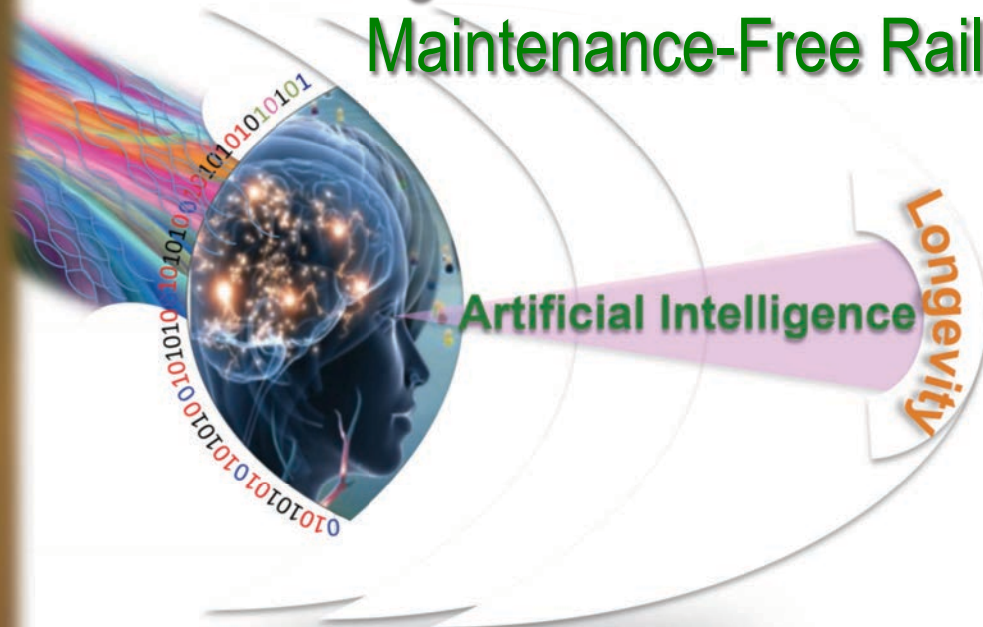




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# Intelligent Health State Awareness Framework for Maintenance-Free Railway System Vision



**Presented to:**  
2<sup>nd</sup> International Workshop on  
Structural Health Monitoring for  
Railway System  
Qingdao, China  
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**Texas Tech University (TTU)**  
**Office of the Vice President for Research**  
Institute for Materials, Manufacturing, and Sustainment (IMMS)  
**Lubbock, Texas - USA**

# Presentation Outline

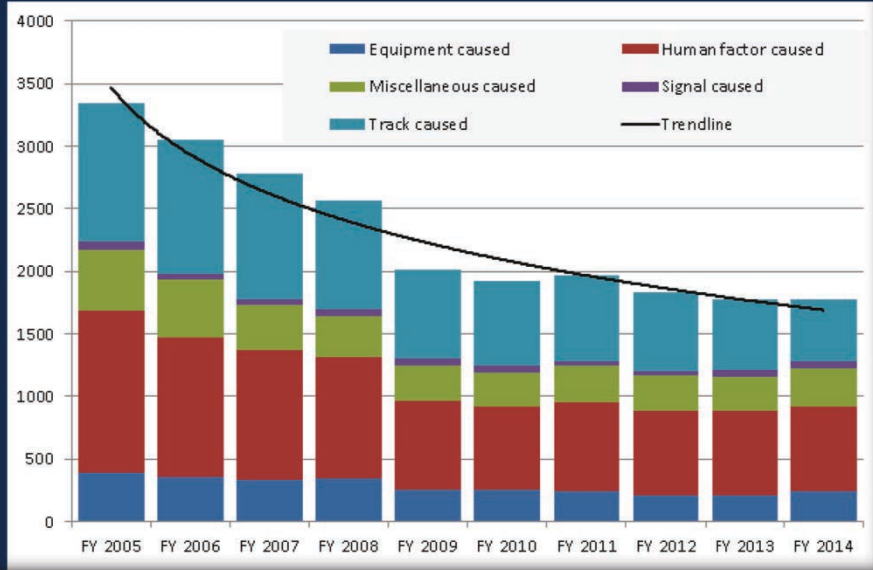
- Why “*Maintenance-Free Railway*” ?
- Defying “*Impossibilities*”
- Envisioning “*Discoveries*”
  - Finding & catching “*Materials Damage Precursors*”
  - Searching for “*Wheel-Rail Interaction Derailment Precursors*”
  - Enabling “*Self-Healing*” and “*Reconfiguration and Adaptive*”  
*System*
- Developing and integrating “*Next-Generation of Artificial Intelligence*” to increase railway system safety and longevity
- Developing “*Intelligent Health State Awareness*” framework for achieving “*Maintenance-Free*” railway
- Conclusions

