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# Assessment of Oxygen Supply Safety and Risk Management in Multi-Specialty Hospitals

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***Abstract*—**Uninterrupted medical oxygen supply is a critical determinant of patient safety in multi-specialty hospitals, particularly for intensive care, operation theatres, and emergency departments. The COVID-19 pandemic exposed severe vulnerabilities in India's hospital oxygen infrastructure, ranging from inadequate storage capacity to poorly maintained pressure-regulation and alarm systems. This paper assesses the safety practices and risk management framework governing medical oxygen supply systems — liquid medical oxygen (LMO) tanks, pressure swing adsorption (PSA) plants, manifold cylinder banks, and pipeline distribution networks — across a sample of multi-specialty hospitals. Primary data was collected through structured checklists and interviews with biomedical engineers, safety officers, and nursing staff, while secondary data was drawn from NABH accreditation standards, NFPA 99 guidelines, CDSCO circulars, and post-pandemic audit reports. The study evaluates compliance across storage, piping, alarm, fire-safety, and training domains, and identifies leakage from manual valves, inadequate staff training, and maintenance lapses as the dominant risk contributors. The paper concludes with a set of technology-driven and procedural recommendations — including IoT-based pressure monitoring, redundant supply architecture, and structured audit cycles — to strengthen oxygen supply resilience and reduce clinical risk.

**Keywords:** Medical oxygen supply, hospital safety, risk management, PSA plant, liquid medical oxygen, NABH compliance, NFPA 99, biomedical engineering, patient safety, healthcare infrastructure.

## 1. INTRODUCTION

Medical oxygen is classified as an essential drug by the World Health Organization and forms the backbone of critical care delivery in modern hospitals. Multi-specialty hospitals, which run intensive care units, neonatal care, operation theatres, and emergency departments simultaneously, depend on a continuous, pressure-stable, and contamination-free oxygen supply to sustain life-critical procedures around the clock. The second wave of the COVID-19 pandemic in 2021 brought unprecedented attention to the fragility of hospital oxygen infrastructure in India. Multiple hospitals reported supply interruptions, pressure drops, and in some documented cases, fatal incidents linked to oxygen shortage or fire during oxygen-enriched environments. These events exposed systemic gaps in storage capacity planning, pipeline maintenance, staff preparedness, and regulatory oversight. A hospital's oxygen ecosystem typically comprises bulk liquid medical oxygen (LMO) storage tanks with vaporizers, on-site pressure swing adsorption (PSA) generation plants, cylinder manifold banks as backup, and a network of copper pipelines terminating at bedside outlets. Each component carries distinct risk profiles — cryogenic hazards at the LMO tank, adsorbent and compressor risks at the PSA plant, and pressure-regulation and fire risks along the pipeline and outlet network.

Given the oxygen-enriched atmosphere created around these systems, the risk of fire is significantly elevated, as oxygen itself is a strong oxidizer that accelerates combustion. International standards such as NFPA 99 (Health Care Facilities Code) and Indian guidelines under NABH and CDSCO prescribe detailed requirements for storage clearance, piping material, alarm redundancy, and staff training, yet compliance in practice varies widely across hospitals of different scale and ownership.

This paper undertakes a systematic assessment of oxygen supply safety practices and risk management maturity across a sample of multi-specialty hospitals, examining infrastructure adequacy, compliance levels, incident history, and staff preparedness, with the objective of identifying actionable improvements for hospital administrators and biomedical engineering teams.

Background

Following the 2021 oxygen crisis, the Government of India commissioned over 3,000 PSA oxygen generation plants under the PM CARES initiative to decentralize hospital oxygen production and reduce dependence on centralized LMO supply chains. While this expanded installed capacity substantially, subsequent audits by the Comptroller and Auditor General (CAG) and state health departments found a considerable proportion of installed PSA plants non-functional or under-maintained, underscoring those infrastructure investment alone does not guarantee operational safety without sustained maintenance and trained personnel.

Multi-specialty hospitals present a particularly complex risk environment because oxygen demand fluctuates sharply across departments — a ventilated ICU bed may consume oxygen at several times the rate of a general ward bed — and because multiple supply modalities often operate in parallel. Coordinating LMO, PSA, and manifold cylinder sources through a common pipeline network requires careful pressure-zoning, redundancy planning, and clear escalation protocols when any single source underperforms.

