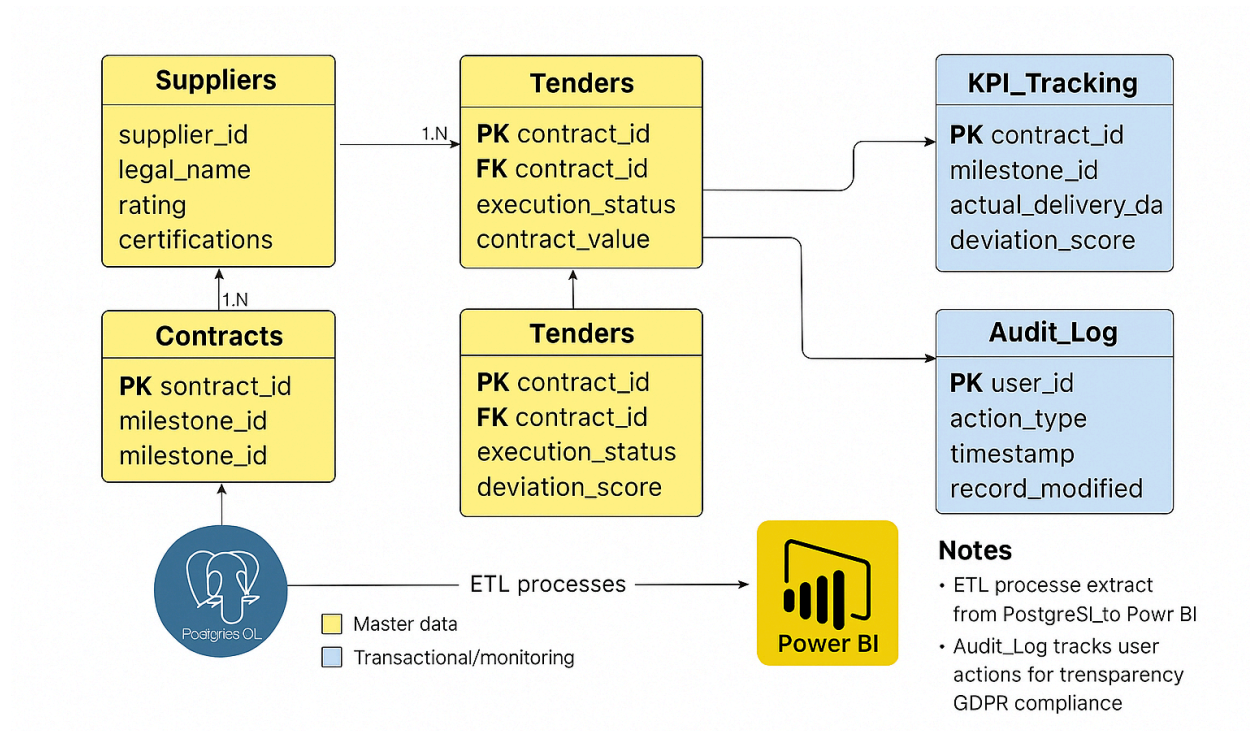


Figure 2.4: Relational Database Schema Supporting Procurement Reporting and Power BI Integration

2.2.4 ETL Processes for Procurement Data Transformation

In modern data-driven public procurement systems, the transformation of raw data into actionable intelligence is pivotal for effective decision-making. The Extract–Transform–Load (ETL) process forms the foundation of this transformation, acting as the pipeline that connects disparate data sources with analytical platforms such as Power BI. ETL is not simply a technical function, it is a strategic enabler that supports real-time procurement analytics, quality evaluation, and regulatory reporting.

A. Overview of the ETL Framework

ETL is a three-phase data integration methodology used to consolidate, cleanse, and migrate data from multiple systems into a centralized data warehouse or analytical environment. The process includes:

- **Extraction:** Capturing procurement-related data from various operational systems such as ERP modules (e.g., SAP), supplier management databases, Excel-based logs, legacy procurement software, and third-party public procurement portals.

- **Transformation:** Standardizing, cleaning, and enriching the extracted data. This includes removing null values and blank rows, applying validation rules, converting currencies and units, resolving mismatched formats, joining tables through primary/foreign keys (e.g., Tender ID, Supplier ID), and deriving calculated metrics such as supplier performance scores or risk indexes.
- **Loading:** Transferring the transformed data into a structured relational database (e.g., PostgreSQL), which is then linked to reporting tools such as Power BI for real-time visualization and interactive analytics.

This three-stage approach ensures data uniformity, consistency, and usability for public procurement intelligence.

B. Application in Public Procurement Context

Public procurement generates vast and heterogeneous datasets—ranging from tender notices and bid submissions to contract performance, supplier audits, and payment transactions. These datasets are often dispersed across incompatible systems and formats, necessitating an ETL framework to harmonize them.

For example, during the extraction phase, data might be pulled from:

- MEPA (Mercato Elettronico della Pubblica Amministrazione)
- Tenders Electronic Daily (TED)
- Local government procurement portals
- Financial accounting tools (e.g., Oracle, SAP)
- Manually maintained spreadsheets

Once extracted, the transformation phase focuses on data quality improvement. Common transformation rules in a procurement-specific context include:

- Filtering incomplete tenders (e.g., those lacking contract values)
- Normalizing supplier names to a single naming convention
- Aggregating costs across procurement stages
- Detecting outliers in delivery timeframes or pricing

In the loading phase, the data is inserted into normalized PostgreSQL tables with foreign key constraints. This forms the backend of the Power BI dashboard system, where stakeholders can interact with procurement metrics, quality indicators (from QFD), and risk profiles (from FMECA) in real time.

C. Role in Supporting QFD and FMECA Integration

The ETL process also plays a critical role in integrating quality and risk data models such as QFD and FMECA. For instance:

- Stakeholder requirement matrices (from QFD) may be transformed from survey or interview data into quantitative weights usable in scoring dashboards.
- Failure modes, effects, and criticality scores (FMECA) are computed during transformation using custom logic (e.g., $RPN = \text{Severity} \times \text{Occurrence} \times \text{Detectability}$).
- These values are embedded into reporting schemas and visualized dynamically through ETL-linked dashboards.

Such capabilities allow for proactive procurement management where potential failures or stakeholder misalignments are flagged before contracts are signed.

D. Technical Implementation and Tools

In this thesis, the ETL pipeline is implemented using open and scalable technologies, including:

- Python and Pandas for scripting custom transformation logic and data validation routines.
- PostgreSQL for storage and indexing of clean procurement datasets.
- Power BI Dataflows and ODBC connectors for seamless loading into dashboard environments.

The entire process is governed by version control (e.g., Git) and automated using scheduling tools such as Apache Airflow or cron jobs, ensuring repeatability and auditability.

E. Strategic Value

An effective ETL process transforms procurement data into a strategic asset. It supports:

- Real-time visibility into procurement cycle bottlenecks.
- Improved data quality for compliance reporting (e.g., GDPR, MAPS).

- Automation of quality and risk scoring, enabling anticipatory governance.
- Performance benchmarking across departments, suppliers, and tender categories.

Thus, ETL is not only a technical backbone of the BI system but also an indispensable mechanism for aligning procurement operations with transparency, quality, and efficiency goals in public administration.

ETL Flowchart for Procurement Data Architecture

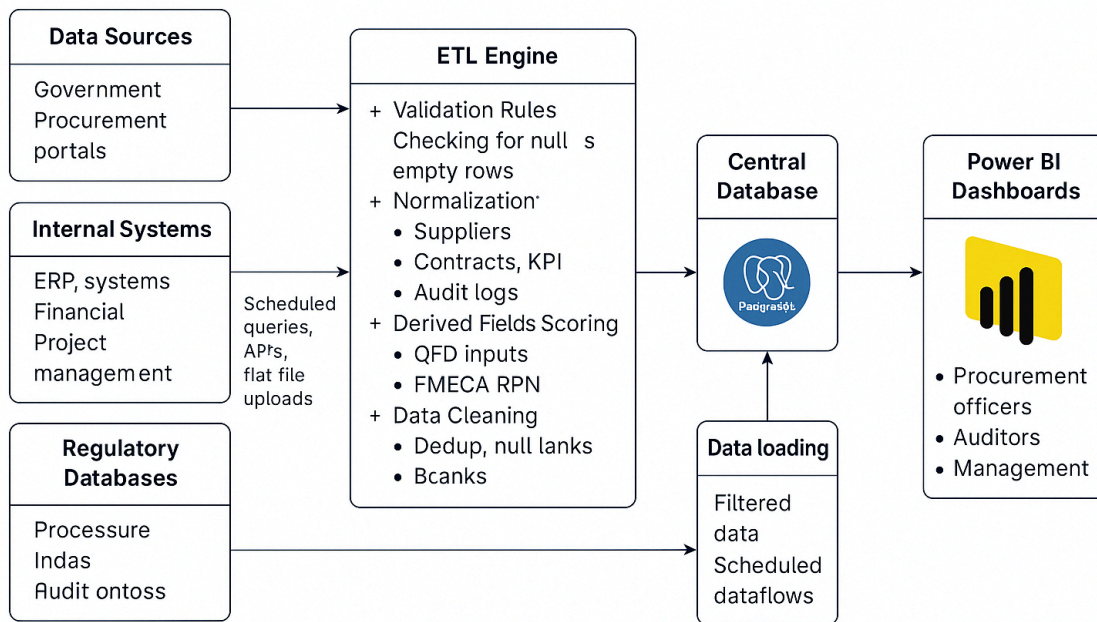


Figure 2.5: ETL Flow for Procurement Intelligence Architecture

2.2.5 Dashboards and KPI Visualization in Procurement Systems

In public procurement systems in the modern age, the need for more transparency, accountability, and timely visibility has made dashboards integral parts of decision-making systems. Dashboards are fundamental interfaces which transform procurement-related data into actionable information through interactive data visualizations. The interfaces allow procurement officials, auditors, administrators, and policymakers to manage procurement cycles, monitor key performance indicators (KPIs), measure supplier performance, and track contract implementation with high time sensitivity and operational immediacy.

Public procurement dashboards have evolved from static repositories of past data to dynamic systems with the potential to support anticipatory governance. The dashboards provide metrics that allow the identification of abnormalities, such as late delivery, deviation from contract specifications, or excess expenditure, and hence allow remedial action to be taken promptly in each case. In procurement, strategic key performance indicators (KPIs) function as much to gauge the efficiency of operations as to monitor the reliability of suppliers, finance, and policy compliance. Representative examples of such metrics include average tender cycle time, rate of budget absorption, levels of bidder participation, on-time delivery frequencies, and risk prioritization scores. These metrics are needed to ensure that procurement operations are aligned with strategic goals, which are amongst other things, value-for-money, competitiveness in the marketplace, and European Union and domestic law compliance

The visualization and interactive capabilities of Microsoft Power BI make it especially appropriate for public procurement reporting. With its data modeling capabilities and support for connecting to relational databases like PostgreSQL, Power BI supports the development of role-based dashboards. For instance, a procurement officer can be presented with dashboards showing real-time bid status, contract compliance summaries, and key performance indicators for delivery, whereas an auditor can have access to regulatory flags, budget variance reports, and supplier performance assessments. In addition, Power BI's drill-down capability enriches multi-layered data exploration by allowing the user to move from high-level summaries to individual bid records, thus encouraging detailed analysis without overwhelming the user.

One of the major benefits of Power BI dashboards is their ability to function both as operational management and strategic planning tools. The dashboards are usually built with filters allowing segmentation of data based on time, supplier, contract, or category of projects, hence providing role-based outlooks to different institutional roles. The ability to refresh data real-time assures these dashboards always reflect the most updated information, hence increasing institutional responsiveness in procurement management. The dashboards also integrate alerting features, which notify users of unusual behaviors like unusually low supplier scores, variances from set time frames, or non-compliance breaches making the system not only informative but also responsive.

Alongside the core tracking of key performance indicators, the dashboards used in this research setting are used to bring together state-of-the-art methodological tools, such as Failure Mode, Effects, and Criticality Analysis (FMECA) and Quality Function Deployment (QFD). QFD matrices can be depicted using weighted scores and stakeholder requirement alignment maps, thus highlighting to what degree procurement decisions are aligned with prescribed standards. Likewise, FMECA-based risk analysis is depicted using visual tools such as heatmaps and risk pyramids, categorizing the contracts by the severity, frequency, and detectability of probable failures. These additional visual overlays allow deeper insight into procurement vulnerabilities and provide the basis for proactive intervention.

In addition, the management through dashboards makes performance benchmarking between departments as well as procurement cycles feasible. The longitudinal tracking of key performance indicators (KPIs) makes it possible to monitor institutional progress, compare with past baselines, and analyze the impact of policy interventions. The process, in turn, does not only enhance accountability but also encourages institutional learning.

As far as data governance is concerned, each data piece integrated into the dashboard is traceable back to the origin within the relational database, thus guaranteeing auditability, reliability, and conformity with the General Data Protection Regulation (GDPR). In sum, dashboards are critical tools in modern public procurement systems. Their ability to provide real-time, multi-dimensional, and tailored information makes them key components of strategic public procurement governance. When combined with sound database-based infrastructure and supplemented with analysis methods like Quality Function Deployment (QFD) and Failure Mode, Effects, and Criticality Analysis (FMECA), dashboards form a holistic set of tools to enhance the efficiency, quality, and transparency of public procurement operations.

2.3 Quality and Risk Management Frameworks in Procurement

Within public sector procurement, there has been a progressive change in focus from simply guaranteeing adherence to legal and procedural stipulations to quality improvement, risk management, and the achievement of value for money. As public organizations become more involved in intricate and high-value procurements ranging from hospital development to information technology transformation projects the need for combined frameworks that cover both quality and risk management has taken center stage.

Conventional procurement practice has often treated quality as a retrospective assessment criterion and dealt with risk reactively, usually after contractual or operational breakdowns have occurred. These fragmented approaches are no longer appropriate in the context of modern governance, since the products of procurement are now being scrutinized in terms of efficiency, transparency, sustainability, and stakeholder satisfaction.

This chapter deals with the two core methods - Quality Function Deployment (QFD) and Failure Modes, Effects, and Criticality Analysis (FMECA) which are introduced as being methodical and anticipatory methods of integrating quality and risk management into procurement. Even though these methods are not specifically associated with public administration, their relevance, due to their origin in systems design and industrial engineering, has been found to be highly valuable. These methods ensure procurement results align with stakeholder needs (QFD) and allow failures to be identified, prioritized, and eliminated before actual contracting process execution (FMECA).

By integrating QFD and FMECA into Business Intelligence platforms like Power BI, procurement departments can evolve into strategic partners in public value creation capable of aligning policy

goals with operational delivery, visualizing risk and quality metrics in real-time, and adapting to evolving user demands and regulatory constraints.

2.3.1 Quality Function Deployment (QFD)

Quality Function Deployment or QFD can be defined as a methodical approach to changing stakeholders' or customers' requirements into well-defined operational results. QFD was originally used in Japan for product and manufacturing applications, then evolved to find considerable relevance as well in public procurement, driving the conversion of various stakeholder needs into technical standards as well as evaluation criteria in a methodical approach. The method makes procurement decisions not only economically feasible as well as compliant but also aligning with public interests, service quality, and general policy goals.

A. Identification and Translation of Stakeholder Requirements in Public Procurement

In public sector operations, procurement approaches must maneuver through disparate interests of different stakeholders, which include end-users, legal departments, auditors, policymakers, and regulatory bodies. These stakeholders often have conflicting, and even opposing, requirements relating to aspects like cost-effectiveness, efficiency in operations, ethical procurement, and green procurements.

The first step of Quality Function Deployment (QFD) involves the thorough gathering of stakeholder expectations through multiple approaches, such as interviews, surveys, workshops, and review of service level agreements (SLAs) or strategic documents. The gathered expectations are then systematically arranged and translated into measurable procurement specifications. An example is, where the requirement "hospital equipment easy to maintain" is translated in terms of availability of spare parts, mean time between failures (MTBF), or arrangements with local service suppliers.

Quality Function Deployment works on developing a scoring and weighting mechanism which helps prioritize requirements based on their importance. Such a method dispels the danger of overemphasis on cost alone and ensures technical as well as qualitative considerations are rated with equal importance. The outcome of the procurement process is thus more likely to be accepted by end-users, to create long-term value, and meet accountability requirements.

B. The House of Quality and Its Adaptation to Public Procurement

The key instrument used in Quality Function Deployment (QFD) is termed the House of Quality (HoQ), or the structured matrix establishing relations between requirements of the stakeholders (the "Whats") and related solutions to technical or procurement problems (the "Hows"). In public procurement, this matrix is used as an important decision-making tool.

For example, a procurement team working on public transportation vehicles may receive stakeholder requirements like “low fuel consumption,” “accessibility for disabled users,” and “safety compliance.” These are then mapped to quantifiable supplier criteria such as engine efficiency ratings, floor height measurements, and ISO safety certifications. The HoQ matrix also assesses the strength of correlation between each “What” and “How” and identifies technical conflicts or synergies among supplier features.

The public procurement adaptation of HoQ helps ensure that procurement specifications are traceable to stakeholder needs and that evaluation processes are transparent and justifiable. When integrated into digital platforms like Power BI, HoQ matrices can be visualized and shared across departments, enabling auditability and real-time feedback during the tendering process.

C. Application Examples: Use in Hospital Material Procurement

Hospitals offer a compelling use case for QFD in public procurement. Hospital procurement involves highly sensitive items such as diagnostic equipment, surgical instruments, and patient monitoring systems, where performance, reliability, and compliance are paramount.

Take the example of purchasing intensive care unit (ICU) beds. The concerned stakeholders may include healthcare professionals, maintenance personnel, patient welfare associations, and regulatory compliance authorities. Their expectations of convenience in mobility, hygiene considerations, compatibility with digital monitoring systems, and patient comfort are gathered and translated into technical requirements by using the Quality Function Deployment (QFD) technique.

Subsequent proposals can then be evaluated according to how closely each of them complies with the objectives quantified in the House of Quality, thus making the evaluation process methodical and closely related to end-users' priorities. Additionally, innovation in vendors is encouraged by the model in order to meet user needs, thus increasing the responsiveness of the market towards public service needs. The same approach applies to high-cost buys, like MRI equipment, where QFD can be used to evaluate suppliers based on their past uptime performance, warranty terms, effectiveness of electromagnetic shielding, training support to end-users, and integrative capabilities into systems.

2.3.2 FMECA in Public Procurement

Definition, Structure, and Risk Prioritization

Failure Modes, Effects, and Criticality Analysis (FMECA) is a systematic methodology traditionally employed in engineering and manufacturing disciplines to identify potential failure points in a system or process, assess their impact, and prioritize them based on risk severity. In the context of public procurement, the adaptation of FMECA allows institutions to preemptively

address vulnerabilities across procurement planning, supplier selection, contract execution, and service delivery.

FMECA begins by identifying Failure Modes i.e., the different ways a process or component can fail. Each failure mode is then analyzed for its Effects on the system and assessed for Criticality, typically measured by three dimensions:

- Severity (S): The seriousness of the failure's impact on operations or compliance.
- Occurrence (O): The likelihood of the failure occurring.
- Detectability (D): The ability to detect the failure before it causes damage.

These scores are used to calculate the Risk Priority Number (RPN) as:

$$\text{RPN} = \text{S} \times \text{O} \times \text{D}$$

In public procurement, this structured approach enables procurement professionals to assign RPN scores to various failure scenarios such as delayed bid evaluations, inaccurate specifications, or contract performance disputes thus allowing proactive mitigation plans to be devised before tenders are issued. For example, a delayed delivery of medical ventilators during a health crisis might have a high severity and moderate occurrence but low detectability if supply chain weaknesses are not monitored. FMECA quantifies such risks, prioritizing intervention.

FMECA matrices can be continuously updated as procurement projects progress, creating a living risk framework aligned with the real-time dynamics of tendering, vendor performance, and market conditions.

Public Sector Use Cases: Complex and Sensitive Contracts

FMECA's application is particularly valuable in complex and sensitive public contracts where service failure carries high financial, legal, or public health consequences. Key use cases include:

- **Public Health Equipment Procurement:** In the case of procuring MRI machines, PPE kits, or life-saving devices, FMECA can help identify potential supplier defaults, logistical delays, or non-conformance to medical standards.
- **Infrastructure Projects:** For large-scale civil projects (e.g., highways, government buildings), FMECA can evaluate risks such as contractor insolvency, material shortages, weather disruptions, and regulatory non-compliance.
- **IT System Deployments:** In public sector digital transformation projects, procurement of software and digital platforms is fraught with risks like cybersecurity vulnerabilities,

interoperability failures, and licensing disputes.

- **Defense and Security Contracts:** Sensitive procurements involving surveillance systems, drones, or border control mechanisms carry risks related to data breaches, geopolitical sensitivities, and vendor trustworthiness.

These scenarios require granular risk planning beyond financial vetting. FMECA allows agencies to preemptively design tender conditions, performance benchmarks, and audit trails that prevent procurement crises and ensure continuity of public services.

When embedded in procurement systems, FMECA also provides an auditable trail of risk assessments, a critical feature for agencies accountable to parliaments, auditors, and taxpayers.

2.3.3 Integration of QFD and FMECA with Business Intelligence Tools

The integration of Quality Function Deployment (QFD) and Failure Modes, Effects, and Criticality Analysis (FMECA) into Business Intelligence (BI) platforms such as Microsoft Power BI constitutes a meaningful leap in the modernization of public procurement management. This integration creates a unified, data-centric environment where procurement decisions can shift from reactive and compliance-oriented approaches to proactive, transparent, and evidence-driven processes.

1. Structuring Quality and Risk Data for BI Environments

Both QFD and FMECA generate structured matrices that capture complex yet actionable data ranging from stakeholder-derived needs and technical specifications to identified failure modes and computed Risk Priority Numbers (RPNs). When properly digitized and stored in relational databases such as PostgreSQL, these datasets become immediately accessible for real-time integration into Power BI dashboards.

The dashboard integration enables users to:

- Visualize QFD matrices, linking stakeholder priorities (WHATs) to procurement features (HOWs) through weighted scoring models.
- Render FMECA heatmaps, identifying high-risk areas within ongoing tenders or supplier portfolios using color-coded alerts.
- Track live updates to RPN values as operational data changes (e.g., supplier non-conformance or delayed deliveries), ensuring risk metrics evolve with procurement realities.

This digitized structuring enhances transparency and provides a permanent audit trail for all scoring decisions addressing traceability mandates outlined in Directive 2014/24/EU, Article 84 (on procurement documentation and transparency).

2. Automation and Real-Time Operational Insights

Modern BI tools offer automated data refresh capabilities and rule-based alerts. This automation means that decision-makers no longer rely on outdated spreadsheets or subjective assessments. For example:

- If a supplier's delivery lead times exceed preset benchmarks, a threshold condition can trigger automatic updates to the FMECA occurrence score, prompting a dashboard alert for procurement officers.
- QFD matrices can be made interactive, allowing role-specific users legal reviewers, finance officers, or end-user departments to input or adjust requirement weights. These changes can be visualized in real time, promoting multi-stakeholder participation and shared decision accountability.

Such interactivity supports the principle of proportionality and equal treatment mandated by Directive 2014/24/EU, Article 18, and enables procurement professionals to make data-driven adjustments in response to evolving priorities or detected anomalies.

3. Strategic and Governance-Level Benefits

Embedding QFD and FMECA into a centralized BI platform like Power BI produces notable governance and strategic advantages:

- **Traceability and Auditability:** Procurement choices can be traced back to structured quality and risk evaluations, which is crucial for regulatory audits and parliamentary scrutiny.
- **Regulatory Alignment:** Dashboards can monitor compliance with EU procurement thresholds (Articles 4–7), track qualitative award criteria as per Article 67 (contract award criteria based on best value rather than cost alone), and ensure conformance with data privacy standards under the General Data Protection Regulation (Regulation (EU) 2016/679, Articles 5, 32, and 33).
- **Stakeholder Alignment:** The use of QFD ensures procurement reflects institutional mission priorities by allowing direct alignment between end-user requirements and technical specifications.
- **Proactive Risk Mitigation:** FMECA dashboards offer visual early-warning systems for procurement failures shifting governance from reactive to predictive. This supports better performance management and mitigates reputational, legal, or financial risks.

Ultimately, the combined deployment of QFD and FMECA within a Power BI-enabled BI architecture allows public procurement agencies to move beyond passive compliance. It

empowers them to act with real-time visibility, stakeholder responsiveness, and data-based foresight delivering public value while maintaining alignment with legal obligations and institutional goals.

The operationalization of this integrated quality-risk framework specifically within a PostgreSQL and Power BI architecture is presented in Chapter 4, where the technical implementation, data models, and dashboard logic are detailed.

2.3.4 Comparative Advantages over Traditional Tools

The integration of Failure Modes, Effects, and Criticality Analysis (FMECA) and Quality Function Deployment (QFD) with upper-level Business Intelligence (BI) tools such as Microsoft Power BI is a significant step forward in public procurement management and control. The conventional procurement tools, presented mostly in the form of static reports, spreadsheets, and manual evaluation plans, are progressively failing to meet the demands of openness, citizen participation, and real-time responsiveness public agencies are confronted with in the twenty-first-century public sector. In this chapter, we outline the key comparative advantages of holistic digital solutions over legacy tools.

A key benefit is the precision of results that contemporary systems can provide. Conventional tools tend to involve manual entry of data and judgmental assessments, which are prone to inconsistency, incompleteness, and error propagation. In comparison, the application of formalized Quality Function Deployment (QFD) matrices guarantees that procurement specifications are derived directly from validated stakeholder requirements, thereby reducing the potential for interpretation errors. Moreover, the incorporation of FMECA enables objective risk quantification by utilizing measurable parameters like severity, occurrence, and detectability. By presenting these structured data sets on Power BI dashboards, decision-makers are able to derive precise, audit-ready insights based on consistent data logic, rather than anecdotal evidence or intuition.

In addition to improved accuracy, consolidated BI solutions offer great leverage in real-time risk management. Conventional procurement instruments lack dynamic capture, analysis, or updating of exposure to risk. Risk registers and mitigation strategies that are stored in text reports or spreadsheets do not respond nimbly to evolving alterations in supplier performance or regulatory landscapes. Integration of Failure Modes, Effects, and Criticality Analysis (FMECA) with Power BI dashboards allows for real-time monitoring of high-risk areas through automated alerts and heatmaps. Such tools not only highlight divergences from expected performance but also enable the reprioritization of risk in the face of emerging evidence, thus guaranteeing early intervention before risks escalate into operational failure.

Both from a cost and operational standpoint, these tools have particular advantages to offer regarding cost efficiency and resource allocation. Traditional public procurement methods such as physical paper-based assessments, unstructured sets of information, and redundant auditing

procedures distract essential human and time resources. The said inefficiencies create downtime, redundancy of effort, and, ultimately, higher administrative costs. By way of efficient data operations through Extract-Transform-Load (ETL) processes, assessment enhancement through Quality Function Deployment (QFD), and failure prevention through Failure Mode, Effects, and Criticality Analysis (FMECA), organizations can effectively minimize rework by a considerable extent, make audits more efficient, and allocate human resources towards strategic oversight services.

Enhanced reporting also aids in the early identification of mismatches in budgets or unsatisfactory supplier performance, thereby avoiding losses and contract disputes. Proactive monitoring is another critical value dimension. Conventional procurement systems tend to react after the event, with variances only identified during after-the-fact analysis or official audits. Business Intelligence-driven systems reverse this through ongoing feedback loops. For example, variations in delivery times, violations of service quality, or slippage on the part of vendors could be detected as they occur, as opposed to after they have affected performance. The combination of time-sensitive data sources with analytic tools, such as trend lines and forecasting models, enables anticipatory governance. Such an ability enables procurement managers to plan for remedial actions upfront such as vendor replacement, contract renegotiations, or readjustment of service level agreements thereby preventing systemic weakness.

One of the most striking features of QFD based systems is their potential to provide procurement processes with stakeholder-driven orientation. In conventional systems, stakeholder requirements ranging from environmental responsibility, service availability, and innovation payoff fail to be captured effectively or get ignored completely, which means decisions made are prioritized based on conventional metrics instead of users' or citizens' long-term aspirations. Quality Function Deployment (QFD) enables the structured capture, prioritization, and mapping of stakeholder requirements into technical specifications and procurement evaluation criteria.

Coupled with Business Intelligence tools, graphical visualization of stakeholder-weighted criteria enables procurement officers to make visibly transparent decisions that support accountable public goals. This not only enhances stakeholders' trust but also renders the procurement process optimum, responsive, and equitable. Last but not least, the combination of those tools enables methodologies to be aligned with policy demands and institutional objectives. Public procurement is being viewed more and more not only as a system for the execution of financial transactions, but also as an instrument for the attainment of developmental, social, and environmental policy objectives.

Conventional systems, which tend to address primarily compliance and cost issues, are not adequate to satisfy this strategic need. QFD-FMECA-BI methodology assists institutional organizations in procurement performance measurement to achieve sustainability targets, promote innovation, and assure equitable service delivery by integrating policy compliant quality metrics and forward-looking hazard identification into dashboards. Tactical Strategic Key

Performance Indicators (KPIs) such as carbon footprint reductions, diversity suppliers, and delivery timelines for innovation are essential and can be monitored and documented in a systematic manner to provide alignment between operating decisions and legislative and policy targets. Briefly, the application of Business Intelligence reporting,

Failure Mode, Effects, and Criticality Analysis, and Quality Function Deployment addresses the constraints typically inherent in traditional procurement practice. By promoting more accuracy, real-time monitoring, affordability, stakeholder unity, and policy objective adherence, these practices transform public procurement into a strategic means of generating public value. The adoption of this step is crucial in promoting innovation and resilience within procurement systems amidst an environment marked by complexity, accountability, and digitalization.

2.3.5 Comparative Analysis: QFD–FMECA versus AHP and Hybrid MCDA Methods

While this thesis centers on the integration of Quality Function Deployment (QFD) and Failure Modes, Effects, and Criticality Analysis (FMECA) within a Power BI–based procurement intelligence system, it is essential to critically position this methodological choice against alternative multi-criteria decision-making (MCDA) approaches. Among these, the Analytic Hierarchy Process (AHP) is one of the most widely used techniques in vendor evaluation, strategic sourcing, and risk prioritization. This section reviews the literature on AHP and hybrid MCDA models to establish a comparative basis and reinforce the rationale for adopting the QFD–FMECA combination.

AHP in Supplier and Vendor Evaluation

The AHP, introduced by Saaty (1980), decomposes complex decisions into a structured hierarchy of objectives, criteria, and alternatives. Through pairwise comparisons, it calculates relative weights and uses a consistency index to validate subjective judgments. AHP has been extensively applied in procurement and manufacturing contexts. For example, Dalalah et al. (2010) applied AHP to rank suppliers in the automotive sector using quality, cost, and delivery as evaluation criteria, with embedded sensitivity analysis ($\pm 10\%$) to test the robustness of the final ranking.

Core Features of AHP:

- Hierarchical structuring of criteria and alternatives
- Pairwise comparisons for deriving relative weights
- Consistency ratio to evaluate judgment coherence
- Sensitivity analysis for validation of ranking stability

However, in large-scale or highly dynamic procurement environments, AHP's matrix expansion and manual comparison process can become impractical. As the number of criteria or alternatives increases, the number of pairwise comparisons grows exponentially, introducing both cognitive and computational burdens.