# Railway Accidents



## Ten-Year Trend for Accident Reductions

\*Fiscal Year Representing Absolute Numbers  
Source: FRA

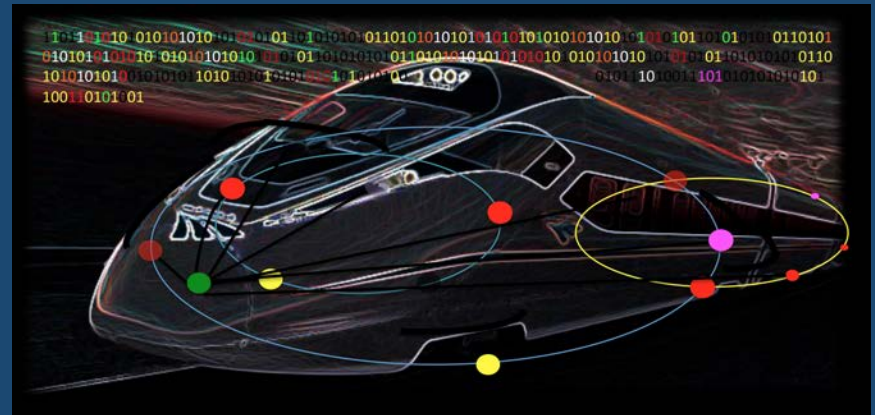


Source: U.S. Federal Railroad Administration

# Value Proposition

## Intelligent Health State Awareness Vision for Digital Maintenance-Free Railway Systems

### Unleashing



### Revolutionary Capability

- Reduce sustainment costs
- Increase safety and availability

**One event: 33 Freight cars derailed:  
Damage costs > \$35M**

**Safety Concerns and Economic Burdens**

**Cause: Undetected defects of joint bars**





# Defying Impossibilities and Envisioning Discoveries

## - A System Level Approach -



CBM Tech  
Maintenance-  
Free Systems

Reliability

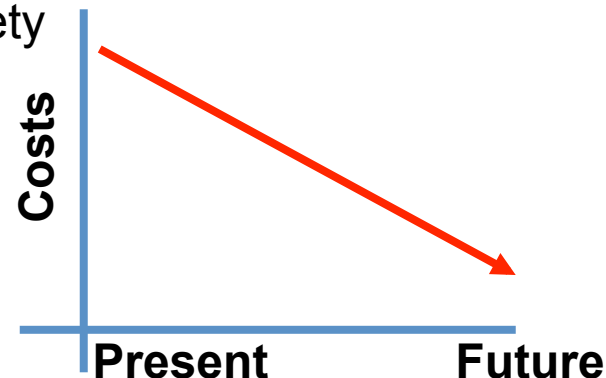
Intelligent Health State  
Awareness Technology

