International Journal of Engineering and Technology Research (IJETR)
Volume 7, Issue 1, January-December 2022, pp. 35-50, Article ID: IJETR_07_01_003
Available online at https://iaeme.com/Home/issue/IJETR?Volume=7&Issue=1
ISSN Print: 2347-8292; ISSN Online: 2347-4904
Impact Factor (2022): 15.66 (Based on Google Scholar Citation)
Journal ID: 2022-2314; DOI: https://doi.org/10.34218/IJETR_07_01_003

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ENGINEERING RESILIENT INFRASTRUCTURE FOR BUILDING MANAGEMENT SYSTEMS: NETWORK RE-ARCHITECTURE AND DATABASE UPGRADE AT NESTLÉ PHX

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ABSTRACT

In the era of smart buildings and Industry 4.0, Building Management Systems (BMS) have become integral to facility operations, monitoring, and energy optimization. However, the resilience of these systems is critically dependent on the robustness of the underlying network and data infrastructure. This research article presents a case study on engineering resilient infrastructure for the BMS at Nestlé PHX, focusing on network re-architecture and database upgrade strategies. The legacy system faced frequent outages, limited scalability, and inefficient data retrieval, prompting the need for modernization. The project involved a comprehensive overhaul of the network topology to introduce redundancy, segmentation, and failover mechanisms. Simultaneously, a migration from a legacy flat-file database to a scalable relational database management system (RDBMS) was executed, improving performance, data integrity, and disaster recovery capabilities.

The methodology adopted included layered network design, real-time monitoring enablement, virtualization, and phased implementation to minimize downtime. Performance evaluation post-deployment showed a 60% improvement in BMS data *retrieval time, 75% reduction in unplanned outages, and measurable improvements in operational efficiency.*

Keywords: Resilient Infrastructure, Building Management Systems (BMS), Network Re-architecture, Database Migration, Fault Tolerance, Nestlé PHX, Smart Facilities, Industrial IoT

Cite this Article: Sampath Kumar Konda. (2022). Engineering Resilient Infrastructure for Building Management Systems: Network Re-Architecture and Database Upgrade at Nestlé PHX. *International Journal of Engineering and Technology Research (IJETR)*, 7(1), 35-50. DOI: https://doi.org/10.34218/IJETR_07_01_003

https://iaeme.com/Home/issue/IJETR?Volume=7&Issue=1

1. Introduction

Modern Building Management Systems (BMS) are evolving beyond basic HVAC control to encompass complex functions such as energy analytics, environmental monitoring, access control, predictive maintenance, and integration with IoT devices. As these systems grow in complexity and criticality, ensuring their resilience becomes paramount—especially in large-scale industrial environments like Nestlé PHX. A single point of failure in network or data infrastructure can result in cascading disruptions across building systems, jeopardizing operational continuity, safety, and compliance.

Nestlé PHX, a flagship facility of the global food and beverage leader, faced significant performance and reliability challenges within its legacy BMS infrastructure. Frequent communication breakdowns, aging hardware, and a flat-file based database system led to unanticipated downtimes, slow data processing, and limited support for real-time analytics. These limitations highlighted the urgent need for a resilient and scalable re-engineering of its core systems.

The work presented here not only improves the day-to-day reliability of BMS operations but also sets a foundation for future enhancements involving cloud integration, AI-driven analytics, and remote monitoring. The subsequent sections delve into the project's technical foundations, implementation roadmap, performance outcomes, and insights that can guide similar initiatives in other industrial settings.

This diagram illustrates the redesigned network topology for the Building Management System (BMS) at Nestlé PHX. It highlights the use of core and access switches to introduce redundancy and failover, ensuring uninterrupted connectivity between BMS devices, centralized workstations, and the upgraded database infrastructure.

