A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor
and
Wireless SHM-RFID-IoT Smart Fatigue Damage SENSOR NETWORK
and
An Internet of Things-IoT Based Intelligent Predictive Maintenance Management System

for Structural Health Monitoring Applications

By
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A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network (INTRODUCTION)

- **Fatigue plays a critical role for design of structures or critical mechanical systems under cyclic dynamic loads. Several fatigue design methodology are used for fatigue design of mechanical components or structures. All these techniques are relied on STOCHASTIC MEDHODOLOGIES.**
- **Any failure in one of the structural members of the system causes catastrophic failure with serious consequences costing lives and property. It is foreseen that the proposed RFID-IoT Smart Fatigue Sensor will revolutionize the concept of fatigue design and also will revolutionize the fatigue inspection and maintenance management methodologies by using the RFID-IoT Smart Fatigue Sensor Network Data.**
- **Since the distributed fatigue sensor network system periodically or continuously is monitoring the fatigue health state conditions of structures, the database of the sensor network system will be used for condition based inspection, sensor based maintenance management and development of new fatigue design tools for fatigue sensitive complex and large engineering structures or mechanic systems.**
- **Health status of structural members which undergo cyclic stress need to be monitored continuously and fatigued parts need to be replaced well before the failure limit is reached. Railway Systems, Aircrafts, Helicopters, Wind Turbines, Mega Cranes, Highway Bridges and Marine Vessels are especially considered as systems vulnerable to this sort of fatigue damage accumulation.**

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

(IoT PREDICTIVE INTELLIGENT FATIGUE SENSOR)

- **A Novel Smart RFID Fatigue Damage Sensor aiming to the prediction of fatigue residual strength of critical mechanical and structural components for Structural Health Monitoring has been DEVELOPED and PATENTED (PATENT N0. US 8,746,077 B2).**
- **The proposed smart sensor system is designed for early detection and estimation of the structural health cumulative fatigue damage level and wirelessly transferring the information using an active or passive RFID integrated system.**
- **The developed RFID fatigue sensor system has a specially designed geometry with multiple parallel oriented unidirectional, bidirectional or multi directional breakable C, U or V type notched beams having different fatigue lifetimes to predict not only unidirectional or bidirectional fatigue damage but also multidimensional cumulative fatigue damage level of structural or mechanical elements including composite structures.**
- **It is foreseen that the proposed RFID-IoT Smart Fatigue Sensor will revolutionize the concept of fatigue design and also will revolutionize the fatigue inspection and maintenance management methodologies by using the RFID-IoT Smart Fatigue Sensor Network Data.**

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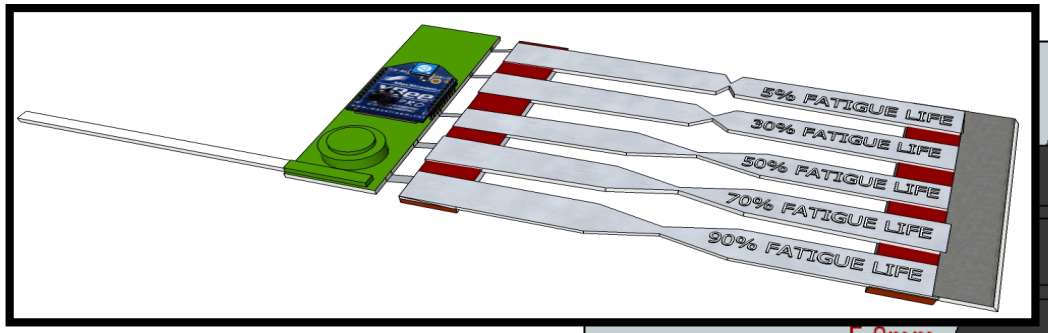
(IoT PREDICTIVE INTELLIGENT FATIGUE SENSOR)



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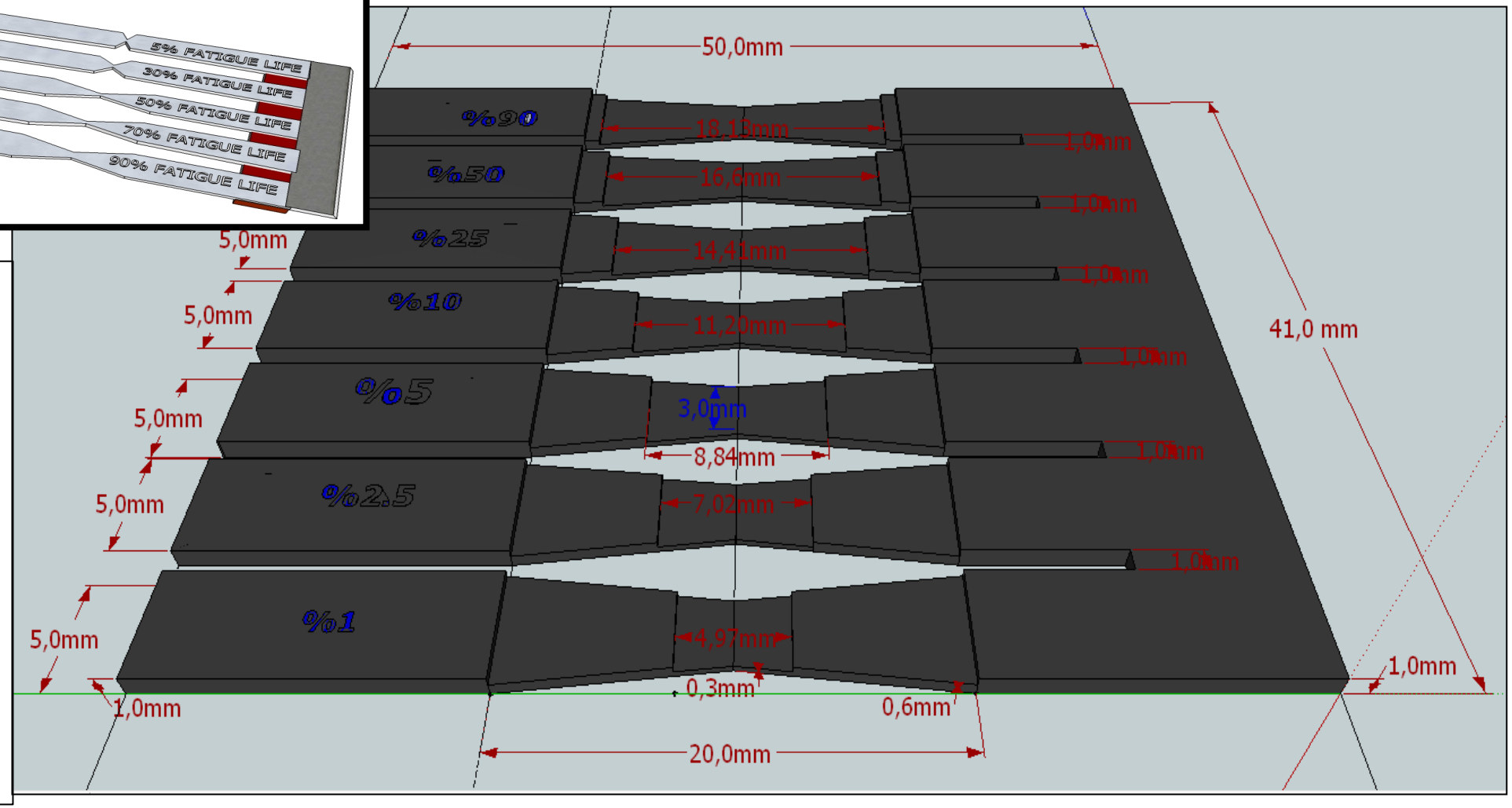

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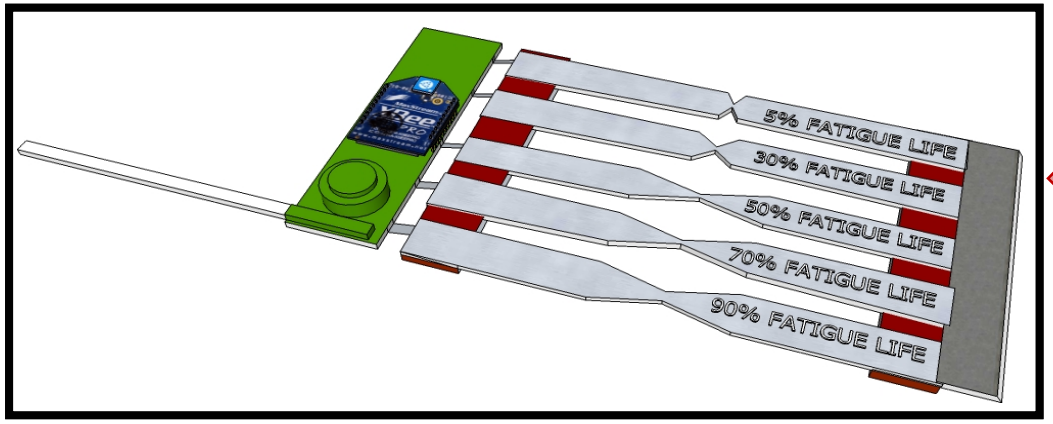
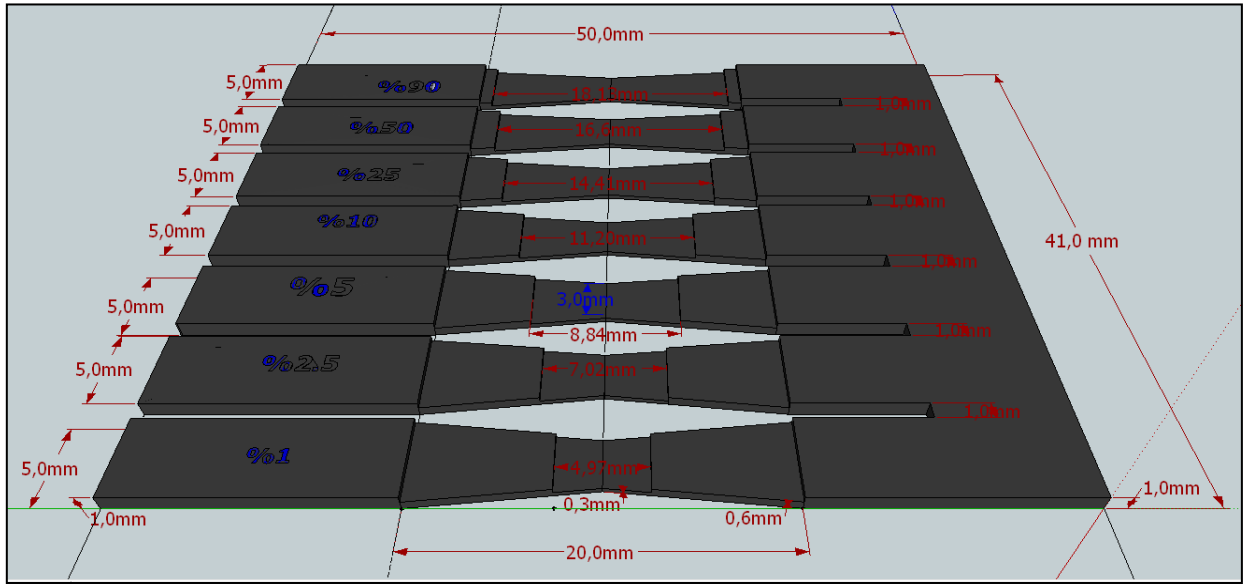
(FATIGUE DAMAGE SENSOR- PATENTED)



FATIGUE SENSOR (PATENT N0. US 8,746,077 B2)



- There are two versions of the fatigue sensor, one with a battery version and another one which works with RF power. The one with the battery uses Zigbee or similar low power sensor networking to interrogate the sensor about the state of breakable fingers.
- The sensor nodes relay information from one node to the other to communicate with the master node.