Adaptive Positive Train Controls

Dynamics Interaction Model & Self-Healing & Reconfiguration

Damaged Mechanical and Structural Detection & Precursor - Failure Correlation

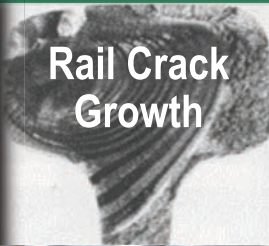
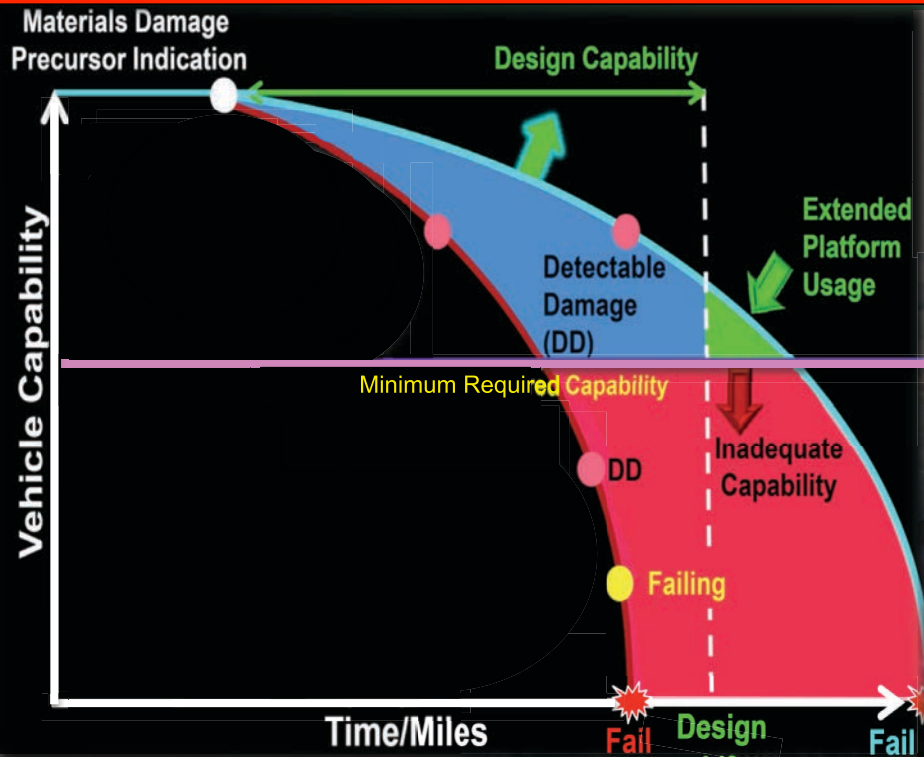
- Empower operators with “breakthrough” technologies & capabilities to operate railway systems with *substantial reduction in maintenance* costs while ensuring safety



- **Benefits to operators:** Enable railway digital health monitoring, effective “big data” management
  - Immediate vehicle **health state**
  - Moving beyond Condition-based Maintenance (CBM) to informed **material state-based awareness**
  - Automated component health tracking

