

Engineering Strategies for High-Availability Mission-Critical Facilities: A Survey

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Abstract—Mission-Critical Facilities in Diverse Domains investigates the key features, engineering requirements, as well as design provisions that allows continuous operation in high-consequence environments. The paper identifies that mission-critical facilities are becoming more important in various sectors, including data infrastructure, healthcare, defense, and manufacturing, and that they are sensitive to reliability, security, and resilience. It scans classification structures in terms of operational urgency and defines performance expectations which stimulate redundancy, real-time monitoring and disaster preparedness. Contributions of mechanical engineering are examined in reference to the redundancy strategy (including N+1, 2N strategy) and the task of adaptive controls in alleviating dynamic uncertainty. Structural and civil engagements are analyzed using modular construction and structural optimization practices that increase performance in terms of efficiency, safety and lifecycle. The research provides a multidisciplinary basis to the understanding and enhancement of mission-critical systems and balances design practices with current requirements of fault tolerance and always-on operation.

Keywords—Mission-critical facilities, Mechanical systems, Real-time monitoring, High-consequence systems, Critical infrastructures.

I. INTRODUCTION

A facility that houses any operations that, if disrupted, might adversely affect business [1] operations is often referred to as a mission-critical facility. Disruptions to data centres [2] or telecom centres [3], for instance, might result in significant financial losses and endanger public safety. Legal compliance or national security may be jeopardised by military installations or jail systems. Hospitals, labs, or public safety facilities may result in fatalities and be unable to serve the public interest. These are only a handful of the several procedures that may be deemed mission-critical. Increasing energy and/or climatic resilience is the aim of adding redundancy to the structures that house these operations.

High availability guarantees that the service continue to function even in the event of a hardware malfunction or software update [4] high availability may be defined as a set of principles used to assess if an information system is available and performing at its best, meaning it has few outages and is available for the most of the time. Finding and removing potential single points of failure—that is, locations at which the service either stops functioning or just functions partially—is the aim of high availability. High availability that is properly set up may also handle potential hardware and software problems [5][6][7]. Systems and services that employ this idea should be completely automated, meaning that no human intervention is necessary for the high-availability concept to function correctly [8]. They should also be capable of autonomously managing performance, foreseeing certain kinds of failures [9], and taking action in the event of a catastrophic circumstance.

Reliability and availability are major concerns in Industry 4.0 [10]. Research and development need currently relate to innovative solutions in the integration of intelligent machines or systems, with a focus on modifications in production

processes intended to increase production efficiency or equipment dependability, due to these developments and the complexity of engineering systems. Development of competitive economies worldwide is seen to be greatly aided by the creation of new technologies and business models based on innovation, networks of collaboration, and the improvement of endogenous resources [11]. In this context, innovation and engineering that prioritize sustainability, dependability, and resource availability are crucial.

In system design and development, particularly in system of systems (SoS) engineering, the notion of a mission is crucial. Nevertheless, various application of the word mission in different fields of study frequently leads to ambiguity as to the role of the mission in the practical implementation of the mission-based engineering assignments. Clear-cut and accurately delineated missions enhance communication between stakeholders and assist in interdisciplinary gaps bridging. The US Department of Defence today practices mission engineering, a discipline that serves as the primary source of expertise for operations [12]. The field of system of systems (SoS) and mission engineering are closely related, especially in two intersecting perspectives: (1) both view the interactions and integrations of multiple systems towards a common goal; and (2) conceptualisation and representation of the mission can be a key component that unifies the engineering activities. Interoperability across component systems is one of the criteria that determines mission completion in both mission engineering and SoS contexts. The concept of interoperability has progressively emerged as an issue in intricate systems where various stakeholders, disciplines or industries are involved.

A. Structure of the Paper

The paper is structured as follows: Section II outlines mission-critical facility characteristics and requirements. Section III examines mechanical engineering contributions to

redundancy and reliability. Section IV deals with critical infrastructures, structural, and civil factors. Section V contains relevant literature, and Section VI provides future research directions.

