DECEMBER 2025

VIEWPOINT

OFFICIAL QUARTERLY MAGAZINE OF CEAI

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Asset Management for Sustaining Built Facilities

CEAI Consulting Engineers Association of India

Creating Value Ethically for Engineers

Over 60 Years

Service to Consulting Engineers

50th ANNIVERSARY

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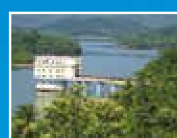
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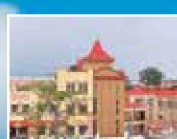
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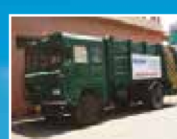
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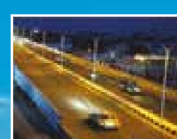
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Membership of CEAI

Enhance Your Professional Career

- CEAI is a FORUM for developing and upgradation of skills, gaining knowledge about the emerging global trends and building the capabilities of its Members and Associates.
- CEAI provides an excellent opportunity to present papers in seminars, technical lectures and webinars organised from time to time.
- CEAI aids in skill development through regular training programmes, including training on FIDIC Conditions of Contract and sharing of legal issues in the Indian context.
- The CEAI document "Handling of Complaints on Violation of Code of Ethics" helps to resolve disagreements between Members.
- Several CEAI Members are exporting consultancy services and are registered with all the major international funding institutions.
- Membership of CEAI is being increasingly recognised as a mark of credibility. Many users of consultants shortlist CEAI Members.

Networking - Make Connections

- Being the Member Association of FIDIC in India, CEAI connects Members globally.
- CEAI provides a platform to interact with other Members, Institutions, State & Central Governments.
- The CEAI website opens up an opportunity for its Members to upload their expertise and capabilities to worldwide exposure.
- Participate in topical seminars, training programmes, conferences and meetings.
- The Four Regional Centres and a few City Chapters in the country assist in establishing linkages.
- A Monthly Newsletter is circulated to Members for quick dissemination of information.
- "ViewPoint" - a quarterly publication on a wide range of subjects, communicates effectively with Members and users of consultancy services.

Learning - Find Insights and Resources

- Newsletter: An email newsletter sent out monthly to all current members, giving updates regularly, sharing news, activities, events or other information in the future.
- ViewPoint: A quarterly journal, which is theme-based, that presents very informative and useful technical papers of high scientific and technical standards. Articles are written by practising consulting engineers and academia from around the world and reflect the high standards of CEAI.
- CEAI published documents: CEAI has a wide range of materials and information to help those who want to start practice as a consulting engineer.
- FIDIC Publications: A Link is given to all the FIDIC contract documents and other publications, for direct purchase. Alternatively, they could be procured through CEAI.

Interaction with FIDIC and other International and National Bodies

- FIDIC undertakes a wide variety of activities on a global basis. FIDIC Member Associations and their member firms, therefore, can potentially benefit from any number of FIDIC activities.
- CEAI looks after the interest and enhances the status of the Consulting Engineering profession in India and is equally concerned with quality development, productivity enhancement and promotion of ethical practices.

CEAI has established linkages and strong bonds with its counterparts in various countries and is a staunch advocate of global networking and cooperation.

- CEAI has entered into a MEMORANDUM OF UNDERSTANDING with different international bodies to promote the development of the engineering industry in India and abroad.
- CEAI has close relations with other Indian Associations with similar objectives.
- CEAI has entered into an Agreement with the Institution of Engineers India (IEI) to promote development of a closer working relationship for the mutual benefit of Members.
- Improve Business Skills - Step into a Leadership Role
- To recognise and promote the engineering consultancy profession, Annual Awards are presented for Excellence in Engineering Consultancy Services and contribution towards professional excellence.
- It also provides an opportunity to participate in international awards announced by FIDIC from time to time.
- Technical workshops and interactive sessions are organised regularly to publicise professional works and to provide a platform to enhance business and develop newer markets.

Participation in Learning and Imparting Knowledge

- CEAI organises FIDIC Training programs at regular intervals on the FIDIC Conditions of Contract. FIDIC Conditions of Contracts are being used the world over in developed economies and where multi-lateral development banks or bilateral funding agencies provide the funding.
- To endeavour to disseminate knowledge and information on matters of relevance to the Consulting Engineering profession, CEAI organises Workshops, Seminars, Training programs, Webinars, etc. at national and international levels.

Young Professionals/ Future Leaders Forum

- CEAI started the Young Professional/ Future Leaders Group, which connects with young professionals internationally through the FIDIC route.
- To recognise, honour and promote new talent of Young Engineers, CEAI celebrated 2016 as Young Engineers' Year
- CEAI organises special webinars for Young Engineers.

Thus,

- CEAI promotes the interest and enhances the status of the consulting engineering profession in India.
- CEAI advocates global networking and co-operation.
- CEAI helps one to keep in touch with the latest professional updates - technical, regulatory, legal, financial, health & safety, environmental, etc.
- CEAI provides an excellent opportunity to present papers in seminars and technical lectures organised from time to time.
- CEAI aids in skill development through regular training programmes, including training on FIDIC Conditions of Contract and sharing of the legal issues based on the Indian contex.t
- CEAI takes up various issues confronting the profession with government and other authorities from time to time to make the conditions of engagement on a fair and equitable basis, so that Consulting Engineers can function in the best interest of the country.
- CEAI promotes the cause of Women Engineers with a view to ensuring a rightful place for them in the engineering consultancy arena.
- CEAI helps to develop Young Engineers who are the Future Leaders.

DEAR MEMBERS AND READERS

May the NEW YEAR bring you exciting new frontiers to explore and conquer, all pursued with the highest professional ethics & integrity

Wishing all great success and fulfilment in 2026!

CEAI

Message from President

As we begin the calendar year 2026, it is an opportune moment to pause, reflect, and take collective pride in what the Consulting Engineers Association of India has accomplished over the past year. It is equally important to look ahead with clarity and purpose at what needs to be accomplished in the year 2026.

The period from April to December 2025 has been one of sustained engagement and renewed momentum for CEAI. Despite an increasingly complex and demanding infrastructure landscape, our Association remained active, relevant, and visible. Through a rich calendar of technical webinars, seminars, workshops, and conferences, CEAI addressed contemporary challenges ranging from post-disaster rehabilitation and sustainability in materials, to BIM, digital twins, AI, project appraisal, road safety, and integrity in infrastructure delivery. Our Annual Conference in New Delhi, with participation from over 200 professionals, reaffirmed CEAI's position as a respected platform for dialogue across the infrastructure ecosystem

Equally significant was the strengthening of institutional partnerships—through MoUs, collaborations with global and national bodies, and our growing engagement with FIDIC, ADB, and peer associations. The work of the CEAI Academy deserves special mention. Focused training programmes on forensic engineering, construction law, FIDIC contracts, IRC bridge codes, and specialised design domains reinforced our belief that **capacity building is the single most critical investment in the future of our profession**

Our members also brought immense credit to the Indian consulting fraternity through national and international recognitions, awards, and thought leadership—demonstrating that Indian consulting engineers are not only keeping pace with global standards, but often setting them.

As we step into 2026, CEAI's priorities are clear.

First, advocacy will remain central to our mission. As India embarks on building resilient, climate-responsive, and future-ready infrastructure, the role of independent, competent consulting engineers is paramount. CEAI will intensify its engagement with government planners, policymakers, and implementing agencies to promote quality-based procurement, fair contracting frameworks, appropriate risk allocation, and greater reliance on professional expertise in decision-making.

Second, **we will actively expand and deepen our membership network**. CEAI must truly reflect the diversity of disciplines, geographies, and generational talent that define India's consulting engineering ecosystem. A broader, younger, and more multidisciplinary membership base will strengthen our collective voice.

Third, hosting the FIDIC Global Infrastructure Conference (GIC) 2026 is both an honour and a responsibility. It is an opportunity to showcase India's engineering capabilities, share our infrastructure story with the world, and position Indian consultants as trusted global partners. Preparations for GIC 2026 will be a major focus area in the coming year.

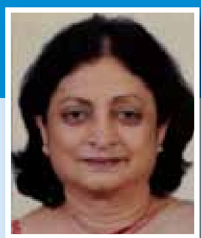
Finally, training and professional development will be scaled further. Continuous learning—technical, contractual, digital, and managerial—is essential if consulting engineers are to remain relevant in a rapidly evolving environment. CEAI will continue to invest in structured, practice-oriented capacity building through the CEAI Academy.

Resilient and sustainable infrastructure is the foundation of a better future. Consulting engineers sit at the very heart of this endeavour—bridging vision with execution, innovation with prudence, and ambition with accountability. CEAI will work tirelessly to ensure that our profession receives the recognition, respect, and role it rightfully deserves.

I thank the Governing Council, our members, partners, and well-wishers for their continued support. I look forward to your active participation as we move confidently into 2026—together shaping CEAI as the authoritative voice of consulting engineers in India.

Warm Regards,

Prashant Kapila
President, CEAI



Message from Chief Editor

As India accelerates towards becoming a $5 trillion economy, the national conversation on infrastructure is largely focused on scale in high-impact sectors - more highways, more metros, more power, more manufacturing. Yet, beneath these developments lies a quieter, more consequential challenge: the management of the assets once they are built.

Engineers have traditionally excelled at creating tangible assets, whose development and efficient upkeep add value to an asset. It is a living economic resource whose value depends on how well it is designed, operated, maintained, upgraded, and eventually retired responsibly and cost-effectively. The next frontier is ensuring that these assets perform optimally throughout their lifecycle - delivering economic returns while minimising environmental harm and enhancing social outcomes.

Sustainable asset management sits at the heart of this challenge. It is no longer sufficient to chase efficiency alone. Today's assets must consume less energy and water, generate less waste, and last longer, even as performance expectations rise. Simple but deliberate interventions - such as preventive maintenance of HVAC systems, adoption of water and energy-efficient fixtures, or integration of renewable energy - can dramatically reduce operating costs and carbon footprints over time. Multiplied across India's vast infrastructure base, these gains become nationally significant.

The stakes are high for India. Massive investments are underway in transportation networks, economic corridors, urban infrastructure, renewable energy, and industrial capacity. Through initiatives like the National Infrastructure Pipeline, the country has laid out an ambitious roadmap for asset creation. Complementing this is the government's asset monetisation strategy, which seeks to unlock value from existing brownfield assets by leasing them to private players and recycling capital into new projects. But monetisation without robust asset management is a short-lived solution; value extraction must be matched by value preservation.

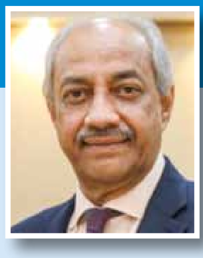
This makes sustainability not an optional add-on, but a design imperative. Environmental considerations must be embedded from the earliest design stage and carried through construction, operations, maintenance and eventual decommissioning. Lifecycle thinking - long advocated, rarely practised - must now become standard operating doctrine.

For the engineering consulting fraternity, this moment presents both a challenge and an opportunity. Asset management remains an underexplored business domain, yet demand from asset owners and stakeholders is unmistakably rising. Digital tools, global best practices, and data-driven decision-making are transforming how assets are monitored and managed worldwide. Indian engineering Consultants must build capacity, adopt these tools, and claim their space in this evolving ecosystem.

This edition of *ViewPoint* aims to spark that journey - by offering practitioners' insights, real-world case studies, and perspectives from both government and private-sector experts. The message is clear: India's infrastructure future will not be judged by what we build alone, but by how wisely we manage what we already have.

Wishing our Readers a *Very Happy and Prosperous New Year !!*

Wish best regards
Sayona Philip

Message from Guest Editor

As the new year dawns, we are delighted to address our community through this special year-end issue of *ViewPoint*. The past year has been one of renewed introspection, technological acceleration, and an expanding sense of responsibility in the consulting engineering profession. *ViewPoint* continues to be a crucial platform where these conversations converge - carrying forward the legacy of thoughtful, practice-oriented, and future-ready discourse.

Infrastructure and built-environment assets form the backbone of India's economic growth, urban development, and social well-being. As the scale, complexity, and expectations from these assets continue to grow, so does the need for a disciplined, value-based, and lifecycle-oriented approach to their management. It is in this context that the Consulting Engineers Association of India brings out this issue of *ViewPoint* dedicated to the theme of Asset Management.

ISO:55000 defines "asset management as the co-ordinated activity of an organisation to realise value from assets". "An asset is an item, thing or entity that has potential or actual value to an organisation". Note that this can include anything of potential or actual value, including non-physical things such as intellectual property, data, knowledge or reputation of the organisation.

Asset Management, as articulated in the ISO 55000 suite of standards, represents a significant shift from traditional approaches focused primarily on construction and maintenance. It emphasises the alignment of assets with organisational objectives, informed decision-making across the asset lifecycle, risk-based prioritisation, and the delivery of value to stakeholders. For consulting engineers, owners, operators, and policy-makers alike, this approach provides a common language and framework to bridge technical, financial, digital, and strategic considerations.

Across Europe, Asia, USA, Japan, China and Australia, asset management has already transformed how governments and private owners view their built environments. Asset management is no longer a peripheral subject; it is a national necessity.

India today stands at a pivotal moment. Massive investments are being made in transport, energy, water, urban infrastructure, and public buildings. At the same time, ageing assets, constrained resources, climate risks, and rising service expectations demand that we extract maximum value from existing infrastructure, and design and build new infrastructure to deliver sustainable value to the asset owner, the wider society, and the environment. Formal asset management practices offer a powerful means to address these challenges - enabling organisations to optimise performance, manage risk, ensure safety and compliance, and improve long-term sustainability. Companies or certain sectors of companies, such as Power Grid Corporation of India, Reliance Infrastructure, Vedanta, Balasore Alloys, Balco, Delhi International Airport AGL and L&T Construction are already certified to ISO:55000. The Public Works Departments and many other Government Departments have their laid down standards which the Public Sector enterprises, which were created later, either adopted or formed their own. The National Building Code of India 2015 introduced Asset & Facility Management to outline the requirements for buildings. However, the NBC and all the standards only deal with limited aspects, and they need to be updated to bring them in line with the current thinking and practice of asset management, as well as to adopt the use of digitalisation.

This issue brings together a diverse collection of technical articles from practitioners, academics, and industry experts, each offering unique perspectives on the physical asset management of infrastructure and built-environment assets. The contributions span a wide range of topics, including asset management frameworks and maturity, lifecycle planning, asset criticality and risk assessment, digital enablement, condition monitoring, governance, skill development, and the integration of sustainability considerations into asset decisions. Together, they illustrate both the depth and breadth of asset management as a professional discipline.

Importantly, the articles highlight that asset management is not a one-size-fits-all solution. While the principles of ISO 55000 are globally applicable, their effective implementation requires contextualisation to local regulatory environments, organisational capabilities, and sector-specific realities. Consulting engineers play a crucial role in this journey - translating standards into practical strategies, designing systems and processes, and supporting owners and operators in embedding asset management into everyday decision-making.

CEAI has long been committed to advancing professional excellence and thought leadership in the engineering profession. By curating this issue on Asset Management, CEAI seeks to raise awareness, stimulate informed dialogue, and encourage the wider adoption of structured asset management practices across India's infrastructure ecosystem. We hope that this issue of *ViewPoint* will serve not only as a source of technical insight, but also as a catalyst for change – prompting organisations to view assets not merely as physical objects, but as strategic enablers of value, resilience, sustainable development – all making good business sense.

The common purpose of CEAI and the Institute of Asset Management (IAM) India Chapter is to promote the message of Asset Management. IAM had its first conference on **Asset Management – Unlocking Value for India** on 10^{th} -11^{th} December 2025 in Mumbai. Some of the articles in this issue of *ViewPoint* are based on the presentations made by the authors at this conference. CEAI thanks IAM India for this support and collaboration. Further details about the conference can be found at https://www.linkedin.com/feed/update/urn:li:activity:7408107124230316032.

We thank all the authors for their valuable contributions and invite readers to engage deeply with the ideas presented in this issue. As India continues to build and manage the infrastructure of the future, ***Asset Management*** will undoubtedly play a central role in ensuring that these assets deliver enduring value for generations to come.

Enjoy reading this issue and gainfully deploy the principles and practices mentioned herein.

Wishing Everyone A Happy & Prosperous New Year!

Dr. Harshavardhan Subbarao
Chairman & Managing Director,
Construma Consultancy Pvt. Ltd.
Chair, CEAI Western Region
Director, Institute of Asset Management India
President, International Association for Bridge & Structural Engineers, Zurich

Dr. Navil Shetty
President, Institute of Asset Management India
Co-Founder, Glentec Digital Technologies Pvt. Ltd.

Announcing....

FIDIC **Global Infrastructure Conference (GIC) 2026** being organised

13 - 15 September 2026 at New Delhi

Further details on the conference theme, programme, speakers, and participation opportunities will be made known soon......

Mark the dates in your calendar and join us for this important event to boost the image of Consulting Engineers in India

CEAI
Consulting Engineers Association of India

01

Asset Management for Sustaining Built Facilities: Practical Overview for Today's Built Environment

Vasudevan Suresh
Fmr Chairman HUDCO;
Chairperson, NBC Committee,
Bureau of Indian Standards

Arun Kumar S
Head, NBC Cell
Civil Engg Department,
Bureau of Indian Standards

Abhishek Sharma
Scientist
Civil Engg Department,
Bureau of Indian Standards

Introduction

Buildings are among the most important assets created by any society. Once constructed, they are expected to serve people for many decades. However, a building does not remain functional on its own. Every facility, whether an office, residential complex, hospital, school, or industrial plant, requires regular care and systematic management to function optimally throughout its lifespan.

This is where asset management becomes essential. The National Building Code of India, through its chapter on Asset and Facility Management, provides guidance on how buildings should be operated and maintained after construction. This has become very important for buildings, per se, but crucial for tall buildings. The aim is simple: to ensure that built facilities remain safe, reliable, comfortable, and resource-efficient at all times.

With rapid urban development in India, the demand for organised maintenance and skilled facility management has increased significantly. Well-managed buildings not only improve user experience but also reduce costs and enhance the overall life of the asset.

Understanding Asset and Facility Management

Asset management refers to the planned care of the physical components of a building, its structure, electrical systems, plumbing networks, HVAC installations, lifts, and fire safety systems. It ensures that every part of the building performs the way it was intended.

Facility management, on the other hand, focuses on the day-to-day services that support the building's functioning. These include housekeeping, waste collection, pest control, landscaping, and security services.

Both together help in maintaining a building in good condition and ensuring that the occupants are in a safe and comfortable environment.

Why Asset Management is Important

Buildings serve the functions for which they are intended for many years after construction, and most of their life-cycle cost arises during that long phase. If maintenance is neglected, problems such as rainwater leakages, plumbing leakages, electrical faults, poor indoor air quality or lift failures start appearing. These issues not only disturb daily activities but also reduce the life of the facility.

Organised asset management offers several benefits, as shown in Figure 1.

Figure 1: Benefits of organised Asset Management

Well-maintained buildings also contribute to sustainability goals by reducing waste and environmental impact. (Refer Figure 2).

Figure 2: Well-Maintained Buildings

Key Components of an Asset Management System

An effective asset management system requires a few essential elements. (Refer Figure 3).

1 **Asset Register:** A complete record needs to be kept of all the assets in the building, their specifications, installation dates, and maintenance history. The record forms the foundation of planning their upkeep.

2 **Documentation:** As-built drawings, operation manuals, warranties, and maintenance instructions must be preserved and updated. These documents help the facility management teams understand how the systems are designed and how they should be maintained.

3 **Maintenance Planning:** Every building needs a structured plan that identifies what maintenance is required, how frequently it should be done, and who is responsible. This prevents unexpected failures.

4 **Condition Assessment:** Regular inspections help in identifying early signs of deterioration. This allows timely repairs and reduces the chances of emergency breakdowns.

5 **Risk Classification:** Some assets are more critical than others. Systems such as fire pumps, fire-rated

Figure 3: Key Components of an Asset Management System

doors/ shutters, electrical panels, and lifts require higher priority because any failure can lead to major safety concerns.

6 **Skilled Facility Personnel:** Qualified engineers, technicians, supervisors, and trained staff are essential for proper management of a building. Their coordination ensures smooth operations.

7 **Use of Technology:** Modern buildings increasingly use digital tools like Building Management Systems (BMS), Computerised Maintenance Management Systems (CMMS), sensors, and digital dashboards to monitor performance and improve efficiency. The use of digital technology serves to maintain accurate and updated records, which makes maintenance and repairs more efficient and effective.

Types of Maintenance

Maintenance activities can be broadly grouped into planned and unplanned categories.

1 **Planned Maintenance**

This includes work done at regular intervals to prevent faults.

a) Preventive Maintenance: Scheduled cleaning, lubrication, adjustments, and replacements of parts.

b) Condition-Based Maintenance: Maintenance carried out based on actual equipment condition observed through physical inspection or sensors.

c) Reliability-Centred Maintenance: Focused attention on the most critical systems.

d) Shutdown Maintenance: Major repairs done during planned facility shutdowns.

2 **Unplanned Maintenance**

This involves action taken when unexpected faults occur.

a) **Corrective Maintenance**: Repairs needed when minor issues are detected.

b) **Breakdown Maintenance**: Repairs after complete failure of equipment.

c) **Emergency Maintenance**: Immediate response required to avoid safety hazards or operational stoppage.

Planned maintenance is always more economical and effective, besides requiring less time than unplanned maintenance.

Management of Hard Services

Hard services refer to the technical and structural systems of a building, as shown in Figure 4. They comprise:

1 **Building Structure and Fabric:** Roofs, false ceilings, walls, flooring, windows, and other physical elements must be checked regularly for cracks, seepage, corrosion, and wear.

The false ceiling system also needs to be checked to ensure that the hangers/ suspenders, anchors, supporting grid members, etc., are in proper condition.

2 **Plumbing and Drainage:** Pumps, pipelines, overhead tanks, sewage systems, and wastewater treatment plants need ongoing attention to prevent leakages, blockages, or contamination. Gas lines and connections would call for more frequent checks.

3 **HVAC Systems:** Heating, ventilation, and air-conditioning systems influence comfort and indoor air quality. Filters, ducts, chillers, fans, and cooling towers must be cleaned and serviced as per schedule. Filters, at times, get choked with combustible material, which could become a source of fire, and hence the periodicity of their checking should be suitably planned.

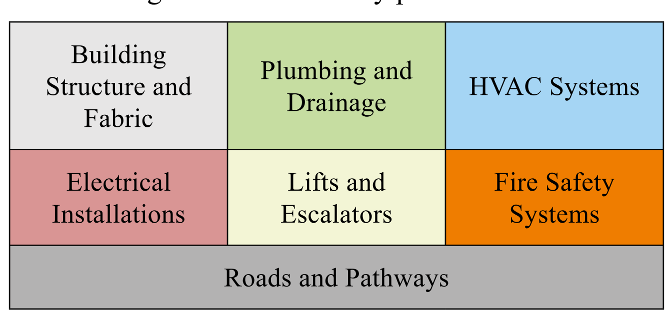


Figure 4: Hard Services for a Building Facility

4 **Electrical Installations:** This includes switchgear, wiring, earthing UPS, distribution boards, and generators. Electrical systems must be tested frequently to prevent failures and ensure safety.

5 **Lifts and Escalators:** The people and goods movers, plus the fire lifts require daily inspections, periodic testing, and annual third-party evaluations to ensure safe vertical transportation.

6 **Fire Safety Systems:** Fire alarms, sprinklers, hydrants, extinguishers, and emergency lighting must be checked regularly to ensure that they work during an emergency.

7 **Roads and Pathways:** Internal roads, pavements, signage, and lighting also form part of the facilities' assets that require maintenance.

Management of Soft Services

Soft services support cleanliness, hygiene, and the overall quality of the built environment, refer Figure 5. They include:

1 **Housekeeping:** Regular cleaning of floors, corridors, washrooms, and common areas ensures a healthy and pleasant environment.

2 **Pest Control:** Scheduled treatment prevents rodents and insects from damaging building components and affecting hygiene.

3 **Waste Management:** Waste must be properly segregated, collected, and disposed of in line with local regulations. Many facilities now include composting and recycling.

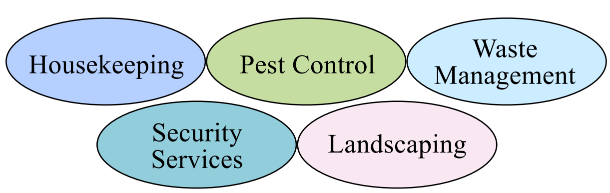


Figure 5: Soft Services for a Building Facility

4 **Security Services:** Security and thus safety needs to be provided not only by physical barriers and guards but also by means of the requisite Security systems involve monitoring access & egress, maintaining visitor records, operating CCTV systems, motion detectors, and ensuring the overall safety of the occupants and the facility.

5 **Landscaping:** Maintenance of gardens, lawns, trees, and green areas enhances the building's appearance and improves the environmental quality. All of them also need to be given individual attention.

Procurement and Financial Planning

Effective facility management requires proper budgeting and clear procurement processes (Figure 6).

Figure 6: Procurement & Financial Planning

1 **Budgeting:** Owners must allocate funds for routine maintenance, repairs, spare parts, and major replacements. Regular budgeting would avoid sudden financial shocks.

2 **Outsourcing Services:** Many buildings appoint external agencies to carry out maintenance and facility services. Agencies should be selected carefully based on qualifications, experience, manpower strength, and performance track record. Their work, in any case, needs to be monitored.

3 **Service-Level Agreements (SLAs):** SLAs define the responsibilities and performance standards expected from service providers. This improves accountability and ensures quality and timeliness.

4 **Common Area Maintenance (CAM) Charges:** In shared buildings, CAM charges must be calculated transparently so that occupants clearly understand how their maintenance contributions are used.

Safety, Health, and Environmental Considerations

A safe and healthy environment is central to facility management (Refer 7).

Figure 7: Safety, Health, and Environmental Considerations

1 **Occupational Safety:** Workers must be trained in safe work practices, the use of personal protective equipment, and emergency procedures. Permit-to-work systems are required for high-risk tasks.

2 **Environmental Care:** Proper ventilation, temperature control, and waste reduction practices help reduce environmental impact. Water conservation and energy efficiency measures are now essential components of maintenance planning.

3 **Indoor Air Quality:** Good indoor air quality supports occupant health and productivity. Maintenance of HVAC system - fresh air supply, and clean filters play a major role here.

Role of Digital Technologies

Digital tools are increasingly being used to manage building performance more effectively (Figure 8).

1 **Building Management Systems (BMS):** These systems automatically control HVAC, lighting, water pumps, and energy systems, improving efficiency.

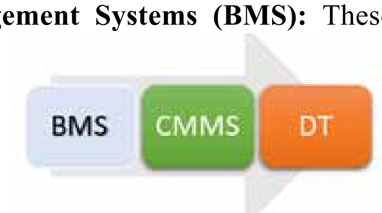


Figure 8: Digital Tools

2 **Maintenance Software:** CMMS platforms help in scheduling tasks, tracking performance, recording complaints, and managing inventory.

3 **Digital Twin:** The Digital Twin, a virtual model of the building, enables much better planning of activities for maintenance, studying the performance of the building and systems, and simulating emergency responses.

Technology-supported management results in faster decision-making and better reliability.

Disaster Preparedness

Every building must be prepared to respond to emergencies. Facility Managers should maintain plans for (refer figure 9):

a) Fire evacuation
b) Earthquake response
c) Flood management
d) Power failures
e) Health emergencies

Figure 9: Disaster Preparedness

The National Building Code of India (NBC) also recommends regular drills, inspections, and updating of emergency equipment. Disaster preparedness helps protect life and property during unexpected events.

Conclusion

Asset Management is essential for preserving the value, safety, and usefulness of built facilities. A well-maintained building not only serves its occupants better but also reduces operational costs and remains valuable for a longer period.

The guidance provided in the NBC helps owners, engineers, and facility managers adopt organised and practical methods to manage buildings throughout their design service life. As India's built environment continues to expand, the importance of systematic asset management will only increase. With proper planning, skilled manpower (who need to regularly upgrade and update their knowledge and capabilities), and responsible operations, buildings can remain safe, efficient, and sustainable for many decades.

02

Asset & Facility Management: A Choice, Not a Chance - Enhancing Operations

Dr. C Velan
Chief Executive Officer
Ceebros Group
Convenor Chapter 12 (Asset & Facilities Management)
National Building Code of India 2025
Bureau of Indian Standards

Abstract: Operational Excellence Is a Decision

Asset & Facility Management (AFM) sits at the intersection of strategy, operations, finance, and people. It influences how reliably equipment performs, how safely people work, how efficiently resources are used, and how sustainably organisations grow. When treated as a reactive support function, AFM becomes a cost burden. When embraced as a strategic discipline, it becomes a powerful enabler of operational performance.

In an era marked by rising operational costs, ageing infrastructure, sustainability pressures, and increasing stakeholder expectations, organisations can no longer afford to leave performance to chance. Operational excellence is not accidental - it is engineered through deliberate choices, disciplined execution, and long-term thinking. One of the most decisive yet often underestimated choices organisations make is how they manage their assets and facilities.

Traditionally, asset and facility management have been viewed as necessary cost centres - focused primarily on maintenance, repairs, and compliance. This perception is rapidly changing. Modern organisations recognise that physical assets and facilities directly influence operational continuity, workforce efficiency, customer experience, and financial performance.

A strategic AFM approach aligns asset life cycles with business objectives. Instead of reacting to failures, organisations plan, predict, and optimise. The result is reduced downtime, controlled costs, improved asset utilisation, and stronger operational resilience. Thus, AFM is considered today differently, from a Cost Centre to a Strategic Enabler.

AFM sits at the intersection of strategy, operations, finance, and people. It influences how reliably equipment performs, how safely people work, how efficiently resources are used, and how sustainably organisations grow. When treated as a reactive support function, AFM becomes a cost burden. When embraced as a strategic discipline, it becomes a powerful enabler of operational performance.

This paper explores how Asset & Facility Management, when chosen intentionally rather than left to chance, enhances operations. That is supported by real-world examples across industries.

Importance of Asset & Facility Management

To emphasise the critical need for structured Asset and Facility Management, the **National Building Code of India (NBC) 2015** introduced a **dedicated chapter –**

Creating Value Ethically

Part 12: Asset and Facility Management. This marked a significant step toward formalising AFM practices across the built environment.

Part 12 provides comprehensive guidelines covering the importance, scope, and implementation of AFM, along with detailed **checklists** that span:

- Soft services (housekeeping, landscaping, support services)
- Technical services (MEP systems, building maintenance)
- Safety and Security measures
- Insurance and Risk Management
- Regulatory compliance and Statutory requirements

The code also highlights the use of advanced technologies, including Digital Twin, Building Information Modelling (BIM), and digital platforms, to enhance operational efficiency, predictive maintenance, and informed decision-making.

Core Principles of Asset & Facility Management

The principles of AFM are primarily driven by three key objectives:

a) **Asset Value Maximisation:** Ensuring optimal performance, extended asset life, and enhanced return on investment through planned maintenance and lifecycle management.

b) **Continuity of Services:** Guaranteeing uninterrupted operations and reliability of critical services at all times.

c) **Well-Being and Comfort of Occupants:** Providing safe, healthy, and comfortable environments that improve productivity, satisfaction, and overall user experience.

Beyond these, effective AFM delivers a strong business advantage by building confidence among customers, stakeholders, and occupants, reinforcing organisational credibility and long-term sustainability.

Redefining Asset & Facility Management

AFM encompasses the coordinated management of physical assets and the facilities in which organisations operate. These assets include:

- Production equipment and machinery
- Buildings and infrastructure
- Utilities and energy systems
- Transportation and logistics assets
- IT and operational technology environments

Facilities provide the environment for people, processes, and technology to function efficiently, while assets deliver operational capability. Managing them together creates synergy and operational coherence.

Why AFM Is a Strategic Choice

Organisations that excel operationally do so because they choose to manage assets and facilities with purpose. This choice manifests in several strategic dimensions.

1 **Alignment with Business Objectives**

Assets and facilities must serve business goals - not operate independently of them. Strategic AFM aligns asset performance with objectives such as:

- Production reliability
- Customer satisfaction
- Cost leadership
- Safety excellence
- Sustainability targets

2 **Example – Manufacturing Sector**

A global manufacturing company faced frequent production stoppages due to ageing equipment. Instead of continuing reactive repairs, leadership aligned AFM with the company's growth strategy. Critical assets were identified, lifecycle costs analysed, and replacement priorities defined. Within two years, unplanned downtime was reduced by 35%, directly supporting increased production output.

Proactive Management: Moving Beyond Firefighting

1 **Preventive and Predictive Maintenance**

A core choice in AFM is whether to prevent failures or respond to them. Preventive maintenance schedules tasks based on time or usage, while predictive maintenance uses condition data to anticipate failures.

2 **Example – Utilities Sector**

An electricity distribution company transitioned from reactive maintenance to predictive maintenance using condition monitoring on transformers. Early detection of insulation degradation prevented catastrophic failures, reduced outages, and improved customer reliability indices.

3 **Operational Impact**

The shift to proactive maintenance results in:

- Reduced emergency repairs
- Improved safety conditions
- Better planning of labour and spare parts
- Increased confidence in operational schedules

Operational stability is rarely accidental - it is built through foresight.

Data-Driven AFM: Turning Information into Advantage

1 **The Role of Digital Tools**

Modern AFM relies heavily on accurate, accessible data. Tools that provide insights into asset health, performance trends, and energy consumption are:

- Computerised Maintenance Management Systems (CMMS)
- Enterprise Asset Management (EAM) systems
- Building Management Systems (BMS)
- Internet of Things (IoT) sensors

2 **Example – Healthcare Facilities**

A hospital network implemented an integrated CMMS across multiple sites. Equipment maintenance histories, compliance records, and failure data became centrally visible. The result was improved regulatory compliance, faster response times for critical medical equipment, and enhanced patient safety.

The hospital did not improve by chance - it chose transparency, data, and accountability.

Lifecycle Thinking: Managing Total Cost of Ownership

1 **Beyond Initial Investment**

One of the most common AFM mistakes is focusing on acquisition cost while ignoring lifecycle implications. Assets that appear cheaper initially often incur higher costs through:

- Frequent breakdowns
- High energy consumption
- Costly spare parts
- Short operational life

2 **Example – Commercial Real Estate**

A property developer compared two HVAC system options. While one had a lower purchase price, lifecycle analysis showed higher energy and maintenance costs over 20 years. Choosing the more efficient system resulted in lower operating expenses, improved tenant comfort, and higher building valuation.

Lifecycle thinking transforms AFM into a financial decision-making tool.

Facilities as Enablers of Workforce Performance

Facilities are not passive structures - they shape how people work, collaborate, and perform.

1 **Safety, Productivity, and Well-being**

Well-managed facilities contribute to:

- Safer working environments
- Reduced absenteeism
- Higher employee engagement
- Improved productivity

2 **Example – Logistics and Warehousing**

A logistics company redesigned warehouse layouts, improved lighting, and implemented preventive maintenance on material handling equipment. Workplace incidents declined, order fulfilment speed increased, and employee turnover reduced significantly.

Facilities that support people enhance operations naturally and sustainably.

Risk Management and Compliance: Choosing Control Over Exposure

1 **Managing Operational Risk**

Assets and facilities carry inherent risks - mechanical and electrical equipment failures, fire, environmental and climatic incidents, and regulatory non-compliance. Strategic AFM identifies, prioritises, and mitigates these risks systematically.

2 **Example – Oil & Gas Facilities**

An upstream oil facility implemented risk-based inspection and maintenance for pressure equipment. Critical assets received focused attention, while low-risk items were optimised. This approach reduced inspection costs while maintaining high safety and compliance standards.

Risk reduction is not luck - it is the result of disciplined asset governance.

Sustainability and Energy Efficiency Through AFM

Sustainability goals increasingly depend on how assets and facilities are managed.

1 **Energy and Environmental Performance**

AFM influences:

- Energy consumption
- Water usage
- Emissions
- Waste generation

2 **Example – Airport Facilities**

An international airport adopted energy monitoring and optimised facility operations, including lighting, HVAC, and escalator usage. Energy consumption per passenger decreased, supporting both cost reduction and environmental commitments.

Sustainable operations are achieved through intentional facility and asset choices.

The Human Factor: Skills, Culture, and Leadership

1 **People Make the Difference**

Even the most advanced systems fail without capable people. Successful AFM organisations invest in:

- Competency development on a continuous basis
- Clear roles and responsibilities
- Cross-functional collaboration
- A culture of ownership

2 **Example – Public Infrastructure Agency**

A transport authority invested in training maintenance teams on reliability-centred maintenance principles. Technicians were empowered to analyse failures rather than simply fix them. Asset reliability improved, and morale increased as teams saw the impact of their work.

AFM excellence is built by people who understand why their choices matter based on the policies, processes, procedures, work methodology and specifications for a particular job/ work.

Integration Across the Organisation

AFM delivers maximum value when integrated with:

- Operations and production
- Finance and capital planning
- Health, safety, and environment (HSE)
- Sustainability and ESG strategies

AFM with Specific Focus on Pandemic Preparedness

1 How Facility Management Focuses on Pandemic Preparedness

Pandemics such as COVID-19 have redefined the role of Facility Management (FM). No longer limited to maintenance and space management, FM has become a frontline function responsible for health protection, operational continuity, and resilience. Pandemic preparedness in FM is a structured, proactive approach that integrates people, policy, processes, procedures and infrastructure.

a) Proactive Risk Planning

Facility Management begins pandemic preparedness by identifying health-related risks and their impact on buildings, occupants, and services. This includes:

- Risk assessments for high-occupancy and high-touch areas
- Identification of critical systems such as HVAC, water, power, and sanitation
- Scenario planning for reduced manpower and restricted access

Preparedness plans are embedded into business continuity and emergency response frameworks.

b) Safe Building Design and Engineering Controls

FM focuses heavily on engineering solutions that reduce transmission risk, such as:

- Enhanced ventilation and indoor air quality management
- High-efficiency air filtration and increased fresh air circulation
- Space reconfiguration to support distancing and isolation
- Touchless technologies for doors, washrooms, and access systems

These controls provide long-term health and safety benefits beyond pandemics.

c) Enhanced Cleaning, Hygiene, and Waste Management

FM leads the implementation of advanced hygiene protocols, including:

- Increased frequency of cleaning for high-touch surfaces
- Use of approved disinfectants that do not damage building assets
- Safe handling and disposal of PPE and biomedical waste
- Training of housekeeping teams in infection control practices

These measures help create confidence among occupants and stakeholders.

d) Occupant Health and Access Management

Facility Management plays a key role in protecting building occupants through:

- Entry screening and access control measures
- Occupancy monitoring and crowd management
- Clear isolation protocols for suspected cases
- Support for flexible occupancy and staggered schedules

FM acts as the interface between occupants, health guidelines, and building operations.

e) Workforce and Vendor Preparedness

Pandemic preparedness depends heavily on people. FM ensures:

- Cross-training of essential staff
- Backup manpower plans

- Pandemic response clauses in service contracts
- Health and safety compliance for all vendors

This reduces dependency on individual resources and ensures service continuity.

f) **Communication and Confidence Building**

Facility Management ensures transparent and consistent communication by:

- Displaying health and hygiene signage
- Sharing SOPs and safety updates with occupants
- Coordinating with HR, HSE, and the leadership team

g) **Recovery and Continuous Improvement**

FM preparedness extends into recovery planning, which includes:

- Phased re-occupancy and recommissioning of assets
- Catch-up maintenance for deferred activities
- Review of performance and lessons learned

Facilities use these insights to strengthen future preparedness.

Conclusion: Choosing Excellence Over Chance

Asset & Facility Management is a choice, not a chance. Organisations that leave asset performance to reactive decisions, outdated practices, or fragmented responsibilities accept unnecessary risk and inefficiency. Those that choose strategic AFM - aligned with business goals, powered by data, supported by skilled people, and focused on lifecycle value - achieve superior operational outcomes.

Across industries, the message is clear:

- Reliability does not happen accidentally
- Safety is not a coincidence
- Sustainability is not achieved by hope

Operational excellence is designed, implemented, and sustained through deliberate Asset & Facility Management.

The question for leaders is no longer *whether* AFM matters - but whether they are prepared to choose it intentionally**.**

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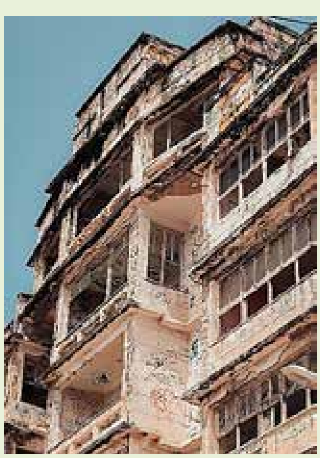
Good Asset Management Makes Sense – Both Moneywise and Safety-wise



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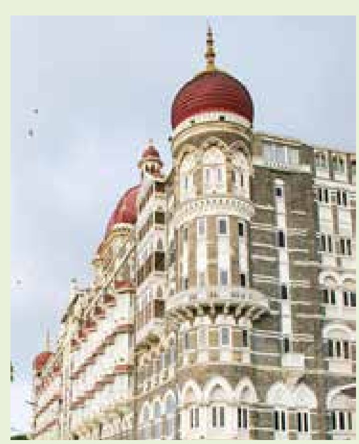

Poorly Maintained ₹ ↓

Well Maintained ₹ ↑

03

Capability – The Foundation and Success Factor for Excellent Asset Management

Andy Watts
Director
Asset Wisdom Ltd., partner of KLA, India

Introduction: Beyond Systems and Strategies

In the relentless pursuit of operational excellence, organisations often gravitate toward technological innovation, sophisticated systems, and strategic frameworks. These elements are undeniably important, but they are not the ultimate differentiator. The true foundation of sustainable success lies in capability - the skills, knowledge, and mindset of the people who bring strategies to life.

Asset Management (AM) is a discipline where this truth resonates profoundly. Asset Management decisions influence long-term value creation, risk mitigation, and performance delivery. Without capable individuals, even the most advanced systems and processes fail to deliver their intended outcomes. Capability is not a peripheral concern; it is the beating heart of asset management excellence.

Why Capability Is the Critical Success Factor

Every successful organisation shares a common thread - a strong commitment to developing capable people. While frameworks and tools provide structure, it is people, empowered with the right skills and supported by a culture of learning, who transform ambition into achievement.