# Finding and Catching "Materials Damage Precursors"

## - Through Intelligent built-in Sensing Network & Multifunctional Materials



Rail Crack Growth



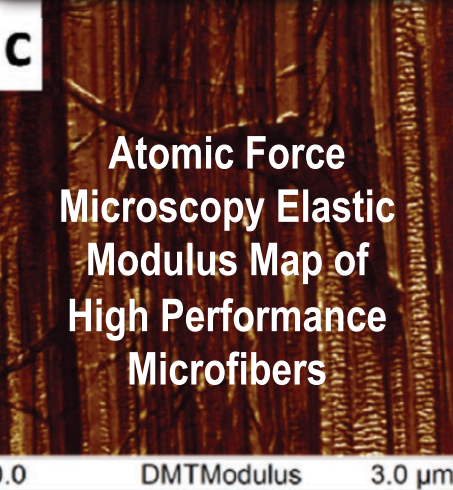
Wheel Failure



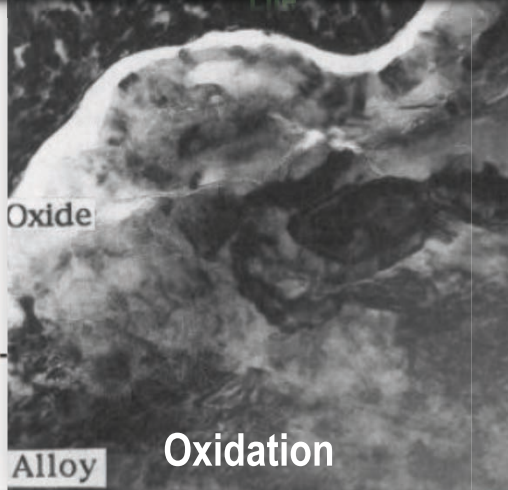
Broken Rail



Rail Defect

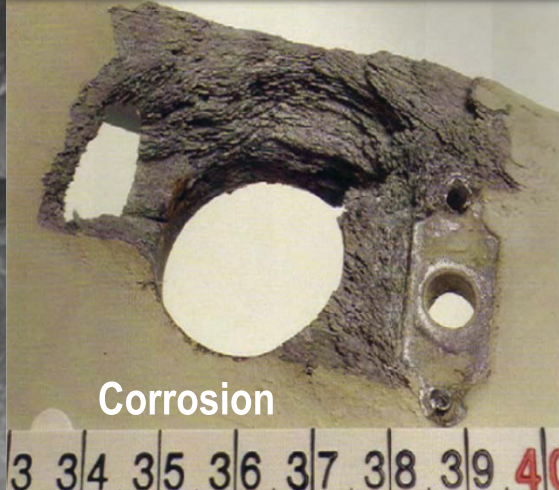


Atomic Force Microscopy Elastic Modulus Map of High Performance Microfibers