II. MISSION CRITICAL FACILITIES: CHARACTERISTICS AND REQUIREMENTS

The fast-paced technological era, mission-critical facilities are crucial in the uninterrupted working of industries across sectors, such as government, finance, healthcare, and telecommunications [13]. The reliability, security, and resilience of these facilities include data centers [14], emergency response centers, industrial [15] control systems, and cloud infrastructure hubs. Highly available systems experience few system failures among other troubling outcomes that include financial losses alongside operational interruptions and public safety concerns. Engineering techniques that focus on improving continuous operation together with disaster preparedness have become essential elements for creating, maintaining, and optimizing these infrastructures. The mission-critical facilities [16] act as essential systems which ensure organizational survival. They are made very dependable and outage resistant. Systems analysis determines the typical operating point of the aspect ratios and its operating space, and additional focus is on the plasma and technical limits. The significant uncertainty when achieving required parameters demands robustness as a solution.

A. Classification of Mission-Critical Facilities

The most important facilities are often distinguished in terms of the reliability, availability and resilience they must have to maintain the continuation of the important services. The simplest category of grouping facilities is based on the outcomes of failure; these run the gamut of inconvenience and a monetary loss to extreme dangers to public safety, national security or even human life. Greater levels of classification require an increased redundancy of the power, cooling, communications, and structural systems, as well as a high level of security and constant monitoring and recovery. The higher the criticality, the more stringent the design standards are based on fault-tolerance, geographic and system redundancy and strict operational standards. The classification framework assists planners, engineers and operators in demonstrating the importance of the mission of the facility in balancing the investment in infrastructure, risks management and operational strategies.

1) Data Centers

Data centre has become vital component of the server, storage, and operational management facilities needed to operate mission-critical business systems are now part of the IT infrastructure. While there are several aspects that affect a company's overall business resilience, one of the most crucial ones when constructing its mission-critical business systems is the quantity and placement of its data centres. Given that data center construction is expensive and facilities are expected to last decades, a poor selection of data center site locations can be both costly and disruptive to the business [17]. The data center topology selection is the result of a process that starts with the examination of the overall IT environment, including the business and regulatory requirements that the client has to deal with. An understanding of the risks associated with data center facilities has to be

developed. These requirements and risks are factors used as input to the selection of an appropriate data center topology.

2) Healthcare Systems

The healthcare systems [18] are the core constructs of the community health and serve various functions other than just diagnosing and curing the diseases, they also offer preventive medical services. The relevance of a healthy functioning healthcare system [19] is heightened particularly during crises, whether it's a natural disaster, an infectious disease epidemic, or a man-made calamity.

3) Additive Manufacturing

Using a wide range of materials, additive manufacturing (AM) is used to create complicated components. AM offers several benefits, including reduced lead times, on-demand manufacturing, the creation of intricate bespoke designs that don't require tools, and design sharing across long distances. However, as is typical of many manufacturing technologies, quality and reliability concerns limit the use of AM on essential components in big missions. Manufacturing might be one method of increasing the adoption of AM-built components for mission-critical components [20] highly reliable parts, setting up of strong quality standards, and constant increment of part properties.

B. Mission-Critical Manufacturing

The processes and systems involved in mission-critical manufacturing (MXM) are essential for the smooth operation of vital infrastructure, systems, or goods. In order to keep the system operating constantly, MXM provides the flexibility to create new parts as necessary [21]. The notion can be used, for instance, to produce malfunctioning parts for military operations when replacements must be available in a matter of minutes, hours, or days. When choosing the MXM technician, the following aspects need to be taken into account:

1) Reduced Mean Time to Repair

The average time required to fix a system following a breakdown is known as the mean time to repair (MTTR), as seen in Figure 1. The concepts of mean time to failure (MTTR), mean time to failure (MTTF), and mean time between failure (MTBF) discussed in more detail in the sections that follow. Repair and testing time are included in MTTR. To make a component available as soon as possible, the MTTR should be as low as feasible. A proactive maintenance approach is crucial because it guarantees that systems always function, particularly in mission-critical environments. For mission-critical operations, it is frequently difficult to carry out planned maintenance actions. Due to logistical challenges in delivering replacement parts and service repair people by helicopters or other modes of transportation, military maintenance operations are frequently postponed in isolated or dangerous locations.

