Navigating the Future: Sustainable & Resilient Infrastructure

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Pathways to Sustainability

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DEPARTMENT OF TRANSPORTATION THE STATE OF NEW JERSEY

SUSTAINABLE AND RESILIENT INFRASTRUCTURE

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PRESENTATION AGENDA

- Decoding Infrastructure: What does it mean?
- Critical Infrastructure & Causes of Failures
- Infrastructure Resilience & Sustainable Development
- Industries, Innovation, Technology & Infrastructure
- America's Infrastructure, Life Cycle Principles & Resource Optimization
- Risk Management Process
- AI in Civil Infrastructure - Research Gap
- Harnessing the Power of AI
- Recommendation
- Conclusion

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DECODING INFRASTRUCTURE: WHAT DOES IT MEAN?

- Essential physical and organizational structures and facilities needed for a society or enterprise to function.
- Set of structural elements that support our day-to-day lives and influence the direction of humanity.
- Foundational Services that are critical to society.
- Act as the foundation of Economic Activity and quality of Life.

Infrastructure can be classified as:

- Critical Infrastructure
- Non-Critical Infrastructure

CRITICAL INFRASTRUCTURE

Critical infrastructure is the body of systems, networks, and assets so essential that their continued operation is required to ensure national security, public health, safety, and economic security [10].

There are 16 critical infrastructure sectors whose assets, systems, and networks, whether physical or virtual, are considered so vital to the United States. Presidential Policy Directive 21 (PPD-21) identifies 16 critical infrastructure sectors[10]:

Table-1 Critical Infrastructure PPD-21

Chemical Sector	Dams Sector	Financial Services Sector	Information Technology Sector
Commercial Facilities Sector	Defense Industrial Base Sector	Food and Agriculture Sector	Nuclear Reactors, Materials, and Waste Sector
Communications Sector	Emergency Services Sector	Government Facilities Sector	Transportation Systems Sector
Critical Manufacturing Sector	Energy Sector	Healthcare and Public Health Sector	Water and Wastewater Systems Sector

CRITICAL INFRASTRUCTURE FAILURES

The functioning of critical infrastructure systems is under constant threat from a wide range of security threats, which can be categorized into the following basic groups as shown below [16]:

- Climate-related threats
- Geological threats
- Biological threats
- Technological threats
- Criminal threat

Figure 1 Causes of Infrastructure Disruptions.

DISRUPTIONS TO AN ELEMENT IN A CRITICAL INFRASTRUCTURE

- Disruptions to critical infrastructure parameters reduce performance.

- Figure 2 shows that decline is inversely proportional to the emergency intensity and the resilience of critical infrastructure elements [16].

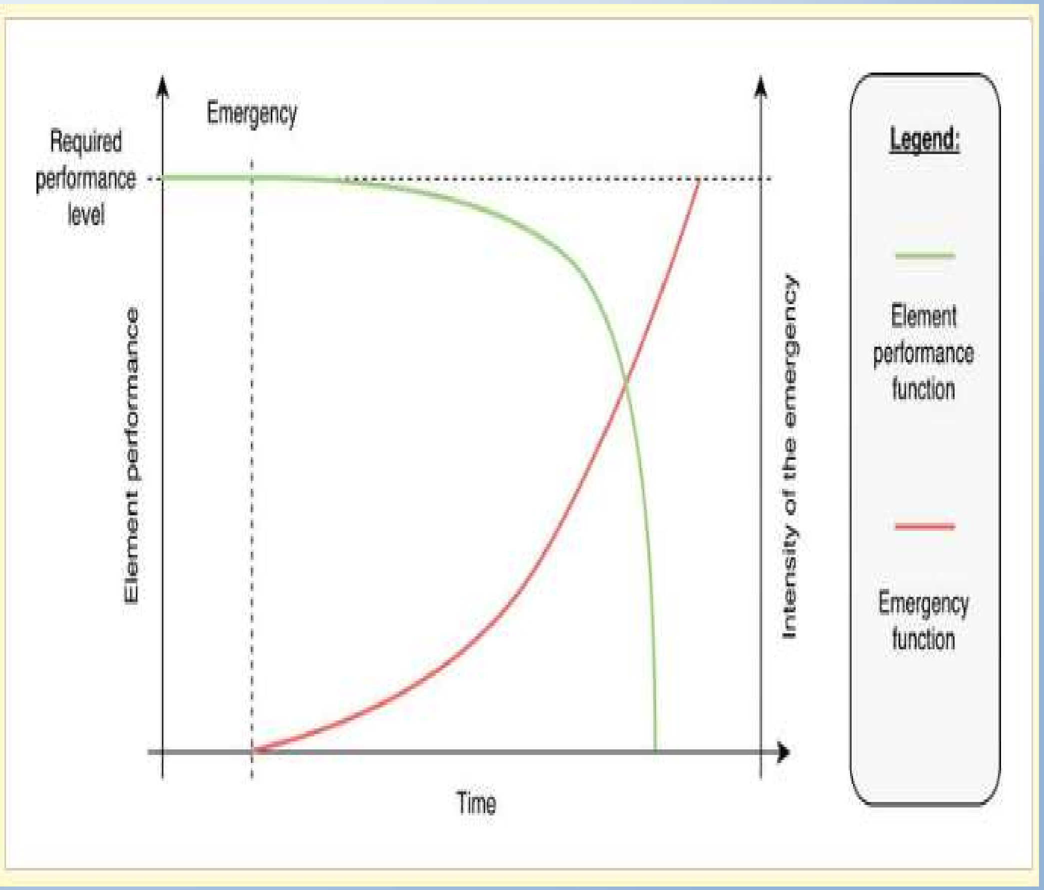

Figure 2 Disruption to an Element in a Critical Infrastructure System [16]

INFRASTRUCTURE RESILIENCE

- Resilience is the ability of assets, networks, and systems to anticipate, absorb, adapt to, and recover from a disruptive event or series of events [18].
- Resilience is about maintaining the continuity of a service in the presence of disruptive events [18].
- Infrastructure resilience depends on planning for contingencies and effective infrastructure design [18].