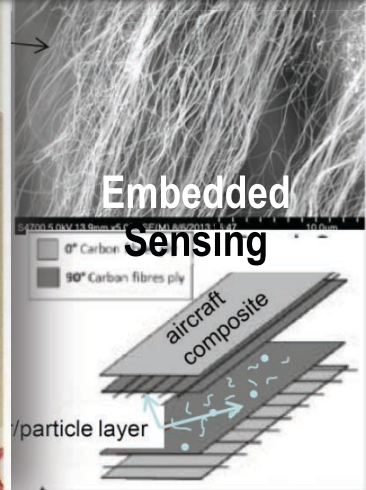


Oxide

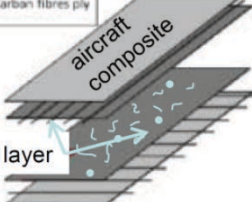
Oxidation



Corrosion

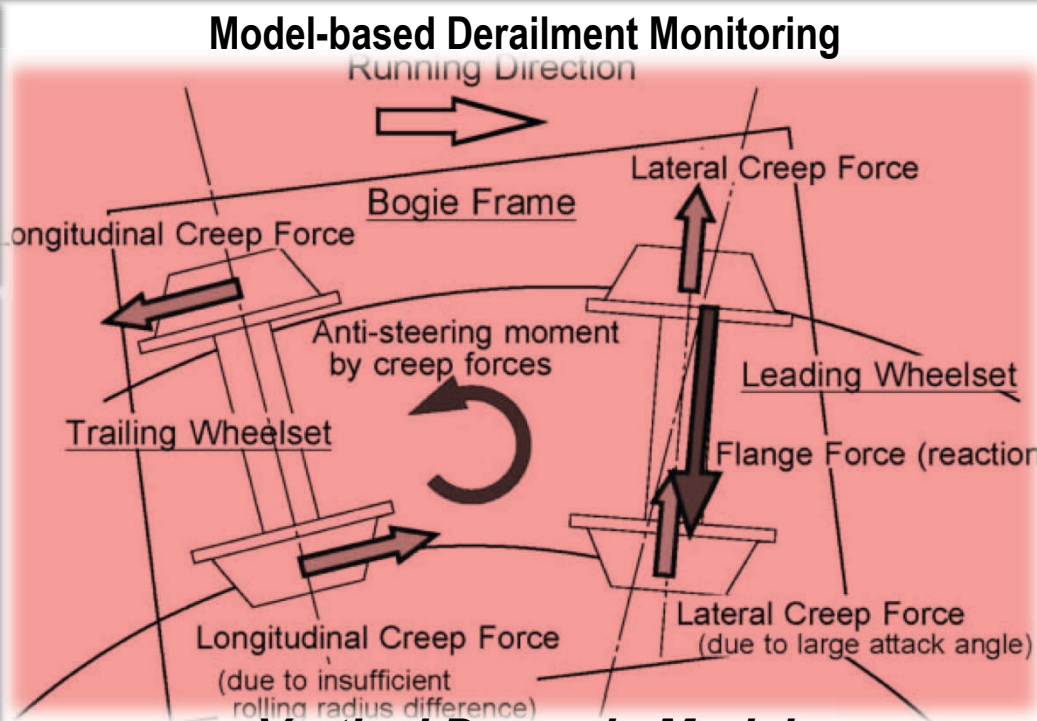
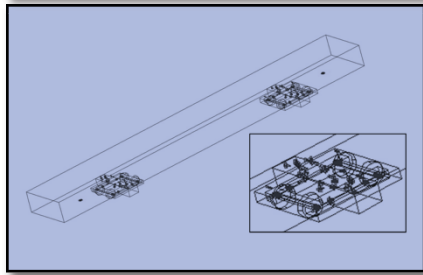
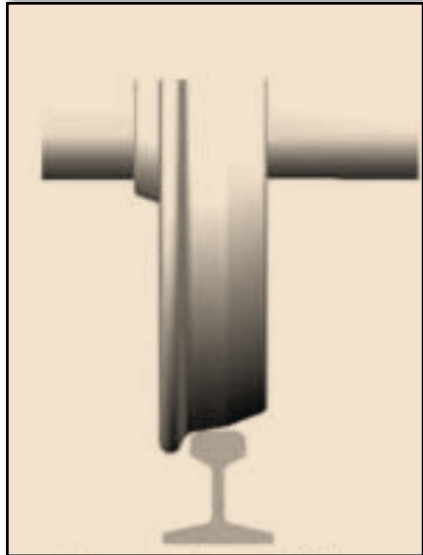
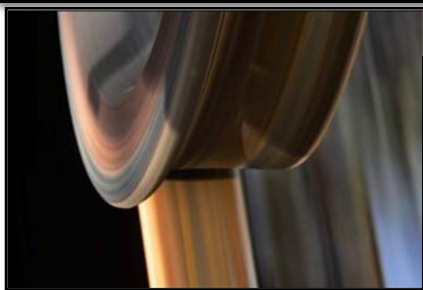


Embedded Sensing

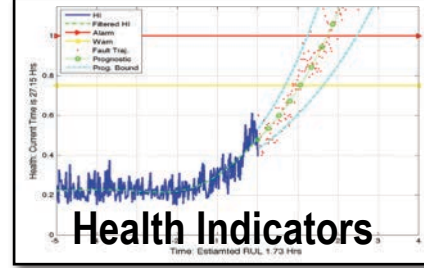
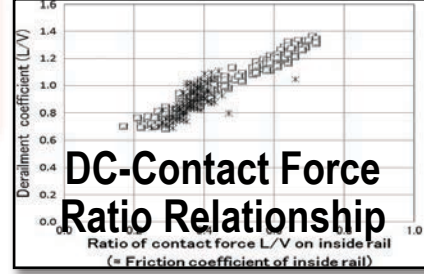
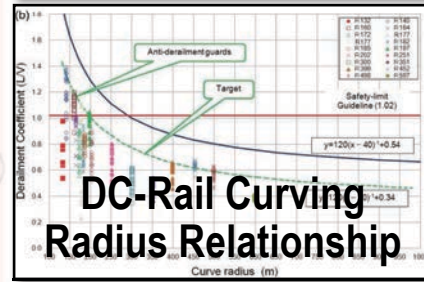




