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DEVELOPMENT OF THE ENVIRONMENT READINESS INDEX (ENRI) FOR SUPPORTING INFRASTRUCTURE ASSESSMENT IN CNSD FACILITIES

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Abstract: The reliability of Communication, Navigation, Surveillance and Data Processing (CNSD) facilities depends on the readiness of their supporting infrastructure. However, existing assessment methods generally evaluate infrastructure components independently, limiting comprehensive readiness evaluation. This study proposes the Environment Readiness Index (EnRI) as an integrated framework for assessing supporting infrastructure readiness in CNSD facilities. A quantitative approach involving field observations, interviews, and infrastructure assessments was conducted across 172 CNSD facilities. EnRI integrates five assessment domains: Thermal and Humidity Control, Power Quality and Continuity, Grounding and Lightning Protection, Physical Environment, and Monitoring and Control System (RCMS). The framework enables readiness measurement, gap analysis based on Tier III and ANSI/TIA-942 principles, and prioritization of infrastructure improvements. The results demonstrate that EnRI provides a systematic decision-support framework for improving infrastructure reliability and supporting long-term maintenance planning in CNSD facilities.

Keywords: Environment Readiness Index, CNSD, Supporting Infrastructure, Tier III, Remote Control and Monitoring System.

Introduction

Communication, Navigation, Surveillance and Data Processing (CNSD) facilities constitute critical infrastructure supporting the safety, regularity, and efficiency of air navigation services. The operational performance of these facilities depends not only on the reliability of communication, navigation, surveillance, and data processing equipment, but also on the readiness of the supporting infrastructure that ensures continuous operation under various environmental and operational conditions. Failures in supporting infrastructure—such as electrical power interruptions, excessive temperature and humidity, inadequate grounding systems, lightning-induced disturbances, and the absence of real-time monitoring—may significantly reduce equipment reliability and service availability.

To improve operational reliability, international standards such as the **Uptime Institute Tier Standard** and **ANSI/TIA-942** emphasize that supporting infrastructure should be designed with high availability, redundancy, maintainability, and environmental control. These standards have been widely adopted for evaluating data centers and other mission-critical facilities. However, their application to CNSD facilities remains limited because the operational characteristics, environmental conditions, and supporting infrastructure requirements differ considerably from those of conventional data centers.

Previous studies have generally focused on evaluating individual infrastructure components, including power systems, cooling performance, grounding effectiveness, lightning

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protection, or environmental monitoring. Although these studies provide valuable technical insights, they assess each subsystem independently and do not provide an integrated evaluation of the overall readiness of supporting infrastructure. Consequently, decision makers often face difficulties in identifying infrastructure priorities and determining investment strategies that improve the overall reliability of CNSD facilities.

To address this limitation, this study proposes the **Environment Readiness Index (EnRI)** as an integrated assessment framework for evaluating supporting infrastructure readiness in CNSD facilities. Unlike previous approaches, EnRI combines five critical assessment domains—**Thermal and Humidity Control**, **Power Quality and Continuity**, **Grounding and Lightning Protection**, **Physical Environment**, and **Monitoring and Control System (RCMS)**—into a single readiness index. The framework enables a comprehensive evaluation of infrastructure conditions, supports gap analysis against Tier III and ANSI/TIA-942 principles, and provides objective recommendations for infrastructure improvement.

The proposed EnRI framework was implemented through field assessments involving **172 CNSD facilities**. The assessment results were used to measure infrastructure readiness, identify critical deficiencies, and formulate improvement priorities to enhance operational reliability and service availability. The findings are expected to provide practical guidance for infrastructure planning, maintenance prioritization, and long-term investment decisions in aviation navigation facilities.

The primary contribution of this research is the development of the Environment Readiness Index (EnRI) as an integrated assessment framework specifically designed for evaluating the readiness of supporting infrastructure in CNSD facilities**.** In addition to providing a comprehensive readiness score, the proposed framework establishes a systematic basis for infrastructure evaluation, gap analysis, and continuous improvement aligned with internationally recognized reliability principles.