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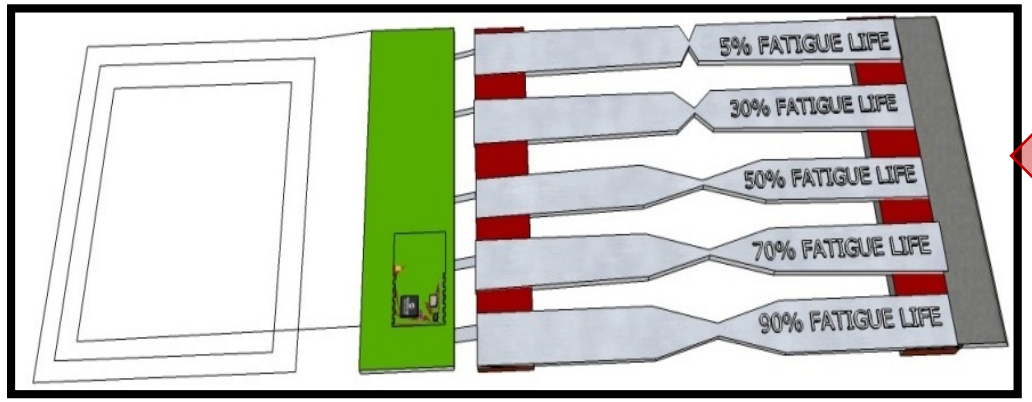
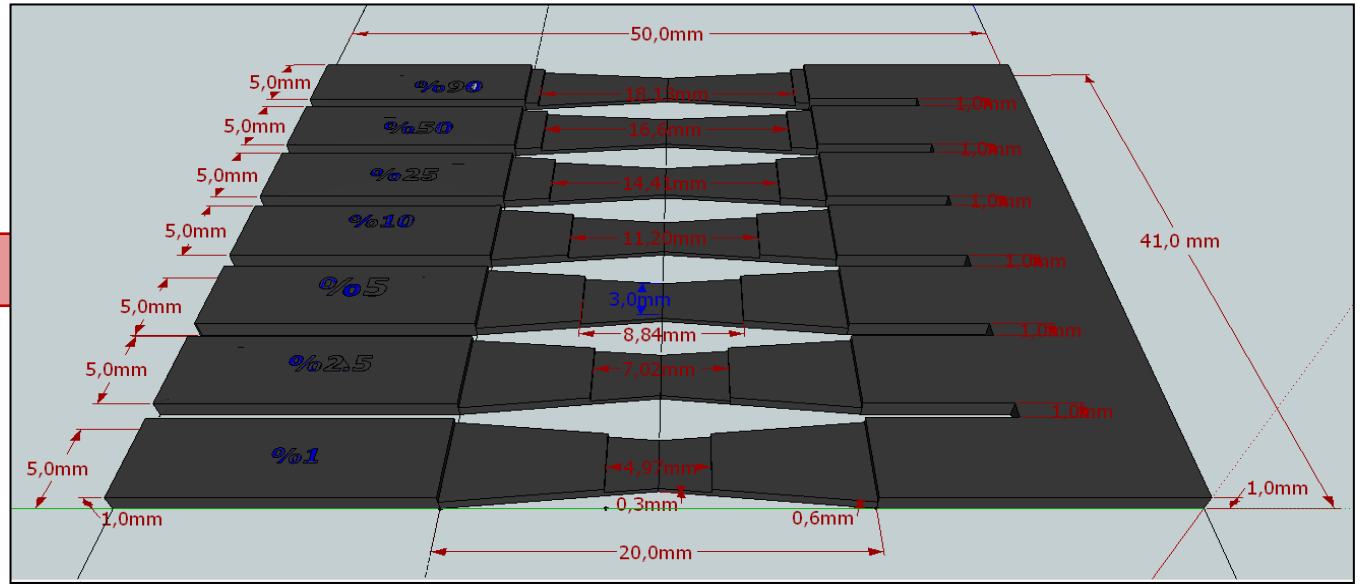
(PASSIVE FATIGUE DAMAGE SENSOR-PATENTED)

Wireless Enabled RFID-IoT SMART (FATIGUE) SENSOR



FATIGUE SENSOR (PATENT N0. US 8,746,077 B2)



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- **The sensor nodes relay information from one node to the other to communicate with the master node.**

NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS (ACHIEVEMENTS)

- **Predictive fatigue damage maintenance sensors (HARDWARES) for MONITORING OF FATIGUE DAMAGE ACCUMULATION LEVEL OR REMAINING USELFUL LIFE OF STRUCTURAL SYSTEMS**
- **A predictive maintenance decision-support system (A SOFTWARE) able**

to identify and localize damage,
to assess damage severity,
to predict damage evolution,
to assess remaining asset life,
to reduce the probability of false alarms,
to provide more accurate failure detection,
to issue notices to conduct smart maintenance actions,
and ultimately
to increase in-service efficiency of TRANSPORTATION SYSTEMS.

- **Increase availability and maintainability by …%**
- **Reaching …% of time spent on predictive maintenance**
- **Reduce failure-related accidents by ….%**
- **Reduce energy consumption by …..%**
- **Reduce raw material consumption by ….%**

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Predictive maintenance model

- The underlying architecture of a preventive maintenance model is fairly uniform irrespective of applications. Analytics usually reside on various IT platforms, with layers systematically described as:
- Data acquisition, storage – Cloud or edge systems
- Data transformation – Conversion of raw data for machine learning models
- Condition monitoring – Alerts based on asset operating limits
- Asset health evaluation – Diagnostic records based on trend analysis if asset health declines
- Prognostics – Failure predictions through machine learning models, estimate remaining life
- Decision support system – Best action recommendations
- Human interface layer – Information accessible in easy-to-understand format
- Failure prediction, fault diagnosis, failure-type classification, and recommendation of relevant maintenance actions are all a part of predictive maintenance methodology.

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Artificial intelligence for predictive maintenance

- Cutting-edge technology keeps machinery working efficiently, reduces maintenance, repair costs.
- Leveraging artificial intelligence (AI) models to identify anomalous behavior turns equipment sensor data into meaningful, actionable insights for proactive asset maintenance – preventing downtime or accidents.
- Commonly known as predictive maintenance, this intelligence forecasts when or if functional equipment will fail so its maintenance and repair can be scheduled before the failure occurs.
- Considering the aggressive time-to-market required for aerospace products and services, identifying causes of potential faults allows companies to deploy maintenance services more effectively, improving equipment up-time.
- Critical features that help predict faults or failures are often buried in structured data, such as year of production, make, model, and warranty details, as well as unstructured data such as maintenance history and repair logs.

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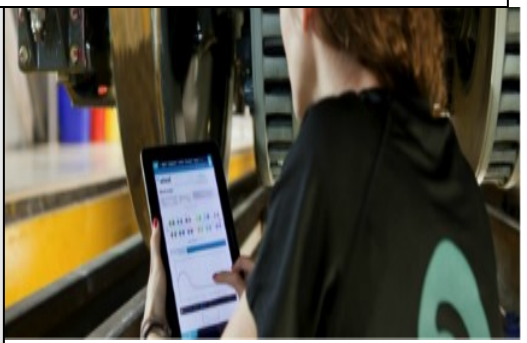
(SYSTEM MODEL)

- **The intelligent sensor technology system** which extracts data from monitored assets to provide highly **automated diagnostics** and fleet condition management.
- **The Intelligent sensor network brings all data and information together**, determines the health of assets, **predicts future conditions** and notifies of potential asset failures. It delivers **optimization of operations and maintenance activities**.
- **Extending the life of wheelsets and bogies in railways** and rolling stock provides solutions and services to **maximize lifecycles**, while increasing productivity and availability.
- Through wheel condition monitoring, **The Wheel System Data provides full management of the long-term planning of railway bogie and wheelset maintenance**, reducing uncertainty in the planning of maintenance activities throughout the lifetime of wheelsets in the rolling stock fleet.
- INTELLIGENT SENSOR SYSTEM Solutions offers expert solutions and services for **railway wheel life extension, productivity improvement,** condition monitoring and business-driven data management.



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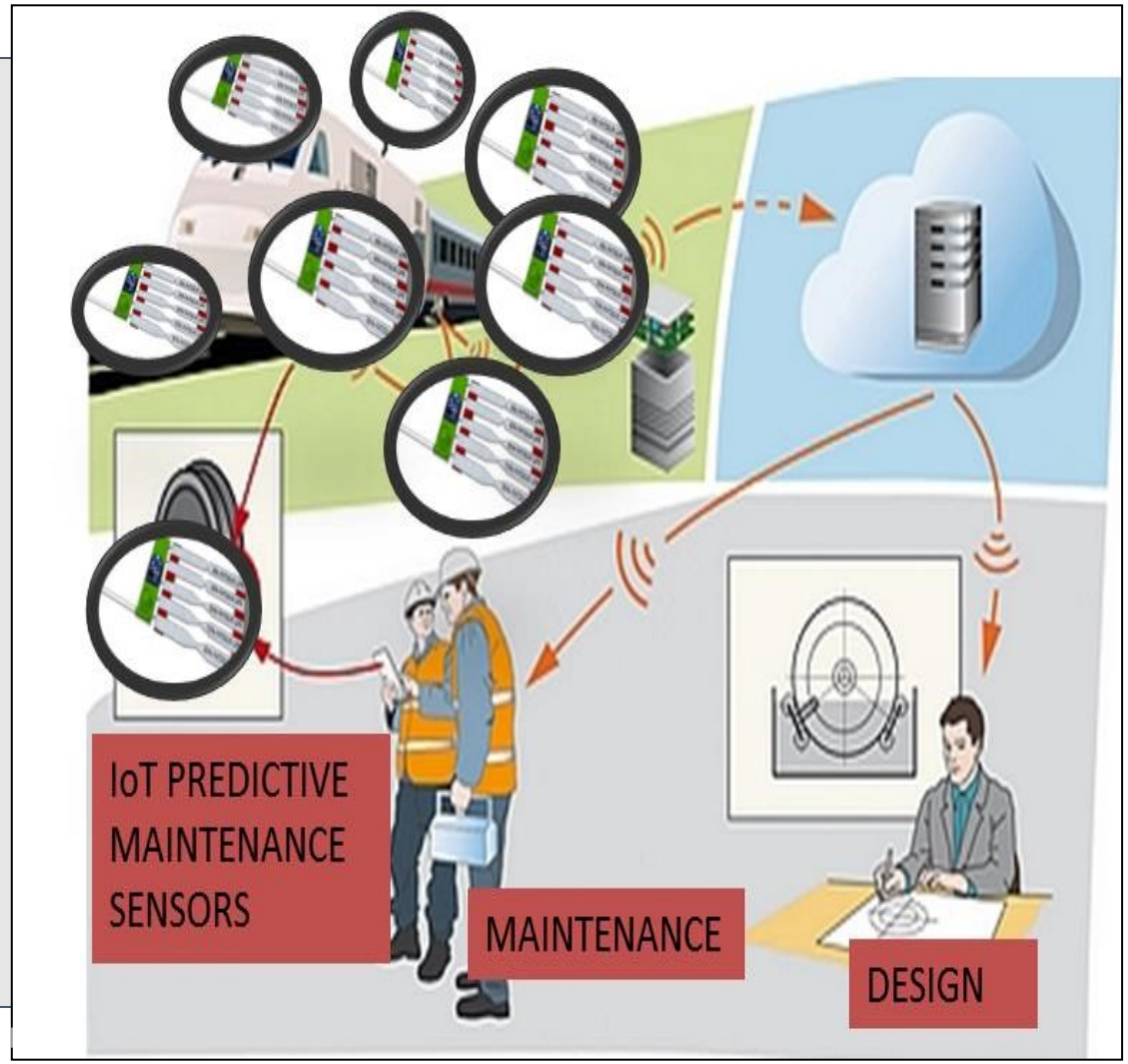
(SYSTEM MODEL)

IoT PdM Wireless sensor networks (WSNs) can be used for monitoring the railway infrastructure such as bridges, rail tracks, track beds, and track equipment along with vehicle health monitoring such as chassis, bogies, wheels, and wagons

Developing innovative specific failure mechanisms and fault detection methods for selected components based on a prioritization of their relevance for PREDICTIVE MAINTENANCE-PdM;

- **These will be integrated with improved maintenance rules, limits and procedures, resulting in an integrated predictive maintenance procedure.**
- **A tool for maintenance policy optimization, able to use health monitoring information to define an optimal maintenance policy**



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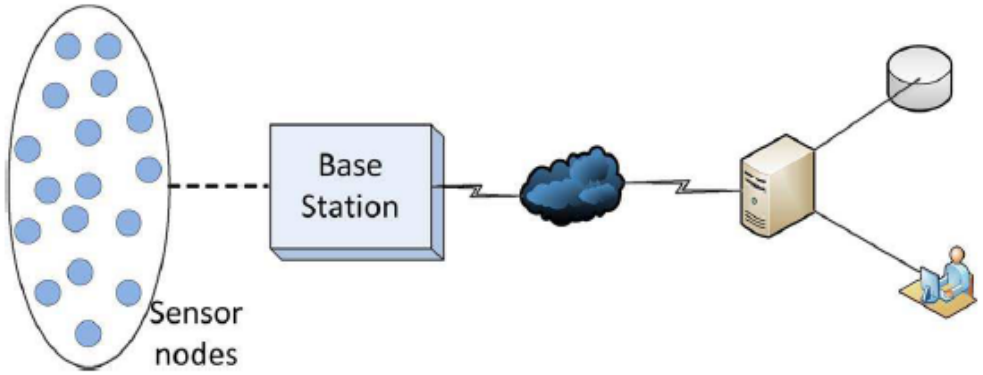

Fig. 4. In a typical WSN, the sensor nodes are arranged in a star, tree, or mesh topology and transmit data to the base station, which relays the data to the control center via longer range communications.

- **In recent years, the range of sensing technologies has expanded rapidly, whereas sensor devices have become cheaper.**
- **This has led to a rapid expansion in condition monitoring of systems, structures, vehicles, and machinery using sensors.**
- **Key factors are the recent advances in networking technologies such as wireless communication and mobile *ad hoc* networking coupled with the technology to integrate devices.**
- **Wireless sensor networks (WSNs) can be used for monitoring the railway infrastructure such as bridges, rail tracks, track beds, and track equipment along with vehicle health monitoring such as chassis, bogies, wheels, and wagons**

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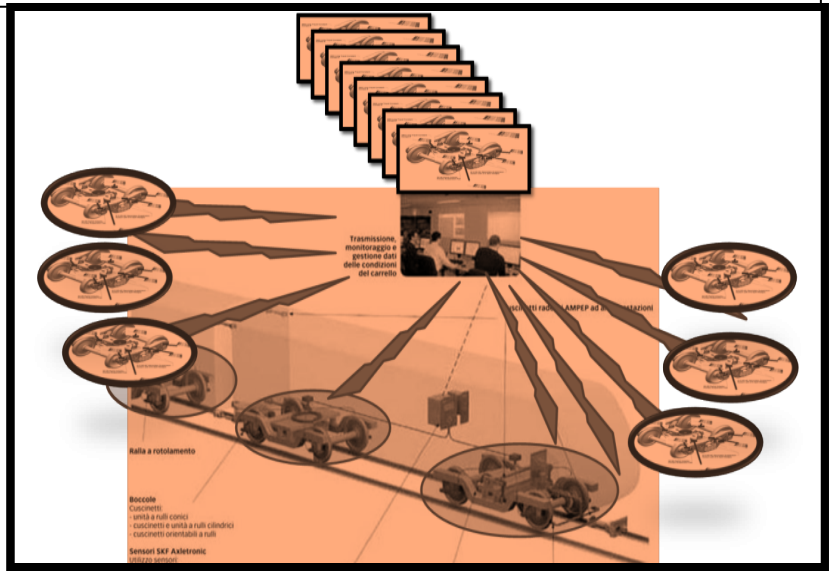
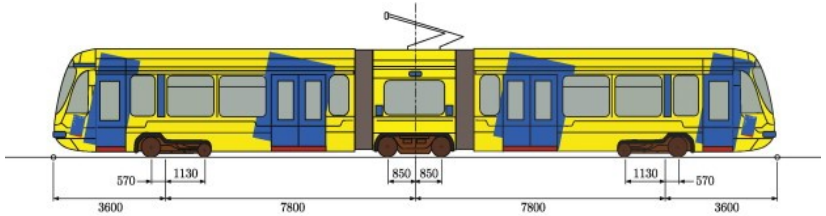
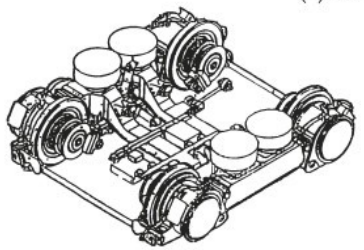
- The main purpose of monitoring RAIL structures is to support regular visual examinations or inspections based on non-destructive testing techniques.
- INTELLIGENT Sensor networks can be used to monitor a certain region of a structure providing data about different physical measures.
- Some properties to be measured in-situ are the Eigenvibrations of the structure, humidity and temperature outside and inside the structure, unusual stress and strain, and the detection of cracks and other deteriorations.
- Continuous or Periodic structural health monitoring provides data from the inside of a structure to better understand its structural performance and to predict its durability and remaining lifetime.
- There are a significant number of factors that influence structure fatigue life including loading, corrosion and temperature cycling.