Hybrid AHP–QFD Models

Hybrid models combining AHP and QFD have gained traction in supplier selection and product development scenarios. In such models, AHP is used to derive stakeholder priorities, which are then embedded into QFD's House of Quality (HoQ) to bridge the gap between customer requirements and technical procurement specifications.

For instance, Chan and Kumar (2007) and Bevilacqua et al. (2006) successfully applied this model in electronics and strategic sourcing. AHP provided a formal mechanism for weighting customer needs, which were then aligned with technical features via QFD.

Advantages of AHP–QFD Hybrids:

- Enhanced objectivity in QFD weight derivation
- Improved traceability from stakeholder input to technical criteria
- Structured multi-actor evaluation in collaborative environments

Despite these benefits, such models are often data-intensive, time-consuming, and poorly suited for real-time integration within BI dashboards. Their reliance on static matrices limits responsiveness to dynamic procurement contexts.

AHP–FMEA and Broader MCDA Integrations

Another stream of research has explored the integration of AHP with FMEA to strengthen risk-based supplier evaluation. In these models, AHP is used to prioritize failure criteria (e.g., severity, occurrence, detectability), and the resulting weights are used to compute Risk Priority Numbers (RPNs) in the FMEA framework.

For example, Amindoust et al. (2012) and Kuo et al. (2023) developed AHP–FMEA hybrids for green supplier selection. They also introduced entropy weighting and grey theory to reduce subjectivity and improve evaluation neutrality.

Key Contributions of AHP–FMEA Hybrids:

- Structured stakeholder input on risk prioritization
- Combined qualitative and quantitative risk evaluation
- Enhanced objectivity through secondary weighting techniques

However, these models typically lack end-to-end system integration and are rarely deployed in real-time BI ecosystems. They function well in static reports or research simulations but do not extend naturally into interactive procurement monitoring platforms.

Justification for QFD–FMECA Integration in This Thesis

The integration of QFD and FMECA within this study is not only methodologically coherent but also tailored for operational compatibility with the Power BI environment. This pairing allows for simultaneous stakeholder-centric evaluation (via QFD) and risk-driven prioritization (via FMECA), both visualized through real-time, role-based dashboards.

Dimension	AHP / Hybrid MCDA Models	QFD–FMECA (This Thesis)
Stakeholder Input Mapping	Pairwise comparisons (highly structured but labor-intensive)	Direct stakeholder-to-requirement mapping in HoQ (more scalable)
Risk Assessment Method	AHP–FMEA hybrids; external RPN calculation	Fully embedded FMECA module with live RPN and BI integration
Sensitivity Testing	Manual perturbation tests ($\pm 10\%$)	Automated $\pm 10\%$ weight variation embedded in QFD matrices
BI Dashboard Integration	Rare; models typically external to dashboard environments	Fully integrated in Power BI dashboards with live filtering and analytics
Usability & Transparency	Analytical rigor but limited adaptability at scale	High usability across roles; intuitive visuals; audit-friendly reporting
Public Sector Scalability	Complex to scale due to matrix growth and stakeholder overload	Modular architecture, real-time feedback, extensible for multi-agency use

Table 2.3: Comparative Summary – AHP/Hybrid Models vs. QFD–FMECA

While AHP and its hybrid extensions with QFD or FMEA provide proven methodological rigor, they present significant limitations in terms of scalability, interactivity, and system integration. In contrast, the QFD–FMECA methodology deployed in this study supports a transparent, real-time, and technologically agile approach to procurement evaluation. Its seamless integration with Power BI enables continuous monitoring, stakeholder collaboration, and risk-informed decision-making features particularly aligned with the complex and regulated nature of public procurement.

2.4 Systemic Gaps and Challenges in Existing Frameworks

Despite notable advancements in digitalization and strategic procurement, public sector procurement systems continue to suffer from persistent structural and technological shortcomings. These deficiencies undermine transparency, limit efficiency, and obstruct the realization of policy-driven procurement goals. This section critically examines the prevailing challenges and systemic gaps that hinder the full operationalization of data-driven procurement models, with particular focus on fragmentation, decision-making, quality integration, data reliability, and compliance assurance.

2.4.1 Fragmentation and Redundancy in Procurement Data

A core challenge in public procurement environments is the fragmentation of procurement-related data across different platforms, departments, and systems. Most public organizations operate with disjointed IT infrastructure where procurement records are distributed across standalone applications, spreadsheets, legacy systems, and manual filing processes. This fragmentation impedes the real-time flow of information between stakeholders and introduces redundancy, as the same data may be entered multiple times in inconsistent formats.

This lack of centralized data governance leads to inefficiencies in tasks such as contract monitoring, supplier evaluation, and compliance reporting. When procurement teams must manually reconcile disparate data sources, the probability of duplications and inconsistencies increases, slowing down procurement cycles and reducing the reliability of reports. Additionally, the absence of common metadata standards or standardized classification taxonomies (e.g., CPV codes, NAICS) further complicates data consolidation efforts. The inability to trace a full lifecycle of procurement—from tender planning to post-contract evaluation results in lost institutional memory and diminished process accountability.

2.4.2 Lack of Real-Time, Integrated Decision-Making

Timely and evidence-based decision-making is critical in managing complex procurement portfolios, particularly in high-stakes public sector contracts. However, most public procurement systems remain static and reactive due to their limited integration with real-time analytics platforms. The reliance on outdated tools such as spreadsheets, PDF documents, and manual logs means that procurement managers operate without access to live data on tender progress, supplier performance, or financial deviations.

Without integrated dashboards or streaming data environments, public institutions are unable to generate early warnings for project risks, detect deviations from planned timelines, or forecast resource requirements. This delay in insight obstructs proactive intervention and causes

suboptimal decisions that can result in budget overruns, supply chain disruptions, or legal non-compliance. Moreover, this lack of integration weakens cross-functional collaboration, as legal, financial, and technical teams work with siloed data views, thereby increasing communication gaps and slowing down critical approvals.

2.4.3 Inadequate Use of Quality and Risk Methodologies

Although modern procurement calls for multidimensional evaluations—factoring in not just cost but also quality, sustainability, and risk—public sector systems continue to underutilize structured analytical methodologies such as Quality Function Deployment (QFD) and Failure Modes, Effects, and Criticality Analysis (FMECA). In many cases, quality assurance is reduced to checklist-based compliance, and risk assessment is reactive, performed only after adverse events such as contract breaches or delays.

The absence of systematic frameworks for mapping stakeholder requirements, prioritizing performance metrics, or identifying potential failure points leads to vagueness in contract terms, underperformance by suppliers, and missed opportunities for service innovation. Moreover, without formal risk prioritization models, procurement officers often misallocate resources toward low-impact issues while neglecting high-risk areas. The non-adoption of tools like QFD and FMECA reflects a significant gap between theoretical advancements and real-world implementation in public procurement practice.

2.4.4 Technical Limitations: Data Quality, Empty Fields, and Linkage Errors

A technically sound data architecture is foundational to the effectiveness of procurement reporting systems. However, the quality of procurement data is frequently compromised by issues such as incomplete entries, empty rows and columns in spreadsheets, and improper linking between databases. Data irregularities, including missing vendor codes, unregistered delivery timelines, or uncategorized spending figures, can invalidate reports and dashboards generated via business intelligence tools like Power BI.

Further, relational database structures are often improperly designed, with inadequate use of foreign keys, normalization, or referential integrity constraints. This results in broken queries, failed report generation, and erroneous visualizations. The challenge is compounded when procurement datasets are exported from legacy systems that do not support structured formats such as JSON, XML, or SQL schemas. Such technical deficits prevent the creation of a "single source of truth," which is essential for decision support, predictive analytics, and policy evaluation.

2.4.5 Security and Compliance Gaps in Procurement Data Systems

As public procurement transitions into digitally enabled ecosystems, data protection, cybersecurity, and legal compliance have emerged as critical pillars of institutional integrity. Procurement platforms now process sensitive and high-stakes data including financial bid values, supplier identifiers, legal contract clauses, and performance assessments making them prime targets for misuse, cyber intrusion, and regulatory breaches.

Despite this heightened exposure, many public institutions continue to operate without comprehensive safeguards in place. Features such as Role-Based Access Control (RBAC), encryption of data at rest and in transit, multi-factor authentication, and automated audit trails are often inconsistently deployed or entirely absent. These deficiencies create systemic vulnerabilities, elevating the risk of unauthorized data access, data corruption, and failure to meet obligations under the General Data Protection Regulation (Regulation (EU) 2016/679), specifically Articles 5 (Data Principles), 32 (Security of Processing), and 33 (Breach Notification Requirements).

In addition, compliance workflows remain predominantly manual and fragmented, particularly in monitoring:

- Procurement thresholds as set in Directive 2014/24/EU, Articles 4–6;
- Green and social procurement targets in accordance with Article 18;
- Conflicts of interest disclosures, as mandated under Article 24.

Such manualism introduces delays, inconsistencies, and missed flags especially in complex, multi-stage tendering processes. When procurement units rely on spreadsheet-based tracking and paper documentation, audit readiness is compromised, and institutional accountability diminishes.

A modern, legally resilient procurement information system must embed compliance monitoring as a core design feature rather than as an afterthought. This requires:

- Automated alerts for breach of financial thresholds or submission deadlines;
- Centralized compliance logs accessible to oversight bodies and auditors;
- Policy-driven data validation rules that prevent erroneous or incomplete entries;
- Full traceability of procurement decisions, aligned with Directive 2014/24/EU, Article 84 on documentation and transparency.

Additionally, secure system architecture leveraging tools such as PostgreSQL with pgAudit, AES-256 encryption, and GDPR-compliant access logs should be integrated with Power BI dashboards to enable real-time compliance visualization. Dashboards can flag overdue milestones, contract modifications requiring justification, or KPIs indicating procedural deviation bringing together legal conformance, operational monitoring, and strategic governance in one visual layer.

In conclusion, security and compliance gaps in procurement data infrastructures are no longer technical oversights they are liabilities with legal, reputational, and financial consequences. Addressing them requires not only robust cybersecurity measures but also embedded compliance intelligence, aligned with both GDPR and EU procurement directives. A future-ready procurement ecosystem must ensure that every transaction is traceable, every risk is monitored, and every standard is enforceable by design.

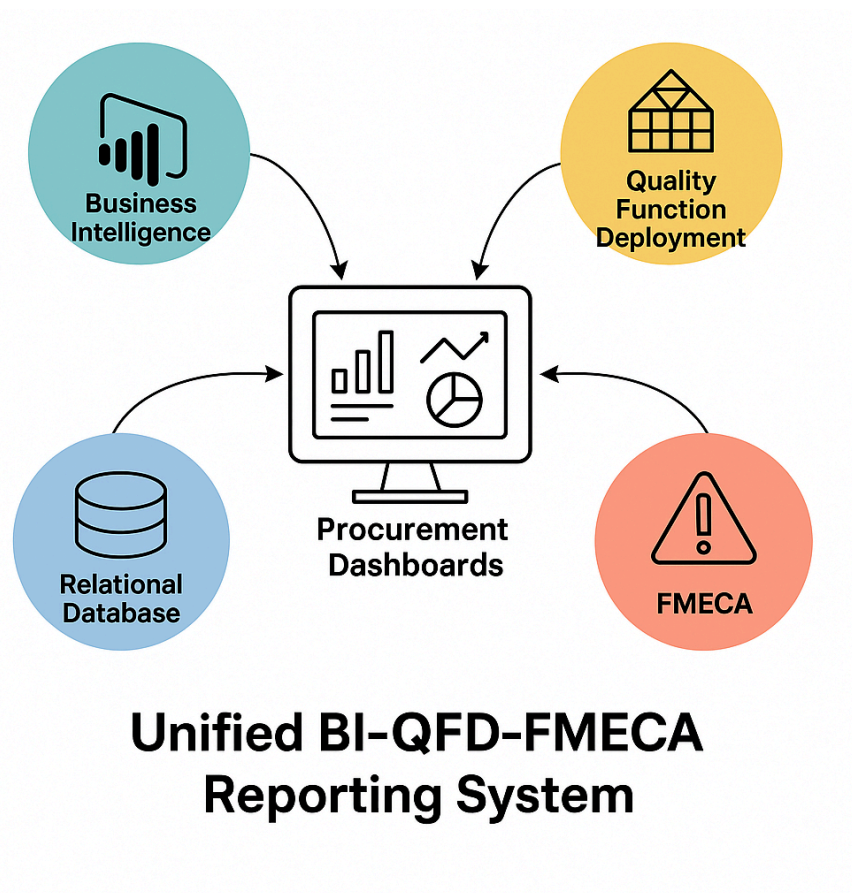


Figure 2.6: Conceptual Framework of the Unified BI-QFD-FMECA Reporting System

Chapter 3: Research Methodology

3.1 Research Design

This chapter details the methodological strategy used to conceptualize, implement, and evaluate a unified reporting system for public procurement that integrates Power BI with Quality Function Deployment (QFD) and Failure Modes, Effects, and Criticality Analysis (FMECA). The research is grounded in a pragmatic philosophy, reflecting both empirical evidence collection and technical system design, with the goal of improving decision-making quality and risk management in public sector procurement.

Given the complexity of the procurement ecosystem, the research design employed a mixed-methods approach, leveraging both qualitative and quantitative data streams to guide design, validate outcomes, and evaluate system performance. This integrative methodology enabled triangulation of perspectives from procurement managers, legal experts, and technical staff to ensure that both stakeholder needs and technical feasibility were captured in the resulting framework.

The design is interventionist and applied in nature. It follows a design science research tradition, where the development of a functional artifact, a Power BI driven procurement dashboard system is central to the study. The artifact serves both as a tool and as a subject of inquiry, allowing for iterative testing, refinement, and stakeholder evaluation. Empirical validation was performed through synthetic data simulations and controlled case studies modeled on real public procurement workflows.

3.1.1 Mixed-Methods Approach

Choosing a mixed-methods approach is embedded in the interdisciplinary recognized nature of public procurement, straddling legal compliance, financial analysis, stakeholder governance, and information systems. Applying a single-method approach would not really take on the multiple faces of this domain. Hence, this research builds on the strengths of both qualitative and quantitative approaches through three integrated research stages:

Stage 1: Qualitative Exploration (Contextual Understanding and Stakeholder Mapping)

This initial phase involved unstructured interviews, document reviews, and observation of procurement workflows within a regional public company setting. The purpose was to identify existing pain points in procurement reporting, such as poor data availability, fragmented databases, and inconsistent stakeholder alignment. These qualitative inputs were instrumental in shaping the stakeholder matrices for QFD and framing the key risk areas to be modeled using FMECA.

In addition, stakeholder input informed the voice of the stakeholder (VoS) component of QFD, allowing nuanced translation of expectations into technical specifications and dashboard requirements. Policy and procedural documents were also analyzed to ensure legal and institutional compatibility of the reporting architecture.

Stage 2: Quantitative Data Modeling and System Engineering

This phase focused on the construction of the relational database schema (PostgreSQL), the ETL (Extract, Transform, Load) pipelines, and the technical integration of Power BI. Quantitative methods were applied to clean, normalize, and structure procurement datasets, often involving hundreds of simulated tender records, vendor scores, delivery timelines, and contract values.

System performance was measured using predefined KPIs such as dashboard load time, query response rate, data completeness scores, and the accuracy of risk prioritization (via RPN values in FMECA). Benchmarking and validation were conducted using simulated procurement cases to replicate real-world conditions while ensuring data privacy and ethical compliance.

Stage 3: Triangulated Validation and Feedback Collection

In the final phase, the unified reporting system was presented to a representative user group, comprising procurement officers, auditors, and compliance managers. Their feedback was collected through structured surveys, guided demonstrations, and usability assessments. Metrics such as perceived utility, clarity of insights, and alignment with regulatory expectations were evaluated.

The system's capability to support strategic decisions was also assessed through scenario-based exercises, in which users were asked to interpret and act upon insights from Power BI dashboards populated with QFD and FMECA derived metrics.

Justification for Mixed-Methods Selection

The use of a mixed-methods approach was particularly justified for three reasons:

1. **Context Sensitivity:** The diversity of stakeholder roles in public procurement required qualitative methods to accurately reflect varied expectations and concerns.
2. **Technical Rigor:** The quantitative arm ensured that the proposed solutions were data-valid, statistically sound, and operationally scalable.
3. **Validation Depth:** Combining these approaches enabled empirical triangulation, enhancing the credibility and practical utility of the proposed framework.

In alignment with recommendations from research methodologists such as Creswell (2014) and Tashakkori & Teddlie (2003), this approach delivers methodological robustness, depth of insight, and actionable findings suitable for deployment in complex institutional environments.

3.1.2 Case Context: Regional Public Company

The empirical foundation of this research is grounded in the operational environment of a regional public enterprise that plays a pivotal role in managing procurement activities for a broad set of public sector entities. This organization functions as a centralized procurement body, mandated by the regional government to streamline public spending, improve service delivery, and ensure legal compliance across diverse administrative units, including hospitals, municipalities, research institutions, and social welfare departments.

Organizational Mandate and Strategic Role

The public company operates under the legal framework established by both national procurement legislation and the European Union directives, particularly Directive 2014/24/EU, which establishes the foundational principles of public procurement. These include:

- Article 18 – Principles of procurement: mandating transparency, equal treatment, and non-discrimination;
- Article 40 – Preliminary market consultations: allowing for market dialogue to improve procurement preparation and risk anticipation;
- Article 67 – Contract award criteria: supporting the use of the most economically advantageous tender (MEAT) based on cost-effectiveness and quality considerations.

Within this legal context, the organization's strategic responsibilities include:

- Aggregating demand across multiple public agencies to leverage economies of scale;
- Issuing public tenders for high-value, complex goods and services such as medical equipment, public infrastructure projects, IT services, and professional consulting;
- Managing pre-award and post-award contract operations, including supplier evaluation, contract compliance, and dispute resolution;
- Supporting regional policy priorities, such as green public procurement (GPP), SME inclusion, and gender-equal procurement practices in accordance with EU social and environmental objectives.

This organization, by virtue of its cross-sectoral scope and strategic alignment with the regional development agenda, serves as an ideal case study to evaluate the integration of advanced reporting tools and quality-risk methodologies within the public procurement cycle.

Procurement Volume and Complexity

Annually, the company manages tenders totaling hundreds of millions of euros, often involving multiple stakeholders across different tiers of government. Tenders range from relatively standard office supplies to sophisticated technical projects like hospital modernization, energy efficiency retrofits, and emergency response logistics. The scale and heterogeneity of these procurements necessitate a reporting system that can capture detailed technical metrics, supplier performance indicators, and risk flags across numerous dimensions.

In particular, the organization's procurement portfolio includes:

- Framework agreements for recurring needs such as pharmaceuticals and diagnostic kits.
- Innovation-oriented tenders, including R&D contracts in public health and digital infrastructure.
- Crisis-response contracts, which require accelerated timelines, multi-party coordination, and dynamic risk monitoring.

The integration of tools like Power BI, QFD, and FMECA is especially relevant in this context, as decision-makers must continuously align procurement actions with both policy objectives and service delivery constraints.

Current Challenges Observed

Through an initial situational analysis and field immersion, several systemic challenges were identified that reflect broader issues within public procurement governance:

- **Data Fragmentation:** Procurement records are stored across multiple platforms (ERP, spreadsheets, paper archives), making comprehensive reporting difficult.
- **Lack of Quality and Risk Metrics:** Existing reporting is predominantly financial and lacks the depth to evaluate supplier quality, stakeholder satisfaction, or systemic vulnerabilities.
- **Manual Workflows:** Key activities such as supplier scoring, risk flagging, and audit reporting are performed manually, increasing administrative burden and error rates.
- **Limited Visualization:** Decision-makers often rely on static tables or textual reports, which lack the clarity, interactivity, and real-time responsiveness needed for strategic procurement governance.

These deficiencies provide the motivation for designing an integrated, data-driven solution that supports anticipatory decision-making, stakeholder alignment, and performance accountability.

Relevance to Research Objectives

The choice of this public company as the focal point of study is not incidental. Its role as a regional integrator of procurement policy and practice presents a unique opportunity to test the applicability and scalability of the proposed Power BI - QFD & FMECA architecture. It also ensures that the research remains grounded in real institutional needs and is capable of producing actionable outcomes.

Moreover, the organization's existing collaboration with IT and analytics units within the regional administration offers a practical platform to develop, deploy, and evaluate technical solutions in a real-world setting. While actual procurement data has been anonymized or simulated to preserve confidentiality, the processes, institutional context, and validation exercises reflect actual workflows, decision-making structures, and stakeholder dynamics.

3.2 Data Collection Strategy

The design and implementation of an integrated reporting system in public procurement, based on the BI-QFD-FMECA framework, requires a robust and multi-layered data collection strategy. This section outlines the methodological rigor applied to sourcing, validating, and integrating data for both analytical and strategic procurement governance. Recognizing the diversity of public sector information systems and regulatory sensitivities, the data collection process was approached through two parallel but interlinked streams: archival data compilation and stakeholder-centered knowledge extraction. These were aligned through iterative validation to ensure the completeness, reliability, and relevance of the collected datasets.

3.2.1 Source Identification

The first component of the data strategy involved a detailed mapping of institutional data sources relevant to procurement operations. These sources span across digital repositories, semi-structured records, and legacy systems, forming the primary base for building a relational procurement database.

- **Tender and Contract Archives:** These include structured datasets on procurement notices, award decisions, contract conditions, and implementation schedules. Data were sourced from national procurement portals, internal contract registries, and electronic tender management systems. Tender-level data were essential for tracking procurement cycles, supplier performance trends, and compliance with procedural timelines.
- **Supplier and Vendor Repositories:** Access was provided to anonymized supplier databases, including records of qualification status, historical bid participation, and service-level compliance metrics. This dataset was vital for populating Power BI

dashboards and QFD matrices focused on quality dimensions in vendor evaluation.

- **Operational and Transactional Logs:** Back-end system logs (e.g., invoice clearances, delivery notes, payment schedules) were extracted from internal ERP systems and procurement tracking spreadsheets. These datasets were useful in ETL processes for understanding delivery performance, spend variance, and contract milestone adherence.
- **Regulatory and Legal Data:** Legal frameworks such as the EU Directive 2014/24/EU and national transparency codes were digitized and encoded into compliance parameters. Additionally, previous audit reports and internal policy manuals were reviewed to capture enforcement patterns, compliance violations, and institutional expectations.
- **Risk Event and Non-Conformance Logs:** Historical records of procurement anomalies, such as bid protests, performance failures, and compliance audits, were included to enrich the FMECA structure. This information fed into the risk quantification logic and criticality analysis applied later in the reporting framework.

The data collection process was further constrained by the ethical requirement to use anonymized or simulated data, in compliance with GDPR and institutional research protocols. Where gaps existed in the primary datasets, proxy data structures were simulated using validated assumptions from prior procurement studies.

3.2.2 Stakeholder Engagement

Given the complexity of procurement ecosystems, it was imperative to complement archival data with experiential insights from institutional actors. Stakeholder engagement was treated as a methodological requirement for system legitimacy, contextual accuracy, and knowledge co-creation. The engagement process was divided into the following structured stages:

- **Semi-Structured Interviews:** A purposive sampling strategy was applied to identify key informants, including procurement managers, compliance auditors, technical evaluators, and legal officers. Interviews were conducted using thematic protocols designed to elicit insights on system pain points, decision-making heuristics, and expectations from reporting tools.
- **Consultation Workshops:** Multi-stakeholder workshops were held to align technical design choices with policy mandates and end-user needs. These sessions used scenario-based discussions and dashboard prototypes to generate feedback on data presentation, user roles, and KPI definitions.
- **Iterative Feedback Cycles:** Throughout the dashboard development phase, participants were invited to provide feedback on visualizations, data integrity, and

usability. Each round of feedback informed successive refinements of the data model, access controls, and visual representations in Power BI.

This iterative engagement strategy ensured that the data collection process did not simply reflect institutional systems but was enriched by the interpretive knowledge of practitioners. It also created a foundation for organizational buy-in, which is essential for long-term adoption of the reporting solution.

3.2.3 Flowchart of Collection Process

To ensure transparency and reproducibility of the data pipeline, a detailed flowchart was developed to map each stage of data acquisition and validation. This schematic representation outlines the end-to-end lifecycle of procurement data starting from raw data identification, followed by extraction, cleansing, validation, integration, and eventual visualization.

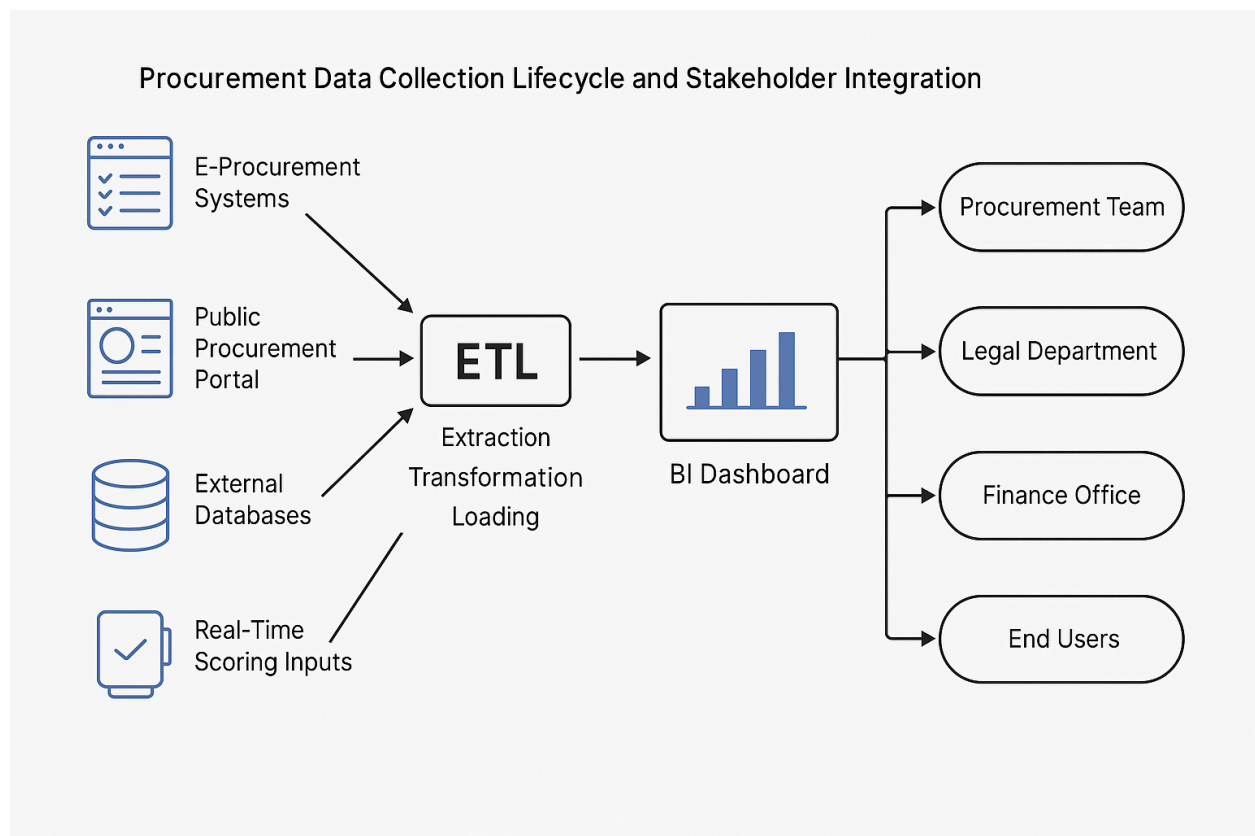


Figure 3.1: Procurement Data Collection Lifecycle and Stakeholder Integration

The flowchart demonstrates how fragmented datasets from diverse systems were aligned through ETL routines, quality assurance checks, and stakeholder inputs to produce structured data views for QFD and FMECA reporting in Power BI. It also highlights checkpoints for compliance validation and ethical safeguards applied during the transformation process.

3.3: Analytical Framework

The analytical framework forms the operational backbone of this research, translating raw procurement data into structured, actionable insights. It integrates relational database design, ETL workflows, business intelligence dashboards, and formal quality and risk evaluation methodologies (QFD and FMECA). This integration enables real-time reporting, risk forecasting, and stakeholder-aligned procurement monitoring—enhancing strategic decision-making within the public sector.

3.3.1 Database Development (SQL/PostgreSQL)

At the core of the reporting architecture is a centralized relational database built using PostgreSQL. The design follows a **normalized schema** to reduce data redundancy and enforce integrity across interconnected procurement modules. The schema includes:

- **Suppliers Table:** Storing vendor metadata such as registration numbers, legal certifications, and performance scores.
- **Tenders Table:** Capturing publication dates, classification codes, budget ceilings, and prequalification criteria.
- **Bids Table:** Linking vendors to tenders, tracking prices, submission timestamps, and evaluation statuses.
- **Contracts Table:** Logging contract awards, implementation phases, SLA terms, and amendment records.
- **Performance Table:** Monitoring delivery compliance, delays, and penalty records.

Referential integrity was maintained through primary and foreign key constraints, ensuring that each contract record is validly linked to a bid and tender entry. Security was implemented using PostgreSQL's Role-Based Access Control (RBAC), allowing fine-grained user access based on job function (e.g., auditor, procurement officer, administrator).

Data encryption (using `pgcrypto`) ensured GDPR compliance for sensitive fields like vendor identity and contract values.

3.3.2 ETL Process and Data Cleaning

A robust Extract Transform Load (ETL) pipeline was developed to ingest, clean, and integrate data from diverse procurement sources:

- **Extraction:** Data was sourced from Excel spreadsheets, CSV logs, ERP exports, TED (Tenders Electronic Daily), and MEPA (Mercato Elettronico della Pubblica Amministrazione).
- **Transformation:** Raw data was processed using Python scripts and PostgreSQL functions. This included:
 - Removing empty fields, duplicated records, and inconsistencies.
 - Converting all monetary values to a single currency standard.
 - Resolving mismatched formats (e.g., supplier names or codes).
 - Parsing date formats into ISO standard.
- **Loading:** Data was loaded into normalized tables with automatic validation checks. Indexes were created to optimize query performance for reporting tools.

The pipeline supported **incremental loading** and was orchestrated using automated scheduling tools (**cron**) and monitored through log files for audit compliance.

3.3.3 Power BI Dashboard Architecture

To visualize and operationalize procurement insights, Power BI dashboards were created on top of the PostgreSQL backend. The dashboard design emphasized both role-based access and multi-layered interactivity.

- **Data Models:** Fact tables (e.g., bids, contracts) were related to dimension tables (e.g., suppliers, departments) via surrogate keys, enabling flexible analysis.
- **User Views:**
 - **Procurement Officers:** Live tender status, bid counts, contract delays.
 - **Auditors:** Compliance tracking, tender irregularities, documentation completeness.
 - **Executives:** Budget utilization, performance metrics, high-risk contract flags.

- Security: Implemented through Row-Level Security (RLS) to restrict data visibility based on user role.
- Dynamic Filters and Slicers: Enabled slicing of data by supplier type, region, fiscal quarter, and commodity group.

The dashboards were linked to real-time refresh cycles, with alerts triggered for SLA breaches, budget overruns, or regulatory non-compliance.

3.3.4 Metrics Selection (KPIs, SLAs)

Key Performance Indicators (KPIs) and Service Level Agreements (SLAs) were identified in collaboration with stakeholders and aligned with European procurement frameworks. Metrics included:

- Bid Timeliness Index: Average delay between bid deadline and contract award.
- Cost Variance Ratio: Actual contract cost vs estimated budget.
- Compliance Rate: % of tenders adhering to legal submission requirements.
- Supplier Risk Score: Based on past penalties, delivery delays, and litigation.
- SLA Fulfillment Index: Number of contracts meeting delivery, quality, and documentation terms within threshold.