In asset management, this is vital, particularly considering the complexity of asset management decisions that must balance cost, risk, and performance over multiple lifecycles of assets and asset systems. These decisions require judgment, foresight, and adaptability; qualities that cannot be hard-coded into a system - they must be cultivated in people.

The updated IAM 10-Box Model[1] reinforces this principle. It identifies capability as a core enabler across all dimensions of asset management. This is not incidental; it reflects a growing recognition that organisational maturity depends on human capability as much as on process compliance. This is seen across the world and has not only driven the update of the IAM's thinking, but also a redraft and update of the International Standard for Asset Management, ISO 55000.

The changes made to the IAM capability model reflect the growing acceptance that the human influence on good asset management practices is a differentiator. Within the expanded 10-box model, refer to Figure 1, this paper focuses on three of the new high-level elements

Figure1: IAM's 10 Box Model, © 2024 The Institute of Asset Management

that support the importance of asset management capability and the need for understanding the operating environment of the organisation.

Organisational purpose and context are drawn out at the head of the model. They are the foundation for creating and maintaining an Asset Management System that delivers long-term objectives. ISO 55001 places this first because understanding what the organisation aims to achieve for stakeholders - and how this may evolve - is critical to creating and protecting value. Asset Management leadership must consider all aspects of the operating environment, both current and future, as changes can present opportunities or risks. Proactive planning and execution are essential to manage these dynamics effectively.

Leadership is another new element, brought visibly to the forefront of the model as a true game changer. It must exist and be strong at all levels to be essential for effective asset management. It is not limited to top management; leaders throughout the organisation set direction and priorities for developing capabilities that achieve strategic objectives. This leadership goes beyond traditional management - it involves challenging the status quo, fostering innovation, and driving improvements in processes and systems. Effective leaders demonstrate emotional intelligence, resilience, and strong communication skills, inspiring creativity and motivating teams to embrace positive change that strengthens the Asset Management System.

And thirdly, Value and Outcomes - Value realisation is the process of achieving desired outcomes from an organisation's assets, considering not just outputs but impacts and for whom they matter. Asset management focuses on maximising the value assets deliver to the organisation and its stakeholders, across multiple timeframes and dimensions. Value extends beyond money to include cost, risk, performance, safety, sustainability, reputation, compliance, and environmental impact. The concept of the six capitals - financial, manufactured, intellectual, human, social and relationship, and natural - captures this broader perspective. An outcomes-based value framework should define objectives and stakeholder expectations, guiding decisions, resource use, and progress monitoring.

The Strategic Imperative: Capability as a Business Asset

Capability is not just an HR concern - it is a strategic asset. Organisations that treat capability development as a compliance exercise miss the opportunity to unlock competitive advantage. Resilience in uncertainty is one of the most compelling reasons to invest in capability. Markets shift, technologies evolve, and regulations change, but capable people adapt faster than rigid systems. Skilled professionals make better decisions, optimising asset performance and lifecycle costs. Competent teams anticipate and mitigate risks before they escalate into crises. In short, capability drives outcomes that matter to Boards and Shareholders. It is the invisible engine behind operational excellence and strategic agility.

Building Capability: A Journey, not a Task

Developing capability is not a one-off project; it is a continuous journey. Organisations must move beyond ad-hoc training and embrace structured, strategic approaches. This begins with mapping the capabilities required across the organisation, including technical skills, leadership competencies, and cultural attributes.

Once these needs are clear, the next step is to identify gaps and use tools like the IAM's SAM2025-AMA to assess capability maturity. This formal review highlights strengths and weaknesses, providing a baseline for improvement. From there, organisations should design tailored learning journeys that align with organisational goals and individual career aspirations.

Learning should not be confined to occasional workshops; it must be embedded in the culture, starting at induction and continuing throughout employment. An example of topics covered in an asset management Hybrid Learning Journey is shown in Figure 2. They are a mix of self-study to maximise flexibility and virtual or face-to-face discussion sessions to broaden and embed the learning, adding enhanced value to both the learners and their organisations. The example aligns with the IAM Certificate and Diploma qualifications.

Finally, capability development should be reviewed regularly to ensure it keeps pace with changing business needs. This approach transforms capability from a checkbox into a strategic lever for growth.

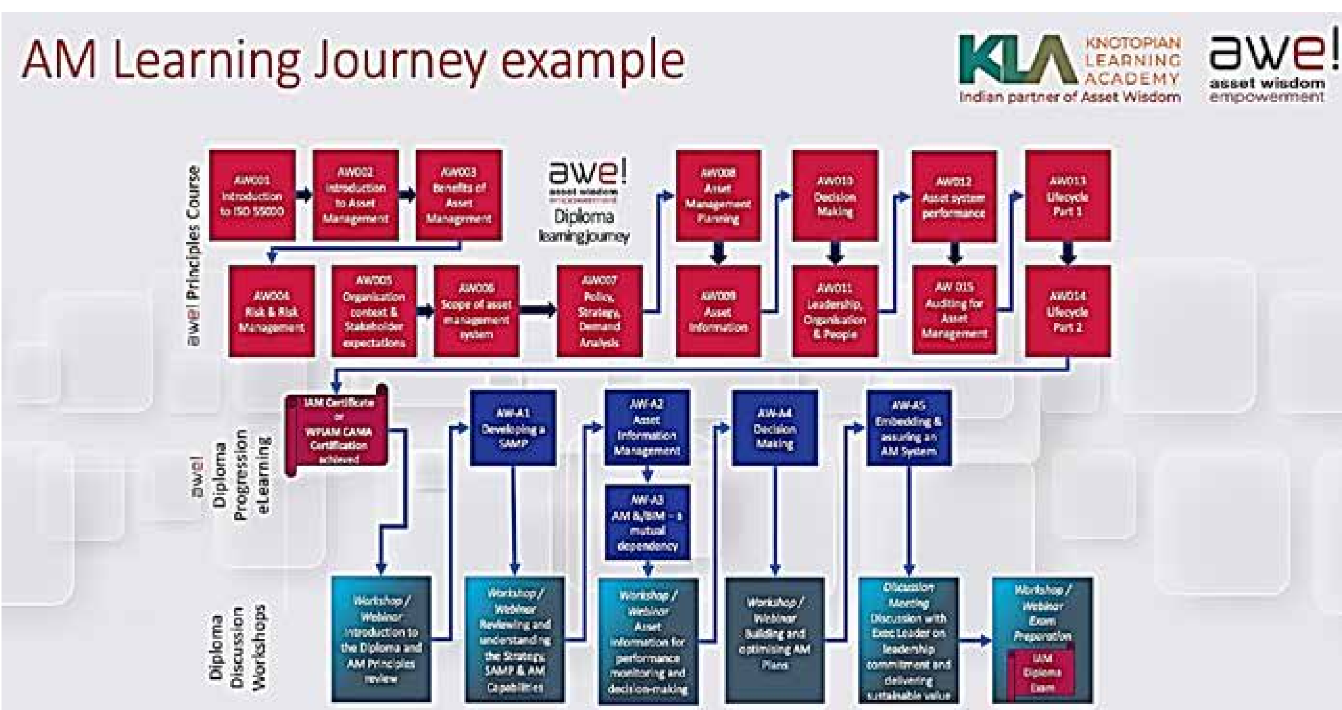

Figure 2: AM Learning Journey Example

Tools and Frameworks: Turning Vision into Action

The Institute of Asset Management provides a body of knowledge and resources to support capability development, including:

- Asset Management – An Anatomy v4 (2024), which defines the principles and practices of AM.
- A Competency Framework that offers a structured guide to the skills and behaviours required for effective asset management.
- Learning journeys and qualifications that enable individuals and organisations to progress from awareness to mastery.
- The recently released SAM2025-AMA tool allows organisations to assess their own maturity against the 10-box model.

These resources are not just academic; they are practical instruments for embedding capability into organisational systems and culture.

Case in Point: Capability as a Catalyst

Consider organisations that have embraced capability as a strategic priority. They report tangible benefits such as improved decision quality, where teams equipped with robust AM knowledge make decisions that optimise cost, risk, and performance.

Enhanced compliance is another outcome, as capability development supports adherence to standards like ISO 55001, reducing audit stress and reputational risk. Perhaps most importantly, a focus on learning fosters cultural transformation, driving engagement, innovation, and collaboration. These outcomes are not accidental; they are the result of deliberate investment in people.

The Future of Asset Management: Human-Centric Excellence

Looking ahead, the asset management landscape will become more complex. Digital technologies, sustainability imperatives, and regulatory pressures will reshape the operating environment. In this context, capability is not optional; it is existential. Technology will change. Markets will shift. But the power of capable people endures. Organisations that recognise this truth and act on it will not only survive - they will thrive.

The future of Asset Management will be defined by complexity and rapid change. Digital technologies such as AI, IoT, and predictive analytics are transforming how assets are monitored, maintained, and optimised. Sustainability imperatives are driving organisations to rethink lifecycle strategies, embedding environmental and social considerations into every decision. At the same time, in many countries, regulatory pressures are intensifying, demanding greater transparency, compliance, and accountability.

In this evolving landscape, capability is not optional - it is existential. Technology will continue to advance, and markets will shift unpredictably, but these changes only amplify the need for skilled, adaptable people. Systems and tools can process data, but they cannot interpret context, balance competing priorities, or make nuanced decisions that align with organisational purpose and stakeholder expectations. That responsibility rests with capable leaders and teams.

Human-centric excellence means investing in people as the ultimate differentiator. It requires cultivating technical expertise alongside critical thinking, emotional intelligence, and resilience. It demands leaders who can inspire innovation, challenge the status quo, and navigate uncertainty with confidence. Organisations that prioritise capability development will not only keep pace with change, but they will shape it. They will turn disruption into opportunity, leveraging technology as an enabler rather than a crutch.

The future belongs to organisations that recognise this truth and act decisively. Those that embed capability into their culture, strategy, and systems will thrive in a world where adaptability and insight matter more than ever. In asset management, the power of capable people endures - and it will remain the cornerstone of sustainable success.

The Call to Action

The question is not whether one can afford to invest in capability. The question is whether one can afford not to. For leaders, this means elevating capability development to a Board-level priority, allocating resources for structured learning and assessment, and embedding capability into strategic planning and performance metrics. Capability is the foundation and success factor for excellent asset management. It is the hidden engine that powers resilience, innovation, and the creation of value. The time to act is now, and adopt a simple action plan to set up a review and improvement programme for the organisation:

a) Review and document what capabilities are needed across the organisation,

b) Identify capability gaps and develop appropriate Learning Journeys,

c) Implement a Capability Enhancement Programme, including embedding AM awareness and learning into Induction/ Onboarding programmes, and

d) Review regularly through the organisation's continuous improvement processes and programmes.

Thus, the organisation can build a strong asset management capability within itself.

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1) The Institute of Asset Management – 10 Box Model from *Asset Management – An Anatomy v4 (2024),*

Russia explores the possibility of building a second nuclear power plant in India

The two sides decided to expand their nuclear cooperation, including fuel cycle, life cycle support for operating Kudankulam Nuclear Power Plant and non-power applications.

India and Russia will take their nuclear cooperation further with the discussion over building a second nuclear power plant finding mention in the talks between the Russian President Vladimir Putin and the Indian Prime Minister Narendra Modi.

The two sides had a detailed discussion over extending the strategic partnership between the two countries that has stood the test of time. Both sides noted that the partnership has remained resilient in the backdrop of the prevailing complex, challenging and uncertain geopolitical situation.

The two sides noted the importance of further discussion on building a second nuclear power plant for India. The Indian side will "strive to finalize formal allotment of the second site in accordance with earlier signed agreements."

The talks over a second nuclear power plant come at a time when the government is planning to ease the entry of private players in the tightly controlled nuclear power space. The Atomic Energy Bill is in advanced stages of preparation and is expected to also focus on easing the liability clause that will further facilitate the entry of foreign suppliers.

The two sides decided to expand their nuclear cooperation, including fuel cycle, life cycle support for operating Kudankulam Nuclear Power Plant and non-power applications.

Source: Excerpts from Money Control

Asset Management for Sustaining Built Facilities: Enhancing Lifecycle Value through Digital & Data Driven Strategies

04

Dr. Aditi Nautiyal
Assistant Manager -DATBU
TATA Consulting Engineers Ltd.

Abstract

In capital-intensive industries such as Oil refineries, LPG, LNG, chemical & industrial plants, the physical assets represent a significant proportion of the investment and operational costs are high. In large-scale infrastructure projects for roads & highways, railways & metros, airports, docks & harbours, the investments are also large, but the operational costs vary. Robust Asset Management (AM) frameworks enable organisations to optimise asset performance, minimise life-cycle costs, and align maintenance and operations activities with business objectives. Artificial Intelligence (AI), allied with digitisation techniques such as laser scanning, Internet of Things (IoT) sensors, Digital Twins and predictive analytics, can improve availability, lower whole-life costs, and support ISO 55000-aligned governance. This paper synthesises recent literature and practice, describes core digital/ data-driven strategies - scan-to-BIM, condition monitoring, predictive maintenance, optimisation and reliability techniques. It also discusses standards and organisational enablers and barriers, and presents a concise table mapping technologies to benefits and challenges. The research draws on recent literature and operational case studies to support practical application.

Keywords: Asset Management, Artificial Intelligence, Lifecycle Cost, Asset Digitisation, Predictive Maintenance, ISO 55000, Industry 4.0, Reliability, Maintenance Strategy.

Introduction

In today's Industrial landscape, companies engaged in design engineering of refineries, plants and asset-revamp projects face the challenge of maximising value from large portfolios of physical assets, which include process equipment, pipelines, instrumentation, structural assets and supporting infrastructure. They all have long lifetimes and incur significant maintenance, inspection, repair and replacement costs. Inefficient AM results in unplanned downtime, increased safety/risk exposure, higher operational expense and sub-optimal utilisation of capital.

Asset management is a crucial discipline for organisations seeking to optimise the performance and value of their physical assets. Strategically balancing various factors, it enables companies to achieve their defined objectives while managing the entire asset lifecycle. Effective AM goes beyond simple maintenance, focusing on a holistic approach that reduces both operational and capital costs. It is essential for minimising safety, health, legal, and environmental risks associated with asset operation, thereby safeguarding an organisation's reputation and ensuring compliance with regulatory requirements. The core function of AM is to strategically blend activities to achieve an optimal balance of these benefits, ultimately enhancing the organisation's overall performance and value.

Figure 1 illustrates the exterior view of an asset, which is a fully operational industrial plant. The image highlights the structural components and layout of the facility, providing a visual representation of its physical characteristics and functional design.

Figure 1: Plant as an Asset
(Image published with the permission of KRIBHCO. All Intellectual Property Rights in the photograph belong exclusively to KRIBHCO)

An effective asset management framework considers the full lifecycle of the assets from creation/ acquisition through operation to disposal or repurposing, as shown in Figure 2.

The activities that are essential for managing each phase of an asset's lifecycle are:

a) **Planning**

This phase involves defining the strategic direction for AM. The key activities are:

- Identifying needs based on operational requirements and future growth.
- Setting clear objectives aligned with organisational goals.
- Budgeting and resource allocation to ensure financial feasibility.
- Conducting risk assessments to anticipate potential challenges and mitigate them proactively.

b) **Acquisition**

Focused on obtaining the right assets at the right cost and time. The activities include:

- Sourcing and vendor evaluation to select reliable suppliers.
- Purchasing and contract management while ensuring compliance and cost-effectiveness.
- Deployment and installation with minimal disruption to operations.

c) **Operation**

Ensures assets deliver optimal performance throughout their useful life. The activities include:

- Monitoring performance metrics such as efficiency, output, and safety.
- Implementing operational best practices for safe and effective utilisation.
- Compliance with regulatory standards to maintain legal and environmental obligations.

d) **Maintenance**

A critical phase for sustaining asset reliability and longevity. The activities include:

- Preventive maintenance to avoid unexpected failures.
- Predictive maintenance using data analytics and condition monitoring.
- Corrective maintenance to restore functionality after breakdowns.
- Documentation and reporting for continuous improvement.

e) **Decommission/ End of Life (EoL)**

Responsible retirement of assets at the end of their lifecycle. The activities include:

- Decommissioning and dismantling safely.
- Selling or recycling components to recover value and reduce waste.
- Environmentally responsible disposal in compliance with sustainability standards.

Figure 2: Asset Management Framework

Historically, maintenance management focused on breakdown repair; preventive maintenance and scheduled replacement came in later. However, with the emergence of digital technologies, Internet-of-Things (IoT), big data analytics and machine learning, there is a shift towards data-driven decision-making, predictive maintenance and lifecycle asset optimisation. For organisations that involve asset digitisation, 3D modelling, laser scanning and AI/ ML initiatives, integrating such advanced AM practices can significantly improve asset reliability, safety and total cost of ownership.

ISO, the International Organisation for Standardisation, developed and published the ISO 55000-series, which sets out vocabulary, principles, and management-system expectations that organisations should meet to achieve systematic asset value realisation[1, 2, 3]. Embedding AI and digital technologies within the ISO framework facilitates a shift from reactive and calendar-based maintenance to condition-based, predictive, and optimisation-driven decision-making, which improves asset availability and reduces whole-life costs[4].

Digital and Data-Driven Pathway for Asset Management

The digital and data-driven approach involves several key steps, which are as follows:

- **Capturing Accurate As-Built Geometry and Metadata**

  This initial step involves using technologies like laser scanning to create detailed 3D point clouds of physical assets. The data is then converted "scan-to-BIM" (Building Information Modelling), to provide a precise digital representation of the asset's geometry and associated metadata, serving as a foundational digital record[5, 6].

- **Instrumenting Assets with IoT Sensors for Condition Signals**

  Physical assets are equipped with Internet of Things (IoT) sensors that continuously collect real-time data on the asset's condition, such as temperature, vibration, pressure, or other key performance indicators. That provides a constant stream of "condition signals" that reflect the asset's health at that point in time[7].

- **Centralising Data in an Asset Management System (EAM/ CMMS) or Digital Twin**

  The data from the IoT sensors, along with the as-built metadata from step 1, is consolidated into a central platform. This could be an Enterprise Asset Management (EAM) or Computerised Maintenance Management System (CMMS), or a more advanced Digital Twin platform that creates a virtual model of the physical asset and its real-time data[8, 9].

- **Applying ML/ AI Models for Anomaly Detection and Remaining Useful Life (RUL) Prediction**

  Machine learning (ML) and AI models are applied to the centralised data to analyse the condition signals to detect anomalies that may indicate a potential failure before it occurs. They also predict the asset's Remaining Useful Life (RUL), providing a timeline for when maintenance would be needed[10, 11, 12].

- **Optimisation and Decision Support Layers for Maintenance Planning and Investment Prioritisation**

  The insights gained from the ML/ AI models are fed into optimisation and decision-support systems, which help maintenance planners schedule work more effectively, prioritise investments based on asset health and criticality, and determine the most cost-effective strategies to ensure asset reliability and performance[13, 14].

Leading utilities and industries report measurable reductions in unplanned downtime and improved planning as they progress along this path[15, 16, 17].

The information provided in Table 1 describes key facets of modern, data-driven asset management, including the foundational role of ISO 55000 family standards in governance, the impact of digitisation technologies like laser scanning, the application of predictive maintenance and condition monitoring, and the use of digital twins and reliability engineering for operational optimisation.

Table 1: Key facets of modern, data-driven asset management

Strategic Pillars	Key Concepts	Description	Key Application	Benefits	Sources
Standards and Governance	ISO 55000/ ISO 55001	Defines asset management principles, specifies Asset Management System (AMS) requirements, and provides implementation guidance.	Provides governance backbone for digital initiatives, aligning organisational strategy with asset decisions, supported by case studies in transport and utilities.	Ensures that digital initiatives translate into measurable business outcomes, such as better management of risk appetite, improved lifecycle planning, and clear performance metrics.	1, 2, 3
Digitisation	Laser scanning & scan-to-BIM	Uses Terrestrial Laser Scanning (TLS) and LiDAR to produce point clouds, processed into BIM/digital twin models for accurate as-built baselines.	Used for maintenance, retrofit planning, and regulatory compliance in bridges, tunnels, and buildings; reduces surveying time and improves accuracy for condition assessment.	Provides accurate "as-built" baselines for maintenance, planning, and compliance, leading to reduced surveying time and enhanced accuracy in condition assessments and retrofit design.	5, 6
Predictive Maintenance & Condition Monitoring	Predictive Maintenance	Employs sensor data, signal processing, and Machine Learning to detect anomalies and predict remaining useful life (RUL) of assets.	Broad adoption across rotating machinery, HVAC systems, and large infrastructure, though challenges exist with data quality and transferability.	Enables the detection of anomalies and prediction of failures, allowing for proactive intervention to prevent unexpected downtime and associated costs.	18, 19, 20

Strategic Pillars	Key Concepts	Description	Key Application	Benefits	Sources
Digital Twins & optimisation	Digital Twins & optimisation	Combines physics-based and data-driven models for simulation, what-if analysis, and operational optimisation.	Enables scenario planning and integrating AI outputs into workflows; integration complexity, data governance, and fidelity control are noted barriers.	Facilitates powerful simulation and "what-if" analysis, enabling better scenario planning and the integration of AI outputs into operational workflows for optimised decision-making.	21, 7, 22
Reliability Engineering & Maintenance Optimisation	Reliability engineering	Foundational methods like Reliability-Centred Maintenance (RCM) and condition-based maintenance, coupled with AI (RCM 4.0 concepts).	Enables automated prioritisation and plan optimisation subject to risk and cost constraints.	Automates prioritisation and optimises maintenance plans based on risk and cost constraints, moving beyond traditional methods for improved efficiency and asset longevity.	13, 23, 24

Challenges and Enablers in Implementing Advanced Asset Management Systems

Implementing advanced Asset Management systems in industrial plants can greatly improve reliability, efficiency, and lifecycle performance. However, challenges such as poor data quality, cultural resistance, legacy infrastructure, and high costs often hinder adoption and scaling. Success depends on key enablers like strong leadership, robust digital ecosystems, standardised asset data, skilled personnel, and adherence to industry standards. A culture of continuous improvement further ensures sustainable asset performance.

Table 2 summarises the key challenges and corresponding enablers-

Table 2: Challenges vs Enablers in Advanced Asset Management

Challenges	Description & Impact	Enablers	Description & Role
Data Quality and Availability	Many assets lack sensors or accurate historical data, data silos make integration difficult. Poor data leads to unreliable analytics and decision-making.	**Digital Ecosystem & Analytics Capability**	Deploy IoT sensors, digital twin platforms, and advanced analytics (ML/AI) to capture real-time data and enable predictive insights.

Challenges	Description & Impact	Enablers	Description & Role
Organisational Culture	Maintenance, operations, and engineering often work in silos. Moving to strategic asset management requires a cultural shift toward collaboration and data-driven decisions.	**Leadership Commitment & Governance**	Strong leadership sets clear AM policies and creates cross-functional governance structures to break silos and align teams.
Legacy Systems and Assets	Brownfield plants have outdated equipment that resist digital retrofitting, making integration with modern AM systems challenging.	**Asset Data Taxonomy & Digital Asset Twins**	Standardise asset hierarchies and metadata; use digital twins to bridge legacy systems with modern platforms.
Cost and Resource Constraints	High investment needed for sensors, analytics, and digital twins. Budget limitations slow adoption.	**Human Capital & Training**	Skilled reliability engineers, data scientists, and planners ensure efficient use of technology and maximise ROI.
Complexity and Standardisation	Diverse assets from multiple vendors and ages create heterogeneous environments. Standardising taxonomy and hierarchy is difficult.	**Reliability Engineering methods**	Apply RCM (Reliability-Centred Maintenance), RCA (Root Cause Analysis), and LCCA (Life Cycle Cost Analysis) to manage complexity systematically.
Governance and risk alignment	Integrating safety, environmental, and business risks into asset decisions is complex and often overlooked.	**Industry standards adoption**	Frameworks like ISO 55000 provide structured governance and risk alignment for asset management maturity.
Scaling from pilot to enterprise	Organisations often succeed in pilots but fail to scale solutions across the entire asset base due to complexity and cost.	**Continuous improvement mindset**	Use KPIs, dashboards, and lessons learned to refine processes and enable scalable implementation.

Way Forward: Building the Future of Asset Management

Over the years, asset management has undergone a remarkable transformation, but the way to approach it must evolve with technology and business needs. In the past, maintenance strategies were largely **diagnostic**, relying on manual inspections and reactive interventions. That approach, while effective in the pre-automation era, often resulted in inefficiencies and unplanned downtime.

The introduction of **predictive maintenance** marked a significant milestone. By leveraging IoT sensors and machine learning algorithms, maintenance management moved from reactive to proactive, anticipating failures before they occurred. That shift improved reliability and optimised costs, aligning with global standards like ISO 55000.

However, the next phase is even more transformative: **prescriptive maintenance and autonomous agents**. These technologies go beyond prediction; they recommend precise actions and, in some cases, execute them autonomously[24, 25, 26]. Figure 4 shows a block representation of the transition from Manual Inspections to AI-driven Self-healing Systems. Intelligent agents powered by AI can:

- Diagnose issues in real time.
- Suggest corrective measures based on historical and contextual data.

- Enable **self-healing systems** that minimise human intervention.

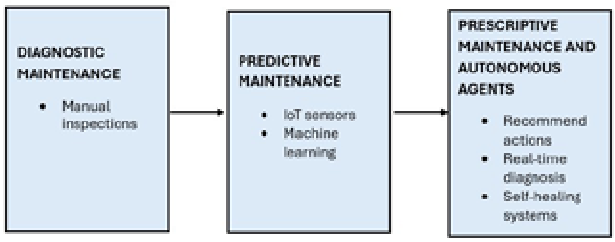

Figure 3: Block Diagram of Asset Management Evolution: From Diagnostic to Prescriptive Maintenance

The evolution is not just about technology; it is about resilience, sustainability, and creating value. As an organisation, the way forward is clear: **embrace agent-driven, prescriptive asset management**. Adopting that will ensure that the assets are not only monitored but are adaptive, intelligent, and capable of maintaining themselves. That is a strategic shift toward operational excellence and future-ready infrastructure.

Conclusion

Considering the challenges and enablers outlined in this paper, AI-driven Asset Management, when integrated within ISO 55000 governance and supported by digitisation (laser scanning, BIM), IoT, and strong data infrastructure, can significantly enhance reliability, reduce lifecycle costs, and improve resilience. While literature and industry evidence confirm these benefits, persistent issues such as data quality, workforce skills, integration complexity, and governance discipline remain critical.

Successful implementations align with the lifecycle perspective as emphasised in this paper, linking asset decisions to business outcomes and embedding digital technologies for proactive management. For asset-intensive industries, this approach delivers improved reliability, safety, cost efficiency, and better capital planning, provided challenges in data, people, process, and technology are addressed.

Looking ahead, digital transformation will accelerate beyond predictive analytics toward **prescriptive maintenance and autonomous agents**. Generative AI will redefine asset hierarchies, enabling dynamic asset registers and intelligent decision-making. Large-scale **Digital Twins** will provide real-time simulation and optimisation, while advanced prognostics will predict not only failures but also prescribe corrective actions. Sustainability integration will become a core requirement, ensuring assets contribute to environmental and social goals.

By adopting ISO 55000 frameworks and leveraging AI/ ML, predictive and prescriptive analytics, and continuous improvement, organisations can unlock greater value and competitiveness through strategic, data-driven asset management. The future is clear: **assets will evolve from being monitored to becoming adaptive and self-healing, powered by intelligent agents and resilient digital ecosystems.**

Acknowledgement

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Global asset-management firms eye diversified infrastructure portfolios.

On the global stage, firms are blending real estate, infrastructure, and logistics assets into diversified portfolios — often through funds or alternative-asset platforms. This reflects a broader trend where construction and infrastructure assets are viewed as investible real-asset classes, beyond traditional contractor/developer players..

Source: Google

05 Asset Management in Pune Metro: Sustaining Complex Urban Transit Infrastructure

Dr. Rajdeep Bhattacharya
Chief Project Officer
Pune Metro

Abstract

The Pune Metro projects, comprising underground tunnels and elevated corridors, represent a significant development of urban transit infrastructure that illustrates the critical importance of strategic asset management for sustaining built facilities. This article explores the long-term asset management challenges encountered, including maintenance of tunnels, stations, viaducts, and rolling stock support facilities, while emphasising sustainability, digital integration, and risk mitigation strategies critical to ensuring operational reliability and extended asset lifecycles.

Introduction

Urban mass transit systems serve as the lifelines of rapidly growing metropolitan cities. Pune Metro, executed by Maharashtra Metro Rail Corporation Limited (MahaMetro), comprises two primary lines: the Purple Line, which is partly underground and partly elevated, and the Aqua Line, which is fully elevated. These lines cover a combined length of about 33 kilometres with 30 operational stations, alongside planned expansions expected to add significant network coverage.

This state-of-the-art metro infrastructure addresses Pune's escalating traffic congestion, reduces environmental pollutants by encouraging public transport usage, and facilitates efficient intra-city travel. Given the scale and complexity of the Pune Metro, sustainable asset management practices become indispensable to preserving asset value and ensuring safety and service quality over the decades-long lifespan of this multimodal urban transport system.

Overview of Pune Metro Infrastructure

Network Composition

The Pune Metro consists of:

- Purple Line: 17.4 kilometres, comprising both underground tunnel sections (5 stations) and elevated corridors (9 stations).
- Aqua Line: Fully elevated, spanning approximately 15.7 kilometres with 16 stations.
- Upcoming extensions and Phase 2 developments aim to add over 35 kilometres, incorporating additional underground and elevated sections.

This blend of underground and elevated infrastructure presents diverse challenges in asset maintenance and lifecycle management due to varied exposure to environmental factors, structural dynamics, and operational requirements.

Facilities and Support Systems

Key infrastructure components requiring proactive management include:

- Underground stations and tunnels with state-of-the-art ventilation, lighting, safety, and waterproofing systems.

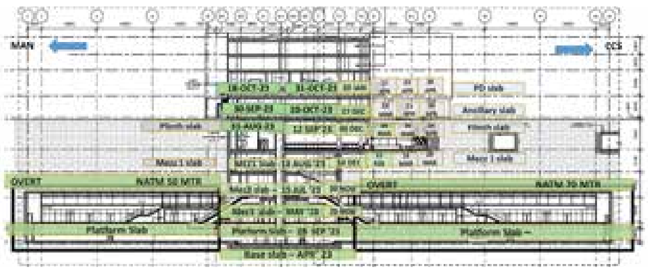


Figure 1: Typical longitudinal section of an underground station

Figure 2: Typical NATM tunnel opening

- Elevated viaducts and pedestrian corridors susceptible to weather-induced stresses.

Figure 3: Typical elevated metro station and viaduct

- Modern stations equipped with automated fare collection, HVAC, surveillance, escalators, and elevators.

Figure 4: Typical inside view of a metro station

- Rolling stock depots facilitating maintenance, parking, and control of metro trains.

Figure 5: Inside View of Metro Depot Workshop

Asset Management Challenges and Strategies

Structural Integrity and Maintenance

The longevity of tunnels and elevated structures hinges on robust maintenance protocols. Continuous Structural Health Monitoring (SHM) is done with sensors to track stresses and deformation in the tunnels and the viaducts. Preventive maintenance and timely repairs mitigate risks of deterioration caused by operational loads, groundwater seepage, or climatic factors.

Facility Operations and Equipment Management

Stations, being high footfall zones, require meticulous upkeep of electrical systems, power backup, communication networks, as well as passenger amenities. Asset Management software schedules inspections, automates repairs, and ensures compliance with safety standards.

Sustainability Integration

Adopting eco-conscious practices is pivotal throughout the asset lifecycle:

- Use of solar photovoltaic panels at metro stations and depots to supplement energy needs.
- Implementation of LED lighting and energy-efficient and CFC-free HVAC systems.
- Rainwater harvesting and wastewater recycling at

stations for sanitation and landscaping.

- Solid Waste segregation and disposal aligned with environmental regulations.

Digitalisation of Asset Management

The Pune Metro leverages cutting-edge digital platforms to:

- Track asset conditions in real-time via IoT devices embedded in the infrastructure elements.
- Automate maintenance workflows and inventory management for spare parts.
- Utilise predictive analytics to forecast failure points and schedule optimal interventions.
- Employ Geographic Information Systems (GIS) for spatial asset mapping and management.
- Such digital enablers enhance operational transparency, reduce downtime, and optimise lifecycle costs.

Risk Assessment and Mitigation

Comprehensive risk strategies address multiple dimensions:

- Structural risks assessed through SHM data and periodic third-party audits.
- Operational risks managed by redundant systems and extensive staff training on emergency protocols.
- Security risks minimised through integrated surveillance and cyber-physical safeguards.
- Environmental risks managed via sustainable design, pollution control measures, and compliance with statutory norms.

Case Study: Underground Tunnel Asset Management

The 17.4-kilometre stretch of underground tunnels of the Purple Line demands exceptional attention to safety and operational continuity, which is achieved by:

Figure 6: Tunnel inside view and a station top view of excavation

- Automated ventilation systems that respond dynamically to passenger volumes and air quality sensors.
- Waterproofing and drainage systems that are routinely inspected to prevent water ingress and structural damage.
- Fire detection and suppression infrastructure undergo scheduled maintenance supported by simulation drills.
- Access control and evacuation protocols have been rigorously implemented to ensure passenger safety.

By adopting a holistic asset management approach and utilising technology-driven monitoring, Pune Metro has maintained high availability and safety metrics.

Stakeholder Collaboration and Governance

Successful asset management in Pune Metro is founded on concerted efforts amongst:

- Government agencies, including PMRDA and Pune Municipal Corporation (PMC), providing regulatory oversight and funding.
- Design and construction partners delivering quality assets with operability and maintainability in mind.
- Operations teams empowered through training, modern tools, and safety culture.
- Technology providers integrating asset management software and IoT solutions.

Regular audits, transparent reporting, and feedback loops ensure continuous improvement in asset sustainment programs.

Future Prospects and Expansion

The ongoing Phase 2 aims to extend network reach with elevated corridors covering fast-growing suburbs. These expansions will:

- Adopt lessons learnt from the earlier phases to enhance asset management practices.
- Incorporate advanced renewable energy and water conservation measures.
- Uphold rigorous maintenance regimes supported by stronger integration of digital asset management tools.
- Prepare for increasing passenger demand and ensure scalable, resilient urban transit infrastructure.

Conclusion

Pune Metro demonstrates how the demand for comprehensive, sophisticated urban transit infrastructure can be met by forward-looking asset management strategies together with sustainability requirements by adopting state-of-the-art methods, processes, procedures and digitalisation. Through diligent lifecycle management, digital innovation, and multi-stakeholder collaboration, the system sets new benchmarks in sustaining complex built facilities. Its ongoing efforts to blend operational efficiency, environmental stewardship, and safety leadership position Pune Metro as a template for transit infrastructure sustainability in India and beyond.

The Central Electricity Authority (CEA) Outlines Framework for Monetising Public Transmission Assets

CEA has released a draft framework to guide how states can monetise their existing power-transmission assets, an effort aimed at helping utilities unlock value and attract private investment without compromising public ownership. At the heart of the proposal is the Acquire, Operate, Maintain and Transfer (AOMT) model, under which selected transmission lines and substations would be placed in a Special Purpose Vehicle (SPV) and operated by a private concessionaire for a defined period before returning to state control. Alongside this, the CEA has issued a detailed concept note on 'Revenue Certainty & Tax Incidence', outlining how tariff treatment, valuation, due diligence, licensing and tax issues may be handled to give both states and investors clarity. While still at the proposal stage, the framework reflects a coordinated push by the Ministry of Power to enable states to leverage brownfield transmission assets to bridge substantial investment gaps in the sector. With India requiring an estimated INR 9.16 trillion in transmission infrastructure by 2032 to integrate expanding renewable energy capacities, the draft model seeks to establish a predictable, transparent and investor-friendly approach to asset monetisation.

Source: CEA

06

Asset Integrity Management for Instrumentation and Control Systems

Latha D S
Senior General Manager and Discipline Head
TATA Consulting Engineers Ltd.

Executive Summary

Asset Integrity Management (AIM) ensures that physical assets perform their required functions effectively and safely throughout their lifecycle. This is especially important for the Instrumentation and Control (I&C) systems of a project since they are critical for maintaining operational reliability, safety, and compliance with industry standards. This article provides an in-depth analysis of the principles, challenges, best practices, and technologies, supported by real-world case studies from industrial applications. The intent is to enumerate a comprehensive framework for implementing AIM strategies that enhance reliability, reduce downtime, and ensure compliance with international standards.

Introduction

Asset Integrity Management refers to a systematic approach to ensure that assets are designed, operated, and maintained to perform reliably and safely. In I&C systems, AIM encompasses sensors, transmitters, controllers, and safety instrumented systems that monitor and control industrial processes. Failures in these systems can lead to catastrophic incidents that make AIM a cornerstone of process safety and reliability. The increasing complexity of industrial automation and the integration of digital technologies have amplified the need for robust AIM frameworks. Industrial production units need to address ageing infrastructure, cybersecurity threats, and regulatory compliance while optimising operational efficiency.

Objectives of AIM in I&C Systems

- Ensure operational reliability and minimise downtime through proactive maintenance strategies.
- Maintain safety and environmental compliance by adhering to international standards such as IEC 61511 and ISO 55000.
- Optimise lifecycle costs and extend asset life using predictive analytics and condition monitoring.
- Enhance resilience against cybersecurity threats in control systems.
- Facilitate informed decision-making through accurate data and documentation.

Core Elements of AIM

- Basic design considerations: Instrumentation and Control Systems need to be designed with due consideration of plant instrumentation and control system requirements, affirming minimum maintenance, plant trip, and plant shutdown.
- Risk-Based Inspection (RBI): Prioritise inspection

activities based on risk assessment to allocate resources effectively.

- Reliability-Centred Maintenance (RCM): Develop maintenance strategies focused on critical components to prevent failures.
- Condition Monitoring and Predictive Analytics: Utilise sensors and IIoT platforms to monitor asset health and predict failures.
- Lifecycle Management: Implement AIM practices from design through decommissioning to ensure long-term reliability.
- Compliance with Standards: Align AIM programs with ISO 55000, API RP 1173, and IEC 61511 for global best practices.

Integrity Challenges of Instrumentation & Control System

Despite its criticality, AIM implementation faces several challenges. Ageing assets and obsolescence of instrumentation components increase the risk of failure. Cybersecurity vulnerabilities in control systems expose organisations to potential breaches that can disrupt operations. Calibration and functional testing require specialised skills and resources, while inconsistent documentation practices hinder effective decision-making. Addressing these challenges demands a combination of technological innovation, a knowledgeable and skilled workforce, and adherence to regulatory frameworks. Figure 1 explains the pain points and advantages of AIM implementation in plants. Ageing assets and obsolescence lead to increased failure rates.

- Cybersecurity risks in control systems due to connectivity and remote access.
- Calibration and functional testing issues impacting measurement accuracy.
- Lack of standardised data and documentation across phases of the asset's life cycle.

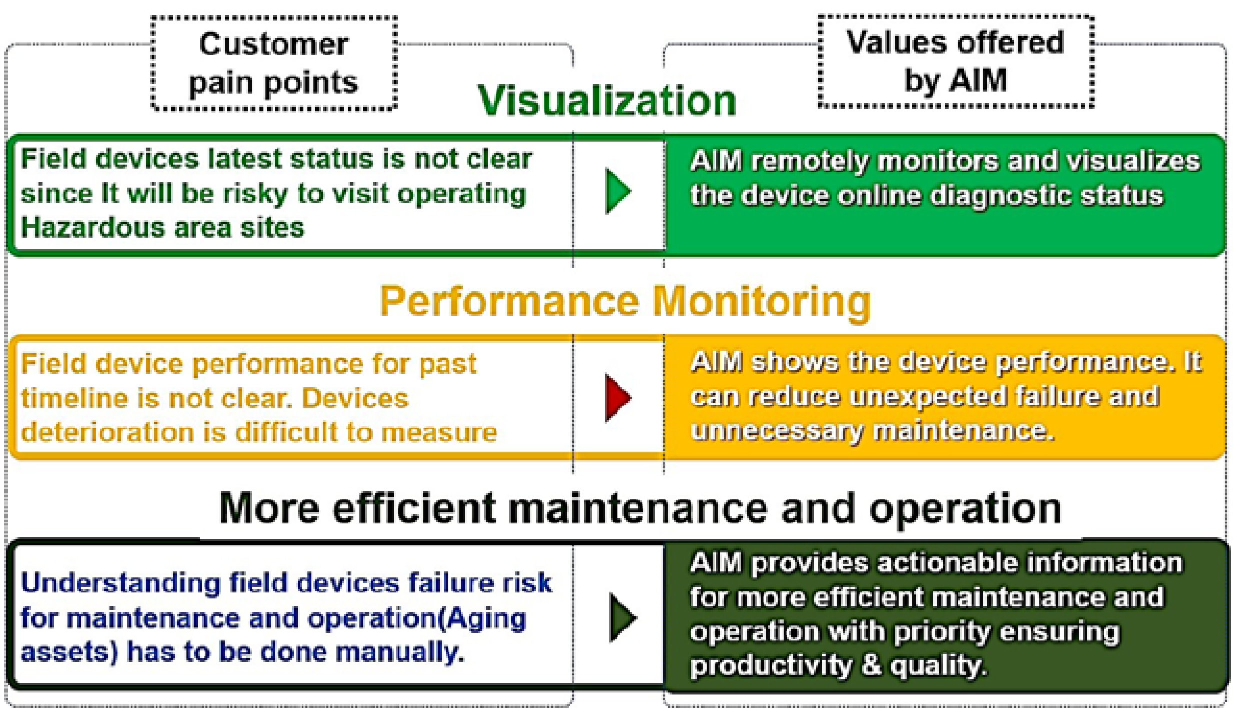


Figure 1: Customer pain points and AIMS implementation advantages

Best Practices

Implementing AIM effectively requires adherence to best practices that integrate technology, processes, and people. Organisations should adopt the Plan-Do-Check-Act (PDCA) cycle to ensure continuous improvement. Digital Twins and IIoT technologies enable predictive analytics, reducing unplanned downtime. Integration of AIM with Process Safety Management (PSM) ensures holistic risk management. Accurate documentation, including P&ID diagrams and instrument indexes, supports compliance and operational efficiency.

- Implement Plan-Do-Check-Act (PDCA) cycle for continuous improvement.
- Use Digital Twins and IIoT for predictive analytics and real-time monitoring.
- Integrate AIM with Process Safety Management (PSM) for comprehensive risk control.
- Maintain accurate P&ID diagrams, instrument index, and calibration records, maintenance spares inventory for compliance and audits.