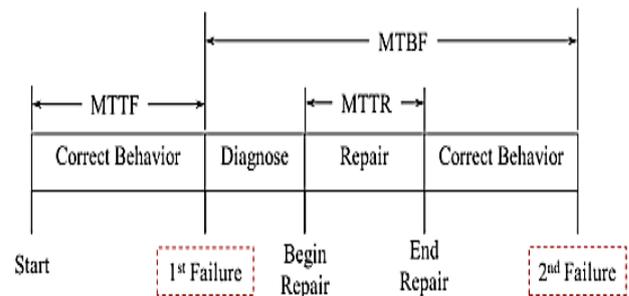


Fig. 1. A schematic diagram of system operations

2) Increased Mean Time Between Failures

A crucial reliability engineering data is mean time between failures (MTBF). It is the average interval between a system or component failing while in use. A schematic depiction of a system's MTBF may be seen in Figure 1. It provide quantitative data on the system's dependability and help determine whether to take preventative action and when to do maintenance.

3) Reduced Points of Failure

Non-redundant components can make a system fail, unlike non-redundant components, causing complete failure of the system. Collapse of a single point of failure (POF) may lead to total system failure, which has a great influence on performance and safety. POFs need high availability and dependability, which makes them unattractive in a system. A vehicle's axle or tyre, for instance, are significant single points of failure in the driving system, where any of the items may fail to cause total functionality loss in the vehicle, greatly affecting the performance and safety of the vehicle.

C. Requirements for Mission-Critical Operations

To achieve a mission's goals, mission-critical operations are essential. The components of the operations must be designed, manufactured, implemented, and maintained with additional protection, high standards, and dependability [22]. Specific characteristics can be used to identify mission-critical operations. Here is a basic overview of the requirements for mission-critical operations:

1) Continuous Operations

Every necessary element should be ready and operate well throughout the process of starting the system and up to the time the mission is accomplished. This twenty-four-seven availability must be thought through carefully in operations in order for the parts to withstand the unforeseen circumstances and requirements of the mission-critical operations.

2) Reliability and Redundancy

The mission-critical system's components should all be extremely dependable. Redundancies are crucial because they boost dependability [23] and increases their capabilities of operating under different conditions. The use of safeguards and backups on site is one of the pre-conditions of mission-critical systems.

3) Real-Time Monitoring

To do mission-critical activities successfully and efficiently, operators must share real-time data. To provide operators of the mission-critical system confidence, component performance must be evaluated in real-time.

III. MECHANICAL ENGINEERING IN MISSION CRITICAL SYSTEMS

Modern engineering cannot do without mechanical systems [24] as they are utilised in a broad spectrum of applications such as manufacturing to transportation. Such systems are frequently exposed to numerous dynamic characteristics including uncertain load changes, frictional forces, and environmental fluctuations, among others, that may have a severe impact on their performance. The adaptive control strategies have been used in a very broad set of mechanical systems over the years, in robotics, automotive systems, aerospace applications, and manufacturing processes. An example is in robotic systems, adaptive control is applied to enhance the accuracy and performance of

manipulators when they are controlled in an uncertain environment or when performing complex tasks. Adaptive control methods in automotive industry [25] active suspension systems apply to enhance stability and comfort of the vehicle [26]. Adaptive controllers have also found application in aerospace systems to improve the behaviour of flight control systems subjected to different conditions, e.g. fluctuations in altitude or payload.

A. Importance of Mechanical Systems in Redundancy

The mechanical systems are also redundant so that they are not affected by a single point of failure. HVAC [27], ventilation or power system disruption in a mission-critical setting can have significant implications. As an illustration, data centers are dependent on accurate cooling to avoid overheating, and hospitals need to ensure that the climate is controlled in order to ensure patient safety and equipment functionality. To ensure that the facility is not affected by downtime, mission-critical facilities adopt a number of redundancy strategies. The decision of the level of redundancy is based on the facility requirements, operational risks and financial limitations. The most used redundancy models are:

- **N+1:** N+1 redundancy is one of the widely used strategies in which a facility is loaded with one more component than the number of components needed (N). When one unit malfunctions, the additional unit replaces it and the performance of the system not suffer. This method is usually used in data center, hospital, and large commercial building HVAC and power systems.
- **N+2 and 2N Redundancy:** N+2 or Redundancy 2N Redundancy add two extra components and that too a layer of backup as compared to N+2 Redundancy but the advantage is that the entire system is added in 2N and that means that one can have complete backup in case of any failure.
- **Parallel Redundancy:** Parallel redundancy is a method in which two or more systems are executed at the same time in order to spread the load. Should one of the components fail, the other units operate without failure. This is generally applied in chiller plants, a chiller-plants whereby more than one chiller is installed so that failure of one chiller does not lead to a failure of the whole system.
- **Geographic Redundancy:** In the case of an organization situated in more than one location, geographic redundancy distributes the mechanical loads in more than one location. It is especially applicable to data centers and manufacturing processes, where it is possible to redistribute workloads to other locations in the event of local failures.