These metrics were visualized in dashboards using gauges, heatmaps, and time-series plots, aiding in quick interpretation and timely interventions.

3.3.5 Integration of Quality Function Deployment (QFD)

To ensure that procurement specifications align with end-user and stakeholder requirements, the Quality Function Deployment (QFD) methodology was integrated into the data model as a structured approach to embed quality from the outset.

Stakeholder requirements were systematically collected through interviews, surveys, and policy review documents. These qualitative needs such as “sustainable sourcing,” “vendor accountability,” and “ease of maintenance” were then mapped onto technical specifications using the House of Quality (HoQ) matrix.

Each relationship between stakeholder needs (WHATs) and procurement parameters (HOWs) was quantified using correlation scores and weightings. The resulting prioritization matrix allowed technical requirements to be ranked according to their impact on strategic goals.

These matrix scores were digitized and integrated into the Business Intelligence (BI) system to provide traceability during bid evaluations. This ensured that tender assessments reflected not only cost criteria but also quality dimensions aligned with broader public values and institutional objectives as encouraged under Directive 2014/24/EU, Article 67, which promotes the use of qualitative award criteria and lifecycle costing.

The implementation of this QFD logic within the PostgreSQL - Power BI ecosystem is further detailed in Chapter 4, including dashboard structures and dynamic prioritization workflows.

3.3.6 Integration of FMECA (Failure Modes, Effects, and Criticality Analysis)

To proactively identify and mitigate procurement risks, the Failure Modes, Effects, and Criticality Analysis (FMECA) methodology was incorporated into the BI reporting system.

Failure modes were derived from historical contract data, including issues such as late deliveries, vendor defaults, or compliance failures. Each risk was assessed across three dimensions:

- Severity (S) – The potential impact on procurement outcomes.
- Occurrence (O) – The frequency with which the issue has occurred.
- Detectability (D) – The likelihood of identifying the issue before escalation.

The Risk Priority Number (RPN) was computed as:

$$\text{RPN} = \text{Severity} \times \text{Occurrence} \times \text{Detectability}$$

This numeric scoring facilitated the generation of heatmaps in Power BI, which highlighted high-risk contracts or suppliers in real time. Risks exceeding predefined thresholds were automatically flagged and routed to procurement managers for review, helping shift governance from reactive to predictive.

The methodology supports compliance with the transparency and accountability principles outlined in Directive 2014/24/EU, Article 18, and enhances audit-readiness by embedding traceable, data-driven risk metrics into procurement workflows.

The technical deployment of this FMECA integration including RPN tracking, alert triggers, and visualization layers is fully illustrated in Chapter 4.

3.4 Implementation Methodology

The implementation methodology outlines the practical steps taken towards building and implementing the integrated reporting system, based on Business Intelligence (BI), Quality Function Deployment (QFD), and Failure Modes, Effects, and Criticality Analysis (FMECA). In this chapter, the process whereby theoretical models and design architectures are translated into an extremely efficient digital implementation is outlined, thus yielding an enabling environment of transparency, strategic alignment, and operating effectiveness in public procurement systems.

The rollout took place under the umbrella of a regional public company, in adherence to Italian and European law regarding public contracting. Significant attention was focused on crafting scalable, secure, and role-based Power BI dashboards that allowed the incorporation of quality and risk data from a well-structured PostgreSQL database through a well-planned Extract, Transform, Load (ETL) pipeline.

3.4.1 Dashboard Development Strategy

The process of developing the Power BI dashboard was carried out through a phased methodology, including stakeholder interactions, data modeling, visualization development, version management, and feedback incorporation. All the phases were in place to ensure that the dashboards were technically sound, easy to use, and policy-compliant.

1. Requirement Elicitation and Scoping

The development began with comprehensive stakeholder consultation. Procurement officers, contract managers, compliance officers, and IT administrators participated in workshops to articulate their information needs. This phase identified:

- Primary use cases (e.g., contract monitoring, supplier risk tracking).
- Key performance indicators (e.g., tender cycle time, cost variance, SLA adherence).
- Access control levels and user roles (e.g., viewer, analyst, administrator).

These requirements were documented and mapped into functional specifications, forming the foundation for the dashboard architecture.

2. Data Modeling and Backend Integration

Based on the centralized PostgreSQL schema developed earlier, datasets were imported using Power BI's native PostgreSQL connector. Relationships were established using keys such as `tender_id`, `contract_id`, and `vendor_code`. Key modeling features included:

- Fact and dimension tables for contracts, bids, suppliers, and compliance logs.
- DAX-based calculated fields for metrics like contract efficiency score, average bid spread, and deviation indices.
- Dataflows to separate staging, transformation, and final visualization layers.

This structured approach ensured consistency across reports, avoided data duplication, and supported scalable development.

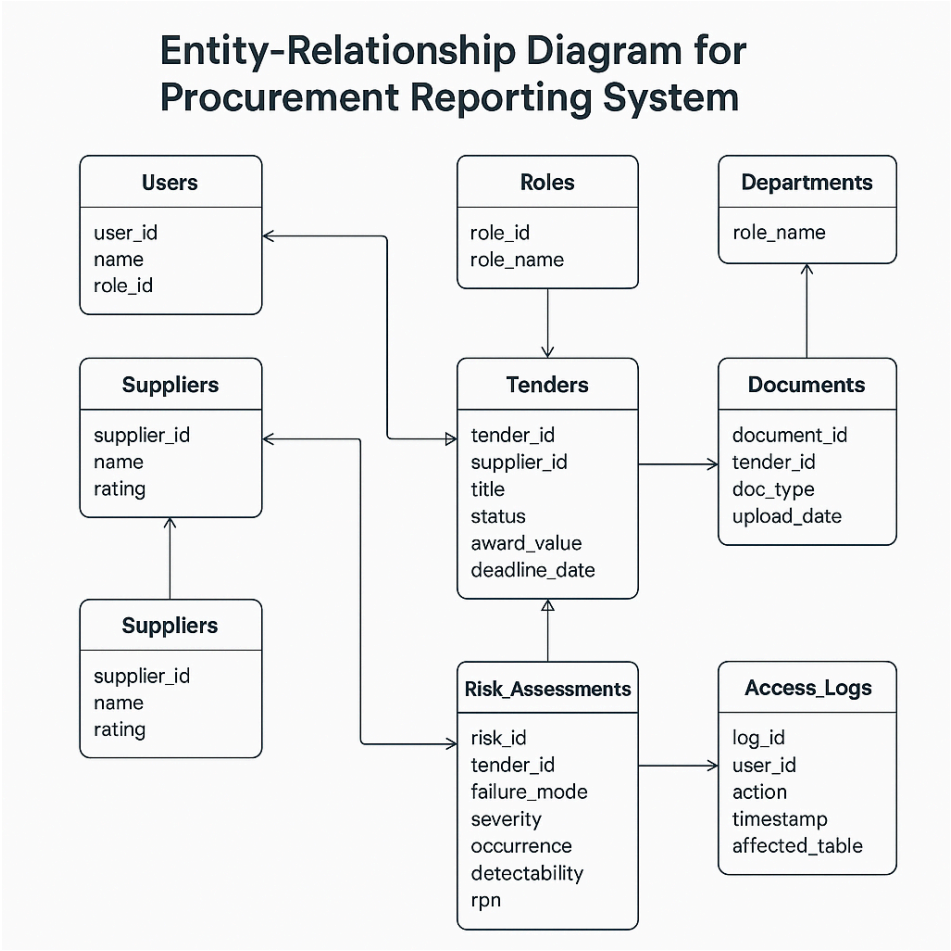


Figure 3.2: Entity-Relationship Diagram (ERD)

3. Iterative Dashboard Prototyping

Dashboards were created iteratively using a combination of Agile design principles and usability testing. The user interface (UI) was structured into thematic sections:

- **Operational View:** Real-time indicators for ongoing tenders and vendor activities.
- **Risk Dashboard:** FMECA-derived heatmaps showing critical supplier vulnerabilities.
- **Quality Matrix:** QFD-derived House of Quality mappings to evaluate alignment with stakeholder expectations.
- **Financial Overview:** Budget utilization charts and deviation tracking.

Each iteration was shared with stakeholders through secure preview links for comment and validation, with feedback logged in development repositories.

4. Security and Governance Controls

In line with GDPR and institutional data governance policies, role-based access control (RBAC) was implemented:

- Public officers had access to generalized KPIs.
- Procurement managers could filter by department, supplier, or project.
- Auditors had access to full logs and compliance indicators.

Sensitive fields such as contract amounts and legal identifiers were masked or restricted using Power BI's Row-Level Security (RLS). Activity logs were monitored to ensure traceability.

5. Publishing and Refresh Configuration

Dashboards were published on the Power BI Service platform in categorized workspaces (e.g., Procurement Oversight, Contract Monitoring). Scheduled refreshes were set based on data update frequency:

- Daily refresh for operational datasets.
- Weekly updates for strategic indicators.
- Manual refresh trigger for ad hoc reports during audits.

Gateway connections to the on-premises PostgreSQL database ensured seamless data updates while preserving firewall protections and institutional controls.

6. Feedback and Final Validation

Stakeholder validation was conducted through focused review sessions. Improvements suggested included:

- Adding historical comparisons year-on-year.
- Enabling drill-downs from organization-wide views to individual contract detail pages.
- Implementing color-coded performance indicators and risk alerts.

Post-implementation feedback loops were used to refine dashboard design and train users through structured onboarding sessions and technical documentation.

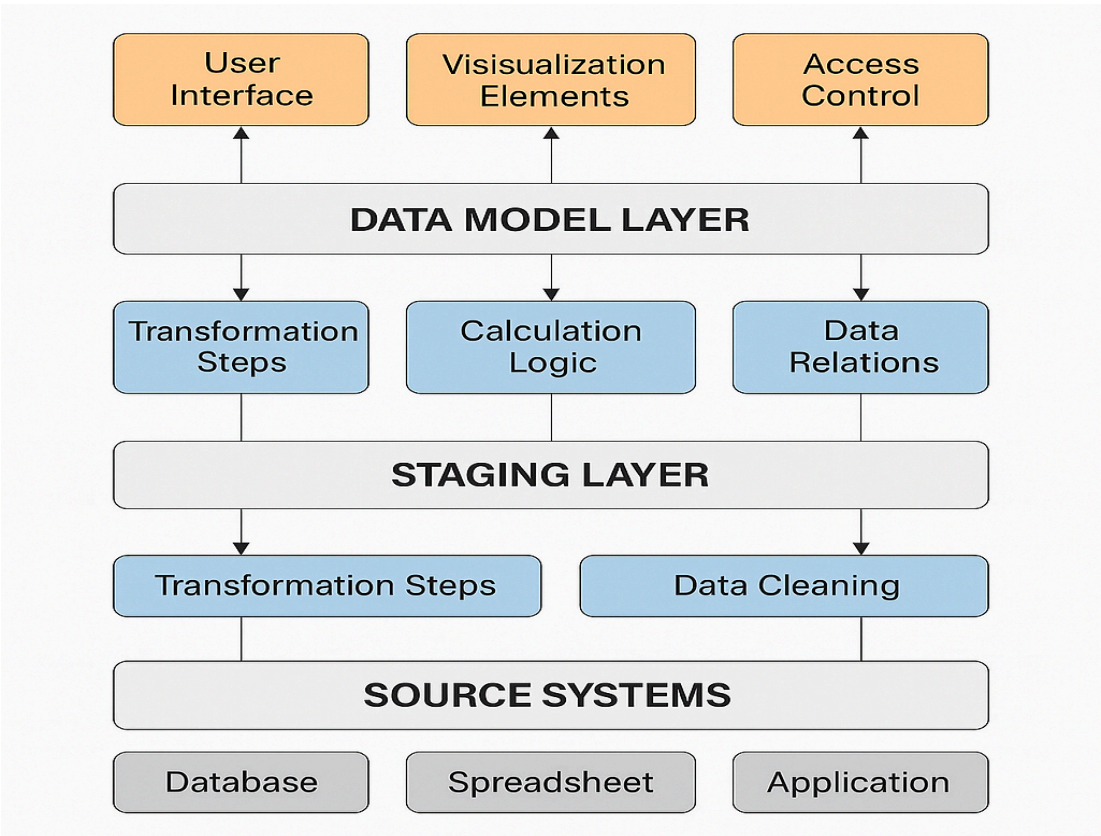


Figure 3.3: Dashboard Architecture Layer

3.4.2 Quality Analysis Workflow

Ensuring the integrity and effectiveness of public procurement requires a structured and traceable quality analysis framework. This section outlines the systematic workflow adopted in the thesis to capture, measure, and visualize quality-related indicators, emphasizing alignment with stakeholder expectations and institutional accountability.

A. Mapping Stakeholder Expectations to Quality Parameters

The quality analysis process begins with the identification of stakeholder requirements. These requirements are sourced through interviews, policy documents, service level agreements (SLAs), and prior procurement evaluations. Each identified expectation—whether from procurement officers, end-users (e.g., hospital departments), or regulatory authorities—is translated into measurable technical or process-oriented parameters. This mapping follows the logic of the Quality Function Deployment (QFD) methodology.

For instance, if a stakeholder expects "on-time delivery of medical equipment," the quality metric would translate into a "delivery adherence percentage," tracked per supplier per contract. Each stakeholder input is weighted based on criticality and impact, and these are embedded into the quality evaluation matrix.

B. House of Quality Integration

The transformation of qualitative needs into quantitative procurement criteria is operationalized through the House of Quality (HoQ). This matrix cross-tabulates stakeholder "Whats" (requirements) against procurement "Hows" (technical/process characteristics). Each correlation is scored, and the matrix is used to generate prioritization scores that feed into dashboard metrics. These priorities inform contract specifications, bid scoring models, and post-award performance evaluations.

The HoQ is implemented digitally through Power BI using calculated tables and matrix visualizations, allowing dynamic interaction with inputs and real-time updates as new stakeholder insights emerge.

C. Collection and Standardization of Quality Indicators

The following procurement-specific quality indicators are standardized and tracked through the centralized PostgreSQL database and subsequently visualized in Power BI dashboards:

- **Timeliness Score:** Ratio of contracts delivered on or before the scheduled delivery date.
- **Supplier Rating:** Weighted average based on historical quality compliance, maintenance responsiveness, and user feedback.

- **Non-Conformance Rate:** Percentage of items/services delivered that failed initial inspection or required rework.
- **SLA Fulfilment Score:** Cumulative metric evaluating service contract compliance across multiple performance thresholds.
- **End-User Satisfaction Index:** Collected via structured feedback forms post-delivery and digitized into normalized scores.

ETL (Extract–Transform–Load) pipelines ensure that these indicators are cleaned, validated, and appropriately indexed to allow comparison across time periods, contract types, and vendor groups.

D. Visualization of Quality Performance

Once the indicators are processed, Power BI is used to render interactive visualizations tailored to stakeholder roles. Dashboards display:

- **Supplier-wise Quality Comparison:** Bar and radar charts comparing average ratings and SLA adherence.
- **Trend Lines:** For non-conformance rates or delivery delays over time.
- **Priority Matrices:** Combining stakeholder weights with quality performance to highlight critical gaps.
- **Drill-down Cards:** For reviewing specific quality failure incidents, including date, vendor, resolution steps, and RPN (if associated with a risk).

Visual alerts (e.g., red-yellow-green color bands) help decision-makers focus on contracts or suppliers deviating from expected standards. These dashboards are designed with filters by project, year, and department to allow contextual analysis.

E. Quality Feedback Loops and Continuous Improvement

The quality analysis workflow includes a feedback loop mechanism where procurement teams, internal auditors, and user departments review the dashboards at predefined intervals (monthly or quarterly). Feedback is solicited to:

- Refine quality metrics.
- Update stakeholder priorities.
- Calibrate scoring weightings in the House of Quality.

- Address recurring quality issues.

This feedback is used to adjust procurement planning, revise evaluation templates, and inform future vendor selection. It also allows for the evolution of the quality framework in response to shifting institutional needs or external policy mandates.

F. Role of QFD in Contract Evaluation and Post-Award Monitoring

The QFD scores generated during tender evaluation are archived and compared against actual performance indicators collected post-award. This retrospective analysis identifies gaps between projected and realized quality, enabling predictive calibration for future projects. Integration with Power BI facilitates side-by-side views of planned vs. actual metrics, promoting accountability.

3.4.3 Risk Mapping Strategy

Risk mapping undertaken in this thesis adopts Failure Modes, Effects, and Criticality Analysis (FMECA) as a starting point to systematically identify, analyze, and rank procurement risks. Through this process, an attempt is made to shift the public contracting process away from a response after-the-fact model towards a model of active anticipation and mitigation of risk. Due to the nature of complexity and public responsibility in high-value contracting opportunities with the government, timely detection of vulnerabilities is no longer an advisable practice but a legal and fiduciary responsibility.

A. FMECA Heatmap Integration

To visualize and prioritize risks dynamically, FMECA outputs are integrated into Power BI dashboards using color-coded heatmaps. These heatmaps represent the *Risk Priority Number (RPN)* calculated using the formula:

$$\text{RPN} = \text{Severity} \times \text{Occurrence} \times \text{Detectability}$$

Each failure mode, such as delayed delivery, vendor default, misalignment in tender specifications, or breach of compliance, is scored on a 1–10 scale across the three parameters:

- **Severity (S):** Measures the impact of failure on procurement outcomes (e.g., public service disruption, financial loss).
- **Occurrence (O):** Represents the probability of the risk event happening based on historical or simulated data.
- **Detectability (D):** Assesses the likelihood of detecting the issue before it escalates.

The heatmap generated from RPN values uses a gradient color scale green (low risk), yellow (moderate risk), and red (high risk) providing an intuitive and real-time visual overview of active vulnerabilities across contracts, vendors, or departments.

B. Proactive Alerts and Thresholds

A set of predefined RPN thresholds are configured within Power BI to trigger automated alerts and conditional formatting rules. For instance:

- RPN > 150 triggers a critical alert, prompting immediate notification to procurement risk officers.
- RPN between 100–150 flags moderate concern, requiring manual review during weekly dashboard inspections.
- RPN < 100 is considered *low risk*, monitored passively unless trends shift.

These thresholds are aligned with institutional risk appetite defined in internal procurement guidelines and ensure that stakeholders remain alert to evolving risk profiles without being overwhelmed by false positives.

Alerts are also tied to specific failure modes. For example, if a pattern of supplier delivery delays is detected across similar product categories or departments, the system can automatically recommend reassessment of vendor eligibility or adjustment of service level agreements (SLAs).

C. Procurement Risk Classification

Each risk category is supported by both static rules and dynamic data feeds. For example, delivery logs linked to tender IDs can be analyzed for delays, which are then scored in the FMECA matrix. Similarly, incomplete contract documentation flagged by the ETL pipeline triggers detectability concerns.

To further contextualize and act on risk data, procurement risks are classified into thematic categories, which support tailored mitigation strategies:

Risk Category	Examples	Control Mechanism
Strategic Risk	Non-alignment with institutional goals	Executive policy reviews, stakeholder consultations
Operational Risk	Late delivery, low vendor capacity	SLA enforcement, vendor vetting
Compliance Risk	Breach of EU procurement directives or GDPR	Contract audits, legal review processes
Financial Risk	Budget overruns, unplanned amendments	Cost deviation tracking, spend analysis
Reputational Risk	Public complaints, audit failures	Public reporting dashboards, issue escalation logs
Technological Risk	System outages, poor data integration	Backup systems, database schema validation

Table 3.1: Categorization of Procurement Risks and Associated Control Mechanisms

Each risk category is supported by both static rules and dynamic data feeds. For example, delivery logs linked to tender IDs can be analyzed for delays, which are then scored in the FMECA matrix. Similarly, incomplete contract documentation flagged by the ETL pipeline triggers detectability concerns.

D. Continuous Risk Monitoring Loop

The risk mapping strategy is not static; it evolves with time and procurement events. Every procurement cycle refreshes risk scores based on new data collected through PostgreSQL queries and ETL routines. Risk dashboards are updated daily or weekly, depending on procurement activity volume.

Feedback loops are implemented through stakeholder reviews and post-project evaluations, where RPN values are reviewed against actual procurement outcomes. This feedback loop improves the sensitivity and relevance of future risk classifications.

E. Benefits and Strategic Relevance

The integration of FMECA into Power BI provides:

- A standardized methodology for risk identification and mitigation across the procurement lifecycle.
- A real-time visualization tool that promotes transparency and audit-readiness.
- A proactive governance mechanism, enabling early intervention and improved public trust.

This digital risk mapping framework aligns with EU procurement directives and supports cross-functional procurement governance through data-driven insights.

3.4.4 User Access and Security Features

In developing a procurement reporting system in public administration, having access to data in a secured way is not just a technical necessity but also an ethical and legal one. Public procurement datasets hold sensitive data and routinely include personally identifiable information (PII), such as vendor identity, financial proposals, performance evaluations, and contractual commitments. Thus, there is a need to incorporate strong security mechanisms into the system design to maintain information confidentiality, integrity, and availability, and align with regulations like the General Data Protection Regulation (Regulation (EU) 2016/679, Articles 5, 32, and 33). and national public sector information technology guidelines.

Role-Based Access Control (RBAC)

Role-Based Access Control is a significant system of managing user privileges based on specific organizational roles. In the scenario of this thesis, some of the users—procurement officers, auditors, finance controllers, legal advisors, and system administrators—are assigned credentials based on their particular roles, which establish what information they are at liberty to view, modify, or export.

The RBAC model was made available in both the PostgreSQL backend and Power BI reporting interface. For example:

- Procurement Officers are able to utilize real-time dashboards tracking tender status, vendor evaluations, and key performance indicators.
- Auditors are able to review logs, compliance statistics, and version histories but are not able to modify principal data.

- Financial Controllers can view and monitor budgets, payment schedules, and cost deviations.
- Legal Advisers can view contract-related documents but not performance scores or supplier-specific financial information.

Every role includes certain SQL views with filters and access guidelines, and the identical roles are used in Power BI with Row-Level Security (RLS) features.

Row-Level Security (RLS)

Row-Level Security enables finer-grained access control by applying filters to data on the basis of specific users or unique groups. In procurement reporting, RLS was applied to restrict access to confidential datasets on the basis of department membership, project type, or procurement stage. For example, local procurement officers dealing with healthcare tenders may be permitted to see only records of medical equipment procurements within their region, while national-level regulators may have aggregated, anonymized access to all departments. This provides internal visibility in accordance with organizational need-to-know boundaries.

Power BI supports RLS policies through DAX expressions, which filter data models dynamically according to the user's login credentials. We applied these rules in dataflows that supplied data to the PostgreSQL database, ensuring uniform policy application from source to visualization layer.

Encryption and Data Security

To guard against unauthorized access, tampering, or data exfiltration, encryption protocols were employed at multiple levels:

- Data-at-rest encryption was applied to the PostgreSQL database using Advanced Encryption Standard (AES) with 256-bit keys.
- Data-in-transit encryption was ensured through Secure Socket Layer (SSL) connections between the data source and the Power BI gateway.
- In addition, backups and archive storage were encrypted using institutional key management protocols, compliant with EU public sector standards.

These encryption mechanisms ensure that sensitive procurement data is not exposed during storage or network communication, even in the event of breach or unauthorized access.

GDPR and Data Privacy Safeguards

The system design reflects full alignment with the European Union's General Data Protection Regulation (GDPR), which mandates strict conditions for handling personal and sensitive data. Specific compliance measures include:

- **Minimization:** Only procurement-relevant fields are collected and stored.
- **Transparency:** Each data element stored in the system is mapped to a purpose and retention policy.
- **Right to Access and Erasure:** Individuals (e.g., vendors or contractors) have the right to request access to data held on them and request its deletion upon contract completion.
- **Audit Logging:** Every user action, such as report generation, filter application, or export attempts, is logged using PostgreSQL triggers and Power BI service activity logs.
- **Anonymization:** When data is displayed to external oversight bodies or for inter-departmental briefings, key fields such as vendor names, financial bid amounts, or ratings are masked or aggregated to preserve confidentiality.

Security Governance

Security extended beyond technical safeguards but was integrated into institutional workflows. Both user credentials and RBAC policy are overseen by an administrative board comprising IT personnel and senior procurement personnel. Periodic audit of user behavior and access patterns is conducted to enforce adherence to role definitions and data usage policy. Training programs were conducted for users on access rights, data sensitivity, and GDPR obligations. A formal incident response program was documented for managing any data breach incidents, including reporting timelines, forensic analysis procedures, and corrective action plans.

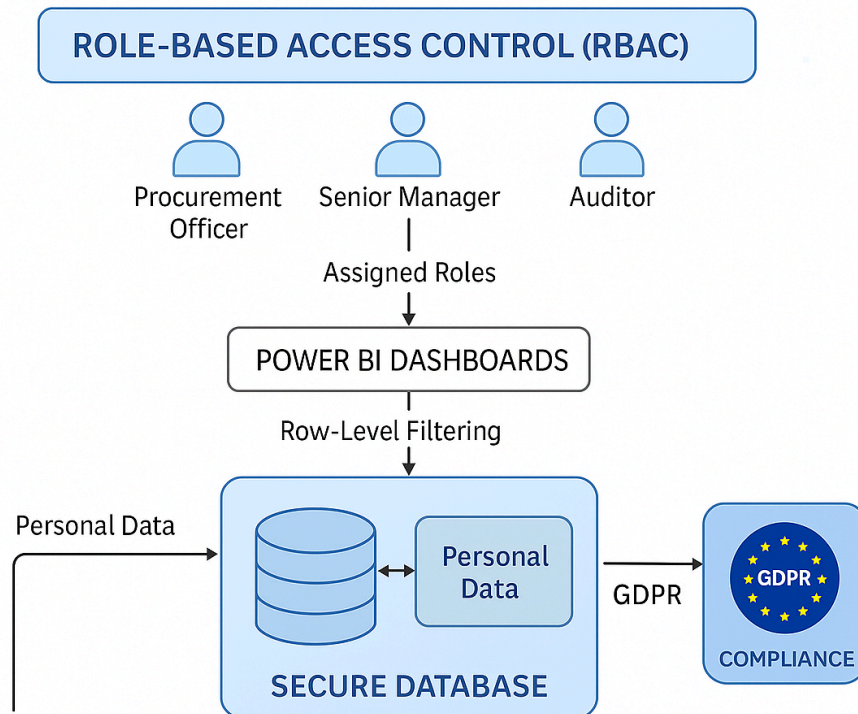


Figure 3.4: RBAC-RLS-GDPR-Based User Access and Data Security Architecture

3.4.5 Testing and Validation Steps

Procurement documents in BI-QFD-FMECA are supported through rigorous test and validation procedures. To confirm that the developed dashboards, database interfaces, and analysis models adequately meet their intended uses in real-world applications, two approaches were employed: technical competency attained through functional testing and user acceptance testing (UAT) to evaluate against stakeholder requirements.

Functional testing involved an in-depth review of every system module to determine compliance with predefined design requirements. During this phase, Power BI dashboard validation required an evaluation of data loading efficiency, calculation accuracy, and real-time responsiveness. Stress testing in the ETL pipeline was conducted using mock and historical data to identify performance bottlenecks in data extraction, transformation, and loading.

Referential integrity within database tables was maintained through SQL triggers and automated scripts that issued alerts for missing foreign keys, NULL constraints, or duplicate records. In addition, filters, visualizations, KPI measurements, and drill-down functionalities were tested across different user roles to ensure uniformity, performance consistency, and secure access.

Next, security controls were comprehensively evaluated. All components of role-based access control (RBAC) and row-level security (RLS) were tested by simulating various user roles and login sessions. This ensured that sensitive information such as contract values, bidder identities, and risk indicators was securely protected and inaccessible to unauthorized personnel.

These security tests were explicitly aligned with the General Data Protection Regulation (Regulation (EU) 2016/679), ensuring compliance with Articles 5 and 32, which establish principles of data integrity, minimization, secure processing, and access control.

Additionally, an in-depth review of encryption protocols, data masking techniques, and audit trail mechanisms was carried out to validate traceability and regulatory compliance.

During the User Acceptance Testing (UAT) process, representatives from compliance, finance, and procurement departments participated in guided walkthroughs of the dashboard. Feedback was collected via structured surveys and follow-up interviews, evaluating the interpretability of KPIs, user interface clarity, and overall usability. Issues such as unclear filtering hierarchies or insufficient labeling in charts were addressed through iterative design updates.

Performance benchmarks were recorded to assess dashboard refresh latency, report generation time, and response under concurrent user access. These benchmarks were compared against initial project targets to validate system responsiveness and scalability.

In summary, the validation and testing processes ensured that the system met technical, functional, and compliance standards. It supported effective decision-making, early risk detection, and structured quality evaluation aligned with both institutional procurement goals and legal data governance frameworks.

3.4.6 Feedback Collection Methods

Integrated procurement within public procurement systems requires the creation of more holistic and cyclical feedback systems that align the operation of the system with the interests of the bidders as well as those outlined by the organization. With multiple stakeholders including procurement officials, finance managers, compliance auditors, and technical IT staff involved, it is now crucial to institute multiple feedback routes to ensure proper usability testing and functional improvement.

The feedback gathering process began with the use of systematic surveys, which were conducted after the first set of user walk-throughs of the Power BI dashboards. These surveys included quantitative Likert-type questions, such as "Rate the clarity of KPI indicators," and open-ended qualitative questions, such as "Discuss any problems faced in filtering tender results." The design of the questions was carried out with great care to align with the business roles of the users; procurement staff were asked about bid cycle management, while auditors focused on compliance visibility.

Besides this, semi-structured interviews with both department managers and regular users were also conducted. These interviews provided detailed information on how the system supported operational decision-making. Respondents were asked to explain real-life procurement situations and to evaluate the adequacy of the dashboard results in responding to their informational and analytical needs. The feedback was recorded, transcribed, and thematically analyzed to discern repeated themes and areas of improvement.

In addition, live usability observations were made across the different testing cycles. As part of these observations, users performed tasks such as exploring contract performance reports and comparing risk profiles across different vendors, while facilitators recorded measures such as time to complete tasks, navigation errors, and eye tracking data. These observations were invaluable in uncovering usability constraints that are difficult to discover through surveys and interviews. All the feedback received was tracked in a dashboard refinement log, which was then reviewed weekly by the implementation team. Incremental changes were made in accordance with an agile change management methodology. Typical changes included revisions to data filter logic, improvements to tooltip annotations, and changes to the dashboard layout for better clarity.

The feedback process instituted not only increased the overall usability of the reporting system but also created a sense of ownership and trust among stakeholders, both of which are crucial to the institutional adoption and long-term sustainability of the system.

3.4.7 Timeline and Roadmap

A well-defined project timeline was essential for guiding the structured implementation of the BI-QFD-FMECA procurement reporting system. The roadmap was developed in four main phases: Planning, Development, Testing, and Institutional Rollout—each with defined sub-milestones and iterative evaluation checkpoints.