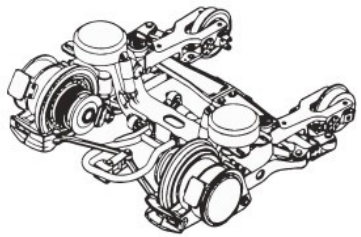




(a) Main dimensions



(b) Central bogie BR4×4



(c) Leading bogie BA2000

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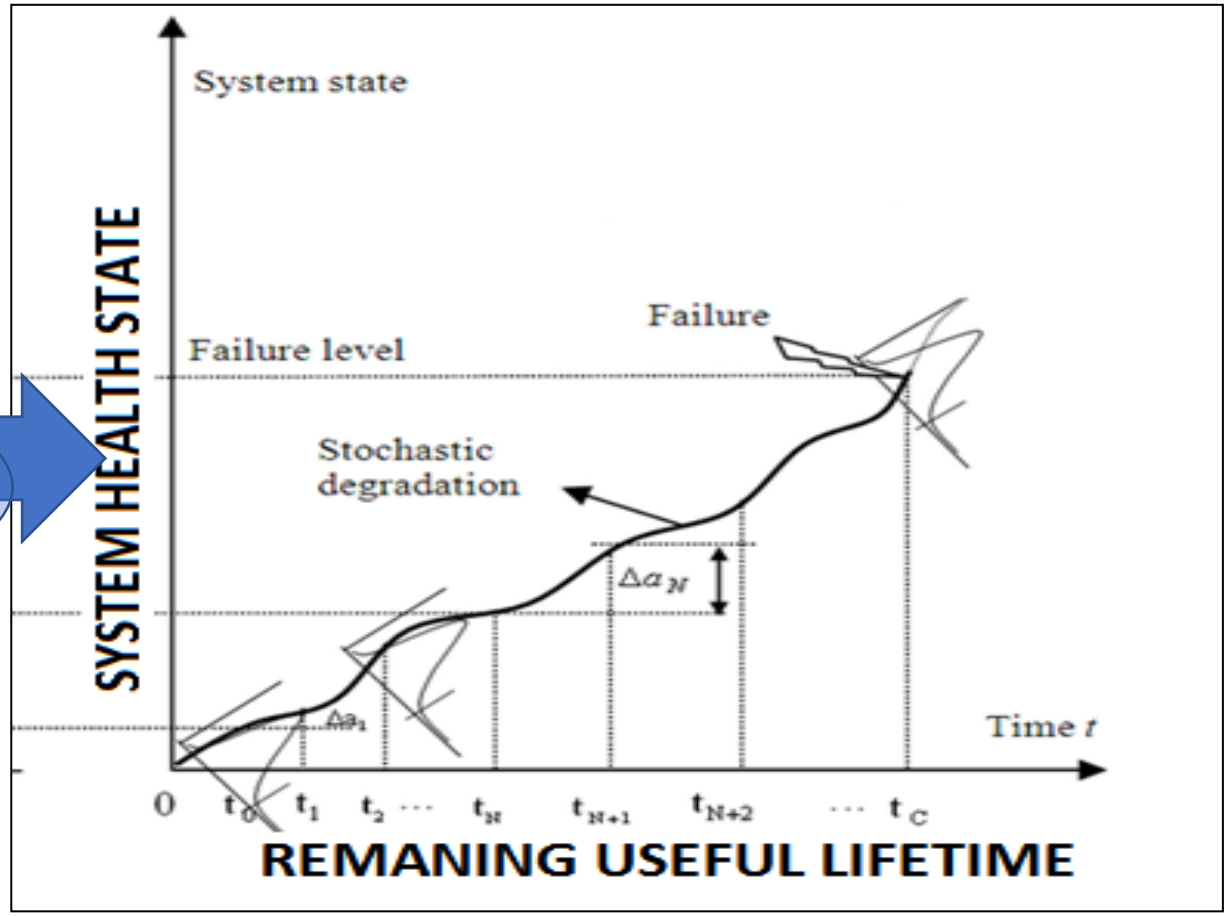
- **Artificial intelligence models can identify anomalous behavior, the information derived from the equipment sensors can be turned into meaningful and actionable insights for proactive maintenance of assets, further preventing incidents that result in asset downtime or accidents.**
- **Commonly known as predictive maintenance, this added intelligence enables organizations to forecast when or if functional equipment will fail so that its maintenance and repair can be scheduled before the failure occurs.**
- **Failure prediction, fault diagnosis, failure-type classification and recommendation of relevant maintenance actions are all a part of predictive maintenance methodology.**

NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT SYSTEM TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

- The area of predictive maintenance is, like machine learning in general, an inherently sensor based data-driven science.
- Because the nature and implementation of a predictive maintenance scheme is in a physical system, creating a l of degradation system model and fault diagnostics require that enough data about the system is available.
- Additionally, this data needs to be relevant to the intended usage of it. As such, not only the quantity of the underlying data is of importance, but also the quality of it.



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- **Considering the aggressive time-to-market required for aerospace products and services, identifying causes of potential faults allows companies to deploy maintenance services more effectively, improving equipment up-time.**
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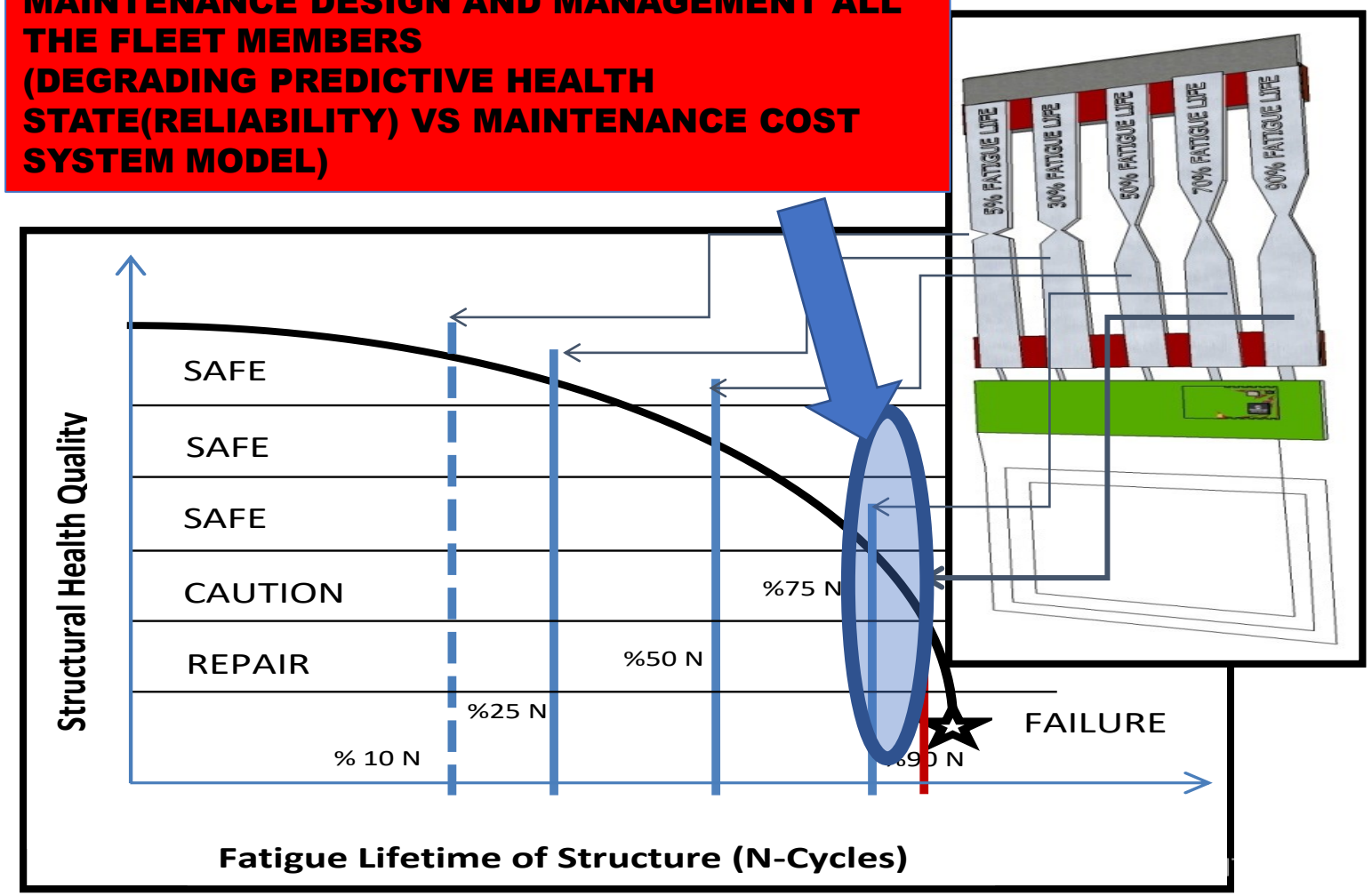
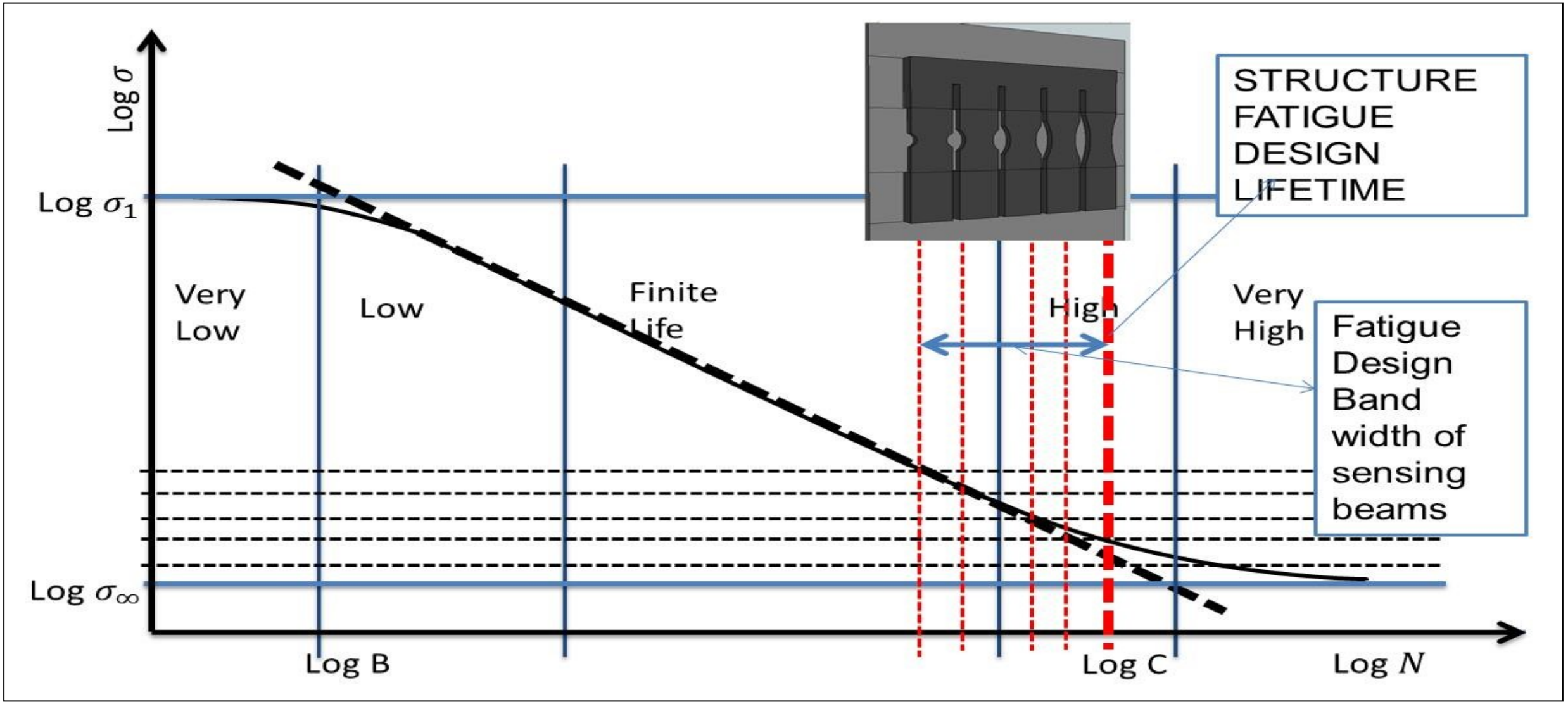
Wireless Enabled RFID-IoT SMART (FATIGUE) SENSOR