B. Key Components of Redundant Mechanical Systems

Many important mechanical systems that are critical to the mission are reduced by adding redundancy.

1) HVAC Cooling Systems

- Chillers and handlers of air that have redundant units are used to ensure that the temperature and humidity are not at a faulty level.
- There are backup cooling towers and refrigeration that are used to maintain constant climate control.
- Redundant ventilation systems provide fresh air circulation and elimination of contaminants in critical

environments are offered by the redundant ventilation systems.

2) Power and Backup Systems:

- UPS are used to supply mechanical systems with power at times of fluctuation.
- Redundant generators: This is to eliminate outages by providing emergency power.
- Battery storage systems have more backup energy in cases of outage.

3) Fire Suspension and Safety Systems

- Facilities are guarded by several fire suppression teams against possible hazards.
- There are redundant smoke and gas detectors that give warnings.
- Exhaust fans and ventilation Backup exhaust fans and ventilation: [in case of failure] Hazardous accumulation.

C. Best Practices for Designing Redundant Mechanical Systems

The introduction of redundancy in the mechanical systems should be done with proper planning and design. The best practices can be used to improve the system resilience, and these include:

- **A thorough procedure:** that identifies problem areas is called a risk assessment, and Conduct a risk assessment: priorities the redundancy requirements [28]. The analysis of operational risks as well as environmental factors and past failure history should be studied to plan redundancy based on the facilities.
- **Implement regular maintenance and testing:** Alternate systems should be maintained and tested to be operational when it required. Routine checking, testing [29] of performance and planned maintenance minimizes the chances of failures of the backup parts.
- **Utilize automation and monitoring:** Progressive monitoring schemes identify the abnormalities and initiate backup processes automatically [30]. Building management system (BMS), Smart sensors, and predictive analytics assist in optimizing the redundancy efficiency and warning the operator about possible failure before it takes place.
- The facilities that are mission critical must plan to provide redundancy systems to facilitate **Plan for Scalability:** future growth. Scalable solutions enable adding capacity without major changes to be made which makes them reliable in the long term.
- **Optimize energy efficiency:** A redundancy that has not been configured to run well may burn more energy. Design techniques, which are energy efficient like variable speed drives, heat recovery, and advanced load balancing, contribute towards efficiency maintenance as well as favouring redundancy.

IV. STRUCTURAL AND CIVIL ENGINEERING CONSIDERATIONS

Construction, operation, and maintenance of buildings and infrastructure, covering a range of projects including homes, bridges, and highways, are the domains of civil engineering [31]. Despite making up a sizable portion of the economy, the architecture, engineering, and construction (AEC) sector is frequently seen as having high labour intensity, low efficiency, and significant environmental implications. As a

result, efforts to enhance the social, economic, and environmental performance of civil engineering projects have grown in popularity. In the last few decades, optimisation strategies based on mathematical programming techniques have been suggested and accepted in the field of civil engineering due to the development of computer tools for structural design and analysis since the 20th century. Civil engineers have shown an interest in moving away from relying on existing prescriptive rules (with limit state format) to designing with performance based criteria (especially for fire and seismic engineering) [32]. It is important to appreciate that they see one of the drivers to be the need to change from design limited by consideration of the "probability of failure" alone, to consider equally the consequence of "risk of failure".