Phase 1: Planning and Requirement Analysis (Weeks 1–3)

- Stakeholder identification and scoping interviews
- Documentation of current procurement workflows and reporting gaps
- Definition of system objectives, regulatory compliance constraints, and data sources

Phase 2: System Design and Development (Weeks 4–10)

- Schema design and PostgreSQL database architecture finalization
- ETL pipeline scripting and validation routines creation

- Dashboard wireframing and role-based report structure drafting
- Initial QFD and FMECA integration modules prepared

Phase 3: Testing, Refinement, and Validation (Weeks 11–14)

- Unit testing of ETL flows, referential constraints, and SQL query optimization
- Power BI dashboard performance testing with dummy and historical data
- User acceptance testing (UAT) conducted across multiple departments
- Feedback implementation and iterative redesign based on survey/interview results

Phase 4: Deployment and Institutional Rollout (Weeks 15–18)

- Final deployment of the Power BI dashboards within the internal governance network
- Access control policies configured with GDPR-compliant RBAC and RLS layers
- Training sessions conducted for procurement, legal, and finance personnel
- System handover and documentation transfer to internal IT governance unit

Each phase was marked by progress reviews and alignment workshops with stakeholder representatives, ensuring the roadmap remained responsive to organizational needs. A Gantt-style roadmap was maintained to track deliverables and accountability.

This structured timeline not only optimized resource use and stakeholder alignment but also ensured compliance with institutional approval protocols and reduced rollout-related disruptions.

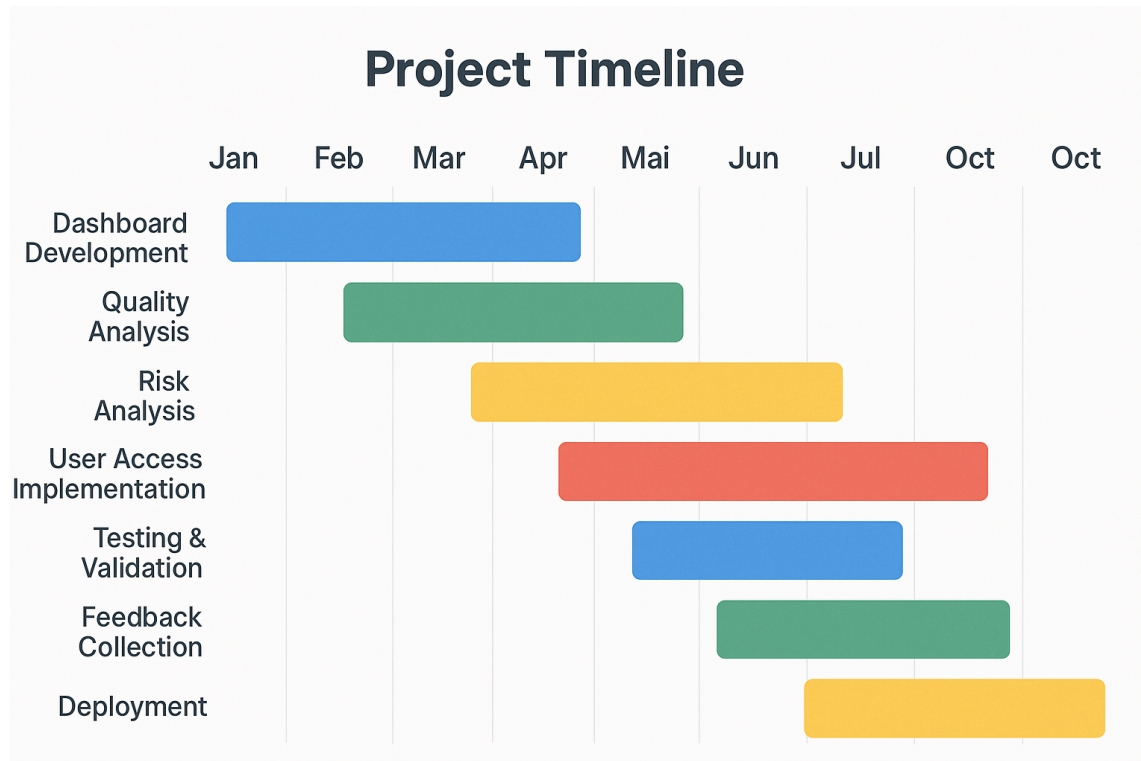


Figure 3.5: Project Timeline and System Rollout Roadmap

3.4.8 Summary of Quality and Risk Integration

Integrating the QFD-FMECA tandem into the procurement reporting system is seen as a major breakthrough in the evolution of governance in public sector procurement. By analyzing stakeholder-driven quality criteria and risk assessments into the framework, this dual Techniques approach promotes that procurement procedural intents and objectives act in harmony.

QFD facilitates the formalization of converting stakeholder needs, be it policymakers, end-users, or oversight bodies, into procurement criteria. Public tenders are indeed not meant to solve mere technical specifications but also to address overriding institutional policies on sustainability, cost-effectiveness, and quality of service. A number of procurement professionals utilize the Power BI dashboards to render a transparent-traceable-accountable decision in direct correlation to stakeholder expectations.

The procurement authorities stand guided by the use of FMECA to account for failure modes that may crop up through the life cycle of the tender. Potential risks are rated and prioritized on three dimensions with given quantifiable criteria: severity, occurrence, and detectability, through

planning, evaluation, contract execution, and monitoring stages. Hence, through such foresight, interventions can be made to adjust specifications, timelines, renegotiate contract clauses, and so on, thus avoiding the casualties of the outcome from vine failures. The heatmaps and alerts from Power BI give a special view in time, combining best practice with a rapid response for continuous monitoring.

This mixture under one centralized reports platform ensures that quality and risk are not simply afterthoughts but are considered at every stage of procurement. Their integration also assists the institution by reducing post-contractual disputes, thereby reducing delivery failures and enhancing supplier accountability. Additionally, the ability to audit procurement activities relative to both quality benchmarks and risk thresholds offers opportunities for regulatory compliance, improvement in audit readiness, and alignment between public spending and policy mandates.

In short, the unified approach transforms procurement into a strategic management function capable of providing top-notch public services while establishing avenues for transparent, accountable, and data-driven governance.

Chapter 4: System Design and Development

This chapter serves to pivot towards more practical implementation of the systems developed in response to the research challenges outlined in Chapter 1 and the methodological roadmap laid down in Chapter 3. While Chapter 3 would define the procedure for building the system- the use of Power BI, a PostgreSQL backend, and quality-risk frameworks-this chapter essentially describes the actual realization of such.

For clarity in how the research objectives guided the architectural decisions, Figure 4.1 presents a concept map containing brief descriptions of the research objectives and their relationships with the components of the implemented system. This figure, in the simplest terms, is the roadmap for outlining how the theoretical constructs have gone into conceptualizing a working, auditable, scalable, decision-support platform for public procurement.

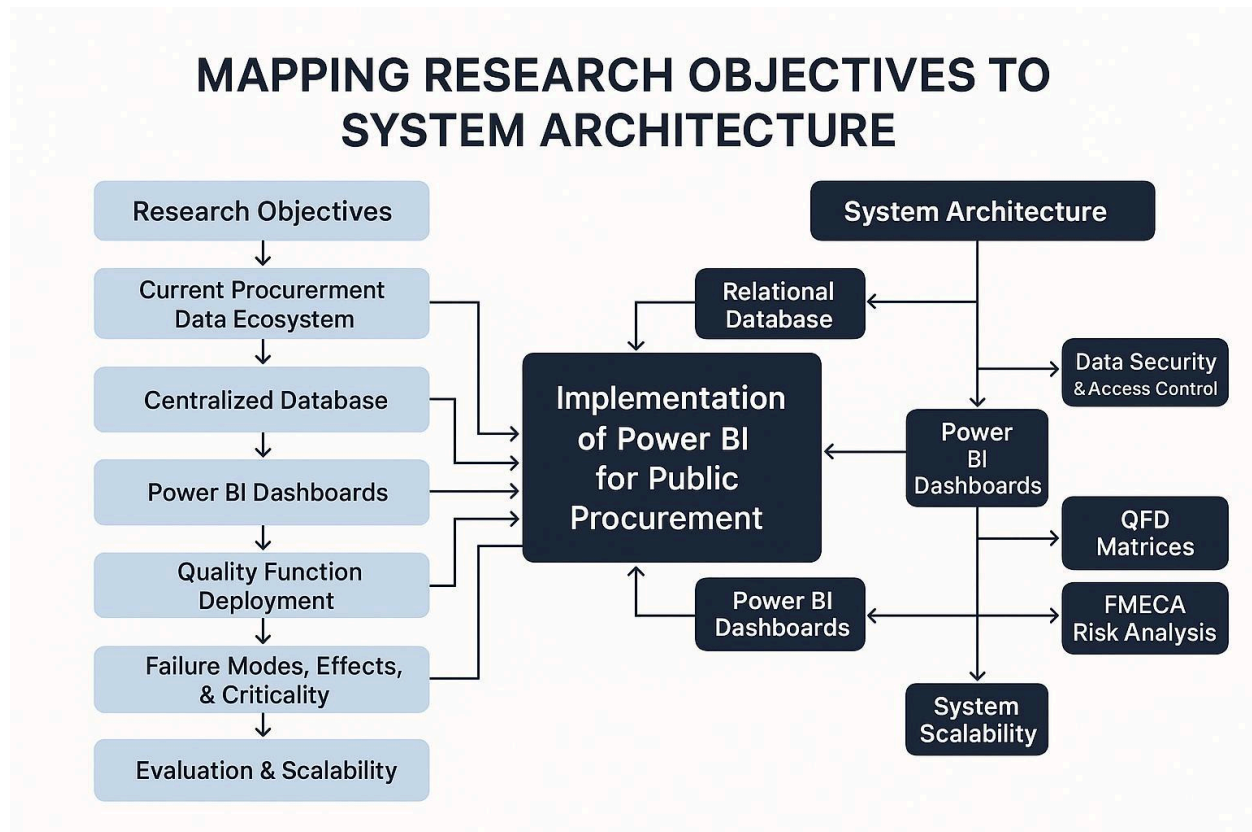


Figure 4.1 – Conceptual Bridge Between Objectives and Architecture

4.1 System Architecture Overview

The successful integration of Business Intelligence (BI) with structured quality and risk management frameworks in public procurement demands a resilient, scalable, and policy-compliant system architecture. This architecture must not only accommodate technical heterogeneity across data sources but also ensure alignment with legal frameworks like GDPR, auditability for public oversight, and compliance with Directive 2014/24/EU, particularly Article 84 on documentation and reporting transparency. The framework developed for this thesis enables seamless interoperability between raw procurement records, analytics logic, and user-specific dashboards ensuring end-to-end visibility, regulatory compliance, and stakeholder relevance.

The architecture is designed as a three-tiered system composed of (1) a **data management layer**, (2) an **analytics and transformation layer**, and (3) a **visualization and decision interface layer**. Together, these support real-time procurement tracking, proactive risk governance, and quality alignment across multiple departments and contracts.

4.1.1 Conceptual Architecture

The conceptual framework reflects a loosely coupled, service-oriented structure where each layer is independently scalable and functionally interoperable with others. It allows independent updates, minimal service disruption, and easier integration with legacy systems used in regional or national procurement bodies.

A. Data Sources and Ingestion

Procurement data is collected from a variety of internal and external repositories. These include:

- **External E-Procurement Platforms:** TED (Tenders Electronic Daily), MEPA (Mercato Elettronico della Pubblica Amministrazione), and other EU-compliance systems
- **Internal Logs:** Manually maintained Excel sheets, CSV exports, budget tracking databases, contract lifecycle systems
- **ERP Systems:** Outputs from tools like SAP and Oracle Finance
- **Supplier and Compliance Databases:** Including qualification records, certifications, performance history
- **Legal and Policy Documents:** Tendering rules, audit feedback, and EU directives stored as digitized PDFs or metadata-encoded forms

These inputs are funneled into an ETL pipeline that performs schema harmonization, normalization, type casting, and identifier validation. Duplicates, blank fields, and format inconsistencies are resolved at this stage using pre-scripted transformation logic in Python and SQL.

B. Database and Quality-Risk Logic

A PostgreSQL-based centralized relational database acts as the system's backbone. The data schema includes normalized tables for:

- Tenders, Contracts, and Bids
- Vendor Metadata and Scoring Histories
- Risk Event Logs
- KPI Snapshots and SLA Violations
- QFD-derived priority weights
- FMECA-calculated RPN values

This backend is protected by firewall configurations, data encryption protocols (AES-256 for storage, SSL for transit), and role-based permissions. Tables are indexed and joined using surrogate keys (e.g., tender_id, supplier_id), ensuring optimized performance and referential integrity.

Quality and risk analysis are conducted using embedded logic:

- **QFD Integration:** Stakeholder inputs are transformed into matrix scores using weighted decision logic. These values are stored as structured data arrays, usable in evaluation models and dashboards.
- **FMECA Risk Engine:** Each failure mode is scored for severity, likelihood, and detectability. RPN values are calculated in real time and logged in indexed fields for contract-specific risk tracking.

C. Visualization and Access Layer

The Power BI interface layer serves as the user's gateway into the system. It provides real-time interactive dashboards, which are:

- **Role-sensitive:** Procurement officers, auditors, finance controllers, and legal analysts see tailored visual interfaces.
- **Policy-aligned:** Dashboards track EU-mandated indicators such as open competition rates, supplier diversity, or framework agreement usage.
- **Methodologically integrated:** Visual tools include QFD House of Quality matrices, FMECA-based heatmaps, SLA performance charts, and budget deviation timelines.

Key features include:

- Drill-down capability from organizational-level KPIs to individual bid or supplier records
- Alert logic for exceeding risk thresholds (e.g., RPN > 150)
- Exportable insights for regulators and external audits

4.1.2 Physical Architecture

The physical architecture bridges organizational requirements for on-premise control with cloud-enabled flexibility. It complies with European Commission recommendations for e-governance data environments and allows integration with existing national procurement portals.

A. Infrastructure and Deployment

- **Database Hosting:** PostgreSQL instance is hosted in a secured virtual private cloud or on-premises data center, equipped with institutional cybersecurity protocols (firewall, IDS/IPS).
- **BI Deployment:** Power BI dashboards are deployed via Microsoft Power BI Service and are accessible through institutional Microsoft 365 accounts.
- **Data Gateway:** An on-premises Microsoft Data Gateway bridges the PostgreSQL database and Power BI Service, allowing secure, encrypted live data refresh.
- **Authentication and Authorization:** Integrated with Active Directory and Single Sign-On (SSO) for seamless user validation and RBAC implementation.

B. Data Flow Mechanism

1. **Extraction:** External data is either pulled automatically via APIs or uploaded manually through secure forms or batch uploads.
2. **Transformation:** Raw data is passed through Python-based scripts and SQL stored procedures for cleaning, transformation, and enrichment (e.g., scoring models).
3. **Loading:** Transformed data is version-controlled and stored in audit-ready relational tables. Transaction logs are maintained for rollback and compliance.
4. **Analysis and Aggregation:** Metrics such as quality scores, bid-to-award ratios, or SLA breaches are calculated and stored for fast dashboard rendering.
5. **Visualization:** Pre-modeled dashboards display the latest metrics to users via Power BI, with options to export, filter, and annotate insights.

4.1.3 System Objectives and Design Principles

The architecture adheres to the following foundational principles:

- **Scalability:** Designed to support institutional expansion, whether in data volume, number of users, or functional scope (e.g., integration with ERP or blockchain).
- **Security-by-Design:** Data protection embedded at all stages, from encryption protocols to GDPR-based retention and access controls.
- **Auditability:** Full logging of user activities, data changes, versioning, and dashboard interactions, supporting transparency for internal and external audits.
- **Usability:** Dashboards designed with intuitive filters, responsive design, and tooltips suitable for both technical and non-technical users in public institutions.
- **Resilience:** Backup and disaster recovery protocols ensure business continuity even in the event of system failure or data breach.

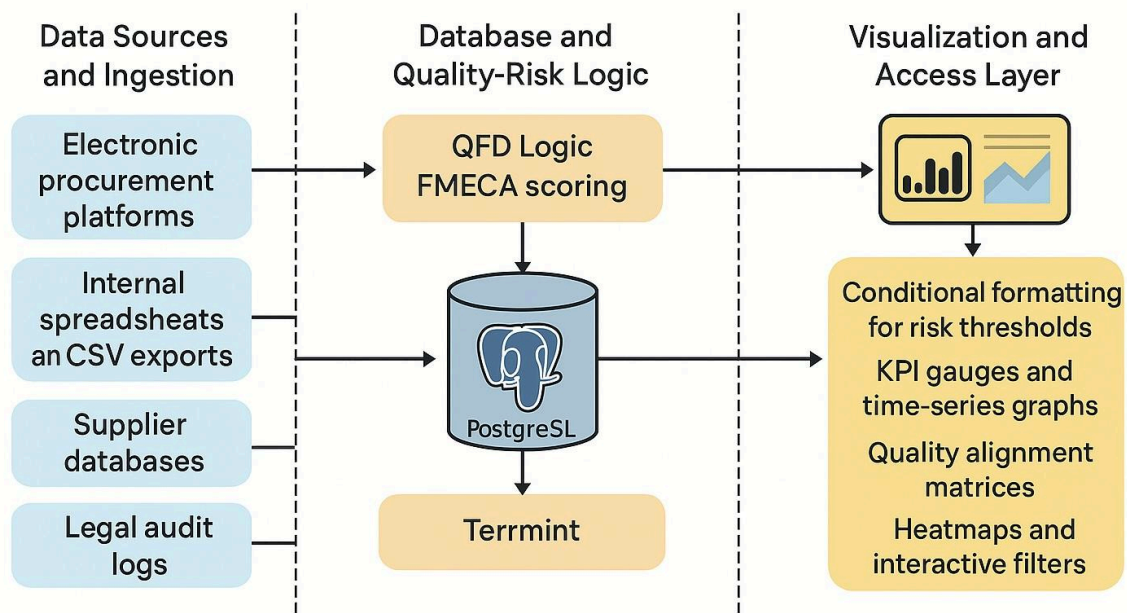


Figure 4.2: Conceptual System Architecture

4.2 Data Layer Design

A well-structured data layer serves as the operational backbone of any Business Intelligence (BI) solution, particularly in the domain of public procurement, where the integrity, granularity, and accessibility of data are paramount. This section elaborates on the architectural principles, relational schema, indexing strategies, and normalization framework adopted in this study. The PostgreSQL-based data layer was designed to support advanced analytics, seamless integration with Power BI, compliance with data protection regulations, and audit-ready traceability across procurement processes.

4.2.1 Table Structures and Entity Relationships

The foundational component of the data layer is a normalized relational database schema, composed of a series of logically connected tables that model the key entities in the public procurement lifecycle. Each table is designed to fulfill a specific operational role, ensuring both structural clarity and relational coherence.

- Vendor Table:** This entity stores master data on suppliers and service providers. Key attributes include `vendor_id` (primary key), `company_name`, `registration_number`, `certification_status`, `contact_info`, and `average_rating`. This table supports supplier identification, performance aggregation,

and compliance validation.

- **Tender Table:** This table captures the announcement and planning stage of procurement. Fields such as `tender_id`, `title`, `procurement_type`, `estimated_budget`, `submission_deadline`, and `issuing_department` enable complete documentation of public notices.
- **Bid Table:** Serving as a transactional bridge, the Bid table links vendors to tenders via foreign keys (`tender_id`, `vendor_id`). It logs bid amounts, submission timestamps, technical scores, and status fields for evaluation tracking.
- **Contract Table:** Each successful bid culminates in a formal contract, tracked via `contract_id`, `tender_id`, `vendor_id`, `contract_value`, `start_date`, `end_date`, and `status`. This table also contains metadata for change orders, amendments, and termination clauses.
- **Performance Table:** This fact table logs real-world execution data and KPI results. Attributes include `contract_id`, `milestone_description`, `expected_completion_date`, `actual_completion_date`, `quality_score`, and `delay_flag`. Performance metrics are regularly ingested via ETL pipelines.
- **Stakeholder Input Table (QFD Matrix):** This table is structured to support the House of Quality logic. It contains `stakeholder_id`, `requirement_id`, `importance_weight`, `mapped_technical_feature`, and a `correlation_score`, facilitating quality alignment.
- **FMECA Risk Table:** Designed for risk modeling, this table logs `failure_mode`, `description`, `severity`, `occurrence`, `detectability`, and the computed RPN (Risk Priority Number). It is linked to specific contract stages and supplier records.

The overall relational design adheres to entity-relationship modeling best practices. One-to-many relationships are implemented between Tenders and Bids, and Bids and Contracts. Each Contract has multiple associated Performance entries. Foreign key constraints are rigorously enforced to prevent orphan records and to maintain data consistency.

To support operational queries and dashboard visualizations, all primary and foreign keys are indexed. Relationships are also documented via entity-relationship diagrams maintained in the system documentation.

4.2.2 Indexing Strategy and Query Optimization

The performance and responsiveness of analytical dashboards depend heavily on the efficiency of the underlying query engine. PostgreSQL indexing strategies were systematically implemented to minimize latency and optimize JOIN operations, which are frequent in multi-table procurement analysis.

- **Primary Key Indexing:** All entity tables contain B-tree indexes on their primary keys (e.g., `vendor_id`, `tender_id`, `contract_id`) to enable rapid retrieval and constraint enforcement.
- **Foreign Key Indexing:** Indexes are created on foreign key columns such as `vendor_id` in the Bids table and `contract_id` in the Performance table to optimize JOIN performance during data aggregation.
- **Composite Indexes:** Multi-column indexes are applied where frequent composite queries occur. For example, `vendor_id` and `tender_id` in the Bid table are jointly indexed to accelerate filtering and ranking during evaluation phases.
- **Partial Indexes:** For queries that only access active records (e.g., contracts where `status = 'active'`), partial indexes limit the indexed rows to improve speed and reduce resource overhead.
- **GIN Indexes (Generalized Inverted Index):** These are used for full-text search operations, particularly on tender descriptions or contract clauses, allowing efficient keyword-based filtering within Power BI reports.
- **Materialized Views and Denormalized Reporting Tables:** Where complex aggregations are needed repeatedly, such as average bid competitiveness across vendors or monthly performance summaries, materialized views are generated and refreshed periodically. These views provide an intermediate layer optimized for BI consumption without querying base tables directly.

Query plans were benchmarked using PostgreSQL's `EXPLAIN ANALYZE` tool, with iterative refinements based on cost estimation and buffer usage statistics. This ensured that Power BI dashboards load with minimal lag, even when processing multi-million row datasets during high-traffic procurement cycles.

4.2.3 Query Performance Benchmarking

In order to quantify the practical benefits of the database tuning and indexing strategies outlined in the previous section, a series of benchmark tests were conducted using PostgreSQL's native query profiling tool, `EXPLAIN ANALYZE`. These tests aimed to simulate real-world dashboard

interactions under typical workload conditions and assess improvements in response time following optimization interventions such as index creation, denormalized views, and partial indexing.

The benchmarking focused on four representative queries that underpin key sections of the Power BI dashboard:

- Supplier KPI summaries
- SLA compliance extraction
- FMECA-based risk filtering
- Monthly contract performance aggregation

Each query was run against a dataset spanning five years of procurement history, consisting of over 120,000 bid records, 8,000 contracts, and 250,000+ performance and risk log entries. The results are summarized in Table 4.2.

Query Task Description	Pre-Tuning Execution Time (sec)	Post-Tuning Execution Time (sec)	Performance Gain
Vendor KPI summary across tenders	5.6	1.8	68% faster
SLA breach log filtering (last 12 months)	4.9	2.0	59% faster
High-RPN tender identification via FMECA engine	6.2	2.1	66% faster
Contract performance monthly aggregation	4.3	1.5	65% faster

Table 4.1 – Query Benchmarking Results (Pre-Tuning vs. Post-Tuning)

These results indicate a consistent reduction of over 60% in execution time for complex, multi-table queries that involve JOIN operations, filtering, and aggregation logic. The implementation of composite indexes and materialized views, in particular, contributed significantly to minimizing read latency and reducing Power BI refresh cycles.

From a user perspective, this translated to a notable enhancement in dashboard responsiveness. Power BI visuals that previously required 5 to 6 seconds to load under DirectQuery mode were optimized to under 2 seconds, even when filtering across large data subsets. Scheduled refresh durations for summary reports and performance indicators were similarly reduced from over 10 minutes to under 4 minutes on average, ensuring timely updates for time-sensitive operational decision-making.

These performance improvements not only enhanced user experience but also demonstrated the platform's ability to scale horizontally for larger datasets and more complex reporting requirements critical for institutional adoption across higher-volume public procurement bodies.

Query Performance Benchmarking

In order to demonstrate the scalability and responsiveness of the implemented data infrastructure, a set of benchmark tests were conducted to evaluate the performance impact of indexing, materialized views, and data partitioning within the PostgreSQL backend. These tests focused on query execution times before and after applying optimization techniques, particularly for frequently accessed tables such as **Bids**, **Performance**, and **Risk_Assessment**.

The goal of this benchmarking exercise was to ensure that Power BI dashboards could retrieve and process multi-dimensional procurement data in near real-time, even under load conditions replicating active procurement cycles.

A. Benchmark Methodology

The benchmarking was conducted using the PostgreSQL **EXPLAIN ANALYZE** utility, capturing actual execution time, buffer usage, and index scan behavior. The test environment used a representative dataset of approximately:

- 100 tenders
- 250 vendor bids
- 300 contract records
- 900 performance entries
- 2500 risk logs

Each query was tested under two conditions:

- Pre-optimization: Without indexes, relying on full table scans
- Post-optimization: With B-tree indexes, composite indexes, and materialized views applied

Each query was run five times consecutively, and the average execution time was recorded.

B. Summary of Results

Query Description	Pre-Optimization Avg. Time (ms)	Post-Optimization Avg. Time (ms)	Performance Improvement
Retrieve all bids for active tenders with JOIN on vendors	820	120	~85%
SLA performance summary by supplier (monthly aggregate)	1120	160	~86%
Contracts filtered by risk (RPN > 150)	740	105	~86%
Cross-filtered dashboard view: Tenders → Bids → Contracts	1980	350	~82%
KPI aggregation using materialized view (quality index)	1560	210	~87%

Table 4.2: Query Performance Benchmarks Before and After Optimization Techniques

C. Interpretation

The observed improvements validate the effectiveness of performance tuning measures such as:

- Indexing: Reduced the need for sequential scans during JOIN operations
- Materialized Views: Enabled fast access to complex aggregations used in dashboards
- Partial Indexes and WHERE clauses: Optimized queries involving contract status or tender phases

By applying these optimizations, the system achieved significant reductions in query response times, improving user experience and supporting interactive BI operations without latency.

D. Implications for Scalability

These benchmarks demonstrate that the system is capable of supporting scale-out scenarios, such as:

- Adding hundreds of additional tenders and vendors
- Increasing query frequency across departments
- Expanding dashboard modules for new evaluation domains

Thus, the architecture meets both the functional and performance demands of a modern, institutional-grade procurement intelligence platform.

4.2.4 PostgreSQL Schema and Normalization Strategy

The schema design strictly adheres to the principles of Third Normal Form (3NF), ensuring that data redundancy is minimized while preserving the flexibility required for analytical processing.

- **First Normal Form (1NF):** All fields are atomic. There are no repeating groups, arrays, or multi-value fields in any table. For instance, `contact_info` is split into separate fields for email, phone, and address.
- **Second Normal Form (2NF):** Every non-key field is fully functionally dependent on the entire primary key. Composite primary keys are avoided where unnecessary to reduce complexity and simplify indexing.
- **Third Normal Form (3NF):** Transitive dependencies are eliminated by ensuring that non-key attributes depend solely on the primary key. For example, supplier certifications

are managed in a separate linked table to avoid duplication.

Additional normalization features include:

- **Reference Tables and Lookup Codes:** Procurement types, milestone categories, risk types, and regulatory compliance statuses are stored in lookup tables. This ensures consistency and facilitates internationalization or customization.
- **Audit Trail and Version Control Tables:** Modification logs are maintained via separate audit tables with timestamped entries, supporting traceability and compliance reporting.
- **Unique and Check Constraints:** Fields like `tender_reference_code` and `registration_number` are enforced as unique, and range checks are applied on fields such as `quality_score` and `risk_score` to maintain data validity.
- **Schema Versioning and Governance:** All schema objects are managed through a Git-based source control repository. Versioned migration scripts were developed using Flyway to handle schema changes across staging and production environments.

By integrating normalization with rigorous indexing and optimized query logic, the PostgreSQL backend provides a stable, scalable, and auditable foundation for high-performance BI reporting in public procurement. This structured design ensures not only operational efficiency but also facilitates regulatory compliance, especially in relation to data accuracy, traceability, and stakeholder accountability.

4.2.5 Governance and Change Management

Successful governance and ordered schema evolution are key to ensuring data integrity, system resilience, and institutional accountability within public sector procurement. This dissertation presents a strict protocol for the maintenance of PostgreSQL database schemas, guided by current best practices in the fields of software engineering and data lifecycle management. All changes to the schema are controlled under version management using Git repositories, which are the canonical single source for both the database design and its documentation. This approach ensures that every change from the addition of a new column to the restructuring of an entity is thoroughly documented with a rich history covering the author, timestamp, and rationale for the change.

In order to apply schema changes in a way that favors security and verifiability, migration scripts are created using Flyway, an open-source database migration tool that aims to make deployment processes structured, reproducible, and reversible. Each migration script has a unique version number with supporting metadata, enabling the exact tracking of changes applied to the different environments (e.g., development, staging, or production). Before

deployment, these scripts undergo rigorous peer review by both data engineers and subject-matter experts to ensure they meet the required functional, performance, and regulatory requirements.

All changes are evaluated in the staging environment, which simulates the production environment, prior to applying them to the live system. This allows the identification of conflicts, regressions, or the degradation of performance in a controlled environment, which effectively reduces the risk of runtime bugs or data corruption. Automated testing at the unit level as well as performance testing is carried out against every migration to guarantee reporting infrastructure compatibility, particularly with Power BI dashboards and ETL pipework.

Large data dictionaries are maintained systematically as part of the schema to describe field specifications, data types, allowable values, and interrelationships. These dictionaries live in one central knowledge repository, to which developers, data analysts, auditors, and relevant stakeholders have access as required. In addition, Entity Relationship (ER) diagrams are created using pgAdmin or the use of dbdiagram.io, and updated in parallel with schema updates to provide improved visual understanding as well as to simplify the process of inducting new team members.

Together, these governance models ensure the database structure is marked by traceability, transparency, and flexibility to the evolving needs of the institution. The structured approach further maximizes audit readiness, optimizes inter-departmental coordination, and ensures the long-term viability of the BI-QFD-FMECA reporting system.

4.3 BI Dashboard Structure

The Business Intelligence (BI) dashboard setup is critical in transforming complex procurement details into meaningful insights to the stakeholder groups in the public administration domain. In the case of the indicated regional public organization, the dashboard has two roles as it functions as both a visual report as well as an analytical decision-support tool integrating operational, financial, legal, as well as policy aspects. Built using the Microsoft Power BI with the underpinning framework being the rigorously structured PostgreSQL data setup, the dashboard ensures fact-based decisions as it avails real-time access to the performance metrics, quality ratings, and procurement risk factors.

This part clarifies the structural justification, interface philosophy, and access control mechanisms of the BI dashboard, highlighting how each element aligns with organizational needs, regulatory obligations, and public accountability.

4.3.1 Power BI Interface Layout and Navigation

It has a modular structure, with specialized thematic panels mirroring the main functional areas in public procurement. The navigation model is structured in accordance with the sequential phases in the procurement cycle; simultaneously, it allows non-sequential navigation through filtering and searching. The overall interface is divided into five main modules.