Lifecycle Approach

AIM must be embedded throughout the asset lifecycle as represented in Figure 2, starting from design to decommissioning. In the design phase, selecting robust instruments and planning redundancy ensures reliability. During operation, scheduled inspections and alarm management prevent failures. The decommissioning phase involves safe disposal and thorough documentation to maintain compliance and knowledge transfer.

Figure 2: AIM system Lifecycle

- Design Phase: Select robust instruments, redundancy planning, and compliance with standards.
- Commissioning Phase: Schedule testing, calibration, and Site acceptance test for control systems as per Design and detail engineering documents and in compliance with statutory regulation requirements.
- Operation Phase: Scheduled inspections, alarm management, and condition monitoring.
- Decommissioning Phase: Safe disposal, documen-tation, and lessons learned for future projects.

A few case studies that spell out the type of instruments and the operational parameters related to AIM Lifecycle are described below:

Case Study-1: Design Phase

In general, shutdown valves are designed, installed, and maintained for the primary purpose of achieving rapid isolation of plant equipment or areas containing hazardous substances in the event of failure of the primary containment or control system. With manual operation or automatic remote actuation, shutdown valves are closed, providing the required isolation, ensuring plant safety and equipment safe shutdown.

The process team normally specifies fail-safe conditions for shutdown valves in piping and instrumentation diagrams. However, there are two different failure conditions, i.e., air supply failure and signal failure, depending on the process application requirement. Failure positions could be either: Valve Close position (FC), Valve Open position (FO) or Valve Stay Put (SP-Hold in last state) position. The design of the shutdown valve needs to take care of failure positions wherein there can be two cases.

Case-(a): Air Failure
Default Air failure positions FC and FO are available with all Shutdown valve OEMs as a standard. A Spring return single-acting actuator with a 3/2 Solenoid Valve (SOV) suffices for the application requirement.

However, in the case of valves with SP, Air Lock relays are required as part of the shutdown valve to retain its Hold/ Last State position.

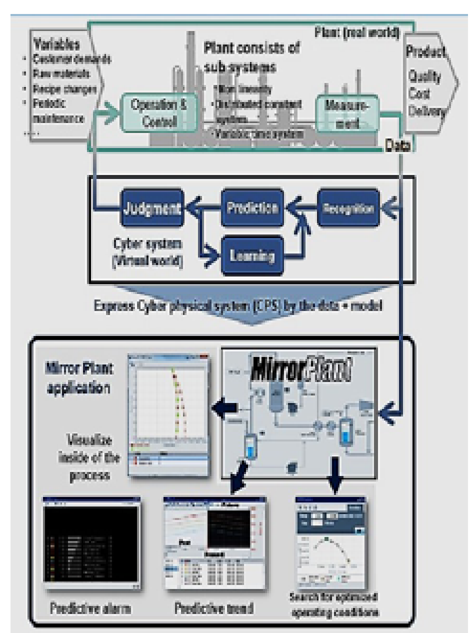
Case-(b): Signal Failure
Default Signal Failure positions FC and FO are available with all Shutdown valve OEMs with 3/2-SOV or 5/2-SOV as a standard. However, in case of valves with SP, dual coil 5/2-way SOV are required as part of the shutdown valve to retain its Hold /Last State Position, and two digital outputs (Separate for Open command & Close command) are envisaged from the Control system to the 5/2 Solenoid valve.

Further, Volume tanks are specified for ensuring uninterrupted and adequate instrument air, enabling valve operations.

Instrument datasheets and Control System design include these specific requirements to ensure Fail Safe positions are achieved to ensure asset integrity.

Case Study-2: Commissioning Phase

A classic example of Operator Training is the introduction of training simulators during the commissioning phase of the project, wherein the operator performs a site acceptance test, synchronises simulator design data with the plant control system, and gets familiarised with the plant routine operations, startup, shutdown, and emergency operation activities. Figure 3 shows Operators being trained with Simulators. This activity plays a vital role in asset maintenance and management, considering the fact that Plant Operators are trained to operate the plant much ahead of the actual plant monitoring and operational functions.



CEAI Creating Value Ethically

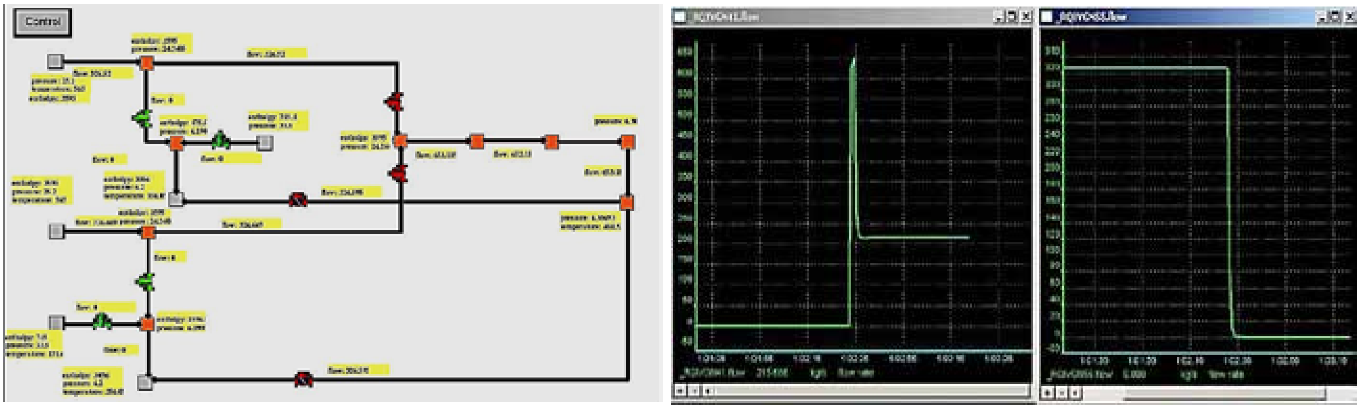


Figure 3: Plant operation preparedness using Training Simulators during project commissioning phase

Case Study-3: Operation Phase

The Operation Phase in the cycle of the Asset Management System for Instrumentation and Control (I&C) systems is when the assets deliver their intended functionality reliably and safely. This phase is the longest in the lifecycle and focuses on performance, reliable operation, data-driven decision making, statutory compliance and cost optimisation. The Highway Addressable Remote Transducer (HART) management system and condition monitoring system used in industrial plants improve decision-making and support AIM.

Implementation and use of the HART Management System (HMS) in industrial plants enables remote management of field devices from the control rooms during plant operation. The system collects data from HART-enabled field instruments and is basically used to configure field instrument settings like calibration & range adjustments. In addition, HMS diagnoses issues like wire break, instrument malfunction and predicts failures before they happen. It also documents and stores connected device information.

Utilisation of condition monitoring systems for monitoring machine parameters like temperature, vibration, pressure, oil level, flow, current and voltage facilitates the determination of changes in the machine operating condition. The system measures data, compares measured parameters at regular intervals, interprets based on trending of key parameters and provides predictive alarms to the Operator to take corrective actions and prevent failures/ plant shutdown. A screenshot of the Condition Monitoring System is shown in Figure 4.

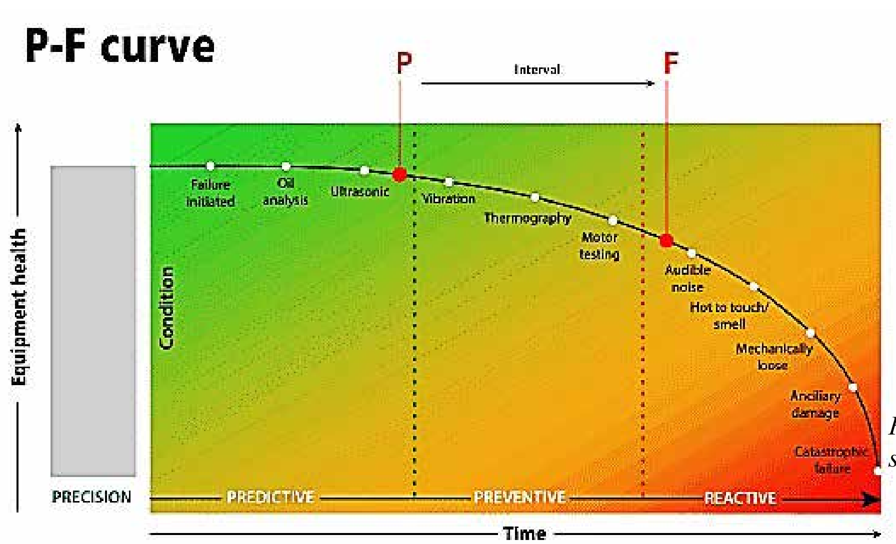


Figure 4: Equipment health monitoring screen

Case Study-4: Decommissioning Phase

The Decommissioning Phase in an Asset Management System for Instrumentation and Control (I&C) systems is another critical stage in the asset's lifecycle.

For decommissioning Instrumentation and Control Systems, the first step is a site survey wherein studies are conducted to determine the functional health of the control system and the field instruments. The Control system and the Field instruments are checked for end-of-life and obsolescence. Recommendations are made in case some of the equipment could be reused in other plants, and thus provide some revenue for the plant owner. Original Equipment Manufacturer documents, including Decommissioning Procedures, are a part of AIMS, and their availability during the decommissioning of the plant ensures safe removal, compliance with regulations, data integrity and cost optimisation.

Technologies & Tools

Modern AIM programs leverage advanced technologies to enhance efficiency and reliability. AIM software platforms readily available in the market provide centralised dashboards for asset health monitoring. Integration with Computerised Maintenance Management System (CMMS) and Enterprise Resource Planning (ERP) systems ensures seamless data flow across departments. Data Visualisation tools enable stakeholders to make informed decisions quickly.

- AIM software platforms for centralised asset management.
- Data Visualisation and Dashboards for real-time decision-making.
- Integration with CMMS and ERP systems for streamlined workflows.

Conclusion and Recommendations

Proactive AIM in Instrumentation and Control Systems is a necessity not just for operational excellence but for SAFETY. Organisations should embrace digital transformation, integrate AIM with enterprise systems, and adhere to international standards. The future trends include AI-driven predictive maintenance, enhanced cybersecurity protocols, and alignment with sustainability goals.

Acknowledgement

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TCE's Role in Asset Integrity Management: Tata Consulting Engineers Limited are involved in the implementation of Asset Integrity Management Systems in public and private sector projects, with a focus on the utilisation of the latest technologies for promoting effective asset utilisation and optimised management, thereby improving plant efficiency by minimising plant trips using strategic alarm monitoring and predictive maintenance techniques.

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07 Building Reliability: The Evolving Science of Asset Management in Rail and Metro Systems

Sunil Srivastava
Managing Director
Balaji Railroad Systems Pvt. Ltd.
Member, Supervisory Board, Uzbekistan Railways

Introduction

In the world of rail and metro transportation, passengers rarely think about what lies behind a smooth, comfortable, and punctual journey. Yet beneath every effortless ride exists a universe of highly engineered assets - track, rolling stock, power systems, signalling, civil structures, depots, and digital infrastructure - each with its own lifecycle, failure modes, and maintenance needs. Managing these assets effectively is both a science and a strategic discipline. In an era of expanding urban metros, high-speed corridors, and ageing railway infrastructure, asset management has emerged as a cornerstone for safety, sustainability, and financial responsibility.

Why Asset Management Matters Today More Than Ever

Modern rail systems face three converging pressures.

- **First**, capacity utilisation is increasing. Metros like Delhi, Bengaluru, London, and Hong Kong operate at near-peak loads for most of the day. With trains arriving every 90 seconds on some corridors, any asset failure instantly cascades into network-wide disruption.
- **Second**, infrastructure is ageing. Global railway networks in Europe, Japan, and parts of India have assets dating back several decades. Replacing them wholesale is financially unfeasible, but running them unreliably is equally unacceptable.
- **Third**, the cost of downtime has skyrocketed. A single hour of disruption in a major metro can affect hundreds of thousands of passengers, impact the city's economy, and erode public confidence.

Asset management offers a structured approach to address these challenges - integrating engineering, operations, finance, and data science to deliver reliability at optimal lifecycle cost.

The Shift from Maintenance to Asset Management

Historically, railways followed a "fix it when it fails" approach - a reactive maintenance paradigm. Even scheduled maintenance, while better, was still time-based, not condition-based.

Modern asset management is fundamentally different. It focuses on:

- Lifecycle planning, not isolated maintenance tasks

- Risk-based prioritisation, rather than equal attention to all assets
- Condition monitoring and predictive analytics, not intuition-driven decisions
- Integration of engineering, operations, and financial planning
- Maximising asset value over decades, not annual cost minimisation

Standards like ISO 55001 now guide organisations toward structured asset governance. The leading metros globally - Singapore LTA, London Underground, Hong Kong MTR, and Sydney Metro - have institutionalised asset management frameworks that link technical data to investment decisions, funding strategies, and risk controls.

UIC Railway Asset Management Framework

What a Rail Asset Management System Really Does

At its core, a rail asset management system establishes visibility, predictability, and control.

- Asset Register & Hierarchy. Every physical asset is catalogued with metadata - age, specifications, location, maintenance history, failure patterns, and remaining life.
- Condition Assessment. Field inspections, automated systems (e.g., track geometry cars, ultrasonic rail testers, drone inspections), and sensors feed real-time data.
- Failure Mode Analysis. Tools such as FMECA and RAMS analysis identify critical assets and quantify reliability expectations.
- Predictive Maintenance. Analytics forecast when a component will degrade, allowing for planned interventions.
- Lifecycle Costing. Budgets are aligned with long-term renewal schedules, helping avoid peak shocks - like the "renewal cliff" faced by some ageing metros.
- Decision Support. Asset data drives prioritisation: which assets need replacement, which require refurbishment, and which can safely continue.
- Feedback Loop. Every failure and intervention feeds into continuous improvement.

This framework transforms asset management from a maintenance function into a strategic capability.

Case Study-1: London Underground – Turning Data into Uptime

London Underground (LU) famously moved from frequent service disruptions in the late 1990s to becoming one of the world's most reliable metro systems. The turnaround was driven by a multi-decade asset renewal and management programme.

The key elements included:

- A comprehensive digital asset register
- Automated track inspection systems mounted on passenger trains
- Predictive modelling for track, power rails, and point machines
- Renewal planning aligned with long-term funding agreements

LU's predictive maintenance trial on point machines reduced failures by over 40% in five years. By integrating asset health data with traffic impact models, London Underground could justify renewals to government stakeholders using quantifiable risk and cost impacts.

Case Study-2: Hong Kong MTR – The Gold Standard for Asset Reliability

Hong Kong MTR is globally recognised for achieving 99.9% on-time performance over decades. This success is built on a deeply embedded asset management culture.

MTR's approach includes:

- A complete ISO 55001-compliant asset management framework
- Five-yearly engineering planning cycles linked with financial commitments
- Extensive use of CBM (Condition-Based Maintenance)
- Proprietary systems like RailGen for rail wear prediction
- A strict engineer-to-asset ratio ensuring adequate domain expertise

The renewal of rolling stock and signalling across the MTR network is sequenced based on data-driven optimisation, ensuring manageable capex and minimal passenger impact.

Case Study-3: Delhi Metro – Asset Management at Indian Scale

Delhi Metro Rail Corporation (DMRC), one of India's most successful urban transit systems, has increasingly shifted toward structured asset management.

The key initiatives include:

- Deployment of track geometry cars and ultrasonic flaw detection
- Implementation of Enterprise Asset Management (EAM) software for rolling stock and infrastructure
- Mid-life refurbishment strategies for rolling stock
- RAMS-based procurement for new systems
- Integration of asset performance indicators into O&M contracts

DMRC's focus on condition-based maintenance for escalators, lifts, and HVAC systems significantly reduced service outages and improved station availability.

The move toward predictive analytics is still evolving, but Delhi Metro provides a strong model for metros across India seeking reliability at scale.

The Rise of Predictive and Digital Asset Management

Digitalisation is transforming asset management more rapidly than ever before.

- IoT and Smart Assets: Sensors now monitor rail temperature, vibration signatures, axle-box conditions, OHE tension, and rolling stock systems in real time.
- Digital Twins: High-speed corridors in Europe, and metro projects in Singapore and Sydney, use digital twins to simulate asset deterioration, optimise maintenance windows, and visualise risk hotspots.
- AI-Driven Forecasting: Machine learning models are increasingly used to forecast ballast fouling, traction motor failure, and rail fatigue growth.
- Integrated Command Centres: Modern metros integrate asset health dashboards directly into operations control centres, enabling cross-functional decisions during incidents.
- Remote Inspection Technologies: Drones, track-mounted robots, and lidar (laser imaging, detection, and ranging) systems reduce human exposure and improve accuracy.

These tools are redefining the expectations for reliability and availability.

The Policy and Funding Dimension

Asset management intersects directly with governance and finance.

- Lifecycle cost modelling supports sustainable funding cycles.
- Regulators increasingly expect structured asset management plans.
- PPP and O&M outsourcing contracts now include RAMS (Reliability, Availability, Maintainability, and Safety) based performance KPIs (Key Performance Indicators).
- Government agencies use asset data to prioritise budget allocations.

Countries like Australia, the UK, and the UAE mandate asset management frameworks for metro operators. India is gradually moving in that direction, particularly for new Metro Rail Acts and regulatory reforms.

The Road Ahead: From Discipline to Culture

The future of Asset Management lies in transforming it from a technical function to an organisational culture. Successful rail administrations - from Tokyo to Hong Kong - treat asset reliability as a shared responsibility between engineering, operations, and leadership.

For emerging metro systems in India, the opportunity is immense:

- Build asset management frameworks from day one
- Establish robust digital registries and maintenance records
- Embed RAMS principles into procurement
- Invest in data science capabilities for predictive management
- Develop multi-year integrated renewal plans
- Build in-house expertise rather than relying solely on contractors

As India's metro networks grow from 1,000 km today to more than 3,000 km by 2047, asset management will determine whether these systems remain reliable, safe, and financially sustainable.

08

Asset Integrity Management System (AIMS) For Static Equipment: A Deep Technical Framework

Shireesh S Swami
Associate Vice President & Head
Mechanical Engineering

Dr Sneha R. Iyer
Senior Manager, Technology

TATA Consulting Engineers Ltd.

Abstract

Asset Integrity Management System (AIMS) for static equipment is pivotal in ensuring safe, reliable, and cost-effective operations across process industries, particularly in refineries and petrochemical facilities. Static assets such as pressure vessels, heat exchangers, storage tanks, reactors and distillation columns operate under severe conditions, making their structural integrity critical to process safety and business continuity. This paper presents a comprehensive technical framework that integrates Fitness-for-Service (FFS) assessments, Mechanical Integrity (MI) programs, and Remaining Life Assessment (RLA) studies within a unified AIMS approach. The proposed model addresses gaps arising from siloed implementation of Asset Integrity Management (AIM) and Process Safety Management (PSM), enabling a proactive shift from reactive maintenance to risk-based strategies. Key elements include probabilistic risk modelling, inspection optimisation through Risk-Based Inspection (RBI), and advanced Non-Destructive Examination (NDE) selection tailored to damage mechanisms. A few case studies have been discussed in detail, which demonstrate certain aspects of AIMS integration. By aligning AIM with PSM principles such as Mechanical Integrity, Management of Change, and hazard analysis, this approach enhances asset reliability, optimises lifecycle costs, and mitigates catastrophic failure risks, offering actionable guidance for industry stakeholders and regulatory authorities.

Introduction

Asset Integrity Management System (AIMS) is a structured approach aimed at ensuring industrial assets operate safely, reliably, and efficiently throughout their entire lifecycle1. Yet, this definition barely captures the complexity behind its implementation. Deploying AIMS remains a significant challenge for both seasoned professionals and newcomers in the field2. Its role becomes even more critical in high-risk environments such as refineries and petrochemical plants, where maintaining asset integrity is essential for safety, compliance, and operational continuity3.

AIMS plays a vital role in safeguarding health, safety, and the environment while optimising asset performance and plant profitability1,4. It encompasses all stages of an asset's life from design, fabrication, and installation to commissioning, operation, maintenance, and eventual decommissioning through systematic processes, inspections, and quality assurance programs1,5.

The primary objective of AIMS is to maintain assets in a fit-for-service condition while cost-effectively extending their remaining life. This involves integrating risk identification and evaluation techniques such as Failure Mode Effect and Criticality Analysis (FMECA), Hazard and Operability Analysis (HAZOP), and Fault Tree Analysis (FTA). For static equipment, Risk-Based Inspection (RBI) is widely adopted to prioritise inspection based on corrosion, erosion, and other degradation mechanisms6. Complementary studies such as Fitness-for-Service (FFS) assessments, Remaining Life Assessment (RLA), and mechanical integrity (MI) evaluations ensure compliance with international standards like API 580, API 581, and PAS 55, as well as local regulatory requirements1,7.

AIMS cannot function in isolation; it must integrate seamlessly with other organisational processes, including risk management, health and safety, maintenance, and production3,8. As equipment design standards evolve and operational demands increase, a robust AIMS framework becomes indispensable for managing risks, ensuring regulatory compliance, and sustaining commercial viability1,3.

Background and Standards

Static equipment, such as pressure vessels, piping, heat exchangers, storage tanks, and process columns, forms the structural backbone of process industries. The failure of these assets can result in severe consequences, including loss of containment, fires, explosions, environmental damage, and significant financial losses3.

AIMS for static equipment is built upon three foundational pillars:

- Mechanical Integrity (MI): A structured program ensuring that equipment is designed, inspected, repaired, and maintained in accordance with applicable codes, standards, and recognised engineering practices8.

- Fitness-for-Service (FFS): An engineering assessment methodology that evaluates the structural integrity of damaged or defective equipment and provides technically justified decisions regarding continued operation, repair, or decommissioning7.

- Remaining Life Assessment (RLA): A predictive approach that estimates the remaining safe operating life of equipment using degradation models, inspection data, and probabilistic analysis5.

It is intended for engineers, integrity managers, and RBI practitioners, offering a blend of standards-driven practices and modern analytical techniques to ensure reliability, safety, and cost optimisation throughout the asset lifecycle2. Engineers implementing Asset Integrity Management (AIMS) commonly refer to industry standards for inspection and risk management. These include pressure vessel and piping inspection (API 510, API 570), damage mechanism assessment (API RP 571), and fitness-for-service evaluations (API 579-1).

AIMS Architecture and Governance

AIMS ensure that the assets remain safe and reliable throughout their life cycle by integrating planning, control, and monitoring. They help industries, especially those with tight margins such as refining and petrochemicals, shift from reactive repairs to preventive and predictive maintenance, thereby reducing catastrophic risks and safeguarding health, safety, environment, and reputation4. The key challenge is balancing high performance with the cost of Testing, Inspection, Maintenance, and Substitution (TIMS), while staying flexible to market changes and adhering to safety standards. Organisations can adopt international best practices or develop customised risk-based inspection systems6.

Figure-1 elucidates a comprehensive AIMS framework where the first step in building it is defining the operating areas and assets involved in Testing, Inspection, Maintenance, and Substitution (TIMS). The system should align with existing safety, risk management, and quality programs, using either qualitative or quantitative methodologies based on occupancy factors. Asset selection depends on standards, regulations, current management systems, and future development plans. A thorough review ensures completeness and prevents omissions1.

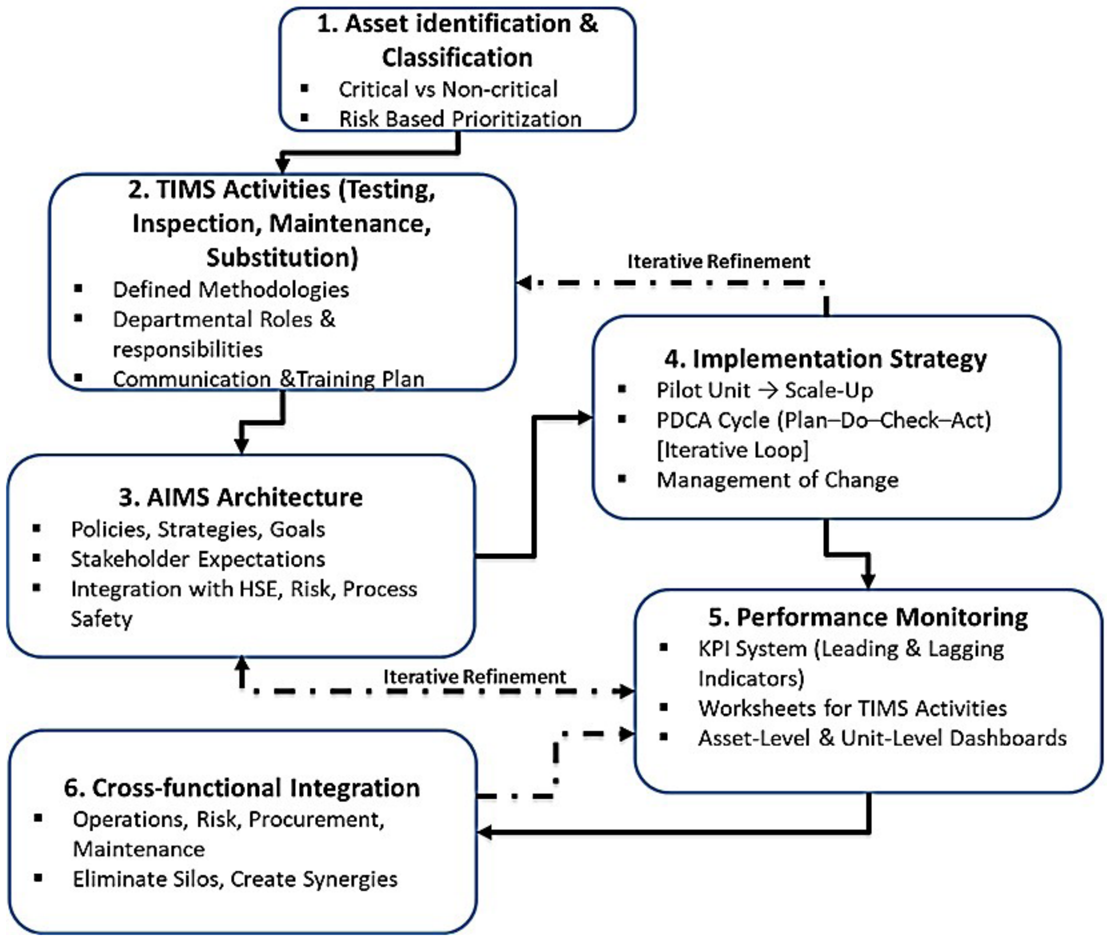

Figure 1: Adaptive AIM–PSM Framework: From Identification to Integration

AIMS development requires reviewing current practices to identify strengths, gaps, and improvement opportunities5. An action plan is then developed, prioritising steps based on cost, benefit, and timeline, along with risk assessments and corresponding countermeasures. The final report summarises the "as-is" state, highlighting strengths, quick wins, obstacles, and performance gaps, based on interviews with stakeholders, field inspections, and documentation5.

The next step is identifying assets for TIMS (Testing, Inspection, Maintenance, and Substitution) activities through a systematic, collaborative process aligned with industry standards and best practices. Critical assets are classified based on their impact on safety, operations, and business continuity, using analyses such as HAZOP, SIL, and FMEA to assess risks and determine criticality levels (A–D). Finally, TIMS methodologies must be clearly defined, integrating standards with organisational knowledge, assigning roles, setting KPIs, and fostering cross-departmental collaboration to embed AIMS into existing processes without creating silos1.

The subsequent stage of AIMS development involves creating a structured system and implementing it through a phased approach, starting with a pilot unit and then scaling across the organisation. Implementation follows the PDCA (Plan–Do–Check–Act) cycle for continuous improvement, identifying gaps and training needs. The process delivers three main outputs: a hierarchical list of critical assets across all units, detailed worksheets for TIMS activities with schedules and resource allocation, and a KPI framework combining leading and lagging indicators to monitor performance and tailor the system to organisational needs8. These outputs form the foundation for a robust, scalable AIMS that enhances reliability, safety, and operational efficiency8,17.

Mechanical Integrity

Mechanical Integrity (MI), a critical element of Process Safety Management (PSM) under OSHA 1910.119, ensures that all equipment handling hazardous materials is designed, installed, operated, and maintained safely and reliably throughout its life cycle. It forms a subset of asset management and reliability programs, emphasising proactive monitoring, inspection, and maintenance to mitigate risks and ensure compliance9.

An effective MI program involves structured phases: management responsibility, equipment selection, and implementation through inspection, testing, and proactive maintenance. Equipment boundaries are defined early, documented in asset management systems, and prioritised based on criticality. Personnel qualifications, including training and certification, are essential for safe execution. The MI process integrates these phases into a comprehensive framework aligned with asset management principles for safety, reliability, and environmental protection4.

Inspection Plans for Mechanical Integrity Programs:

A robust inspection plan is essential for ensuring the mechanical integrity of static equipment and associated pressure-relieving devices. These plans must comply with applicable codes and standards and be developed collaboratively by qualified inspectors and engineers. Corrosion specialists play a critical role in identifying potential damage mechanisms and pinpointing areas susceptible to degradation, particularly where localised corrosion or cracking may occur. Their expertise is vital for equipment operating at elevated temperatures (above 750°F / 400°C) or below the ductile-to-brittle transition temperature10.

Inspection plans are derived from comprehensive data analysis, including historical inspection records, operating conditions, and risk-based assessments. Static equipment should be evaluated for existing and potential damage mechanisms, and the suitability of Non-Destructive Examination (NDE) methods must be confirmed to ensure accurate detection and severity assessment. Grouping equipment into circuits or categories with common damage mechanisms helps optimise inspection techniques. Ultrasound Testing (UT) is a common NDE method for wall thinning and corrosion, while Phased Array UT excels at weld defects. Radiographic Testing identifies internal volumetric flaws but involves radiation risks. Each method has specific advantages and limitations, making selection dependent on material, damage type, and accessibility11.

Plans must be dynamic, reviewed, and updated when variables affecting deterioration rates emerge, such as findings from inspection reports or process changes. Refer to API 574 for detailed guidance on inspection plan development. A well-structured plan ensures reliability, safety, and compliance, forming a cornerstone of effective Mechanical Integrity programs.

Fitness For Service (FFS) Assessments

Fitness-for-Service (FFS) evaluations involve a series of quantitative engineering analyses aimed at determining whether an in-service component or piece of equipment remains structurally sound. These assessments are typically applied when the equipment has flaws, damage, or is operating under conditions that could potentially lead to failure. Equipment health and useful life depend on various factors like equipment design and fabrication, its operation and frequency of inspection and maintenance12. API 579-1/2 and ASME FFS-1/2 provide detailed guidelines for performing Fitness-for-Service (FFS) evaluations. These standards outline methodologies specifically designed for pressurised equipment. The purpose of these assessments is to support decisions on whether to continue operating, repair, or replace a component.

The methods and procedures outlined in the FFS standard are designed to complement the requirements of codes such as API 510, API 570, API 653, and other post-construction standards that reference Fitness-for-Service evaluations, including NB-23. The FFS standard has a broad scope because its procedures rely on allowable stress principles and plastic collapse criteria for non-crack-like flaws. For crack-like flaws, the approach is based on the Failure Assessment Diagram (FAD) methodology13.

FFS assessment procedures address both the current integrity of a component and its estimated remaining service life14,16. They provide guidance for determining remaining life and operational margins under anticipated conditions and environmental factors. The standard includes methods for evaluating flaws such as corrosion, pitting, blisters, hydrogen damage, weld misalignment, shell distortion, and crack-like defects, including dents, environmental cracking, laminations, and gouges. It also covers condition assessments for issues like brittle fracture resistance, creep damage, and fire damage14.

Remaining Life Extension

Operating ageing assets beyond their intended design life can lead to significant risks. Time-dependent degradation mechanisms, such as corrosion and fatigue, increase maintenance requirements and reduce equipment availability. The older the asset, the more problems there might be. Life extension methods help to use facilities beyond their planned service life. With limited inspection budgets and resources for ageing assets, strategies should prioritise risk-based, targeted, and data-driven inspection and maintenance rather than routine practices. Therefore, assessment of ageing assets for life extension includes risk assessment of the components and recommendations to control the risk of high-risk components. The assessment process should evaluate the current structural integrity of facilities while ensuring their capability for extended service life. Generally, risk control measures such as inspection and monitoring are performed to keep the failure risk of the asset under a predefined value. As assets age, both the frequency and scope of inspections typically increase, but risk control options can incur significant costs. Therefore, rigorous cost-benefit analysis is an essential part of any life extension program7.

Life extension programs are particularly vital for offshore facilities15. Offshore environments present extreme challenges due to their highly corrosive nature, driven by seawater exposure and salt spray. In addition, dynamic forces from wave action and high winds impose cyclic stresses, which, when combined with corrosion, accelerate degradation through corrosion-fatigue mechanisms16.

Asset Life Assessment (ALA), often termed Remaining Life Assessment (RLA), is a strategic approach to evaluate deterioration and confirm an asset's ability to withstand operational loads while supporting production requirements17.

Case Studies

The following case studies in Asset Integrity Management (AIM) demonstrate the application of MI and FFS methodologies to resolve complex engineering challenges, ensuring asset reliability, operational safety, and regulatory compliance through innovative and practical solutions.

Case Study 1: Retrofitting Storage Tanks in a Chemical Terminal

A chemical marketing terminal with over 75 storage tanks of varying sizes, built more than 25 years ago, was acquired by an international chemical logistics company. The objective was to upgrade the facility to comply with local regulations (OISD), company safety standards, and enable flexibility to store a wide range of chemicals regardless of flash point, liquid class, density, wind, or seismic conditions. This required verifying tank designs against the latest codes and revised conditions, including design pressure for nitrogen blanketing and remaining wall thickness after corrosion, based on client inspection reports.

The inspection data were analysed to determine corrosion extent and residual thickness for redesign. Recommendations were made as per API 650 and API

653, addressing whether bottom plates or shell courses should be retained or replaced, and incorporating features like compression rings at shell-to-roof junctions. Revised foundation loads due to updated design conditions were communicated to the civil team for structural verification and retrofitting requirements. The retrofit strategy balanced compliance, structural integrity, and operational flexibility, enabling the terminal to handle diverse chemicals efficiently.

Case Study 2: Fitness-for-Service Assessment of a Process Column

A chemical processing facility required a Fitness-for-Service (FFS) assessment for a Naphthalene process column that exhibited significant service-related and manufacturing defects identified during inspections conducted over several years. These inspection reports formed the basis for the FFS study, which was carried out in accordance with API 579 guidelines using measured minimum thickness values.

Finite Element Analysis (FEA) was performed to evaluate design margins and factors of safety under various load cases and combinations. The analysis revealed that local metal loss was below the minimum required thickness, and safety factors were slightly lower than the acceptable limit of 1.1. To ensure reliability under worst-case scenarios and assess stress sensitivity to defects, multiple iterations were conducted.

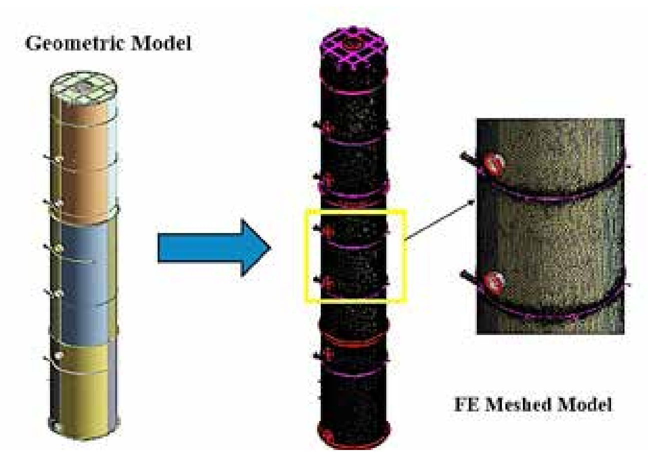

Figure 2: Geometric Model and FE Meshed Model of Process Column

Crack propagation analysis was also performed to evaluate the observed shell crack, comparing stress intensity factors with allowable fracture toughness to predict potential growth under operating conditions. Based on these findings, targeted repair and strengthening measures were recommended to restore structural integrity and ensure safe operation. As shown in Figure 2, this case highlights the critical role of advanced Fitness-for-Service (FFS) techniques such as Finite Element Analysis (FEA) and Fracture Mechanics in extending equipment life while ensuring safety and regulatory compliance.

Case Study 3: Stability Check for Procured Equipment

A set of process equipment originally designed and fabricated for different climatic conditions, including wind and seismic loads, was repurposed for installation at a coastal site in India. The relocation required a comprehensive stability check to ensure mechanical integrity under revised environmental and process conditions. Approximately 35 pieces of static equipment were evaluated, considering governing external loads and updated process parameters that differed from the original design basis.

Extensive design validation and advanced analyses, including Finite Element Analysis (FEA), were performed to assess compliance with site-specific requirements. Cost-effective solutions were proposed to salvage the equipment and minimise project delays. Two critical cases are highlighted below:

Process Column: This was a tall self-supported column, was found to fail under wind loading due to higher wind speeds at the new site compared to the original design. Excessive stresses were observed at the dish-to-skirt junction and base ring, necessitating reinforcement. Instead of major shell modifications, a structural support frame was recommended around the tower, with guides to absorb wind-induced deflection. This approach minimised site work, cost, and time while ensuring structural integrity.

Evaporator: Figure 3 illustrates a stacked heat exchanger (evaporator) that required detailed Finite

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Element Analysis (FEA) because its large nozzle diameters exceeded the limits specified by design codes. Analysis under high wind conditions revealed localised high stresses caused by mesh aspect ratio issues rather than actual design inadequacy. After refinement, the equipment was deemed fit for service without modifications.

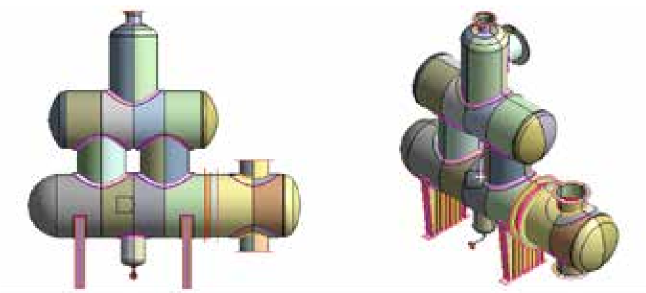

Figure 3: Geometric Model of Ammonia Evaporator

These cases underscore the importance of stability checks and adaptive engineering solutions when relocating equipment to environments with significantly different design conditions.

Conclusion

Asset Integrity Management Systems (AIMS) play a critical role in sustaining the reliability and safety of static equipment operating under severe conditions in process industries. The integrated framework presented in this paper combines Fitness-for-Service (FFS) assessments, Mechanical Integrity (MI) programs, and Remaining Life Assessment (RLA) studies to address gaps in traditional siloed approaches. By aligning AIM with Process Safety Management (PSM) principles, the model enables a proactive transition from reactive maintenance to risk-based strategies, reducing unplanned downtime and mitigating catastrophic failures. Incorporating advanced tools such as probabilistic risk modelling. Risk-Based Inspection (RBI) and optimised Non-Destructive Examination (NDE) techniques ensure targeted resource allocation and cost-effective lifecycle management. Furthermore, life extension programs for ageing assets, supported by rigorous risk assessment and cost-benefit analysis, provide a structured approach to maintain integrity beyond design life. Case studies demonstrate the practical application of these methodologies and the innovative solutions employed to comply with regulatory standards while enhancing operational flexibility. This holistic approach to AIMS offers actionable guidance for industry stakeholders, enabling improved asset performance, optimised inspection planning, and sustainable operations in increasingly challenging environments.

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TATA Consulting Engineers Limited has been providing innovative solutions to comply with regulatory standards while enhancing operational flexibility using a holistic approach to Asset Integrity Management Systems in public and private sector projects

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India's construction sector continues to show strong growth potential

India's construction industry is set to expand by 7.1% in real terms in 2025, driven by rising FDI inflows and strong public-private investment in transport and energy infrastructure. FDI rose 15% YoY to $18.6 billion in Q1 FY2025–26, while major allocations, including INR 260.7 billion for 128km of new roads in Delhi, highlight sustained government spending. Private investment momentum also continues, with CapitaLand committing INR 192 billion to business parks, data centres, logistics hubs, and industrial parks in Maharashtra. Short-term risks remain, including project cost escalation, approval delays, high public debt, and global trade pressures. Still, the industry is projected to grow at an average annual rate of 6.1% between 2026 and 2029, supported by major manufacturing, infrastructure, and clean-energy initiatives. Key developments include NTPC's plan for 20GW of hydropower and new pumped-storage projects totalling 6.5GW.

Source: Summarised from a ***GlobalData*** report

09

IoT Based Solutions for Centralized Management and Optimization of Building Systems

Sudhir Nair
CEO
Nergylive Solutions Pvt Ltd

Abstract

The rapid evolution of the Internet of Things (IoT) has transformed the building management landscape by enabling real-time visibility, centralised control, and automated optimisation of critical systems such as HVAC, lighting, energy metering, security, and indoor air quality (IAQ). Traditional Building Management Systems (BMS) rely on proprietary protocols, limited interoperability, and static control logic, resulting in suboptimal energy utilisation and increased operational costs. This paper presents a scalable IoT-based framework for centralised management and optimisation of building systems. The work discusses system architecture, communication protocols, data acquisition strategy, cloud-based analytics, AI-driven optimisation, and cybersecurity requirements. A case study from a live deployment demonstrates improvements in energy efficiency, operational resilience, and occupant comfort.

Introduction

Modern buildings consume 30-40% of global energy, with HVAC systems having the largest share. Conventional BMS platforms often suffer from limited interoperability, distributed siloed controls, high installation costs, and a lack of real-time optimisation.