A. Structural Optimization in Civil Engineering

In civil engineering, optimisation may be used to all phases of a project's life cycle, including design, construction, operation, and maintenance. Structural optimisation is one of the most used optimisation techniques. "Structural optimisation" in this subject refers to an optimisation that seeks to determine the optimal configuration of structures or structural elements to accomplish certain goals under specified circumstances [33], while disregarding the adopted materials' characteristics. The performance of civil engineering constructions is greatly influenced by its material, which is an essential component. The most prevalent applications for concrete-based composite materials, such as pre-stressed concrete, reinforced concrete, and plain concrete, are in buildings and civil engineering infrastructure [34]. Because it is computationally challenging to evaluate the material distribution of structures, structures that only include one type of material are typically taken into consideration in terms of structural optimisation, even though some civil engineering structures have many types of materials [35]. The following four categories apply to structural optimisation:

- **Size Optimization:** It is sometimes referred to as size optimisation, and it uses the cross-sectional areas of structural parts or structures as design variables.
- **Shape Optimization:** It is sometimes referred to as configuration optimisation, and it uses the structure's nodal coordinates as design variables.
- **Topology Optimization:** This is concerned with the way the nodes or the joints are connected and supported in a way that the way more redundant structure members are removed to attain the best design.
- **Multi-Objective Optimization:** In order to get superior optimisation outcomes, it concurrently takes into account two or more of the aforementioned optimisation objectives; this type of optimisation is also referred to as layout optimisation.

B. Design Considerations in Modular Constructions

Modular construction involves the use of certain design frameworks that guarantee powerful and effective structures. Modular constructions are designed by taking into account many factors that are critical in ensuring the effective and efficiency of the building process. These components include the kind of connections, installation techniques, material selection, and module placement.

1) Materials

The demoulding strength is the main consideration in the mix design of concrete used in modules. at order to enable the

quick production process of modular construction, the modules at the off-site plant are often demoulded after 12 to 24 hours of casting so that another module is prepared for casting. Table I shows the average demoulding strength of concrete needed and the concrete's strength after 28 days. It has been observed that the demoulding strength is typically 50% of the necessary 28-day strength. During the production of concrete modules, rapid hardening cement, steam curing, and electrical heating are utilised to increase the concrete's early age strength. Because Self Compacting Concrete (SCC) improves wall finishes and uses fewer vibrators, it has become more and more popular in modular building.

TABLE I. STRENGTH OF CONCRETE ELEMENTS

Component	Required Strength at 28 days (N/mm ²)	Demoulding Strength (N/mm ²)
Slab	40	20-25
Loading Bearing Wall	50	25-30

2) Layout of Modules

The size, modularization, weight, and portability of the modules all have a major impact on the layout design. To maximize the utilization of the module formwork moulds, the designer and module maker should work together to develop the module's size and the building's modularization. When creating the module layout, it is important to make sure that load-bearing walls are properly aligned vertically. In modular construction, two common module layout techniques are used: (i) clustering modules and (ii) arranging modules in a corridor, as seen in Figure 2. To achieve this, the cluster arrangement involves the arrangement of numerous modules around a central core or communal space, usually of shared facilities, stairways, or lifts. The design is commonly used in residential or hotel buildings, whereby the modules can optimally exploit shared areas without compromising structural performance. Cluster designs offer small format designs and decrease the amount of interconnections required between modules. The modules layout is in form of a corridor, where modules are laid in a line formation or a corridor. This design is popular in institutional buildings, like schools and hospitals, where accessibility and movement are given priority. Corridor forms ensure continuous connectivity of modules and improve the easy integration of the HVAC (heating, ventilation, air conditioning), plumbing, and electrical system services along the corridor axis.

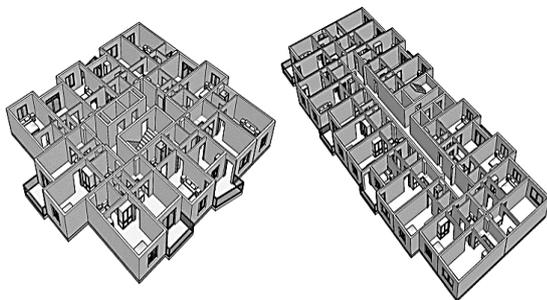


Fig. 2. Typical Layout of Modules (a) Clustered Layout (b) Corridor Layout

3) Lifting, Transportation and Installation

One of the major features of modular technology is installation. The crane capacity on-site and at the precast yard, transportation, and accessibility are a few of the installation's design factors. To avoid fractures in the concrete slab wall