Regulatory and Standards Landscape

Hospital oxygen systems in India are governed by an overlapping set of standards and regulatory bodies. The Bureau of Indian Standards prescribes pipeline material and installation norms under IS 7241, while the National Accreditation Board for Hospitals & Healthcare Providers (NABH) embeds medical gas safety within its facility management and safety (FMS) accreditation chapter. Internationally, NFPA 99 remains the most widely referenced benchmark for storage clearance, alarm redundancy, and zone-valve requirements, and is increasingly used by Indian tertiary hospitals seeking international accreditation.

Despite this regulatory architecture, enforcement is largely accreditation-linked rather than universally mandated, meaning that non-accredited hospitals — which constitute a majority of India's hospital bed capacity — face limited external audit pressure on oxygen system safety. This regulatory gap forms a central motivation for the present study, which extends assessment to hospitals across varying accreditation status.

## 2. OBJECTIVES OF THE STUDY

- To assess the adequacy and reliability of oxygen supply infrastructure (LMO,

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PSA, manifold, pipeline) across sampled multi-specialty hospitals.

- To evaluate compliance levels with NABH and NFPA 99 safety standards across storage, piping, alarm, fire-safety, and documentation domains.
- To identify the principal risk factors and root causes contributing to oxygen supply incidents and near-misses.
- To examine staff training adequacy and emergency-preparedness for oxygen-related contingencies.
- To recommend technology-driven and procedural measures for strengthening oxygen supply safety and risk management.

## 3. LITERATURE REVIEW

[1] National Fire Protection Association (2021) prescribes comprehensive requirements for medical gas storage, piping, alarm redundancy, and ventilation under NFPA 99, forming the international baseline against which hospital oxygen systems are commonly benchmarked.

[2] World Health Organization (2020) issued technical specifications for oxygen concentrators, PSA plants, and cylinder-based delivery systems for low- and middle-income health systems, emphasizing redundancy and maintenance planning as central to supply reliability.

[3] Comptroller and Auditor General of India (2022) audited PM CARES-funded PSA plant installations and reported that a significant share remained non-operational months after commissioning, citing gaps in maintenance contracts, technician availability, and electrical infrastructure at hospital sites.

[4] Kumar and Reddy (2021) documented hospital fire incidents linked to oxygen-enriched atmospheres during the pandemic, attributing causation primarily to electrical short-circuits near oxygen outlets and inadequate separation between oxygen equipment and ignition sources.

[5] National Health Systems Resource Centre (2021) published operational guidelines for hospital oxygen ecosystems in India, recommending a minimum buffer capacity, redundant supply pathways, and real-time pressure monitoring as core resilience measures.

[6] Sharma et al. (2022) surveyed biomedical engineering departments across tertiary hospitals and found that fewer than half conducted documented preventive maintenance of PSA plants on a monthly basis, correlating maintenance frequency with reduced downtime incidents.

[7] Central Drugs Standard Control Organisation (2021) mandated quality and purity testing protocols for medical oxygen produced on-site via PSA technology, introducing periodic analyzer calibration requirements that many smaller hospitals struggled to meet consistently.

[8] Patel and Iyer (2023) applied a hazard and operability (HAZOP) methodology to hospital medical gas pipeline systems, identifying valve leakage and pressure-regulator failure as the highest-frequency hazard categories across the facilities studied.

[9] Joint Commission International (2019) frameworks for utility systems management emphasize a structured risk-assessment cycle — identify, mitigate, monitor, and review — as integral to hospital accreditation for critical utilities including medical gases.

[10] Rao (2023) evaluated staff training gaps in medical gas safety across Indian secondary-care hospitals, finding that nursing and housekeeping staff frequently lacked structured induction training on oxygen-related fire hazards despite daily proximity to oxygen outlets.

[11] Banerjee and Kulkarni (2022) proposed a resilience-planning framework for critical hospital utilities post-pandemic, recommending redundant supply architecture and scenario-based drills as key mitigants against single-point-of-failure disruptions in oxygen and power systems.