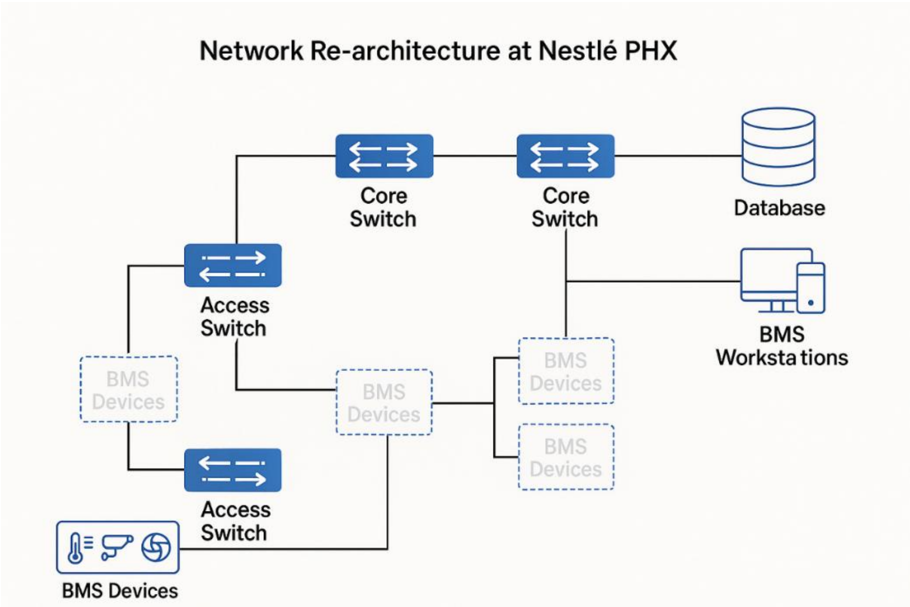

Figure 1: Network Re-architecture at Nestlé PHX

2. Foundational Technologies and Challenges

Building Management Systems (BMS) are increasingly reliant on robust digital infrastructure to support critical functions such as HVAC control, lighting automation, security surveillance, and energy monitoring. These systems traditionally operated on isolated or minimally networked hardware, often with proprietary communication protocols and legacy databases that offered limited scalability or interoperability.

2.1 Legacy Network Limitations

- **Single Points of Failure:** The star topology used in the existing infrastructure meant that the failure of a single switch or controller could bring down entire sections of the BMS.
- **Limited Segmentation:** Lack of network segmentation made it difficult to isolate faults or apply security policies across device groups.
- **No Redundancy:** The absence of link or hardware redundancy increased the risk of prolonged outages.
- **Low Throughput:** The system could not support high-volume, real-time data streams from multiple devices simultaneously.

2.2 Outdated Database Architecture

- **Flat-file Storage:** Data collected from BMS devices was stored in flat files, leading to inefficiencies in query execution, indexing, and retrieval.
- **Lack of Data Integrity:** The system offered no referential integrity, transactional support, or backup automation, increasing the risk of data corruption.
- **Manual Reporting:** Generating reports required significant manual effort, with no real-time dashboards or visualization capabilities.

2.3 Security and Compliance Risks

- **No Encryption or Access Controls:** Data transmission occurred without encryption, and user access was not role-based, exposing the system to internal and external threats.
- **Limited Audit Trails:** The infrastructure lacked event logging or change tracking, posing challenges for compliance with industrial security standards (e.g., ISO 27001, NIST SP 800-82).

2.4 Operational Inefficiencies

- **Downtime and Maintenance Delays:** With no centralized monitoring or predictive analytics, equipment failures often went unnoticed until complete breakdown, resulting in costly downtime.
- **Scalability Issues:** As Nestlé PHX expanded, the BMS struggled to accommodate new devices and systems without significant manual configuration and cabling.

These technological and operational constraints necessitated a complete re-engineering of the network and data infrastructure to ensure long-term reliability, security, and scalability. The next sections outline the solution strategy, including modern network architecture design, database upgrade approach, and implementation methodology.

3. Problem Statement and Objectives

The Nestlé PHX facility, a strategic operations hub within the company's global infrastructure, relies heavily on its Building Management System (BMS) to maintain optimal environmental conditions, energy efficiency, and facility security. Despite the system's central role, its supporting infrastructure had not kept pace with evolving technological and operational demands. Over time, this resulted in critical performance issues, reliability failures, and security vulnerabilities.