deformation during handling and transportation, serviceability limit tests should be carried out. To raise the entire module securely and distribute the load equally among all lifting points, the lifting points should be positioned strategically to create a sufficient bond anchoring. To prevent the module from being subjected to slanted forces from the lifting wires, it is hoisted using a steel collar frame. The maximum size and volume of each module design are determined by logistics for module transportation from the factory to the site, which impacts the number of modules needed to finish the layout design [36]. The modules' dimensions have been finalised to allow for public road transportation. The modules' flexural design takes into account the handling stresses brought on by dynamic forces during handling, lifting, and erection. To ensure that modules are handled, transported, and erected safely, load factors must be given to the module's self-weight (Table II). When being transported, the load factor is set higher than 1.5 as there are more vibrations and impact forces experienced on the road. To allow for smaller dynamic impacts of lifting and positioning, yard handling and erection should have a load factor of 1.2. Because these load factors are incorporated into the design calculations, the modules' structural integrity preserved at all levels, and handling and assembly not result in damage. This emphasises how crucial it is to take into account dynamic effects in modular design to lower handling and installation risks.

TABLE II. EQUIVALENT LOAD FACTORS TO ACCOUNT FOR DYNAMIC LOADS

Stage	Load Factor
Yard Handling	1.2
Transportation	1.5
Erection	1.2

V. LITERATURE REVIEW

Mission-critical facility analysis is done to provide structural stability, operational reliability, and long-term performance under high temperature, reactive and dynamic conditions. In the next section, analytical, numerical, and experimental research on performance, degradation, and design considerations are reviewed in such a challenging environment in different domains.

Elrajoubi et al. (2025) presented a comprehensive assessment of power quality (PQ) disturbances in the industrial power network of the Deutsch's Elektronen-Synchrotron (DESY), a leading research facility for particle physics. The study leverages high-resolution measurements (7-days) from Fluke 435 Series II and long-term monitoring data (6-months) from Janitza UMG 512 analyzers to characterize PQ issues. Measurement data were collected from various substations and Points of Common Coupling (PCC) to evaluate harmonics, voltage fluctuations, flicker, and transient events. The high-resolution data (sampled at 500 ms) revealed voltage deviations of up to $\pm 4\%$, current unbalance exceeding $\pm 10\%$, and flicker spikes reaching 0.63 Pst, all attributed to nonlinear load dynamics and switching events [37].

Sarshartehrani et al. (2024) presented a Digital Twin training platform that simulates three key cybersecurity concepts: Input Manipulation, Output Manipulation, and denial-of-service attacks in relation to WTPs. These ideas are related to four crucial functions: the microbial water purification process, water temperature, chlorine level, and water level. This paper primarily focuses on the design and

development of the VR component of their digital twin platform, as well as the integration process with their hardware testbed. Initial investigations demonstrated significant potential for the experiential learning platform, serving as an effective tool for educating users about cybersecurity issues in mission-critical facilities such as WTPs [38].

Van Bossuyt et al. (2024) examined the use of Artificial Intelligence and Machine Learning (AI/ML) and Large Language Models (LLM) in conjunction with cyber-security research to provide a continually updated resilience study. The system's hardware and software are modelled, and LLMs and AI/ML are used to continually look for new software vulnerabilities and input that data into resilience models that are updated on a regular basis. A drone case study is given to illustrate the potential of the suggested approach [39].

Azad et al. (2023) To enable encoded packet exchange between the contacting nodes, UDTN-Prob's current binary packet spraying mechanism is improved. The World Ocean Simulation System (WOSS) package and the Design, Simulate, Emulate and Realise Test-beds (DESERT) underwater simulator were used in a thorough simulation to obtain a more realistic account of acoustic propagation in order to determine the efficacy of the suggested protocol. Three scenarios are taken into consideration throughout the simulation campaign: one that focusses on calculating the overhead ratio, another that varies the area size, and a third that varies the data transmission rate. On the other hand, three

metrics are considered for the first two scenarios: normalised throughput, latency, and normalised packet delivery ratio [40].

Sun et al. (2023) intended to synthesise HC reliability research in order to assist the reliable and explicable SHM of bridges. The authors conduct a synthesis of research that looked at methods related to the highlighted HC reliability difficulties using a bridge inspection instance. The difficulties that the industry has in monitoring, forecasting, and managing HC dependability in bridges were identified by this synthesis. Finally, a research roadmap was presented to tackle the identified problem [41].