CRITICAL DATA FIELD USED FOR AI AND MACHINE LEARNING TO SMART PREDICTIVE MAINTENANCE DESIGN AND MANAGEMENT ALL THE FLEET MEMBERS (DEGRADING PREDICTIVE HEALTH STATE(RELIABILITY) VS MAINTENANCE COST SYSTEM MODEL)



- **The required maintenance decisions and the health state of critical parts of structures are given according to the RFID Fatigue Sensor Network data.**
- **The RFID Fatigue Sensor network information is mandating, the time of the fatigue damaged parts or locations should be repaired or replaced.**

Wireless Enabled RFID-IoT SMART (FATIGUE) SENSOR



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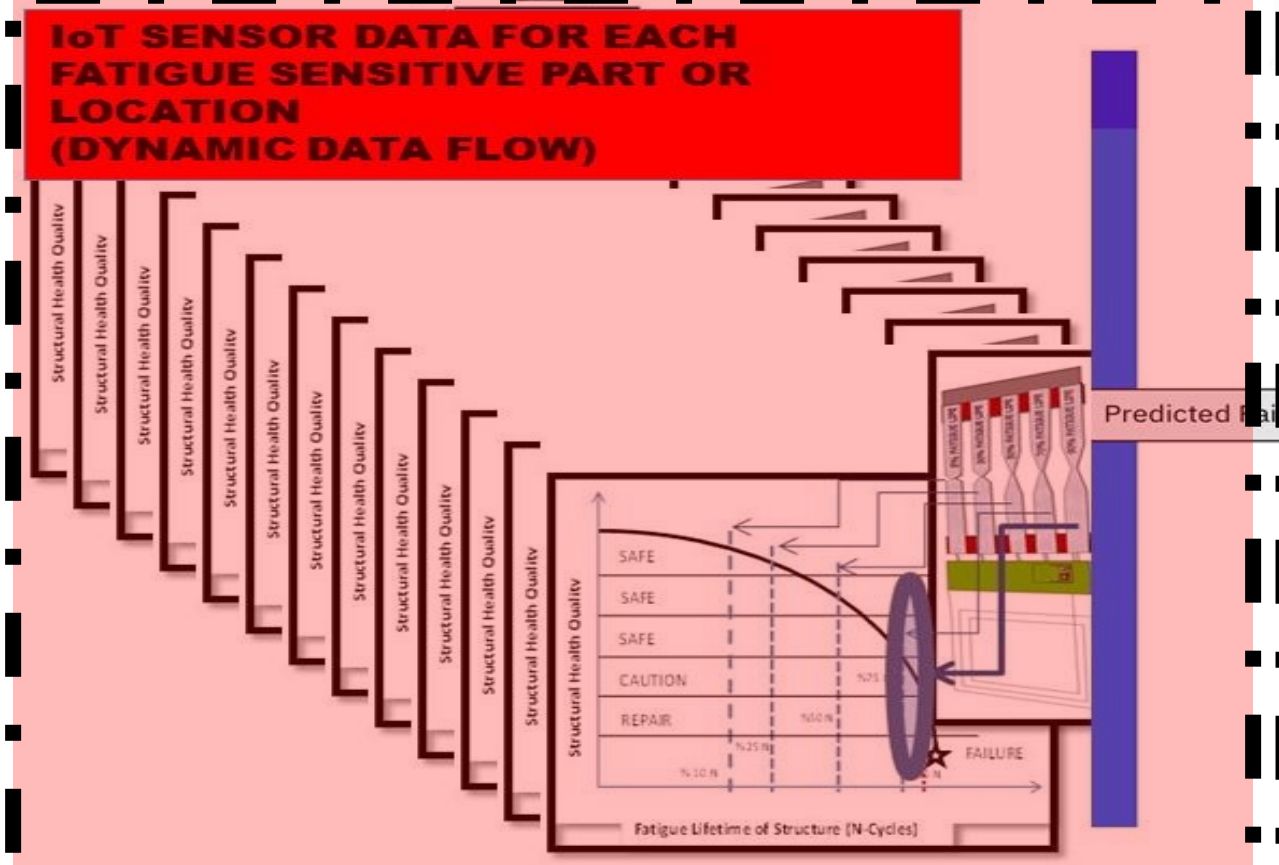
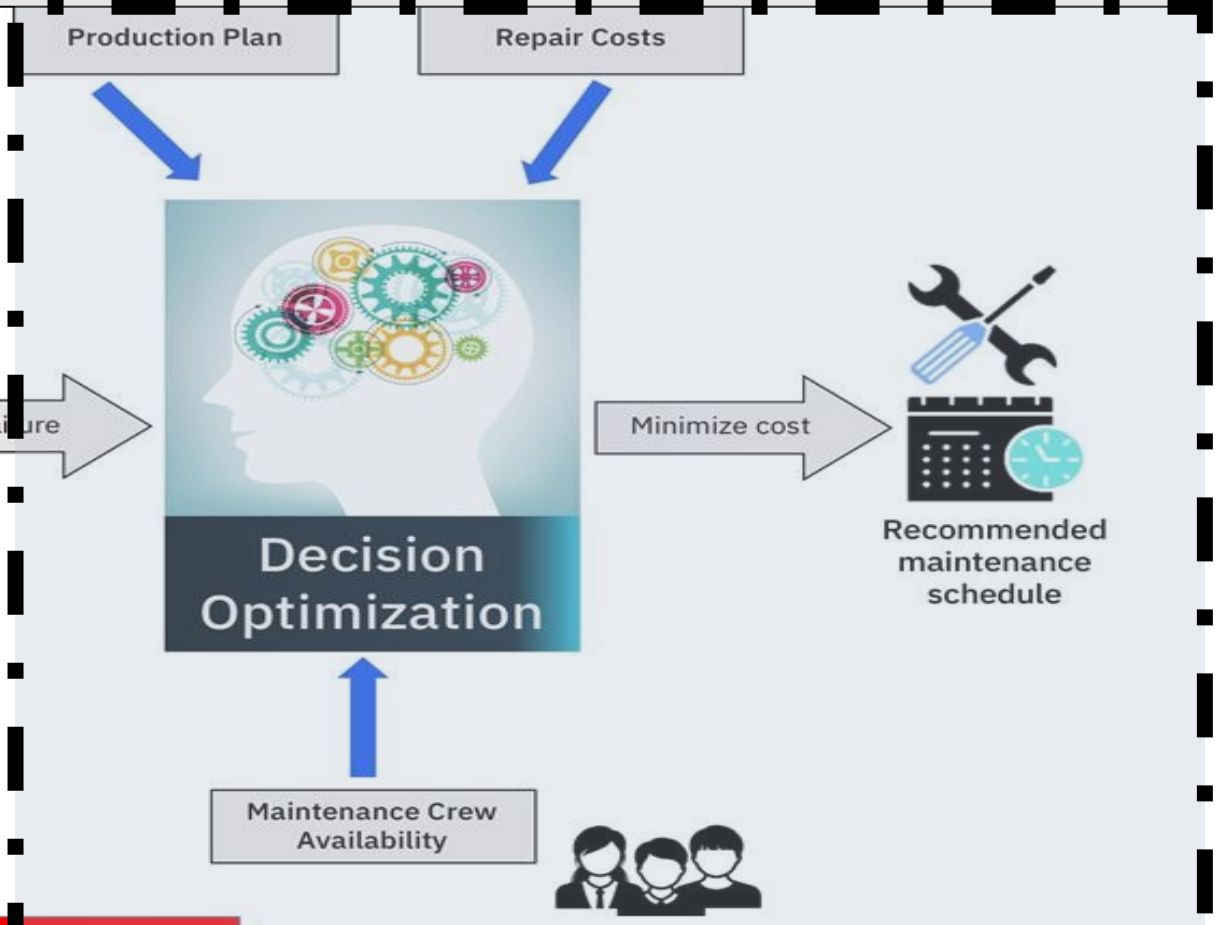
IoT SENSOR DATA FOR EACH FATIGUE SENSITIVE PART OR LOCATION (DYNAMIC DATA FLOW)



Predicted Failure



CRITICAL SENSOR DATA FIELD USED FOR AI AND MACHINE LEARNING TO SMART PREDICTIVE MAINTENANCE DESIGN AND MANAGEMENT ALL THE FLEET MEMBERS (DEGRADING PREDICTIVE HEALTH STATE(RELIABILITY) VS MAINTENANCE COST SYSTEM MODEL)

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Wireless Enabled SHM-RFID-IoT Smart Sensor Network OUTCOMES:

- Reliability-driven analysis of existing data, structural health monitoring of railway wheelsets
- Cost-driven and reliability-driven analysis of existing data, SHM of wheelsets and suspension components, integration of monitoring and models in predictive maintenance
- Reliability-driven analysis of existing data, models for wheel wear, support to the implementation of PM policies
- Cost-driven and reliability-driven analysis of existing data SHM for wheels, model of roller bearing damage, support to the implementation of PM policies
- Reliability-driven analysis of condition monitoring data, SHM of roller bearings and other critical parts including FATIGUE DAMAGE
- Provision of historical data and data for LCC evaluation
- Compliance of PM policies with the existing regulation

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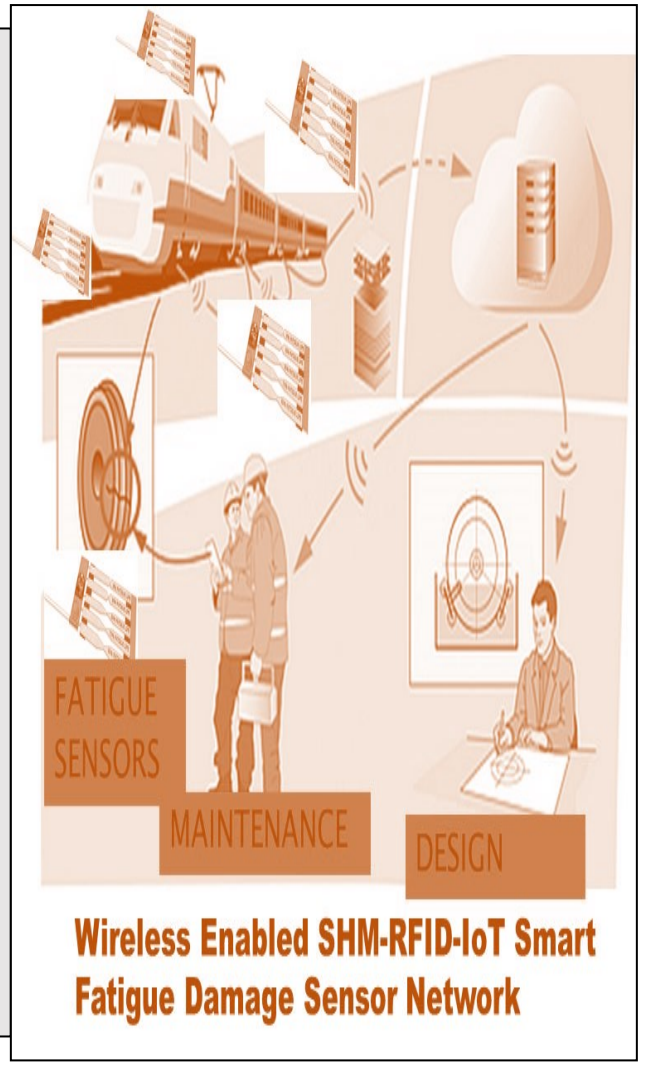
INTELLIGENT Condition monitoring systems for railways

Our Solution's focus on productivity improvement, products include:

- **A predictive system for condition-based maintenance planning based on the early-detection and warning of potential equipment failures depending on FATIGUE AND OTHERS**
- **Effective implementation and management of PARTS and THE SYSTEM condition monitoring.**
- **A fully configurable management system that acquires, manages and classifies data alerts from subsystems across multiple fleets**
- **Business-driven data management solutions. In-depth knowledge of business and industry is required to understand the management of data and information with regards to a company's core business purpose.**
- **These Solutions has the capacity to offer total control of business, based on complex assets and combining in-house expertise in the railway industry with big data techniques and business intelligence.**



Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network

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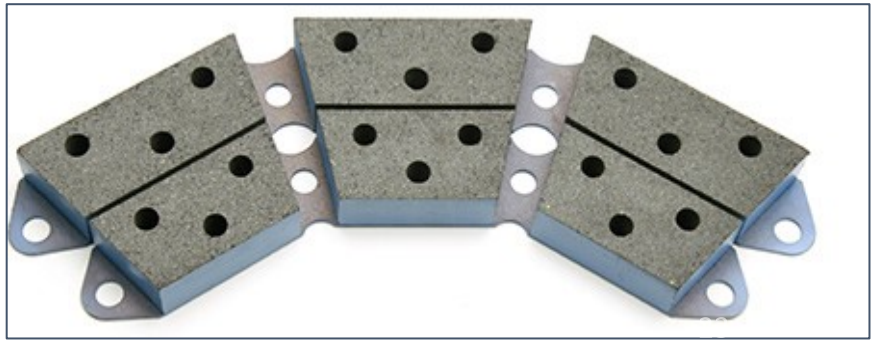
- **The economic savings** enabled by PdM are mainly in terms of **reducing the downtime** of the wagon and the related opportunity costs
- Based on the results of the reliability-driven analysis, important benefits can be expected by the implementation of monitoring and PdM in terms of **increased reliability and safety.**
- **The effectiveness of the predictive maintenance policy** will be assessed on a life cycle cost (LCC) basis. This will allow the selection of the most **suitable maintenance strategy that will optimize the overall cost of component** during its whole life.
- A Decision Support System (DSS) that enables maintenance operators to take decisions about the most adequate maintenance policy considering historical data and real-time (or close-to-real) health data of the component