IoT-enabled smart building solutions address these limitations by integrating sensors, controllers, gateways,

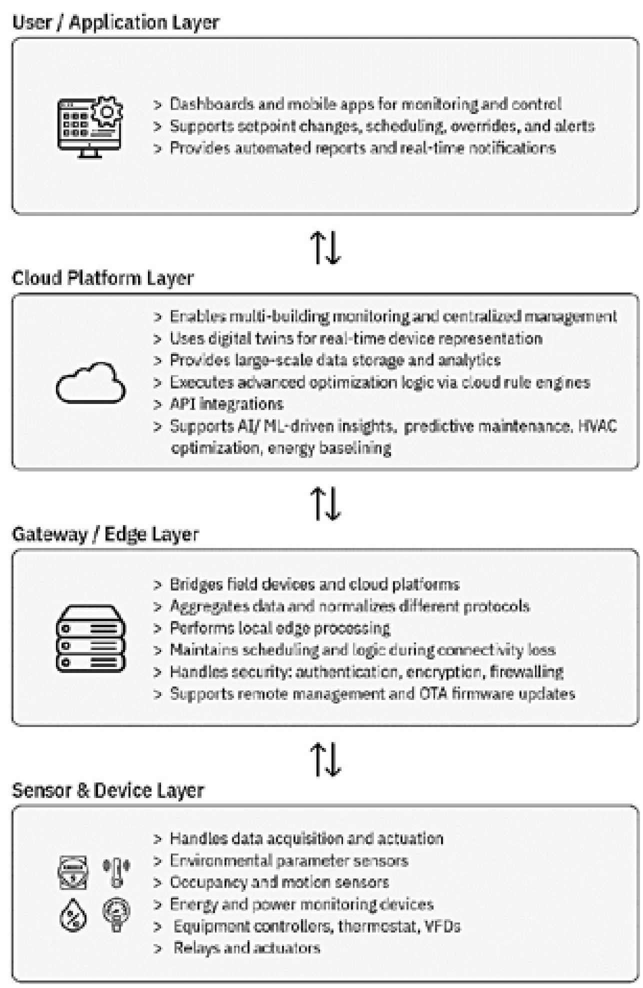

Figure 1: Functional layers in IoT system architecture

and cloud analytics into a centralised platform. This enables rule-based automation, predictive algorithms, and remote operations, which together improve energy efficiency and comfort.

System Architecture

A scalable IoT-based building and energy management system architecture is typically organised into four functional layers, each responsible for a distinct set of operations, from physical sensing to cloud intelligence and user interaction. This layered approach ensures interoperability, modularity, and ease of deployment across diverse building environments.

1. **Sensor and Device Layer**
   The Sensor and Device Layer form the foundation of the IoT building ecosystem, consisting of all field-level devices responsible for monitoring environmental, electrical, and mechanical parameters and controlling building equipment. This layer functions primarily as the data acquisition and actuation layer, feeding real-time information to gateways and receiving control commands from supervisory systems. Common types of sensors and devices include:

   a) Environmental Sensors: temperature, relative humidity, pressure, CO_2, VOCs, particulate matter, lighting level.

   b) Occupancy & Motion Sensors: PIR sensors, people counters, door contact sensors.

   c) Energy & Power Devices: single-phase and three-phase energy meters, power quality analysers, BTU meters.

   d) Flow Measurement Devices: Water flow meters, fuel flow meters, air flow measurement stations.

   e) Equipment Controllers: chiller/boiler controllers, AHU/FCU controllers, thermostats, lighting controllers, VFDs, actuators.

   Devices in modern buildings use a mix of wired and wireless communication technologies. Most common protocols include BACnet, Modbus, MQTT, HTTPS, LoRaWAN, Zigbee.

2. **Gateway/ Edge Layer**
   Gateways serve as the bridge between field devices and the cloud. They provide data aggregation, local intelligence, and secure communication pathways. Gateways collect raw telemetry from multiple field devices and normalise diverse protocol formats into standard IoT data models. This ensures interoperability between heterogeneous equipment from different vendors. A critical gateway function is converting traditional BMS/ industrial protocols into modern IoT communication standards. This enables cloud platforms to read data without directly handling low-level building protocols.

   To reduce cloud dependency and ensure operational continuity, gateways perform limited local processing such as threshold-based event detection, preliminary fault detection, data smoothing and noise reduction, and local safety logic. In case of connectivity loss, gateways maintain essential logics and time-based scheduling. Gateways also handle device authentication and identity management, encrypted communication, local firewalling and over-the-air firmware updates.

3. **Cloud Platform**
   Cloud platforms support portfolio-level visibility, enabling building owners and facility teams to monitor and optimise multiple buildings from a single interface.

   The cloud layer ensures centralised intelligence, long-term storage, analytics, and multi-site management capabilities. Each connected device is represented as a digital twin, reflecting real-time operational status, telemetry, and control parameters. This allows the platform to manage devices at scale. Cloud services maintain time series databases capable of handling high-frequency sensor data. Processing pipelines enable trend analysis, anomaly detection, predictive modelling, and load profiling

   Cloud-based rule engine executes complex, multi-variable logic that may involve IAQ-based ventilation adjustments, energy demand limiting strategies, predictive scheduling of equipment and cross system optimisation. Machine learning models can be trained on historical datasets to offer predictive maintenance, HVAC plant optimisation, energy baselining, and deviation alerts.

4. **User/ Application Layer**
   This layer is responsible for presenting information, enabling control, and supporting facility operations through intuitive interfaces. Users access real-time building data through web-based dashboards and mobile applications. Authorised users can remotely adjust temperature setpoints and other system parameters, modify equipment schedules, perform system overrides, configure alert thresholds, configure control logics, configure custom dashboards and reports, and acknowledge or act on alarms.

   The application layer provides automated reporting such as Hourly/Daily/weekly/monthly energy consumption reports, IAQ compliance summaries, equipment uptime and performance reports and regulatory data logs.

   Users receive real-time notifications via mobile push alerts, email and SMS. These alerts may be triggered by parameter deviations, equipment failures, energy anomalies, or IAQ breaches.

   Open APIs allow integration with existing BMS systems, ERP platforms, maintenance management systems and third party analytics tools.

   The four-layer IoT architecture creates a flexible and resilient framework for modern building automation. This structure ensures interoperability, real-time responsiveness, and future scalability, enabling buildings to move toward fully data-driven and autonomous operation.

Communication Framework

Efficient and secure communication is a core requirement of IoT-based building and energy management systems. A robust communication framework ensures seamless interoperability between field devices, edge controllers, and cloud platforms, enabling real-time monitoring, analytics, and automation. The communication stack can be broadly categorised into field level protocols and IoT/cloud protocols, each serving distinct roles within the system.

1. **Field Protocols**
   Field protocols enable reliable, deterministic communication between sensors, meters, actuators, and controllers in building systems.

   Modbus is widely used in HVAC and energy management for its simplicity and vendor neutrality. Modbus RTU runs on RS485 for multi-drop field networks, while Modbus TCP uses Ethernet for faster, IP-based integration. BACnet is purpose built for building automation. BACnet MS/TP operates over RS485 and is common in HVAC controllers, while BACnet/IP runs on Ethernet. Its object based data model supports complex automation needs.

   To integrate mixed legacy and modern equipment, IoT gateways normalise Modbus and BACnet data into standardised IoT formats, providing a unified semantic layer that simplifies analytics, automation, and cloud connectivity.

2. **Cloud/ IoT Protocols**
   IoT protocols enable communication between edge gateways, smart devices, and cloud platforms, supporting scalable, low bandwidth, and secure connectivity.

MQTT is the most widely used IoT protocol due to its lightweight publish/subscribe model. It supports low bandwidth usage, asynchronous messaging, topic based data routing, and QoS levels, making it ideal for real-time telemetry, alarms, and device-to-cloud communication in buildings. HTTPS/REST is commonly used for device provisioning, configuration, diagnostics, and bulk data transfer. While more resource intensive than MQTT, it offers strong security, broad compatibility, and ease of integration with enterprise systems.

IoT security is ensured through measures such as TLS encryption, certificate based authentication, secure boot and firmware signing, RBAC, and mutual TLS, protecting systems from unauthorised access and data interception. Together, field protocols and IoT protocols form a robust, scalable, and cloud-ready communication foundation for modern building and energy management systems.

Data Management and Analytics

Effective IoT-based building and energy management depends on robust data acquisition, storage, processing, and analytics to support real-time decisions, long term insights, and AI-driven optimisation.

1. **Real-Time Data Acquisition**
   Sensors, meters, and controllers continuously send telemetry to edge gateways, typically at 5 to 60-second intervals based on parameter criticality. Gateways preprocess data through validation, filtering, compression, anomaly detection, and local buffering, and can trigger local alarms for immediate response during critical events or network outages.

2. **Cloud Storage and Analytics**
   Processed data is ingested into cloud-based time series databases optimised for high volume, time-stamped data. These systems support fast trend analysis, scalable multi-site deployments, and cost efficient retention using high resolution recent data and aggregated historical data. Cloud platforms enable Fault Detection and Diagnostics (FDD) using rule-based and statistical models, enhanced by contextual data such as weather, tariffs, occupancy, and maintenance records.

3. **AI/ML Optimisation**
   AI and ML models use historical and real-time data to optimise HVAC and energy systems, improve efficiency, predict faults, and support autonomous operation.

Together, edge processing, scalable cloud storage, and AI-driven analytics form an intelligent data pipeline that enables efficient, predictive, and smart building operations.

Cyber Security Architecture

Security is fundamental to IoT-based building and energy management systems due to distributed devices, critical HVAC and energy operations, and cloud connectivity. A robust cybersecurity architecture protects devices, networks, cloud infrastructure, and user access to ensure confidentiality, integrity, and availability.

1. **End-to-End Encryption**
   All communications between devices, gateways, and cloud platforms should use industry standard encryption (TLS 1.2+ for MQTT/HTTPS, DTLS where applicable, and AES-256 at the device level). Sensitive data and credentials must also be encrypted at rest within gateways and cloud storage.

2. **Network Segmentation (IT/OT Separation)**
   IT and OT (Operational Technology) systems should be isolated using dedicated VLANs or subnets, with gateways acting as controlled bridges. Firewalls enforce strict traffic rules, reducing attack surfaces.

3. **Certificate Based Authentication**
   Each device and gateway must have a unique cryptographic identity using PKI and mutual TLS. User access is protected through MFA, RBAC, least privilege policies, and comprehensive activity logging.

4. **Secure Firmware and Software Updates**
   Devices should support secure boot, signed firmware, and encrypted OTA updates with rollback, version control, and audit trails to safely patch vulnerabilities.

5. **Continuous Monitoring and Vulnerability Management**
   Regular vulnerability scans, intrusion and anomaly detection, and centralised security logging enable proactive threat detection, incident response, and compliance reporting.

6. **Physical Security and Incident Response**
   Physical protection of equipment, along with defined incident response, backup, and recovery procedures, ensures resilience and continuity of building operations.

   Together, these measures create a secure, resilient IoT cybersecurity framework that safeguards modern building and energy management systems.

Use Cases

IoT-based building and energy management systems support a wide range of applications across HVAC, energy, indoor air quality, and cold chain environments. By integrating high frequency sensing, edge computing, and cloud analytics, these systems enable real-time monitoring, control, alerts, optimisation, predictive maintenance, and improved operational transparency.

1. HVAC Optimisation

HVAC systems represent the largest energy consumers in commercial and industrial buildings. IoT-driven optimisation improves efficiency, enhances comfort, and reduces equipment wear.

Chiller Plant Automation: Chiller plants operate under highly dynamic load conditions. IoT systems optimise performance using real-time data from temperature sensors, pressure sensors, humidity sensors, flow meters, power meters, equipment controllers, occupancy sensors, and weather stations. Key capabilities include:

- Dynamic Chilled Water Temperature Setpoint Adjustments: Continuously optimises the chilled water temperature setpoint using real-time feedback from conditioned zones, prevailing weather conditions, occupancy data, and historical operating data. This enables the plant to operate at the highest feasible chilled water temperature without compromising zone conditions or occupant comfort. Operating at higher evaporator temperatures reduces compressor lift, improves the coefficient of performance (COP), and lowers overall energy consumption.
- Automatic chiller sequencing: Selecting the most efficient chiller based on real-time load, Coefficient of Performance (COP), and historical performance.
- Pump and cooling tower VFD control: Adjusting pump speeds and fan speeds to maintain optimal chilled water and condenser water conditions.
- ΔT (temperature differential) optimisation: Detecting low ΔT syndrome and adjusting flows or setpoints to restore efficiency.
- Automated start/stop schedules: Based on occupancy or predicted cooling demand.

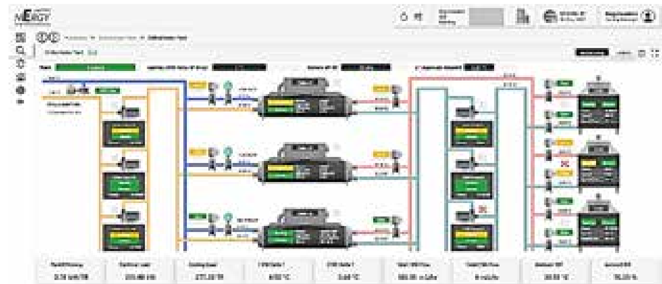

Figure 2: Cloud-based Monitoring & Control dashboard for a Chilled Water Plant

AHU/ FCU Optimisation: Air Handling Units (AHUs) and Fan Coil Units (FCUs) can significantly benefit from data-driven optimisation. Enhancements include:

- Supply Air Temperature (SAT) reset: Adjusting AHU SAT based on load, zone conditions, outdoor temperature, or occupancy trends.
- VFD-based fan modulation: Reducing fan energy while maintaining airflow and pressurisation requirements.
- Fresh Air Control: Using IAQ metrics (CO_2, VOC) and occupancy data to determine optimal fresh air intake.
- Adaptive cooling strategies: Minimising reheating and preventing simultaneous cooling/heating events.

Figure 3: Cloud-based Monitoring and Control dashboard for an AHU

Fault Detection for HVAC Components: IoT systems continuously monitor equipment health and detect anomalies such as:

- Sensor drift or failure
- Valve misalignment or actuator failure
- Damper stuck positions
- Dirty or clogged filters
- Coil fouling
- Abnormal behaviour
- Inefficient operation
- Overheating, vibrations, and noise

Early detection reduces downtime and improves system reliability.

2. **Energy Management**

IoT-enabled energy management systems provide comprehensive visibility into real-time and historical energy usage across building assets.

Real-Time Energy Dashboards: Energy meters feed live data into dashboards for monitoring:

- Power consumption by equipment, floors, or zones
- Voltage, current, and power factor
- Phase imbalances
- Load distribution

Operators can quickly identify inefficiencies or abnormal patterns.

Load Profiling: Time series energy data allows:

- Hourly/Daily/weekly/monthly consumption pattern analysis
- Base load and peak load assessment
- Identification of operational inefficiencies
- Understanding peak load contributors

These insights form the basis for energy saving initiatives.

Peak Demand Alerting: IoT platforms monitor real-time demand and notify operators when consumption approaches utility peak thresholds. Actions may include:

- Automatically adjusting non-critical loads
- Automatically reducing HVAC intensity temporarily in selected zones based on criticality
- Staggering startup of large equipment

This helps avoid expensive demand charges.

Energy Anomaly Detection: Using rule-based or AI-driven algorithms, systems can detect:

- Sudden spikes in consumption
- Equipment running outside scheduled hours
- Energy leaks or losses
- Component degradation causing inefficiency
- Inefficient HVAC modes

Automated alerts support proactive intervention.

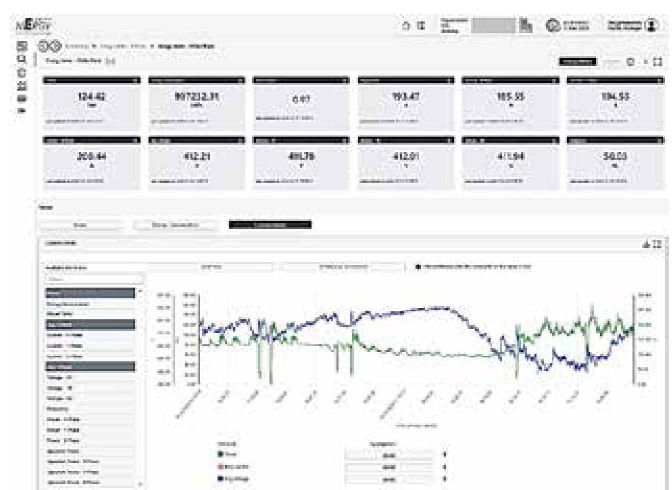

Figure 4: Cloud-based Energy Monitoring dashboard

3. **Indoor Air Quality (IAQ)**

Indoor Air Quality is critical for occupant health, comfort, regulatory compliance, and productivity. IoT-based IAQ management uses real-time sensing combined with automated ventilation controls.

Creating Value Ethically

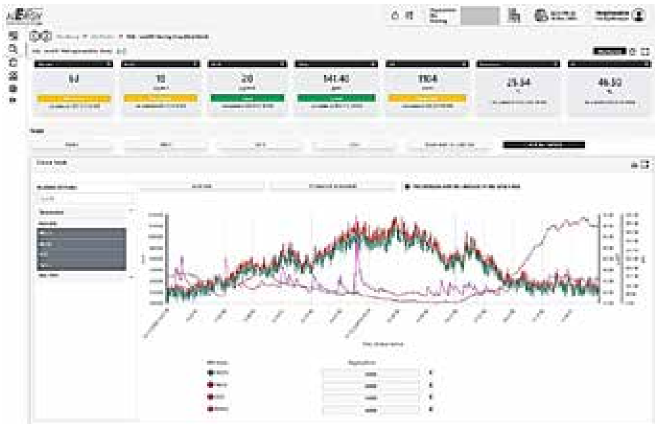

Figure 5: Cloud-based Indoor Air Quality (IAQ) dashboard

CO_2 Based Demand Controlled Ventilation: CO_2 sensors measure occupancy driven air quality. When CO_2 concentrations exceed preset thresholds, the system can increase fresh air intake, adjust supply fan speed, and activate mechanical ventilation systems. When occupancy drops, ventilation is reduced to conserve energy.

PM2.5/ PM10 Monitoring for Health Compliance: Particulate matter sensors allow buildings to maintain compliance with health standards, particularly in hospitals, labs, and urban buildings. Actions may include:

- Automatically activating filtration stages
- Automatically adjusting damper positions when outdoor air quality is poor
- Triggering maintenance alerts for clogged filters
- Logging compliance for audits

Predictive Filter Maintenance: Differential pressure trends across filters enable predictive algorithms to estimate filter life. Operators receive notifications when filters approach clogging, allowing maintenance to be scheduled proactively rather than reactively.

4. **Cold Room and Healthcare Environments**

Cold rooms and healthcare facilities require precise environmental monitoring to ensure product safety, regulatory compliance, and operational reliability.

Temperature and Humidity Excursion Alerts: IoT-enabled temperature or temperature and RH sensors continuously monitor cold rooms, freezers, incubators, and critical storage areas. Alerts are triggered when temperatures or RH exceed or fall below acceptable thresholds or change rapidly due to door openings or equipment failures. This prevents spoilage of perishable goods and pharmaceuticals.

24×7 Remote Monitoring: Continuous remote access to environmental conditions enables staff to:

- View live temperature/RH data
- Track performance of compressors and fans
- Detect abnormal door open durations
- Verify backup power status

This is especially crucial during off-hours.

Compliance Reporting for Pharma, Healthcare & Food Processing Industries: Regulated industries require detailed historical records of environmental parameters, and IoT systems automate these records to ensure traceability and facilitate audits.

The use cases presented illustrate how IoT-powered building and energy management systems deliver improvements in energy efficiency, HVAC reliability, IAQ quality, and compliance. By leveraging real-time data, automation, and analytics, buildings can achieve higher performance, lower operating costs, and improved occupant well-being across a wide range of environments.

Technical Evaluation of Energy Savings Achieved Through Adaptive Control in a Chilled Water Plant

An IoT-enabled adaptive control strategy was deployed on a chilled water plant consisting of two 200 TR VFD screw chillers, variable speed CHW pumps, and fixed speed condenser pumps and cooling towers. Baseline operation maintained a static chilled water setpoint of 7 °C with primary pumps running at 85% speed. Under adaptive control, the system dynamically adjusted the chilled water temperature setpoints and chilled water pump speeds based on real-time zone conditions, weather data and history data while retaining automatic staging and sequencing.

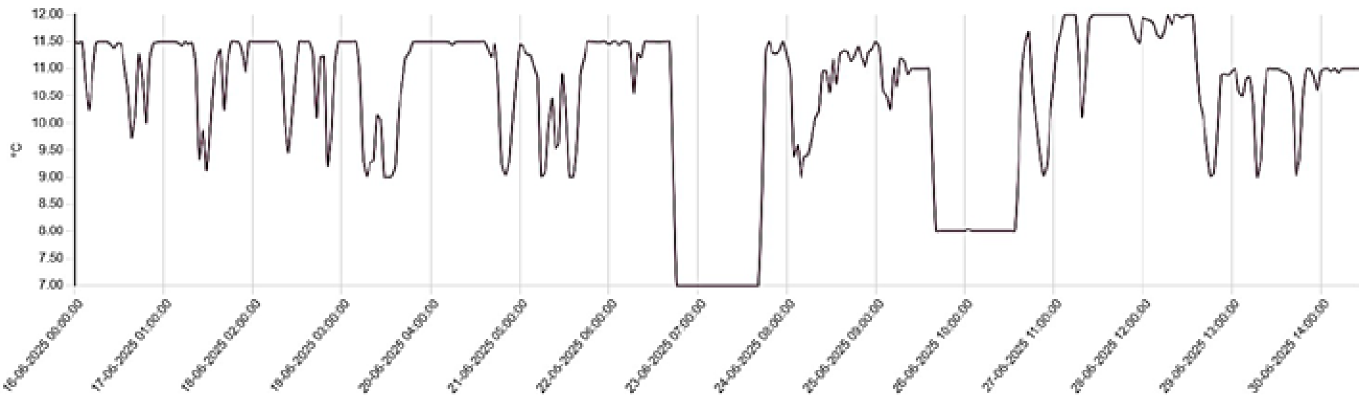

Figure 6: Chilled Water Temperature Setpoint trend with IoT-based Adaptive Controls enabled

A comparative analysis showed that **the adaptive control methodology delivered 15.07% overall energy reduction**. These findings highlight the effectiveness of data-driven, IoT-based supervisory optimisation in improving energy performance without compromising thermal comfort.

Conclusion

IoT-based building and energy management systems offer a powerful pathway for centralised optimisation of HVAC, IAQ, energy, and other building services. By integrating modern sensing, edge analytics, and cloud intelligence, buildings can achieve significant energy savings, improved occupant comfort, and predictive operations.

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Error

In the VIEWPOINT September 2025 edition, for the article 'When Pre-Determined Compensation … The Site Access Dilemma', by Nippon Koei, the designation of one of the authors may please be read as 'Mr Rupesh Jain, General Manager, Metro/Railways' instead of 'Manager, Metro/Railways'. The error is regretted…Ed

CEAI Creating Value Ethically

10

Pavement Asset Management and Use of Machine Learning Models

Dr Swapan Kumar Bagui
HoD, PMG

S K Puri
Executive Director

Soumadeep Bagui
Ex-Student, Jalpaiguri Government Engineering College

Intercontinental Consultants and Technocrats Private Limited

Abstract

This paper presents a brief review of asset management for road pavements based on a literature survey to define asset management, introduces Artificial Intelligence (AI) and Machine Learning (ML), and dwells on System Goals in an asset management framework, pavement asset and condition identification, and asset condition valuation. It also reviews key applications of ML in pavement asset management, including pavement condition assessment, pavement deterioration modelling, maintenance planning, and renewal planning.

A case study is presented using pavement condition and roughness data obtained from a Network Survey Vehicle (NSV). The data is analysed using different Machine Learning (ML) models to identify the best-performing model. The models evaluated include the Confusion Matrix, K-Nearest Neighbour (KNN) Model, Linear Regression Model, Support Vector Regression (SVR) Model, Random Forest (RF) Model, Decision Tree Model, and Gradient Boosting Model.

This paper presents a methodology for multi-criteria decision-making in highway asset management under certainty, risk, and uncertainty. Based on this, the study concludes that the best-performing models for predicting the entire Pavement Condition Index (PCI), Rut Depth, and International Roughness Index (IRI) are the KNN model, the Random Forest model, and the KNN model, respectively.

Introduction

Before 1995, asset management was mainly a private-sector practice, though transportation agencies in Australia, New Zealand, and the United States (US) State Department of Transports (DOTs) began exploring its adoption, Norwell et al., 1997[1]. In 1996, the American Association of State Highway and Transportation Officials (AASHTO) and Federal Highway Administration (FHWA) held the first public-private asset management workshop, FHWA-RD-97-046[2], followed by a second in 1997 and the creation of AASHTO's Transportation Asset Management Task Force, AASHTO, 1998[3]. Growing interest led FHWA to establish the Office of Asset Management to provide technical support. The paper reviews the background of asset management, summarises a survey of practices in different states of the USA. and outlines ongoing initiatives and developments.

Road Asset Management is a systematic process of maintaining, upgrading and operating physical assets cost-effectively by combining engineering principles with sound business practices and economic theory. It provides tools to facilitate organised and logical approaches to decision-making, which help meet public expectations of the works executed under Government plans and policies. To assist the road asset manager in carrying out the above tasks, there often exists a set of core principles that drive the practice and facilitate better decision-making by supplementing engineering judgment with financial and economic analysis. Highway asset maintenance/ preservation generally refers to the set of activities (reconstruction, rehabilitation, and maintenance) that are carried out to keep a facility in usable condition until the next reconstruction activity, IRC: 130-2020[4].

Definition of Asset Management

Asset management is defined as a systematic process for maintaining, upgrading, and operating physical assets cost-effectively, combining engineering principles, sound business practices, and economic theory to support informed decision-making and both short- and long-term planning (FHWA-RD-97-046[2]; Austroads, 2022[5]). While interpretations vary, efficiency remains the central theme. Since the mid-1990s, the asset management community has advanced its understanding, emphasising the integration of asset management with finance, human resources, customer management, and information technology to improve overall performance.

The Guide to Asset Management (GAM) highlights managing road assets and the broader transport system through strategic, tactical, and operational levels. National initiatives - such as AASHTO and FHWA workshops, the creation of the AASHTO Asset Management Task Force, and NCHRP guide have enabled better knowledge sharing. The FHWA Office of Asset Management supports these efforts through policy, training, and technical guidance. The American Public Works Association (APWA)[6], Task Force (1998) confirmed asset management's growing importance across public works disciplines. Many states, including New York, have launched their own asset management initiatives, reflecting a nationwide commitment to coordinated, cost-effective infrastructure stewardship.

Artificial Intelligence and Machine Learning

Machine Learning (ML) is a statistical approach used to develop models from data. The term *learning* refers to the adaptation of model parameters, typically to minimise a loss function. ML techniques are commonly applied to tasks such as regression, clustering, classification, prediction, and forecasting (i.e., making predictions over time), all of which share the core characteristic of deriving models from data.

Artificial Intelligence (AI), on the other hand, is a broader field encompassing a wider range of problems, algorithms, and representations. Consequently, ML is often considered a subset of AI - although the view is not universally accepted. Due to the absence of a formally recognised taxonomy, many experts prefer to focus on selecting appropriate methods from either AI or ML based on the specific problem at hand. An ML dataset consists of samples described by multiple features, typically assumed to be independent, with a loss of objective function guiding optimisation - such as minimising classification errors based on labelled data, Austroads 2022[5].

Highway facilities are among the most valuable public assets, requiring substantial annual investment for preservation and operation. To manage these assets effectively, transportation agencies use systems such as Pavement Management Systems (PMS), Bridge Management Systems (BMS), Congestion Management Systems (CMS), Safety Management Systems (SMS), and Maintenance Management Systems (MMS). PMS, BMS, and MMS focus on the physical asset conditions, while CMS and SMS the address network performance.

With increasing data availability, integrating these systems has become crucial for informed decision-making and coordinated project planning. This paper presents a methodology for multi-criteria decision-making in highway asset management under certainty, risk, and uncertainty.

System Goals in Asset Management Structure

A goal defines the desired state or ideal function of a highway network, National Cooperative Highway Research Program, NCHRP Synthesis 238[7]. In this study, goals - identified through consultation with agencies and users - include system preservation, agency and user costs, mobility, safety, and environmental performance. Preservation focuses on maintaining assets and extending service life, while agencies aim to deliver high service levels cost-effectively, and users seek reduced vehicle operating costs and improved mobility and safety.

Highway asset management programs aim to preserve, enhance, and expand assets while maintaining service levels. In some places, these include bridge and pavement preservation, safety and roadside improvements, system expansion, state facility management, Information Technology System (ITS) installations, and other multimodal or maintenance initiatives.

Performance indicators measure how well investment outcomes meet system goals, NCHRP 238, 1997[7]. As programs target different objectives, specific indicators are used to assess effectiveness under each goal.

Methodology

Highway asset management involves multiple system goals - such as system preservation, cost efficiency, mobility, safety, and environmental sustainability - making it inherently a multi-criteria decision-making process. This process generally consists of two components: trade-off analysis and system optimisation.

Trade-off analysis evaluates competing alternatives within or across programs. For example, it may compare a pavement maintenance project with a pavement rehabilitation project (within a single program) or a pavement project with a bridge project (across programs). Trade-off analysis assesses both the economic implications and service levels associated with reallocating funds between programs.

System optimisation, on the other hand, focuses on identifying the most cost-effective combination of projects under budgetary constraints. Because system goals are typically expressed in non-commensurable units, benefits must be normalised to enable valid comparisons. Utility theory can be applied to convert diverse performance measures into dimensionless, comparable values.

Decisions in asset management may be made under three conditions: certainty, risk, or uncertainty.

- Certainty implies deterministic outcomes.
- Risk occurs when all possible outcomes and their probabilities are known.
- Uncertainty arises when outcomes are only partially known, and probability distributions cannot be reliably defined due to insufficient information.

Incorporating risk and uncertainty ensures that the analyses remain realistic and robust, accounting for the dynamic nature of highway networks in terms of condition and usage.

Development of System-Wide Utility Functions

Since highway asset management programs serve distinct purposes for different asset types or system uses, system-wide multi-attribute utility functions were developed separately for each program. The process involves five steps:

1) Determining the relative weights of system goals
2) Assigning weights to performance indicators under each goal
3) Developing single-attribute utility functions for individual performance indicators
4) Constructing multi-attribute utility functions under various system goals
5) Formulating a comprehensive, system wide multi-attribute utility function for each program

Emerging Roles of Machine Learning (ML) and Artificial Intelligence (AI)

Pavement asset planning and investment are well established across Austroads authorities, but modelling remains complex, relying on practitioner expertise and institutional knowledge that is often hard to document or transfer. Variations in expert opinions, incomplete records, and locally adapted methods hinder standardisation.

Emerging AI and ML applications address these challenges through condition forecasting, automated image-based assessments (e.g., crack detection), asset inventory extraction, and network-level project optimisation. Their use aims to capture institutional knowledge, reduce reliance on individual experts, improve decision quality and consistency, accelerate evidence-based practices, handle growing data complexity, and assess the effects of poor-quality data on AI/ ML adoption.

Overview of AI and ML Concepts

Machine Learning (ML) is a statistical approach for building models from data by adjusting parameters to minimise a loss function. It is widely used in regression, classification, clustering, prediction, and forecasting. Artificial Intelligence (AI) is broader, with ML often considered a subset, though experts emphasise choosing techniques based on the problem.

ML datasets consist of independent samples described by multiple features, with problems defined by objective, cost, or loss functions. Supervised learning uses labelled data, reinforcement learning relies on reward signals, and unsupervised learning finds patterns without labels. Model training seeks to minimise loss, but the key goal is generalisation - performing well on unseen data assessed using separate validation and test sets.

Pavement Asset and Condition Identification

Data collection is essential for pavement renewal planning and preventing overlap with maintenance management. Advances in computer vision and low-cost computing have enabled automated pavement asset and defect detection, improving service-life estimation and maintenance planning, Peraka & Biligiri, 2020[8]. The Australian Road Research Board (ARRB) operates sensor-equipped vehicles and deflectometer trailers with a Global Positioning System (GPS) for geo-referencing, Moore, 2020[9].

3D imaging technologies, including photogrammetry and LiDAR, have been reviewed for distress detection, Mathavan et al., 2015[10]; Farhadmanesh et al., 2021[11] . Photogrammetry is more cost-effective, while LiDAR suits faster data collection and longer-range sensing. Image-based methods detect cracking effectively, but fight with roughness and rutting.

Deep learning and neural networks, such as Crack-Net, automate crack detection from 3D images, Gopalakrishnan 2018[12]; Yang et al., 2019[13], with Australian projects like Road Crack testing multiple systems, Wix & Leschinski, 2012[14]. Remote sensing can efficiently survey large areas, reducing the need for manual inspection (Schnebele et al., 2015[15]). While machine learning for automated defect detection is well-studied, few studies have focused specifically on its applications for pavement renewal planning.

Asset Condition Assessment

Assessing pavement condition from measurements is often delayed by incomplete, sparse, biased, or inconsistent data. To address this, researchers have explored Machine Learning (ML) methods for objective, statistically validated condition prediction. Falling Weight Deflectometer (FWD) data have been used with neural networks to predict Pavement Condition Index (PCI), though results vary, and incorporating additional factors like traffic and weather is recommended, Zaremotekhases et al., 2020[16].

Bashar and Torres-Machi 2021[17] found that ML algorithms - ANNs, Random Forests, and SVMs - captured 15.6% more variability in International Roughness Index (IRI) predictions than traditional methods. Deep learning applied to 2D and 3D images also produced PCI predictions closely matching historical records, reducing the need for manual assessment, Yang et al., 2019[13]. Using YOLO and U-Net models on Google Street View imagery further demonstrated ML's practical potential, despite variable image quality and privacy considerations.

However, not all ML approaches succeed. Random Forest models, even when enhanced with Genetic Algorithms, sometimes yield poor PCI and IRI predictions, highlighting the critical importance of high-quality, standardised, and sufficiently large datasets for effective ML-based pavement condition assessment.

Key Applications of ML in Pavement Asset Management

Pavement Condition Assessment

Automated detection techniques are widely used to identify cracks, rutting, potholes, and other surface defects using image-based or 3D sensing data.

The techniques deployed are (1) Computer Vision: Convolutional Neural Networks (CNNs); and (2) Deep Learning: Extraction of features from 2D or 3D pavement images.

Pavement Deterioration Modelling: This involves predicting pavement performance indicators such as the PCI and International Roughness Index and IRI over time.

Maintenance and Renewal Planning: Machine Learning techniques help optimise the selection and scheduling of pavement maintenance treatments across entire roadway networks.

Machine Learning Analysis for Pavement Asset Management

Data Collection

Sources: Pavement Management Systems (PMS), Bridge Management Systems (BMS), Maintenance Management Systems (MMS), traffic data, weather data, sensors, drones, LiDAR, cameras.

Types of Data: Images, deflection data, roughness, rutting, cracks, traffic volume, and environmental factors.

Data Preprocessing

- Cleaning & Standardization
- Missing Data Handling
- Feature Extraction (e.g., cracks, rut depth, surface roughness)
- Data Labelling for supervised learning

Machine Learning Modelling

Supervised Learning: Predict Pavement Condition Index (PCI), International Roughness Index (IRI).

Algorithms: Neural Networks, Random Forest, Support Vector Machines, Deep Learning (U-Net, YOLO)

Unsupervised Learning: Detect patterns or clusters in pavement deterioration

Reinforcement Learning: Optimise maintenance and renewal strategies

Model Training & Validation

Split Data: Training, Validation, Testing

Loss Functions: Classification error, Regression residuals

Hyperparameter tuning

Performance Metrics: Accuracy, RMSE, R^2, Precision, Recall

Condition Assessment & Prediction

Automated Pavement Distress Detection (e.g., cracks, rutting, roughness)

Predict future pavement deterioration

Estimate Remaining Service Life (RSL)

Decision Support & Optimisation

Prioritise maintenance and renewal projects

Evaluate trade-offs: Cost, mobility, safety, environmental impact

Multi-Criteria Decision-Making (MCDM) integration

Case Study

A case study is presented on a selected section of a National Highway. Pavement condition was determined using Network Survey Vehicle (NSV) whereas the pavement condition rating and maintenance, and rehabilitation were carried out using IRC: 83-2023. Table-1 gives the maintenance recommended based on PCI. The procedure mentioned in IRC: 83-2023 for evaluation of Pavement Condition Index (PCI) was adopted.

Table 1 Maintenance Recommendation Based on PCI

Condition	Excellent to Good		Satisfactory to Fair		Poor to Fail	
Excellent		Good	Satisfactory	Fair	Poor	Fail
PCI Rating	>90 to 100	>80 to 90	>60 to 80	>40 to 60	>20 to 40	0 to 20
Recom-mendation	Routine Mainte-nance	Preventive Mainte-nance	Renewal	Minor Rehabili-tation	Major Rehabili-tation	Recon-struction

Crack, ravel, rut depth, roughness, pothole and patch were the major pavement distresses obtained from NSV surveys used PCI calculation. These data were taken at 0.5 km intervals (taking the average value of 0.5 km), and an Excel file was prepared for a 130 km stretch of the road. It was prepared based on the guidelines mentioned in Sections 8.2 and 8.3 of this paper. Pavement condition data were analysed using different Machine Learning Models and are presented here.

The IRI Actual vs Predicted IRI calculated using KNN Model are presented in Figure 1. The Heat Map of the Pavement Condition is shown in Figure 2.

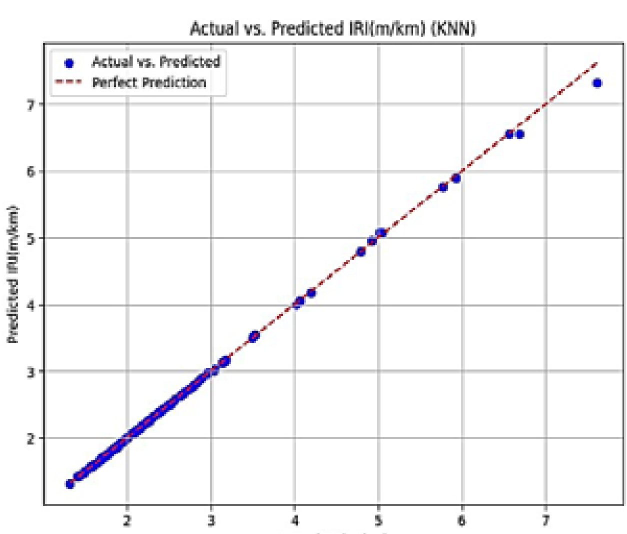

Figure 1: Actual IRI vs Predicted IRI

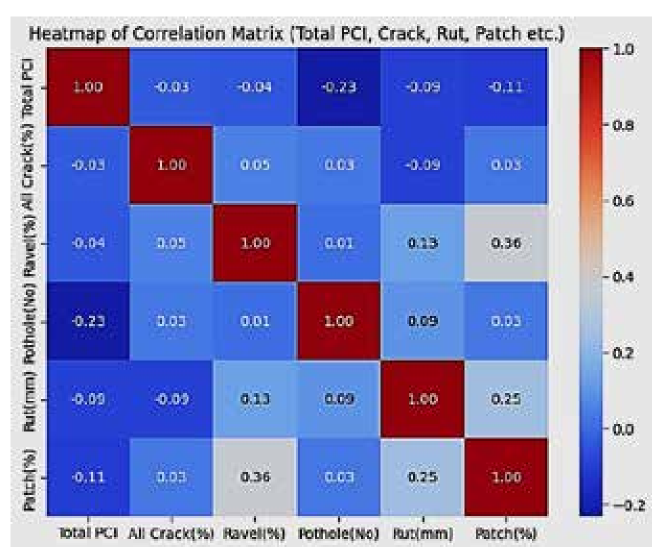

Figure 2: Heat Map

CEAI Creating Value Ethically

From Figure 1, it is seen that there is a good correlation between Actual IRI vs Predicted IRI with $R^2=0.99$ when the data was analysed using the KNN Model and $R^2=0.39$ when using the Random Forest Model. The KNN Model is reportedly the best Model for the analysis of IRI Data.

Similarly, Heat Map correlation values and colour combinations are analysed and presented in Figure 2, from which the following can be deduced.

- Red shades: Positive correlation - as one variable increases, the other also increases. Darker red means a stronger relationship.
- Blue shades: Negative correlation - as one variable increases, the other decreases. Darker blue means a stronger relationship.
- White/ light shades: Weak or no correlation.
- Numbers in cells: Correlation coefficients (range: -1 to +1).
    - o +1 → perfect positive correlation
    - o - 1 → perfect negative correlation
    - o 0 → no linear correlation

Regression Coefficients

- Intercept: Predicted value of the target when all predictors are zero (e.g., PCI = 81.20 when all defects = 0).
- Coefficients: Show how the target changes with a one-unit change in a variable, keeping others constant.
    - o Positive coefficient → increases target value.
    - o Negative coefficient → decreases target value.

Example:

Total PCI = 81.20 - 0.06 ×*All Crack (%) + 0.11*× Ravel (%) - 1.75× *Pothole (No) - 0.26* ×Rut (mm) - 0.53×Patch (%)

In this case, each extra pothole reduces the PCI by 1.75, thus showing a negative impact on pavement condition.

The correlation analysis for 'Total PCI' with other parameters has been carried out, and a summary of the key findings is:

- PCI IRI (m/km): 0.915
- PCI Pothole (No): 0.228
- PCI Patch (%): 0.107
- PCI Rut (mm): 0.088
- PCI Ravel (%): 0.037
- PCI All Crack (%): 0.033

These show that the PCI-related components are, as expected, well correlated with the Total PCI score. The Total PCI is strongly influenced by the component PCI scores, particularly PCI, IRI (m/km). That indicates that the pavement's roughness (IRI) is a major driver of the overall Pavement Condition Index. Among the raw defect measurements, IRI (m/km) shows the most significant inverse relationship with the Total PCI. This is a crucial collaboration of what is physically observed: as the road surface gets rougher (higher IRI), its overall Total PCI (condition) decreases substantially. Other raw defects like Pothole (No) and Rut (mm) also show negative correlations, indicating that an increase in these defects also contributes to a lower Total PCI, though its impact is less pronounced than IRI (m/km). Best Models for Total PCI, Rut and IRI are determined using KNN, Linear Regression, SVR, Decision Tree, Random Forest and Gradient Boosting Model. The Mean Square Error, R^2 and Coefficient of Variation (CoV) for each model are determined and presented in Table 2. The best models for Total PCI, Rut depth and IRI are the KNN Model, the Random Forest Model and the KNN Model, respectively.