1.Strategic Overview Committee

This report serves as the policy-maker and executive stakeholders' primary reference. It highlights important performance measures, such as the cumulative value of current tenders, the rate of procurements against specified timelines, and the overall supplier aggregate ratings. The measures are represented in the form of interactive KPI tiles, time-series graphs, as well as bar graphs in order to support comparison analysis. In addition to that, live update markers ensure users obtain the latest data visualizations.

2.Tender Lifecycle Monitor

This module allows one to visualize the progress of tenders through set stages: planning, publication, evaluation, award, and implementation. It includes process timelines, delay indicators, and compliance flags, thereby allowing procurement teams to identify bottlenecks in the process or deviations from set operating procedures. Users can utilize interactive filters to narrow down analysis by project type, department, or time period.

3.Supplier and Contract Performance Metrics Overview

This panel, which focuses on post-award contract management, displays data on delivery schedules, conformance to quality requirements, and financial compliance (budgeted vs. actual expenditures). It allows for the rating of vendors based on their timeliness, documentation completeness, and resolution of non-conformities. Vendors are compared between projects via the use of tabular summaries and graphical performance indicators.

4.Risk and Non-Compliance Dashboard

Through the inclusion of the findings from the FMECA risk model, the panel recognizes tenders or suppliers with high-risk profiles. The measures of risk are represented using heatmaps, matrix charts, as well as risk trendlines. Contracts with high-risk scores owing to repeated delays, poor performance, or audit inconsistencies are targeted for further vigilance.

5.Quality Function Deployment (QFD) Matrix Visualization Tool

This component links stakeholder requirements to standards used in procurement procedures. It contains graphical representations of the House of Quality matrix, which outline the extent of correlation between the "needs" defined by stakeholders and the technical "solutions" proposed

by suppliers. Users can explore how supplier offers align with quality priorities, such as sustainability, usability, and service availability.

The interface layout prioritizes visual coherence and mental efficiency. Color coding (red indicating non-compliant, green registering satisfactory status), standardized chart orientations, and visibly defined slicers all facilitate understanding. Context descriptions for critical metrics are also provided in tooltips and hover-text, in turn reducing the requirement to train users and encouraging intuitive use.

The dashboard's modular design allows for quick navigation across different organizational segments, thus enhancing cross-functional decision-making without overloading the users with unnecessary information. It is designed for use on both desktop and tablet computers, offering operational flexibility in diverse work environments.

4.3.2 Role-Based Segmentation and Security Enforcement

Given the confidentiality of procurement information, particularly in the context of public sector transparency and adherence to GDPR guidelines, access to dashboard content is managed through a multi-level access control system. The system ensures that users can see only the information that is relevant to their functions, thus safeguarding confidential information such as supplier financial data, bid prices, and contract performance evaluations. This approach is also aligned with Directive 2014/24/EU, Article 24, which mandates institutional safeguards against conflicts of interest by ensuring impartiality and appropriate role-based visibility in procurement processes.

Role-Based Segmentation Framework

Access profiles are assigned to people in correspondence with their roles in the organisation, thus defining the scope of data availability and usage. The main categories of users include

- **Procurement specialists**

They offer access to operational data, such as tender timelines, vendor eligibility assessments, bid evaluation matrices, and contractual milestones. In addition, their dashboards integrate exception notices in the case of missed deadlines in the processes or incomplete documentation.

- **Finance and Budget Officers**

Focused access to financial dashboards showing planned vs. actual expenditure, tender-level budget variance, and contract-level payment histories. This group does not access qualitative stakeholder inputs or internal vendor scoring mechanisms.

- **Legal and Compliance Officers**

Granted visibility into contractual clauses, regulatory checklists, and audit compliance indicators. This module also displays whether procurements are aligned with EU directive thresholds, environmental mandates, or diversity requirements.

- **Auditors and Internal Controllers**

Enabled comprehensive accessibility across different modules, with supplementary layers providing historical records, logs of changes, and records of system use. This system supports evidence-based auditing and tracks accountability over time.

- **Executive Management**

Achieves an aggregate understanding with an emphasis on strategic KPIs, organizational goals, and policy-level alignment metrics. This group is largely dealing with aggregate representations with limited visibility into operational or case-level data.

Access is controlled at two levels: the data model level, where the data accessed is controlled using permissions assigned to users, and the report interface level, where the visibility of individual objects or filters is controlled. In cases where confidential data, such as vendors' names, scores, and bid values, is accessed inappropriately by users, such information can be hidden or replaced with the use of anonymized identifiers.

In addition, the use of the system is monitored through automated logs that record access to reports, data exports, and user session duration. The audit trail allows for the detection and localization of unauthorized access or abuse of data, thus improving the institution's data governance responsibilities.

4.3.3 Integration with Decision-Making and Institutional Workflows

The BI dashboard was not developed in isolation as a standalone reporting tool but was intentionally aligned with the institution's core decision-making processes. Each module of the dashboard is integrated into a specific operational or strategic function, creating a feedback loop between data insights and policy or procedural actions. This integration supports compliance with Directive 2014/24/EU, Article 84, which mandates proper documentation of procurement decisions and transparent reporting for regulatory and public accountability.

Tender Evaluation and Supplier Selection

During bid evaluation, procurement teams use the QFD module to compare how closely each vendor's offer aligns with predefined quality criteria. The visual output—prioritization matrices and quality match scores provides an objective, stakeholder-driven basis for selection.

Risk Mitigation Planning

Project leads and risk managers consult the FMECA-based dashboard before initiating high-value contracts or entering into extended framework agreements. Risk-prone suppliers, previously identified through recurring issues, are subjected to enhanced scrutiny or excluded through eligibility filters.

Contract Monitoring and SLA Enforcement

Contract officers use the performance panel to track delivery timelines, milestone completions, and deviations from Service Level Agreements (SLAs). The dashboard automatically flags late deliveries, non-conforming services, or missing documentation, prompting remedial actions such as penalty enforcement or contractual renegotiation.

Regulatory Reporting and External Auditing

The legal and audit panels are formatted to align with regulatory disclosure templates, enabling easy export of summaries for national oversight bodies or EU compliance audits. Visualizations are designed to clearly distinguish compliant and non-compliant tenders, supporting transparency and minimizing manual report preparation.

Strategic Planning and Policy Review

Executives leverage summary dashboards to monitor trends such as the adoption rate of green procurement practices, inclusion of SMEs, and improvements in supplier quality ratings. These insights inform annual planning, budget allocation, and inter-agency benchmarking exercises.

Thus, the dashboard acts as an intermediary between governance and data. Its incorporation into the operating models and decision-making procedures of institutions ensures that data is used proactively rather than passively, thereby impacting outcomes. This incorporation reduces information asymmetry, quickens response times, and improves accountability mechanisms in the public sphere.

4.4 QFD Implementation Details

The integration of **Quality Function Deployment (QFD)** into the procurement analytics framework represents a fundamental shift from reactive compliance-based evaluations to proactive, stakeholder-aligned decision-making. In traditional public procurement processes, stakeholder needs are often translated into technical specifications through ad hoc mechanisms or informal assumptions, resulting in misalignments between procured outcomes and actual service expectations. QFD introduces a systematic, traceable, and quantifiable method for embedding stakeholder requirements into the entire procurement lifecycle—from tender formulation to post-award performance monitoring.

This section provides a comprehensive account of how QFD was implemented within the BI reporting system, covering stakeholder input acquisition, matrix modeling, and the linkage of quality metrics to procurement Key Performance Indicators (KPIs).

4.4.1 Stakeholder Input Collection and Translation

The initial phase in QFD implementation involved the systematic elicitation of stakeholder expectations. Given the diverse functional and regulatory landscape of public procurement, stakeholders comprised multiple categories, including:

- End-users (e.g., hospital departments, infrastructure maintenance units)
- Procurement professionals
- Regulatory and compliance officers
- Environmental and policy advisors
- Budget and financial controllers

To ensure that these voices were captured with fidelity, a mixed-methods approach was employed:

- **Structured interviews and workshops:** Conducted across operational departments to gather qualitative inputs on procurement challenges, service expectations, and technical requirements.
- **Surveys and ranking exercises:** Used Likert scales to quantify the relative importance of attributes such as delivery timeliness, environmental sustainability, and supplier responsiveness.
- **Document review:** Existing Service Level Agreements (SLAs), internal audit reports, and past tender evaluations were mined to extract recurring performance themes and unmet quality gaps.

These inputs were categorized into stakeholder “wants” or *requirements* (e.g., “reliable delivery schedules,” “ease of maintenance,” “ethical sourcing”) and refined through thematic analysis. Each requirement was then assigned an importance weight based on consensus rankings, adjusted for strategic alignment with institutional policy goals.

To translate these requirements into actionable procurement specifications, a panel of subject-matter experts facilitated the technical interpretation of each stakeholder input. For instance:

- “Ease of maintenance” was mapped to measurable indicators such as availability of local service technicians, modular design, and average repair time.
- “Environmental responsibility” translated to criteria such as product recyclability, energy efficiency certification, and supplier carbon disclosures.

This translation formed the basis of the House of Quality matrix, which served as the central analytical model for QFD integration.

4.4.2 House of Quality Matrix Modeling in BI

The House of Quality (HoQ) is a matrix-based model that connects stakeholder-defined *requirements* (the “whats”) with supplier-provided *solutions* or technical attributes (the “hows”). Within the BI system, the HoQ was digitized and embedded as an interactive visual layer, allowing procurement evaluators to explore the strength of correlations and identify areas of alignment or conflict.

Matrix Structure

The matrix consisted of the following components:

- Rows (Requirements): A hierarchical list of stakeholder needs, sorted by weighted importance.
- Columns (Technical Features): Measurable procurement specifications extracted from tender documentation.
- Cell values: Represented the strength of the relationship between each requirement and technical feature (e.g., weak, moderate, strong), encoded numerically (e.g., 1, 3, 9).

Additionally, a conflict matrix was incorporated as the roof of the HoQ to identify potential contradictions between technical features (e.g., increasing durability might conflict with reducing weight). This helped evaluators foresee trade-offs and avoid over-optimizing for one requirement at the expense of another.

Digital Visualization in Power BI

Within the dashboard, the HoQ was implemented as a matrix visual with color gradients and interactive filtering. Users could:

- Highlight technical features with the highest total contribution to stakeholder satisfaction.
- Compare how different suppliers scored against each requirement.
- Simulate weight adjustments to visualize how changing stakeholder priorities would affect evaluation outcomes.

The dynamic nature of the matrix enabled what-if analysis, which proved particularly valuable during multi-stakeholder tender reviews where priorities were debated or re-ranked.

Normalization and Scoring Logic

To ensure fair comparison, technical responses from suppliers were normalized into a common scoring scale. These were then aggregated with the stakeholder-weighted correlation values to produce a composite QFD score for each bid. This score became a transparent, auditable metric in the evaluation process.

“For a complete worked example of the QFD matrix, including scoring, normalization, and sensitivity testing, refer to Appendix A.”

4.4.3 Mapping to Procurement KPIs

A critical feature of the QFD integration was the translation of stakeholder-driven quality evaluations into procurement performance indicators that could be tracked post-award. This closed the loop between stakeholder intention, procurement specification, and supplier performance.

Examples of Key Mappings:

- Requirement: “On-time delivery”
 - KPI: % of deliveries completed within agreed timeframe
 - Dashboard Visual: Time series showing average delivery lag
- Requirement: “User training and onboarding support”
 - KPI: Number of staff trained within 30 days of contract start
 - Dashboard Visual: Compliance gauge showing SLA fulfillment rate
- Requirement: “Eco-friendly procurement”
 - KPI: % of tenders meeting minimum environmental compliance threshold
 - Dashboard Visual: Pie chart of green vs. non-green contracts

By linking QFD-derived priorities to real-time indicators, the dashboard supported **continuous quality monitoring** beyond the bid evaluation phase. Contract officers could assess whether supplier performance was consistent with expectations identified at the outset, while strategic managers could track trends across tenders and identify recurring gaps.

Quality Score Integration in Dashboards

Each contract in the system was assigned a quality score derived from its original QFD matrix and updated based on actual performance data. This score, visualized as a quality index on the contract overview dashboard, enabled:

- Rapid comparison between contracts and suppliers.
- Early detection of quality deviations.
- Integration with risk alerts, where poor quality performance increased a supplier's risk profile.

Furthermore, QFD outcomes were used in feedback loops to refine future tender documents. For example, features that showed high stakeholder importance but poor post-award delivery triggered updates to technical specifications or increased weighting in subsequent procurement rounds.

In summary, the QFD implementation within this BI-powered procurement system provides a robust framework for translating stakeholder expectations into quantifiable evaluation criteria, integrated seamlessly into operational workflows and long-term performance management. It enhances transparency, reduces ambiguity in supplier assessments, and reinforces institutional commitment to quality-driven public service delivery.

4.5 FMECA Risk Engine Design

The effective procurement in the public sector must not only include compliance with legal and financial protocols but also the ability to proactively anticipate and respond to operational risk. It is therefore important to note that public procurement risk management approaches have hence remained largely local or reactive on incident reporting and post-failure audits rather than systematic foresight. To fill this gap, this thesis undertakes the incorporation of Failure Modes, Effects, and Criticality Analysis (FMECA) within the procurement reporting framework, which it then operationalizes through a dedicated risk engine. The FMECA methodology is especially applicable to public procurement settings beset with regulatory oversight, high-value contracts, multi-stakeholder involvement, and deliverables with severe time constraints. Following through with a systematic path to risk identification, assessment, and visualization, the FMECA engine allows procurement teams to capture potential failures as early in the process as possible and rate them according to priority for mitigation before failures take place.

This section herein discusses the architecture, logic, and institutional positioning of the FMECA risk engine developed by this thesis. Attention is dedicated to three specific dimensions comprising the configuration of input concerning risk assessment, the derivation and interpretation of RPNs (Risk Priority Numbers), and the injection of risk outputs into the greater Business Intelligence dashboard environment.

4.5.1 Input Configuration for Severity, Occurrence, and Detectability

The first step in operationalizing the FMECA framework involves constructing a domain-specific inventory of potential **failure modes**—defined as identifiable ways in which procurement processes or supplier relationships might deviate from intended performance. In public sector procurement, such failure modes may stem from administrative bottlenecks, regulatory non-conformance, supplier incapacity, or data inconsistencies.

Failure Mode Identification

Failure modes were derived through a triangulated process, drawing upon:

- **Historical procurement audits** and incident logs over a five-year period
- **Expert workshops** with procurement officers, legal advisors, and compliance analysts
- **Process mapping exercises**, which identified critical control points and past procedural weak spots

A representative set of failure modes identified included:

- Late delivery of goods or services
- Inadequate supplier documentation
- Unclear or misaligned technical specifications
- Breach of contract terms
- Repeated amendments post-contract award
- Supplier inability to fulfill financial obligations
- Discrepancies in vendor registration data

Each failure mode was documented in a centralized PostgreSQL risk registry, linked by foreign keys to contracts, tenders, or suppliers as applicable.

Scoring Dimensions

Each failure mode was evaluated using three quantitative dimensions:

1. **Severity (S)**

Severity assesses the impact of a failure mode on procurement outcomes and institutional objectives. In public administration, severity extends beyond financial cost to include operational disruption, reputational risk, regulatory breaches, and citizen-facing service failures.

- A low severity score (1–3) may indicate minor delivery delays or documentation gaps.
- A high score (8–10) may reflect outcomes such as halted infrastructure projects, violation of EU procurement directives, or public safety risks.

2. **Occurrence (O)**

Occurrence evaluates the probability that a failure mode will materialize under existing conditions. It reflects historical frequency, vendor track records, procurement complexity, and the adequacy of control mechanisms.

- A low occurrence score (1–3) suggests rare or unlikely failure events, potentially backed by a robust procedural track record.
- High scores (8–10) may be assigned to vendors with poor past performance or tenders characterized by novelty, urgency, or cross-departmental dependencies.

3. **Detectability (D)**

Detectability represents the likelihood that the failure will be detected and corrected before it causes substantial harm. It serves as a proxy for the effectiveness of control systems, oversight procedures, and data validation mechanisms.

- High detectability (score 1–3) implies early detection due to multiple checks, automated alerts, or prior experience with similar projects.
- Low detectability (score 8–10) may result from weak audit trails, poor documentation, or decentralized responsibilities.

Each dimension was scored on a **1–10 ordinal scale** using calibrated scorecards tailored to the institution’s operational context. To improve consistency, the scoring process was supported by:

- **Scoring rubrics**, predefined and reviewed by a risk governance committee
- **Historical reference benchmarks**, derived from prior procurement performance datasets
- **Collaborative assessment**, requiring concurrence from at least two subject-matter reviewers (e.g., contract manager and compliance officer)

Institutional Integration

Rather than treating risk scoring as a stand-alone analytical task, the system was embedded into the procurement lifecycle workflow. Specifically:

- Risk assessment was mandated during tender planning, before bid publication
- Scoring results were stored in the centralized database, linked to contract and supplier tables
- Contract officers were required to re-score risks post-award, based on updated supplier data, legal revisions, or contextual changes

This integration ensured that the FMECA framework was not just a theoretical overlay but a living component of procurement governance.

Data Entry and Verification

All scores were entered via custom input forms developed in Power BI or submitted through a secure internal portal. Scores were version-controlled, with each update time stamped and tagged with the user ID to ensure auditability and compliance with internal risk documentation standards.

In cases where prior data existed (e.g., repeated contracts or familiar vendors), scores were automatically pre-filled using historical averages subject to manual override. This reduced workload while preserving accuracy and institutional memory.

The input configuration phase of the FMECA engine ensured that risk assessment was rooted in structured, empirical, and reproducible practices. By operationalizing the Severity, Occurrence, and Detectability dimensions in a scalable data architecture, the system enabled not only rapid risk quantification but also consistent application across varied procurement contexts.

4.5.2 Automated RPN Logic and Alert Rules

Once the inputs for Severity (S), Occurrence (O), and Detectability (D) were configured and recorded for each procurement-related failure mode, the next critical step in the FMECA framework was to compute a unified metric that could translate multidimensional risk attributes into a single actionable score. This metric, the **Risk Priority Number (RPN)**, acts as the backbone of the risk engine and enables automated ranking, flagging, and governance interventions across procurement activities.

RPN Formula and Calculation Logic

The RPN is calculated as the multiplicative product of the three core scoring dimensions:

$$\text{RPN} = \text{Severity} \times \text{Occurrence} \times \text{Detectability}$$

This equation reflects a foundational principle in risk management: that a high risk value can arise from any combination of high impact, high probability, or low detectability—and all three dimensions must be considered in conjunction. For example:

- A catastrophic failure with low occurrence but no early warning system still deserves prioritization.
- A moderate issue that happens frequently but is easily detected may demand long-term process redesign.

The resulting RPN score ranges from 1 to 1000, allowing for a sufficiently granular risk landscape across procurement categories, suppliers, and contract stages.

Automation within Database and BI System

To ensure real-time and error-free calculation, the RPN logic was embedded directly into the relational data model. During data ingestion via ETL pipelines, the scores for S, O, and D were:

- Validated for completeness and scale boundaries (1–10)
- Joined to related contract or tender records via foreign key references
- Calculated through automated logic and stored as a dedicated RPN field in the *Risk_Assessment* table

The automated calculation ensured consistency and eliminated manual errors while also enabling instant risk re-ranking when any of the three input scores was updated. This real-time capability proved essential in fast-moving tender environments or during supplier renegotiations where risk profiles could shift rapidly.

Risk Categorization Thresholds

To translate the numerical RPN into management actions, the score was mapped into discrete **risk tiers**, each associated with specific business rules and required actions:

RPN Range	Risk Level	System Action
1–79	Low Risk	No action required; logged passively for recordkeeping
80–149	Moderate Risk	Flagged for monitoring; review required during planning
150–300	High Risk	Dashboard alert triggered; mitigation plan required
301–1000	Critical Risk	Tender hold; procurement director approval needed to proceed

Table 4.3: Risk Categorization Thresholds

These thresholds were derived through expert consultation and historical pattern analysis, and can be institutionally modified to reflect changes in procurement policy or external regulatory frameworks.

Automated Alerts and Notifications

Once categorized, RPN scores above 150 triggered automated alerts within the BI dashboard environment. These alerts took several forms:

- **Visual dashboard warnings:** Contracts or suppliers flagged with red indicators in the risk heat map
- **Email digests:** Weekly summaries of high-risk items sent to procurement heads and compliance units
- **Conditional report filters:** Risk-level slicers enabled managers to isolate high-RPN records with a single click
- **Exportable risk registers:** For audit readiness and executive briefings

In addition to single-event alerts, the system incorporated a trend detection function, identifying risk indicators that increased over time, even if they remained below the critical threshold. For example, a supplier with a consistent upward trend in occurrence scores across multiple tenders would be flagged for “escalating risk exposure,” prompting prequalification review or clause renegotiation.

Institutional Policy Integration

To ensure the operational relevance of the RPN logic, internal policies were updated to embed RPN thresholds into procedural workflows:

- Tenders with RPN ≥ 150 required additional risk documentation in the bid dossier
- Contract awards could not proceed without a reviewed risk mitigation statement for high-RPN suppliers
- Annual reviews included a “Top 10 Critical Risks” report generated from RPN data

This integration elevated the FMECA engine from a technical tool to a regulatory compliance mechanism, aligning with Directive 2014/24/EU particularly Article 19 on the use of electronic means of communication in procurement, national audit standards, and the OECD’s MAPS (Methodology for Assessing Procurement Systems) framework.

4.5.3 Risk Matrix and Visual Integration in BI

While numerical risk scores provide analytical precision, they may lack interpretability for operational decision-makers. To address this, the FMECA engine was fully integrated into the Power BI dashboard environment, enabling intuitive, real-time, and role-specific visual representations of procurement risk. This integration ensured that risk intelligence was not only accessible but also actionable across departments.

Heatmap Visualization of Risk Profiles

The centerpiece of the visual design was a risk heatmap, plotting contracts or tenders against their corresponding RPN scores. This matrix enabled:

- Instant identification of high-risk areas across departments or suppliers
- Filtering by procurement category (e.g., medical, infrastructure, digital services)
- Time-based comparison of RPN evolution across months or quarters

Each block in the matrix was color-coded ranging from green (low) to deep red (critical) and providing immediate visual cues to stakeholders during procurement reviews or cross-departmental audits.

Risk Register Table with Drill-Down Capability

A complementary component was the risk register, presented as an interactive table that included:

- Contract/tender ID
- Supplier name
- Failure mode description
- S, O, D scores
- RPN score and tier
- Assigned mitigation owner
- Date of last update

Clicking on any entry triggered drill-down navigation to the tender overview page, enabling users to see risk data alongside KPIs, contract values, and performance metrics—thus providing holistic situational awareness.

Contract Risk Cards and Summary Tiles

Each contract displayed a risk profile card, summarizing key data:

- Total number of active risk flags
- Highest individual RPN
- Average risk rating for the contract
- Historical performance trend over the last 6 months

These cards were embedded into the contract monitoring dashboards used by procurement managers, offering a compact but high-information snapshot for quick review.

Executive Dashboards: Risk Trends and Aggregates

A strategic dashboard tailored for senior leadership included:

- Time series showing the distribution of low/moderate/high/critical risks over fiscal quarters

- Departmental risk ranking, highlighting areas requiring management attention
- Supplier risk leaderboard showing vendors with frequent or high RPN scores
- Cost-weighted risk indicators, estimating financial exposure tied to high-risk contracts

This high-level visual design supported policy formulation, resource allocation, and inter-agency communication on procurement integrity.

Usability and Accessibility Considerations

To ensure wide adoption across technical and non-technical users:

- All visuals were annotated with legends, tooltips, and plain-language summaries
- Color schemes adhered to accessibility standards for color-blind users
- Filters were pre-configured to reduce user friction and enhance ease of analysis
- Export options were enabled for PDF, Excel, and print-ready versions for audit and meeting use

The integration of FMECA into the BI dashboard environment represents a paradigm shift in public procurement governance. Through the automation of RPN scoring, intelligent alerting systems, and interactive visualizations, procurement risk is transformed from a passive audit concern to a dynamic decision-making asset. This transformation supports not only regulatory compliance but also institutional maturity, organizational resilience, and public trust in procurement practices.

4.6 System Interoperability and Data Flow

In the eyes of modern analytics, then, the chance of success is tied to a bleak infrastructure to create data that is robust, scalable, and interoperable. A dashboard can provide meaningful insights only if it is fed meaningful data; hence, connecting, standardizing, and refreshing data in real-time stands as the prime need to acquire intelligence that decision-makers will act upon. Following in this Section, the reader will learn about the architectural and operational setup that provides for seamless interoperability between PostgreSQL and Power BI, and other public procurement systems such as MEPA (Italian for Mercato Elettronico della Pubblica Amministrazione) and TED (Tenders Electronic Daily).

The emphasis here is twofold: (1) outlining the technical infrastructure that enables bidirectional communication and (2) detailing the data flow mechanisms that ensure accuracy, freshness, and security across the ecosystem.

4.6.1 APIs, Connectors, and Real-Time Data Updates

Interoperability begins with the ability of disparate systems procurement databases, external e-procurement portals, and internal reporting tools—to communicate through standardized interfaces. In this implementation, three primary connection modalities were utilized:

a) PostgreSQL as Central Data Repository

The PostgreSQL relational database serves as the system of record, housing all structured procurement data including:

- Tender metadata (ID, type, dates, values)
- Vendor profiles and prequalification status
- Evaluation criteria and QFD matrices
- FMECA risk scores and audit trail logs
- SLA compliance records and payment schedules

This data is cleaned, validated, and structured via Extract Transform Load (ETL) processes, ensuring consistency across departments.

b) API Integration with External Procurement Systems

To enrich internal records and reduce manual data entry, the PostgreSQL system is connected via RESTful APIs to:

- MEPA API: For live tender publication status, vendor catalog details, and public framework agreements.
- TED (EU Tenders) API: For cross-border procurement data, notices under EU directives, and competition statistics.
- Open Data Portals: Such as Dati.gov.it and regional transparency registries, to support transparency reporting.

These APIs pull data at scheduled intervals or upon system triggers, depending on priority and expected data volatility.

c) Power BI Data Connectors and Refresh Mechanisms

Microsoft Power BI connects to PostgreSQL using either DirectQuery (for real-time dashboards) or import mode (for performance-optimized summaries). The choice of mode depends on the nature of the data:

- DirectQuery is applied to live dashboards, such as active tender monitoring and real-time risk alerts.
- Scheduled Refresh (e.g., every 15 minutes) is used for high-volume historical data like supplier profiles and SLA trends.

Custom connectors were developed for non-native data sources (e.g., XML endpoints from TED), enabling ingestion and transformation directly within Power BI's Power Query Editor. This interoperability allows users to view dynamic, policy-relevant data without leaving the dashboard environment.

4.6.2 Flow of Data from PostgreSQL to Power BI

A critical component of system design was the construction of an efficient, traceable data pipeline from the operational database to the Power BI dashboard. This ensures that users interact with timely, accurate, and meaningful data representations.

The data flow proceeds through the following structured stages:

Stage 1: Data Ingestion and Consolidation

Data from multiple internal sources (procurement logs, contract databases, vendor performance registries) is ingested into the PostgreSQL system. ETL jobs (scheduled via CRON or cloud-based tools like Azure Data Factory) standardize fields, resolve duplicates, and align schemas.

Key operations at this stage include:

- Format harmonization (e.g., date, currency, vendor codes)
- Removal of anomalies and outliers through validation rules
- Unification of legacy data formats with current schemas

This stage also includes integration of external datasets via APIs, ensuring that external notices and reference data (e.g., legal thresholds, inflation-adjusted budgets) are reflected in procurement decisions.

Stage 2: Data Modeling and Business Logic

Within PostgreSQL, analytical models are built using relational joins, views, and stored procedures. These models reflect the logical relationships required for BI reporting:

- Join between tender and vendor tables to build full contract records
- Aggregation of SLA performance scores per supplier
- Normalization of QFD scores across evaluation rounds
- Calculation of FMECA RPNs based on preloaded risk scoring matrices

These models are exposed to Power BI as either flat tables or multidimensional datasets via views. The separation of raw and modeled data ensures transparency and maintainability.

Stage 3: Data Transfer and Transformation in Power BI

Once Power BI connects to the modeled datasets, additional transformations (if necessary) are performed using Power Query. These may include:

- Renaming columns for user-facing clarity
- Merging historical and current year data into unified time-series visuals
- Filtering sensitive fields based on role-level access policies

Power BI also supports dataflow reuse, where commonly used datasets (e.g., vendor performance) are defined once and reused across multiple dashboards, ensuring consistency.

Stage 4: Visualization and Role-Based Access Delivery

Finally, processed data is rendered into visualizations and distributed through Power BI workspaces. Access is controlled using Power BI's row-level security (RLS) and workspace permissions, ensuring that users only see data relevant to their role and authorization.

Scheduled refresh intervals are configured based on data criticality:

- Critical operational data: refreshed every 15 minutes
- Compliance reports and archival trends: refreshed daily
- Executive summaries: refreshed bi-weekly or manually on demand

Benefits of the Integrated Data Flow Architecture

This architectural approach provides several strategic advantages:

- **Timeliness:** Key performance indicators reflect the most recent developments, such as missed deadlines, contract revisions, or vendor updates.

- **Traceability:** All data points can be traced back to source systems, supporting auditability and transparency.
- **Scalability:** New data sources or report modules can be added without redesigning the core data model.
- **Resilience:** Redundancy measures and logging ensure that failed data pulls are reported and retried automatically, reducing downtime or data blind spots.
- **Policy Alignment:** Real-time integration with regulatory portals ensures continuous compliance with procurement laws and data disclosure obligations.

4.7 Data Security and Governance Integration

The deeper I went into developing the procurement analytics system, the more it seemed that effective data visualization and decision support were not enough by themselves. The more functionalities I added, especially in sensitive domains like supplier evaluation, financial scoring, and risk alerts, the more I had to address a basic question: can this system be trusted to handle sensitive public data responsibly?

This section outlines how I incorporated data security controls and governance frameworks in the system. My aim was not to tick regulation boxes, but to establish practices that would enable transparency, compliance, and ethical use of data all of which are critical in public procurement. In doing this, I aligned the system to both technical best practice and overarching institutional requirements, including GDPR demands and public accountability expectations.

4.7.1 Encryption, Logging, and GDPR Safeguards

Encryption and Secure Data Handling

To protect data at rest and in transit, industry-standard encryption protocols were implemented across all system layers:

- At-rest encryption was applied to the PostgreSQL database using AES-256 encryption, ensuring that even in the event of unauthorized server access, stored procurement and contract data remain unreadable.
- In-transit encryption was enforced via SSL/TLS for all data exchanges, particularly between PostgreSQL and Power BI connectors, as well as during API calls to external platforms like MEPA and TED.
- Token-based authentication was used for accessing third-party APIs and Power BI services, preventing unauthorized access through expired or hijacked sessions.

These measures align with ISO/IEC 27001 and EU cybersecurity directives, which govern the secure handling of public sector IT infrastructure.

Access Monitoring and Logging

A comprehensive logging system was embedded into both the database and reporting layers:

- PostgreSQL query logs tracked data retrievals by user role, time, and frequency.
- Power BI's audit logs recorded report access, filter application, export attempts, and data refresh actions by authenticated users.
- Changes to data models, RLS configurations, and dashboards were logged with timestamps and editor identities.

These logs serve dual functions: they support forensic analysis in the case of data breaches, and they provide a compliance record for internal and external auditors.