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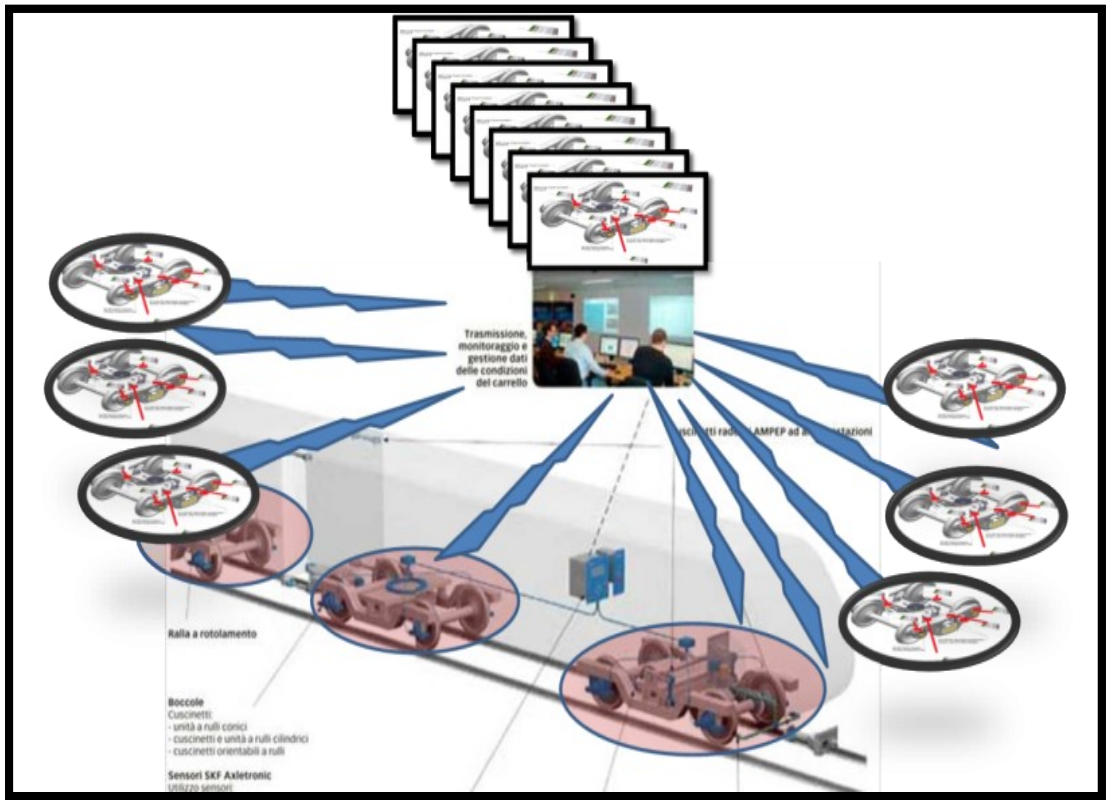
HARWARE AND SOFTWARE Products related to INTELLIGENT Solution's business management capabilities include:

- **A flexible computerised maintenance management system specifically designed for the railway industry, where the key information is properly handled to generate valuable knowledge and to make decisions aimed at optimizing your business**
- **One single place for interacting with all the key information from resource planning software, and any other data source needed for business-driven data management**



WIRELESS INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS NETWORK

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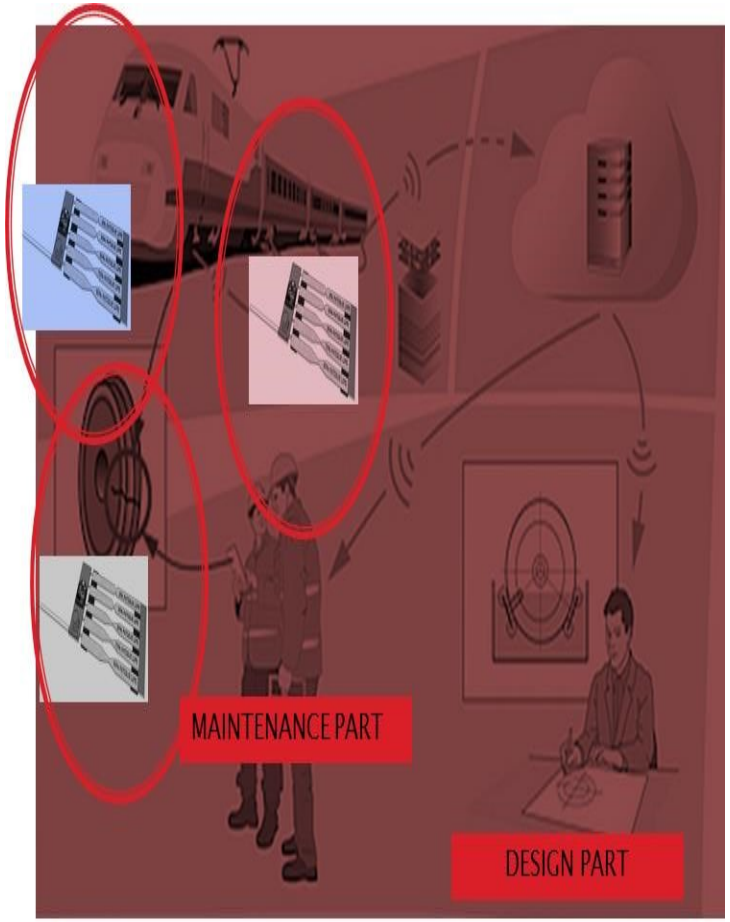
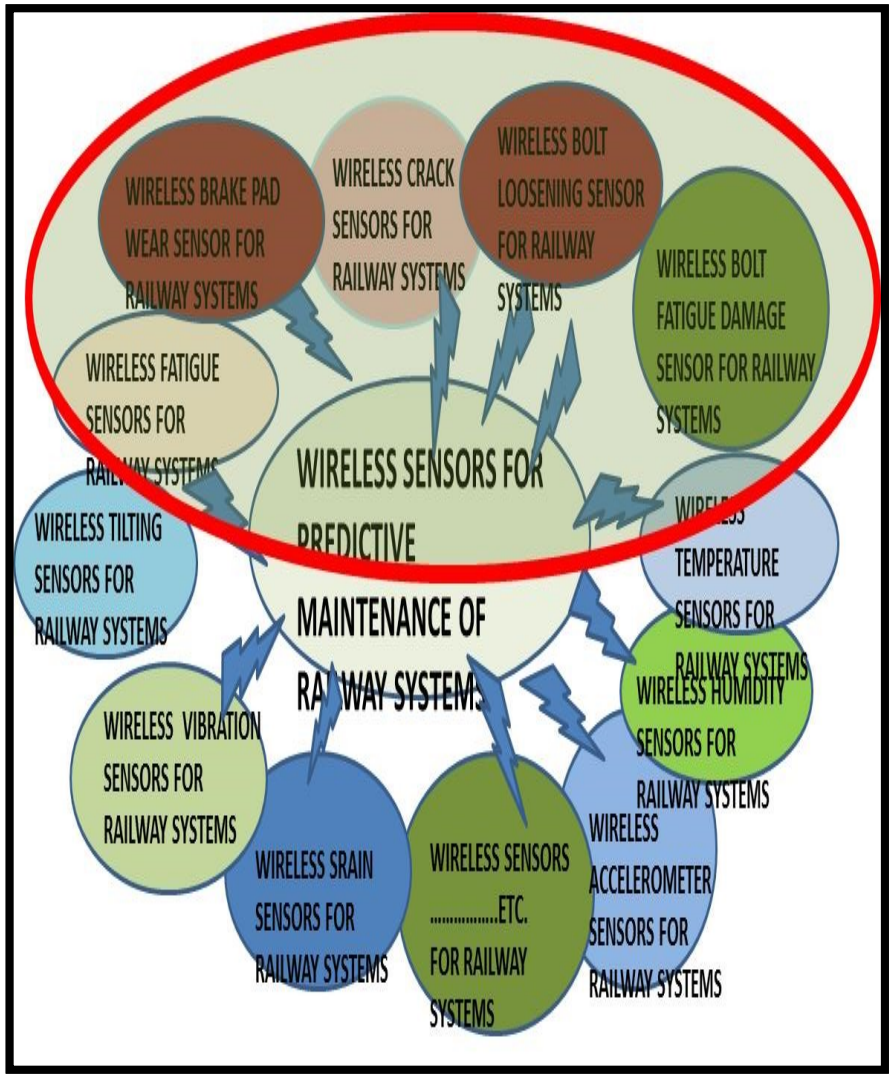
- **Condition monitoring reduces human inspection requirements through automated monitoring, reduces maintenance through detecting faults before they escalate, and improves safety and reliability. This is vital for the development, upgrading, and expansion of railway networks.**
- **Wireless sensor networks (WSNs) are very important for Asset management, condition monitoring, decision support systems, event detection, maintenance engineering, preventive maintenance, railway engineering.**
- **The wireless sensors network technology for monitoring in the railway industry for analyzing systems, structures, vehicles, and machinery.**
- **The practical engineering solutions, principally, which smart sensor devices are used and what they are used for; and the identification of sensor configurations and network topologies. It identifies their respective motivations and distinguishes their advantages and disadvantages in a comparative review.**



Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

- **The main objectives of the sensor network** are to eliminate uncertainties for operations and maintenance (O&M) productivity improvements, and **to anticipate and avoid failure** through knowledge extraction and behavior prediction.
- The principal process of the sensor network system is to create behavioural patterns of asset normality using historical data and the automated generation of behavioural models.
- **Deviations from normality** are then monitored and processed in periodic or real-time continous, with warnings and alerts provided.
- Diagnostic methods used include analysis of FATIGUE, CRACK, WEAR, BOLT LOOSE, BOLT FATIGUE, GEARS FATIGUE, vibrations, temperatures, pressures, tilting, noise, electrical parameters, oil sample analysis, intensities, and other measurable physical attributes.

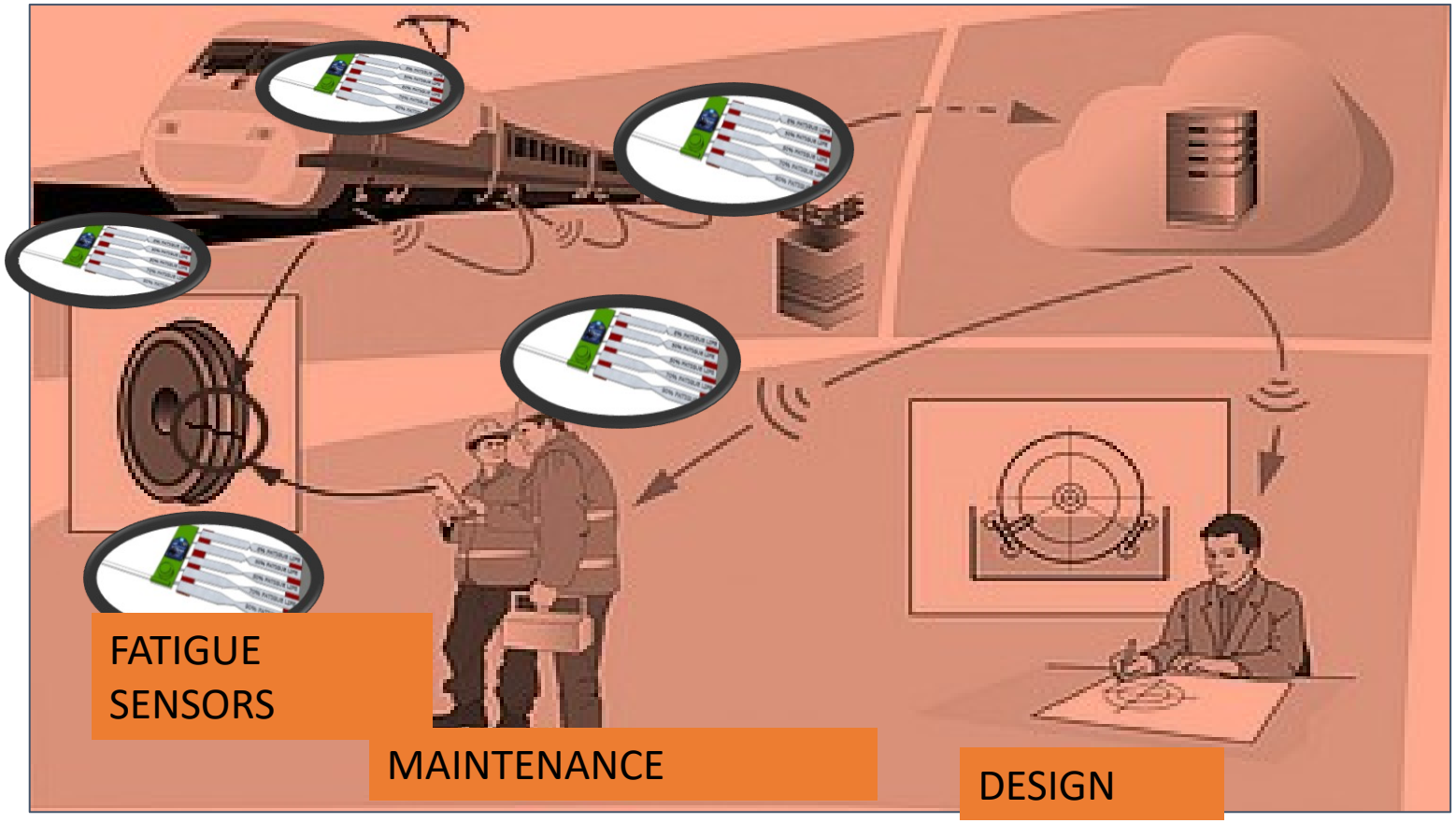


Wireless Enabled SHM-RFID-IoT Smart Sensor Network (RFID SENSOR TECHNOLOGIES)