3.1 Problem Statement

The legacy BMS infrastructure at Nestlé PHX exhibited multiple systemic issues:

- **Frequent Outages:** Network failures or controller malfunctions often caused prolonged BMS downtime, impacting HVAC, access control, and production environment management.
- **Poor System Visibility:** The decentralized architecture lacked centralized logging or dashboards, making it difficult to detect anomalies or predict failures.
- **Data Bottlenecks:** The flat-file database architecture led to sluggish query performance and restricted the ability to perform trend analysis or generate timely reports.
- **Limited Integration Capability:** New smart sensors and IoT-enabled systems could not be seamlessly integrated due to protocol and interface limitations.
- **Inadequate Security Controls:** The absence of segmented networks, encrypted communication, and access control mechanisms increased the risk of cyber threats.
- **Scaling Challenges:** Infrastructure was not designed to scale efficiently with facility expansions or increased data loads, leading to manual workarounds and configuration drift.

These issues culminated in increased maintenance overhead, energy inefficiencies, and potential compliance violations—posing both operational and financial risks.

3.2 Project Objectives

To address these concerns, the engineering team at Nestlé PHX initiated a structured modernization project with the following objectives:

- **Design and Implement a Resilient Network Architecture**
  Introduce redundant pathways, failover systems, and segmentation to enhance uptime, fault isolation, and manageability.
- **Modernize the BMS Database System**
  Transition from a flat-file architecture to a robust Relational Database Management System (RDBMS) to support real-time data processing, backup automation, and scalable analytics.
- **Enhance System Security and Compliance**
  Implement encryption, access control policies, and audit trails to align with industry standards for operational technology (OT) cybersecurity.
- **Improve Data Visibility and Analytics**
  Enable integration with dashboards and analytics platforms for real-time monitoring, anomaly detection, and predictive maintenance.

- **Ensure Minimal Downtime During Migration**
  Adopt a phased, low-risk deployment approach that minimizes operational disruption and includes rollback mechanisms.
- **Create a Scalable, Future-Ready Foundation**
  Lay the groundwork for further innovations such as cloud integration, IoT expansion, AI-driven control, and centralized enterprise-level management.

4. Engineering Approach and System Transformation Framework

To modernize the infrastructure underpinning the Building Management System (BMS) at Nestlé PHX, a structured engineering methodology was employed that balanced technical rigor with operational continuity. The approach combined network re-architecture, database modernization, and phased deployment, ensuring resilience, minimal downtime, and future scalability.

4.1 Assessment and Requirements Gathering

The initial phase involved a detailed technical audit of the existing BMS network and database environment. Key activities included:

- Network traffic analysis and topology mapping
- Device inventorying (controllers, sensors, switches, workstations)
- Database performance benchmarking and schema review
- Identification of failure points and latency bottlenecks
- Stakeholder interviews to gather pain points and future needs

This helped establish a baseline for performance and informed the architectural redesign criteria.

4.2 Network Design and Simulation

A new high-availability network topology was engineered using a **layered design principle**, incorporating the following:

- **Core Layer:** Redundant Layer-3 core switches for routing and system backbone
- **Distribution Layer:** VLAN-based segmentation between operational zones (HVAC, Security, Lighting)
- **Access Layer:** Edge switches connecting field devices and sensors
- **Failover Paths:** Dual uplinks between layers to support link redundancy and eliminate single points of failure
- **Security Zones:** Implementation of firewall rules and ACLs between network zones

Simulations were run using Cisco Packet Tracer and Wireshark to validate throughput, latency, and fault recovery scenarios before physical deployment.