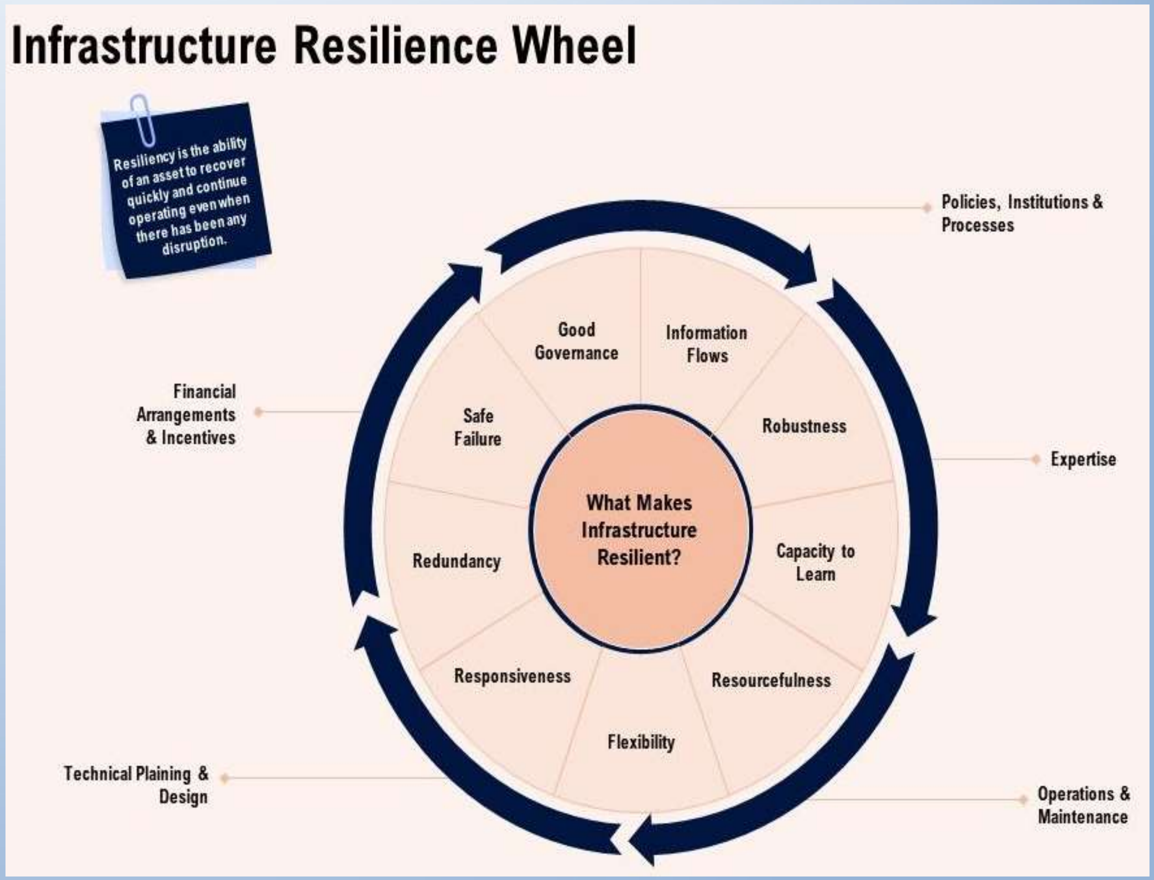

Fig 3 Infrastructure Resilience Wheel (SlideTeam, 2021)

RESILIENT INFRASTRUCTURE

Resilient Infrastructure has four major Characteristics.

- Resistance: Provide protection against anticipated events/attacks.
- Reliability: Components should be designed to operate under various anticipated conditions.
- Redundancy: The system should be designed with appropriate backup plans.
- Response & Recovery: Should be able to respond quickly to disruptive events by limiting the damage and ensuring public safety.

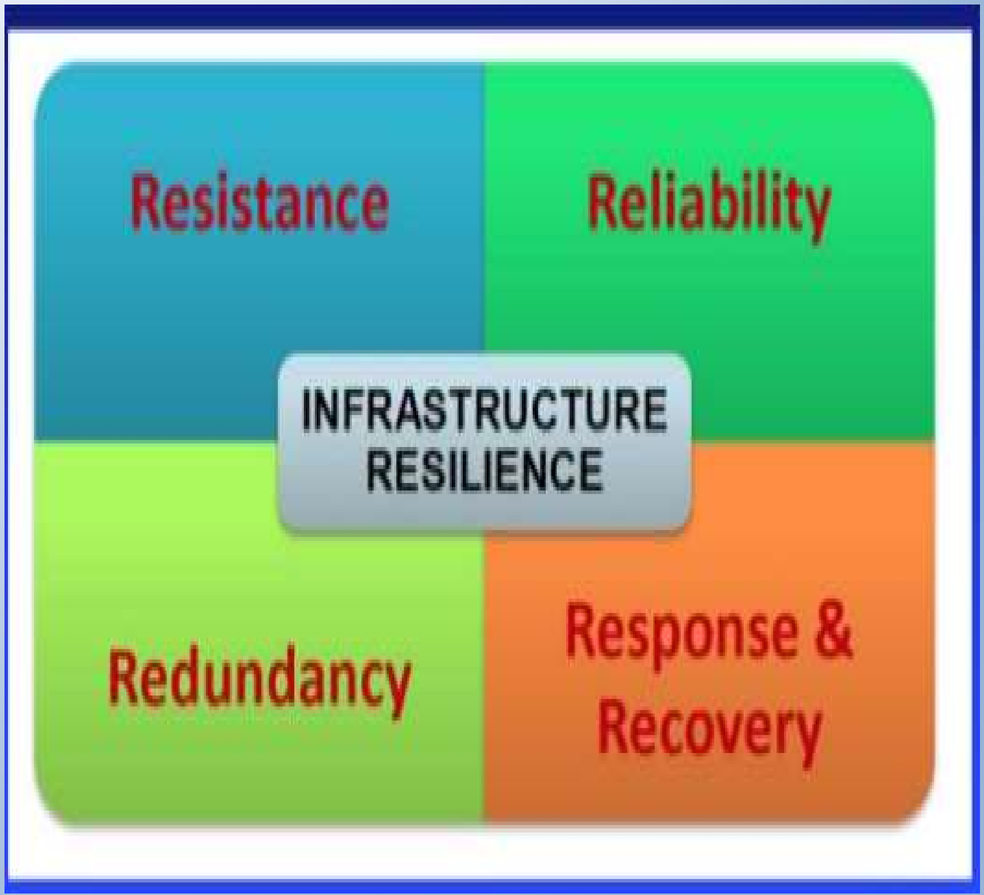

Figure 4 Infrastructure Resilience [18]

A LACK OF RESILIENT INFRASTRUCTURE HARMS SOCIETY AND FIRMS [9]

- Unreliable infrastructure causes severe disruptions and costs, as infrastructure systems, economic activities, and humans are interconnected.
- Infrastructure disruptions directly impact humans' well-being and affect businesses, jobs, and incomes.
- Figure shows how natural hazards and shocks impact infrastructure systems, affecting communities and firms.

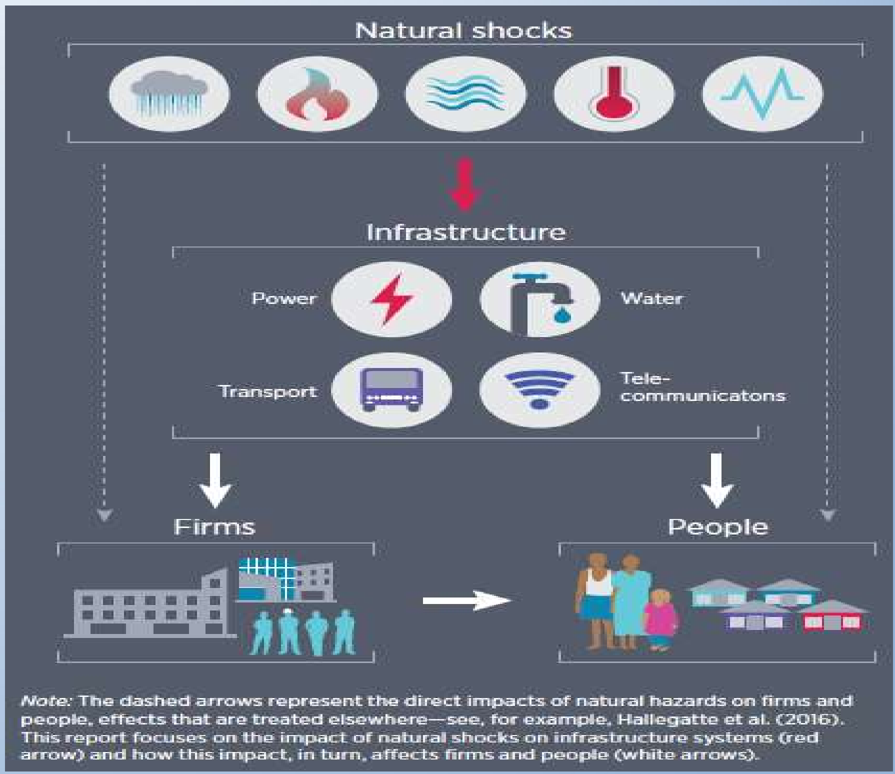

Fig 5 How Natural shocks Affect communities and Firms through their Impact on infrastructure [9]

INFRASTRUCTURE DEPENDENCIES

- Infrastructure dependencies are complex, and solving their associated risks is extremely difficult.
- Almost all infrastructure elements rely heavily on power and communication networks.
- The failure and unavailability of these infrastructures would severely impact local and global economies and society as a whole.
- Critical Infrastructure operates as a system of systems where elements like Transportation, Public Safety, and Public Health are interconnected and interdependent.