An INTELLIGENT predictive maintenance strategy for the intelligent wagons
Development of an integrated predictive maintenance approach using both condition monitoring and historical data, and further support the implementation of predictive models and tools in rolling stock maintenance programmes:

- **Identify methods for the predictive maintenance of freight wagons in order to increase substantially the performance and cost effectiveness of rail transport;**
- **Define a prioritization of RAIL vehicle components and sub-systems in terms of their relevance for predictive maintenance;**
- **Investigate failure mechanisms and fault detection methods for the selected vehicle components and sub-systems highly significant to the whole vehicle's LCC and reliability;**
- **Select the available condition monitoring and failure history data for selected critical wagon components and sub-systems, and develop predictive models and detect trends in the monitored condition towards a failure state with a time-to-failure prediction;**
- **Develop guidelines for maintenance procedures to implement predictive maintenance practices for the cases studied**
- **Perform an assessment of the benefits provided by the developed predictive maintenance strategies.**

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS



WIRELESS INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS NETWORK

STRUCTURAL FATIGUE DAMAGE MONITORING, MAINTENANCE AND DESIGN of different components of RAIL SYSTEMS

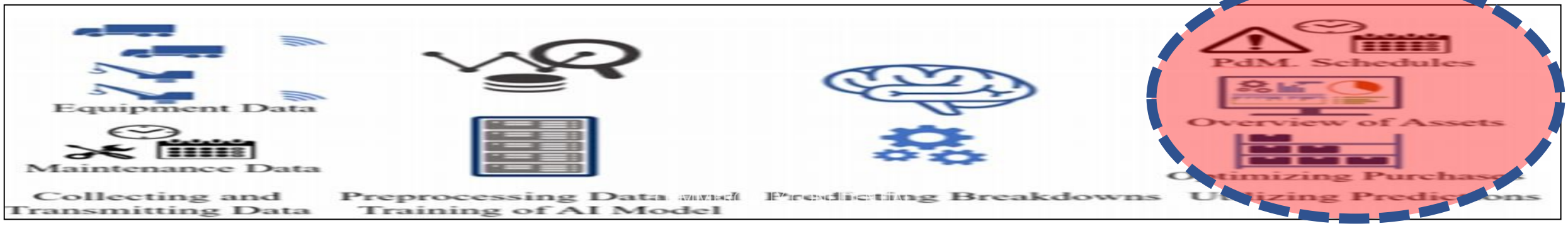
- **bogies,**
- **car body frames**
- **fatigue specific-sensitive bolts,**
- **gearboxes,**
- **shafts,**
- **break pads wear etc.**

during normal operation conditions.

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

SOFTWARE FOR INTELLIGENT MAINTENANCE MANAGEMENT FOR STRUCTURAL HEALTH MONITORING OF A UNIT AND A FLEET

- The required maintenance decisions and the health state of critical parts of structures are given according to the RFID Sensor Network data. The RFID Sensor network information is mandating, the time of the fatigue damaged parts or locations should be repaired or replaced.
- Therefore, the proposed RFID Sensor based Intelligent Predictive-Condition Based Maintenance Model is very efficient and effective strategic system since it increases service life and reliability and reduces maintenance and operations expenses.
- The proposed RFID Sensor Based Structural Health Monitoring and Maintenance Strategy are based on the periodic or real-time sensor information to optimize maintenance resources.



TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS (IoT INTELLIGENT FATIGUE DAMAGE SENSOR APPLICATIONS)

A Novel Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network (INTRODUCTION)

- **Fatigue plays a critical role for design of structures or critical mechanical systems under cyclic dynamic loads. Several fatigue design methodology are used for fatigue design of mechanical components or structures. All these techniques are relied on STOCHASTIC MEDHODOLOGIES.**
- **Any failure in one of the structural members of the system causes catastrophic failure with serious consequences costing lives and property. It is foreseen that the proposed RFID-IoT Smart Fatigue Sensor will revolutionize the concept of fatigue design and also will revolutionize the fatigue inspection and maintenance management methodologies by using the RFID-IoT Smart Fatigue Sensor Network Data.**
- **Since the distributed fatigue sensor network system periodically or continuously is monitoring the fatigue health state conditions of structures, the database of the sensor network system will be used for condition based inspection, sensor based maintenance management and development of new fatigue design tools for fatigue sensitive complex and large engineering structures or mechanic systems.**
- **Health status of structural members which undergo cyclic stress need to be monitored continuously and fatigued parts need to be replaced well before the failure limit is reached. Railway Systems, Aircrafts, Helicopters, Wind Turbines, Mega Cranes, Highway Bridges and Marine Vessels are especially considered as systems vulnerable to this sort of fatigue damage accumulation.**

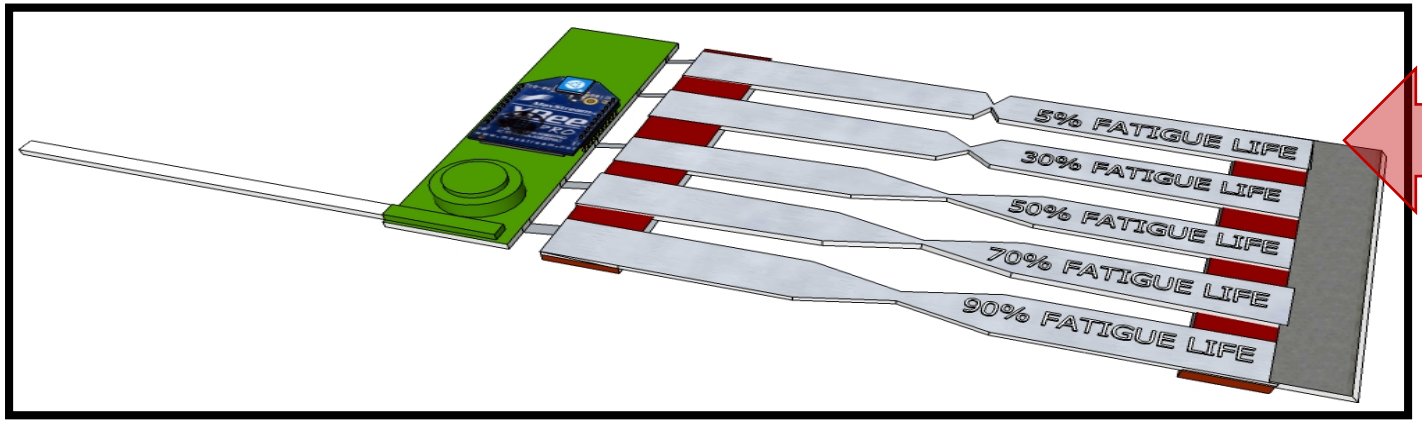
TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

(IoT PREDICTIVE INTELLIGENT FATIGUE SENSOR)

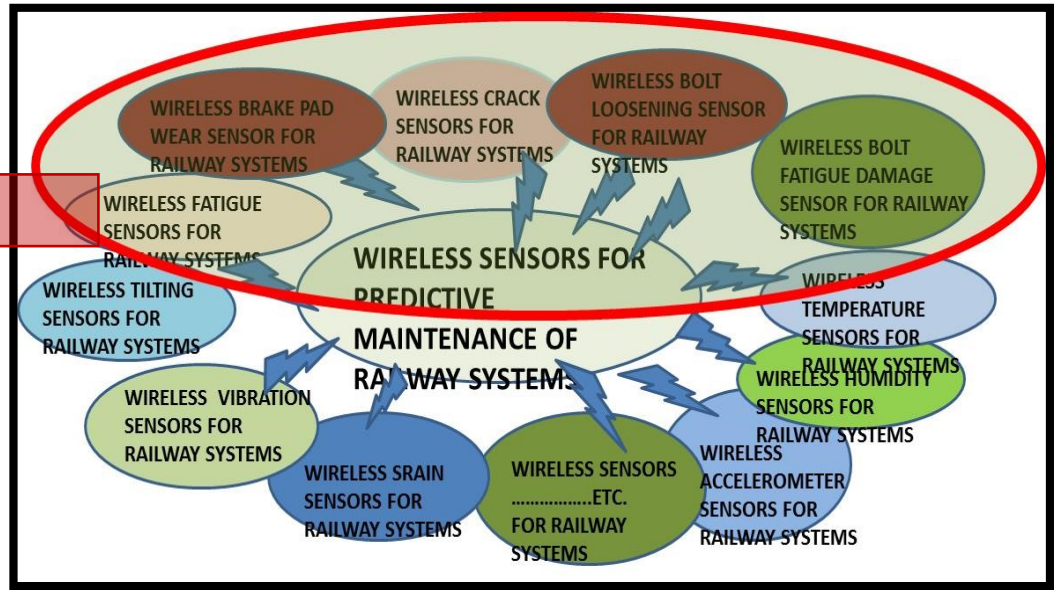
- **A Novel Smart RFID Fatigue Damage Sensor aiming to the prediction of fatigue residual strength of critical mechanical and structural components for Structural Health Monitoring has been DEVELOPED and PATENTED (PATENT N0. US 8,746,077 B2).**
- **The proposed smart sensor system is designed for early detection and estimation of the structural health cumulative fatigue damage level and wirelessly transferring the information using an active or passive RFID integrated system.**
- **The developed RFID fatigue sensor system has a specially designed geometry with multiple parallel oriented unidirectional, bidirectional or multi directional breakable C, U or V type notched beams having different fatigue lifetimes to predict not only unidirectional or bidirectional fatigue damage but also multidimensional cumulative fatigue damage level of structural or mechanical elements including composite structures.**
- **It is foreseen that the proposed RFID-IoT Smart Fatigue Sensor will revolutionize the concept of fatigue design and also will revolutionize the fatigue inspection and maintenance management methodologies by using the RFID-IoT Smart Fatigue Sensor Network Data.**

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

(FATIGUE DAMAGE SENSOR-INTELLIGENT THINGS PATENTED)



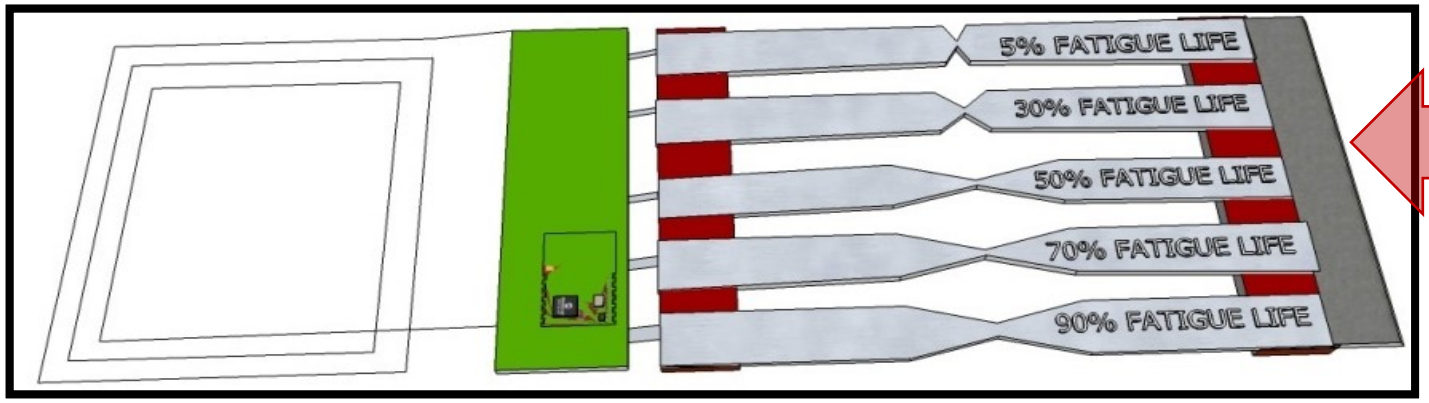
FATIGUE SENSOR (PATENT N0. US 8,746,077 B2)



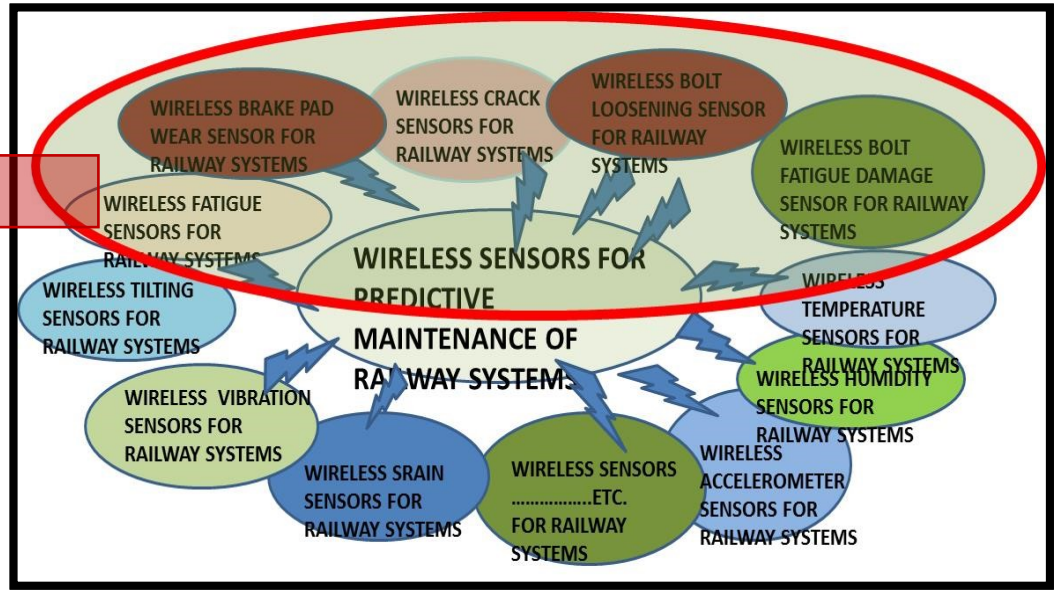
- **There are two versions of the fatigue sensor, one with a battery version and another one which works with RF power. The one with the battery uses Zigbee or similar low power sensor networking to interrogate the sensor about the state of breakable fingers.**
- **The sensor nodes relay information from one node to the other to communicate with the master node.**