# Searching for Wheel-Rail Interaction Derailment Precursors - Through Coupled Multi-body Wheel-Rail Physics-Based Models



- ✓ **- Vertical Dynamic Model -**  
Suspension and wheel-rail as system
- ✓ **- Lateral Dynamic Model -**  
Lateral displacement, roll, yaw – monitoring hunting, rail curving effect, and derailment
- ✓ **- Longitudinal Dynamic Model -**  
Effect of train braking on whole train and potential derailment through curved tracks



Sources: (1) – (6) Akira Matsumoto, "Continuous observation of wheel/rail contact forces in curved track and theoretical considerations", *International Journal of Vehicle Dynamics and Mobility*, 2012 – (7) Bechhoefer, E., Augustine, M., Kingsley, M., "Architecture for a Lightweight helicopter HUMS", 68th AHS Forum, 2012

# Enabling "Reconfigurable & Self-Healing Elements"



## - Bio-Inspired with Multifunctional & Self-Adaptable Capabilities -

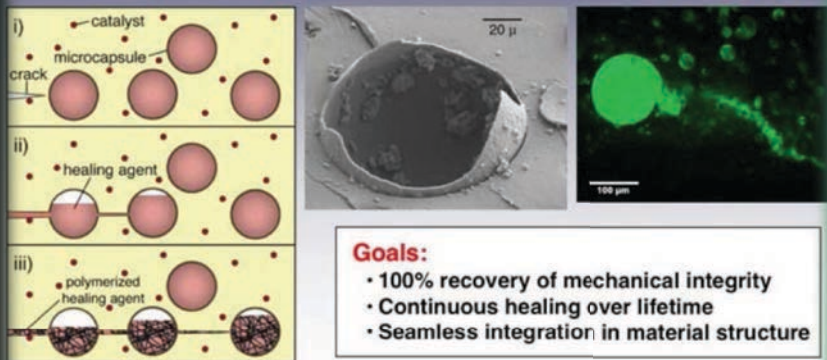
Potential new process for new types of active, reconfigurable materials for structural morphing & healing, vibration attenuation, and dynamic load mitigation

- Fire ants collectively entangle themselves to form an active structure capable of changing state from liquid to solid when subject to applied loads

### Self-Healing Polymers

**Materials System:**

- microencapsulated healing agent
- suspended catalyst phase
- polymeric matrix



**Goals:**

- 100% recovery of mechanical integrity
- Continuous healing over lifetime
- Seamless integration in material structure

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Self-Healing

- Embedded microvascular networks within structural materials
- Continuous transport of healing agents throughout structural lifetime

Can this technology be applied to composites materials with fiber reinforcement in the resin?



Can we dynamically alter interconnections among subsystems to direct the flow of energy and entropy within networks to achieve desired macroscopic properties?