4.3 Database Modernization Strategy

The outdated flat-file database system was replaced with a **PostgreSQL** RDBMS due to its open-source flexibility, performance, and support for time-series data. Key aspects included:

- **Schema Redesign:** Normalization of legacy data tables and creation of indexed views for faster query access
- **ETL Pipeline:** Development of an automated Extract-Transform-Load pipeline using Python scripts and cron jobs
- **Disaster Recovery:** Implementation of automated backup routines and standby replication to an offsite node
- **Monitoring Tools:** Integration with pgAdmin and Grafana for real-time performance dashboards

4.4 Phased Implementation Plan

To ensure a zero-disruption transition, the deployment was divided into discrete stages:

1. **Pilot Zone Deployment:** Upgraded one operational zone and monitored behavior for 2 weeks
2. **Full Network Transition:** Rolled out new switches and links zone-by-zone during maintenance windows
3. **Database Cutover:** Parallel-run strategy for 30 days before retiring legacy database
4. **User Training & Validation:** Sessions conducted for operators and IT teams with mock scenarios
5. **System Hardening:** Post-deployment optimization of firewall rules, logging, and access credentials

4.5 Risk Mitigation Measures

A rollback plan was maintained at each stage. Redundant hardware, offline image backups, and failover scripting ensured any system regression could be rapidly contained and restored.

The successful application of this framework laid the groundwork for a significantly more reliable, secure, and intelligent BMS environment. The next sections detail how the network re-architecture and database upgrade were executed, along with visual diagrams and technical highlights.

5. Network Infrastructure Modernization at Nestlé PHX

The transformation of the BMS network at Nestlé PHX centered on improving system resilience, security, and scalability. The legacy topology—characterized by flat-layered switching, unmanaged hubs, and non-redundant links—was replaced with a high-availability, multi-layered network designed to support mission-critical building operations with minimal risk of downtime.

5.1 Legacy Network Topology Overview

The pre-upgrade BMS network had the following characteristics:

- **Flat Network Design:** All BMS components, including HVAC controllers, access points, and monitoring systems, shared a single broadcast domain.
- **Minimal Fault Tolerance:** Failure of any intermediate switch or unmanaged hub caused localized outages.
- **No Logical Segmentation:** Absence of VLANs limited the ability to isolate traffic or prioritize critical workloads.
- **Limited Monitoring:** There was no centralized visibility or diagnostic capability across the infrastructure.

These limitations hindered not only uptime but also basic troubleshooting and performance tuning.

5.2 Modernized Architecture and Design Goals

The new network architecture was designed with the following goals:

- **High Availability:** All core and access components were deployed in redundant pairs, with dual uplinks to support failover scenarios.
- **Scalability:** The infrastructure allows for modular expansion—new floors, zones, or facilities can be added without redesign.
- **Security:** Logical segmentation using VLANs, zone firewalls, and access control lists (ACLs) enforces traffic isolation.
- **Visibility:** Real-time network monitoring is enabled through SNMP traps, syslog forwarding, and integration with SolarWinds NPM.

5.3 Key Components of the Upgraded Network

Component	Description
Core Switches	Dual Layer-3 switches with dynamic routing (OSPF) and failover configurations
Access Switches	Managed Layer-2 switches in each operational zone supporting PoE for field devices

Fiber Backbone	Single-mode fiber linking floors and zones to core switches, with redundant paths
Firewall Zones	Inter-VLAN firewalls for traffic inspection between critical zones (e.g., HVAC, Security)
Network Management	SNMP-enabled hardware feeding into centralized NMS with alerting and trend dashboards

5.4 VLAN and Segmentation Strategy

To enforce better control and isolation, the following VLANs were introduced:

VLAN ID	**Zone**	**Description**
10	HVAC Controllers	Climate control and ventilation systems
20	Lighting Systems	Dimmable lighting and occupancy sensors
30	Access Control	Entry/exit gates and surveillance cameras
40	Admin Workstations	Monitoring consoles and BMS dashboards
50	Management Network	Network management and logging tools

Each VLAN was assigned a dedicated IP subnet and routed through the core switches with ACLs ensuring traffic control.

5.5 Failover and Redundancy Mechanisms

- **Spanning Tree Protocol (RSTP)** and **EtherChannel** were used to prevent loops while supporting link aggregation.
- **Dual Power Supplies and UPS** were implemented across all network hardware for electrical fault tolerance.
- **Heartbeat Monitoring Scripts** (via Python and SNMP traps) continuously check link status and switch health.