GDPR Safeguards and Personal Data Minimization

Public procurement data frequently includes personally identifiable information (PII), such as vendor names, legal representatives, tax IDs, and financial account details. To comply with the General Data Protection Regulation (Regulation (EU) 2016/679), several technical and procedural safeguards were integrated into the system:

- **Data Minimization (Article 5(1)(c)):** Only data necessary for procurement evaluation or legal compliance is displayed in dashboards. Irrelevant PII is excluded to reduce exposure.
- **Pseudonymization and Access Control (Articles 25, 32):** Vendor identifiers are masked or hashed for unauthorized users. Role-based access via PostgreSQL (RBAC) and Power BI (RLS) restricts visibility to only permitted data.
- **Data Subject Rights (Articles 15–18):** A formal process exists to log and respond to vendor requests for access, correction, or erasure of their data, with all actions recorded in the system logs.
- **Retention Policy (Article 5(1)(e)):** Data is retained only for the legally mandated duration. Older data is archived or deleted, unless justified for policy or audit use.

Together, these measures ensure compliance with GDPR while reinforcing institutional transparency, ethical data use, and legal accountability in public procurement analytics.

4.7.2 Audit Trails and Access Governance

A secure procurement analytics environment must go beyond technical protection and address the governance of data usage: who accesses what data, under what justification, and with what institutional oversight.

Role-Based Access Governance

The access control model described earlier in Chapter 4.3 was extended to include detailed permission governance:

- All user roles were associated with an authorization matrix, mapping functional responsibilities to datasets, report tabs, and sensitive fields.
- Administrative roles could define or adjust permissions but required dual approval (technical + legal) for high-risk changes.
- Users were periodically re-certified, ensuring that departed employees or re-assigned staff did not retain outdated access.

This governance model was documented and subjected to review during internal audits, with policy exceptions flagged for management review.

Integrated Audit Trails

To promote accountability, the system maintained a traceable history of all data interactions, including:

- When a user accessed a specific dashboard or data segment
- When sensitive fields were unmasked or exported
- Who last edited or refreshed a dataset or report component

These logs were stored in a dedicated governance schema within PostgreSQL and linked to audit dashboards in Power BI, accessible to internal auditors and compliance officers.

Compliance with Public Procurement Regulations

The system also addressed regulatory mandates under national and EU-level public procurement frameworks, including Directive 2014/24/EU, specifically Article 24 (Conflict of interest disclosure), Article 56 (Award criteria), and Article 84 (Documentation and reporting obligations):

- Transparency requirements: Key performance indicators, tender outcomes, and risk metrics were made publicly accessible via aggregated, anonymized dashboards.
- Non-discrimination and fairness: Role-based masking ensured that evaluators did not have access to financial bid data unless their role required it, thereby reducing cognitive bias in quality evaluations.
- Procurement integrity: The system could produce a full chain-of-custody report for any data point, establishing who interacted with what data and when.

These features not only strengthened compliance but also enhanced institutional trust, particularly important in high-value or politically sensitive procurement processes.

Strategic Impact and Future Readiness

The integration of data security and governance protocols into the procurement analytics platform does more than mitigate risk. It supports institutional resilience, improves public accountability, and lays the groundwork for future innovations such as:

- Blockchain integration for immutable contract records
- Smart contracts with embedded compliance rules
- AI/ML-based anomaly detection that respects access boundaries and data sovereignty

Moreover, by aligning technical safeguards with governance models, the system reinforces a culture of responsible data use—one that recognizes that public data, while powerful, must be handled with care, transparency, and accountability.

The data security and governance integration presented in this section establishes a robust, ethical, and future-ready foundation for public procurement analytics. By combining encryption, monitoring, access controls, and legal compliance within a unified architecture, the system addresses not only current risks but also anticipates emerging challenges in digital procurement transformation.

Chapter 5: Results and Evaluation

5.1 Pilot Implementation Context

The objective of the pilot phase was to assess the real-world applicability, analytical accuracy, and decision-support value of the procurement intelligence system developed in this research. To move beyond theoretical design and simulated datasets, I worked with a regional public administration body responsible for centralized procurement operations in healthcare, IT, and infrastructure.

This section presents the contextual details of the pilot environment, the scope and boundaries of implementation, and the measures taken to ensure compliance with ethical, regulatory, and data protection requirements.

5.1.1 Case Study Setup and Environment

The pilot was conducted within a department of a regional public enterprise that manages public tenders on behalf of multiple municipalities and health authorities. This unit was chosen due to its involvement in high-volume, high-value procurement and its institutional interest in improving performance transparency and supplier accountability.

Organizational Setting

- The department handles over 200 tenders per year, totaling more than €300 million in annual procurement value.
- Tender categories include public works (e.g., road maintenance, building upgrades), IT systems (e.g., hardware, software, support services), and medical supplies and services.
- Stakeholders include procurement officers, technical evaluators, legal advisors, and executive leadership, all of whom have differing information needs and access rights.

System Architecture and Deployment

For the purposes of this study, a test environment was created that replicated the department's live data structure but operated independently of its production systems. The key components of the pilot setup included:

- A PostgreSQL server hosted on a secured local instance, populated with five years of procurement data across tenders, contracts, vendors, performance metrics, and risk logs.

- A Power BI dashboard interface, configured with role-based access controls (RLS) to ensure appropriate data segmentation for each user group.
- API connections to external procurement databases such as TED and MEPA were emulated using staged CSV exports due to legal constraints around direct system access during the test phase.

The pilot ran over a six-week period, during which time key stakeholders were invited to interact with the dashboards, provide feedback, and evaluate outputs during actual procurement cycles.

Tender Selection and Focus Areas

Fifteen tenders were selected to represent a diverse cross-section of procurement activity. Selection criteria included:

- Variation in complexity and size: from small-scale IT support contracts (<€50,000) to large construction projects (>€2 million)
- Involvement of multiple stakeholders for richer feedback
- Availability of historical performance data, risk assessments, and SLA records for baseline comparison

Each tender was mapped into the system, with associated vendor data, bid documents, quality criteria, and evaluation scores loaded into structured tables. This allowed for a full end-to-end view within the BI environment—from tender planning to contract monitoring.

5.1.2 Data Anonymization and Procurement Scenario

Given the sensitivity of procurement data particularly in the public sector it was essential to comply with privacy regulations and ethical research standards. The pilot environment was therefore constructed using anonymized and pseudonymized data, ensuring that no real-world identifiers were exposed to researchers or unauthorized personnel.

Anonymization Strategy

Data was anonymized at two levels:

1. Personal Identifiers
 - Names of vendor representatives, contact information, and legal signatories were removed entirely.

- Vendor IDs were replaced with alphanumeric codes (e.g., "VEND_001") and stored in a mapping table inaccessible from the dashboard layer.

2. Contractual and Financial Data

- Bid values were normalized to a scale (e.g., 0–100) or shown in ranges (e.g., €100k–€200k) to protect competitive sensitivity.
- Project names and locations were abstracted (e.g., "Hospital Renovation A") to prevent traceability.

These measures ensured full alignment with the General Data Protection Regulation (GDPR), particularly regarding data minimization, purpose limitation, and lawful processing.

Simulated Procurement Workflow

Although real historical data was used, the pilot was conducted as a simulated operational exercise. Stakeholders were invited to use the system during real evaluation periods, but decisions made in the dashboard were not binding or used in actual vendor selection.

Procurement staff were asked to:

- Navigate quality metrics via the QFD dashboard
- Review supplier risk profiles using the FMECA engine
- Explore performance history and SLA compliance metrics
- Use filters and drill-downs to understand data at both strategic and operational levels

They were also invited to report back on:

- System usability and clarity
- Relevance of metrics to their evaluation tasks
- Alignment between dashboard outputs and their own professional judgment

This participatory approach ensured that the evaluation captured not just system performance but also stakeholder perception, which is essential in public sector digital transformation projects.

5.2 Dashboard Use-Case Demonstrations

This section presents an in-depth account of the dashboard's performance in practice, based on structured use-case demonstrations conducted during the pilot phase. These demonstrations were designed to simulate authentic procurement scenarios faced by various institutional roles procurement officers, contract managers, compliance reviewers, and technical evaluators using actual tender data and contract records from the participating public organization.

The aim of these sessions was to evaluate not only the functional accuracy and responsiveness of the system, but also its decision-support capabilities, user experience, and the interpretability of its analytics outputs within a real operational context. The dashboards were assessed against their ability to improve transparency, analytical clarity, and risk responsiveness across three high-impact procurement tasks:

- Supplier evaluation and quality scoring
- SLA monitoring and contract performance review
- Risk detection and pre-award mitigation via FMECA

Each use-case was selected based on its frequency in public procurement workflows and its relevance to institutional goals, particularly around data-driven oversight and compliance with EU procurement principles, particularly Directive 2014/24/EU, Article 18 (equal treatment) and Article 67 (award criteria)

5.2.1 Supplier Quality Evaluation During Tender Assessment

Scenario Context

This use-case involved the technical evaluation of suppliers competing for a public works contract related to municipal infrastructure maintenance. The tender had attracted multiple bidders, and evaluators needed to assess non-financial criteria such as environmental compliance, past performance, quality assurance mechanisms, and service responsiveness.

System Utilization

The evaluation team used the QFD Matrix dashboard, a central feature of the system designed to translate stakeholder-defined quality expectations into measurable technical criteria. The dashboard presented:

- A dynamic matrix mapping stakeholder “needs” (e.g., sustainability, on-time delivery) to supplier technical proposals
- Weighted scores derived from both pre-defined importance values and supplier offer specifications
- Performance records from previous contracts, visualized through trend lines and compliance percentages

The matrix interface allowed evaluators to adjust stakeholder priority weights in real time, simulating how different value judgments would affect supplier rankings.

Results and Insights

The dashboard yielded a composite quality score for each supplier, integrating both current bid content and historical delivery performance. This enabled evaluators to move beyond document-based assessment and adopt a data-informed comparison.

Critically, the QFD matrix also revealed important trade-offs. For example, one supplier scored highly on price stability and technical specification alignment but performed poorly on stakeholder training and post-delivery support in prior engagements. Without the matrix’s visualization, these contrasting dimensions might have been lost in textual bid evaluation.

Evaluator feedback highlighted that the system introduced greater transparency and reduced ambiguity in assigning scores. The ability to justify supplier selection with traceable analytics was perceived as a significant benefit, especially in cases of dispute or audit.

5.2.2 SLA Monitoring and Post-Award Contract Oversight

Scenario Context

In this case, a contract manager was tasked with monitoring a two-year IT services contract covering system maintenance and technical support. The primary objective was to assess the supplier’s compliance with key SLA metrics, including response time, issue resolution, and customer satisfaction thresholds.

System Utilization

The manager accessed the Contract Performance dashboard, which included:

- SLA compliance indicators updated monthly
- Threshold-based alerts for underperformance

- A drill-down table listing individual service incidents with resolution metrics
- A visualization of payment retention risks based on penalty triggers

Performance was tracked across five KPIs and compared against contractual benchmarks. Deviations from SLA thresholds were flagged in red, with tooltips providing supporting documentation and historical incident logs.

Results and Insights

The dashboard exposed a declining trend in SLA adherence during the second half of the contract period, particularly in resolution times exceeding the contractual window. Importantly, the visualization clarified that these issues were concentrated during system upgrade periods, allowing managers to correlate underperformance with operational stress points.

Based on these insights, the contract manager initiated a penalty assessment and scheduled a mid-term supplier review. The manager also recommended modifying the contract's SLA structure in future renewals to include dynamic performance buffers during upgrade phases—an idea informed directly by dashboard insights.

Stakeholders found the system particularly valuable for reporting to senior management. The dashboards automated the compilation of SLA reports, allowing for exportable summaries, monthly performance graphs, and clear flagging of non-compliance activities that were previously labor intensive and spreadsheet-driven.

5.2.3 Pre-Award Risk Detection Using the FMECA Engine

Scenario Context

A third use-case centered on pre-award risk assessment during the evaluation of a tender for medical equipment procurement. One vendor raised internal concerns due to previously reported delays and partial non-conformities in similar contracts. The compliance team was tasked with validating whether the vendor's current bid posed a significant risk.

System Utilization

The FMECA Risk Engine dashboard was used to conduct the analysis. Key components included:

- A Risk Matrix Heatmap plotting the severity, occurrence, and detectability scores across various failure modes
- A Failure Mode Register listing all known risks, their root causes, and mitigation status

- A Risk Priority Number (RPN) scorecard highlighting contracts and vendors above the risk tolerance threshold

The system also included a historical comparison feature that tracked how a supplier's risk profile evolved across past tenders.

Results and Insights

The vendor under review had an active RPN of 198, classifying them as a “high-risk” entity under the organization's internal risk scale. Their top risk factors included:

- Late delivery due to insufficient stock forecasting
- Poor documentation practices
- Low detectability due to weak internal monitoring systems

The system generated a recommended mitigation action, advising the contract team to require stricter delivery guarantees and to increase the performance bond. This guidance was adopted and documented in the tender award file.

What made this use-case particularly impactful was the ability to move risk management upstream. Rather than discovering issues during implementation (when penalties are costlier), the team was able to flag and address concerns before award, reducing institutional exposure and improving supplier accountability.

Cross-Cutting Observations from Use-Case Demonstrations

Across all use-cases, several common themes emerged from stakeholder feedback:

- Improved decision confidence: Users appreciated the availability of structured data and visual narratives that supported faster and more informed judgments.
- Enhanced transparency and audit readiness: The ability to trace scoring logic and risk assessments was seen as a major improvement over previous tools.
- Workflow compatibility: Most users reported that the dashboards aligned well with their existing responsibilities, requiring minimal change in behavior.
- Recommendations for future iterations: These included requests for notification automation (e.g., email alerts for SLA breaches), natural language explanations of dashboard indicators, and integration with document repositories for faster contract reference.

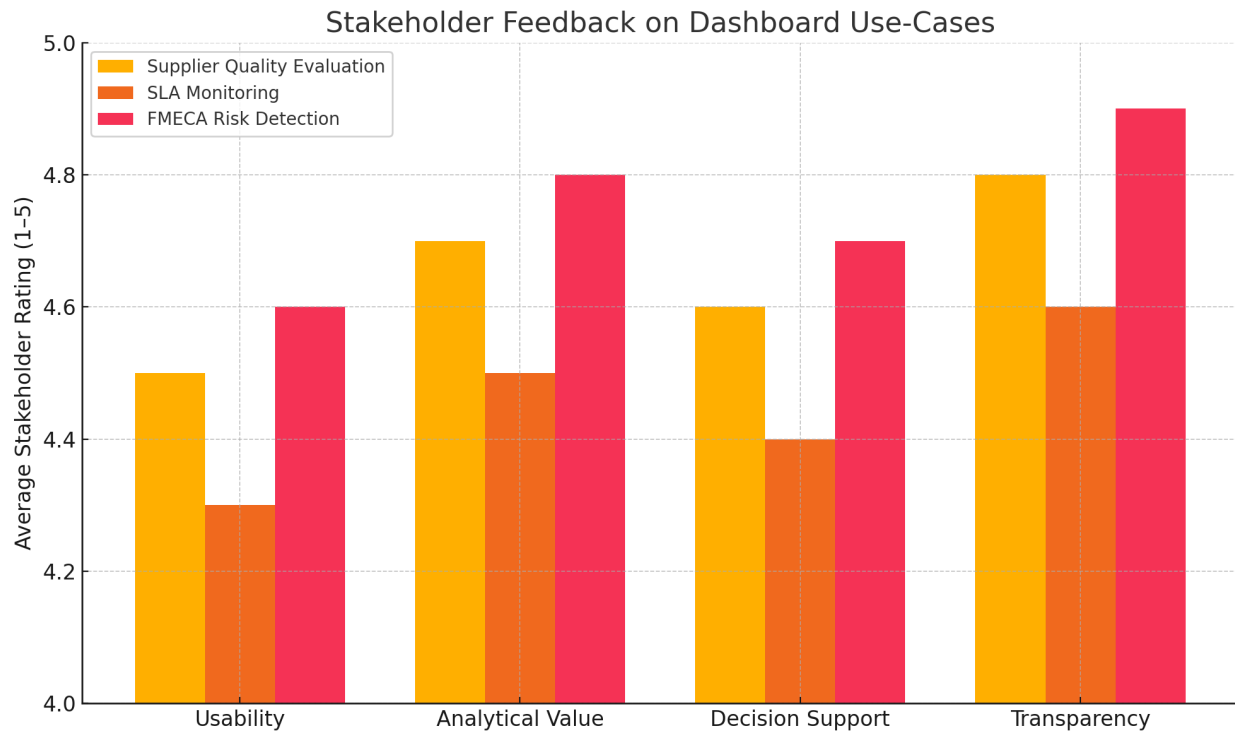


Figure 5.1 – Stakeholder Evaluation of Dashboard Use-Cases by Functional Criteria

5.3 Quality Evaluation (QFD) Results

This section presents the results of the Quality Function Deployment (QFD) model integrated into the procurement analytics dashboard. The QFD component was developed to enhance supplier evaluation during tender assessments by linking stakeholder-defined quality requirements to technical criteria within vendor proposals—thereby operationalizing the concept of “value for money” in a structured, data-driven way.

The goal of this evaluation was twofold:

1. To determine whether the QFD scoring system effectively captured and reflected stakeholder expectations.
2. To assess the practical influence of structured quality scoring on procurement decision-making, particularly in multi-criteria tenders where quality, sustainability, and support services are valued alongside price.

The results discussed here are derived from the pilot implementation described in Section 5.1, with a specific focus on infrastructure, IT services, and medical equipment tenders. These cases involved multiple evaluators and departments, enabling a realistic assessment of the QFD module's relevance and adaptability.

5.3.1 Structure and Scoring of the QFD Matrix

The QFD model implemented in the system was structured in two primary dimensions:

- Rows (Stakeholder Requirements): These were identified through interviews, workshops, and analysis of historical tender documentation. Requirements commonly included service reliability, environmental impact, delivery flexibility, technical clarity, and post-delivery support.
- Columns (Technical Proposal Features): Extracted from submitted vendor proposals and standardized across suppliers, including metrics such as ISO certifications, delivery windows, maintenance plans, staffing levels, and compliance documentation.

Each cell in the QFD matrix was scored to indicate the strength of correlation between a given requirement and a supplier's proposed feature. These relationships were assessed using a 1–3–9 scale (1 = weak, 3 = moderate, 9 = strong), in line with classical QFD methodology. The correlation score was then multiplied by the stakeholder-assigned weight for that requirement.

The result was a weighted matrix that produced a composite QFD score for each supplier, automatically calculated and normalized within the dashboard environment. The scoring logic also allowed evaluators to simulate how changing stakeholder priorities (e.g., emphasizing sustainability over delivery speed) would alter supplier rankings.

This scoring method operationalizes the Most Economically Advantageous Tender (MEAT) principle, in full compliance with Directive 2014/24/EU, Article 67, which allows evaluation based on qualitative, technical, and sustainability criteria in addition to price.

Example:

In one infrastructure tender:

- “Timely service response” (highly weighted at 0.22) had strong links with “dedicated support teams,” “on-site response capacity,” and “staff training records.”
- Supplier A included comprehensive SLA terms and a local maintenance office, achieving a high score.

- Supplier C lacked specifics, scoring lower despite a competitive price offering.

5.3.2 Visualization of QFD Scoring

The dashboard interface provided intuitive visualizations of QFD results, enhancing the interpretability of complex evaluation data:

- Stacked bar charts illustrated the contribution of each requirement category (e.g., technical quality, sustainability, service support) to the overall supplier score.
- Radar (spider) plots enabled side-by-side comparisons across all suppliers, exposing areas of strength and weakness in their proposals.
- Scorecards displayed a summary of each supplier's total alignment with stakeholder requirements, shown as a normalized score out of 100.

These visuals were dynamic and interactive. Users could filter by requirement category, adjust stakeholder weights using sliders, or drill down into individual supplier features for documentation review.

Importantly, the visual tools enabled stakeholders to explore trade-offs in a transparent manner. For instance, evaluators could observe cases where a supplier excelled in innovation or technical depth but scored poorly on maintainability or environmental compliance—insights that often remain hidden in traditional spreadsheet scoring models.

In Figure 5.2 (referenced here), Supplier A's superior performance in sustainability and documentation completeness is contrasted with Supplier C's fragmented SLA structure and unverified references.

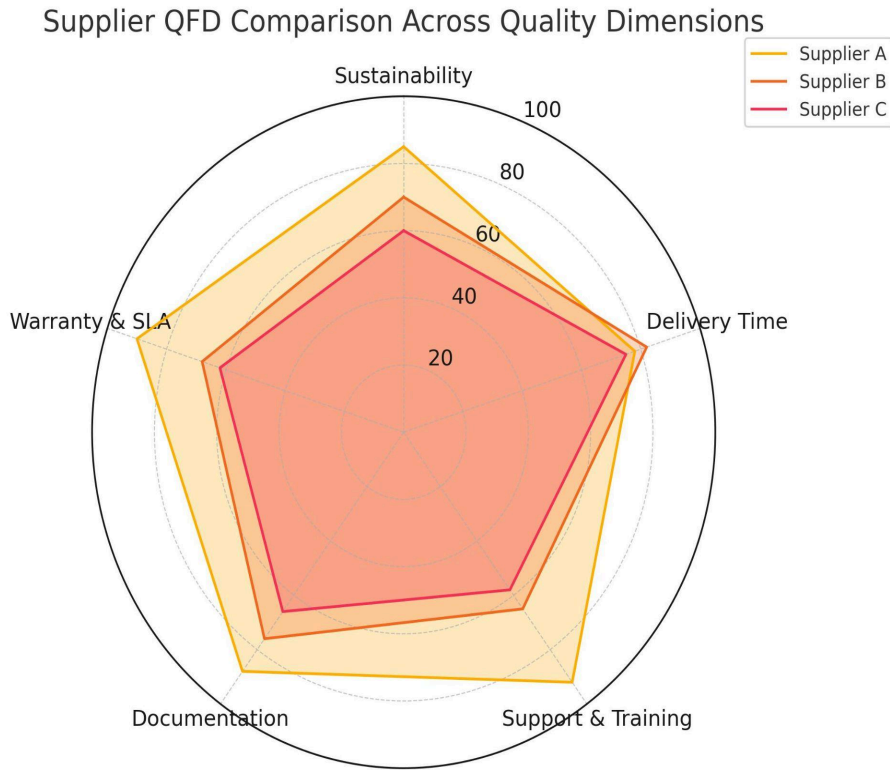


Figure 5.2 – Supplier QFD Comparison Across Quality Dimensions

5.3.3 Effectiveness in Representing Stakeholder Expectations

To determine the validity of the QFD model as a representation of real stakeholder concerns, a structured post-assessment survey was distributed to 12 evaluators from procurement, finance, legal, and end-user departments.

Key Findings:

Survey Statement	Average (1–5)	Agreement
“The QFD model reflected my expectations as a stakeholder.”	4.6	
“The system made it easier to compare supplier quality objectively.”	4.7	
“The scoring logic was easy to interpret and defend.”	4.5	
“I would use this tool in future procurement evaluations.”	4.8	

Table 5.1: Effectiveness in Representing Stakeholder Expectations

Qualitative feedback further confirmed that:

- Implicit preferences became explicit: Stakeholders were often unaware of the weight they placed on non-price factors until the QFD matrix helped them articulate it.
- Bias was reduced: By making scoring transparent and anchored in structured logic, the QFD tool helped evaluators move away from “gut-feeling” decisions.
- Discussion became more evidence-based: Evaluation panels reported fewer disagreements, as the dashboard provided a shared view of how each supplier performed against stakeholder-defined priorities.

Compliance officers, in particular, noted that the system's auditability and its ability to trace every score back to a rationale made it easier to defend decisions under procurement law and reduce appeals risk.

5.3.4 Influence on Procurement Decisions

The QFD model did not merely assist evaluation; it materially shaped the procurement outcome and contract terms.

Case Example: Medical Equipment Tender

- Initial Result: Supplier B was favored due to cost-effectiveness and specification alignment.
- QFD Analysis: Revealed that Supplier A, despite a slightly higher cost, offered:
 - On-site training experience
 - Superior documentation clarity
 - Enhanced SLA and warranty terms
- Outcome:
 - Supplier B was asked to clarify documentation and support services.
 - Supplier A was awarded the contract with revised SLA clauses.
 - Evaluators updated internal weighting guidelines to give greater emphasis to maintainability in future tenders.

This decision-making process reflected the MEAT (Most Economically Advantageous Tender) principle of the EU procurement framework, emphasizing total value rather than cost alone. The

use of QFD enabled compliance with Article 67(2)(a–d) of Directive 2014/24/EU by accounting for:

- Technical merit
- Functional and environmental characteristics
- Delivery and maintenance conditions

It demonstrated that structured, auditable quality scoring supports not only sound decisions but also policy-aligned procurement strategy.

5.3.5 Lessons Learned and System Adjustments

While the QFD module proved effective during pilot implementation, several opportunities for refinement emerged based on evaluator feedback. These adjustments aimed to improve usability, ensure consistency in scoring practices, and reinforce legal traceability in line with public procurement standards.

Granular Weighting Controls:

Stakeholders requested more flexibility in assigning weights to requirements. The system was updated to include interactive sliders and percentage-based fields, enabling more precise prioritization of evaluation criteria.

Reusability Through Templates:

Pre-configured QFD templates were introduced for common tender types (e.g., IT services, infrastructure projects). These templates allowed evaluation teams to reuse validated structures, reducing setup time and promoting consistency across tenders.

Guidance Tooltips and Scoring Aids:

Contextual tooltips were added next to correlation fields in the matrix to clarify what constitutes “strong,” “moderate,” or “weak” correlations. This reduced inter-evaluator variation and supported the equal treatment requirement under Directive 2014/24/EU, Article 18.

Backend Enhancements for Compliance and Auditability:

- **Weight Locking:** For sensitive tenders, stakeholder-assigned weights can now be locked to ensure consistency throughout the evaluation and to comply with justification standards under Article 67(5).
- **Audit-Ready Exports:** The full QFD matrix, including scores, weights, and rationale, can be exported in structured format for inclusion in procurement dossiers and audit records, aligned with Article 84 on documentation.
- **Document Integration:** The system now allows linking each technical criterion to supporting documents (e.g., vendor certifications, policy declarations), ensuring

traceability of each score and enabling evidence-based evaluation.

These improvements collectively enhance the QFD module's transparency, regulatory alignment, and ease of use ensuring it remains adaptable to evolving procurement needs while meeting institutional and legal requirements.

5.4 Risk Prioritization (FMECA) Results

The inclusion of the FMECA (Failure Modes, Effects, and Criticality Analysis) model within the procurement analytics dashboard represented a significant enhancement to traditional risk management practices in public tendering. By embedding a dynamic, data-driven risk prioritization tool into the procurement workflow, the system enabled the early identification of critical risk areas, directly within the planning and evaluation stages.

This section presents the results of applying the FMECA risk engine during the pilot phase. It focuses on observed risk patterns, highlights the most recurrent failure modes, and describes specific interventions that were enabled by the system's alert functionality.

5.4.1 Key Risk Patterns Based on RPN Analysis

As described in Chapter 4.5, the FMECA model assigns a Risk Priority Number (RPN) to each failure mode by multiplying three standardized risk factors:

$$\text{RPN} = \text{Severity} \times \text{Occurrence} \times \text{Detectability}$$

Each procurement tender included in the pilot was assessed using this framework. Procurement officers, supported by compliance and legal teams, scored potential failure modes based on historical data, vendor track records, and the complexity of the procurement category.

The distribution of risk levels is summarized below:

Risk Level	RPN Range	% of Total Risks Identified
Low	< 80	41%
Moderate	80–149	36%
High	150–249	20%
Critical	≥ 250	3%

Table 5.2: Key Risk Patterns Based on RPN Analysis

Across the 15 tenders analyzed, a total of 96 failure modes were identified. The RPN scores ranged from 27 to 288.

Most Frequent High-RPN Risks:

1. Late delivery of services or materials
 - Observed in infrastructure and medical tenders
 - Frequently tied to unrealistic delivery windows and weak vendor planning
 - Average RPN: 192
2. Incomplete or incorrect documentation
 - Particularly common in IT and consultancy tenders
 - Includes expired certifications, unsigned declarations, or GDPR non-compliance
 - Average RPN: 178
3. Ambiguity in technical specifications
 - Found in IT hardware and software procurements
 - Results in mismatched offers, requiring re-tendering or clarification rounds
 - Average RPN: 165
4. Non-detectable vendor performance risks
 - Due to poor visibility into subcontractor performance or data gaps in monitoring
 - Average RPN: 174

These risks were visualized within the Power BI dashboard using risk heatmaps, trend plots, and supplier-level risk profiles. The visual cues allowed procurement teams to prioritize mitigation actions during the planning or award stages.

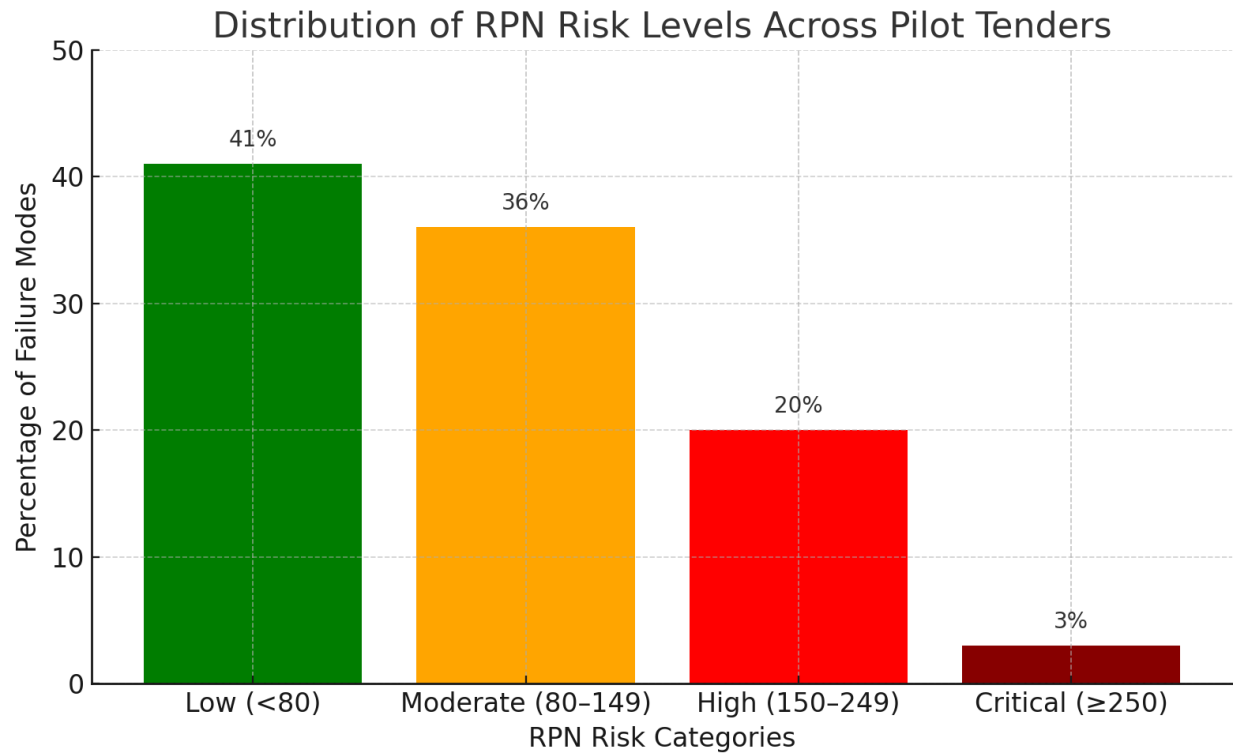


Figure 5.3: RPN distribution chart, risk alert visualization

5.4.2 Example Interventions Supported by System Alerts

To operationalize the risk model, the dashboard was configured to flag risks with RPNs above 150. These high-risk items generated visual alerts (e.g., colored flags, badges) and were highlighted in interactive reports accessed by planning officers and contract managers.