Table 2: Parameters for Identification of Best Model

Description	Model					
Total PCI	KNN	Linear Regression	SVR	Decision Tree	Random Forest	Gradient Boosting
MSE	61.60	122.30	129.70	87.1	63.50	70.80
R^2	***0.51***	0.009	-0.051	0.30	0.490	0.43
CoV	79.70	134.70	148.2	102.30	77.40	74.50
Rut Depth						
MSE	2.17	6.120	6.17	6.08	1.57	2.09
R^2	0.65	0.02	0.01	0.66	***0.75***	0.68
CoV	2.04	5.90	6.084	2.60	1.92	1.99
IRI						
MSE	0.42	1.10	1.20	0.68	0.49	0.52
R^2	***0.64***	0.05	-0.04	0.41	: 0.572	0.55
CoV	0.71	1.49	1.66	1.11	0.79	0.86

In data analysis, a cluster refers to a group of data points that are similar to each other in some way and dissimilar to data points in other groups (clusters). Clustering is performed to try to find these natural groupings within a dataset without any prior labels.

In the present analysis, K-Means clustering on the 'Total PCI' values is used. This algorithm grouped the pavement segments into 5 distinct clusters (0, 1, 2, 3, 4) based on their 'Total PCI' scores. Each cluster represents a different 'pavement condition state' as characterised by its average PCI value and the spread of PCI values within it. For example, some clusters might represent 'excellent' pavement, while others represent 'poor' or 'failing' pavement. Table 3 gives a Summary of the data of the clusters.

Table 3: Summarised Results of Clusters

Cluster	Average	Standard Deviation	Coefficient of Variation	Number of Total PCI Data
0	77.22	1.77	0.023	283
1	44.85	4.30	0.095	202
2	60.08	3.99	0.066	85
3	71.21	2.85	0.032	78
4	88.48	2.97	0.034	37

A Box Plot (also known as a Box-and-Whisker Plot) is a standardised way of displaying the distribution of data based on a five-number summary:

1) Minimum: The smallest value in the dataset.
2) First Quartile (Q1): The 25th percentile, meaning 25% of the data falls below this value.
3) Median (Q2): The middle value of the dataset, dividing it into two halves. 50% of the data falls below this value.
4) Third Quartile (Q3): The 75th percentile, meaning 75% of the data falls below this value.
5) Maximum: The largest value in the dataset (excluding outliers).

The 'Box' in the plot extends from Q1 to Q3, representing the interquartile range (IQR), which contains the middle 50% of the data. A line inside the Box marks the median. 'Whiskers' extend from the Box to the minimum and maximum values within 1.5 times the IQR from Q1 and Q3, respectively. Any data points beyond the whiskers are typically considered **outliers** and are plotted individually as dots.

In this present analysis, Box Plots are used to visualise the distribution of 'Total PCI' values *within each cluster*. That helps to see how varied the PCI values were within each cluster and how the median and spread of PCI values differed across the clusters. For instance, a cluster representing 'excellent' pavement would show a Box Plot with a high median PCI and potentially a small spread, while a 'poor' pavement cluster would show a low median PCI. The Box Plot is presented in Figure 3.

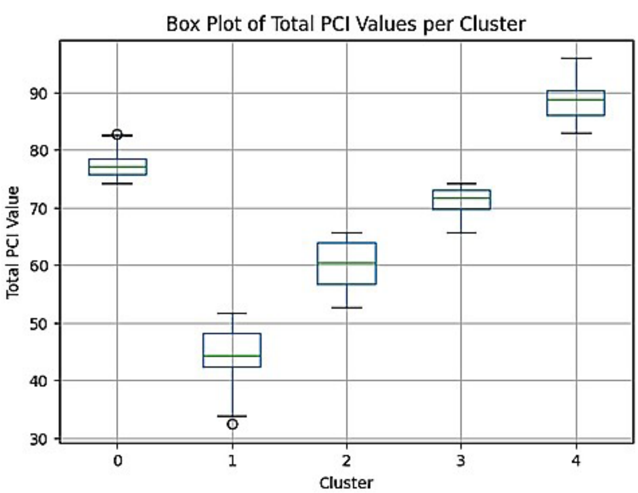

Figure 3: Box of Cluster for Total PCI

Conclusions

This paper presents a review of asset management and the use of Machine Learning (ML) in pavement asset management. Based on the present study, the following conclusions may be drawn.

- ASHTO, Austroads, FHWA, NCHRP guidelines and IRC:130 may be used for asset management for Indian highway asset management.
- Highway facilities are among the most valuable public assets and require significant annual investment for their preservation and operation. To manage these assets effectively, transportation authorities/ agencies need to use various management systems such as Pavement Management Systems (PMS), Bridge Management Systems (BMS), Congestion Management Systems (CMS), Safety Management Systems (SMS), and Maintenance Management Systems (MMS).
- Assessing pavement condition based on field measurements is challenging due to incomplete, sparse, biased, or inconsistent data. To overcome these limitations, researchers have increasingly adopted Machine Learning (ML) techniques for objective and statistically validated condition assessment and prediction.
- Predicting the Pavement Condition Index (PCI) and International Roughness Index (IRI) over time, as well as estimating the appropriate timing for preventive, structural, or functional maintenance, can be effectively achieved using time-series ML models.
- ML models can be applied for the prediction of PCI and IRI values.
- The PCI calculation procedure specified in IRC: 82-2023 is to be followed.
- The colour matrix provides the correlation among pavement distress parameters using different colour combinations, as presented in this paper.
- Mean Square Error (MSE), R^2, and Coefficient of Variation (CoV) need to be computed for each model to identify the best-performing one.
- Based on the present study, the best models for predicting Total PCI, Rut Depth, and IRI were found to be the KNN Model, the Random Forest Model, and the KNN Model, respectively. These results may vary depending on the NSV field data and prevailing pavement conditions on a case-by-case basis.
- Cluster analysis and Box Plot are useful analyses, and they should be carried out for understanding and visualisation.

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11 Role of Asset Integrity Management in Electrical Systems

Punitha R
Discipline Head – Electrical
TATA Consulting Engineers Ltd.

Abstract

In today's industrial and computerised world, electrical systems form the critical backbone that supports operation, stability, and reliability. For them to function as desired, Asset Integrity Management (AIM), which structured, data-driven approach to ensure that the physical assets operate safely, reliably, and efficiently throughout their lifecycle, is essential, and its application to electrical systems is equally vital. Electrical assets, including transformers, switchgear, cabling, and protection systems, form the core of industrial operations, and failure of these systems can lead to severe safety hazards and costly downtime. This article discusses the importance of AIM in electrical systems, its key components, frameworks, and methodologies for risk-based decision making and data management. The integration of digital technologies such as predictive analytics, sensors, and digital twins is also explored.

Case studies of AIM for two existing plants are also discussed.

Introduction

Built facilities in heavy industry, such as power generation plants (thermal, hydro, nuclear), steel manufacturing plants, and energy-intensive industrial infrastructure, depend on robust electrical systems to sustain operations. As these systems age or experience operational stress, the risk of equipment failure increases. AIM provides a structured approach for maintaining the design integrity, technical integrity, and operational integrity of the electrical assets.

A well-implemented AIM program reduces downtime, optimises maintenance, extends asset life, and ensures compliance with standards such as ISO 55000, which emphasises sustainable asset management.

Objectives of AIM

The main goals of electrical system asset management are to maximise asset reliability and availability while minimising whole life costs through efficient maintenance and lifecycle planning. It focuses on managing operational and safety risks to ensure uninterrupted operations and compliance with standards. Additionally, asset management supports energy efficiency and sustainability by optimising system performance and reducing environmental impact. It also enables digital transformation through advanced monitoring, diagnostics, and analytics, allowing organisations to make informed, data-driven decisions for long-term asset integrity and performance.

AIM for Electrical Systems

Electrical systems have unique characteristics such as insulation ageing, thermal loading, and electromagnetic effects that require specialised integrity measures.

AIM covers all components of electrical systems - transformers, switchgear (LV, HV), circuit breakers and relays, electric motors and drives, battery storage systems, and protection systems.

Key Components of Asset Integrity Management

There are 5 key components of AIM as shown in Figure1. They are:

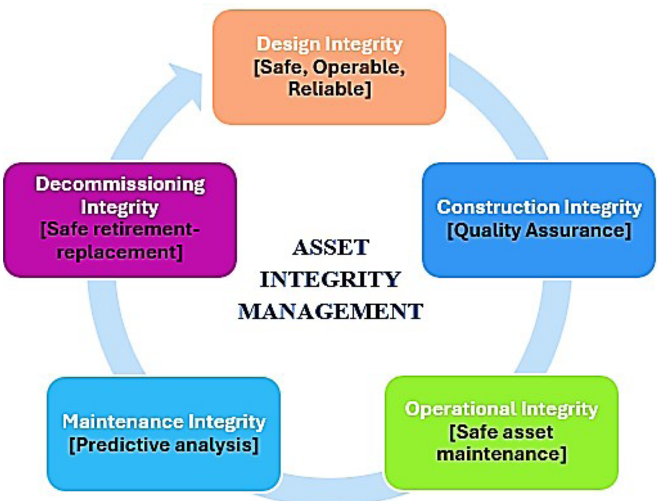

Figure 1: Components of Asset Integrity Management

a) Design Integrity – to confirm that electrical assets are designed according to the relevant performance and safety specifications.

b) Construction/ Installation Integrity – to ensure that the installations comply with engineering standards and quality requirements.

c) Operational Integrity – to check that the assets are operating within safe limits (e.g. current, voltage, temperature).

d) Maintenance Integrity – covers inspections, testing, repairs, and predictive analytics.

e) Decommissioning Integrity – enables the safe retirement and replacement of assets.

Framework and Methodologies

A typical AIM framework comprises:

a) **Asset Register and Configuration Management**

A complete, accurate asset register (including specifications, design data, installation details, maintenance history, and as-built drawings) is the foundation of AIM. Configuration management ensures that any changes (upgrades, replacements, retrofits) are recorded, preventing gaps between digital records and physical reality.

b) **Risk-Based Inspection and Maintenance**

Criticality assessment ranks assets by the probability-of-failure and consequence-of-failure modelling to optimise inspection intervals. Risk-based approaches focus resources on high-risk assets, optimising inspection and maintenance spend.

c) **Condition-Based and Predictive Maintenance**

Moving beyond calendar-based maintenance, Condition-Based Maintenance (CBM) uses real-time sensor data to determine when and what maintenance is required. Predictive maintenance builds on CBM by applying analytics to forecast failures from asset condition trends, enabling proactive repairs before breakdowns occur. The benefits include:

- Optimized maintenance intervals: Maintenance is performed only when needed, reducing unnecessary interventions and costs.
- Extended asset life: Early detection and targeted maintenance prevent premature ageing and failures.
- Resource efficiency: Spare parts can be procured as required, and labour can be utilised more effectively, optimising maintenance spending.

d) **Condition Monitoring**

Online Condition Monitoring helps detect degrading conditions before they lead to catastrophic failures. The techniques used for electrical equipment include thermal imaging to identify hotspots in connections, switchgear (including breakers), and busbars; partial discharge (PD) testing to detect insulation degradation in transformers, switchgear, and cable systems; and Dissolved Gas Analysis (DGA), OLTC condition for assessing transformer health. Other essential methods include insulation resistance and polarisation index testing, as well as power quality and load monitoring to identify issues such as overloads, harmonics, and imbalances. In addition to those, online monitoring of vibration in motors and generators, tan delta measurement, dielectric discharge, along with continuous battery monitoring, provides a deeper insight into the equipment condition. Together, these techniques strengthen Condition-Based Maintenance (CBM) strategies and support the transition from calendar-based to performance-based maintenance programs.

e) **Integration of Digital Tools**

The deployment of Enterprise Asset Management (EAM) tools enables effective tracking of asset data, mobile devices, analytics, and complete lifecycle visibility. This is supported by seamless data integration from systems such as SCADA, Project Management Information System (PMIS), Computerised Maintenance Management System (CMMS), and various inspection databases, ensuring a unified and accurate view of asset conditions. Advanced analytics, including machine learning techniques, enhance this capability by enabling fault detection, anomaly identification, and estimation of remaining useful life. Additionally, digital twins of critical assets allow organisations to simulate performance under different operating scenarios, improving decision-making and maintenance planning. To safeguard these digital systems and asset information, strong cybersecurity measures are essential to protect both data integrity and control systems.

Case Study-1: Asset Performance Management in a Brown Field Electrical Plant

The Asset Performance Management (APM) system was deployed at an operating electrical plant as a brown-field initiative to monitor over 5,000 assets, with an initial pilot on 20 assets. The pilot demonstrated the system's capability to track a range of equipment, including switchgears (and breakers), transformers, and motors, by digitising plant data and integrating multiple data sources into a centralised predictive platform.

To meet monitoring and reliability requirements, multiple systems were digitised and integrated with the Asset Performance Management (APM) platform. SCADA collected extensive real-time data from Intelligent Electronic Devices (IEDs) using protocols such as IEC 61850, 104, 103, 101, SPA, Courier, and Modbus RTU/TCP. Data converters and concentrators transferred this information to the control centre SCADA server through an IEC 61850 network ring. An Electronic Document Management System (EDMS) supported the storage and retrieval of drawings, design documents, FAT reports, and related records through a structured navigation tree.

Preventive maintenance activities and routine inspections were digitised using Hand-Held Devices (HHDs) equipped with RFID-tag scanning capability, enabling technicians to record condition data directly against asset forms for subsequent upload. In addition, wireless self-powered sensors continuously monitored temperature and humidity on switchgears and transformers, with data concentrators gathering sensor information over ZigBee.

The integration of SCADA, EDMS, HHDs, sensors, and historians created a unified digital environment where APM harmonised all data streams. The platform processed this combined information through an in-built analytics model to present asset health status, alerts, and recommendations via an intuitive graphical user interface. APM functioned as a centralised predictive and decision-support system that aggregated operation history from SCADA, equipment disturbances, maintenance and lifecycle data, and telemetry from condition-monitoring devices such as temperature, humidity, oil analyses, and vibration sensors. A five-layer data architecture was implemented to manage the diverse data sources, with assets categorised by failure type and severity to enable focused analytics.

Through predictive dashboards, APM provided trends showing asset condition progression, such as circuit breaker ageing when fault-current exposure exceeds 50%. The system computed key attributes, including Asset Health Index and Remaining Life/End-of-Life status for breakers, transformers, motors, and other assets.

Figure 2 and Figure 3 show the Health Index of a motor, which was analysed by the APM tool using various attributes such as tan delta, partial discharge, dielectric discharge, polarisation index, and insulation resistance. The resulting Health Index of 57% indicated the asset's remaining life expectancy was between 5 and 10 years.

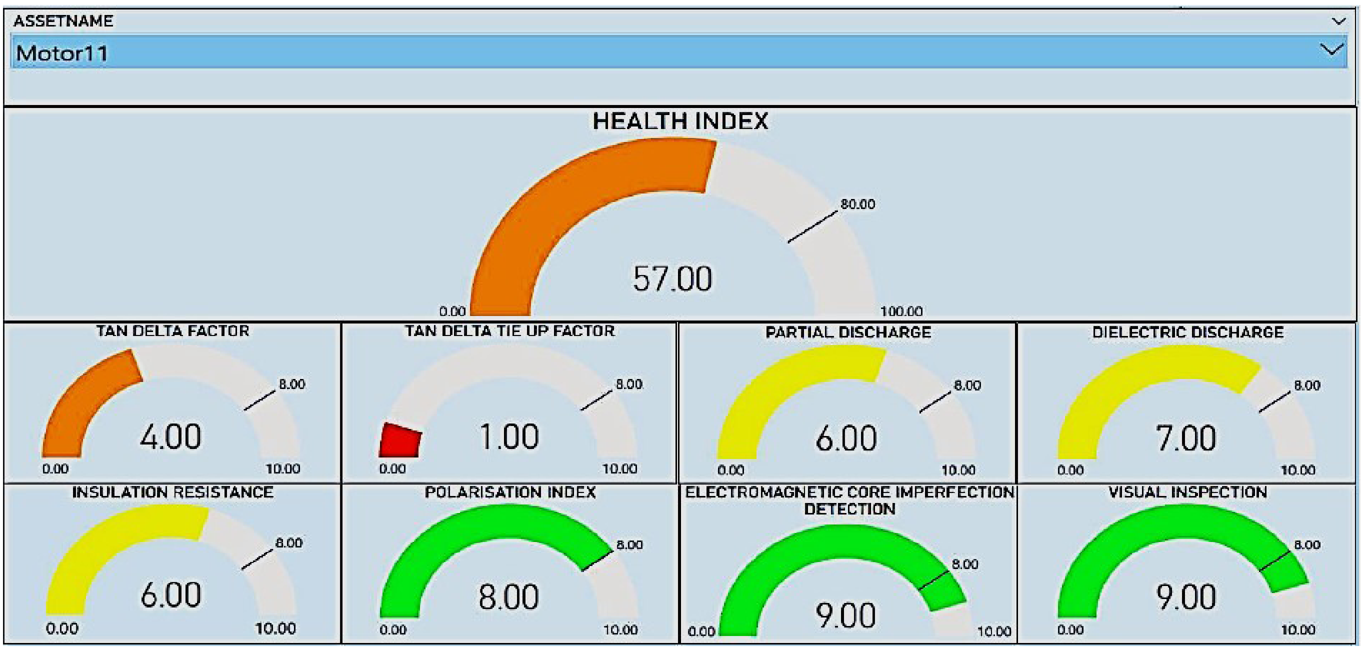

Figure 2: Health Index of a Motor

Health Index	Condition	Description	Expected Life
85-100	Very Good	Some aging or minor deterioration of a limited number of components	> 15 years
70-85	Good	Significant deterioration of some components	>10 years
50-70	Fair	Widespread significant deterioration or serious deterioration of specific Components	[5,10) years
30-50	Poor	Widespread serious deterioration	< 5 Years
0-30	Very Poor	Extensive serious deterioration	At end of life

Figure 3: Probable Life Expectancy of a Motor

Figure 4 indicates the Health Index of a transformer, which was analysed by the APM tool using various attributes such as DGA, bushing condition, partial discharge, polarisation index, and winding resistance. The resulting Health Index of 74.68% indicated the asset's remaining life expectancy was up to upto10 years as seen in Figure 5.

Figure 4: Health Index of a Transformer

Health Index (HI)	Rating	Life Expected
[100,90)	V.Good	More than 15 year
[90,80)	Good	More than 10 year
[80,50)	Fair	Up to 10 year
[50,30)	Poor	Less than 5 year
[0,30)	V.Poor	At End of life

Figure 5: Probable Life Expectancy of a Transformer

By identifying major probable failure causes and generating prioritised alerts with recommended actions, APM supported proactive maintenance, optimised investment planning, and improved performance of the assets.

The pilot successfully demonstrated that integrating SCADA, HHD, EDMS, wireless sensors, and historians into a unified APM platform significantly enhances asset management. The AIM was extended for all remaining assets, which delivered real-time health monitoring, predictive insights, and practical recommendations. This integration enables optimised maintenance, improved reliability, and better-informed decision-making, providing a strong foundation for cost-effective, long-term asset management across the plant.

Case Study-2: Asset Integrity Management in a Brown-Field Steel Plant

The Asset Integrity Management (AIM) system was deployed in an operating steel plant to extend the lifecycle of critical equipment.

An Electrostatic Precipitator (ESP) is a vital pollution-control device in steel plants that removes fine particulate matter from the flue gases, ensuring regulatory compliance and protecting downstream equipment such as the vacuum system, pneumatic system, and drag chain system. However, as ESP hoppers age, mechanical, thermal, and corrosion issues reduce their ability to discharge dust effectively, leading to dust buildup and higher emissions.

As a part of the life extension of the ESP and the downstream equipment, and to ensure the best performance, a heat tracing arrangement for the ESP Hoppers was considered.

The heat tracing and insulation refurbishment of ESP hoppers was planned as a preventive measure to address corrosion caused by SO_2 and CO_2 condensation, which occurs when the gas temperature (around 140°C) falls below the acid dew point of 152°C. Under these conditions, rapid cooling of dust and hopper surfaces leads to sulphuric acid formation and mist generation, resulting in corrosion of ESP electrodes, casings, ducts, and hoppers.

The heat tracing arrangement in the ESP hoppers helps raise the temperature of the collected dust to the top surfaces, thereby preventing SO_2 gas condensation at the acid dew point temperature. The heat tracing arrangement is complemented with insulation and lagging work, supported by a temperature sensing and control system for automatic switching ON/OFF, status display, remote monitoring, and alarm annunciation features to ensure maximum safety and operational reliability.

The Electrical Heat Tracing (EHT) system includes electrical heating elements of modular design, PT100 temperature sensors, a heat-tracing panel (power distribution cum controller panel), heat tracing controllers, heat tracing cables, signal cables, network cables, junction boxes, diagnostic tools, etc., as illustrated in Figure 6.

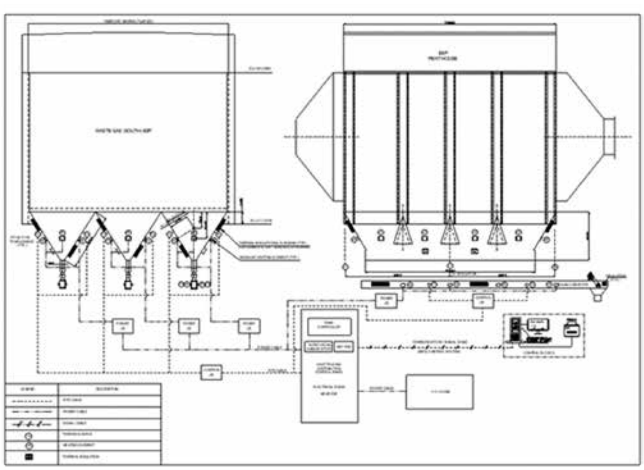

Figure 6: Electrical Heat Tracing System for ESP Hoppers

Electrical Heat Tracing (EHT) in ESP hoppers significantly enhances their long-term reliability and operational stability, making it a vital asset integrity improvement measure. By maintaining hopper temperatures above the dew point, EHT prevents moisture-related corrosion, sticky dust formation, and structural degradation. It ensures free-flowing ash, minimises blockages, and prevents re-entrainment of dust into the ESP fields, thereby protecting downstream equipment and maintaining consistent emission control performance. With reduced manual intervention and fewer thermal stress cycles, the hopper experiences less mechanical damage and extended service life. Overall, EHT supports continuous environmental compliance, improves ESP efficiency, lowers maintenance costs, and ensures sustainable long-term asset performance.

Conclusion

Asset Integrity Management plays a critical role in ensuring the safety, reliability, and efficiency of electrical systems. By combining structured processes, advanced diagnostics, risk assessment, and digital technologies, AIM provides a holistic framework for managing electrical asset health across its lifecycle. Despite challenges such as resource constraints (limited budget, time constraints or lack of adequate tools and technology) and technical complexities, the benefits strongly justify its implementation. Organisations that adopt AIM can expect reduced downtime, enhanced safety, and extended asset life, ultimately contributing to operational excellence and sustainable infrastructure management.

Acknowledgement

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TATA Consulting Engineers Limited has been involved in the implementation of Asset Integrity Management Systems in public and private sector projects with a focus on utilisation of the latest technologies for promoting effective asset utilisation.

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12

Asset Management for Sustaining Built Infrastructure: Global Practices, Emerging Technologies, and a Digital Roadmap

Mumtaz Afzal
Vice President & Head – Digital Transformation
SYSTRA India

Introduction: The New Era of Asset Stewardship

Engineering assets - railway systems, metro corridors, highways, bridges, airports, and urban utilities - are facing unprecedented pressure since the networks are growing rapidly, the funding cycles are tightening, and users expect near-zero downtime. Against this backdrop, Asset Management (AM) is no longer a maintenance function; it has become a strategic discipline essential for sustaining the built infrastructure.

Many countries, such as the UK, Singapore, Australia, Japan and the Middle East, have formalised asset management as their strategic priority. Standards like ISO 55000, Railway RAMS norms (EN 50126/50128/50129), and PAS 2080 for carbon management have elevated asset management from operations into a holistic lifecycle philosophy.

India, with the world's fastest-growing urban transport and infrastructure, is also approaching a similar inflection point. Clients are seeking partners who can help them anticipate risks, optimise lifecycle investments, minimise failures, and transform asset operations through digital intelligence.

This article distils global best practices, explores emerging trends, and outlines how digital technology is shaping the next generation of digital asset management for India and worldwide.

The Global Shift: From Maintenance to Lifecycle Asset Intelligence

Moving Beyond Reactive Maintenance

Historically, most asset owners followed a "repair after failure" model. Globally, the shift is toward predictive and prescriptive models driven by:

- **Data from IoT sensors and SCADA:** Modern infrastructure assets continuously stream data on vibration, temperature, voltage, and equipment behaviour. This real-time telemetry allows operators to detect early signs of degradation before failures occur.
- **AI algorithms predicting Remaining Useful Life (RUL):** Machine learning models analyse historical failures, operational patterns, and sensor data to estimate how much life an asset has left. This helps O&M teams schedule interventions at the optimal time, reducing unnecessary maintenance.

- **Digital Twins simulating scenarios**: Digital Twins create a virtual representation of an asset or system, enabling engineers to simulate stress, wear, operating conditions, and failure modes. This allows decisions to be tested digitally before being implemented in the field.
- **Risk-based prioritisation**: Assets are ranked based on likelihood of failure and impact on operations, safety, and service quality. This ensures maintenance resources focus on the assets that matter most, improving reliability and reducing downtime.
- Optimised maintenance windows to reduce disruptions with predictive insights, operators can strategically schedule interventions during off-peak |periods or low-demand windows. This minimises service disruption without compromising safety or performance.

This approach significantly reduces failures, enhances service reliability, and lowers lifecycle costs.

Data-Centric Asset Management

Modern AM frameworks rely on connected data ecosystems, integrating:

- **Design Data (BIM / IFC):** BIM models contain detailed information about the assets' geometry, specifications, and installation context. When linked to operations, they provide an accurate digital reference for maintenance planning and system understanding.
- **Construction Execution Data (CDE, QA/QC):** Inspection reports, test certificates, checklists, and commissioning records captured during construction help validate asset performance baselines and warranty conditions during operations.
- **O&M telemetry (SCADA, BMS, TCMS, IoT):** Operational data streams reflect real-world asset behaviour, capturing load patterns, environmental conditions, and equipment states. This provides the foundation for predictive analytics and condition assessment.
- **Work Order history and Performance Logs:** Maintenance logs give insights into recurring issues, asset criticality, and root-cause trends. Analysing this history helps refine maintenance strategies and improve asset reliability.
- **Condition Assessment Inspections:** Structured inspections offer qualitative insights such as visual defects, noise, vibration, and structural changes. When combined with telemetry, they provide a holistic health portrait of the asset.

The most forward-thinking countries, such as Australia and the UK, have mandated Asset Information Requirements (AIR) at the time of project inception so that end-of-life maintenance strategies can be defined early, not after commissioning the asset.

Digital Twins as the New Backbone

Global leaders such as Cross Rail, Sydney Metro, Dubai RTA and Singapore LTA are using **Digital Twins** to integrate geometry, telemetry, inspections, reliability data, and maintenance workflows. Refer Figure 1.

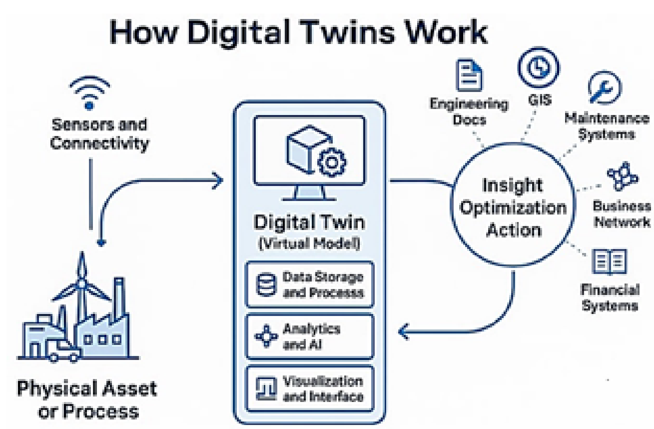

Figure 1

A Digital Twin offers:

- **A single source of truth**: Digital Twins unify data from BIM, SCADA, IoT, GIS, and maintenance systems into one consistent model. Stakeholders across engineering, operations, and maintenance reference the same digital environment.
- **Simulation of asset performance**: Engineers

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can test "what if" conditions - like higher loads, temperature changes, or ageing effects - to predict how assets would behave. This supports scenario planning and resilience evaluation.

- **Visualisation of degradation trends**: Digital Twins visually represent asset condition over time through heatmaps, trend curves, and 3D overlays. This helps maintenance teams quickly identify hotspots and emerging risks.
- **Impact assessment of maintenance decisions**: Before scheduling major works, O&M Engineers can evaluate service disruptions, cost implications, and downstream effects. This reduces uncertainty and enhances decision confidence.

In many global metros, Digital Twins are helping reduce service disruption by up to 30% and maintenance overhead by 15–20%.

Challenges Faced Worldwide - and Relevance to India

Based on international studies and audits of large infrastructure programs, the main pain points include:

Fragmented systems and information silos

Asset data often lives across:

- **Multiple vendor systems**: Each subsystem - signalling, power, rolling stock, station equipment - often runs on separate OEM software platforms that do not communicate with each other.
- **Excel sheets**: Critical maintenance and inspection data is frequently stored in spreadsheets, making it hard to consolidate, validate, or analyse holistically.
- **OEM maintenance portals**: Vendors maintain their own diagnostic tools, resulting in asset data being scattered instead of integrated into a central asset management framework.
- **SCADA/ BMS**: These systems monitor real-time status but lack historical context, predictive capabilities, or integration with maintenance workflows.
- **Enterprise ERP systems**: ERP platforms track finance, inventory, and procurement, but rarely integrate deeply with O&M systems - creating blind spots in lifecycle cost visibility.

This fragmentation leads to an incomplete understanding of asset health.

Unanticipated Failures & Poor Condition Visibility

Most failures arise because:

- **Asset condition is not monitored continuously**: Many assets rely on periodic manual inspections rather than sensors, which continuously monitor conditions, leading to gaps in understanding how quickly equipment is deteriorating.
- **Rules-based alarms generate noise without insights:** Basic threshold alarms detect failures too late and often bombard operators with false positives, making it hard to identify critical issues.
- **No unified view exists for cross-asset dependencies:** Failures in one subsystem - like power or ventilation - can cascade into others. Without system-wide visibility, timely interventions are not done.

Lack of risk-based decision making

Without structured risk models, maintenance becomes calendar-based instead of reliability-driven, increasing both cost and downtime.

Limited usage of lifecycle cost models

Globally, asset owners who adopt whole-life costing save up to 25% on long-term budgets. India is just beginning to adopt this discipline.

Absence of integrated digital workflows

Inspection data, maintenance data and asset health trends rarely talk to each other. This prevents proactive interventions and early detection of systemic issues.

Best Practices: What Leading Nations Are Doing Right

Implementing ISO 55000-aligned AM frameworks

A structured AM framework includes:

- **Asset Strategy**: Defines how assets support organisational goals and sets performance expectations across their Lifecycle.
- **Risk Models:** Assess the Probability and Impact of Failure, allowing for Informed Prioritisation and Resource Allocation.
- **Maintenance Regimes**: Structured Programs - Preventive, Predictive, Or Condition-Based - Ensure assets are maintained optimally.
- **Performance Indicators**: KPIs such as Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), availability, and lifecycle cost help measure asset performance objectively.
- **Governance:** Clear roles, responsibilities, and decision protocols provide consistency and accountability across the organisation.

Such systems enable decision makers to align maintenance with organisational objectives.

Condition-based and Predictive Maintenance adoption

This is done by using:

- **Vibration Sensors**: Detect bearing wear, imbalance, and misalignment before catastrophic failures occur.
- **Temperature/ Humidity data**: Identify overheating, insulation degradation, or environmental stress factors affecting equipment lifespan.
- **Defect Logs**: Historical defects help predict recurrence patterns and identify design or operational weaknesses.
- **Machine Vision for OHE & Tracks**: High-resolution imaging and AI detect cracks, corrosion, wire wear, and component errors faster than manual checks.
- **Lidar for Tunnel and Civil inspections**: Lidar scans generate precise 3D models that reveal structural deformations invisible to the naked eye.

Predictive maintenance increases asset availability dramatically in metros like Hong Kong MTR and London Underground.

Strong Competency Building

Japan, Germany and Singapore invest heavily in AM training for:

- **Inspection TEAMS**: Need training on modern digital tools and structured methodologies for condition assessment.
- **Field Engineers**: Must understand asset behaviour, failure modes, and optimal maintenance interventions.
- **Data and Digital Professionals**: Interpret telemetry, develop dashboards, and operate predictive analytics platforms.
- **RAMS Specialists**: Ensure assets meet safety, reliability, and availability targets throughout their lifecycle.

Clear Asset Information Requirements (AIR)

AIR ensures that the infrastructure is designed and commissioned with AM in mind - preventing long-term data gaps that cripple maintenance planning.

The Rise of Digitalisation in Asset Management

Digitalisation is transforming AM globally through:

IoT/ SCADA/ TCMS-connected infrastructure

Real-time data provides actionable health insights for power, signalling, rolling stock, ventilation, and stations.

Asset Management Platforms (EAM/ APM)

Enterprise Asset Management (EAM) and Asset Perfor-

Figure 2

mance Management (APM) are commonly deployed, as shown in Figure 2. The EAM systems enable:

- **Work Order Automation**: Systems auto-generate tasks based on PM plans, inspection failures, or predictive analytics.
- **Condition monitoring**: Continuous health assessments provide visibility into degradation trends over time.
- **Asset health prediction**: Machine learning models estimate failure likelihood, allowing targeted interventions.
- **Analytics & lifecycle costing**: Dashboards help evaluate long-term financial and operational performance.

AI & Machine Learning

AI is now used to:

- **Detect anomalies**: AI identifies deviations from normal operation patterns, often before alarms are triggered.
- **Predict failures**: ML models determine when equipment is likely to fail based on history and sensor data.
- **Recommend maintenance actions**: AI models suggest the optimal maintenance response, balancing cost, risk, and downtime.
- **Cluster defects in civil structures**: The Algorithms group defect patterns across assets to identify systemic issues.
- **Read compliance logs**: Natural language models extract insights from maintenance reports, manuals, and inspection notes.

Computer Vision (refer Figure 3) is rapidly becoming standard for inspecting:

- Tracks and ballast
- Overhead equipment
- Concrete defects
- Escalator steps
- Tunnel linings

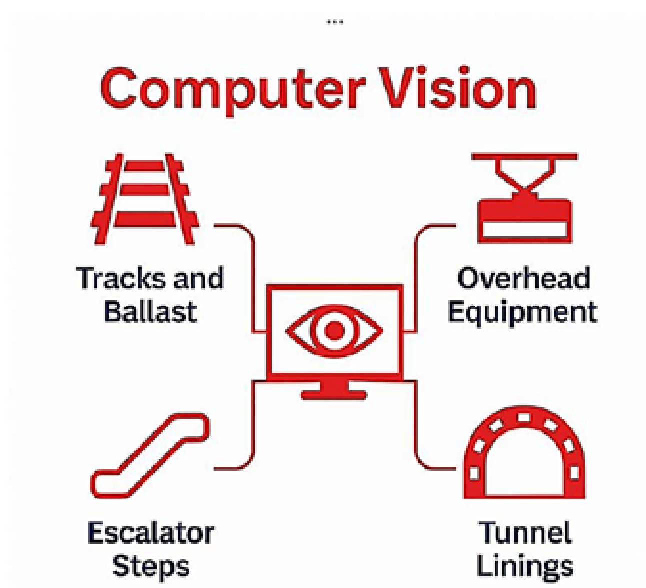

Figure 3

Digital Twins for O&M

Digital Twins establish a digital thread from design → construction → operations by integrating:

- **BIM/ IFC:** Provides accurate geometry and metadata for structures, equipment, and spatial relationships.
- **CDE data**: Ensures construction records, QA/QC logs, and commissioning documents are aligned with the digital twin.
- **SCADA signals**: Operational data streams keep the twin updated with real-time status.
- **IoT streams:** Complement SCADA with granular, high-frequency asset performance data.
- **GIS**: Adds geospatial context, essential for linear assets like track, tunnels, and utilities.
- **Maintenance records**: Integrate work orders, repairs, and inspections for comprehensive asset histories.

Mobile-first O&M

Field crews globally are shifting to:

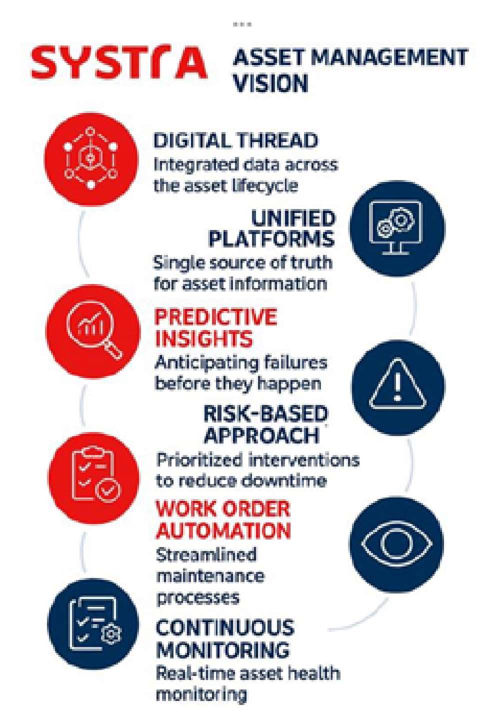

Figure 4

- Tablet-based inspections
- Augmented Checklists
- Voice-assisted data capture
- AR overlays for complex equipment

This prevents gaps between field observations and AM systems.

Building the Next Generation of Digital Asset Management

For Digital Asset Management, the complete project lifecycle, i.e. Engineering, Construction & Operation, should be integrated through an end-to-end digital workflow, thus providing a digital eco-system.

Asset Management Philosophy

The focus should be on:

- Lifecycle thinking – from design, to construction, to operations
- Reliability and Safety – embedded RAMS culture
- Digital-first AM delivery – data-driven and integrated
- Sustainability – aligning AM with decarbonisation goals
- People empowerment – enabling engineers with modern tools

The Way Forward: Building Resilient and Sustainable Infrastructure

Prioritise Digital AM Adoption

Regulators and clients must mandate:

- Asset Information Requirements (AIR)
- Digital handover of models
- Data governance frameworks

Build Skills

AM increasingly requires:

- Data engineers

- Reliability engineers
- RAMS professionals
- Digital technicians

Move Toward Autonomous O&M

Future-ready metros will adopt:

- Automated inspections
- AI-driven scheduling
- Predictive work orders
- Self-learning models
- Integrated Digital Twins with Real-Time simulation

Align AM With Sustainability

Asset management plays a critical role in:

- Reducing energy consumption
- Extending asset life
- Minimising carbon footprint
- Enabling green procurement

Conclusion

Asset management is at the centre of sustaining built infrastructure. Globally, it is transforming into a digitally intelligent, predictive, risk-sensitive discipline. India is poised to leapfrog into this future, driven by metro expansions, high-speed rail, and smart urban infrastructure initiatives.

The Digital integration - combining engineering excellence with AI, IoT, mobility, Digital Twins, and data-driven lifecycle insights, aims to reshape how assets are optimised, managed and preserved.

As infrastructure becomes more complex, the only sustainable path forward is a digitally empowered asset management ecosystem that anticipates failures, enhances safety, reduces lifecycle cost, and ensures long-term resilience.

Acknowledgement

I extend my sincere thanks to CEAI for the opportunity to contribute to this important topic on asset management. I am equally grateful to my colleagues at SYSTRA India, whose insights have greatly helped me put forward the perspectives presented in this article.

India ranks 3rd in rare earth reserves, but trails in production due to structural bottlenecks in mining

India has the world's third-largest rare earth reserves, but its production remains among the lowest compared to major global players, highlighting a sharp gap between resource availability and actual output, according to a report by Amicus Growth.

Data showed that India holds about 6.9 million tonnes of rare earth oxide (REO) reserves, placing it behind only China and Brazil. China tops the list with 44 million tonnes of reserves, followed by Brazil with 21 million tonnes.

Despite its strong reserve position, India's production remains limited. In 2024, India produced only 2,900 tonnes of rare earths, ranking seventh globally. In comparison, China produced 270,000 tonnes, making it the clear global leader. The United States was the second-largest producer with 45,000 tonnes, followed by Myanmar (31,000 tonnes). Australia, Thailand and Nigeria each produced around 13,000 tonnes.

Source: Excerpts from Economic Times

13

Asset Monetisation – The Key to India's Infrastructural Success

Vandana Randhawa
Director and FIDIC Procurement Specialist
Legacy Law Offices LLP

Introduction

The driver for asset monetisation is beyond its fiscal impact. It is not just a funding mechanism, but an overall paradigm shift in infrastructure operations, augmentation and maintenance[1]- Niti Aayog

In November 2025, the National Highways Authority of India (NHAI) expressed an intention to offer six Toll-Operate-Transfer (ToT) bundle projects to investors in a bid to strengthen the asset monetisation efforts for achieving the INR 40,000 crore target in 2025-26. While the procurement procedures for the initial projects faced issues arising out of revenue sharing arrangements, NHAI sought to rekindle the momentum by innovative solutions to reignite the interests of private investors[2].

Asset Monetisation (AM) is not a new term for the Indian infrastructure sector. In its various forms, AM has brought realisation to our ambitions of achieving a steady economic growth through dynamic infrastructural development.

Having been formally introduced in 2012 by the Vijay Kelkar Committee, AM is a lucrative way for India to promote the development of large-scale construction and engineering projects through a substantial reduction of the risks that often discourage private financiers from investing in the industry. That said, even though the active adoption of AM as a preferred method of development in land-locked parts of the country has opened new avenues, there remain a few policy hurdles, which have mired an optimal execution, thus, substantially reducing the pace, requisite for the country to attain its USD 5 trillion economy dream[3].

Asset Monetisation and its Relevance to India

The Covid-19 pandemic took an unprecedented toll on the Nation's economy. With a complete halt to development activities, growth became stagnant, thereby putting the country in need of innovative solutions. India, being the largest democracy with limited land, was on the lookout for methods that would promote development through an optimum use of the available resources, including land, but the latter was rather limited. Thus came the idea of AM and recycling.