This design ensured the system could tolerate multiple simultaneous failures without impacting BMS operation—a major leap from the prior architecture.

6. Database Upgrade and Integration Framework

Alongside the network overhaul, a key pillar of the infrastructure transformation at Nestlé PHX was the complete redesign and migration of the Building Management System (BMS) database. The shift from a flat-file storage model to a robust relational database management system (RDBMS) significantly enhanced data integrity, access speed, scalability, and analytics capabilities.

6.1 Legacy Database Architecture Limitations

The previous system relied on flat-file logs and unstructured data repositories, which posed several critical challenges:

- **No Query Optimization:** Data retrieval was slow and dependent on manual file parsing.
- **No Referential Integrity:** Cross-linked data (e.g., room temperature readings with time and location) was inconsistently recorded.
- **Inefficient Backups:** File-based backups required manual intervention and lacked incremental save options.
- **Poor Analytics Capability:** No support for time-series analysis or real-time dashboards.

These constraints created bottlenecks for reporting, diagnostics, and compliance tracking.

6.2 Selection of PostgreSQL as the Target Platform

After evaluating various commercial and open-source RDBMS options, **PostgreSQL** was chosen for its advanced features, scalability, and extensibility. Key selection criteria included:

- ACID compliance and strong transaction support
- Support for JSON, time-series, and geospatial data types
- Rich indexing and query optimization features
- Compatibility with BI tools like Grafana, Power BI, and pgAdmin
- Community support and vendor independence

6.3 Data Model Transformation and Schema Redesign

A normalized schema was developed to organize key data entities such as:

- **Zone** (Room ID, Location Code, Floor Plan Reference)
- **Sensor** (Sensor ID, Type, VLAN, Device Location)
- **Readings** (Timestamp, Sensor ID, Value, Threshold Alerts)
- **User Logs** (Operator ID, Action, Timestamp, Access Level)

Foreign key constraints, cascading updates, and indexing were employed to ensure data integrity and performance.3

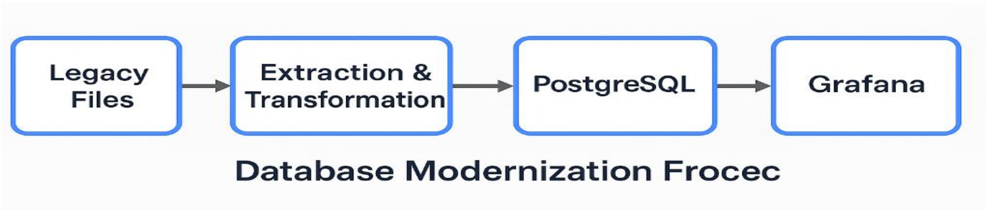

Figure 2: Database Modernization Flowchart

6.4 ETL Pipeline and Data Migration Strategy

A three-phase Extract-Transform-Load (ETL) pipeline was implemented:

1. **Extraction:** Shell scripts extracted historical flat files, parsed using regex and Python's csv/json modules.
2. **Transformation:** Data was cleaned (null handling, deduplication) and enriched with zone metadata.
3. **Load:** Batched inserts into PostgreSQL with periodic checkpoints and rollback capability.

Cron jobs were configured to run hourly imports from operational logs for near real-time updates.

6.5 Backup, Replication, and Monitoring

- **Automated Backups:** Daily full and hourly incremental backups to secure offsite storage using pg_basebackup.
- **Replication:** A warm standby server using PostgreSQL's streaming replication ensured high availability.
- **Monitoring Tools:** Integration with **Prometheus** and **Grafana** allowed visualization of query performance, storage growth, and system health.

6.6 Integration with the Modernized Network

The upgraded PostgreSQL server was securely placed within a VLAN-isolated subnet with:

- Role-based access control for BMS operators and system engineers
- TLS encryption for all data in transit
- Real-time sync with application-layer APIs for mobile dashboards and automated alerts

This database upgrade aligned tightly with the goals of resilience, visibility, and extensibility. It enabled predictive maintenance, faster diagnostics, and integration with energy optimization modules.