The primary contributions of this research are threefold. First, it introduces the Environment Readiness Index (EnRI) as an integrated assessment framework specifically designed for supporting infrastructure in CNSD facilities. Second, it integrates five critical infrastructure domains into a unified readiness assessment model capable of providing comprehensive infrastructure evaluation. Third, the proposed framework was implemented across 172 operational CNSD facilities, demonstrating its applicability for readiness assessment, gap analysis, and infrastructure improvement planning aligned with internationally recognized reliability principles.

Method

This study employed a **quantitative descriptive approach** to develop and validate the **Environment Readiness Index (EnRI)** as an integrated framework for assessing the readiness of supporting infrastructure in Communication, Navigation, Surveillance and Data Processing (CNSD) facilities. The framework was designed to evaluate infrastructure readiness comprehensively by integrating five critical assessment domains into a single readiness index.

The research consisted of four sequential stages: (1) identification of assessment indicators, (2) field data collection, (3) EnRI score calculation, and (4) gap analysis followed by infrastructure improvement recommendations. The study was conducted on **172 CNSD facilities** distributed across operational service units. These facilities represent various operational characteristics, environmental conditions, and infrastructure configurations. The assessment focused on supporting infrastructure rather than the operational performance of CNSD equipment itself. The supporting infrastructure evaluated consisted of five domains:

- Thermal and Humidity Control
- Power Quality and Continuity
- Grounding and Lightning Protection
- Physical Environment
- Monitoring and Control System (RCMS)

Data were collected using three complementary techniques. Direct observations were conducted to evaluate the physical condition of supporting infrastructure, including electrical systems, HVAC systems, grounding installations, environmental conditions, and monitoring facilities. Interviews were conducted with maintenance personnel and operational staff to obtain information regarding infrastructure operation, maintenance practices, equipment failures, and operational constraints. A structured assessment checklist was developed based on:

- Uptime Institute Tier III
- ANSI/TIA-942
- ICAO recommendations
- CNSD operational requirements

All assessment items were verified through direct observations and supporting documentation to ensure data consistency and reliability. The proposed **Environment Readiness Index (EnRI)** integrates five critical infrastructure domains into a unified assessment framework.

Table 1. EnRI Assesment Domains

Domain	Description
Thermal and Humidity Control	Evaluation of room temperature, humidity, and cooling performance
Power Quality and Continuity	Evaluation of electrical supply reliability, UPS, generator, and redundancy
Grounding and Lightning Protection	Assessment of grounding systems and surge/lightning protection
Physical Environment	Assessment of room condition, cleanliness, access, fire protection, and supporting facilities
Monitoring and Control System (RCMS)	Assessment of monitoring capability, alarms, remote supervision, and operational visibility

Each domain was evaluated using standardized indicators to ensure consistency across all assessed facilities.

EnRI Calculation :

$$EnRI = \frac{\sum_{i=1}^{n} S_i W_i}{\sum_{i=1}^{n} W_i}$$

where

- S_i = score of assessment indicator
- W_i = weighting factor
- n = number of assessment indicators

The overall EnRI score was calculated using a weighted scoring method and normalized to a scale ranging from **0 to 100**. The EnRI score was interpreted using the following classification.

Table 2. EnRI Score

EnRI Score	Classification
85–100	Highly Ready
70–84	Ready
55–69	Moderately Ready
<55	Improvement Required

This classification facilitates infrastructure prioritization and decision-making. Gap analysis was performed by comparing EnRI assessment results with the infrastructure requirements defined in **Tier III** and **ANSI/TIA-942**. Each identified gap was evaluated based on its operational impact, infrastructure criticality, implementation priority, and expected contribution to reliability improvement. The analysis formed the basis for developing objective infrastructure improvement recommendations.Each identified gap was analyzed according to:

- operational impact,
- infrastructure criticality,
- implementation priority, and
- expected reliability improvement.