AM at its core, is a distinct shift from 'privatisation' and 'slump sale' of assets to 'structured partnerships' with the private sector within defined contractual frameworks[4]. Considering that India prominently holds a massive stock of brownfield assets, coupled with the fact that the Government has been working doggedly towards the active promotion of public-private partnerships (PPP) in its infrastructure sector, AM ensures a lucrative deal for domestic and international investors, through a steadfast promise of returns.

While asset monetisation focuses on unlocking financial value from existing public assets, its long-term success is fundamentally dependent on robust asset management practices. Effective asset management, centred around life-cycle planning, performance monitoring, and systematic maintenance, ensures that brownfield assets retain their operational efficiency, safety, and revenue-generating potential, thereby enhancing investor confidence and sustaining monetisation outcomes. In this context, India's monetisation initiatives cannot be viewed in isolation; they must be complemented by structured asset management frameworks that allow for accurate valuation, transparent condition assessments, and predictable performance over the concession period. Integrating these principles will not only support the government's objective of recycling capital but also ensure that the underlying assets remain resilient and productive throughout their life cycle.

A reflection of this realisation of AM's potential was showcased in 2021, when the Government of India (GoI) launched the National Monetisation Pipeline (NMP), which had the objective of invigorating private investor interest in infrastructure projects to ultimately bolster economic growth. The task assigned to the pipeline was simple: generate revenue by unlocking the value of underutilised public assets to fund new infrastructure projects. While the progress was positive, the NITI Aayog (the policy think tank of the GoI), however, reported that during FY 2023-24, against the target of INR 1.8 lakh crore, the achievement was of approximately INR 1.56 lakh crore. Even thereafter, a silver lining was highlighted with the fact that such achievement was about 159% of the achievement in 2021-22[5].

To renew its objective of promoting AM and recycling, the GoI in its Union Budget for FY 2024-25, launched the AM Plan 2025-30, seeking to generate INR 10 lakh crores through the monetisation of public sector assets for investments in infrastructure projects. Introduced as a successor to the NMP, the AM Plan sought to focus on brownfield assets across highways, railways, telecom, power, and aviation sectors. It is, however, essential to mention that the AM Plan, being in its nascent stage, has yet to record any substantial progress.

Other than the aforementioned policies and plans introduced at the union level, many state governments, including those of Orissa, Tamil Nadu, and Kerala, also established state-level AM projects, many of which received financing and support from Multilateral Development Banks, including the World Bank.

Recording Progress and Lessons

The issue arising out of land acquisition has plagued the history of Indian public infrastructure projects. With many projects entering litigation or facing inordinate delays due to project site handover issues or unfair compensation, it may be stated that India poses a volatile profile for certain investors.

In 2020, a similar issue came to the fore when the GoI was on the path to raise USD 12.5 billion through AM of over 6,400 km of highways. This plan proved to be unsuccessful due to a number of reasons, including the inability of the build-operate-transfer (BOT) model, combined with an unattractive land acquisition risk profile, to persuade concessionaires. Upon realisation of such shortcomings, NHAI came up with an innovative solution and introduced the ToT method of procurement, which posed a lesser risk of exposure to private participants and provided them with exclusive toll collection rights. Through the TOT model, the GoI was able to carry out a successful procurement process, which led to the appointment of Macquire Group as the lead investor on the Bundle I projects. That said, while the TOT model proved to be successful in Bundle 1, the remaining projects failed to invite active participation, thus highlighting the *factum* that the latter was not a flawless method of procurement and that other issues, including the offering of attractive assets, were also a cause for concern.[6]

Such issues were also foreseen by the NHAI in 2025, as aforementioned, whereafter the authority sought to reform the revenue-sharing arrangements to facilitate the success of its AM initiatives.

The issues that arose out of the construction of the **Lokpriya Gopinath Bordoloi International Airport (LGB Airport)** being developed on a PPP mode in

Guwahati, are another example where ambiguous policies and procurement procedures overtook the advantages associated with AM and caused hindrances in development. The main point of contention associated with the LGB Airport project seemed to be the extended time frame for the return on investments, which was held to be a consequence of the greenfield nature of the project. Another issue that arose during the project pertained to the fixation of aeronautical tariff, wherein the Airport Economic Regulatory Authority (AERA) refused to factor in all forms of capital expenditures cited by the concessionaire in the determination of tariff. This impasse between the authority and the concessionaire, along with the uncertainties concerning the asset classification, led to certain disagreements. Disputes were partially resolved after the submission of true-up calculations of tariffs by the concessionaire, subsequent to which the authority appointed a Consulting company for assistance in the determination of the correct tariffs.[7]

The project is now reportedly nearing completion and is expected to be operational by November 2025.[8]

Another startling example which arose from contractual issues rather than policy issues is the case of the **Noida Toll Bridge Company Ltd v. Federation of Noida Residents Welfare Association**[9], where the Hon'ble Supreme Court dealt with a unique situation where the AM project concerning the construction of the Delhi-Noida Direct Flyway project (DND Project) was found to be riddled with irregularities flowing directly from the lack of a procurement process and a seemingly infinite concession period. In holding the decision of the High Court restraining the collection of toll fees to be correct in law, the Hon'ble Supreme Court observed that the project involved an overwhelming public element comprising public funds and infrastructure.

It was observed that the contract in question was a ruse which provided the Respondents with an illusion of choice, where it could either allow the extension of the 30-year concession period to the Appellant in the contract, where the determination of the project cost was a variable, or to bear the financial burden itself by causing a payment of INR 5,353 crores through public funds. The result of this unjust choice was thus observed to have a single consequence, the enrichment of the Appellant at the cost of public suffering.[10]

Need for Policy Changes

A perusal of the aforementioned illustrations gives a reasonable inference to the fact that while AM is a sure-shot method of monetising the existing resources in a manner that may be found to be lucrative to private investors, there is a dire necessity for India to reframe or refine its policies to reduce the complexities that are being faced in the actual execution of the projects.

A way to achieve this objective may be to adopt standard forms of contracts which have established duties, concession periods and risk allocation. Adoption of standard forms of contracts, like those established by FIDIC, may reduce the repetition of the NTBC case, where the concession agreement was extended indefinitely due to contractual ambiguities.

Further, adoption of methods other than ToT can also cause an increase in the interests of the investors, as the former has been found to suffer from various irregularities. That said, while the Ministry of Road Transport and Highways has recently expressed an intention to phase out ToT for Infrastructure Investment Trusts (InvITS), NHAI continues to invite bids through ToT, thus highlighting the need for active and expedited action in this regard.

India's tryst with monetisation is not a new thing but an ongoing exercise. There is now a need to systematically adopt initiatives like InvITs and Real Estate Investment Trusts (REITs) across varied asset classes and streamline the frameworks and modalities of such alternatives in a programmatic manner, which can be readily absorbed, evaluated, and replicated[11].

Other methods and policies surrounding actively faced issues like revenue-sharing arrangements may also be prerequisites for the GoI to be able to cause an adequate implementation of its various AM initiatives.

A Way Forward

A detailed study of the various advantages associated with AM and the need exhibited by India to fortify its infrastructural growth can give a reasonable inference to the fact that AM holds the key to India's economic strength. Through structured mechanisms such as PPPs, long-term concessions, and leasing arrangements, AM facilitates the mobilisation of private capital and expertise, seeks to enhance operational efficiency, and can ensure improved service delivery across critical infrastructure sectors, crucial for the overall development of the nation.

It is thus imperative for India to actively pursue the implementation of its AM initiatives, addressing existing regulatory and procedural inefficiencies, to attract robust private sector participation in its infrastructure sector and to ultimately support the 5-trillion economic growth goal of the country.

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BlackRock's infrastructure fund invests ₹ 20 billion (~US $222.5 million) in Aditya Birla Renewables

Aditya Birla Renewables announced on Tuesday that BlackRock's infrastructure fund will invest ₹20 billion ($222.5 million) for a minority stake in the company. The deal also includes a greenshoe option that allows BlackRock's Global Infrastructure Partners to inject an additional ₹10 billion, potentially raising the total investment to ₹30 billion (approximately $335 million).

Source: Business Standard

14

Battery Energy Storage – A Strategic Enabler for Asset Management

D. Geethalakshmi
Senior General Manager
TATA Consulting Engineers Ltd.

Abstract

The global energy transition is driving an unprecedented focus on resilience, flexibility, and sustainability in managing built facilities. Battery Energy Storage Systems (BESS) have emerged as transformative infrastructure assets in the global energy transition, fundamentally reshaping how utilities and distribution companies manage their physical and financial resources. With the global BESS market projected to reach USD 105.96 billion by 2030, these systems are no longer merely ancillary components but strategic enablers in asset management by optimising performance, extending asset life, and reducing total ownership costs across electrical infrastructure. This article explores how BESS enhances asset management by addressing peak demand, deferring capital expenditure, improving renewable energy integration, and mitigating operational risks. The paper presents market trends, the role of BESS in the lifecycle of built facilities, and a real-world case study from a feasibility study undertaken for an Indian power distribution company (DISCOM).

Introduction

Across the power sector, built facilities such as substations, power transformers, transmission lines, industrial feeders, and power plants form the backbone of modern electricity systems. Effective asset management of these facilities requires balancing cost, reliability, and sustainability. Conventional asset management models relied primarily on preventive and corrective maintenance cycles, and these were typically based on deterministic load patterns. However, as grids integrate variable renewable energy and demand patterns become more dynamic, utilities require smarter and adaptive mechanisms to sustain performance and optimise investments. BESS are emerging as a critical tool in this transformation. They not only address immediate operational challenges but also influence long-term asset planning, enabling utilities and industries to extract maximum value from existing infrastructure.

Global Battery Energy Storage Market Overview

Battery storage deployment is accelerating worldwide. The International Energy Agency (IEA), in its World Energy Outlook 2025, reports that annual battery-storage additions surpassed 75 GW in 2024, reflecting a major acceleration in utility-scale deployments across Asia, Europe, and North America. The BESS market is expected to grow from USD 50.8 billion in 2025 to over USD 105 billion by 2030, representing a compound annual growth rate (CAGR) of approximately 15.8%. In India, with a cumulative installed capacity of

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204.5 MW/ 505.6 MWh, the policy frameworks of the Ministry of Power and MNRE aim to achieve 61 GW of energy storage capacity by 2030. The Central Electricity Authority (CEA) has recognised BESS as vital for renewable integration, frequency regulation, and grid stability in its National Electricity Plan (2024–2030). This growing adoption reflects the strategic shift from energy storage as a niche technology to a mainstream asset management instrument within utility and industrial systems. **BESS is thus a Strategic Asset Management Tool.**

The Asset Management Imperative

Asset management for utilities and built facilities involves the strategic coordination of physical assets to optimise performance, risk, and expenditures over their lifecycle.

Three main challenges increasingly impact asset management for electrical infrastructure:

a) Capital Expenditure: Transformers and other grid assets, when sized to meet the maximum anticipated peak load, which often occurs during only a small fraction of annual hours, result in the transformers typically operating well below their rated capacity for most of the year. This mismatch leads to lower operational efficiency and higher energy losses, while simultaneously inflating initial capital expenditure for infrastructure that remains underutilised, representing a hidden economic cost for utilities and facility managers.

b) Asset Degradation and Ageing: Due to the rapid demand growth, most of the existing grid infrastructure is approaching or exceeding design capacity. These scenarios necessitate expensive replacement or augmentation.

c) Operational Inflexibility: Traditional grid assets provide limited flexibility during dynamic grid conditions. A transformer and transmission installed to handle peak capacity cannot be elastically adjusted to match real-time requirements, leading to inefficient usage during off-peak times and leading to suboptimal efficiency and frequent under- or over-utilisation during normal operations. As the electrical grid transitions increasingly towards real-time balancing and decentralised energy management, the inability of these static assets to respond dynamically presents a growing barrier to achieving optimal performance and reliability.

Multi-dimensional Value Streams from BESS

BESS are not merely energy buffers but dynamic assets that can influence the life cycle of other infrastructure elements. They address each of these challenges by introducing a flexible, rapidly deployable capacity that can defer infrastructure investments, extend asset lifespans through load management, and provide dynamic operational capabilities.

a) Peak Load Management and Demand Charge Reduction: Due to an increase in load demand, built facilities often experience high stress during peak load conditions, leading to transformers and feeder overloads. By discharging during peak hours, BESS helps maintain optimal load profiles and mitigates thermal stress on transformers, thereby extending their lifespan. This aligns with asset management principles focused on optimising utilisation and avoiding premature replacement.

b) Capital Expenditure Deferral: By deploying BESS to manage peak loads, it can defer transformer augmentation for multiple years. Studies demonstrate the economic viability of deferring transformer upgrades for 4-6 years using appropriately sized BESS.

c) Renewable Energy Integration: BESS enables the integration of renewable energy sources such as solar and wind. Renewable power, though clean, introduces variability and intermittency. Without storage, these fluctuations increase the stress on grid assets and complicate scheduling. By storing excess renewable generation and discharging it during shortfalls, BESS ensures smoother operation, improving the reliability of built facilities.

d) BESS supports reactive power compensation and frequency regulation. Advanced inverter-based systems can provide both real and reactive power, improving grid voltage stability and compliance with regulatory codes. This function helps utilities avoid penalties under deviation settlement mechanisms (DSM) and enhances the power quality within their networks, thereby helping operational efficiency and OPEX.

e) Enhancing Reliability and Resilience: BESS ensures a stable and continuous power supply, crucial for critical infrastructure. by providing fast-response backup power during grid outages, it ensures business continuity and avoids costly downtime.

Case Study – Battery Energy Storage as a Multi-Value Asset

A feasibility assessment was undertaken for a large private distribution company to evaluate the role of a BESS in strengthening its asset management strategy. The DISCOM operates a dense urban distribution network with a rapidly increasing load base and sought to examine the ability of BESS to support asset management and operational optimisation

As illustrated in Figure 1, the BESS was assessed for multiple value streams - Peak Load Management (PLM), Energy Arbitrage, Transformer Capacity Deferral, and Reactive Power Management.

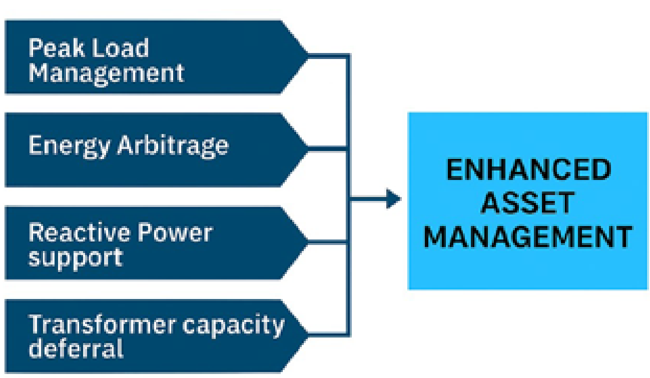

Figure 1: BESS Value Streams

a) **Load Behaviour and Need for Flexibility**

Analysis of long-term demand data showed that the DISCOM recorded a maximum system peak of about ~2,000 MW, while the monthly demand curve exhibited a 300-500 MW gap between average and peak load, with peak conditions occurring only for a few 15-minute blocks. The widening gap indicated that conventional infrastructure reinforcement, particularly transformer augmentation, would lead to under-utilised capacity for most hours of the year. This observation made a case for BESS as a flexible asset that could bridge short-duration peaks rather than relying solely on traditional expansion.

b) **BESS as Asset Deferral Potential**

For optimal sizing of the BESS for the absolute peak of 2 GW, the study adopted a "top-10 daily peak" method, focusing on the highest recurring short-duration peaks.

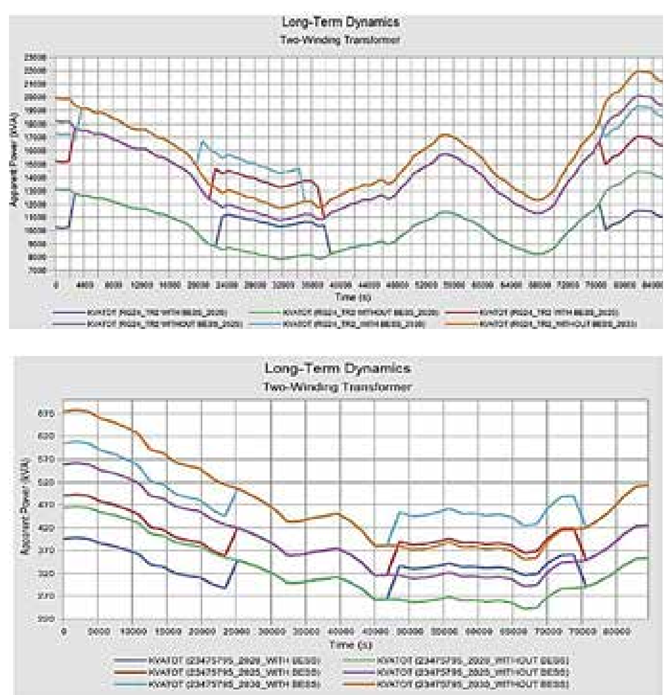

Figure 2: Loading pattern of Transformers with and without BESS

A 50 MW / 100 MWh BESS was identified as the required capacity to manage the highest peaks for five years, preventing transformers from breaching their thermal limits and balancing technical flexibility and economic value. Figure 2 shows the improvement in the loading pattern of a typical power transformer and distribution with BESS. This configuration could defer transformer reinforcement by nearly 5-6 years. The associated annualised capital deferment savings were estimated at ₹ 15 million/year for power transformers and Distribution transformers, consistent with asset management objectives of extending asset life and optimising utilisation.

c) **Peak Load Management and PPA Cost Savings**

The DISCOM's bulk power procurement included fixed charges under long-term Power Purchase Agreements (PPAs). BESS-based peak reduction enabled optimisation of contracted demand, providing substantial fixed-cost relief.

Through operational modelling, the study estimated that a BESS of a minimum capacity of 50MW/50MWh could support the reduction of certain peak-dependent PPAs, translating into fixed and variable cost savings of approximately ₹330 million/year over the project horizon. In the context of asset management, this represents a major optimisation of both financial and physical resources.

d) **Energy Arbitrage Benefit**

BESS of 50MW/100MWh capacity was found capable of shifting energy from off-peak to peak periods, generating annual arbitrage savings of nearly ₹125 million/year. The system also reduced the deviation between the sanctioned and real-time load. Daily over-drawal and under-drawal adjustments lowered mismatch-related penalties, providing additional savings.

e) **Reactive Power Management and Grid Support**

Voltage profile studies indicated that the DISCOM experienced significant reactive power deviations, largely due to dynamic load and long feeders. This resulted in high annual penalties running into millions of rupees.

By operating in reactive power control mode, a 50 MW/ 50 MWh BESS could dynamically regulate voltage and compensate for reactive fluctuations. Over a ten-year operating period, this was projected to provide reactive power savings of approximately ₹10 million/year, while enhancing system stability.

f) **Overall Impact on Asset Management**

The study demonstrated that a 50 MW/ 100 MWh BESS is not just a single-purpose investment but a multi-value asset that strengthens the DISCOM's infrastructure lifecycle.

The key outcomes included:

- Deferral of transformer augmentation, extending asset life and reducing capital expenditure.
- Reduced dependence on peak PPAs, delivering substantial fixed-cost savings.
- Improved operational efficiency through arbitrage and deviation charge reductions.
- Enhanced voltage and reactive power performance, lowering penalty exposure.

Collectively, these findings positioned BESS as a strategic asset management tool, enabling the DISCOM to optimise its existing infrastructure while postponing large capital-intensive upgrades. The case shows how energy storage can transform traditional asset management approaches by combining operational flexibility, financial optimisation, and system reliability in a single platform.

Challenges and Best Practices

Despite its advantages, integrating BESS into asset management frameworks presents several challenges. Battery degradation remains a major concern, as cell chemistry and cycling patterns affect long-term performance. Asset managers must adopt predictive degradation models to estimate remaining useful life accurately. Thermal management, inverter reliability, and fire safety systems must also be included in life-cycle cost assessments.

From an economic standpoint, fluctuating battery prices and evolving market regulations can impact business cases. Therefore, feasibility studies should include sensitivity analyses on key parameters such as energy tariffs, degradation rates, and cost of capital. Integration of the BESS into existing asset management software systems is essential to track performance metrics, State-of-Health (SoH), and lifecycle costs.

International experience shows that successful BESS projects align with ISO 55000 asset management principles, systematic planning, condition monitoring, risk-based decision-making, and continuous improvement. Utilities implementing these principles ensure that storage assets contribute effectively to sustaining built facilities.

Strategic Recommendations for Utilities and Asset Managers

For asset managers and utilities considering BESS integration, several strategic recommendations emerge:

a) Conduct detailed load and stress audits to identify assets operating beyond 85% capacity.

b) Integrate BESS operation strategies with asset life-cycle management plans to optimise loading and reduce failure risk.

c) Use value stacking, combining peak shaving, reactive power support, renewable firming, investment deferral, and energy arbitrage to maximise returns.

d) Adopt digital monitoring platforms that integrate BESS data (SoH, SoC, temperature, inverter status) into the utility's asset management system.

e) Plan for a second life and recycling pathways to minimise environmental impact and enhance sustainability.

f) Develop training programs for asset management teams to understand operational and safety aspects of BESS.

Conclusion

Battery Energy Storage Systems are transforming asset management practices within the power sector. They enable built facilities to operate more flexibly, defer costly infrastructure investments, and integrate renewable energy seamlessly. The DISCOM case study demonstrates significant benefits for asset longevity and financial optimisation. By combining peak load reduction, energy arbitrage, deviation control, transformer investment deferral and reactive power support, the storage system functions as a multi-value asset capable of delivering measurable technical and financial improvements. Such outcomes demonstrate how BESS strengthens asset utilisation, enhances reliability, and mitigates risks associated with demand growth and system variability.

As BESS costs continue to decline and digital management tools mature, storage systems will increasingly become integral components of sustainable asset management frameworks across utilities and industries.

Acknowledgement

The author is grateful to TATA Consulting Engineers Limited for giving permission to submit this article.

TATA Consulting Engineers Limited has been involved in advising DISCOMs for the implementation of Battery Energy Storage Systems (BESS) for better utilisation of the natural fuels.

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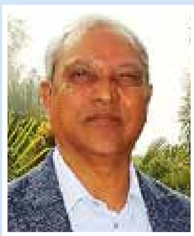
Opportunities and Challenges in Adopting ISO 55000 Standards for Indian Transmission Utilities



Kuleshwar Sahu
CGM-AM

Pankaj Kumar Jha
Ch. Manager-AM

POWERGRID, NR-1

Abstract

The Indian power transmission sector is undergoing rapid expansion, driven by the increasing integration of renewable energy, growing electricity demand, and the need for a more resilient and digitally enabled grid. In this context, an ISO 55000-based Asset Management frameworks provide a structured and internationally aligned approach for achieving cost-effective, reliable, and sustainable asset performance. This paper presents the opportunities, challenges, and transformational impact of adopting ISO 55000 standards in Indian transmission utilities, with a specific focus on the journey of POWERGRID towards ISO 55001 certification. It discusses the strategic policies, digital initiatives, maturity benchmarking, and value delivered through structured asset management. The paper also highlights future pathways for creating a resilient, sustainable, and globally benchmarked transmission system.

Introduction

India hosts one of the world's largest and most complex transmission networks, and POWERGRID is the largest transmission utility of India. As of March 2025, its infrastructure includes 1,556 transmission lines spanning 1,81,803 ckm, 287 substations with 5,81,831 MVA transformation capacity, and an overall system availability consistently above 99.8%. Figure 1 shows an overview of POWERGRID's asset base.

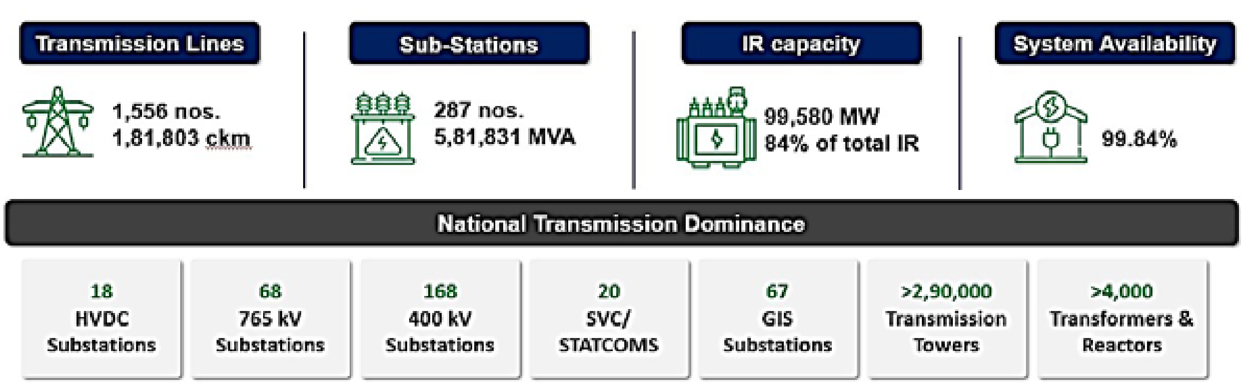


Figure 1: POWERGRID's Asset Base

The growing share of renewable energy, coupled with ageing assets and rising expectations for reliability, has significantly increased the need for structured, data-driven, and standardised asset management practices. ISO 55000 provides a globally recognised framework for integrated asset management, ensuring alignment between organisational goals, lifecycle performance, cost optimisation, and risk mitigation.

Understanding Asset Management

Asset Management, as defined in the ISO 55000 framework, is the coordinated activity of an organisation to realise value from its assets. Value may be financial or non-financial, tangible or intangible, and varies across stakeholders. For transmission utilities, value is derived from reliable power delivery, minimised outages, optimised maintenance, effective resource utilisation, and enhanced system resilience. While utilities have historically managed assets through internal procedures, the shift towards formal Asset Management introduces structured governance, documented processes, data-driven decision-making, and alignment of asset performance with long-term business objectives.

Challenges in Managing Transmission Assets

Transmission utilities face several operational and strategic challenges, including ageing infrastructure, increasing renewable integration, limited budgets, and resource constraints. Utilities must continuously address questions such as: When and what maintenance needs to be performed? How to prioritise thousands of assets spread geographically? What is the condition of ageing equipment? How can data be used to improve decision-making? These challenges necessitate a systematic approach to asset condition monitoring, risk-based maintenance, workforce planning, and lifecycle management. The challenges of an asset owner are shown in Figure 2.

Figure 2: Challenges of Asset Owner

Why ISO 55000 Matters for Transmission Utilities

ISO 55000 provides a structured foundation for addressing the complexities of modern transmission systems. Its adoption enables alignment between organisational objectives and asset performance, enhances governance through policy-driven decision-making, promotes cost-risk-performance balancing, and supports the transition towards digital asset management. For utilities, ISO 55000 adoption helps strengthen internal processes, standardise documentation, and establish globally benchmarked practices.

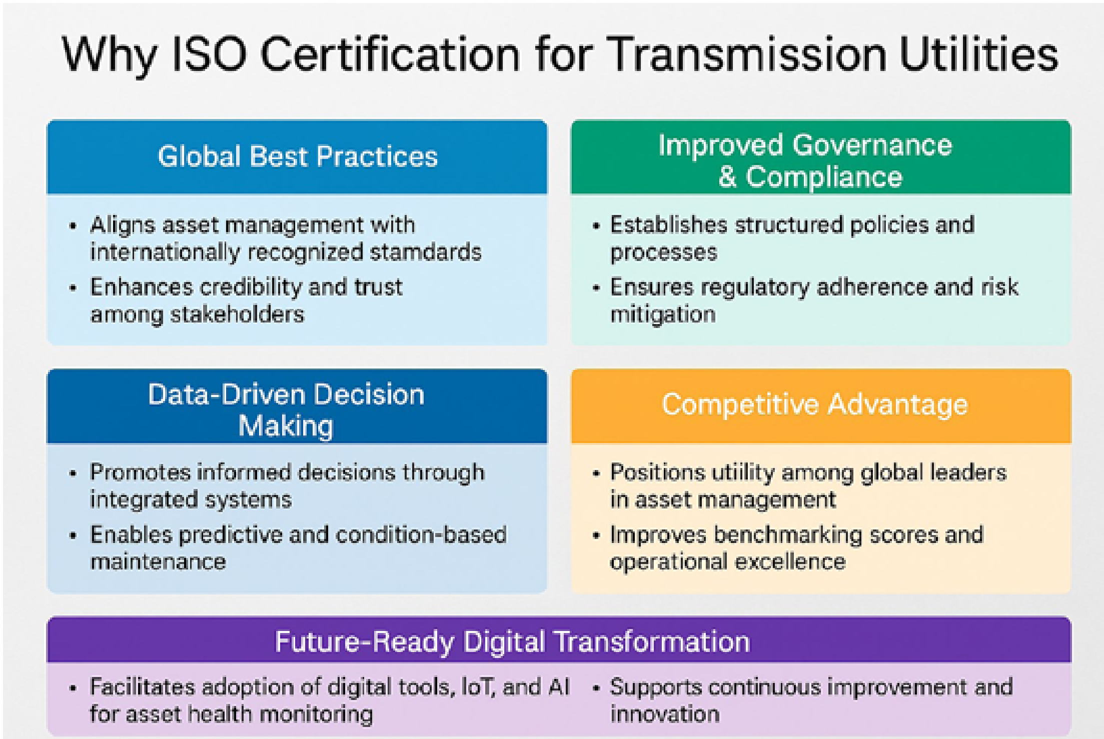


Figure 3: Why a utility should go for the ISO certification

There are some challenges in ISO certification, which are depicted in Figure 4.

Figure 4: Challenges to ISO certification

POWERGRID's Journey Towards ISO 55001 Certification

A comprehensive and structured approach was implemented to align its Asset Management (AM) system with ISO 55001 requirements. The journey began with the implementation of the Asset Management Policy in October 2023, which defined the guiding principles for managing assets throughout their lifecycle. The Strategic Asset Management Plan (SAMP), published in January 2024, further detailed the strategy and framework across 21 chapters covering both physical and intangible assets. The transmission assets were classified into 11 categories, and dedicated Asset Management Plans were developed for each of them. Digitalisation enablement, including sensors, analytics, and IT tools, forms a key pillar of the transformation. Through rigorous audits, process integration, and documentation, the AM system has been successfully aligned with ISO 55001.

Digital Enablement and Data-Driven Decision Systems

Digital transformation plays a pivotal role in realising the ISO 55000 vision. Advanced technologies such as IoT sensors, automated inspection systems, remote operation centres, and data analytics platforms to support condition monitoring and predictive maintenance have been incorporated. Digital tools also facilitate real-time insights, faster restoration, optimised resource deployment, and paperless operations. These initiatives significantly strengthen planning, risk assessment, and maintenance optimisation. Some examples of the digital initiatives are shown in Figure 5.

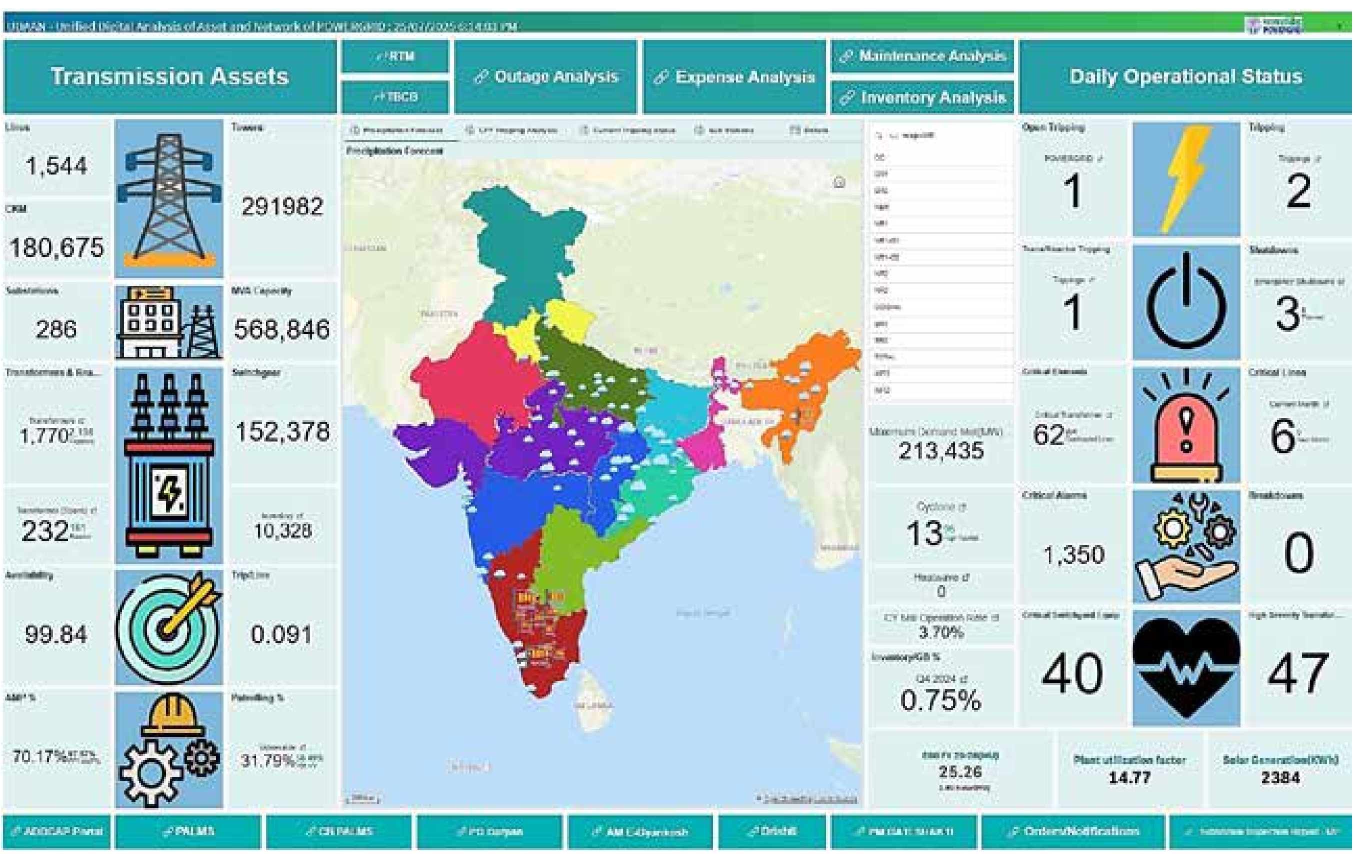


Figure 5 (a): POWERGRID UDAAN Portal

Figure 5 (b): POWERGRID Intelligent Inspection System

Outcomes and Value Delivered

The structured Asset Management practices have delivered tangible benefits. Outages have reduced by approximately 25%, maintenance man-hours by nearly 20%, and the annual inventory budgets have been optimised by over 30%. POWERGRID also achieved a first-quadrant ranking in the International Transmission Asset Management Study (ITAMS), with its AM Performance Score increasing from 3.22 in 2023 to 4.14 in 2025.

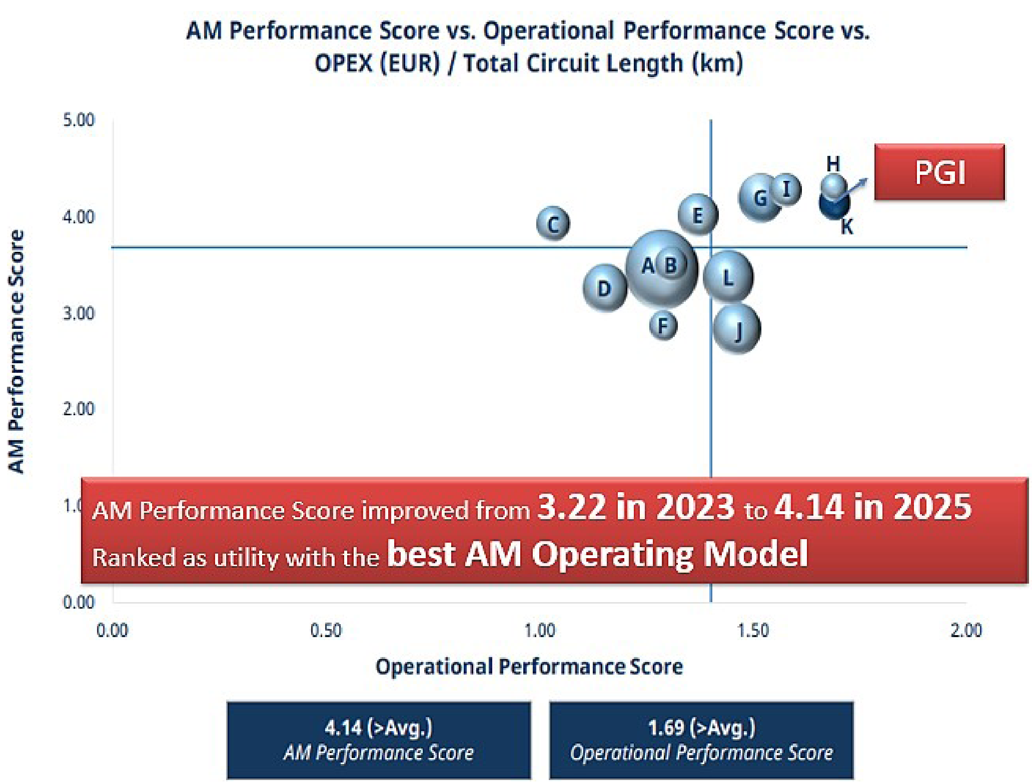


Figure 6: Performance of POWERGRID in ITAMS

POWERGRID was recognised globally for having the best AM Operating Model amongst 12 participating utilities. The performance of POWERGRID in ITAMS is shown in Figure 6.

Future Outlook for Indian Transmission Utilities

As India transitions towards a renewable-rich, decentralised, and digital electricity ecosystem, asset management frameworks must evolve accordingly. The future transmission grid will be shaped by automation, cybersecurity-focused design, sustainability metrics, and resilience enhancement, as shown in Figure 7.

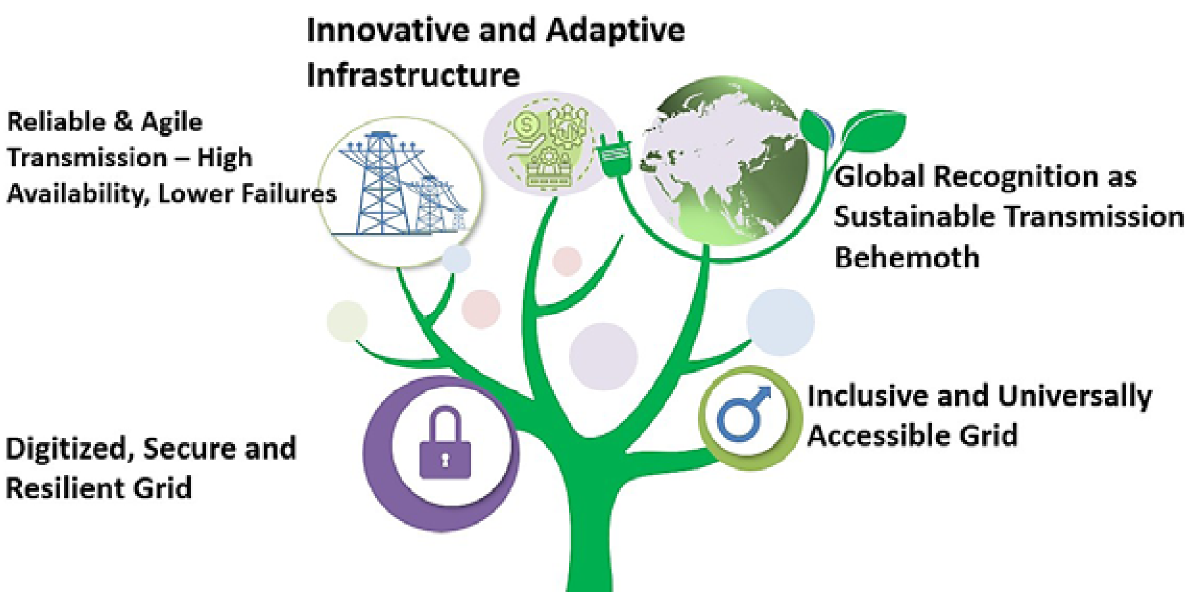


Figure 7: Future Transmission Grid

ISO 55000 adoption provides utilities with a strong foundation to navigate these changes while ensuring operational excellence, stakeholder confidence, and global competitiveness.

Conclusion

ISO 55000 offers significant opportunities for Indian transmission utilities to enhance reliability, optimise costs, and ensure long-term sustainability. POWERGRID's journey demonstrates how structured policies, strategic planning, digital discipline, and global benchmarking can transform asset management practices. As the sector continues to expand and integrate large renewable capacities, ISO 55000-based Asset Management systems will be critical in achieving a resilient, adaptive, and future-ready grid.

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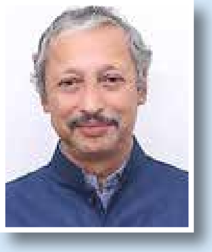
Practical Approach - Asset Management for Civil Engineering Aspects of a Project



H Sivanandan
Proprietor
Shivas Builders

Introduction

Ever since human beings started to construct dwellings to take shelter from the elements of nature, security from wild animals and other humans, maintaining the usability and integrity of the dwelling has become a part of life. In the beginning, tree branches, tree logs, stones and mud were the easily accessible and usable materials. Caves and ledges were also used for dwelling. The type, size and materials of construction of the dwellings have changed as human beings evolved. The initial concepts of need-based have gone way beyond those; now they reflect status and wealth.

Earlier, it was the rajas/ rulers, and now it's the government through its various departments, authorities and bodies, which are the largest owners of built assets. The others are the large business persons and conglomerates.

The government departments, authorities and bodies, over a course of time, developed maintenance schedules, processes and specifications. However, with development, especially for public infrastructure being done on a very large scale involving very high financial cost, they must be maintained regularly in a systematic manner. The public infrastructure comprises the transportation sector – roads, highways, rail, metro, airports, docks & harbours; the power sector – power plants, transmission lines, substations; the public health sector - water & wastewater, drainage; the telecommunication sector; public buildings – hospitals, schools, fire stations, police stations, other amenities & services, etc. The departmental specifications need to be rewritten to take into account the digitalisation and automation that have changed the way of human life.

With asset management being a very vast canvas, this paper suggests a practical approach to the built assets as an outcome of civil engineering projects.

Asset Management

For Asset Management to be usefully done, it is essential that data be collated as spelt out here, updated regularly, and the other processes and procedures followed.