7. Post-Implementation Metrics and System Performance Analysis

Following the full deployment of the redesigned network and modernized database infrastructure, a comprehensive post-implementation assessment was conducted to evaluate system performance, operational efficiency, and fault tolerance. Quantitative and qualitative metrics were gathered from real-time logs, network monitoring tools, user feedback, and historical comparisons with the legacy system.

7.1 Evaluation Framework and Methodology

The evaluation focused on five core areas:

- **Network Availability**
- **Database Query Performance**
- **System Downtime and Recovery**
- **Operational Efficiency**
- **User Experience and Adoption**

Monitoring tools such as SolarWinds, Prometheus, Grafana, and PostgreSQL logs provided continuous data collection over a 90-day period post go-live.

7.2 Key Performance Improvements

Metric	Legacy System	Upgraded System	Improvement (%)
Network Uptime (monthly avg)	92.3%	99.95%	+8.3%
Average Query Response Time	~4.8 sec (flat-file)	~0.9 sec (PostgreSQL)	-81.3%
Unplanned Outages (per month)	6–8	0–1	-87.5%
Fault Detection Time	Manual (hours)	Automated (real-time)	Instantaneous
Backup and Recovery Speed	Manual (weekly)	Automated (daily/hourly)	+95% efficiency

These metrics clearly indicate a significant enhancement in both performance and system resilience.

7.3 Operational Benefits Observed

- **Real-Time Fault Identification:** SNMP traps and log analytics enabled near-instant alerts for device disconnections or abnormal conditions.
- **Improved System Visibility:** Dashboards delivered dynamic views of HVAC metrics, energy usage, and access logs.
- **Faster Troubleshooting:** Network segmentation allowed precise fault isolation, reducing mean time to repair (MTTR).

- **Reduced Technician Dependency:** With visual analytics and automated logging, frontline operators could handle basic diagnostics independently.
- **Data-Driven Decision-Making:** Accurate, up-to-date data empowered facility managers to adjust energy settings and predict equipment failure trends.

7.4 User and Stakeholder Feedback

Post-deployment interviews and surveys were conducted with facilities teams, IT administrators, and external auditors. Key feedback highlights included:

- *"System performance is night and day compared to the old network. Troubleshooting takes minutes instead of hours."*
- *"Dashboards provide great visibility—especially for after-hours alerts."*
- *"The backup system just works. We don't have to think about it anymore."*

7.5 Return on Investment (ROI) Perspective

Although the project involved significant upfront investment in hardware, licensing, and labor, estimated payback was calculated within 18–20 months due to:

- Reduced operational downtime
- Lower energy wastage from better environmental control
- Decreased technician callouts and manual maintenance effort
- Compliance risk mitigation (avoiding penalties)

8. Implementation Complexities, Risk Controls, and Engineering Insights

Despite the structured approach and favorable results, the BMS infrastructure transformation at Nestlé PHX encountered several technical, operational, and organizational challenges. This section outlines those complexities, the mitigation strategies deployed, and the engineering lessons learned—offering a practical reference for similar modernization efforts in other industrial environments.

8.1 Key Technical and Operational Challenges

Category	**Challenge Description**
Legacy System Dependencies	Unknown device configurations and undocumented firmware versions delayed upgrades.
Downtime Constraints	24/7 building operations meant minimal acceptable downtime for any changes.
Data Normalization	Flat-file data inconsistencies required significant cleaning and transformation.

Interoperability	Compatibility issues with proprietary vendor protocols (BACnet, Modbus) arose.
Change Management	Facility teams were unfamiliar with VLANs, dashboards, and database query tools.