Figure 6: Infrastructure dependencies on power & communication network

SUSTAINABLE INFRASTRUCTURE

"Sustainable infrastructure refers to infrastructure projects that are planned, designed, constructed, operated, and decommissioned in a manner to ensure economic and financial, social, environmental (including climate resilience), and institutional sustainability over the entire life cycle of the project" [11]

Figure 7: Sustainable & Resilient Infrastructure starts from planning

SUSTAINABLE DEVELOPMENT

Sustainable Infrastructure supports sustainable development.

Sustainable development is grounded on five dimensions which can be expressed as the five pillars of sustainable development - 5Ps [19].

- People
- Planet
- Prosperity
- Peace
- Partnership

Resilient infrastructure is a lifeline for sustainable development.

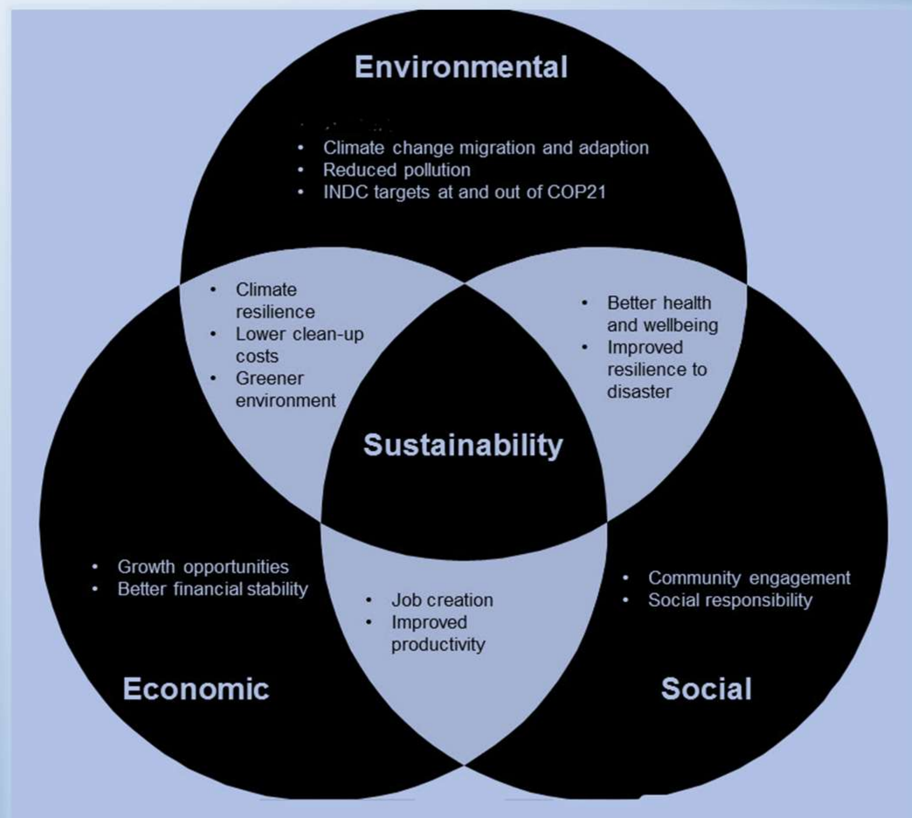

Figure 8 Benefits of Sustainable Infrastructure Investment [24]

INDUSTRIES, INNOVATION & INFRASTRUCTURE (UN's SDG Goal 9 & Goal 11)

Goals

9

Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Goals

11

Make cities and human settlements inclusive, safe, resilient and sustainable

- Drive economic forces, create jobs, and enhance income.
- Promote new technologies to enable the efficient use of resources.

- Disaster Risk Reduction
- Sustainable Transportation
- Sustainable Cities and Human Settlements

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INDUSTRY, INNOVATION & INFRASTRUCTURE

SDG GOAL 9 (sdgs.un.org)

- Investment in infrastructure and innovation drives economic growth.
- With over half the world's population in cities, mass transportation is vital.
- Technological progress addresses economic and environmental challenges, creates jobs, and promotes energy efficiency.
- Fostering innovation and entrepreneurship are key drivers of economic growth.

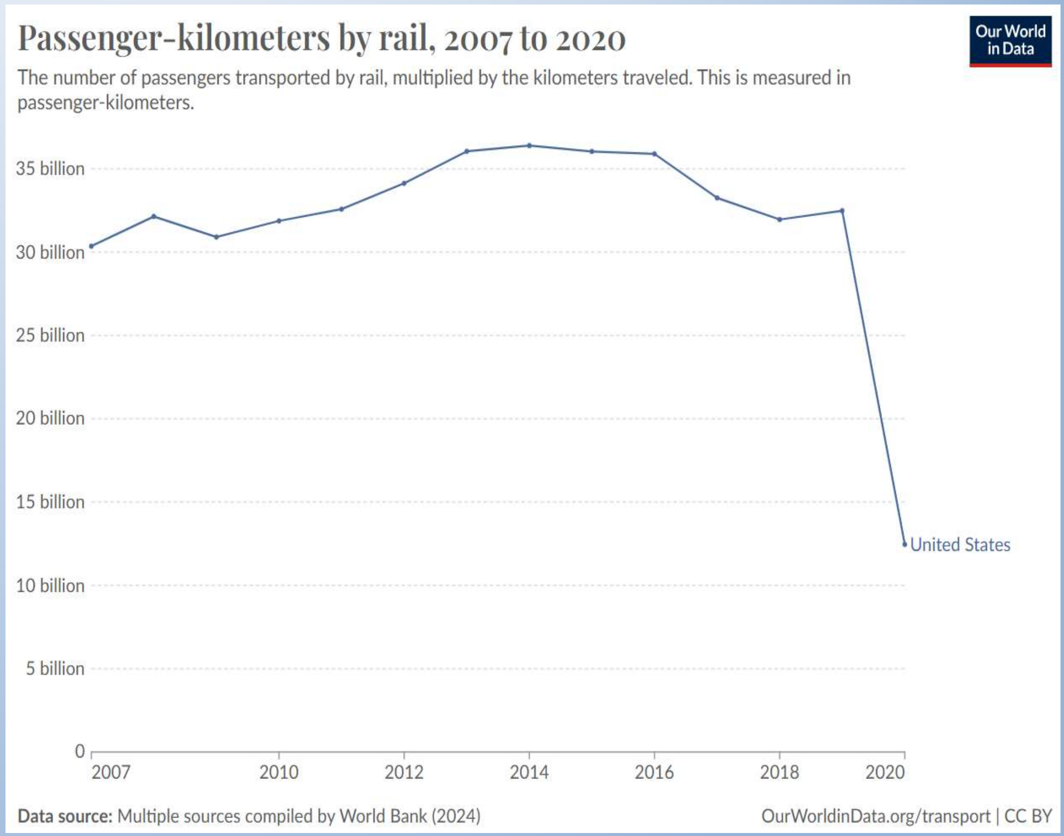

Figure 9 Railways, Passengers carried 2007-2021 [23]

INDUSTRIES, INNOVATION & INFRASTRUCTURE (Cont.)