1) The types of assets could be categorised as:

   a) Immovable - such as buildings, factories, power plants, nuclear plants, oil, gas & chemical plants, etc.

   b) Movable - which would include vehicles, machinery, plant & equipment, temporary structures and materials.

   c) Tangible - vehicles, heavy machinery & equipment, tools & tackles, stored raw materials, office equipment and furniture, and also property, if any, related to the project

d) Intangible – which can be amortised, such as software, applications, and interfaces.

e) Personnel – the personnel concerned and involved with a built asset, from the lowest level to the topmost level.

Where there is an overlap, the classification would need to be based on the accounting practice being followed.

2) Organise information and update the list and the state of the Assets

3) Maintenance of Assets after completion of the maintenance works, the scraps, chemicals, and oil discharges are to be disposed of in a controlled manner.

4) Preservation of Assets when not in use.

5) Training, initial and periodic, of the personnel who are to maintain the assets.

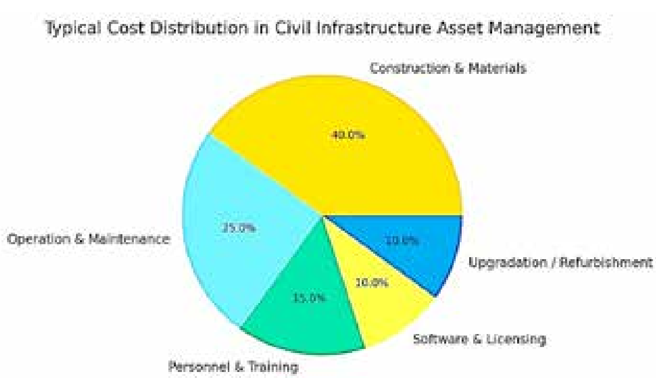


Figure 1: Typical Cost Distribution in Civil Infrastructure Asset Management

Conceptualisation

At the concept stage, the asset owner, be it a Government or Semi-Government department, authority or body, or a Private organisation or individual, must get a due diligence done involving the original concept/ idea, design, construction, the use for which it was planned, design service life of each component of the asset, costs of operation, maintenance, removal at the end of design service life or refurbishing for another usage, cost of personnel - trained and untrained, plant, machinery, equipment, tools, etc., return on capital parameters, cost-benefit ratio, impact survey and assessment before creating the assets.

As stated earlier, the paper is restricted to the field of asset management in Civil Engineering in the construction industry. For a Civil Engineer, managing assets effectively is crucial to ensuring that the infrastructure projects run smoothly and efficiently. For that, end-to-end Asset Management is essential. It is more than just a buzzword; it is a series of critical processes that involve developing, operating, maintaining, upgrading, and eventually disposing of the built assets or repurposing them for other uses, in a way that makes sense both financially and operationally. Each type of asset has its own unique characteristics and management needs on account of the increasing complexity of the infrastructure projects and the growing need for sustainable practices. Thus, a robust asset management strategy is crucial. It helps to maximise the value of the investments, minimise risks, and ensure that the projects continue to meet safety and regulatory standards for the entire period of their use. Moreover, effective asset management contributes to the longevity of the infrastructure, which ultimately benefits the communities it is meant to serve.

In this article, an attempt is made to break down the different types of assets, the importance of keeping organised information, maintenance practices, preservation strategies, and the need for specialised training of the personnel in asset management. A proper and thorough understanding of these elements can enhance the approach to asset management and ensure that the infrastructure projects are not only successful but also sustainable for the future.

Different Types of Assets

Each type of asset needs its own management system.

a) **Immovable assets** comprise land, buildings for offices or workshops or fabrication or storage facilities, and infrastructure on the property of the company.

b) **Movable assets** include equipment and vehicles that can be shifted to wherever needed, while immovable assets like buildings and factories stay put. Both types are crucial. Some Property & Machinery (P&M) setups, like Pre-casting yards, come under movable plant and machinery.

While companies maintain log books and maintenance and costing charts of each crucial plant and machinery, there are also costs involved in inter-site transfers, plant upgrades, and scrapping. Additionally, there are assets related to specific sectors such as infrastructure, community development, defence, science and technology, and facilities, each requiring a tailored approach to management. Specialised cranes used in Launching Girders are an example.

c) **Tangible assets**, which include vehicles, plant and equipment, including heavy machinery, need special attention since their value reduces over time due to wear and tear and consequent depreciation. The training of the operators and specialised service teams also needs to be accounted for to ensure their smooth running. Some of them are accompanied by trade mark and patents, and specialised operation software that must be paid for every use. It is important to factor all these costs, along with depreciation, into the budgets as per the plan for replacements of parts or the machine itself. The asset must be kept operating productively since the idle time of a vehicle or machinery adds to the overhead. Examples could be a Tunnel Boring Machine, Piling Rigs, Road Rollers, Compactors, Bitumen/ Concrete Paving Machines, etc. Every earth-moving equipment, like a Bucket excavator, is connected through the CLOUD and informs the Manufacturer and the owning company on its productive quantity and time based on its bucket operation.

d) **Intangible assets** include proprietary software applications and interfaces that help with project management and design, which could be location and condition-specific; contracts & licenses, intellectual property, brand reputation, and goodwill. The costs of the proprietary software can be amortised to help manage the expenses better. The training costs, the annual license fees, the upgradation costs, replacement with an upgraded or alternate software, the costs of hardware and its upgradation have also to be considered. An example is the licensing of Drafting or BIM software. They contribute significantly to the ability to execute better and faster.

e) **Personnel** connected with any built asset are the biggest assets; they are the true Hard Assets. All the personnel, from the lowest rung to the top, must be fully informed of the functional and technical specification requirements of the project and why it is necessary to perform any activity or execute any action in the order and in the manner as specified and what that would result in. They must also be informed of the consequences of not abiding by the processes and procedures as laid down and necessary. The tolerances to be maintained and why they are essential, and the consequences of not maintaining them, etc., must be driven home by a practical demonstration where possible. There must be good policies so that all personnel are treated with the care and respect that they deserve. It is necessary to make them understand how important their contributions, individually and collectively, are to achieving the goals. Once the personnel concerned are in sync with the requirements, the results are easily achieved.

Figure 2: Impact of Personnel Training on Asset Management

Keeping Information Organised & Updated

One of the most important requirements of asset management is to keep the information organised and updated as and when an addition or a change occurs. It requires detailed records of every asset in its entirety. The information should inter alia include the complete description and specifications, the location where it is, repairs and maintenance history, and current condition. Having a live update system is a game-changer, allowing the asset's status to be tracked in real-time. That enables quick decision-making as regards repairs or upgrades, ensuring that everything stays in good condition and the usage is compliant with safety and regulatory standards.

Maintenance Matters

Regular maintenance is essential so that the plant, equipment, tools, tackles, etc. perform optimally, accurately and safely, and that results in extending the working life of the asset. After maintenance work is completed, the waste must be handled responsibly vis-à-vis the disposal of scraps, chemicals, and oils to protect the environment. It is all about being proactive - developing maintenance schedules that not only address immediate needs but also anticipate future requirements. The proactive approach helps avoid costly repairs and downtime, and any cascading effect that might result from not carrying out the maintenance.

Preserving Assets

When assets are idle, there is a need to focus on preserving them. That requires taking steps to protect them from deterioration, like storing the vehicles and equipment in climate-controlled environments to prevent rust and damage. By being proactive during these downtime periods, the assets would be in good shape and ready to go at short notice when the need arises. Understanding the costs of downtime, most equipment manufacturers like Schwing Setter or Caterpillar work proactively with their customers to ensure that the operators are updated in skills and that the maintenance of the equipment is done regularly, plus that the spares reach even the remote sites in the shortest time. Maintaining customer contact is essential for manufacturers.

Training for Success

Training the personnel for the use and maintenance of construction vehicles, plant and equipment is a very crucial part of relating to the management of all such assets. Engineers, technicians and other maintenance staff need to know how to operate and maintain complex systems effectively. Training programs should cover best practices in asset management, safety protocols, and environmental regulations. Investing in the team's skills helps to improve the management and upkeep of the assets and also ensures that the infrastructure projects are sustainable. Most Indian companies have realised this importance and have developed their own training schedules or used the services of specialised institutions and associations, such as the Indian Concrete Institute, the Indian Plumbing Association, and the like, to upgrade the skills of their personnel through regular training courses.

Conclusion

Asset Management in civil engineering is extremely essential and needs to be a part of the daily repertoire. Understanding and classifying the different types of assets, keeping organised information, focusing on maintenance and preservation, and providing specialised training, go to ensure efficient functioning and sustainability of the built assets. That not only benefits the personnel connected with the works but also supports the communities that are served and the environment that we all share.

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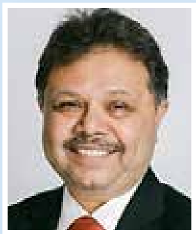
Advanced Sensor Fusion Framework for Real-Time Structural Deflection Monitoring under Dynamic Loads

Vinay Shimpi
Manager-Design

Bhushan Nahire
General Manager-Design



Atul Bhobe
Managing Director

TPF Engineering Pvt. Ltd.

Abstract

This study presents an advanced Kalman Filter–based sensor fusion framework that integrates acceleration and strain gauge measurements to achieve drift-free, full-spectrum deflection estimation for operational bridge monitoring. The method was implemented on ROB-2, a cable-stayed bridge in Goa, where accelerometer and strain gauge sensors were installed at the mid-span of the main steel girder and monitored continuously. The strain-based deflection component captured low-frequency flexural behaviour, while the acceleration-derived component provided high-frequency dynamic response, and their fusion yielded a stable and physically consistent deflection history. The results demonstrate clear deflection patterns influenced by traffic loading and thermal effects, with a peak sag of 7 mm during the afternoon, followed by full elastic recovery at night. The findings confirm the robustness of the proposed fusion approach for real-time monitoring, enabling accurate deflection estimation without reference systems and offering significant potential for long-term bridge asset management.

Keywords: Bridge Health Monitoring, Accelerometer, Kalman Filter, Deflection

Introduction

Bridges are vital components of a nation's transport infrastructure, serving as lifelines that connect regions, sustain commerce, and support economic growth. As India's bridge inventory expands, ensuring its operational safety, durability, and sustainability has become central to asset management for sustaining built facilities. Effective bridge asset management emphasises proactive, data-driven maintenance strategies that optimise resource utilisation, extend service life, and minimise environmental impact throughout a bridge's lifecycle - from design and construction to operation and eventual decommissioning.

Sustainability in bridge asset management increasingly depends on the integration of digital technologies that enable continuous monitoring and informed decision-making. Among these, **Structural Health Monitoring** (SHM) systems have emerged as indispensable tools, combining sensor networks, data analytics, and predictive modelling to assess structural performance in real time. SHM allows engineers to transition from reactive or schedule-based maintenance to predictive and condition-based maintenance, reducing unforeseen failures, material wastage, and economic losses.

Within this framework, accurate measurement of structural deflection plays a critical role in evaluating a bridge's global behaviour under dynamic and environmental loads. Deflection directly reflects stiffness degradation, deflection control, and potential damage progression—key metrics for assessing performance and safety. However, direct measurement of deflection using devices such as Laser Doppler Vibrometers (LDVs), Linear Variable Differential Transformers (LVDTs), or photogrammetric systems remains challenging for in-service bridges. These techniques require fixed reference points, are costly, and often impractical for continuous long-term monitoring in harsh outdoor environments.

Early studies, by Kandula et al.[1] demonstrated deflection estimation via double integration of acceleration signals, highlighting issues of baseline drift caused by low-frequency noise and bias errors. Almarshad[2] investigated signal filtering using high-pass Finite Impulse Response (FIR) filters and modal decomposition methods to reduce drift, though this often distorted the true low-frequency response. Recent studies, including Kwak et al.[3] and Kim et al.[4], applied wavelet-based denoising and modal parameter identification to improve integration accuracy, while Yu et al.[5] used Empirical Mode Decomposition (EMD) for real-time drift correction.

Strain-based methodologies relate measured strain to curvature and subsequently to deflection using Bernoulli-Euler beam theory. Studies such as Salamak and Werkolazinski[6] and Xu et al.[7] used Fibre Bragg Grating (FBG) and resistance strain gauges to reconstruct bridge deformation profiles. FEM-based inverse analysis approaches[8, 9] improved global deflection estimation accuracy by linking local strain data with analytical shape functions. However, these methods remain sensitive to model inaccuracies, boundary condition assumptions, and material uncertainties, limiting their robustness for long-term SHM applications.

Recognising the complementary nature of strain and acceleration data, researchers have developed hybrid fusion frameworks. Cho et al.[10] and Ngeljaratan et al.[11] employed Kalman Filter-based fusion to combine acceleration-derived dynamic responses with strain-derived static components, achieving drift-free and full-spectrum deflection estimation. The Unscented Kalman Filter (UKF) and Particle Filter approaches[12,13] have been further explored to handle nonlinearities and sensor noise in bridge structures. More recent studies, such as Lee et al.[14] and Yoon et al.[15], demonstrated real-time implementation of such filters for operational bridge monitoring, significantly enhancing accuracy and stability of deflection estimation under varying load conditions.

The adoption of these hybrid methods supports predictive maintenance strategies essential to sustainable bridge asset management. Studies such as Kaloop et al.[16] and Ahmed et al.[17] emphasise how digital SHM systems using Kalman Filter-based fusion provide near real-time feedback for evaluating structural performance, enabling early detection of anomalies, and optimising maintenance schedules. By integrating these methods within digital twins and data-driven asset management frameworks, bridge authorities can effectively transition from reactive to proactive maintenance regimes.

In summary, while individual acceleration- or strain-based methods face inherent limitations, hybrid Kalman Filter-based fusion approaches have emerged as the most robust solution for bridge deflection estimation. They provide accurate, drift-free, and full-spectrum deflection histories, aligning seamlessly with sustainable asset management objectives and enhancing the resilience and service life of bridge infrastructure.

Description of Deflection Estimation Technique

The Kalman filter-based approach for deflection estimation integrates acceleration and strain gauge data to provide accurate, real-time structural monitoring. The state vector consists of deflection (u_k) and velocity ({$\acute{u}_k$}), enabling dynamic modelling of structural response. The prediction step uses the state transition matrix F = [[1,Δt],[0,1]] and input matrix G = [[(Δt/2)/2],[Δt]] to propagate the state forward using measured acceleration (a_k), accounting for process noise (Q) that represents modelling uncertainties. Observations include strain-derived deflection ($u_{s(k)}$) and acceleration-based

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deflection ($u_{a(k)}$), combined in the measurement vector z_k. The measurement matrix H = [[1,0],[1,0]] links these observations to the state, assuming both depend only on displacement. The Kalman gain (K_k) optimally balances trust between predictions and measurements based on noise covariances Q and R. The update step corrects the predicted state using the weighted residual between actual and predicted measurements, ensuring accurate deflection estimation. This fusion method leverages strain data for low-frequency accuracy and acceleration data for high-frequency accuracy, producing a smooth, noise-suppressed, and physically consistent deflection estimate.

The key equations governing this methodology are as follows:

The state vector

$$x_k = [u_k, \{\dot{u}\}_k]^T \quad (1)$$

represents deflection and velocity at time step , which are dynamically related.

The prediction equation

$$x_{\{k|k-1\}} = F\, x_{\{k-1|k-1\}} + G\, a_k \quad (2)$$

uses F, the state transition matrix [[1,Δt],[0,1]], to model system evolution over time, and G, the input matrix $\left[\left[\frac{\Delta t^2}{2}\right], [\Delta t]\right]$, to map acceleration into deflection and velocity updates.

The measurement mode

$$z_k = H\, x_k + v_k \quad (3)$$

employs H = [[1,0], [1,0]] to relate observations to displacement, while accounts for measurement noise.

The Kalman gain,

$$K_k = P_{\{k|k-1\}H}^{T\left(H\, P^T_{\{k|k-1\}H} + R\right)^{\{-1\}}} \quad (4)$$

determines the optimal weighting between predictions and measurements based on their uncertainties.

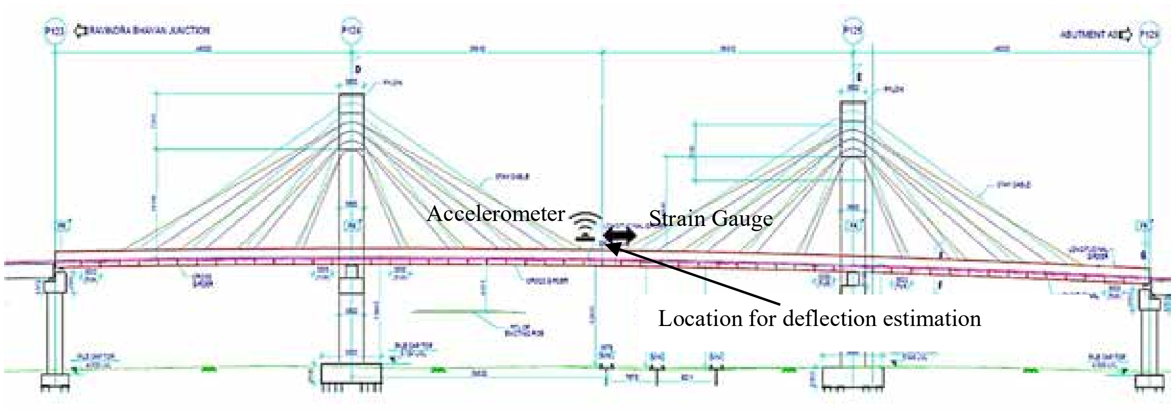
Finally, the update equation

$$x_{\{k|k\}} = x_{\{k|k-1\}} + K_{k\left(z_k - H\, x_{\{k|k-1\}}\right)} \quad (5)$$

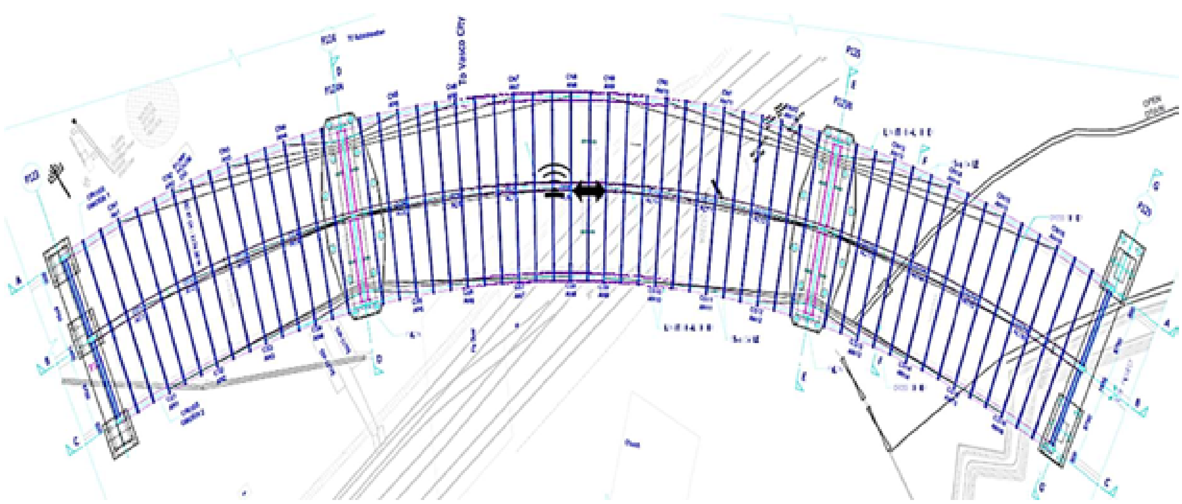
Corrects the predicted state using the measurement residual. Each parameter plays a critical role: and represent process and measurement noise covariances, influencing filter confidence; tracks estimation uncertainty; and ensures adaptive fusion of strain and acceleration data for robust deflection estimation.

About the ROB 2, Goa

The bridge investigated in this study is Road Over Bridge (ROB-2), located between Ravindra Bhavan Junction and the existing ROB as part of the four-laning of NH-17B. The structure is a cable-stayed bridge designed to carry four lanes of highway traffic while maintaining clearance over the railway corridor. The bridge alignment exhibits a horizontal curvature with a radius of approximately 395.32 meters, ensuring geometric continuity with the adjoining approach roads and smooth vehicular movement at the Ravindra Bhavan junction. The bridge extends from chainage 16+115.758A to 16+285.574A, covering a total length of about 170 meters, including side spans. The main span measures 84.47 meters, flanked by side spans of 38.91 meters and 46.00 meters. The superstructure consists of built-up Box-section longitudinal girders (1972 mm web, 600 mm × 25 mm flanges) fabricated from E350 BR grade steel, with cross girders (600–625 mm deep, 325 mm × 25 mm flanges).



(a) Side view of ROB 2, Goa



(b) Top view of ROB 2, Goa

Figure 1: Geometric details of ROB 2, Goa

Deflection Estimation Result

The accelerometer and strain gauge used for deflection estimation were installed at the mid-span location on the top flange of the central main box girder (refer Figure 1), which is the region expected to exhibit the highest vertical response under traffic loading. A full 24-hour continuous dataset was collected from the accelerometer and strain gauge, with both sensors time-synchronised to allow accurate fusion of acceleration-based and strain-based responses. The high-frequency acceleration measurements provided detailed information on the bridge's dynamic response, while the strain readings captured flexural behaviour and low-frequency components that are typically lost during double integration of acceleration. This complete day-long dataset served as the basis for estimating the deflection response of the bridge across the entire monitoring period. The combination of high sampling rate, strategic sensor placement, and synchronised data acquisition ensured that the deflection estimation was both reliable and representative of real operating conditions.

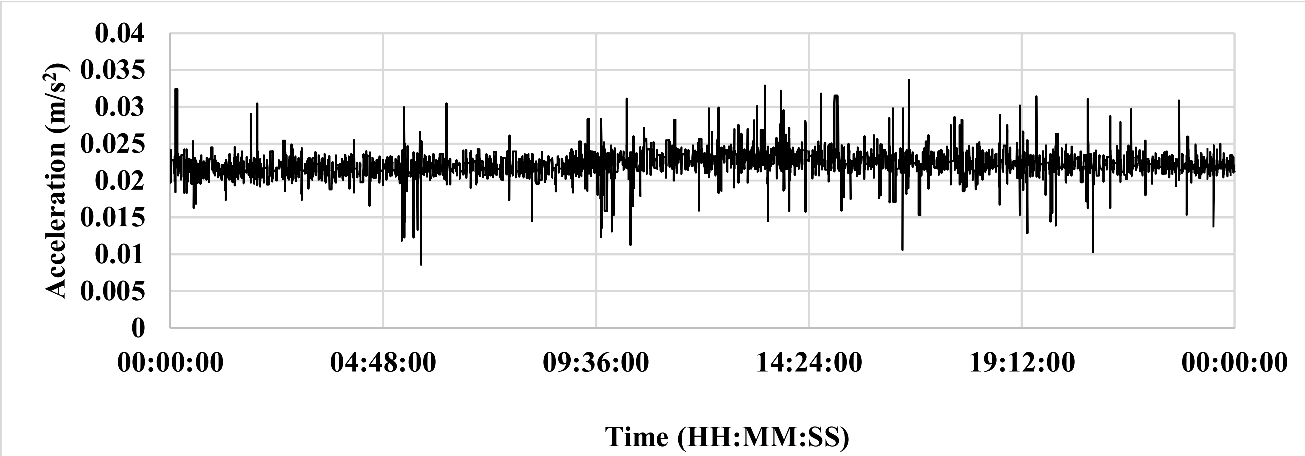


Figure 2: Acceleration data on 01-11-2025

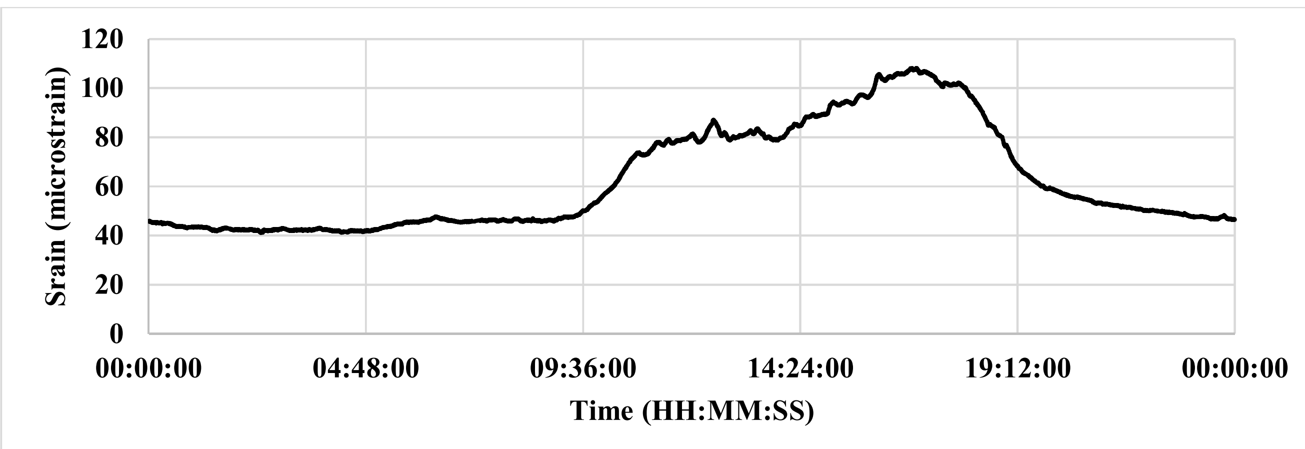


Figure 3: Strain data on 01-11-2025

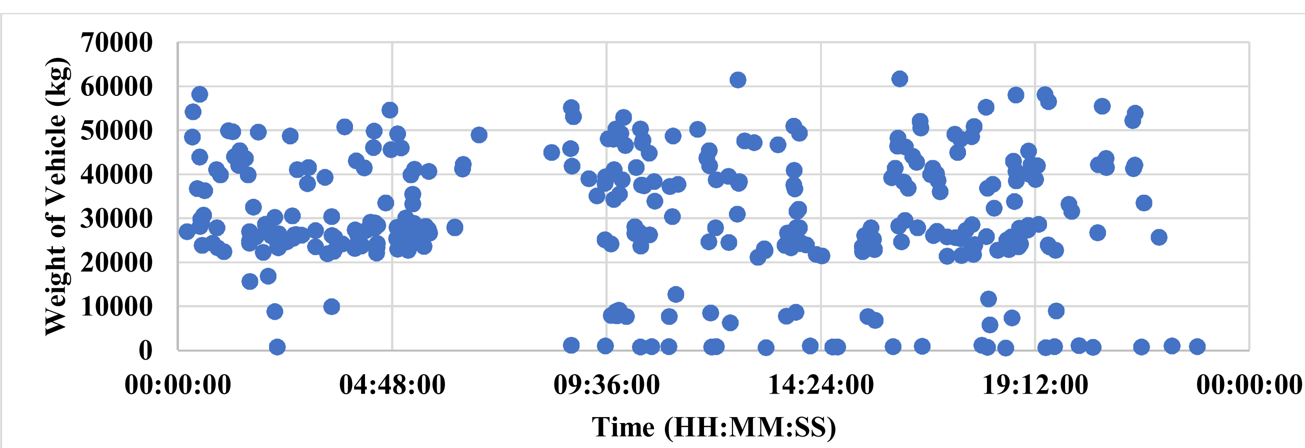


Figure 4: Weigh in motion sensor data for vehicle movement on 01-11-2025

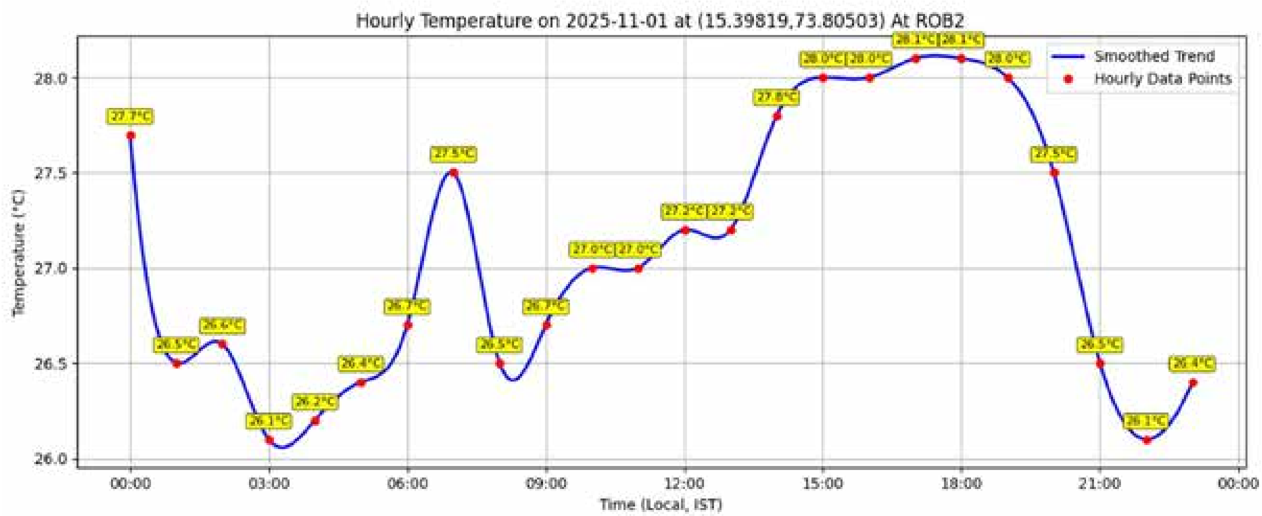


Figure 5: Hourly temperature for ROB 2 on 01-11-2025

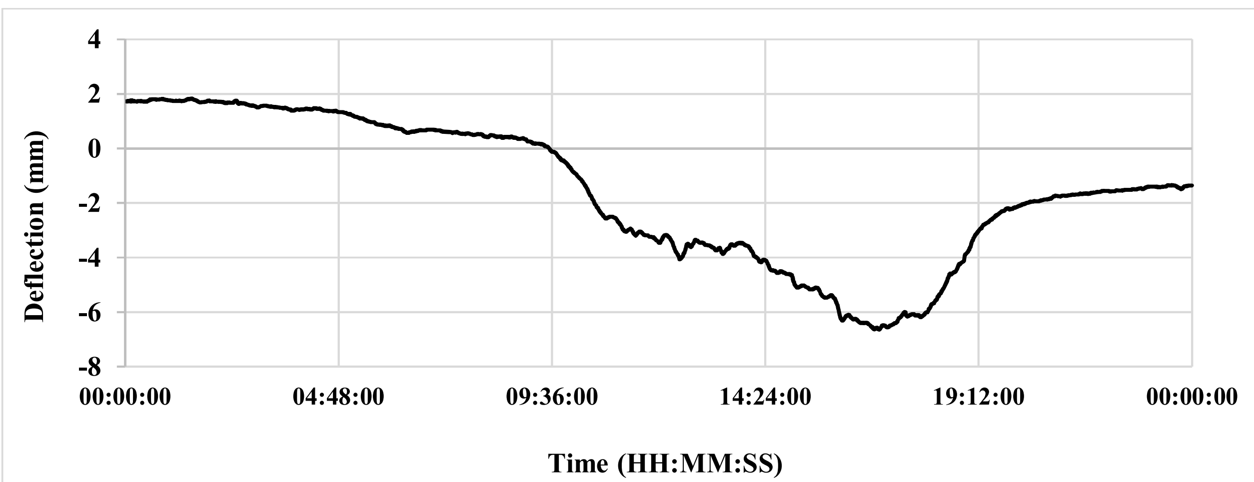


Figure 6: Deflection estimation by fusing acceleration data and strain data

The fused deflection response from synchronised acceleration and strain measurements at the mid-span of the main girder effectively captures the bridge's behaviour under real operating conditions. The 24-hour deflection trend reflects the combined effects of traffic loading, temperature variation, and the flexural characteristics of the steel girder. A gradual downward movement is observed in the morning as traffic intensity and temperature rise, reducing flexural stiffness and increasing mid-span sag. The maximum deflection of about -7 mm occurs in the afternoon, when peak temperatures and heavy vehicle flow coincide. As the temperature drops and traffic reduces in the evening and night, the girder shows a steady elastic recovery, returning close to its initial position by midnight, indicating no residual deformation or stiffness loss.

The fused profile highlights the benefits of integrating acceleration and strain data: accelerations capture high-frequency vehicle-induced vibrations, while strain provides stable low-frequency flexural and thermal behaviour. The Kalman Filter combines these inputs into a smooth, drift-free, and physically consistent deflection curve. The overall sag–recovery pattern aligns with the

CEAI Creating Value Ethically

expected behaviour of a continuous steel box girder, which is sensitive to both bending demand and daily thermal gradients. The strong correlation between deflection, vehicle movement, and temperature confirms that the girder is performing within its elastic service range under combined operational and environmental effects.

Conclusion

This study demonstrates the effectiveness of a Kalman Filter–based sensor fusion technique for accurate and continuous deflection estimation on an operational cable stay bridge. By combining accelerometer and strain-gauge data collected at the mid-span of ROB-2, the proposed method successfully captures both high-frequency dynamic behaviour and low-frequency quasi-static response that cannot be reliably obtained using either sensing modality alone. The resulting deflection history reflects the true structural behaviour under real operating conditions, highlighting clear influences of traffic loading, thermal gradients, and daily environmental cycles. The observed maximum downward deflection of approximately -7 mm during afternoon hours and the subsequent full recovery by midnight confirm that the girder remained within its elastic range and exhibited no signs of stiffness degradation or permanent deformation. The smooth and drift-free nature of the estimated deflection profile validates the reliability of the fusion framework and confirms that the bridge is performing satisfactorily under service loads. Overall, the results underline the substantial advantages of hybrid sensor fusion for structural health monitoring, offering a practical, cost-effective, and scalable solution for deflection estimation in environments where direct measurement is challenging. The methodology has strong potential for integration into digital twin platforms and for supporting predictive, condition-based maintenance strategies essential for sustainable bridge asset management.

Acknowledgement

The authors express their sincere gratitude to Mr Uttam Parsekar, Principal Chief Engineer, Public Works Department, Goa, for extending support and granting the necessary permissions to conduct this research on the ROB-2 cable-stayed bridge. The authors also acknowledge the valuable technical guidance and on-site assistance provided by Mr Tanaji Katkar from TPF Engineering Pvt. Ltd. during the system implementation and data acquisition phases. The support and cooperation of Mr Deepak Bandekar and the construction teams of Gammon India Engineers and Construction Pvt. Ltd. in facilitating the sensor installation and continuous monitoring activities are also gratefully acknowledged.

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About TPF Engineering Pvt. Ltd.

TPF Engineering Pvt. Ltd. (TPFEPL), based in Navi Mumbai, is a leading multidisciplinary engineering consultancy and part of the global TPF Group. With decades of experience, the company provides detailed engineering, proof checking, project management, and advisory services across roads, bridges, buildings, and water infrastructure. Supported by a skilled team and ISO 9001:2015 certification, TPFEPL integrates advanced digital tools such as BIM and 3D modelling to deliver accurate, sustainable, and cost-effective designs. The firm has contributed to several major national infrastructure projects, establishing itself as a trusted and innovative engineering partner.

In late 2025, the **Asian Development Bank (ADB)** approved significant funding for India's development in 2026, focusing on upgrading urban services (water, sanitation in Assam, Kerala, Sikkim, WB), expanding metro and rail (Chennai, Indore, Delhi-Meerut RRTS), improving healthcare (Assam's Astha project), enhancing skill development, and promoting green energy, with major loan packages exceeding $2.2 billion for diverse projects including climate resilience and digital transformation in railways. Key projects include modernising medical colleges, strengthening waste management, and boosting rural connectivity.

Source : Google

18

Short Notes on Buy Out of Built Assets – Roads and Hydro- Power Projects

Gopalan Venkateswaran
Roads & Asset Management Engineer

Introduction

An emerging trend is the purchase of Built Assets by Investors, especially Foreign pension funds of well-executed and well-maintained assets in India, like a stretch of a Toll Expressway or a Hydro-Electric Project, as they reckon that the asset would yield a good and regular Return on Investment. The parameters they consider in their due diligence process include the way the Asset was conceptualised, executed, commissioned and operated. Assets that are well managed attract a better price. It is a new business and is attracting a lot of attention amongst construction companies and fund managers. An attempt is made here to present the parameters that are considered.

This short note deals with the example of a Road project and a Hydro-Power project.

Purchase of a Road Asset

For the purchase of a Road Asset, the various factors to be considered while conducting due diligence, both technically and financially, are given below.

1. **Road Traffic Analysis**
   Though there is a set of defined traffic analyses in the Detailed Project Report and the Contract Agreement of the project, it is essential that the same is conducted based on the present traffic scenario and extrapolated to the lifetime of the asset. An increase of 5% traffic per year vis-à-vis the base year is considered a positive sign for the purchase of the asset.

2. **Leakage Routes and Future Projects**

   Leakage routes have been a pain in the tollway projects in India, owing to lineal development along the highways. These may lead to slippage in toll collection, resulting in financial losses.

   Future projects are always an uncertain part of development in any country, in all sectors. The highway sector is no exception. Hence, it is necessary to foresee if there could be any future projects that may alter the traffic flow. As the traffic reaches the maximum design capacity, the probability of a new project or the extension of the present one by increasing the number of lanes is always a part of development.

3. **MSA and NSV**

   The Million Standard Axles (MSA) is predominantly the basic parameter to identify the lifetime of a pavement. If the initial MSA is low, then there should be an immediate investment in the asset after the purchase of the asset; hence, extreme care should be taken to analyse the MSA of the bitumen layers before the purchase of the asset.

Network Survey Vehicle (NSV) is the basic test that is used to identify all types of defects of a road asset. It provides the roughness, rutting, cracks, and sagging of roads, etc. This would also provide an insight into the immediate maintenance that may be required after the purchase of the asset.

4. Structures and Road Infrastructures

Structures in a road asset are typically bridges, culverts and tunnels. Complete structural analysis of the structures - the foundation, the superstructure and the ancillary structures should be available along with the Bridge Management System (BMS), Tunnel Management System, to ascertain the age, quality, and defects.

Road Infrastructures include the Signage, Road Markings, Gantry, KM Stones, HM Stones, and Metal Beam Crash Barrier (MBCB), Emergency Call stations, Hard Shoulders, Drainage, etc. The presence of all the road infrastructure in line with the contract agreement is mandatory, as these may incur an unintentional cost within a short period of time.

5. Horticulture

This is predominantly found in the Indian road infrastructure, which includes the median plantation and avenue plantation.

6. Types of Maintenance

Major Maintenance – Complete relay of the road with all the defects fixed and replacement of any of the road assets.

Routine Maintenance – Cleaning of the Road and the shoulder, and any damage that may have been caused due to accidents, replacement of plantations, lane markings, inspection of lights and replacement, and any minor structural repairs.

7. Valuation of a Road Asset

The valuation could be done based on the parameters given in Table No.1, Valuation.

Table 1: Valuation of a Road Asset

FY	Major Maintenance				Routine Maintenance	Operating Expenses		
	Road Pavement works	Safety	Structure	Other Infrastructure Works	Regular Routine Maintenance	IT	Equipment	Other Operating Expenses
2025-2026								
2026-2027								
2027-2028								
2028-2029								
2029-2030								

8. **Financial Analysis**

   This typically includes calculating the NPV based on the current IRR. For toll roads, an increase in the toll pricing occurs after a specific period in line with the contract.

   The total time up to breakeven is ascertained before going ahead with a bid. This period is usually half the total tenure of the project.

Purchase of a Hydro-Electric Power Project

India has an assessed large hydro-electric power potential of 1,33,410 MW (projects above 25 MW). As of May 2025, the installed/ exploited hydro-electric power capacity stands at 43,183 MW, which means only about 32.4% of the potential has been utilised. Additional projects totalling around 13 GW are under construction (Source: CEA April 25 Report).

Hydroelectric power projects are very different and complex; hence, the due diligence parameters are also different. Their maintenance includes civil, mechanical, electrical and instrumentation & control assets. As far as the civil infrastructure is concerned, a complete test on the dam(s), a weather forecast study throughout the river regime, and irrigation projects of the government are to be taken into consideration.

The due diligence checklist for a Hydro Power Project Acquisition would comprise:

1. **Legal & Regulatory**
   - Verify land ownership/ title and encumbrances.

   This would include checking:

   i). Whether all cases of opposition due to displacement concerns and cultural sensitivities had been resolved and settled.

   ii). Whether land ownership records had been verified, settled and transferred to the Hydro-Power project organisation.

   iii). Whether all rehabilitation had been done and the project had gained social acceptance.

   - Check licenses and approvals: Environmental clearance, Forest clearance, Water use rights, and Dam Safety compliance.
   - Confirm CEA concurrence for DPR and compliance with the Electricity Act, 2003 and state regulations.
   - Review Power Purchase Agreement (PPA) terms, validity, and tariff structure.
   - Ensure adherence to CERC tariff regulations and Hydro Purchase Obligation norms.
   - Whether all-weather access is available to the project.

2. **Financial**
   - Validate project valuation against industry benchmarks and CERC norms.
   - Review historical financials, audited statements, and revenue from PPAs.
   - Identify liabilities, including but not limited to debt obligations, pending litigation, tax dues, etc.
   - Assess Capex and O&M cost estimates, escalation clauses, and insurance coverage.

3. **Technical**
   - Evaluate plant design and efficiency: Turbine condition, civil structures, electro-mechanical systems, and the instrumentation & control systems.
   - Review water flow/ hydrology data and seasonal variability.
   - Check grid connectivity and evacuation infrastructure; confirm compliance with technical standards.
   - Inspect O&M contracts, spares availability, and historical performance data.
   - Conduct site visit for physical condition and safety systems.
   - Qualified and Trained personnel are available at the plant.

4. **Risk Analysis**
   - Assess risks: flooding, seismic vulnerability, geological risks, dam safety measures, environmental issues, climate-related risks.
   - Review disaster management plans and compliance with CEA/ MoEF guidelines.
   - Identify regulatory risks as policy changes, tariff revisions.
   - Evaluate market risks: Demand projections, competition, and renewable integration impact.

5. **ESG/ Sustainability**
   - Confirm environmental impact assessments and biodiversity management.
   - Check community engagement, Resettlement plans, and benefit-sharing mechanisms.
   - Review compliance with ESG reporting (if applicable).

Conclusion

Purchasing a Built Asset can be rewarding, provided the due diligence is done thoroughly and the asset is well-maintained after acquisition.