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

(PASSIVE FATIGUE DAMAGE SENSOR-INTELLIGENT THINGS PATENTED)



FATIGUE SENSOR (PATENT N0. US 8,746,077 B2)



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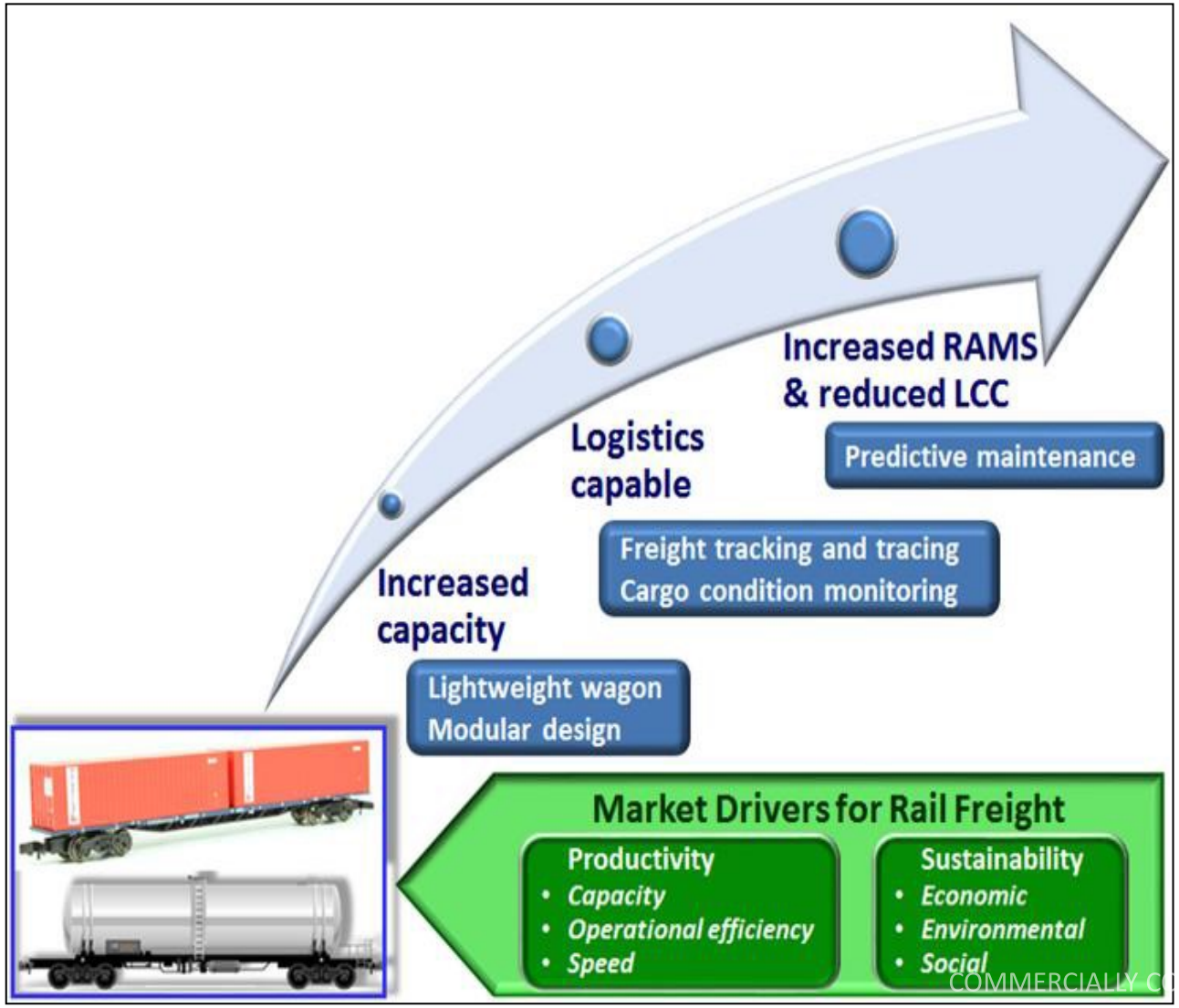
TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS



Increase railway systems capacity by optimizing and light-weighting the wagon design for increasing the ratio payload/wagon are;

- **Increase freight logistic capabilities by:**

i. offering real time data on freight location and condition through a smart self-powered sensor system and communication technologies;

ii. optimized wagon modular design capable to transport various types of goods; and

iii. improved availability to freight customers, enabled by a safer and more reliable and interoperable freight service;

- **By implementing intelligent innovative RFID-IoT INTELLIGENT SENSORS, predictive maintenance analytics, models, and procedures.**

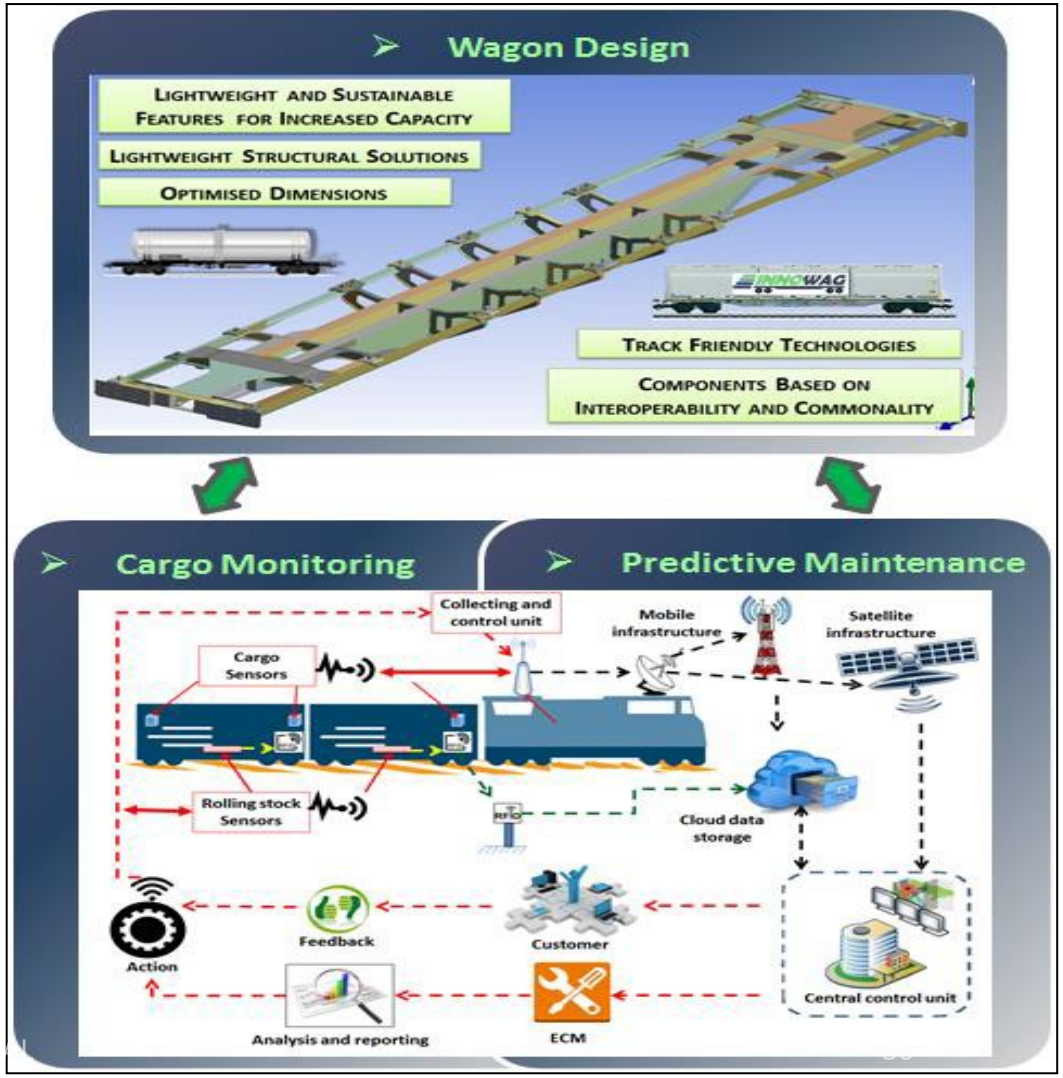
TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

Developing innovations in three macro-areas (intelligent wagon design, cargo condition monitoring, and intelligent predictive maintenance), from concept to laboratory and real environment testing, for further integration and implementation.

1. Intelligent Wagon design:
Integrated with intelligent sensors, novel concept of modular and lightweight wagon;

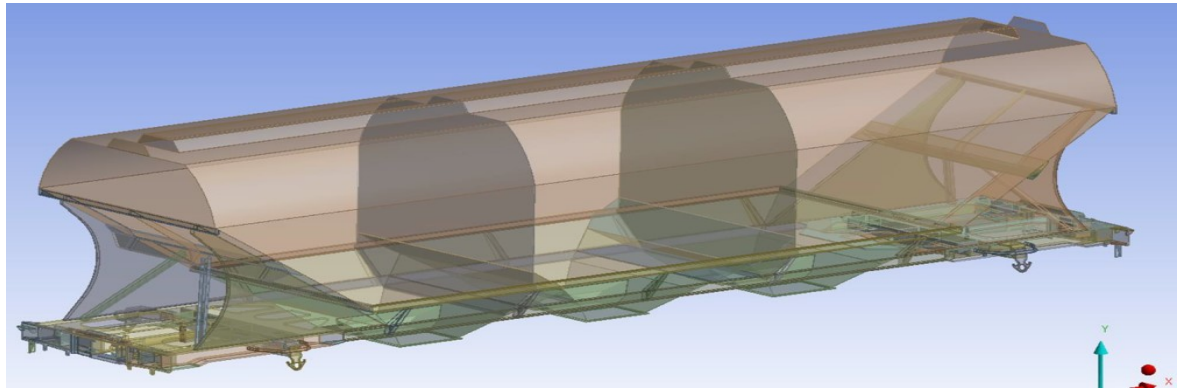
2.Cargo condition monitoring: autonomous self-powered sensor system for cargo tracing and condition monitoring;

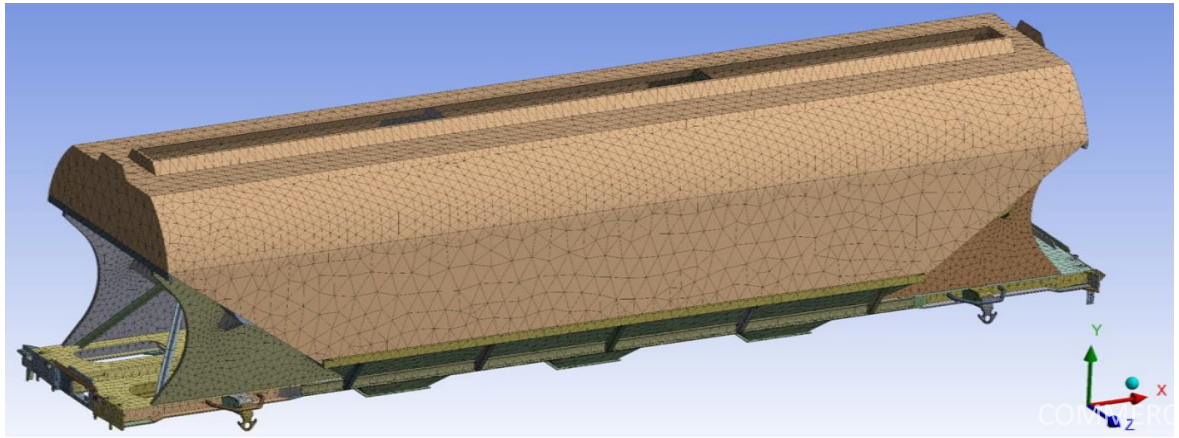
3.Intelligent Predictive maintenance: integrated approach (use of both remote condition monitoring and historical data) to support the implementation of predictive models and tools in rolling stock maintenance programms

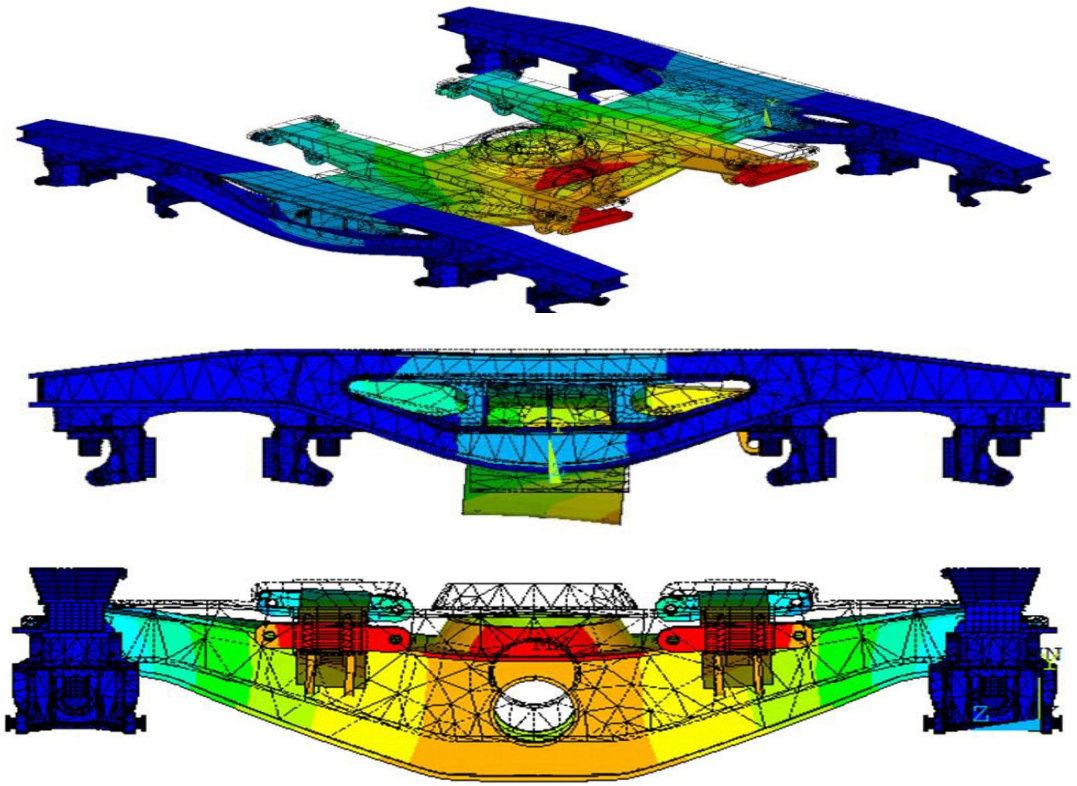


TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

- **INTELLIGENT Sensor networks can be used to monitor a certain preknown critical regions of a structure providing data about different physical measures.**







TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

Open box cars benefit from lower maintenance costs and a longer life when Advanced High Strength Steels are used in vital areas. An example is the use of Domex made by SSAB of Sweden (Figure 27).