- Prevention: Subsystems are designed for robustness and preparedness. Raise awareness with infrastructure operators.
- Absorption: Subsystems can absorb disruptive events without service interruptions.
- Recovery: The ability of subsystems to recover their functionality after a disruptive event.
- Adaptation: The organization's ability to adapt subsystems for future disruptive events.

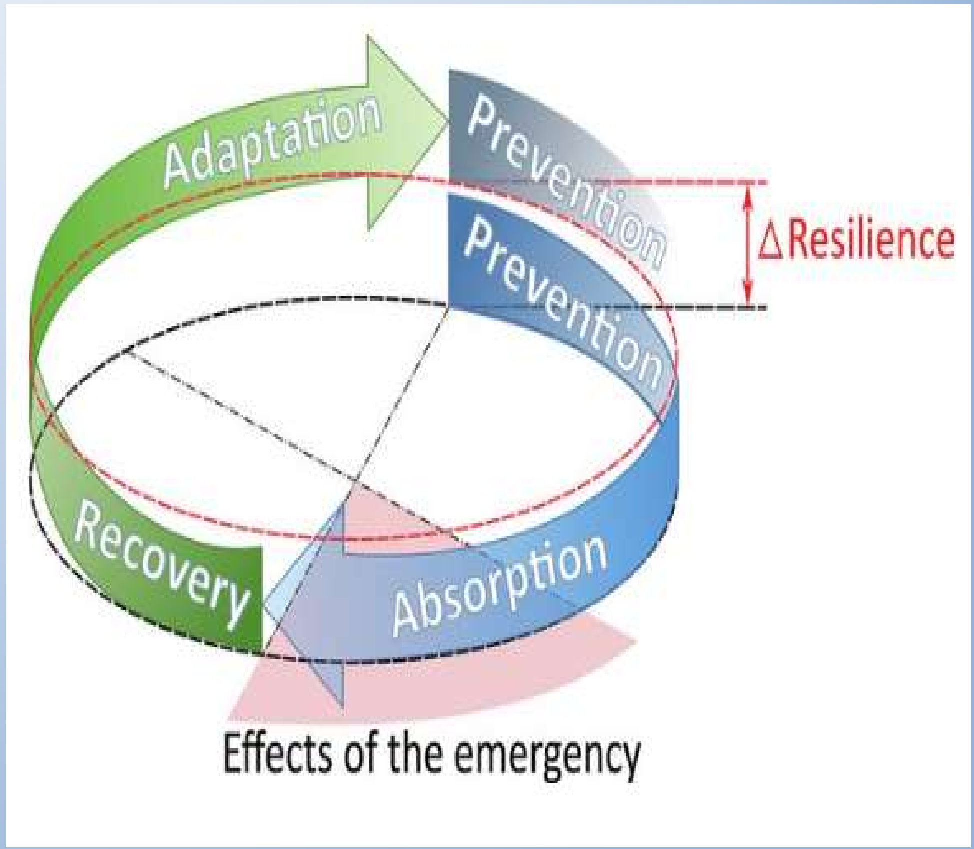

Figure 10 Cycle of Critical Infrastructure Resilience [16]

TECHNOLOGY & INNOVATION DRIVE THE FUTURE OF THE TRANSPORTATION INDUSTRY

Technology helps railroads achieve safety and environmental milestones and gives them a competitive edge in today's fast-paced global economy.

Figure 11 Technology Enhances Rail Safety & Efficiency [1]

NINE MOST IMPACTFUL INNOVATION AREAS FOR THE RAIL INDUSTRY [14]

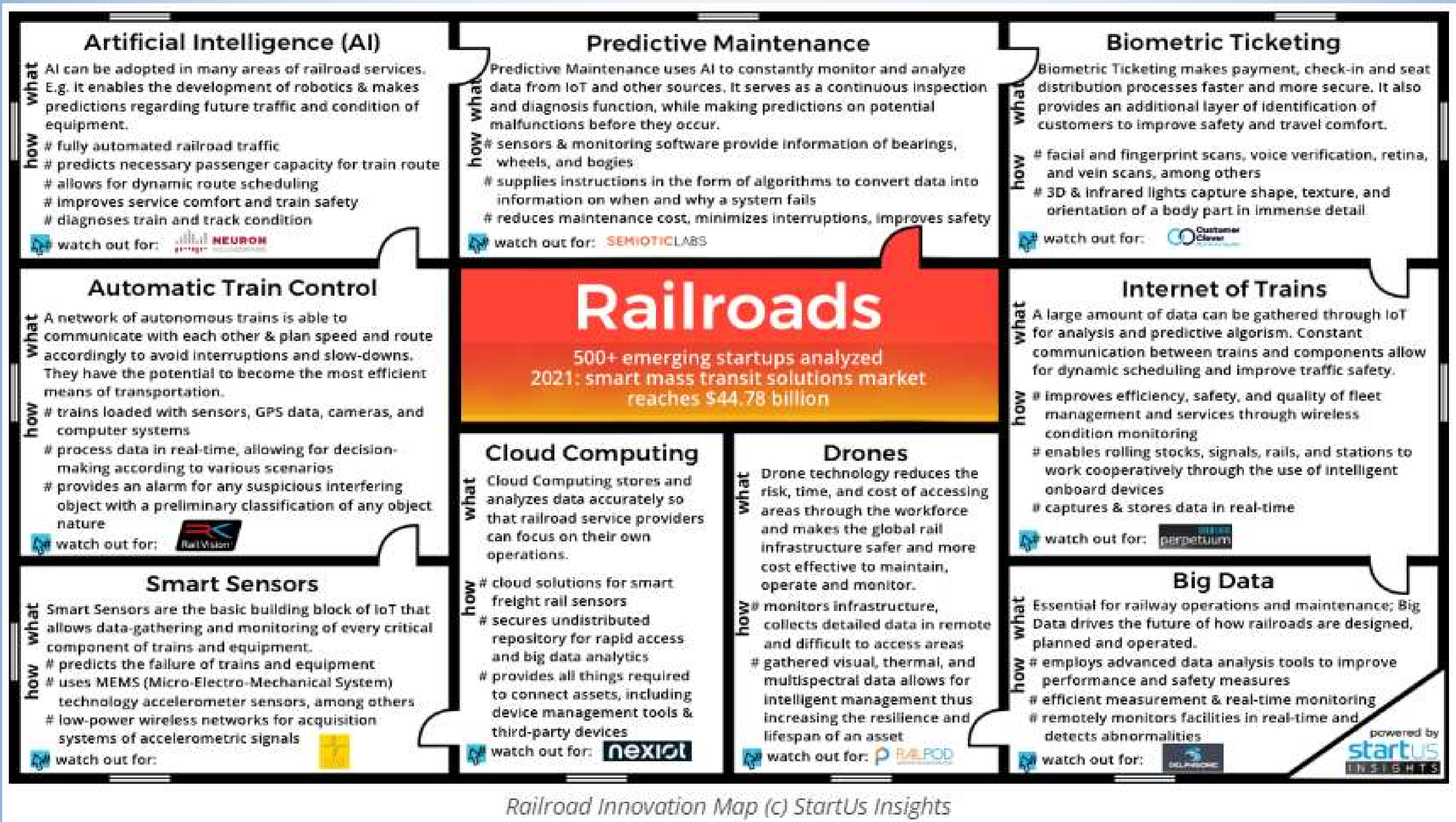

Figure 12 Railroad Innovation map [14]

SUSTAINABLE TRANSPORT IN FUTURE CITIES

- If cities wish to promote sustainable growth, dramatic public transportation growth is essential.