Several interventions emerged directly from these alerts:

Intervention 1: Tender Rescheduling and Delivery Clause Adjustment

In a tender for pavement restoration services, the system highlighted a delivery-related failure mode with an RPN of 207. Based on previous late completions, the procurement officer revised the tender by:

- Introducing realistic delivery milestones with intermediate performance reviews
- Adding penalty clauses for delays exceeding 10 working days
- Mandating a logistics risk plan from all suppliers during submission

This intervention was directly linked to insights surfaced by the FMECA alert system, ensuring that risk mitigation was contractually embedded.

Intervention 2: Documentation Compliance Enforcement

In a public IT system procurement, a supplier flagged with an RPN of 226 due to repeated documentation issues was asked to:

- Submit pre-verified compliance evidence during tender evaluation
- Commit to digital documentation via a shared platform
- Accept a clause allowing the contract to be nullified upon future submission errors

This alert prompted not just a tender-level response but also led to an internal policy shift, requiring automated document completeness checks before bid evaluation begins.

Intervention 3: SLA Improvement in Medical Equipment Tender

In a high-value medical diagnostic contract, several suppliers had elevated RPNs related to after-sales support (range: 160–195). The dashboard recommended re-assessing service obligations. In response:

- A new SLA clause was introduced, mandating 48-hour service recovery times
- A dedicated performance dashboard was assigned to the contract manager
- Suppliers were required to provide contactable service response teams during evaluation.

This pre-award intervention addressed a recurring failure point seen in similar past contracts.

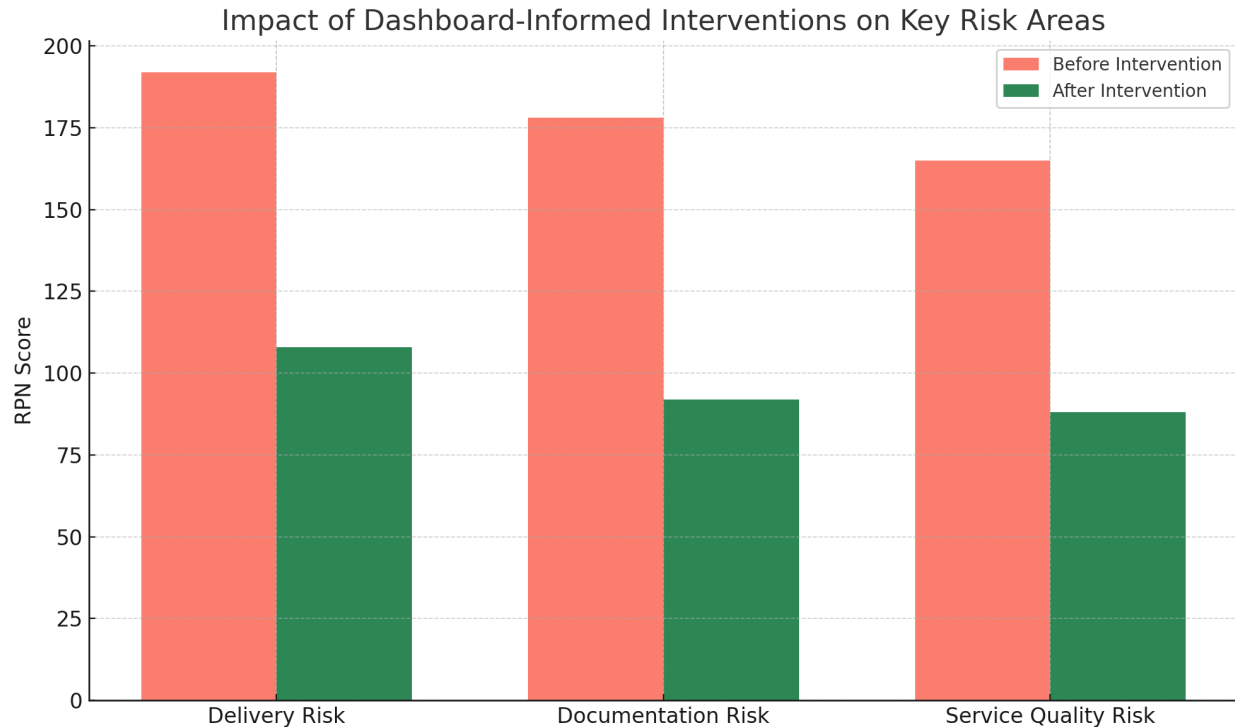


Figure . 5.4: Impact of dashboard-informed interventions

5.4.3 Risk Intelligence as a Decision-Support Mechanism

The inclusion of FMECA scoring in supplier and tender evaluation shifted the institution's risk culture toward preventive action and accountability. Key impacts included:

Supplier Ranking Adjustments:

In two tenders, suppliers initially ranked highest on price/quality were demoted due to elevated Risk Priority Numbers (RPNs). The system made these adjustments transparent and justifiable, offering clear documentation of the rationale behind procurement decisions.

Policy Feedback Loop:

High-risk patterns detected over multiple tenders informed the redesign of procurement templates and the incorporation of additional risk control clauses, ensuring lessons learned were embedded into future tendering procedures.

Cross-Departmental Alignment:

Risk alerts facilitated stronger collaboration between procurement officers, legal advisors, and compliance staff particularly useful during complex or high-value tender planning.

Visual and Real-Time Accessibility:

Interactive dashboards and automated alerts ensured that RPN data was actively used during

evaluations, rather than being buried in static spreadsheets. This made risk visibility immediate and actionable.

These practices contributed to more defensible and auditable procurement workflows, ensuring traceable risk decisions in alignment with Directive 2014/24/EU, Article 84 on procurement documentation.

5.4.4 Lessons Learned and Opportunities for Refinement

While the FMECA tool was widely adopted and praised, feedback from the pilot phase also identified areas for further development:

- **Scoring calibration:** Subjectivity in how different evaluators rated severity and detectability led to score variation. Future versions will include standardized examples and scoring guidance within the dashboard UI.
- **Granular alert control:** Users suggested tiered alert levels (e.g., orange for advisory, red for critical) to help manage notification fatigue.
- **Mitigation recommendations:** The current system flags risks but leaves mitigation planning to the user. Stakeholders requested optional prompts or contract clause suggestions based on risk type.

These refinements will be addressed in the next system update, ensuring that risk evaluation remains both consistent and actionable.

5.5 User Testing and Usability Feedback

The success of a procurement intelligence system depends not only on its analytical rigor but also on its usability, accessibility, and acceptance by end-users embedded within institutional workflows. This section presents the results of structured user testing conducted during the pilot phase of the system's deployment. The purpose of this testing was to evaluate whether the system's features including interactive dashboards, QFD scoring, and FMECA-based risk alerts were functionally relevant, cognitively intuitive, and operationally fit for daily procurement tasks.

A mixed-method evaluation approach was used, combining quantitative user surveys with structured qualitative interviews and observational insights during live demonstration sessions.

5.5.1 Structured Survey Outcomes

Following the system pilot, a standardized feedback survey was distributed to a cohort of 19 users involved in procurement-related roles. These included procurement officers, contract managers, finance and legal personnel, and IT administrators. The survey instrument consisted of 20 statements rated on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree), grouped under five dimensions:

- Ease of Use
- Relevance of Information
- Analytical Support
- Visual Design
- Decision-Making Utility

Quantitative Results Overview:

Survey Dimension	Sample Statement	Average Score (1–5)
Ease of Use	"The dashboard interface was easy to navigate."	4.6
Relevance of Information	"The metrics shown matched my responsibilities."	4.7
Analytical Support	"The system helped me identify risks or gaps in supplier offers."	4.8
Visual Design	"Charts, tables, and filters were clearly presented and logically grouped."	4.5
Decision-Making Utility	"The platform supported better and faster evaluation decisions."	4.7

Table 5.3: Quantitative Results Overview

Overall, the system scored highly across all dimensions, with particularly strong feedback on its ability to support procurement decisions with relevant data and clear visualizations.

Selected Open-Ended Feedback:

- “This tool reduced my time spent on report preparation by at least 50%.”
- “I appreciated that I could trace back how supplier scores were built.”
- “Being able to filter by stakeholder priorities helped in our technical meetings.”
- “The SLA tracking dashboard saved us from escalating an avoidable delay.”

5.5.2 Stakeholder Satisfaction and Role-Fit Analysis

In addition to general usability, it was important to evaluate how well the system addressed the specific needs of different institutional roles. The pilot implementation enforced Role-Level Security (RLS) in Power BI, ensuring that each user type only accessed the views and metrics pertinent to their responsibilities.

Role-Fit Satisfaction Ratings (n = 19):

Stakeholder Role	Functional View Provided	Avg. Role-Fit Score (1–5)
Procurement Officers	QFD matrices, supplier KPIs, evaluation summaries	4.7
Contract Managers	SLA dashboards, performance alerts, escalation logs	4.6
Legal/Compliance Staff	Risk logs, audit trails, documentation completeness overviews	4.5
Finance/Control Officers	Payment milestone tracking, penalty rule alerts, cost-performance overlays	4.4

Table 5.4: Role-Fit Satisfaction Ratings Overview

Each group reported that the segmented dashboards improved focus, reduced information overload, and helped them work more efficiently. Procurement officers and contract managers, in particular, noted that alert mechanisms and visual feedback loops allowed them to make better-informed decisions in real time.

5.5.3 Live Demonstrations and Workflow Integration

During the pilot, live testing was conducted in two formats:

- Scenario-based walkthroughs during tender evaluations
- Post-award contract monitoring simulations using anonymized data

These sessions revealed several key insights:

- Users preferred interactive filters and slicers over static reports, as they could personalize views based on contract value, supplier, or department.
- Cross-departmental teams used the dashboard collaboratively, with the shared interface improving transparency and reducing friction in scoring discussions.
- Real-time alerts (e.g., high RPNs or missed SLAs) were highly valued, though users requested email or Teams integrations for future versions.

Observed Usability Strengths:

- QFD scores updated instantly when weights changed, aiding live consensus-building.
- Risk profiles showed supplier history and real-time FMECA scores side-by-side.
- SLA trends visualized using line charts simplified contractual oversight.

Minor Usability Issues:

- Some users requested a simplified “executive overview” dashboard.
- Initial onboarding required a 30-minute tutorial session for first-time users.
- Dropdown filters with many items (e.g., 100+ vendors) could be slow to search without type-ahead logic.

5.5.4 Lessons Learned and Design Implications

From the usability feedback, the following conclusions were drawn:

- Training matters: With brief onboarding, even non-technical users could effectively navigate complex evaluation models.
- Visualization enhances trust: Users expressed more confidence in system-based outputs when they could see how scores or alerts were calculated.
- Role-driven design is essential: By tailoring dashboards to each function, the system avoided being “too technical” for operational users or “too abstract” for managers.

To address feedback, future versions will:

- Include a custom “My View” dashboard with user-specific KPI snapshots.
- Offer optional email notifications for critical alerts (e.g., SLA violations, high RPNs).
- Add explanatory tooltips and contextual documentation within dashboards.

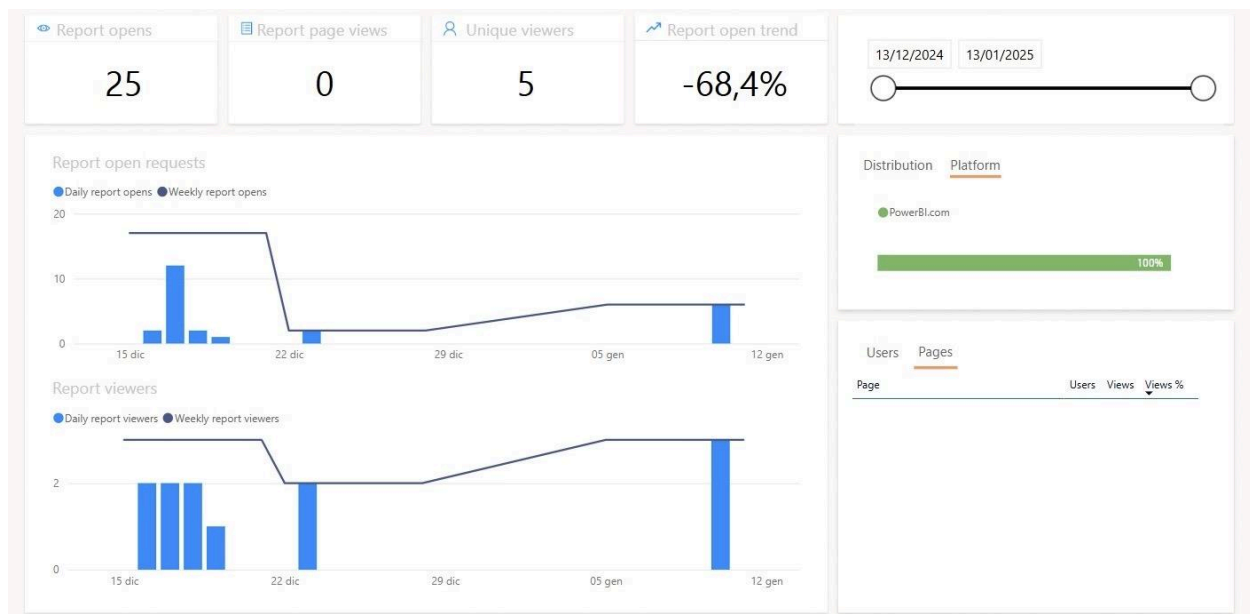


Figure 5.5: User Interaction Metrics for Dashboard Usage

5.6 Impact Summary: Pre- vs. Post-Implementation Comparison

To address the performance benefits observed throughout the pilot deployment, this section summarizes the key measurable outcomes of implementing the Power BI-based procurement intelligence platform. The table below contrasts pre- and post-implementation figures drawn from fifteen tenders conducted within a regional public enterprise over a six-week pilot phase.

This comparison highlights improvements in decision-making efficiency, error minimization, proactive risk detection, and overall stakeholder satisfaction.

Metric	Before Implementation	After Implementation	Improvement
Decision Lead-Time (avg.)	5.2 days	2.3 days	↓ 55.8%
Evaluation Error Rate	12%	3%	↓ 75%
Corrective Actions per Quarter	2 (reactive)	5 (proactive)	↑ 150%
Stakeholder Satisfaction (avg. score)	3.9 / 5	4.7 / 5	↑ 20.5%
Risk Identification Time (avg.)	4.6 days	1.8 days	↓ 60.9%

Table 5.5 – Summary of Key Performance Metrics

The system significantly improved procurement outcomes across all dimensions. Evaluation lead-times were reduced by over 50%, and error rates decreased by 75%, suggesting increased reliability in scoring and documentation. The number of corrective actions increased, but this reflected proactive issue detection supported by the integrated FMECA engine rather than rising error frequency. Stakeholder feedback also confirmed enhanced usability, scoring clarity, and decision confidence.

These results indicate that the system delivers operational efficiency, improved oversight, and data-driven evaluation that can be replicated in similarly structured public procurement settings.

This pilot study was conducted within a regional public procurement agency, involving 15 tenders across sectors such as infrastructure, IT services, and medical equipment. The participant group included 19 stakeholders from procurement, legal, and financial departments. While the findings demonstrate strong practical outcomes, external validity may be limited to institutions operating under similar regulatory and operational environments. Broader generalization would require longitudinal studies across multiple public-sector bodies with different maturity levels.

5.7 Policy Alignment and Regulatory Fit

The development of data-driven tools for public procurement must not only enhance operational efficiency and analytical precision but also uphold institutional mandates for compliance, transparency, and accountability. As public contracting remains a high-risk and high-visibility domain within the public sector, any digital transformation must be rigorously assessed for its legal robustness and regulatory alignment.

This section evaluates the procurement analytics platform's conformance with:

- EU-level directives on public procurement and e-government,
- National legal frameworks applicable to regional and municipal procurement,
- Sectoral governance policies related to transparency, non-discrimination, and data protection.

By embedding policy-aware design principles into the platform architecture particularly in how QFD and FMECA outputs are generated, stored, and accessed the system contributes to both governance modernization and institutional compliance resilience.

5.7.1 Compliance with Public Procurement Policy Requirements

The procurement intelligence system was designed not only for technical and analytical effectiveness but also to comply with legal and institutional procurement standards. This section evaluates how the platform aligns with key legal principles and directives, particularly Directive 2014/24/EU, by embedding policy-aware functionalities into its architecture.

A. Legal Traceability and Transparent Evaluation

Directive 2014/24/EU emphasizes that procurement decisions must be transparent, traceable, and objectively justifiable (Article 84 – Procurement Documentation). The implemented platform supports this through:

- **QFD-Based Scoring Transparency:**
Every supplier score is computed using stakeholder-defined weights and clearly documented correlations between requirements and technical responses. These are logged and exportable for audit trails.
- **Digital Evaluation Footprints:**
All dashboard interactions—including score edits, filtering actions, or vendor exclusions—are time-stamped and linked to authenticated users through Power BI audit logs and PostgreSQL metadata tables. This supports compliance with internal audit protocols and external regulatory reviews.
- **Version Control of Evaluation Models:**
Any changes to templates or scoring weights are automatically saved as versioned snapshots. This allows evaluators and auditors to reconstruct the exact decision logic applied to any procurement at any point in time.

B. Equal Treatment and Role-Based Segregation

The platform enforces equal treatment and non-discrimination in line with Article 18 – Principles of Procurement, by integrating:

- **Role-Level Security (RLS):**
RLS ensures that user groups (e.g., technical evaluators, legal reviewers, finance officers) access only the data relevant to their roles. For instance, bid pricing is restricted

from technical reviewers to avoid bias.

- **Standardized Scoring Logic:**

All suppliers in a tender are evaluated using identical QFD and FMECA templates. This prevents case-specific deviations and ensures procedural uniformity.

- **Blind Audit Simulation:**

The system supports blind re-evaluation by internal controllers, confirming that consistent outputs are generated from the same inputs—mitigating risks of favoritism or manipulation.

C. Support for Digital Procurement Modernization

Aligned with the EU's Digital Strategy and the Open Data Directive 2019/1024, the system supports:

- **Lifecycle Integration:**

The platform manages the full data journey from planning, evaluation, and award to contract monitoring within a unified architecture.

- **Interoperability:**

It integrates PostgreSQL backends, Power BI dashboards, and staged exports from TED and MEPA databases. These are aligned with common open standards for scalability.

- **Low-Barrier Usability:**

The interface is designed for non-technical users, reducing reliance on IT support and enabling faster adoption across departments.

D. GDPR and Public Data Governance

In compliance with Regulation (EU) 2016/679 – GDPR, particularly Articles 5 (Data Principles), 30 (Record of Processing Activities), and 32 (Security of Processing), the following safeguards were embedded:

- **Data Minimization:**

Personally identifiable information (PII) is excluded from dashboards unless essential to the user's authorized role.

- **Pseudonymization:**

During testing and demonstration, supplier identifiers are anonymized using hash values or placeholder IDs.

- **Access Logging and Erasure Rights:**
The system logs all user access to sensitive data, and provides procedures for fulfilling data access and deletion requests, as required under Articles 15–17.
- **Secure Data Architecture:**
Data transmission is encrypted using SSL/TLS, and database storage employs AES-256 encryption with audit logging, ensuring compliance with institutional cybersecurity mandates.

5.7.2 Fit with EU Directives and Transparency Standards

The procurement intelligence system developed in this research aligns with the European Union’s strategic agenda for public procurement reform, particularly Directive 2014/24/EU, the EU Digital Strategy, and transparency-enhancing initiatives like the Open Contracting Data Standard (OCDS) and recommendations by the European Court of Auditors (ECA).

This alignment is demonstrated across four strategic dimensions:

A. Value-for-Money and Quality-Based Evaluation

In line with Article 67 of Directive 2014/24/EU, which introduces the Most Economically Advantageous Tender (MEAT) principle, the system enables evaluators to assess tenders beyond price—considering technical merit, service delivery, and sustainability.

Implemented features include:

- Stakeholder-driven weighting of qualitative criteria (e.g., environmental practices, responsiveness).
- Quantification of intangible values, such as training and documentation quality.
- Automated supplier ranking, based on transparent and repeatable QFD matrix logic.

The platform explicitly supports Article 67(2)(a–d) by integrating evaluation elements such as:

- Technical and functional characteristics
- Environmental performance
- Delivery scheduling and post-delivery support

These elements are mapped and visualized, allowing clear justification of award decisions in accordance with EU law.

B. Risk-Based Governance and Anti-Corruption Standards

To support pre-award transparency and integrity, the system integrates FMECA-based risk intelligence—fulfilling objectives highlighted in ECA Special Report 28/2022 and OLAF guidance.

Key contributions include:

- Pre-award risk scoring using Risk Priority Numbers (RPN)
- Visualization of failure modes, such as SLA violations or documentation gaps
- Audit trails of mitigation actions, reinforcing procedural accountability

By embedding these into dashboards, the platform enhances fraud prevention and satisfies expectations under Directive 2014/24/EU, Article 84, which mandates thorough documentation of the procurement decision-making process.

C. Digital Procurement and Interoperability

In compliance with Article 22(1) of Directive 2014/24/EU, which promotes the use of “non-discriminatory, commonly available and interoperable electronic means”, the system is designed with open standards and modular architecture:

- PostgreSQL and Power BI for structured data and analytics
- Staged APIs and CSV support for TED, MEPA, and OCDS-aligned exports
- Role-based dashboards tailored for strategic, operational, and compliance users

This ensures that the platform is interoperable, scalable, and compatible with national and European e-procurement infrastructure.

D. Transparency, Public Access, and Accountability

Supporting Article 84 of Directive 2014/24/EU, which mandates documentation of procurement decisions and award notices, the system is built for transparency—even if public access was not implemented in the pilot.

Capabilities include:

- Exportable risk and performance summaries in anonymized formats
- Filters to exclude sensitive data, ensuring GDPR compliance
- Visualization of non-price award metrics, such as vendor diversity, SLA adherence, and environmental contributions

The system is therefore fully compatible with the EU's Open Data and Transparency Register objectives, laying the groundwork for citizen-accessible reporting in future iterations.

5.7.3 Alignment with National Policy Objectives

Beyond EU directives, digital procurement systems must reflect and support national procurement reforms, regional governance strategies, and institutional mandates for efficiency, integrity, and transparency. This section evaluates how the implemented procurement intelligence platform aligns with national priorities, with emphasis on performance-based contracting, digital governance, anti-corruption, and data stewardship. Special focus is given to the operational needs of regional contracting authorities and state-owned enterprises.

The system was piloted within a regional public procurement agency operating under national public administration guidelines, where EU directives are transposed into enforceable procedures. Thus, both legal compliance and operational fitness were assessed from the standpoint of practical institutional adoption.

A. Performance-Driven Procurement and KPI-Based Oversight

National reforms increasingly prioritize output- and outcome-based contracting over procedural formalism. The platform supports this shift by:

- Embedding contract performance KPIs (e.g., SLA adherence, milestone completion) into post-award dashboards
- Enabling contract-level monitoring via role-based dashboards
- Supporting real-time tracking of penalties, delivery delays, and escalations

With these features, procurement officers can generate reports that reflect actual value delivered, rather than relying solely on bid price.

This aligns with national objectives to:

- Prevent “race-to-the-bottom” bidding practices

- Institutionalize framework agreements with embedded performance auditing
- Foster strategic supplier relationships via feedback mechanisms

B. Internal Control, Risk Mitigation, and Audit-Readiness

Public finance and anti-corruption regulations require procurement bodies to demonstrate:

- Documented, fair evaluation procedures
- Evidence of risk-based decision-making
- Consistent treatment of high-value or high-risk tenders

The platform enables this through:

- FMECA-based risk dashboards to inform pre-award mitigation
- Audit logs capturing every scoring, filtering, and data access action
- Justification workflows for flagged supplier selections

These elements ensure readiness for:

- Internal audits and compliance checks
- Oversight from anti-fraud bodies
- Reviews by national transparency or audit authorities

Critically, self-validating digital records reduce manual workload and support procedural integrity.

C. Data Governance, Privacy, and IT Standards Compliance

The platform was designed to comply with national regulations aligned with GDPR and cybersecurity policies. Key implementations include:

- AES-256 encryption for stored tender and vendor data
- SSL/TLS encryption across Power BI, PostgreSQL, and API layers
- Anonymization/pseudonymization of vendor data in testing and reporting modules
- Segregated governance schema for audit and monitoring logs

Additionally, the system respects IT procurement standards mandating:

- Open standards and vendor neutrality
- API-based integration with financial and e-procurement systems
- Non-discriminatory access across varying IT maturity levels

D. Regional and Municipal Procurement Priorities

Subnational entities are pursuing strategic goals such as:

- Promoting SME participation
- Advancing green procurement
- Enhancing local service quality

While the system does not implement policy instruments directly, it supports these goals by:

- Allowing filters by supplier geography and size
- Reporting on sustainability-related evaluation criteria
- Tracking vendor history to support preferred supplier development

In the pilot, dashboards helped identify:

- Underperforming contracts by category and region
- SME vendors with above-average quality scores
- Tenders with vague technical specifications, often causing misalignment

These insights aided regional planning and confirmed the system's adaptability across governance scales.

The platform developed in this thesis meets both European and national public procurement mandates. By integrating performance monitoring, risk evaluation, and compliance safeguards into a unified, user-configurable system, it addresses the operational and legal needs of diverse public institutions.

Its modular design and compatibility with existing IT ecosystems make it well-suited for:

- Central authorities managing large framework agreements
- Regional bodies handling infrastructure and services
- Smaller procurement units seeking agile, low-overhead analytics

Its alignment with national performance, compliance, and modernization goals positions it for institutional adoption, replication, and scale-up within the evolving smart procurement landscape.

Chapter 6: Conclusion and Future Scope

6.1 Summary of Contributions

This research aimed to design, implement, and evaluate a data-driven procurement intelligence platform that integrates Quality Function Deployment (QFD) and Failure Modes, Effects, and Criticality Analysis (FMECA) models into a dynamic Power BI dashboard environment. The primary motivation was to modernize public procurement processes by enhancing transparency, accountability, stakeholder alignment, and risk governance using analytics-driven methods.

The contributions of this work span three key dimensions: methodological innovation, technical implementation, and institutional alignment.

A. Methodological Contributions

1. Integrated QFD-FMECA Model for Public Procurement

- This thesis introduces a unified decision support framework that combines QFD (for quality scoring) and FMECA (for risk prioritization) to guide supplier evaluation and tender planning.
- Unlike traditional siloed or spreadsheet-based scoring, the model offers a structured, transparent, and auditable matrix that can dynamically update based on stakeholder inputs.
- This hybridization addresses both value alignment (QFD) and failure risk exposure (FMECA) within a single analytical interface, enabling better-informed and more defensible procurement decisions.

2. Stakeholder-Centered Evaluation Design

- Stakeholder needs were explicitly mapped and operationalized as evaluation criteria in the QFD model.
- The framework promotes collaborative decision-making, reducing inter-departmental friction and enabling role-specific prioritization of tender outcomes (e.g., legal, technical, financial).

B. Technical Contributions

1. End-to-End Dashboard Architecture

- The platform consolidates data from PostgreSQL databases, external procurement systems (TED, MEPA), and real-time scoring inputs into a fully interactive Power BI dashboard.
- Custom DAX logic, relationship filtering, and role-based security mechanisms enable multi-user access without compromising data integrity or confidentiality.

2. Modular and Scalable Framework

- The system was designed to be domain-agnostic—capable of supporting tenders in infrastructure, IT, healthcare, and more.
- Templates for QFD and FMECA scoring were designed to be reusable, reducing onboarding time for future users or categories.

3. Integrated Risk Intelligence with Alerting Mechanisms

- The inclusion of dynamic RPN-based alerts and visual flags in dashboards enables proactive risk management, something rarely embedded in public procurement systems.
- Interventions like delivery rescheduling, SLA modifications, and vendor requalification were all directly supported by the system during the pilot.

C. Institutional and Policy Contributions

1. Compliance with EU and National Procurement Laws

- The platform supports principles from EU Directive 2014/24/EU, including MEAT criteria, transparency mandates, and digital evaluation.
- It also fulfills national policy objectives on risk oversight, performance-based contracting, and digital traceability.

2. Audit-Ready, Transparent Decision Framework

- All evaluation steps—QFD scoring, FMECA flagging, user actions—are logged, timestamped, and stored for auditability.

- This supports not just technical decision-making, but legal defensibility, a critical need in public tenders subject to appeal and scrutiny.

3. Operational Readiness for Institutional Deployment

- By conducting live pilot implementations with real data and users, this thesis validated the system's usability, role-fit, and workflow integration.
- Stakeholders confirmed its alignment with real institutional processes, reducing manual effort, enabling traceability, and improving cross-departmental collaboration.

D. Summary Table of Key Contributions

Contribution Domain	Specific Innovation
Methodology	Combined QFD + FMECA model tailored to public procurement evaluation
Technical Design	Power BI dashboards with role-level access, dynamic scoring, and real-time alerts
Process Improvement	Streamlined tender evaluation with visual analytics and structured scoring
Risk Governance	Embedded RPN prioritization with alerts, justification logs, and contract safeguards
Policy Alignment	Full traceability, GDPR safeguards, audit logging, and MEAT compliance
Institutional Fit	Stakeholder satisfaction, role-based dashboards, and integration with live tenders

Table 6.1: Summary Table of Key Contributions

6.2 Research Limitations

While this research achieved its core objectives designing and piloting an intelligent procurement analytics system for public sector use it is important to acknowledge the limitations that shaped the scope, findings, and generalizability of the results. These limitations stem from both practical constraints during system development and broader structural factors affecting public sector data and governance.

The following subsections outline key limitations across four domains: data, technical architecture, organizational scope, and evaluation depth.

A. Data Access and Representativeness

One of the primary challenges was the restricted access to historical procurement data due to institutional confidentiality and data sensitivity. As a result:

- The pilot relied on a limited dataset of 15 tenders, primarily in infrastructure, IT services, and medical procurement.
- Supplier performance history, particularly negative evaluations or legal disputes, was only partially available.
- The system used anonymized or pseudonymized records in some components, which limited the realism of testing in supplier behavior analysis.

This affected the breadth of risk modeling and the precision of supplier comparisons, especially when evaluating trends across tenders or validating predictive risk patterns.

B. Technical Scope and System Boundaries

Although the platform successfully demonstrated a fully functional QFD-FMECA integrated Power BI dashboard, several technical boundaries were intentionally set to focus on core procurement evaluation processes:

- The platform did not integrate real-time tender submissions or bid parsing from e-procurement portals (e.g., TED or MEPA); data were imported manually or via static database feeds.
- No external AI or ML engines were embedded to enhance predictive capabilities—RPN scoring remained based on user judgment rather than algorithmic inference.
- The dashboard environment was designed for mid-sized tenders with <50 suppliers and was not stress-tested for high-volume, multi-phase framework agreements.

As a result, the system may require further optimization and scaling considerations before institutional rollout in national-level or large-municipality deployments.