# Developing Next-Generation Artificial Intelligence - Physics-Centric Model Based AI -



## - Rule-Based AI -

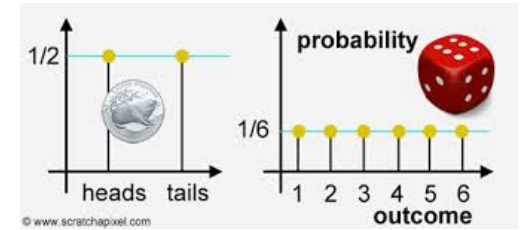
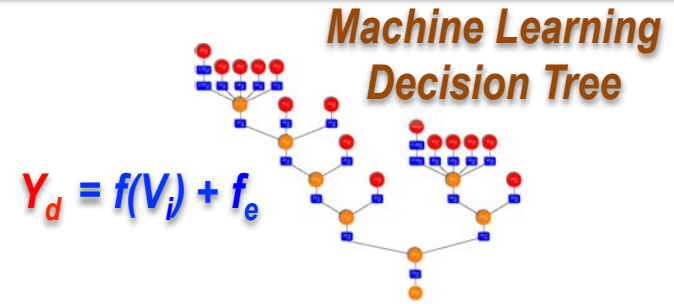
- ✓ Good for well-defined problems and system parameters with good known certainty
- ✓ *Incapable of training and difficult to address new hidden states and uncertainty*

## - Statistical Learning AI -

- ✓ Don't follow exact rules but based on statistical models of certain types of problems – Deal with uncertainty & Probability
- ✓ Artificial Neural Network with different computation layers to process data
- ✓ Couldn't explain informed decision but could tell with level of probability
- ✓ *Difficult to train/address new hidden states*

## - Physics-Centric Model Based AI-

- ✓ Construct and/or update models in real environment & address new hidden states
- ✓ Enable self training
- ✓ *Capable of perceiving, learning, abstracting, and reasoning*



**Probability of Outcomes**



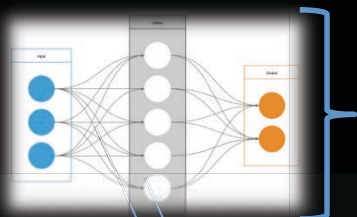
**Cognitive capability with direct feedback and learning**



# Integrating Next-Generation Artificial Intelligence - Increase Railway System Longevity & Safety -



1



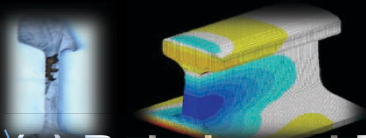
(a) Model of Models

2

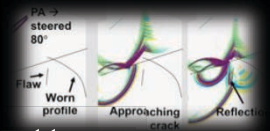


(b) System of Systems

Automated Data Pipeline in Real-Time



(a) Rule-based Pattern Recognition & Statistical Learning



(b) Artificial Intelligence Machine Learning (ML)



(c) Cognitive Capability

Self-Learning

Auto-Feedback

(1) Identify Model of Models properties, e.g., ingredients of longevity or precursors of onset of failure

(2) Enable cognitive cueing and human-machine teaming, interaction, & communication in RT

(3) Facilitate system behavior change for sustaining longevity or self healing to disrupt failure cascade