- The development of mass transit, particularly metro and light rail projects, goes hand-in-hand with sustainable urban growth.

- Public transportation plays a major role in developing the future of sustainable cities. Hence, it is imperative to have sustainable and resilient rail infrastructure.

RAIL BENEFITS FROM SUSTAINABLE INFRASTRUCTURE INVESTMENTS

Figure 13 Rail make urban transportation much easier *Photo: Shutterstock/Abdul Razak Latif*

Population growth and growing middle-income families who cannot afford to live in the city center make rail transport more desirable due to ease of accessibility, reduced travel time, improved quality of life, and reduced environmental footprint [17]

"Rail is the most attractive option for a transport corridor and for the development of the transport backbone of an urban transport system." (Smith, 2019)

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ASCE REPORT CARD FOR AMERICA'S INFRASTRUCTURE
BRIDGES

- **Collaborative Effort:** Various government levels have worked together over the past decade.
- **Objective:** Reduce the number of structurally deficient bridges nationwide.
- **Structural Deficiency:** These bridges aren't necessarily hazardous but need significant investment.
- **Risks:** High risk of future closure or weight restrictions without proper investment.

Bridge Conditions by Year

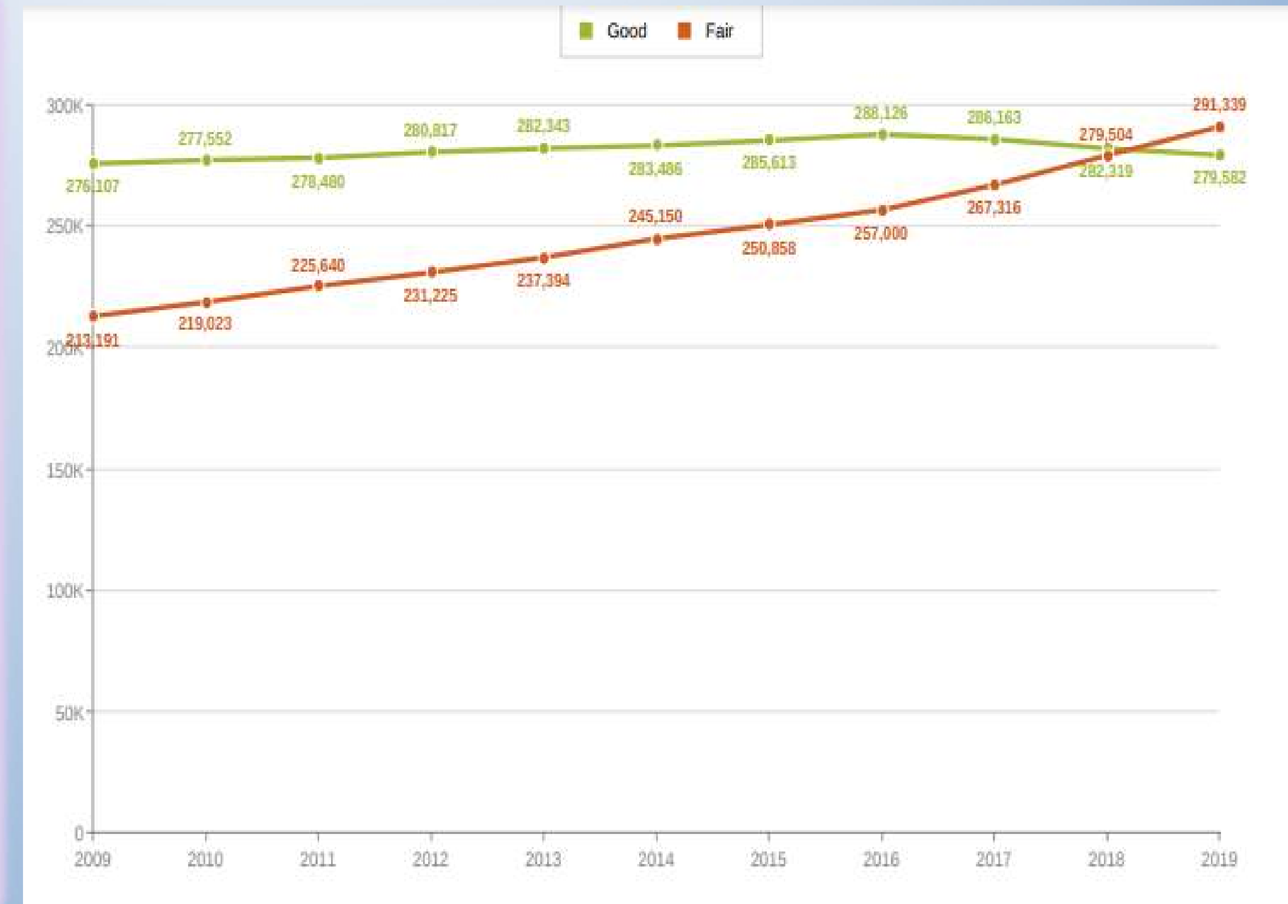

Fig: 14 Source: U.S. Department of Transportation, Federal Highway Administration, InfoBridge: Data: https://infobridge.fhwa.dot.gov/Data/Dashboard