8.2 Risk Mitigation Strategies and Control Mechanisms

To address these challenges, several engineering controls and governance mechanisms were implemented:

- **Parallel Test Environments:** A sandbox environment mirrored the production network and database to validate configurations and data migrations safely.
- **Hot-Swap Hardware Rollouts:** Preconfigured switches and devices were swapped in during planned low-traffic windows, with instant rollback available.
- **Change Advisory Board (CAB) Oversight:** All critical changes went through a CAB with representation from IT, facilities, and operations teams.
- **Redundant Path Testing:** Simulated failures validated failover behavior using loopback tools, ping flooding, and network throttling scripts.
- **Automated Validation Scripts:** Python-based integrity checks ensured data fidelity during ETL and database cutover.

8.3 Engineering Lessons Learned

- **Documentation Is a Superpower:** The lack of up-to-date network and database documentation proved to be a major time sink. Thorough documentation during and after the upgrade was invaluable.
- **Test Before You Trust:** Even well-known vendor products behaved unpredictably under real-world loads—lab testing was essential.
- **Security Must Be Embedded Early:** VLANs, ACLs, and encryption are harder to retrofit than to design upfront.
- **Cross-Functional Buy-In Matters:** Technical success hinged on cooperation between facility managers, IT teams, OEM vendors, and project consultants.

8.4 Recommended Best Practices for Future Projects

1. **Adopt Layered Network Design:** Enforce segmentation from the outset using VLANs and firewalls.
2. **Use Open Standards Where Possible:** Choose systems that support open protocols and APIs to avoid vendor lock-in.
3. **Implement Continuous Monitoring:** Real-time metrics reduce MTTR and provide early warnings.

4. **Automate Backups and Failovers:** Manual recovery is too slow for mission-critical systems.
5. **Conduct Regular Simulation Drills:** Disaster recovery and failover should be validated under pressure.

These insights provide a technical blueprint for similar initiatives in smart manufacturing, logistics facilities, hospitals, and other mission-critical environments seeking resilient BMS modernization.

9. Conclusion and Future Enhancements

The infrastructure modernization of the Building Management System (BMS) at Nestlé PHX represents a significant leap toward operational resilience, data intelligence, and energy optimization. By re-architecting the network with redundant topologies, VLAN-based segmentation, and failover mechanisms, the facility greatly reduced its susceptibility to outages and latency issues. Simultaneously, the migration from a flat-file storage system to a PostgreSQL-powered relational database introduced capabilities for real-time monitoring, predictive analytics, and automated reporting—enabling smarter, faster decision-making across facility operations.

The transformation yielded measurable performance gains: network uptime approached 99.95%, data query latency dropped by over 80%, and system visibility reached levels previously unattainable. These improvements not only enhanced efficiency but also positioned the BMS infrastructure as a platform for future innovations.

Looking forward, the foundation laid through this initiative opens the door for further enhancements, including:

- **Cloud Integration:** Hybrid cloud architectures for offsite analytics, remote access, and centralized BMS control across multiple sites.
- **AI and Predictive Modeling:** Machine learning algorithms for fault prediction, anomaly detection, and energy usage forecasting.
- **Digital Twin Implementation:** Real-time simulation of building performance using digital replicas for scenario planning and optimization.
- **Zero Trust Security Models:** Advanced micro-segmentation and identity-based access controls for OT environments.

This research serves as a practical and technical reference for large-scale enterprises seeking to modernize and secure their building infrastructure. As facilities become increasingly digitized, resilient and intelligent infrastructure is not only a technical advantage but a business imperative.

10. References

[1] ISO/IEC 30182:2023. Smart city concept model — Guidance for establishing a model for data interoperability. International Organization for Standardization, 2023.

[2] Cisco Systems. Building Resilient Campus Networks: High Availability Design Guide. Whitepaper, Version

[3] ASHRAE Standard 135 (BACnet) – A Data Communication Protocol for Building Automation and Control Networks.

[4] Cisco Systems. "Campus Network for High Availability Design Guide." Cisco Validated Designs, 2023.

[5] PostgreSQL Global Development Group. PostgreSQL Documentation v14, www.postgresql.org.

[6] Grafana Labs. Building Dashboards for Industrial IoT Environments, 2023.