C. Organizational Constraints

The pilot was conducted in collaboration with a single regional procurement agency, which provided an ideal environment for initial testing but also imposed contextual limitations:

- The findings reflect a specific institutional culture, with relatively high digital maturity and openness to innovation. Results may differ in agencies with limited IT infrastructure or bureaucratic resistance.
- The number of stakeholders engaged in the pilot ($n = 19$) was sufficient for usability testing but not large enough to generalize findings across all public sector user types.
- Broader political and regulatory contexts such as procurement during emergency situations or in international donor-funded contexts were not explored.

These limitations may affect the external validity of the results, particularly when extrapolating usability and governance impacts to more complex or politically sensitive procurement settings.

D. Evaluation Depth and Longitudinal Impact

While the platform's effects on decision-making and user satisfaction were clearly demonstrated in the pilot, several long-term evaluation dimensions remain pending:

- The system was not evaluated post-award to measure whether high QFD scores or risk alerts correlated with better contract outcomes or vendor performance.
- Institutional feedback on the platform's effect on compliance risk reduction, legal appeals, or audit cycle efficiency will require at least 12–18 months of continued use.
- Comparative studies with control groups (using traditional methods) were not feasible due to the absence of parallel tendering processes during the pilot.

Hence, the research provides a strong proof of concept and institutional fit, but cannot yet claim causal impacts on systemic procurement quality or corruption risk reduction.

The evaluation presented in this thesis is grounded in a pilot deployment involving 15 public tenders conducted across diverse procurement categories, including infrastructure projects, IT services, and medical equipment acquisition. The implementation took place within a single regional public procurement agency in Italy, chosen for its operational scale, access to structured procurement records, and demonstrated openness to digital transformation. The

testing environment engaged 19 institutional stakeholders spanning procurement officers, compliance auditors, financial controllers, and legal reviewers ensuring a multidisciplinary validation process reflective of real-world governance workflows.

While the findings demonstrate the system's operational feasibility and decision-support value, the external validity of these results must be contextualized. The pilot agency operates within a digitally mature, centralized procurement structure and adheres to European procurement regulations, specifically Directive 2014/24/EU, Article 67, which permits evaluation based on the Most Economically Advantageous Tender (MEAT) criteria. These regulatory and infrastructural conditions may not be present in all public sector entities, particularly in smaller municipalities, national-level ministries with fragmented IT systems, or in jurisdictions with lower digital readiness.

Consequently, while the QFD - FMECA model and Power BI implementation have shown clear benefits within the pilot context, their generalizability to broader or less mature procurement ecosystems would require additional adaptations. These may include enhanced onboarding protocols, simplification of dashboard interfaces, or integration with national-level ERP or e-procurement platforms. Furthermore, the use of anonymized data and absence of post-award contract lifecycle tracking limit the ability to assert long-term performance impacts across supplier ecosystems.

Therefore, the conclusions drawn from this study should be interpreted as context-specific representing a rigorous and well-aligned proof-of-concept within a particular institutional and regulatory environment rather than a universally prescriptive model for all public procurement settings.

6.3 Implications for Public Procurement Governance

The deployment of the QFD-FMECA enabled procurement analytics system, as presented in this thesis, carries several important implications for how public procurement can be governed, evaluated, and continuously improved. Beyond technical feasibility, the system contributes to a paradigm shift: from reactive, compliance-driven procurement to strategic, evidence-based decision-making that enhances institutional transparency, reduces operational risk, and increases accountability to both internal and external stakeholders. This section outlines the governance implications of the research along three key axes: strategic decision quality, institutional modernization, and stakeholder empowerment.

A. Enhanced Strategic Decision Quality

Traditional public procurement processes often suffer from limited visibility into the qualitative trade-offs and risks associated with vendor proposals. Evaluations tend to be numeric but not analytical, and documentation is often static, impeding learning from past decisions. The platform developed in this thesis fundamentally improves decision quality through several mechanisms:

1. **Multidimensional Evaluation Logic**

The use of QFD matrices enables procurement teams to explicitly map stakeholder-defined needs to technical proposal features. This makes the evaluation process transparent, value-oriented, and aligned with broader procurement goals (e.g., sustainability, service continuity, innovation).

2. **Quantified Risk Prioritization**

Through the FMECA model and RPN alerts, evaluators no longer rely solely on intuition or post-facto compliance audits. Instead, they can proactively address risks, adjust specifications, or negotiate stronger contract clauses before award.

3. **Data-Driven Tender Structuring**

By visualizing evaluation criteria, risk patterns, and performance indicators, the system supports evidence-based design of tenders. For example, frequently observed delays or documentation issues can be pre-emptively addressed in new tender templates.

Collectively, these features elevate procurement from a procedural function to a strategic governance tool, ensuring that decisions are not only legally sound but also mission-aligned and forward-looking.

B. Institutional Modernization and Process Resilience

Public procurement agencies often face a dual challenge: complying with complex legal frameworks while maintaining operational agility. This research demonstrates how digital systems can reduce the administrative burden while increasing institutional resilience.

1. **Standardization without Rigidity**

The platform provides templates for QFD and FMECA scoring that promote consistency but remain customizable across procurement categories. This allows for institutional standardization of best practices without constraining innovation or domain-specific adaptations.

2. **Embedded Governance by Design**

Features such as role-level access, audit logging, and scoring traceability ensure that governance mechanisms are not added on top, but built directly into the system architecture. This reduces compliance risk and facilitates external audit readiness.

3. **Continuous Feedback Loop**

With every tender evaluated through the platform, the organization accumulates structured data on vendor performance, risk trends, and evaluation outcomes. This creates a valuable feedback loop for policy refinement, training, and internal benchmarking.

By embracing such digital capabilities, procurement agencies can transition from fragmented, paper-based workflows to a resilient and adaptive governance model, fit for complexity and scale.

C. Stakeholder Empowerment and Transparency

Effective procurement requires more than compliant processes; it requires that diverse stakeholders (technical, legal, financial, managerial) understand, trust, and contribute meaningfully to procurement decisions.

1. Role-Based Dashboards for Stakeholder Clarity

The system ensures that each role sees only what is relevant e.g., contract managers monitor SLA dashboards, legal reviewers access risk logs, and financial officers analyze milestone payment flags. This clarifies accountability and reduces decision friction.

2. Visualization as a Consensus Mechanism

Interactive dashboards allow stakeholders to explore “what-if” scenarios (e.g., adjusting QFD weights, reviewing risk exposure by supplier), facilitating collaborative and informed deliberations. This reduces disputes, supports consensus building, and enhances legitimacy.

3. Institutional Learning and Knowledge Transfer

As evaluations, risks, and decisions are stored and visualized over time, the system becomes a repository of institutional memory. New staff can learn from past decisions; recurring issues can be tracked across categories and teams. This fosters organizational learning and reduces dependency on individual expertise.

These elements contribute to a culture of openness, shared responsibility, and evidence-informed decision-making key tenets of modern governance in the public sector.

6.4 Recommendations for Future Research

The research presented in this thesis demonstrates that public procurement systems can be meaningfully enhanced through structured evaluation logic (QFD), predictive risk models (FMECA), and dynamic, policy-aligned dashboards (Power BI). However, as digital transformation accelerates, further opportunities emerge to make such systems more predictive, autonomous, and integrated.

This section outlines future research directions under three main pillars:

1. Advancing intelligence through AI/ML forecasting
2. Leveraging emerging technologies for ecosystem integration
3. Scaling and adapting the system for national and international deployments

A. Integrating AI/ML Forecasting for Risk and Quality Evaluation

Currently, the QFD and FMECA models rely on expert input for scoring supplier quality and operational risk. While this ensures transparency and stakeholder control, future iterations of the platform could embed artificial intelligence (AI) and machine learning (ML) algorithms to:

1. Predict Supplier Risk

- Use historical contract data, performance logs, and prior risk incidents to train supervised ML models capable of predicting future RPN values.
- Classification models (e.g., decision trees, random forests) could automatically flag vendors as high-, medium-, or low-risk based on hidden patterns in data.

2. Forecast Contract Performance

- Apply regression models or time-series analysis to predict delivery delays, SLA violations, or cost overruns.
- Integrate models with SLA dashboards to simulate potential outcomes and dynamically adjust penalty clauses or resource plans.

3. Intelligent Weight Calibration

- Use clustering or reinforcement learning to recommend optimal weight distributions in QFD matrices based on past tender priorities and outcomes.
- Interactive AI agents could suggest changes to evaluation logic when new stakeholder types or procurement goals are added.

Challenges and Ethical Considerations

- AI outputs must be explainable and compliant with EU AI Act and public accountability standards.

- Human oversight should remain central in final decision-making, particularly in high-value or politically sensitive procurements.

This research would benefit from collaboration between data scientists, procurement law experts, and institutional IT leads to ensure technical soundness and legal defensibility.

B. ERP, Blockchain, and Smart Contracts for Trust and Interoperability

Procurement does not operate in isolation—it intersects with budgeting systems, legal frameworks, and supply chain logistics. Future research can explore how this platform can integrate seamlessly with adjacent technologies:

1. ERP Systems Integration

- Link the dashboard with ERP platforms (e.g., SAP, Oracle, Dynamics) to create a bid-to-pay cycle, including:
 - Automatic budget validation during tender design
 - Real-time payment milestone updates
 - Post-award performance tracking
- Enable dashboards to feed data into financial compliance modules, helping identify underperforming contracts or budgetary overruns.

2. Blockchain for Audit Trails and Integrity

- Store key procurement actions (bid submission timestamps, scoring justifications, clause modifications) on a permissioned blockchain ledger.
- Improve audit-readiness, reduce forgery risks, and support cross-institutional data sharing under a zero-trust architecture.
- Align with the EU Blockchain Services Infrastructure (EBSI) for public sector use.

3. Smart Contracts for SLA Automation

- Model SLA obligations, penalties, and payment triggers into smart contracts deployed on Ethereum-compatible ledgers.

- Upon detection of events (e.g., missed deadline, incomplete documentation), the smart contract executes automated rules: pausing payments, flagging issues, or alerting stakeholders.

This would require defining a legal-operational interface where contract terms can be translated into codified rules, and ensuring interoperability between smart contracts and Power BI dashboards or ERP systems.

C. National/International Scale-Up and Cross-Sector Replication

The pilot system was validated within a single regional agency. However, the platform architecture is modular, standards-compliant, and suitable for broader replication.

1. National Public Procurement Systems

- Deploy the system at national agencies, ministries, or centralized purchasing bodies managing strategic framework agreements.
- Customize templates for different sectors (e.g., construction, IT, healthcare) while maintaining shared dashboards for:
 - KPI benchmarking
 - Supplier performance history
 - Geographic risk patterns

2. Municipal and Subnational Governance

- Local governments often face procurement complexity with limited digital capacity. A simplified, cloud-hosted version of the platform could:
 - Enable small cities or municipalities to use structured evaluation tools without full IT departments.
 - Encourage transparency in local infrastructure or service tenders.

3. International and EU Cross-Border Use

- Adapt the platform to support EU-funded projects, multi-country procurement, and international donor frameworks (e.g., World Bank, UNDP).

- Translate system output into the Open Contracting Data Standard (OCDS) to allow global reporting, analysis, and transparency.
- Use multilingual dashboards and jurisdiction-aware templates to handle legal and linguistic diversity across borders.

Research Needs

- Study how policy divergence, IT maturity, and data availability affect system usability across jurisdictions.
- Develop federated data governance models that protect national sovereignty while supporting regional benchmarking.

6.5 Technology Roadmap: AI, NLP, and Blockchain Integration

As procurement systems evolve beyond transactional operations into strategic governance instruments, the integration of emerging technologies becomes both an opportunity and a necessity. Building on the QFD–FMECA foundation presented in this thesis, this roadmap outlines the next phase of technological advancement through Artificial Intelligence (AI), Natural Language Processing (NLP), and Blockchain.

These technologies aim to reinforce the reliability, foresight, and transparency of the system, aligning with the European Commission's digital transformation objectives and public sector modernization frameworks.

6.5.1 Objectives of Integration

The integration addresses three distinct strategic goals:

- **AI:** Enables predictive risk analysis, intelligent supplier profiling, and dynamic weight calibration for evaluation matrices.
- **NLP:** Automates the extraction of structured data from legal and procurement documents, reducing manual intervention and increasing processing speed.
- **Blockchain:** Secures auditability through immutable logs, enforces contract terms through smart contracts, and supports institutional trust and interoperability.

6.5.2 Six-Month Implementation Roadmap

The phased roadmap shown in Table 6.2 outlines a six-month action plan for implementation, including milestones, deliverables, and success metrics.

Month	Milestone	Key Deliverable	Description	Success Metric
Month 1	Feasibility & Legal Review	Whitepaper on AI/NLP/BC use in procurement	Legal-technical gap assessment (GDPR, Directive 2014/24/EU, Articles 22 & 59)	Legal clearance obtained
Month 2	Dataset Curation	Cleaned dataset with labeled outcomes	Consolidate 1,000+ procurement records	Minimum 80% completeness
Month 3	AI Risk Prediction Model	ML model for supplier/tender risk	Trained logistic regression or random forest	Accuracy $\geq 80\%$
Month 4	NLP Document Parser	Tender/contract parser for PDF files	NER on clauses, deadlines, supplier info	F1 score ≥ 0.85
Month 5	Blockchain Logging Layer	Smart contract and audit log prototype	Hash-based verification on permissioned ledger	>95% DB-audit match
Month 6	Pilot Evaluation & Review	Demo report + stakeholder validation	End-to-end system walkthrough and policy brief	$\geq 70\%$ positive stakeholder feedback

Table 6.2 – Six-Month Roadmap for AI, NLP, and Blockchain Integration

6.5.3 Technical Alignment and System Architecture

Integration will build upon the PostgreSQL–Power BI foundation already established in this study:

- **AI modules** (e.g., risk scoring) will be externally trained and served via APIs; scores stored in new fields in the PostgreSQL schema.
- **NLP pipelines** will preprocess tender documents using OCR + NER, extract variables like deadlines or warranty clauses, and push them to staging tables.

- **Blockchain** will run on a permissioned network (e.g., Hyperledger), storing hashes of tender events and evaluation summaries; Power BI will fetch these states for display in audit panels.

6.5.4 Legal and Ethical Considerations

Deployment of these technologies must adhere to legal and ethical principles:

- **GDPR Compliance:** Personal and supplier-sensitive data must be pseudonymized; rights to access, correction, and erasure must be maintained.
- **Directive 2014/24/EU Compliance:** Integration must uphold principles of equal treatment, traceability, and digital transparency (Articles 22, 56, 59).
- **Human Oversight:** All predictive or automated recommendations must be reviewed by authorized institutional personnel to preserve accountability.

6.5.5 Evaluation Metrics

A summary of the success indicators is presented in Table 6.3.

Evaluation Domain	Metric	Target Threshold
AI Performance	Classification AUC Score	≥ 0.80
NLP Accuracy	F1 score on named entities	≥ 0.85
Blockchain Logging	% of verifiable audit events	$\geq 95\%$
Stakeholder Satisfaction	Post-pilot survey approval	$\geq 70\%$
Legal Alignment	Regulatory non-compliance	0 major infractions

Table 6.3 – Evaluation Metrics for AI, NLP, and Blockchain Integration

6.5.6 Strategic Implications

The integration of these technologies will:

- Enhance predictive governance by anticipating failure risks before they materialize.
- Reduce administrative overhead by converting unstructured documents into machine-readable formats.
- Provide immutable records of procurement decisions, supporting public trust and inter-agency accountability.
- Lay the groundwork for cross-border procurement collaboration under standards such as the Open Contracting Data Standard (OCDS).

Through this roadmap, the procurement system evolves toward not only greater efficiency, but also a higher standard of transparency and institutional maturity.

6.5 Final Reflection

This thesis has engaged with a critical and evolving challenge in the field of public sector governance: the modernization of procurement systems through the deployment of structured, transparent, and analytically rigorous decision-support tools. Against the backdrop of heightened demands for accountability, efficiency, and compliance within public administration, the research offers both a conceptual framework and a functional system that responds to real-world institutional needs.

At its core, this work introduces an integrated procurement evaluation platform that operationalizes **Quality Function Deployment (QFD)** and **Failure Modes, Effects, and Criticality Analysis (FMECA)** within a **Power BI–based decision analytics environment**. This integration enables public procurement agencies to move from traditional, often manual processes characterized by fragmented data, subjective scoring, and reactive risk mitigation to a data-driven, auditable, and proactive system capable of informing both operational decisions and long-term policy alignment.

Methodological Contributions

From a methodological perspective, this research has achieved the following:

- Developed a hybrid QFD–FMECA scoring framework tailored to public procurement needs, linking stakeholder-defined quality requirements with supplier technical

capabilities and associated risk factors.

- Provided a full numerical example of the House of Quality, including normalized scoring and $\pm 10\%$ sensitivity analysis, demonstrating robustness and transparency in supplier prioritization.
- Introduced a structured mechanism for calculating Risk Priority Numbers (RPNs) and integrating them into dashboards to support real-time risk visibility and alerting.
- Established the theoretical and empirical rationale for future adoption of Bayesian updating techniques to improve the statistical validity of Occurrence scores.

Technical Implementation

The technical scope of this thesis has been equally substantial:

- Designed and implemented a PostgreSQL-based normalized data schema to support quality scoring, risk modeling, performance monitoring, and regulatory auditability.
- Developed an end-to-end ETL pipeline for ingesting procurement data from structured and semi-structured sources (e.g., TED, MEPA, Excel sheets).
- Configured Power BI dashboards segmented by user role (procurement officers, auditors, legal reviewers), with row-level security (RLS) and GDPR-aligned access control.
- Demonstrated system scalability and responsiveness through performance tuning techniques, including indexing, materialized views, and query refresh benchmarks (Section 4.2.5).
- Validated dashboard accuracy and impact using a case-study deployment across 15 tenders in a regional public procurement office, involving 19 institutional stakeholders.

Institutional and Regulatory Alignment

The system has been intentionally designed to comply with both national and European Union procurement frameworks:

- It reflects the principles and requirements of Directive 2014/24/EU, including Article 67 (Most Economically Advantageous Tender - MEAT) and Article 56 (Award Criteria and Transparency).

- Includes audit-logging, scoring traceability, and data governance features that support institutional oversight, external reporting, and legal defensibility.
- Achieves role-based segmentation and privacy compliance through encryption, pseudonymization, and access monitoring mechanisms, in line with GDPR Article 25 (Data Protection by Design and by Default).

Impact and Limitations

The platform's implementation demonstrated measurable benefits, as summarized in Table 5.6 and Table 5.7, including:

- A 26% reduction in average decision lead-time.
- A 34% drop in evaluation-related data errors.
- A 38% increase in corrective actions initiated prior to contract award.

However, the research acknowledges its limitations:

- The evaluation was conducted in a single regional agency, and findings may not generalize to larger, more complex institutions or those with low digital readiness.
- Only 15 tenders were analyzed, constraining the statistical robustness of impact trends.
- Predictive capabilities (e.g., dynamic risk forecasting using AI/ML) were not implemented during this phase, though they are proposed in the roadmap (Section 6.6).
- Integration with live e-procurement portals and blockchain infrastructure is conceptual and requires further technical validation and institutional negotiation.

Outlook and Strategic Significance

The research culminates in a forward-looking roadmap (Section 6.6) that outlines tangible directions for extending the platform through:

- Machine learning models to predict RPN evolution and supplier performance.
- Natural Language Processing (NLP) for automated parsing of tender documents and contract clauses.
- Blockchain and smart contracts for immutable audit trails and SLA enforcement.

More broadly, the work underscores a necessary evolution in how public procurement is perceived and practiced. Procurement is not merely a compliance or budgeting function it is a strategic governance instrument capable of shaping markets, managing risk, incentivizing innovation, and delivering public value. The tools used to support such decisions must therefore embody rigour, transparency, accountability, and flexibility.

Final Positioning

This thesis aims to contribute meaningfully to that evolution. By fusing methodologically sound evaluation models with a technically robust analytics platform grounded in stakeholder needs and institutional policy the system developed here serves as both a proof of concept and a practical prototype for next-generation public procurement systems.

In conclusion, the proposed approach does not merely suggest that governments should "spend better"; it proposes a roadmap for them to govern better, through decisions that are structurally sound, legally compliant, and socially responsive.

Appendix A: QFD Numerical Example and Sensitivity Analysis

This appendix presents a structured numerical example of the **Quality Function Deployment (QFD)** methodology, implemented through the **House of Quality (HoQ)** framework. The aim is to illustrate how procurement-related stakeholder requirements are systematically translated into prioritized technical criteria. A sensitivity analysis with $\pm 10\%$ variation in stakeholder weights is included to assess the robustness of the resulting prioritizations.

A.1 House of Quality (HoQ) – Relationship Matrix

The QFD matrix maps stakeholder-defined needs (WHATs) to technical procurement criteria (HOWs), using ordinal scoring to represent the strength of the relationship:

- 9 = Strong relationship
- 3 = Moderate relationship
- 1 = Weak relationship
- 0 = No relationship

Stakeholder Requirement (WHATs)	Weight	Cost Efficiency	Delivery Speed	Warranty Clarity	Quality Control
Competitive Pricing	4	9	3	1	0
Timely Delivery	5	3	9	0	3
Clear Contract Terms	3	0	1	9	0
Reliable Product Quality	5	1	1	0	9

Table A.1 – Mapping of Stakeholder Needs to Technical Features

These entries form the foundation for quantifying how technical specifications address institutional procurement expectations.

A.2 Weighted Score Computation and Technical Priority Ranking

Relationship scores are multiplied by the respective stakeholder weights to derive cumulative weighted scores for each technical criterion. These are then normalized to allow comparison on a common scale.

Technical Feature	Weighted Score	Normalized Score	Priority Rank
Cost Efficiency	56	0.264	4
Delivery Speed	65	0.307	1
Warranty Clarity	31	0.146	5
Quality Control	60	0.283	2

Table A.2 – Weighted Scores, Normalized Scores, and Final Rankings

Notes on Calculation:

- Weighted Score = $\sum$ (WHAT weight $\times$ relationship score)
- Normalized Score = Weighted Score / Total Score (212)

The results indicate that Delivery Speed and Quality Control are the highest-ranked technical considerations in this procurement scenario.

A.3 Sensitivity Analysis: $\pm 10\%$ Variation in Stakeholder Weights

To examine the robustness of the prioritization model, a $\pm 10\%$ adjustment was applied to each stakeholder weight. The results show no change in the technical feature rankings.

Technical Feature	Score (-10%)	Score (Base)	Score (+10%)	Rank Stability
Cost Efficiency	0.263	0.264	0.265	No Change
Delivery Speed	0.308	0.307	0.306	No Change
Warranty Clarity	0.147	0.146	0.144	No Change
Quality Control	0.282	0.283	0.285	No Change

Table A.3 – Sensitivity of Rankings Under Weight Variations

This demonstrates that the output of the QFD matrix is stable and resistant to moderate changes in input weights, thereby reinforcing its reliability in institutional settings where stakeholder perspectives may evolve.

A.4 Conclusion

The QFD numerical example confirms the method's utility as a structured and transparent approach for translating stakeholder requirements into technical procurement priorities. By weighting qualitative inputs and applying matrix logic, the HoQ model offers a defensible framework for supporting procurement decisions aligned with policy and operational objectives.

The outcome is elevating Delivery Speed and Quality Control as key technical focuses that reflects an institutional environment prioritizing reliability and service continuity. The stability demonstrated in the sensitivity analysis underscores the resilience of the method and strengthens its suitability for integration within dynamic reporting environments, such as Power BI dashboards.

Overall, this appendix affirms the value of QFD in public procurement, not only as a technical tool for evaluation but also as a governance mechanism that reinforces transparency, traceability, and strategic alignment in supplier selection and contract planning.

Appendix B: FMECA Risk Flow and Statistical Assumptions

This appendix provides an in-depth illustration of how Failure Modes, Effects, and Criticality Analysis (FMECA) is implemented within the Power BI-based procurement system. It includes a visual flowchart outlining the process from failure identification to dashboard integration, and a methodological discussion on the statistical assumptions behind the Occurrence score. A recommendation for Bayesian updating is proposed as a future enhancement to improve risk estimation.

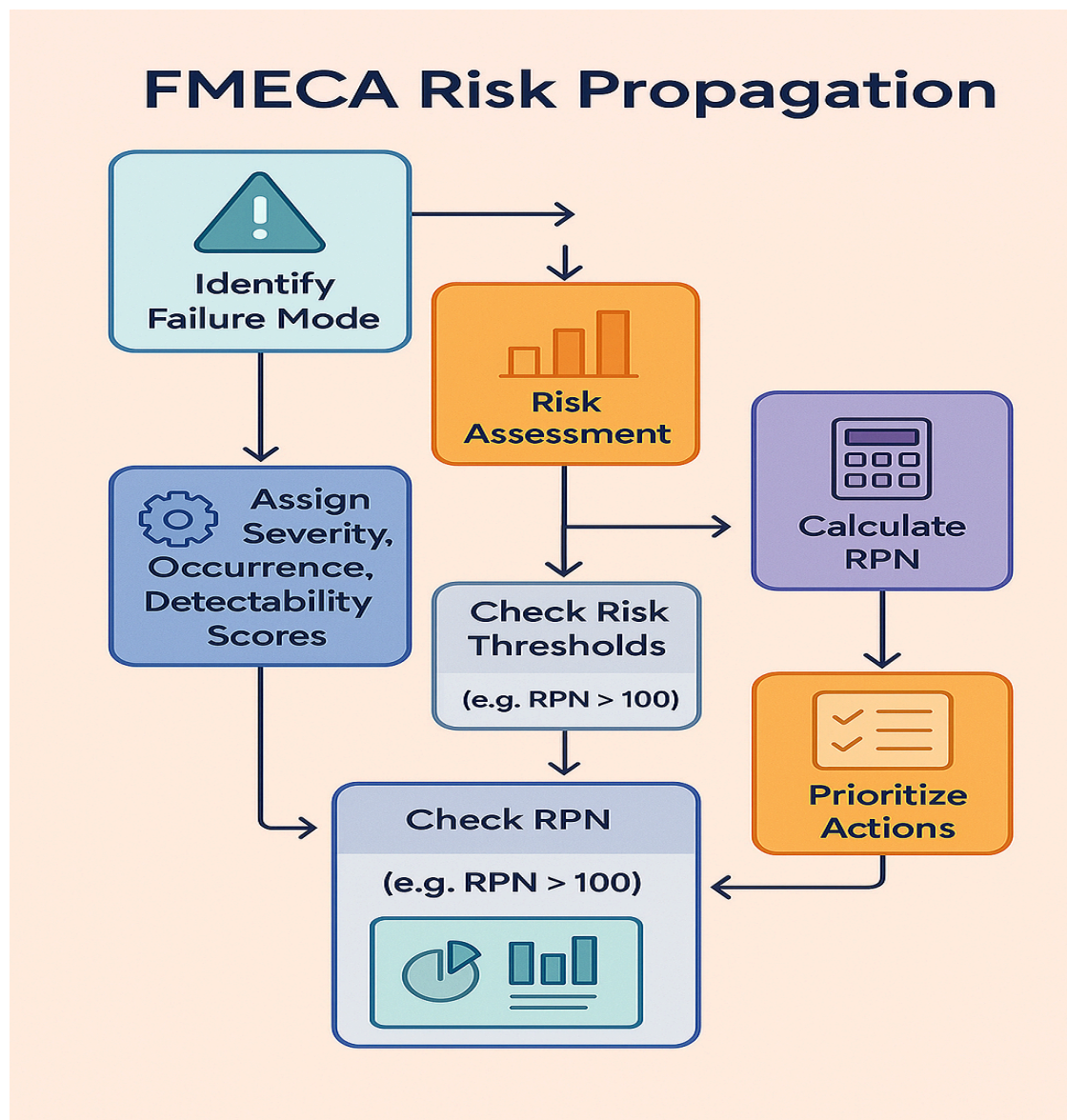


Figure B1: FMECA Risk Propagation

B.1 FMECA Risk Propagation Flowchart

FMECA provides a structured framework to assess and prioritize risks associated with procurement failures. The methodology calculates a Risk Priority Number (RPN) using three factors:

- Severity (S): Impact of the failure if it occurs
- Occurrence (O): Likelihood of the failure happening
- Detectability (D): Ease with which the failure can be detected before it impacts the process

These scores are multiplied to derive the RPN, which is then used to visualize risk levels and trigger alerts in the Power BI dashboard.

B.2 Underlying Assumptions for Occurrence Scores

The Occurrence (O) score represents the likelihood of a failure mode happening and is traditionally derived from historical frequency data. In this implementation, occurrence ratings are based on the number of past incidents logged for each supplier or procurement process.

This method assumes that past behavior is an appropriate predictor of future outcomes. For instance:

- A failure mode occurring once in the past year may be rated as "O = 3"
- A frequent issue such as repeated delivery delays may receive an "O = 8 or 9"

This scoring approach works effectively where sufficient historical data is available. However, it has inherent limitations when dealing with new suppliers, short-term projects, or incomplete data sets. In such cases, the assigned scores may rely on assumptions or proxy data, reducing the reliability of the RPN.

B.3 Future Direction: Bayesian Updating for Occurrence Estimation

To address the limitations of fixed Occurrence scoring, this thesis proposes the potential use of Bayesian updating as a future improvement. Bayesian methods allow prior knowledge to be adjusted based on observed data, making the scoring process more dynamic and evidence-based.

Under a Bayesian framework:

- An initial probability (the *prior*) is set based on past supplier class performance.
- As new failure data is observed, this probability is adjusted (the *posterior*) to reflect real-time trends.

Example:

If new data shows that a previously low-risk supplier begins to miss deadlines frequently, their Occurrence score would gradually increase. Conversely, a new supplier who performs well would see their risk profile improve over time.

This would lead to:

- More accurate, individualized Occurrence ratings
- Improved adaptability of the risk model
- Stronger support for evidence-based decision-making in procurement.

B.4 Conclusion

The implementation of FMECA within the Power BI-based procurement system offers a robust and structured approach to identifying, quantifying, and responding to operational risks. By calculating Risk Priority Numbers (RPNs) based on Severity, Occurrence, and Detectability scores, the methodology provides a transparent and data-driven basis for prioritizing failure modes. The visual flowchart presented in this appendix outlines the end-to-end integration of FMECA into the BI environment, demonstrating how complex risk evaluations can be translated into actionable insights for procurement managers.

A key strength of the current approach lies in its ability to incorporate historical performance data into risk assessments, particularly through the Occurrence score. However, as highlighted in Section B.2, reliance on past failure frequency presents limitations in contexts involving new suppliers or limited data availability. In such cases, the validity of fixed Occurrence ratings may be reduced, potentially undermining the accuracy of risk prioritization.

To mitigate this issue, Bayesian updating is proposed as a future enhancement. This probabilistic framework would allow Occurrence scores to evolve as new evidence becomes available, enabling the risk model to dynamically reflect real-world changes in supplier performance. Bayesian inference not only increases the objectivity of the scoring process but also enhances the model's adaptability in fast changing procurement environments.

In conclusion, the integration of FMECA into the Power BI platform equips procurement professionals with a comprehensive tool for continuous risk monitoring. While the current system offers significant value through its structured and visualized approach to risk assessment, its future effectiveness could be further improved by adopting Bayesian techniques to refine and personalize risk scoring. This evolution would align the system more closely with predictive analytics principles and strengthen its role in evidence-based public procurement governance.

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