LIFE CYCLE PRINCIPLES & OPTIMIZED INFRASTRUCTURE ASSET MANAGEMENT

Asset Renewal for Extended Service Life

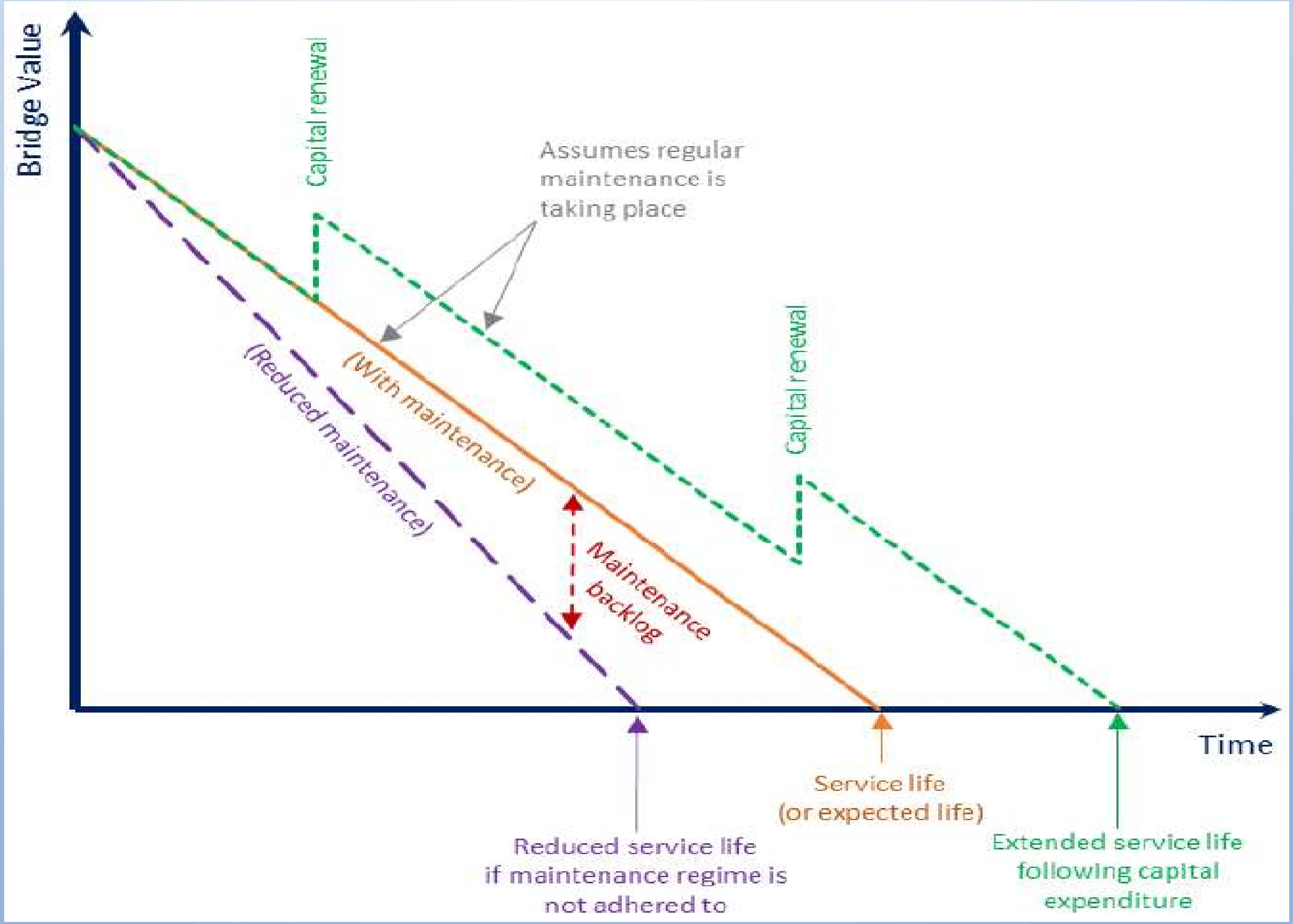

Fig:15 https://austroads.com.au/publications/bridges/ap-g94-21/media/AP-G94-21_Engineering_Guideline_to_Bridge_Asset_Management.pdf

RISK MANAGEMENT PROCESS
Risk Bow Tie Diagram

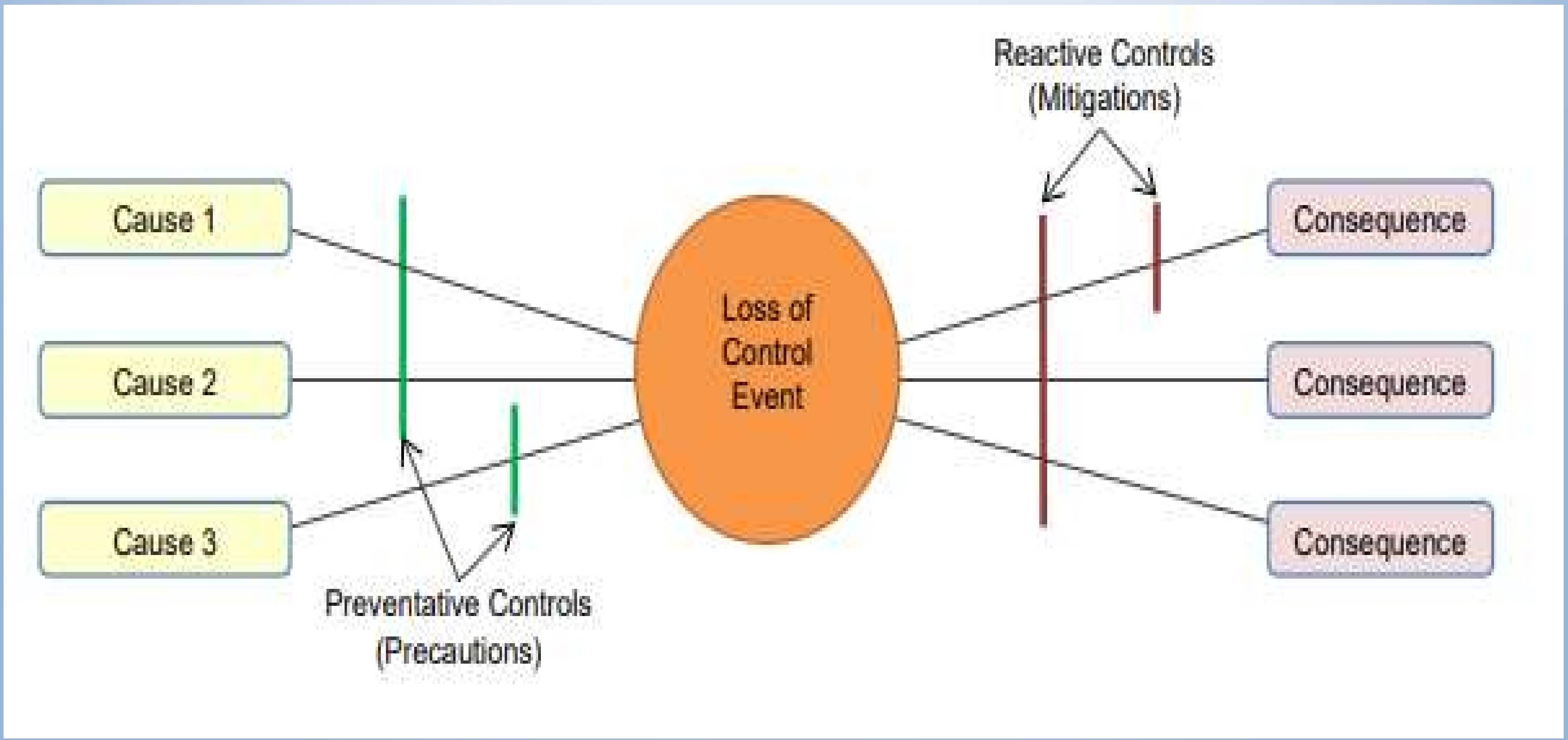

Fig:16 Risk Bow Tie Diagram [25]

RISK MANAGEMENT PROCESS | SAMPLE RISK RATING MATRIX

		Consequences				
		Insignificant	Minor	Medium	Major	Catastrophic
Likelihood	Very Likely	Moderate	High	High	Extreme	Extreme
	Likely	Moderate	Moderate	High	High	Extreme
	Possible	Low	Moderate	Moderate	High	High
	Unlikely	Low	Low	Moderate	Moderate	High
	Rare	Low	Low	Low	Moderate	Moderate

Figure 17: Sample Risk Matrix [25]

INFRASTRUCTURE ASSET MANAGEMENT

Optimizing Resources and Funding: A Visionary Approach"

Optimizing a work program goes beyond just numbers; it needs solid engineering expertise and practical experience. Below, you'll see how safety is prioritized over performance and cost when funding is limited, illustrating how tight budgets influence this balance.