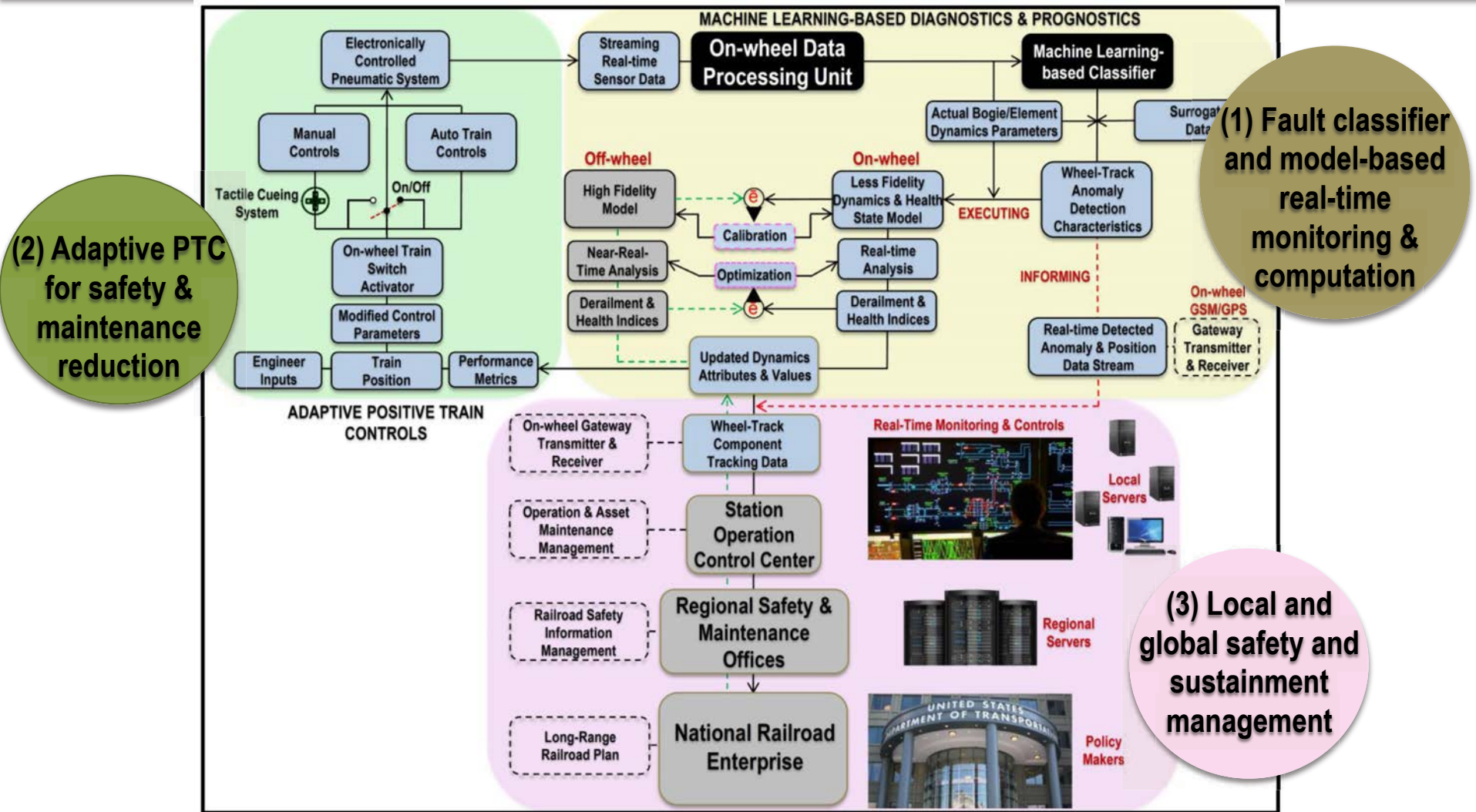
Goal



Achieve "Maintenance-Free" thru intelligent comprehensive integrated solution

# Intelligent Health State Awareness Framework

## - Physics-Centric Model Based AI -



✓ **Maintenance-Free Philosophy:** No maintenance within a predetermined period of time - modify scheduled or inform unscheduled maintenance activities in the most efficient way while ensuring safety, enhancing reliability, and increasing operational availability



## Conclusions

- ✓ Extensive human-manual maintenance labor presents **substantial cost burden for railway operators and stakeholders**
- ✓ Condition based maintenance **lack automation capability** and improving reliability – **not a total solution**
- ✓ Advanced discoveries in the ability to detect and characterize materials **damage precursor** and precursors to **wheel-rail poor dynamic interactions** as well as **adaptive and reconfigurable** capabilities are critical to prevent mechanical failures and train derailments
- ✓ In addition to rule-based and statistic learning, next generation of artificial intelligence will include **physics-models to provide cognitive capability** including direct feedback and learning
- ✓ Maintenance-free strategy while increasing train safety can be achieved via comprehensive **AI-ML integrated health state awareness** technology



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**THANK YOU AND QUESTIONS?**