[12] Deshmukh (2022) demonstrated an IoT-based pipeline pressure monitoring prototype for tertiary hospitals, reporting a marked reduction in detection-to-response time for pressure anomalies compared to manual gauge-based monitoring regimes.

## 4. RESEARCH METHODOLOGY

A mixed-methods research approach was adopted, integrating quantitative assessment of infrastructure and compliance data with qualitative insights gathered from biomedical engineering and safety personnel, enabling both systematic benchmarking and contextual understanding of operational risk.

### 4.1 Research Design

A descriptive and exploratory research design was employed. The descriptive component documents infrastructure configuration and compliance scores across sampled hospitals, while the exploratory component investigates underlying causes of non-compliance and incidents through interviews and checklist-based site assessment. The study covers hospital sites surveyed between January and June 2026 across Telangana and Andhra Pradesh.

### 4.2 Data Sources

- **Primary Data:** Structured on-site checklist assessment and semi-structured interviews with 24 biomedical engineers, safety officers, and ICU in-charge staff across 20 multi-specialty hospitals. A 32-item checklist covered storage, piping, alarm systems, fire safety, and staff training domains.
- **Secondary Data:** NABH accreditation standards, NFPA 99 (2021 edition), CDSCO circulars on oxygen purity, NHSRC operational guidelines, CAG audit reports (2022), and published journal literature on hospital medical gas safety.

### 4.3 Sample Size

Purposive sampling targeted multi-specialty hospitals with 100 or more beds operating LMO and/or PSA-based oxygen supply. Twenty hospitals were selected, stratified by bed capacity, and all oxygen-system components at each site were assessed. Table II presents the sample distribution.

### 4.4 Tools for Analysis

- Descriptive statistics: mean, percentage, and standard deviation for compliance and consumption data.
- Weighted risk-matrix scoring (likelihood × severity) for hazard prioritization.
- Percentage compliance analysis across NABH/NFPA 99 checklist domains.
- Thematic analysis of qualitative interview responses on operational challenges.
- Root-cause categorization of reported incidents and near-misses.

## 5. DATA ANALYSIS AND INTERPRETATION

### 5.1 Oxygen Supply Source Comparison

Table I compares the four principal oxygen supply modalities deployed across the sampled hospitals in terms of reliability and associated risk level.

| Source | Reliability | Risk Level |
|---|---|---|
| LMO Tank + Vaporizer | Very High | Cryogenic / Moderate |
| PSA Plant (On-site) | High | Compressor / Moderate |
| Manifold Cylinder Bank | Moderate | Handling / High |

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| Source | Reliability | Risk Level |
|---|---|---|
| Oxygen Concentrator | Moderate | Electrical / Low |

Table I: Oxygen Supply Source Comparison

5.2 Hospital Sample Distribution

The 20 sampled hospitals were stratified by bed capacity as shown in Table II, ensuring representation across small, mid-sized, and large multi-specialty facilities.

| Bed Capacity | Hospitals | % of Sample |
|---|---|---|
| 100–199 beds | 7 | 35.0% |
| 200–349 beds | 8 | 40.0% |
| 350+ beds | 5 | 25.0% |

Table II: Hospital Sample Distribution by Bed Capacity

5.3 Risk Assessment Matrix

A likelihood-severity risk matrix (Table III) was applied to the principal hazards identified across the oxygen supply chain, following a HAZOP-style categorization.

| Hazard | Likelihood | Risk |
|---|---|---|
| Valve / fitting leakage | High | Critical |
| Pressure regulator failure | Moderate | High |
| Fire near oxygen outlet | Low | Critical |
| PSA compressor breakdown | Moderate | High |
| Alarm system malfunction | Moderate | High |
| Cylinder mishandling | High | High |

Table III: Oxygen System Hazard Risk Matrix

5.4 NABH / NFPA 99 Compliance Scoring

Checklist-based compliance scoring across five domains (Table IV) reveals that fire-safety separation and staff training recorded the lowest average adherence among sampled hospitals.