The results were then translated into infrastructure improvement recommendations.The research methodology adopted in this study is illustrated in figure below.

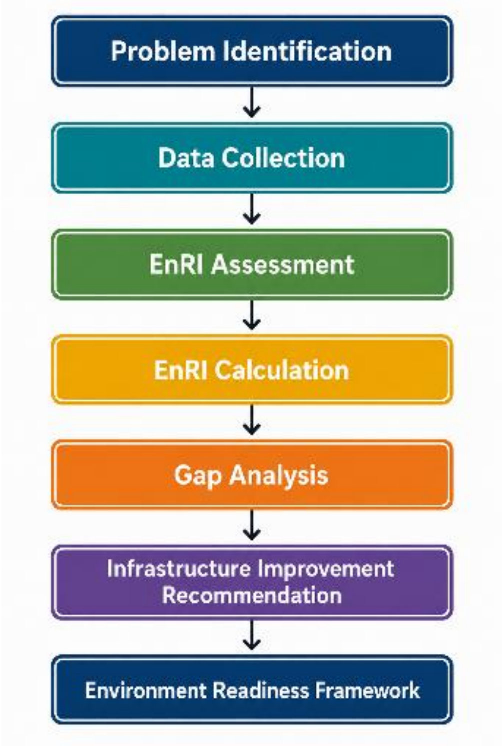

Figure 1. Research Framework

The proposed EnRI framework was evaluated through its application to 172 CNSD facilities representing various operational environments. The implementation results demonstrate that the framework consistently identifies infrastructure readiness levels, infrastructure gaps, and improvement priorities, indicating its applicability as a practical infrastructure assessment tool.

The proposed **Environment Readiness Index (EnRI)** framework was implemented to assess the readiness of supporting infrastructure at **172 CNSD facilities**. The assessment covered five critical infrastructure domains: **Thermal and Humidity Control**, **Power Quality and Continuity**, **Grounding and Lightning Protection**, **Physical Environment**, and **Monitoring and Control System (RCMS)**.

The assessment results indicate that the proposed framework successfully provides a comprehensive representation of infrastructure readiness by integrating multiple technical parameters into a single readiness index. In addition to determining the readiness level of each facility, EnRI also enables the identification of infrastructure deficiencies and supports prioritization of improvement programs based on operational impact and infrastructure criticality. Unlike conventional assessment approaches that evaluate individual infrastructure components separately, EnRI provides an integrated assessment that supports strategic infrastructure planning.

The aggregated assessment results show variations in readiness levels among the five assessment domains. **Power Quality and Continuity** demonstrated the highest readiness level, indicating that most CNSD facilities have implemented reliable electrical infrastructure, including UPS systems, backup generators, and power distribution redundancy. Similarly, **Thermal and Humidity Control** achieved a relatively high readiness score, reflecting adequate environmental control for maintaining the operational stability of CNSD equipment.

Conversely, **Monitoring and Control System (RCMS)** exhibited the lowest readiness level. The assessment revealed that many facilities still rely on manual inspection procedures and lack centralized monitoring capabilities capable of providing real-time operational information. The remaining domains—**Grounding and Lightning Protection** and **Physical Environment**—generally achieved moderate readiness levels. Although these domains satisfy minimum operational requirements, several facilities require infrastructure upgrades to fully comply with Tier III reliability principles. Summarizes the overall readiness performance of the five EnRI domains.

Table 3. Comparative Performance of EnRI Assessment Domains

Domain	Readiness Level	Improvement Priority
Thermal and Humidity Control	High	Medium
Power Quality and Continuity	High	Low
Grounding and Lightning Protection	Moderate	Medium
Physical Environment	Moderate	Medium
Monitoring and Control System (RCMS)	Low	High

Gap analysis was conducted by comparing the assessment results with the infrastructure requirements defined in **Tier III** and **ANSI/TIA-942**. The analysis identified several recurring deficiencies across the assessed facilities, including:

- insufficient redundancy of supporting systems;
- absence of centralized infrastructure monitoring;
- incomplete environmental monitoring;
- inadequate grounding documentation;
- limited predictive maintenance capability.