Cassway, Burch and Dean, (2022) The purpose of the Quality Assurance and Assessment tool (QAAT) is to enable team leaders to evaluate the operational response performance of their team. By using key performance indicators and optimised training methods, the QAAT may inspire change in addition to determining the degree of confidence in a team's or an individual's performance. The tool was constructed using the available resources and consists of two primary parts: an analytical data breakdown of performance outcomes and an operational performance evaluation. In the end, this quality assurance system enable businesses to define and assess their performance, pinpoint risk factors that might affect their regular operations, and inspire organisational transformation from the bottom up [42].

Table III summarizes the literature in terms of study focus, application context, target assets, key novelties, and associated implications

TABLE III. COMPARATIVE LANDSCAPE OF RESEARCH ON RELIABILITY OF MISSION-CRITICAL FACILITIES IN DIVERSE DOMAINS

Citation	Study Focus	Application Context	Target Asset	Novelty	Implications
Elrajoubi et al. (2025)	Assessment of power quality (PQ) disturbances using high-resolution and long-term monitoring data	Industrial power distribution in research facilities	DESY industrial power network (substations & PCCs)	Dual-resolution PQ characterization (7-day + 6-month), capturing harmonics, flicker, unbalance	Enhances situational awareness of nonlinear load effects and improves PQ management in mission-critical research infrastructures
Sarshartehrani et al. (2024)	Digital Twin training platform for cybersecurity learning in WTPs	Cyber-physical training & education in water treatment	Water Treatment Plant (hardware testbed + VR)	VR-integrated digital twin for simulating Input/Output manipulation & DoS cyber-attacks	Improves operator cybersecurity awareness in critical infrastructure, enabling experiential learning
Van Bossuyt et al. (2024)	Integration of reliability and cyber-security analysis via AI/ML and LLMs	Autonomous systems resilience & vulnerability analysis	Drone system (hardware & software modeled)	Continuous resilience modeling updated with AI/ML vulnerability discovery	Supports proactive cybersecurity & reliability co-analysis in autonomous platforms, enabling dynamic resilience assessment
Azad et al. (2023)	Enhanced binary packet spraying for underwater delay tolerant networks	Underwater acoustic networking & communication	UDTN nodes in simulated ocean environment	Encoded packet exchange integrated into spraying protocol + realistic acoustic simulations	Improves packet delivery ratio & throughput under varying underwater networking

	(UDTN-Prob)				conditions, aiding marine communication reliability
Sun et al. (2023)	Human-centered (HC) reliability synthesis for structural health monitoring (SHM) of bridges	Infrastructure inspection & structural monitoring	Bridge SHM processes (inspection & decision-making)	Research roadmap linking HC reliability to explainable and trustworthy SHM	Addresses knowledge gap in HC reliability, guiding future SHM research & trustworthy monitoring deployment
Cassway, Burch & Dean (2022)	Quality Assurance and Assessment Tool (QAAT) for operational performance review	Operational training and response management	Emergency response team performance	Two-component QA tool (performance review + analytics) for capability & confidence assessment	Enables performance evaluation, identifies risks, and drives organizational training improvements

VI. CONCLUSION AND FUTURE WORK

Mission-Critical Facilities in Diverse Domains, the continuity of the critical infrastructure requires the joint performance of mechanical reliability, structural robustness, and system-level resilience. In data centers, healthcare systems, manufacturing sites, and defense implementations, the research indicates that mission-critical performance does not largely depend on advanced technology, but on the designed redundancy, real-time surveillance, and risk-informed design. The availability of mechanical systems is enhanced by means of layered redundancy and proactive maintenance, whereas civil and structural engineering make the most out of it by introducing optimized configurations, modular construction, and performance criteria. Together, such strategies can make the facilities resistant to failures, environmental stressors, and uncertainties in operations. The research has found that, in the future, the multidisciplinary approach has been vital in the development of future mission-critical needs, such that the growing needs of security, scalability and fault tolerance have been accommodated across the various applications.

Digital twins, predictive maintenance based on AI, and cyber-physical resilience modelling should be considered in future studies on the use of Mission-Critical Facilities across a variety of domains to increase the system's dependability. The growth of interdisciplinary systems integrating mechanical, structural, and cybersecurity will provide more intelligent, versatile, and scalable infrastructures for critical missions capable of responding to new operational and environmental pressures.

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