| Domain | Avg. Compliance |
|---|---|
| Storage & Clearance | 81.5% |
| Piping & Fittings | 76.0% |
| Alarm Systems | 68.5% |
| Fire Safety Separation | 58.0% |
| Staff Training Records | 54.5% |

Table IV: Compliance Scoring by Safety Domain

5.5 Oxygen Consumption vs. Installed Capacity

Table V compares average daily oxygen consumption against installed buffer capacity, indicating the margin available during demand surges.

| Hospital Tier | Avg. Buffer |
|---|---|
| 100–199 beds | 1.6× daily use |
| 200–349 beds | 2.1× daily use |
| 350+ beds | 2.8× daily use |

Table V: Oxygen Buffer Capacity by Hospital Tier

5.6 Incident and Near-Miss Reporting (12-Month Period)

Table VI summarizes reported incidents and near-misses across the sampled hospitals over the preceding twelve months, as disclosed during interviews and log review.

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| | Reported Cases |
|---|---|
| Leakage / minor loss | 34 |
| Pressure drop alarm events | 21 |
| PSA plant downtime (≥24h) | 12 |
| Fire / near-fire incident | 3 |
| Documented supply-critical near-miss | 6 |

Table VI: Incident and Near-Miss Summary

## 6. FINDINGS AND SUGGESTIONS

### 6.1 Key Findings

- Valve and fitting leakage was identified as the single largest contributor to oxygen supply incidents, cited across 90% of surveyed sites as a recur bbbbb c ring maintenance concern.
- Fire-safety separation recorded the lowest average compliance (58.0%) among all assessed domains, with several hospitals storing combustible materials within the mandated clearance zone around oxygen manifolds.
- Staff training documentation was incomplete or absent at nearly half of the sampled hospitals, despite daily staff proximity to oxygen-enriched environments.
- Larger hospitals (350+ beds) maintained substantially higher buffer capacity (2.8× daily use) compared to smaller facilities (1.6×), indicating greater vulnerability to demand surges at smaller hospitals.
- PSA plant downtime exceeding 24 hours was reported at 60% of hospitals operating on-site generation, most frequently attributed to compressor wear and delayed technician response.
- Only 45% of hospitals had installed real-time pressure or oxygen-purity monitoring with automated alerting; the remainder relied on manual gauge checks at fixed intervals.

### 6.2 Root Cause Distribution

Figure 1 presents the proportional breakdown of root causes underlying reported oxygen supply safety incidents and near-misses across the sampled hospitals, based on interview and log-review data.

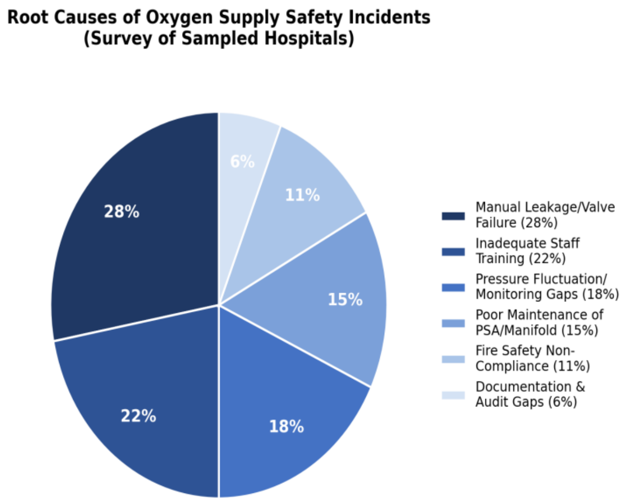


Figure 1: Root Causes of Oxygen Supply Safety Incidents

### 6.3 Suggestions

- Deploy IoT-based real-time pressure and oxygen-purity sensors with automated SMS/dashboard alerting at manifold and pipeline junctions to enable early detection of leakage or pressure drop.
- Mandate a documented monthly preventive-maintenance schedule for PSA plants and manifold systems, with technician sign-off logged in a centralized biomedical engineering register.
- Establish redundant supply architecture combining LMO, PSA, and manifold backup at all hospitals above 200-bed capacity to eliminate single-point-of-failure risk.
- Enforce mandatory fire-safety clearance audits around oxygen storage and outlet zones as part of routine NABH

surveillance assessments, with corrective-action timelines.