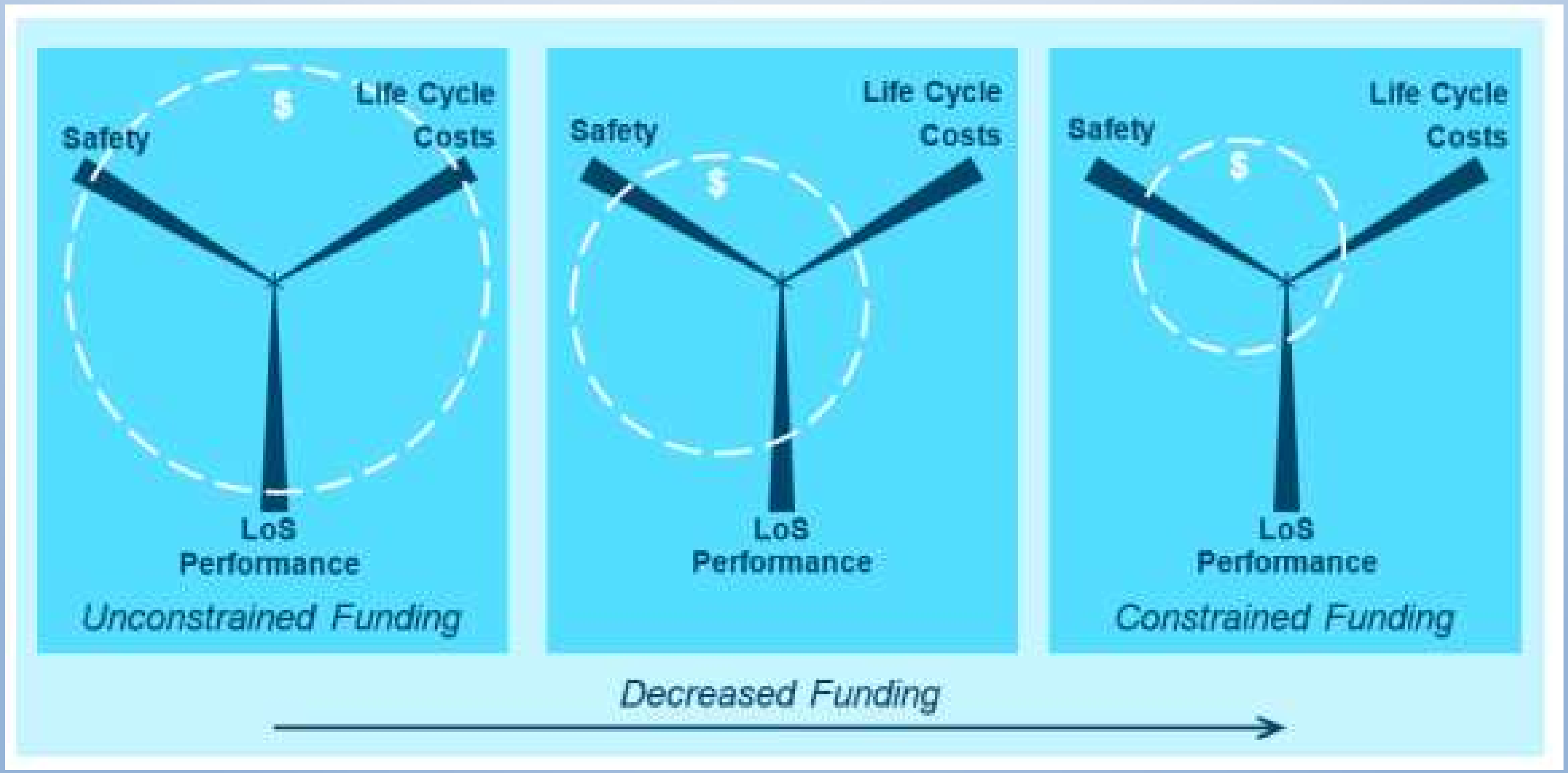

Fig 18 Optimizing Resources and Funding – A visionary Approach [25]

RESEARCH GAPS

Though numerous studies examine climate change impacts, more research is needed on how AI technology affects the sustainability and resilience of civil infrastructure, particularly transportation infrastructure.

AI STUDIES FOR SUSTAINABLE & RESILIENT INFRASTRUCTURE

The surge in AI studies shows the growing momentum in Infrastructure, suggesting that AI's role will expand, driving innovations and applications in the future.

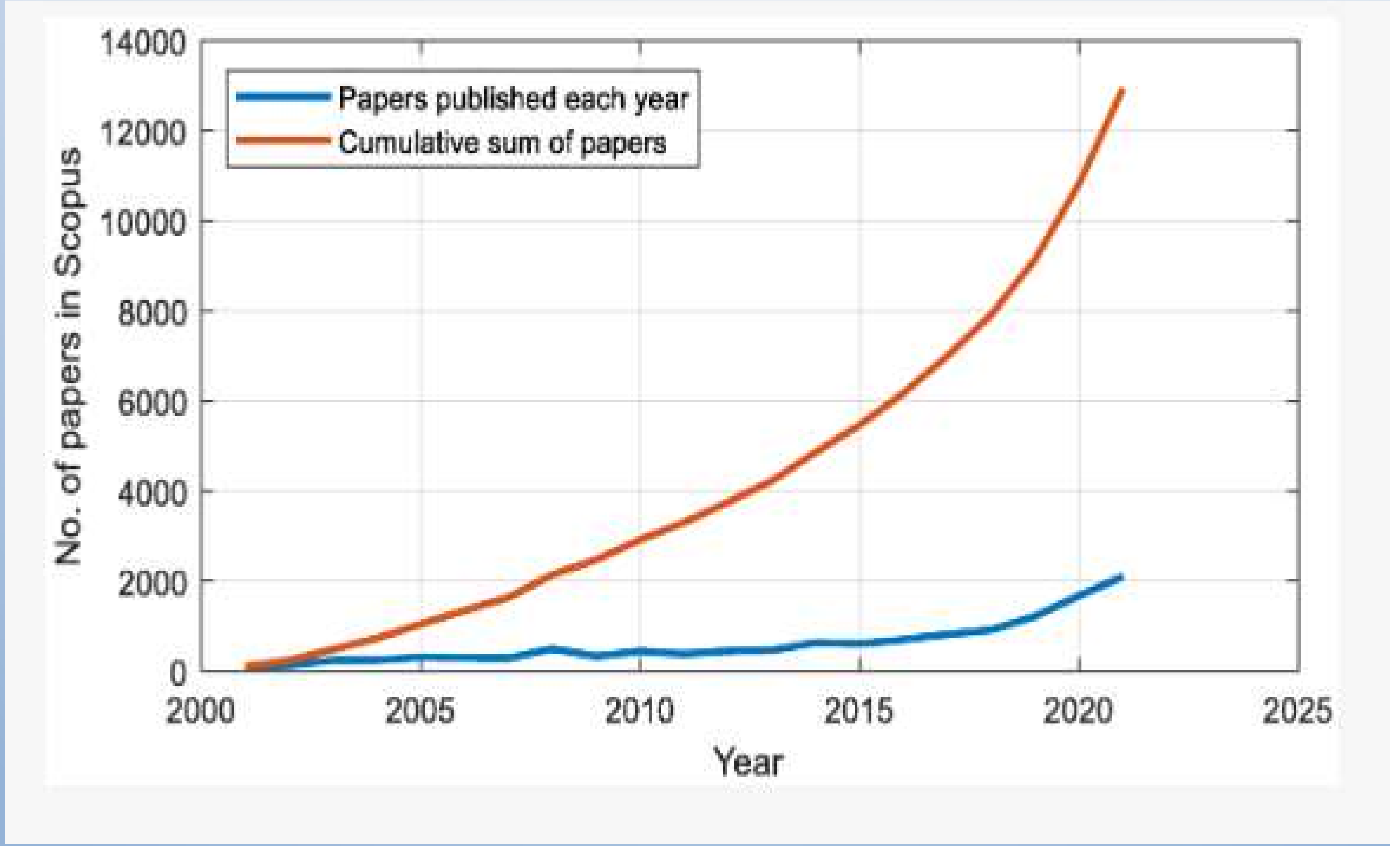

Fig: 19 Published Articles (in Scopus) using AI in civil engineering-related fields (2000-2021) [26]

ARTIFICIAL INTELLIGENCE - AI

Artificial intelligence (AI) replicates human intelligence processes through machines, particularly computer systems. AI systems consume large amounts of labeled training data, examine the data for correlations and patterns, and use these patterns to predict future states.