Microsoft announces $17.5 billion investment in India, its 'largest ever' in Asia. Microsoft announced over Rs 1.55 lakh crore ($17.5 billion) investment in India over four years (CY 2026 to 2029) to advance the country's cloud, AI infrastructure, skilling and ongoing operations. This is its largest investment in Asia.

The US tech giant's investment commitment comes at a time when organisations are enhancing their AI capabilities and upskilling talent. This investment comes on top of the earlier $3 billion investment it announced in January this year.

In their meeting, Satya Nadella and PM Modi discussed the country's AI roadmap and growth priorities. Microsoft's investment in India focuses on three pillars—scale, skills and sovereignty—aligned with the Prime Minister's vision of building a comprehensive ecosystem that drives AI innovation and access at a national scale, the company said in a statement.

The company's new investment will also be used for skilling initiatives. This includes its workforce of more than 22,000 employees across Bengaluru, Hyderabad, Pune, Gurugram, Noida and other cities. One of the key priorities of the company's investment is building secure, sovereign-ready hyperscale infrastructure to enable AI adoption in India.

Source: Excerpted from Deccan Herald

Nidhi Mehandiratta
CHRO, Chief Ethics Counsellor, Head CSR
TATA Consulting Engineers Ltd.

Ethics as a Strategic Pillar in Engineering Consulting: A Civilizational Legacy and a Modern Organisational Imperative

Ethics is often spoken about in the corporate world as a functional requirement, a compliance checkpoint, or a risk-management instrument. However, for those who work in engineering consulting, where decisions influence public safety, national assets, environment, sustainability, and societal well-being, ethics is not just an operational necessity. It is a professional duty of all involved in it, and for the leadership, it is a responsibility.

As CHRO and Ethics Officer at one of India's leading engineering consulting organisations, I have seen first-hand how ethical clarity strengthens not only organisational culture but also outcomes of projects, stakeholder confidence, and long-term institutional credibility. At the TATA Group and at TATA Consulting Engineers (TCE), ethics has never been a policy; it has always been a way of life. That belief has guided our multi-generational teams across industries and continents, not only within India but also across the globe where we are involved.

Ethical Heritage: A Foundation for Modern Professional Conduct

Long before the language of corporate governance emerged, the wisdom and knowledge systems of ancient civilisations articulated a holistic and pragmatic moral framework. The East is called the cradle of civilisation, and it was there that society first formed, as very aptly observed by Will Durant, the American historian and philosopher, in the chapter '*Envoi* OUR ORIENTAL HERITAGE' of his book *The Story of Civilisation Part I, Our Oriental Heritage*

"The third element of civilization is morality-customs and manners, conscience and charity; a law built into the spirit, and generating at last that sense of right and wrong, that order and discipline of desire, without which a society disintegrates into individuals, and falls forfeit to some coherent state."

All these were propounded and prescribed by the leaders of the different 'religions' which were really advocating the way of life to be adopted and which then shaped leadership behaviour, community life, trade practices, and interpersonal relationships.

They emphasised a universal order grounded in truth; they positioned leadership as stewardship. Our ancient literature is replete with rich case studies of ethical dilemmas, responsible decision-making, consequence awareness, and integrity under pressure. These were not mere myths; they were the moral operating systems of society.

Among them are texts that stand out and serve as a remarkable guide for navigating ethical dilemmas we face even today, torn between conflicting duties, personal discomfort, and professional expectations. They provide the philosophical foundation for decision-making rooted in clarity, duty, and courage.

When I reflect on what truly shapes an organisation's culture, I often return to the guiding forces that had sprung in ancient times and project the philosophical context on which the other modern and institutional frameworks are based - the Tata Code of Conduct (TCoC), embodies them.

At first glance, they appear distinct. But when you look closely, the alignment is unmistakable. The older ones provide the timeless philosophy; the TCoC provides the practical framework in today's world. Together, they move ethics beyond compliance and transform it into a culture of consciousness.

How the Ancient Teachings and the TCoC Converge to Shape Culture

1. ***Ancient Teachings and Integrity: A Shared Foundation***

   The ancient teachings emphasise doing what is right simply because it is right. The TCoC echoes that: act with integrity and fairness, regardless of convenience or pressure.

   Duty cannot depend on circumstances. Similarly, the TCoC reinforces that integrity is non-negotiable, immune to commercial, relational, or situational influence.

   I see this alignment every time employees choose accuracy over approval or safety over speed. The idea of what is right quietly underpins our daily decisions.

2. ***Doing the Right Thing Without Attachment***

   The call to act without selfish motive mirrors the TCoC expectation of avoiding conflicts of interest and personal bias.

   I have seen this principle play out when engineers:

   - refuse to dilute a technical report,
   - take a safety-first stance despite resistance,
   - raise concerns even when it is uncomfortable.

   In those moments, they are not merely following policy; they are practising the dictum in a corporate environment.

3. ***Courage as the Core of Ethical Action***

   There is the teaching that adherence to what is right requires courage, the moral strength to choose what is right over what is easy. The TCoC brings that alive through its emphasis on speaking up, zero retaliation, and ethical escalation.

   Every time someone raises a concern, highlights a risk, or questions an ambiguous instruction, they demonstrate exactly what a neophyte experiences: the courage to stand firm in the face of a dilemma.

   Culture is strengthened not by silence, but by the voices that uphold values.

4. ***Leadership by Example: The Oldest Principle, Still the Strongest***

   Ancient literature reminds us that people follow behaviour, not instructions. The TCoC reinforces this by placing higher ethical expectations on leaders.

   Over the years, I have seen that employees do not copy what leaders say; they mirror what leaders do. Ancient wisdom stated this thousands of years ago; the TCoC codified it for modern organisations. Every time someone raises a concern, highlights a risk, or questions an ambiguous instruction, they demonstrate exactly what many have to surmount - the courage to stand firm in the face of conflicting expectations.

5. ***Universal Well-Being: Leading for Collective Good***

   The principle of welfare of the masses, which involves holding all people together through service by acting for societal welfare, is visible across the Tata philosophy: stakeholder responsibility, sustainability, human dignity, and community well-being.

The TCoC formalises that under sections on safety, environment, human rights, fairness, and dignity.

In engineering consulting, every design review, safety assessment, environmental recommendation, or risk advisory is an act that requires that the welfare of the masses is paramount, be kept in mind to result in a contribution to the greater good.

6. ***Ethical Awareness Over Blind Obedience***

Ethical living does not require one to obey blindly, but to understand. Awareness, not fear, must guide the action.

Likewise, the TCoC guides through clarity, not compulsion; it guides through understanding, awareness, and internalisation. Over the years, when employees discuss dilemmas openly, escalate concerns transparently, or seek clarity rather than assume, I see this principle in action. Ethical culture thrives not through instruction but through awareness created and nurtured by patience with the neophytes.

How This Convergence Shapes Culture at TCE

My role and that of all those who strive to make ethics a part of the culture often sit at the intersection of these two frameworks, helping people translate ethical ideals into everyday behaviour. Whether it is:

- guiding a manager through a difficult decision,
- supporting an employee who raises a concern,
- enabling leaders to navigate ambiguity, or
- shaping the moral climate of teams.

I consistently see how the timeless wisdom and the TCoC's practical guidance reinforce each other. Together, they form the ethical backbone that has helped TCE build trust over more than six decades.

Ethics is not about choosing between the obvious right and wrong. It is about staying anchored when the right path is hard, complex, or uncomfortable.

Ethics in Engineering Consulting: Why It Matters Even More

Engineering consulting sits at the intersection of technical excellence and societal impact. Every concept, plan, design, drawing, check & review, environmental assessment, risk assessment, advisory note, safety recommendation, and project decision carries consequences, sometimes immediate, sometimes unfolding over decades.

Ethical conduct in this sector is crucial because:

- decisions impact public finances and public safety,
- engineering choices shape the environment,
- clients rely on unbiased judgement,
- culture guides frontline decision-making,
- project integrity defines long-term trust.

Unlike many industries, the consequences of ethical lapses in engineering are direct, measurable, and often irreversible.

Ethical behaviour takes root when employees feel that ethics is valued, rewarded, and demonstrated by leadership. This moral climate is what sustains integrity across generations.

In engineering consulting, ethics is not an addition to excellence; it is its foundation. As custodians of safety, sustainability, and societal trust, the responsibility we hold is immense.

Ethics does not stipulate limitations; on the other hand, it is the compass that ensures our decisions today do not burden the generations that follow. And as we continue to build the future, this compass embodying the guiding principles, must remain at the centre of everything we do.

CEAI NEWS

❖ CEAI ACADEMY

Intensive Online Training Course on IRC Codes of Practice for Bridge Engineers

The *Intensive Online Training Course on IRC Codes of Practices for Bridge Engineers*, conducted from 5 September to 6 December 2025, was successfully delivered, achieving strong academic outcomes alongside healthy participation and sound financial performance. The program attracted over 135 paid participants from consulting organisations, government bodies, and academic institutions, reflecting sustained demand for structured and systematic training on contemporary IRC bridge design codes.

The course was structured into **six well-curated modules,** each aligned with a key IRC code and designed to support practical application in bridge engineering practice.

Module 1 – IRC:5-2024, IRC:6-2017 and IRC:SP-114-2018

This module provided an integrated overview of general bridge features, loading provisions, load combinations, and earthquake effects. Clause-by-clause explanations, along with discussion on the historical evolution of the codes, enabled participants to clearly understand current provisions, the intent behind individual clauses, and their practical application, including for assessment of older bridges, supported by illustrative worked examples.

Module 2 – IRC:112-2020

Module 2 delivered a practical and in-depth understanding of concrete bridge design in accordance with IRC:112-2020. It covered design methodology, material behaviour, structural safety, durability, sustainability, fatigue, seismic detailing, and serviceability requirements. Expert-led sessions clarified the application of limit-state design principles through illustrative examples.

Module 3 – IRC:22 and IRC:24

This module addressed steel and steel–concrete composite bridge design and detailing. It included clause-by-clause interpretation of the codes, explanation of key design concepts, detailing practices, and important do's and don'ts, along with discussions on material specifications and practical implementation, supported by annexures and worked examples.

Module 4 – IRC:78 (Part 1 and Part 2)

Module 4 provided comprehensive coverage of bridge foundation design provisions. It addressed open, pile, and well foundations, subsurface investigation requirements, load considerations, stability checks, and design philosophy under both Limit State and Working Stress methods, supported by practical design scenarios and worked examples.

Module 5 – IRC:83 (Parts I–IV) and IRC:SP-69

This module focused on bridge bearings, expansion joints, and seismic isolation systems. Participants gained clarity on codal provisions related to the design, manufacture, installation, inspection, and maintenance of various bearing systems, along with quality control, seismic detailing, and long-term performance considerations.

Module 6 – IRC:87-2018

The final module addressed the critical yet often overlooked aspects of temporary and enabling structures in bridge construction. It provided a detailed clause-by-clause understanding of planning, design, detailing, and execution of formwork, falsework, and temporary structures. The module also introduced key concepts from an unpublished IRC draft related to launching girders and bridge deck construction equipment, offering practical insights for safer and more efficient execution.

Participant feedback across all modules was **uniformly positive**, indicating enhanced understanding of IRC provisions and increased confidence in their practical application. The modular structure, clarity of presentation, and relevance to professional practice were consistently appreciated, with suggestions limited to some delivery-related aspects.

The program witnessed active technical engagement throughout, with Q&A sessions supporting meaningful discussion on codal interpretation and application, further reinforcing learning outcomes while maintaining a structured delivery.

Overall, the program **reinforced CEAI Academy's position as a credible platform for high-quality, practice-oriented bridge engineering education.** Its comprehensive module design, strong participant engagement, and positive academic outcomes have laid a solid foundation for future advanced offerings, positioning the initiative as a model for sustained, high-impact continuing education in bridge engineering.

❖ CEAI EVENTS

CEAI Annual Conference & Awards on 26 and 27 November 2025

The CEAI Annual Conference & Awards 2025 brought together over 250 leaders, engineers, policymakers, financiers, researchers, and industry innovators for two days of dialogue on India's infrastructure transformation. Under the theme "Engineering India Forward: Strategy, Sustainability & Innovation for Inclusive Infrastructure," the conference examined pathways to build a climate-aligned, technology-enabled, inclusive, and future-ready infrastructure ecosystem. Delegates represented a wide spectrum of consulting firms, EPC companies, developers, industry bodies, and technology organisations, including Systra, Nippon Koei, Dilip Buildcon, ICT, Tata Consulting Engineers, PNC Infratech, and several others.

Across nine plenaries, international keynotes, leadership messages, and the CEAI National Awards, the event reinforced CEAI's role as the unified voice for engineering excellence—advancing global standards, strengthening collaboration, and accelerating innovation.

President welcoming Mr Shalabh Goel, MD, NCRTC

Mr. Prashant Kapila, President CEAI Opening Address

A full House participation

Delegates described the conference as insightful and well-curated, appreciating the high-quality discussions and eminent speakers. Many noted that such platforms are essential for meaningful networking, sustaining professional momentum, and fostering continuous knowledge sharing.

Conference Objectives:

- Foster collaboration across consultants, EPC firms, vendors, developers, and policymakers
- Accelerate adoption of digital and sustainable engineering practices
- Strengthen contracting standards and policy alignment
- Promote climate-resilient, inclusive infrastructure development
- Recognise engineering excellence through CEAI National Awards

Delegate Networking

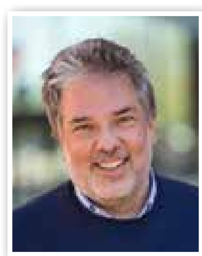
Delegate Registration

Getting Connected

Leadership Messages: Setting the Tone for India's Infrastructure Vision

The conference opened with powerful messages from national and international leaders who underscored CEAI's role in driving India's infrastructure future.

Message from FIDIC President – Mr Alfredo Ingletti



Mr Ingletti highlighted the global relevance of engineering in addressing climate change, inequality, and rapid urbanisation, reaffirming FIDIC's commitment to collaboration, sustainability, and its strong partnership with CEAI.

Message from the CEAI President – Mr Prashant Kapila

Mr Kapila highlighted India's accelerated pace of infrastructure development and the engineering community's responsibility to design systems that are visionary, sustainable, and resilient. He called for collective action to strengthen frameworks related to risk mitigation, financing, technology adoption, and climate-aligned design.

Message from the FIDIC CEO - Ms Susanna Zammataro

The FIDIC CEO stressed the need for measurable sustainability in engineering, referencing initiatives such as the FIDIC Carbon Management Ecosystem. She also announced that New Delhi will host the FIDIC Global Infrastructure Conference 2026—an important milestone for India and CEAI.

Message from Government Leaders and Industry Veterans

Messages of appreciation were received from Shri R. K. Mathur, Former Lt. Governor of Ladakh; Mr Shalabh Goel, Managing Director, NCRTC; Dr Uddesh Kohli, Chairman, ECI; Mr Dineshchandra Agrawal, President, NHBF.

The leaders acknowledged the critical role of consulting engineers in enabling safer, greener, more resilient, and more equitable infrastructure across India, emphasising that engineers today must not only deliver technical excellence but also shape the nation's sustainability agenda, uphold ethical governance, strengthen climate responsiveness, and ensure that infrastructure serves communities inclusively and responsibly.

Inaugural Session: Leadership for a Sustainable and Future-Ready India

The inaugural session featured insights from distinguished guests who shaped the direction of the conference. The Guest of Honour was **Mr Shalabh Goel, Managing Director, NCRTC,** who shared his perspective on India's rapid mobility transformation and highlighted the critical role of engineering judgement, innovation, and stakeholder collaboration in delivering complex projects such as the Regional Rapid Transit System (RRTS).

Mr Shalabh Goel, Managing Director, NCRTC,

Keynote Speakers were Mr Irakli Khergiani, FIDIC Board Member, Mr Manmohan Prakash, Former Senior Advisor, ADB, Mr Palash Shrivastava, Managing Director, IIFCL

Mr. Irakli Khergiani, FIDIC Board Member

Mr. Manmohan Prakash, Former Adviser, ADB

Mr. Palash Shrivastava, MD, IIFCL

Their keynote addresses underscored the importance of globally aligned contracting standards, capacity building, inclusive development strategies, and multi-modal coordination. They emphasized that aligning India's frameworks with international best practices is essential to improve quality, reduce disputes, enhance transparency, and attract long-term investment. They also stressed the need to strengthen institutional capacity, embed social equity in planning, and integrate transport, urban, environmental, and economic systems to deliver efficient, climate-resilient, and future-ready infrastructure.

CEAI National Awards 2025: Celebrating Engineering Excellence

One of the highlights of the conference was the CEAI National Awards. Awards were evaluated by a **distinguished jury** comprising leaders from government, industry and academia:

- Mr Radha Krishna Mathur, IAS, Fmr. Lt Governor Ladakh - Chairman
- Mr Shalabh Goel, Managing Director, National Capital Region Transport Corporation (NCRTC) - Member
- Prof Kumar Naresh Jha, Dept of Civil Engineering, Indian Institute of Technology, Delhi-Member
- Mr Sharath Kumar, Member Technical (CGRF), Tata Steel Utilities and Infrastructure Services Ltd-Member

Awards were evaluated by a distinguished jury comprising leaders from governance, industry, academia, and public administration. The awards reinforce CEAI's mission of setting global benchmarks in engineering consultancy and inspiring a culture of innovation, integrity, and technical excellence.

The awards reinforced CEAI's mission of setting global benchmarks in consultancy and inspiring a culture of innovation, integrity by honouring:

- Category A -Excellence in Project Engineering
- Category B - Engineering Innovation & Sustainability Solutions

The awards were presented to Individuals and Organisations. The awardees were;

Individual

Category A – Project Engineering: Dr C R Parthasarathy

Category B – Engineering Innovation and Sustainability: Mr V N Heggade & Mr Rajdeep Bhattacharya (Joint)

Organisation

Group #1 – Category B: Engineering Innovation and Sustainability:

Winner: CIVTECH Consultants Pvt Ltd

Group #2 Category A- Project Engineering:

Winner: SYSTRA MVA Consultant Pvt Ltd

Merit Awards: - Intercontinental Consultants & Technocrats Pvt Ltd & Nippon Koei India Pvt Ltd

Group #2 Category B – Engineering Innovation and Sustainability:

Winner: RITES Limited

SPECIAL HONOURS:

Professional Excellence Award: **Mr R Balakrishnan**

Shri Mahendra Raj Lifetime Achievement Award: **Dr Vasudev V. Nori**

Picture 1- Category A: Project Engineering: Awarded to Dr C R Parthasarathy

Picture 2- Category B – Engineering Innovation and Sustainability: Jointly Awarded to Mr V N Heggade

Picture 3- Category B – Engineering Innovation and Sustainability: Jointly Awarded to Mr Rajdeep Bhattacharya

Picture 4- Group #1 – Category B: Engineering Innovation and Sustainability: CIVTECH Consultants Pvt Ltd

Picture 5- Group #2 Category A- Project Engineering: Winner: SYSTRA MVA Consultant Pvt Ltd

Picture 6- Merit Award: - Intercontinental Consultants & Technocrats Pvt Ltd

Picture 7-Merit Award: - Nippon Koei India Pvt Ltd

Picture 8-Group #2 Category B – Engineering Innovation and Sustainability: Winner: RITES Limited

Picture 9-Professional Excellence Award: Mr R Balakrishnan

Picture 10-Shri Mahendra Raj Lifetime Achievement Award: Dr Vasudev V. Nori

Plenary Sessions – Key Insights & Sectoral Learnings

The conference program featured nine thematic sessions, each addressing a critical dimension of India's infrastructure journey.

Plenary 1 – Shaping the Future of Consulting Engineering, EPC & Developers

Moderator: Mr Prashant Kapila

This session emphasised the need for deeper synergy between consultants, EPC contractors, and developers. Discussions revolved around modern business models, digital engineering, improved risk allocation, talent transformation, and repositioning consulting engineers as strategic nation-building partners.

Plenary 2 – Embedding Sustainability in Mega Projects

Moderator: Mr Ashish Jain

Panellists explored the integration of ESG principles into large-scale project planning and execution, highlighting climate resilience, resource efficiency, governance alignment, and sustainability as long-term value drivers.

Plenary 3 – Sustainable Infrastructure for Society

Moderator: Mr Yash Singh

Speakers expanded the definition of infrastructure to include social equity, ecological well-being, and resilience, highlighting circularity, SDG alignment, and people-centric planning.

Plenary 4 – Forging Strategic Partnerships: Consultants & Vendors

Moderator: Mr K. Ramesh

The session explored the transformation of consultant–vendor engagement into collaborative, innovation-driven partnerships focusing on early coordination, trust-building, and value-based procurement.

Plenary 5 – Use of New Technologies & Innovations

Moderator: Mr Somenath Ghosh

This discussion showcased emerging digital technologies—AI, digital twins, automation, advanced materials—and the organisational shifts needed for adoption.

Plenary 6 – Innovative Financing Amid Rising Debt

Moderator: Mr Sachin Pant

Panellists examined blended finance, ESG-linked funding, PPP 2.0, asset monetisation, and risk management as tools for resilient infrastructure financing.

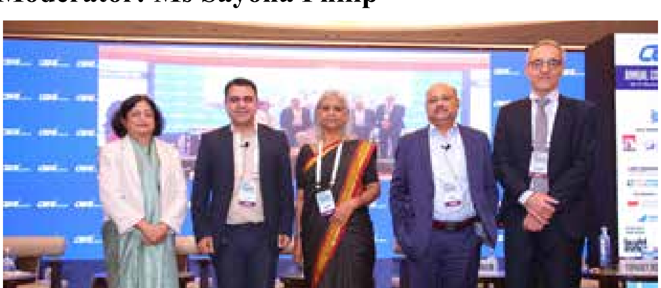
Plenary 7 – Smart Strategies for Dispute Resolution & Cost Overrun Mitigation

Moderator: Mr Gagan Anand

The session offered insights into dispute avoidance, improved contract management, early-warning systems, and digital documentation to ensure predictable project outcomes.

Plenary 8 – Translating Insights into Action

Moderator: Ms Sayona Philip



Experts identified actionable next steps, institutional reforms, and collaborative frameworks needed to convert conference insights into measurable progress.

Plenary 9 – Valedictory Session: Engineering India's Future

Moderator: Mr Prashant Kapila

The closing session synthesised key learnings into a forward-looking agenda, reaffirming CEAI's role as an enabler of best practices, capability building, and sectoral collaboration.

Sponsors, Partners & Exhibitors

The conference was supported by a wide network of industry leaders whose contributions strengthened the programme's reach and impact.

Exhibitors

Exhibitors showcased innovative engineering, design, and digital solutions, enriching the learning environment and encouraging cross-industry collaboration. As listed in the conference brochure, exhibitors included Infoteck Pvt Ltd.

Conclusion: A Collective Commitment to Engineering India Forward

The CEAI Annual Conference & Awards 2025 reinforced a powerful message: India's infrastructure future must be inclusive, responsible, resilient, digitally enabled, and globally benchmarked.

The two-day dialogue showcased CEAI's pivotal role as:

- A thought leader shaping national engineering priorities
- A champion of ethical practice and innovation
- An enabler of collaboration across disciplines
- A catalyst for preparing tomorrow's engineering workforce

As India enters an era of transformative infrastructure expansion, CEAI continues to guide, inspire, and empower the engineering community to build a sustainable and prosperous future.

CEAI Annual General Meeting

The 29th Annual General Meeting of CEAI was held on 18th December 2025 at 11:30 AM at CEAI Centre, New Delhi. It was in hybrid mode, with several members participating online. As the strength of the members present did not constitute the quorum as required by Rule No. 3.5.1 of the Memorandum and Rules of Association of CEAI, the meeting was adjourned. The meeting was re-convened after a gap of half an hour, with the members present, as per Rule No. 3.5.2 of the Memorandum and Rules of Association. The President welcomed the gathering and briefed members on the activities and achievements of the CEAI in the past year and the plans for the coming year

The following business was discussed and concluded at the AGM:

1. The Minutes of the 28th Annual General Meeting held on 10th January 2025 were confirmed
2. The Annual Report of the Association for the year ended 31st March 2025 was adopted
3. The Audited accounts of the Association for the year ended 31st March 2025 were passed.
4. The Auditor for the financial year 2025-26 was recommended for appointment.
5. Concerning other business, President Prashant Kapila gave an update on the preparations for the FIDIC International Conference 2026 and the modalities for conducting the conference. He sought the cooperation of all members to ensure the conduct of this prestigious conference was a resounding success.

Section of the participants physically present

❖ MEMBER NEWS

- On 19th October 2025, Dr Naresh Bana was elected to the IEI Council. He is a peer-recognised international PPP consultant and 'Subject Matter Expert' (SME) with the Government of India-owned entity NHLML. He is MD at BBV Consultants LLP (member of CEAI) and Vice Chairman of the Indo Sri Lanka Chamber of Commerce and Industry (ISCCI). He has published many papers and blogs in reputed papers/ journals, including in

World Bank blogs. PPP remains his passion, and his digital footprints are adequately visible.

- Dr Harshavardhan Subbarao, GC Member, has taken over the charge as President in "The International Association for Bridge and Structural Engineering" from 1st November 2025 for three years.
- Mr Gagan Anand, CEAI GC Member and Managing Partner, has been named "Lawyer of the Year - Client Choice Awards (India)" at the Asialaw Awards 2025 held on 06 November 2025, at the Hilton Saigon in Ho Chi Minh City, Vietnam. This achievement is a testament to his passion, Commitment, and exceptional service to clients over the years.
- Dr A B L Srivastava, CEAI GC Member and Chairman & Director, Almondz Global Infra-Consultant Limited is empanelled with NHAI as an arbitrator.

❖ OTHER NEWS

Panel Discussion on Energizing Sri Lanka's Blue Economy: Offshore Oil & Gas Exploration and LNG Infrastructure as Economic Game Changers

The second edition of "Voyage Sri Lanka" was a maritime conference that brought together public and private sector stakeholders, organised by the Sri Lanka Export Development Board (EDB). CEAI Member **Dr Naresh Bana** was a panellist at the Panel Discussion held on 16 October 2025, titled "Energizing Sri Lanka's Blue Economy: Offshore Oil & Gas Exploration and LNG Infrastructure as Economic Game Changers" at the Kingsbury Hotel in Colombo.

The purpose of this panel discussion was to discuss how offshore oil and gas exploration and LNG infrastructure can be used as economic game-changers for Sri Lanka's blue economy.

Dr Naresh Bana talked about building strategic alliances for offshore energy development projects. He articulated the need to have meticulous project structuring and viability evaluation before bidding out in a transparent format.

World of Concrete India 2025

CEAI Collaborates as Supporting Partner at World of Concrete India 2025

CEAI proudly collaborated as a Supporting Partner for the World of Concrete India 2025, held from 8th to 10th October 2025 at the Bombay Exhibition Centre, Mumbai. Organised by Informa Markets, the event brought together leading professionals, innovators, and organisations from the construction, concrete, and infrastructure sectors, showcasing the latest technologies, sustainable practices, and industry advancements.

In recognition of CEAI's continued contribution to India's infrastructure and construction engineering landscape, Informa Markets extended a special invitation to Mr Somenath Ghosh, Vice President, CEAI, to participate as a VIP guest during the inaugural ceremony. Mr Ghosh addressed the august gathering, highlighting CEAI's commitment to promoting excellence in consulting engineering and the importance of collaboration among industry stakeholders to drive sustainable growth and innovation.

Mr. Somenath Ghosh, VP, CEAI on the podium of WoC 2025, Mumbai

Mr. Somenath Ghosh, Mr. A P Mull, and Mr. Navneet Sharma, CEAI GC Members attending WoC 2025 at Mumbai

Mr. Somenath Ghosh, VP, CEAI at the Podium of WoC 2025, Mumbai along with other dignitaries from the industry

The event also witnessed active participation from members of CEAI's Governing Council. Representing the Western Region, Mr Navneet Sharma and Mr A. P. Mull, both distinguished Governing Council members, attended the exhibition and associated networking sessions, further strengthening CEAI's engagement with industry partners and professionals.

CEAI's association with World of Concrete India 2025 reinforced its ongoing mission to connect, collaborate, and contribute to shaping India's infrastructure and built environment through knowledge exchange, professional excellence, and meaningful partnerships.

FORTHCOMING PROGRAMMES

CEAI Academy program

- Online Intensive Training Course on Detailed Project Report (DPR) Preparation for Highway Projects: A comprehensive overview of the DPR preparation process, scheduled from 10th January 2026 to 21st March 2026. The program covers traffic assessment, geometric and intersection design, hydrological and geotechnical investigations, and topographic surveys. It also integrates sustainability aspects such as climate resilience, alongside pre-construction essentials including land acquisition, utility shifting, and statutory clearances. The course further includes pavement and bridge design, project costing with economic and financial analysis, innovative technologies and materials, and key quality control and assurance practices.
- Online Training Programme on Certified Advanced Technology Professional in Artificial Intelligence (CATPAI): A 12-week training course, starting January end, covers 12 topics:
    - o Artificial Intelligence: The Global Game Changer
    - o Understanding Fundamentals of AI, ML, DL
    - o Evolution of ICT, Big Data, Data Analytics, AI, and ML
    - o Introduction to Large Language Model - Vehicle for AI
    - o Use Cases of Prompting in 5 Professions Most Relevant to Nigeria
    - o Applicability of Generative AI in Business
    - o AI in Creative Arts, Visual Design, Journalism, Media, Education

- o Customising your work with AI
- o Impact of Generative AI on Cybersecurity - Opportunities and Threats
- o Advanced GenAI Threats, Mitigation, and the Human Element in Cybersecurity
- o Ethical & Legal Implications of AI
- o Emerging Trends, Ethics, Global Laws in AI, and Certifications

- Capacity Building Series Sustainable and Low-Carbon Built-Environment: Starting end of January 2025, this three-part capacity-building series equips consulting engineers to support India's climate goals under the Paris Agreement and the Long-Term Low Emission Development Strategy (LT-LEDS). The program focuses on decarbonisation of the built environment, the role of digital technologies, and alignment with national codes, green rating systems, and urban climate frameworks. Through expert-led sessions, real-world case studies, and practical strategies, the series strengthens engineers' ability to design climate-responsive, energy-efficient, and resilient infrastructure that contributes to India's net-zero transition.

VIEWPOINT MARCH 2026

The themes for the quarterly issues of CEAI's magazine "ViewPoint" for the balance period in the years 2025-2026 are given below:

Month & Year	Theme
March 2026	Solid Waste Management and the Need for Stricter Waste Management Policies
June 2026	Climate Change, Urban Flooding, and Landslides
September 2026	Urban Rejuvenation - A Tech-Enabled Approach
December 2026	Smart Cities or Smart Villages: Where Should India Invest More

The theme of the March 2026 edition of Viewpoint is **'Solid Waste Management and the need for stricter waste management policies'.**

Solid waste management is a major and seemingly insurmountable challenge in India today, fuelled by rapid urbanisation, population growth, and grossly deficient infrastructure, coupled with inadequate awareness. The systems for onsite handling/segregation, collection, transfer, transport, treatment and disposal are poor with limited understanding of the potential for 3Rs in waste management. Besides, with the current processes, the volume and complexity of the waste generated pose significant environmental and public health risks.

By leveraging the vast knowledge and experience of CEAI members and other stakeholders, this March 2026 edition of ViewPoint will be used as a platform to discuss ideations, concerns and solutions, and new and emerging business opportunities with articles from various Waste Management Professionals.

Articles for the March 2026 edition of ViewPoint need to reach CEAI by 25 February 2026. Articles have to be in MS Word - Times New Roman 12 with single line spacing with before and after 6 pt and normal margin, on A4 size. A recent, clear and bright passport-size photograph of the author(s) is to be sent along with the article. For details of formatting, please refer to "Format for Articles for CEAI Viewpoint" on CEAI's website, under 'Publications'. The 'CEAI Conditions of Publication' can also be seen on the website.

All Professionals are encouraged to use CEAI's ViewPoint to showcase the capabilities and achievements of Engineers in India and help educate and guide young engineers.

Advertisement in ViewPoint

ViewPoint is circulated to all CEAI Members, FIDIC, Ministries of the Government of India, Public and Private Sector Undertakings, Construction Firms, Contractors, Consultants, Foreign Missions, Multilateral Funding Institutions in India, and other organisations related to or dealing with the engineering profession. Thus, all stakeholders partnering in development and progress are its readers.

Support from CEAI members and stakeholders is sought for increasing the number of advertisements, so that ViewPoint gains in its stature as a unique Technical Publication for the fraternity and the public at large to disseminate information on how Consulting Engineers are helping society improve the quality of assets created and are doing so sustainably. The rates for advertisements in VIEWPOINT are given below:

1) **Viewpoint Advertisement Rates:**

	Rate Per issue* (INR)	Discounted rate at 10% for 2 consecutive issues* (INR)	Discounted rate at 20% for 4 consecutive issues* (INR)
Back Cover	25,000.00	45,000.00	80,000.00
Inside Front Cover	18,000.00	32,400.00	57,600.00
Inside Back Cover	18,000.00	32,400.00	57,600.00
Full Page (Colour)	12,000.00	21,600.00	38,400.00
Full Page (Colour), if a specific page position is required	14,000.00	25,200.00	44,800.00
Full Page (B&W) (Conditions Apply)	8,000.00	14,400.00	25,600.00
Notes: ***GST @ 5% or as prescribed will be added to the above rates***			

2) **Viewpoint Sponsor Advertisement:**

ViewPoint Sponsor Advertisement per issue for "THEME SPECIFIC SOLUTION PROVIDERS/ EXPERTS**":** the Rate will be Rs. 35,000/- and will provide the following:

1. Mention on the front cover
2. Two full-page colour advertisements
3. Descriptive article on topic (not to exceed 300 words)

Tech Quiz

1. **What percentage of the maintenance cost is required for the building structure of the construction cost?**
   a. 1% to 2%
   b. 0.75% to 1%
   c. 2% to 4%
   d. 0.75% to 1.75%

2. **A definition of asset management is:**
   a. The optimal maintenance an organisation undertakes on its assets
   b. The optimal life cycle management of physical assets to sustainably achieve the stated business objectives
   c. A clear understanding of the linkages between each stage in the asset lifecycle
   d. None of the above

3. **Asset Management should deliver:**
   a. The organisation's strategic objectives
   b. The maximum dividends for the organisation's shareholders
   c. The maximum level of service for the organisation's customers

4. **What are the main cost elements of a whole-life cost approach?**
   a. Installation, failure and refurbishment costs
   b. Asset deterioration and reliability costs
   c. Installation, maintenance and operations, and disposal costs

5. **When was the ISO 55000 series first issued?**
   a. 2020
   b. 2010
   c. 2000
   d. 2014

6. **Which company was the first to be certified for ISO 55001 in India?**
   a. Vedanta Limited's Aluminium & Power
   b. Reliance Infrastructure Ltd
   c. Tata Steel
   d. Maruti Suzuki

7. **How much energy is saved by proper maintenance of HVAC equipment in India?**
   a. 5% to 15%
   b. 2% to 10%
   c. 10% to 30%
   d. 20% to 40%

8. **What is a prime activity for asset management?**
   a. Performance monitoring
   b. Proactive maintenance
   c. Lifecycle management
   d. Optimisation of asset value and performance

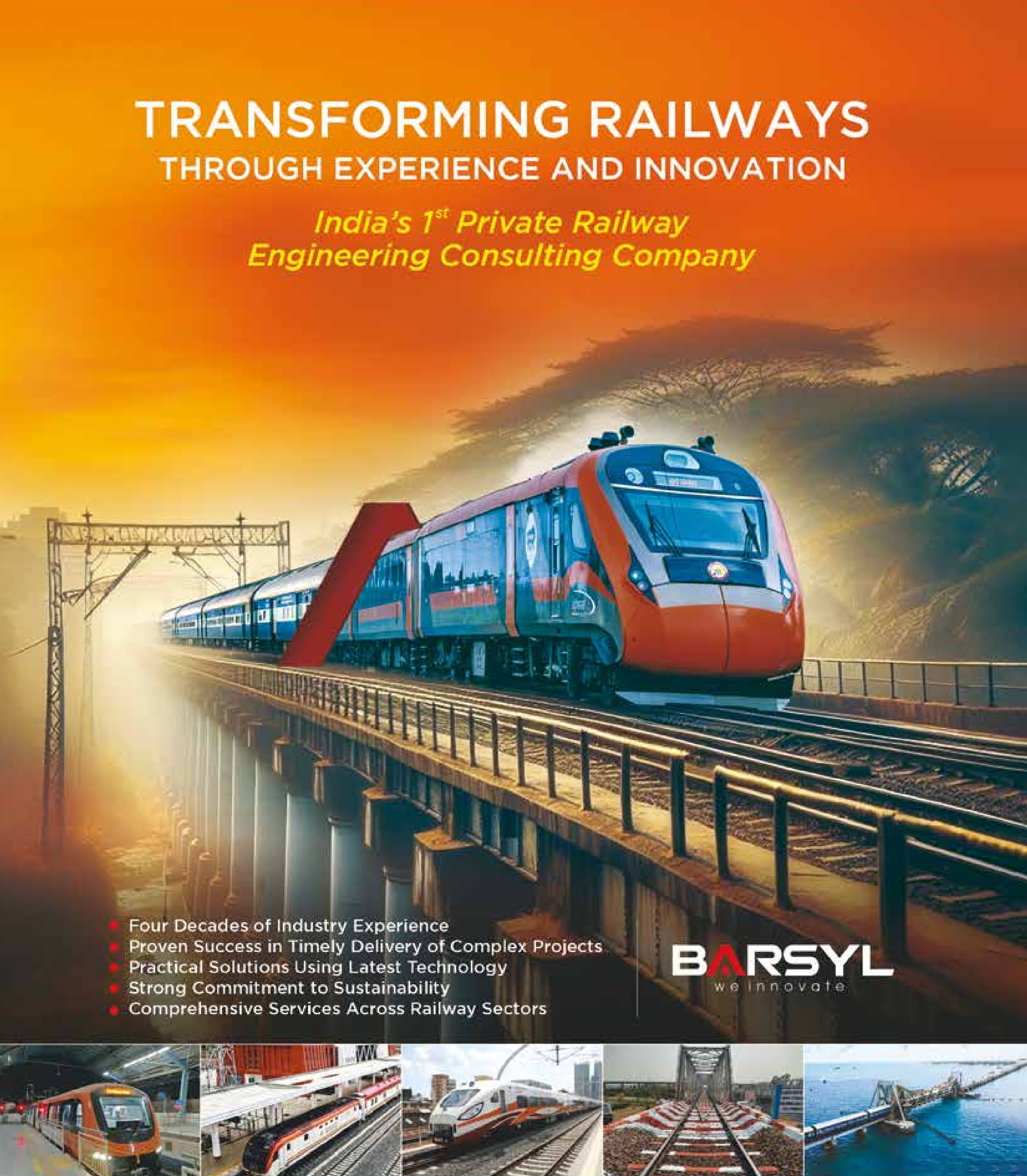
9. **Which of these is NOT a key principle of asset management?**
   a. Linking decisions to the overall business objectives
   b. Applying a whole-life perspective
   c. Reducing the costs of investments

10. **What is the purpose of whole-life cost analysis?**
    a. To determine the option for a particular decision that has the lowest costs over the life of the asset
    b. To determine the most important costs associated with an asset
    c. To determine the renewal costs at the end of an asset's life
    d. All of the above

The first person to email the correct answers to CEAI info@ceai.org.in will get a congratulatory email and be acknowledged by publishing the person's photograph in the next issue.

Compiled by A P Mull/ Neha Jain, TCE / Rajiv Maini, CEAI

Answers to Tech Quiz September 2025 issue
1 (c), 2 (c), 3 (a), 4 (a), 5 (b), 6 (c), 7 (b), 8 (c), 9 (a), 10 (b)



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Office No. 307, 3rd Floor,
NITCO BIZ- Park, Plot No. C-19,
Road No. 16- U, Wagle Estate,
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Maharashtra- 400604, India

CONTACT US

MS. VANDANA RANDHAWA
Mobile - 7597383993
E - vandana.randhawa@legacylawoffices.com

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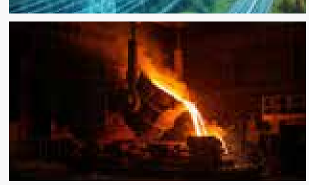
INFRASTRUCTURE

Water, Built Environment, Transportation, Sustainable Infrastructure, Advanced Facilities



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CEAI Facilitates Global FIDIC Certification

CEAI has taken a significant step by collaborating with FIDIC Credentialing Limited (FCL), the global certification arm of FIDIC. Through this initiative, CEAI brings internationally recognised FIDIC Credentialing Certification Programmes to its members and professionals from member organisations, reinforcing CEAI's commitment to strengthening professional competence, enhancing global credibility, and enabling international mobility in the consulting engineering and infrastructure sectors.

FIDIC Certification Programmes Available

CEAI members can now apply for:

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- Recognised internationally by employers, clients, and multilateral agencies
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- Aligns with best practices in consulting engineering, contracts, and procurement

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FIDIC PUBLICATIONS

1	FIDIC Contracts Guide (2nd Ed. 2022)
2	EPC Turnkey Contract 2nd Ed 2017 Silver Book Reprinted 2022 with amendments
3	Construction Contract 2nd Ed 2017 Red Book, Reprinted 2022 with amendments
4	Plant & Design Build Contract 2nd Ed 2017 Yellow Book, Reprinted 2022 with amendments
5	The Short Form of Contract (2nd Edition, 2021)
6	Conditions of Contract for EPC Turnkey Projects (First Edition, 1999)
7	EPC/Turnkey Contract 2nd Ed (2017 Silver Book)
8	Conditions of Contract for Construction (First Ed. 1999)
9	Construction Contract 2nd Ed (2017 Red Book)
10	Conditions of Contract for Plant & Design-Build (First Ed, 1999)
11	Plant and design-build contract 2nd Ed (2017 Yellow book)
12	Dredgers Contract 2nd Ed (2016 Blue-Green Book)
13	Client/Consultant Model Services Agreement 5th Ed (2017 White Book)
14	GUIDE to Conditions of Contract for Design, Build and Operate Projects (2008 GOLD BOOK) 1st Ed 2011
15	Conditions of Contract for Works of Civil Engineering Construction (4th Ed. 1987 Reprinted 2011)
16	Conditions of Contract for Design-Build and Turnkey First Edition 1995 Reprinted 2011
17	Conditions of Contract for Underground works (2019 Emerald Book)

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