Based on the gap analysis, infrastructure improvement priorities are recommended as follows:

1. Implementation of **Remote Control and Monitoring System (RCMS)**.
2. Enhancement of environmental monitoring capability.
3. Improvement of grounding and lightning protection.
4. Upgrading supporting physical infrastructure.
5. Optimization of preventive maintenance procedures.

Unlike conventional approaches that recommend uniform infrastructure upgrades, EnRI enables improvement priorities to be established objectively according to the readiness level of each facility

Discussion

The findings demonstrate that supporting infrastructure readiness significantly influences the operational reliability of CNSD facilities. While international standards such as Tier III and ANSI/TIA-942 provide comprehensive technical requirements, their implementation in CNSD environments requires an assessment framework capable of integrating multiple infrastructure domains into a unified evaluation model. The proposed Environment Readiness Index (EnRI) addresses this requirement by providing a practical assessment framework that combines technical inspection, infrastructure scoring, and gap analysis into a single decision-support mechanism.

A notable contribution of this research is the integration of five infrastructure domains that have traditionally been evaluated independently. This integrated approach enables infrastructure managers to understand not only the condition of individual subsystems but also their combined influence on facility readiness. Another important finding concerns the role of **Remote Control and Monitoring System (RCMS)**. Although power systems and environmental control generally exhibited satisfactory readiness levels, the absence of integrated monitoring reduced the overall capability to detect failures proactively. This observation highlights the importance of RCMS as an enabling technology for predictive maintenance and continuous infrastructure improvement. The principal contribution of this study lies in the development of the **Environment Readiness Index (EnRI)** as an integrated assessment framework specifically designed for supporting infrastructure in CNSD facilities.

The framework contributes to existing knowledge in three ways. First, it integrates five critical infrastructure domains into a unified readiness assessment model. Second, it introduces an objective infrastructure scoring mechanism that supports comparative evaluation among facilities. Third, it provides a systematic basis for infrastructure improvement planning through readiness classification and gap analysis.Consequently, EnRI extends existing infrastructure assessment practices beyond isolated subsystem evaluation toward a holistic infrastructure readiness framework.

Conclusion

This study successfully developed the Environment Readiness Index (EnRI) as an integrated assessment framework for evaluating the readiness of supporting infrastructure in Communication, Navigation, Surveillance and Data Processing (CNSD) facilities. Unlike conventional assessment approaches that evaluate individual infrastructure components separately, EnRI integrates five critical domains—Thermal and Humidity Control, Power Quality and Continuity, Grounding and Lightning Protection, Physical Environment, and Monitoring and Control System (RCMS)—into a unified readiness assessment model. The implementation of EnRI on 172 CNSD facilities demonstrated that the framework is capable of providing a comprehensive evaluation of infrastructure readiness, identifying infrastructure gaps, and supporting the prioritization of improvement programs based on operational impact and infrastructure criticality. The assessment results indicate that Power Quality and Continuity generally achieved the highest readiness level, while Monitoring and Control System (RCMS) remains the primary area requiring improvement in many facilities. The proposed framework offers practical benefits for infrastructure managers by providing an objective basis for readiness assessment, gap analysis, maintenance prioritization, and infrastructure investment planning. Consequently, EnRI supports continuous infrastructure improvement and contributes to enhancing the operational reliability and service availability of CNSD facilities. Future research is recommended to incorporate multi-criteria decision-making techniques, such as the Analytic Hierarchy Process (AHP) or Fuzzy AHP, for determining indicator weightings. Furthermore, integration of EnRI with real-time Remote Control and Monitoring Systems (RCMS) is expected to enable dynamic infrastructure assessment and predictive maintenance, thereby extending the applicability of the proposed framework in modern smart infrastructure environments. The conclusion collects and summarizes the key findings and their implications. The contents of the conclusion include the answer to the research objectives, not a summary of the research results. Brief, clear and concise conclusions are based on research results.

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