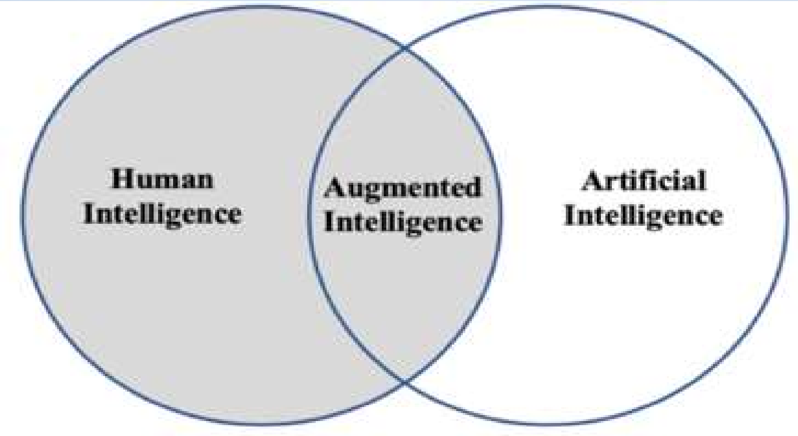

Fig 20 Augmented Intelligence

AI generates solutions using existing data, while humans can think creatively and invent completely new concepts. Human intelligence includes emotional understanding, empathy, and complex social interactions, aspects that AI currently cannot replicate.

Historical and Performance Driven Data

AI uses machine language to identify patterns in disaster data, enabling us to build resilient and sustainable infrastructure for handling climate change-induced disasters.

Many Data Sources

- GIS & GPS Technology
- Sensor Technology
- Historical Data
- IoT Sensors and Drone Data
- Intelligent Transportation System
- Weather System Data
- Asset Management System
- Risk & Maintenance Management

Data Warehouse

Data Lake
(Large set of data from multiple systems)

AI-Driven Decision Support System

- Climate-related Disaster Forecasting
- Risk assessment
- Mitigation Strategies
- Disaster Recovery
- Sustainability & Resilience

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THE POWER OF PREDICTING THE FUTURE

AIs predictive power for Natural Disasters:

- Hurricanes – Track & Intensity Forecasting
- Earthquakes – Advanced prediction
- Floods – Predict Flood Timing, Severity & Damage
- Wildfires – Identify Wildfire hotspots
- Volcanic Eruptions- Sensors provide rich datasets
- Fires – Sensors provide datasets to detect chemicals, smoke particles, and gases

AUCKLAND HARBOUR BRIDGE TSUNAMI

Fig 22 Auckland Harbour Bridge Artist: Warwick   Auckland Harbor Bridge Tsunami

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AI & CIVIL INFRASTRUCTURE

AI revolutionizes civil engineering by enhancing the design and simulation process. AI algorithms can process vast amounts of data to optimize designs, considering materials, cost, and environmental impact.

- Enhanced Predictive Capabilities
- Early Warning System
- Dynamic Traffic Management
- Improved Risk Assessment
- Real Time Monitoring and Adaptation
- Improved Safety: Reduces accidents by taking over risky tasks and detecting hazards.
- Efficiency: Automates repetitive tasks, boosting construction speed and efficiency.
- Asset Management and Maintenance Optimization
- Cost Efficiency & Resource Optimization
- Climate Resilient and Optimized Design & Construction
- Resilience Planning and Decision Support.
- Inspection: Inspects Transportation infrastructure.

RESEARCH QUESTIONS / HYPOTHESIS

Research Questions:

- What are the primary climate change factors affecting civil infrastructure?
- How do these factors impact different types of civil infrastructure?
- How can AI-driven techno-economic solutions mitigate the climate-related impacts on civil infrastructure, particularly for cost efficiency and sustainability?

Hypothesis:

AI-driven solutions can significantly reduce the climate-related impacts on civil infrastructure by optimizing cost efficiency and enhancing sustainability, leading to more resilient and adaptable infrastructure in the future.

METHODOLOGY & RESEARCH APPROACH

Method: The research will utilize both Qualitative and Quantitative data for Hypothesis Testing & Exploratory Analysis

Data Collection: Data collection includes but not limited to:

- Historical Climate Data & Infrastructure Performance Data
- Broad range of past events and their Impacts
- Feedback from Infrastructure professionals
- Stakeholder Interviews, Case Studies, Surveys etc.

Analysis: Simulations of future climate scenarios and their impacts will be derived from analyzing a broad range of past events. The Analysis will utilize statistical methods via Excel, Modeling Tools, and, Case Studies.

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EXPECTED OUTCOME

Findings: Anticipate identifying critical vulnerabilities in critical infrastructure caused by climate change and explore how AI can enable the design, construction, and maintenance of sustainable and resilient systems.

Impact: This research will offer invaluable insights, enabling policymakers and infrastructure teams to design and maintain sustainable and resilient systems with greater efficiency and effectiveness through the strategic application of Artificial Intelligence.

THE ROLE OF GOVERNANCE IN SHAPING SUSTAINABLE & RESILIENT CRITICAL INFRASTRUCTURE

Policymakers and regulatory authorities at various levels play a critical role. They are essential in shaping sustainable infrastructure goals and addressing the finance gap in three primary ways.[14]

A. Policy measures
- Clear, transparent, and supportive policy
- Ensure anti-corruption

B. Information flow
- Publish project plans and project benefits
- Communicate and collaborate

C. Mobilizing finance:
- Financing
- Tax incentives
- Attracting public investment
- Boosting capital market

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RECOMMENDATIONS

MAKING INFRASTRUCTURE MORE RESILIENT REQUIRES A CONSISTENT STRATEGY [9]

- Infrastructure disruptions are symptoms of chronic shortcomings.
- In most cases, the disruptions occur because infrastructure systems are not designed to keep up with the rising demand.
- Hence, to make infrastructure systems resilient, the first step is to make them reliable in normal conditions
- Table 2 has summarized the five recommendations to address the five obstacles to resilient infrastructure.

Table 2: Five Recommendations to Address the Five Obstacles of Resilient Infrastructure [9]

Recommendation	Actions
1: Get the basics right	1.1: Introduce and enforce regulations, construction codes, and procurement rules 1.2: Create systems for appropriate infrastructure operation, maintenance, and postincident response 1.3: Provide appropriate funding and financing for infrastructure planning, construction, and maintenance
2: Build institutions for resilience	2.1: Implement a whole-of-government approach to resilient infrastructure, building on existing regulatory systems 2.2: Identify critical infrastructure and define acceptable and intolerable risk levels 2.3: Ensure equitable access to resilient infrastructure
3: Create regulations and incentives for resilience	3.1: Consider resilience objectives in master plans, standards, and regulations and adjust them regularly to account for climate change 3.2: Create economic incentives for service providers to offer resilient infrastructure assets and services 3.3: Ensure that infrastructure regulations are consistent with risk-informed land use plans and guide development toward safer areas
4: Improve decision making	4.1: Invest in freely accessible natural hazard and climate change data 4.2: Make robust decisions and minimize the potential for regret and catastrophic failures 4.3: Build the skills needed to use data and models and mobilize the know-how of the private sector
5: Provide financing	5.1: Provide adequate funding to include risk assessments in master plans and early project design 5.2: Develop a government-wide financial protection strategy and contingency plans 5.3: Promote transparency to better inform investors and decision makers

CONCLUSION

- Quality of Life: Sustainable infrastructure enhances the quality of life and increases positive impacts.
- Resource Protection: Helps protect vital natural resources and the environment.
- Challenges: Developing sustainable and resilient infrastructure is complex, involving several performance indicators.
- Economic Growth: Investment in infrastructure and innovation drives growth and development.
- Resilience: Building Resilient Infrastructure and Fostering Innovation are the key.
- Future Impact: Today’s Infrastructure development is crucial for future resilience. Let’s embrace the power of AI to make it better.

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- Supporting members: Janet Leli & Ryan Stiesi (CAIT)

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