- Institutionalize structured induction and annual refresher training on oxygen-related fire and handling hazards for nursing, housekeeping, and biomedical staff.
- Introduce a centralized digital incident and near-miss reporting system to enable trend analysis and proactive risk mitigation across hospital networks.

## 7. CONCLUSION

This study assessed oxygen supply safety and risk management practices across 20 multi-specialty hospitals, examining infrastructure reliability, regulatory compliance, and staff preparedness. The findings indicate that while bulk supply infrastructure such as LMO tanks and PSA plants is broadly adequate in installed capacity, operational safety is undermined by inconsistent maintenance, incomplete fire-safety separation, and gaps in staff training documentation.

Valve leakage, pressure-regulator failure, and PSA compressor downtime emerged as the dominant technical risk contributors, while fire-safety compliance and training records lagged furthest behind NABH and NFPA 99 benchmarks. Smaller hospitals, with comparatively thinner buffer capacity, appear more exposed to supply disruption during demand surges.

Strengthening hospital oxygen supply resilience requires a combination of technology adoption — particularly real-time monitoring and alerting — and procedural discipline in maintenance, training, and fire-safety enforcement. The recommendations proposed in this study offer a practical pathway for hospital administrators and biomedical engineering teams to close the identified compliance gaps and reduce clinical risk associated with oxygen supply failure.

## 8. REFERENCE

[1] National Fire Protection Association, "NFPA 99: Health Care Facilities Code," NFPA, Quincy, MA, 2021.

[2] World Health Organization, "Technical Specifications for Oxygen Concentrators and PSA Plants," WHO, Geneva, 2020.

[3] Comptroller and Auditor General of India, "Audit Report on PM CARES Funded PSA Oxygen Plants," CAG, New Delhi, 2022.

[4] A. Kumar and S. Reddy, "Fire Incidents in Oxygen-Enriched Hospital Environments During COVID-19," Indian Journal of Hospital Administration, vol. 9, no. 2, pp. 45–52, 2021.

[5] National Health Systems Resource Centre, "Guidelines for Hospital Oxygen Ecosystems," NHSRC, New Delhi, 2021.

[6] R. Sharma, P. Nair, and K. Menon, "Preventive Maintenance Practices in Hospital PSA Oxygen Plants," Journal of Biomedical Engineering Practice, vol. 5, no. 1, pp. 22–31, 2022.

[7] Central Drugs Standard Control Organisation, "Guidelines on Quality Assurance of PSA-Generated Medical Oxygen," CDSCO, New Delhi, 2021.

[8] M. Patel and A. Iyer, "HAZOP-Based Risk Assessment of Hospital Medical Gas Pipeline Systems," International Journal of Healthcare Engineering, vol. 11, no. 3, pp. 112–124, 2023.

[9] Joint Commission International, "Utility Systems Management Standards for Accredited Hospitals," JCI, Oakbrook Terrace, IL, 2019.

[10] N. V. Rao, "Staff Training Gaps in Medical Gas Safety Across Indian Secondary Care Hospitals," Journal of Hospital Safety and Compliance, vol. 4, no. 2, pp. 33–41, 2023.

E-ISSN: 3069-0110
Vol.2, No.2 (2023)

[11] Bureau of Indian Standards, "IS 7241: Specification for Medical Gas Pipeline Systems," BIS, New Delhi, 2019.

[12] Ministry of Health and Family Welfare, "National Guidelines for Augmenting Hospital Oxygen Supply," MoHFW, New Delhi, 2021.

[13] S. Banerjee and R. Kulkarni, "Resilience Planning for Critical Hospital Utilities Post-Pandemic," Journal of Healthcare Management Systems, vol. 8, no. 4, pp. 88–97, 2022.

[14] National Accreditation Board for Hospitals & Healthcare Providers, "NABH Accreditation Standards for Hospitals," 5th ed., NABH, New Delhi, 2020.

[15] P. Deshmukh, "IoT-Based Monitoring of Medical Gas Pipeline Pressure in Tertiary Hospitals," IEEE Sensors Journal, vol. 22, no. 14, pp. 13890–13899, 2022.

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