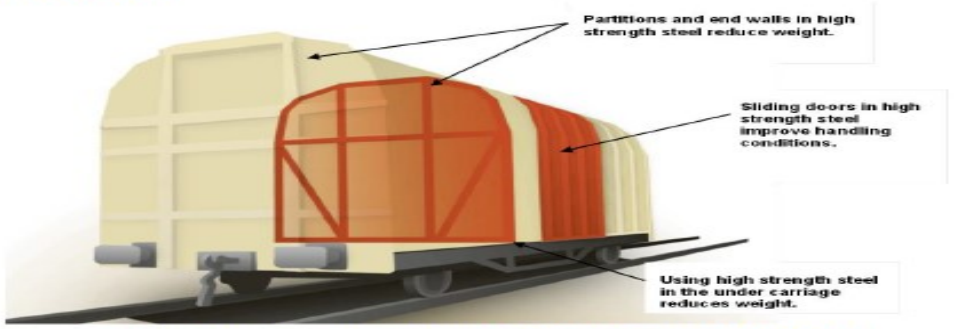


Figure 27 Domex – high tensile steel by SSAB of Sweden (SAAB, 2012)

Another relevant option is the use of ***High-Strength Low-Alloy steels (HSLA)***. A good example is offered by FreightRail, which used ultra-high strength steel (UHSS) to:

- Lighten the wagon weight
- Reduce maintenance costs of operators
- Contribute to sustainability

An E71-type gondola wagon with the initial structure made of S235JR, a structural steel with good corrosion resistance properties, was set as the benchmark. It had a tare weight of 27 tonnes and payload of 80 tonnes (Figure 28).

Figure 28 E71-type gondola wagon (ArcelorMittal, 2011)

The wagon was re-designed using HSLA steel with improved specifications, in two different feasible versions. The *outcomes* of the new designs:

Increase railway systems capacity by optimizing and light-weighting the wagon design for increasing the ratio payload/wagon are;

- **Increase freight logistic capabilities by:**

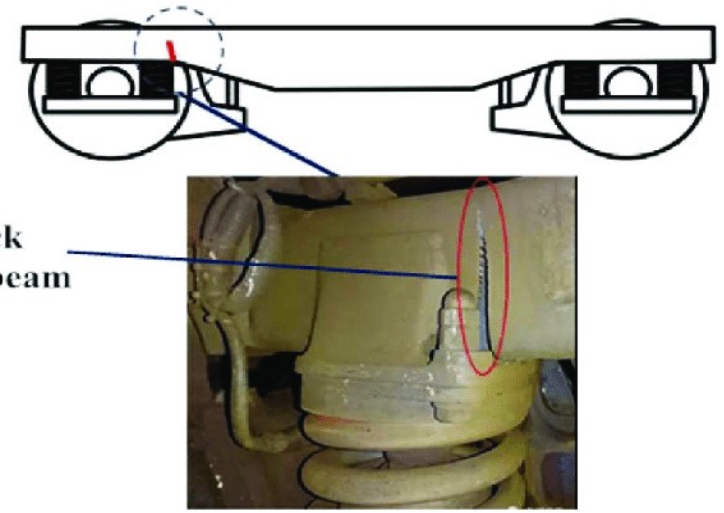
i. offering real time data on freight location and condition through a smart self-powered sensor system and communication technologies;

ii. optimized wagon modular design capable to transport various types of goods; and

iii. improved availability to freight customers, enabled by a safer and more reliable and interoperable freight service;

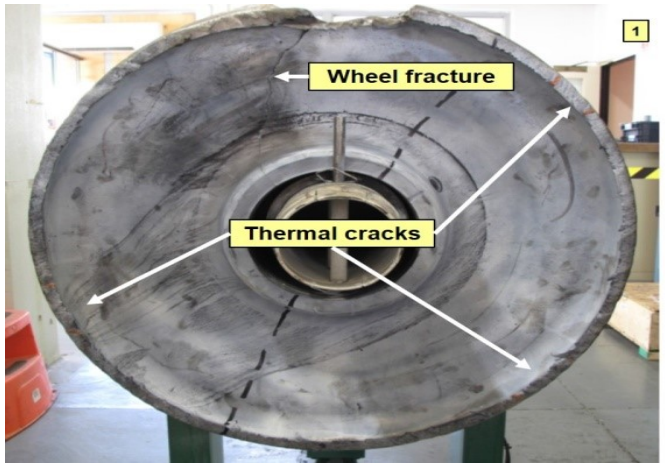
TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

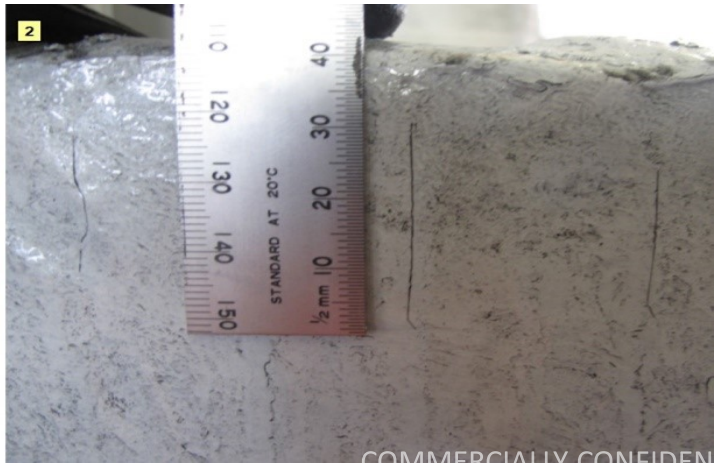
- **Fatigue characteristic is important not only to railway systems but also to many other machines and large sructures**
- **The fatigue strength reliability, one of the important study themes is the strength or fatigue characteristic of each railway system component that is subject to repeated loads during use.**
- **The reason why it is necessary to consider the fatigue characteristic carefully is that fatigue is a microscopic fracture caused by the initiation and propagation of a crack due to a cyclic slip deformation of the size of a single grain, that fatigue occurs even under a stress smaller than the strength characteristic under a static load (e.g., tensile strength), and that it can suddenly lead to a fatal fracture without causing any macroscopic plastic deformation.**

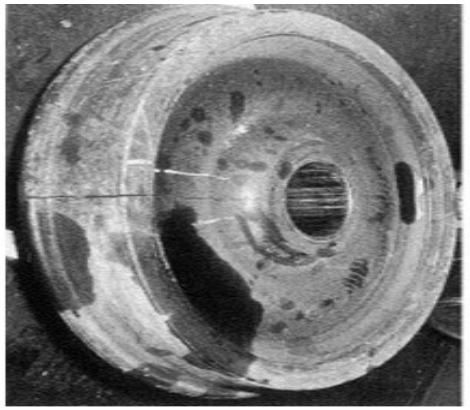


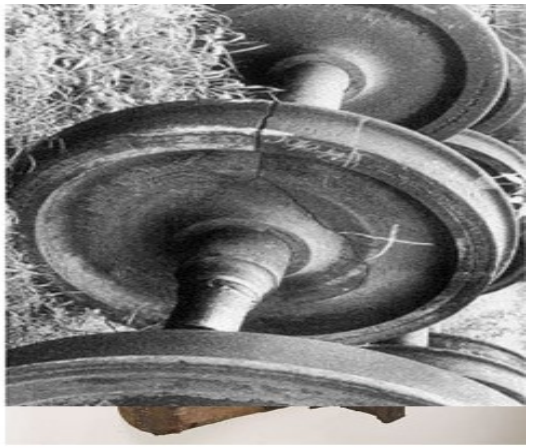
TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

- **WITH INTELLIGENT SENSOR SYSTEM, the availability of 'big sensor data' techniques provides smart solutions with the ability to extend wheel lifecycles in accordance with customer needs.**
- **This leads to more efficient and effective maintenance, as well as increased fleet availability for service operations.**
- **The wheel network system manages and integrates the information coming from wheel monitoring devices,**
- **WITH INTELLIGENT SENSOR SYSTEM, critical damage warning systems for consistency in operations and maintenance**



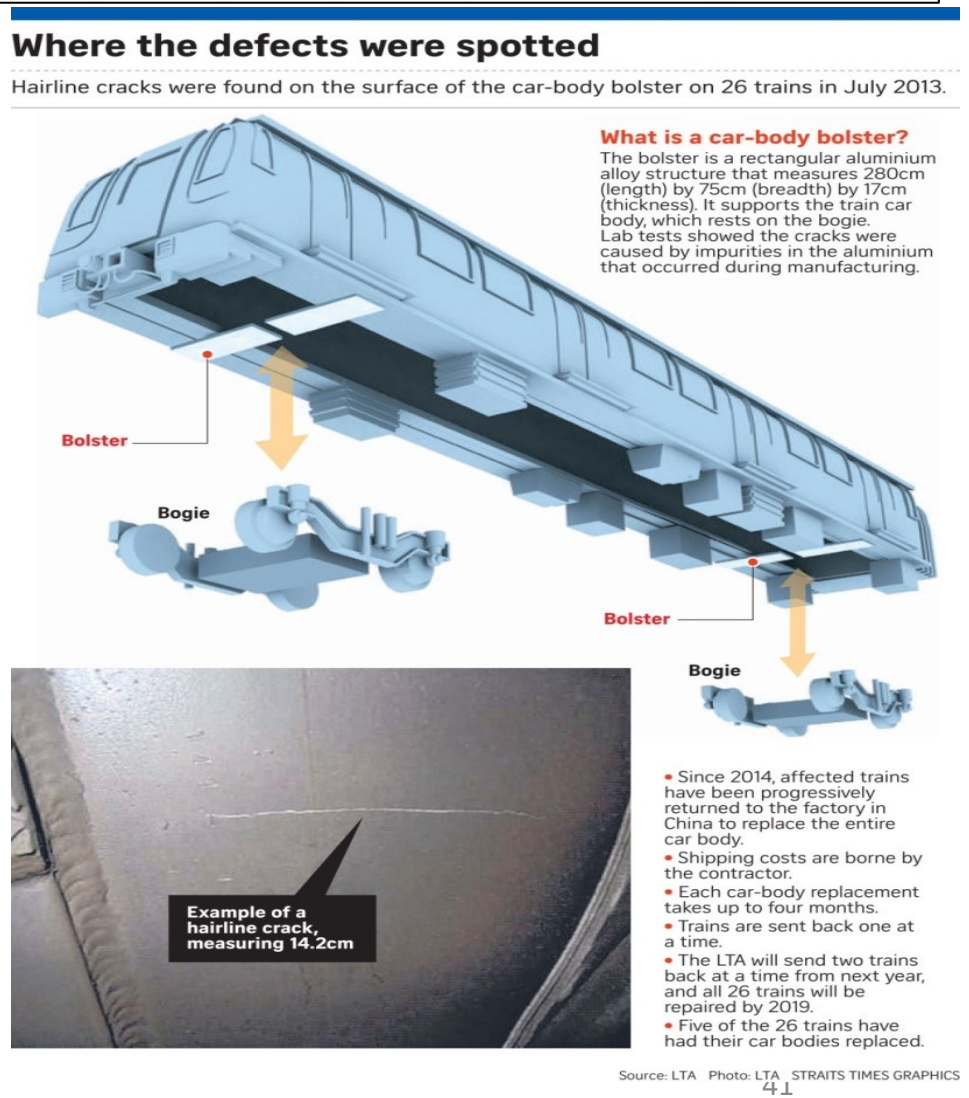






TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

- **The sensors to be placed on the wagon thanks to the wireless communication send back to the locomotive or the monitoring center and the maintenance center can get all necessary information for organizing a predictive maintenance reducing the number of very costly on-line incidents.**
- **All information on wagon and cargo status are forwarded to interested parties securing the reorganization of the supply chain in case of incidents.**
- **Such information are extremely useful coupled with an updated Information produced by the infrastructure manager in charge of the path reallocation.**



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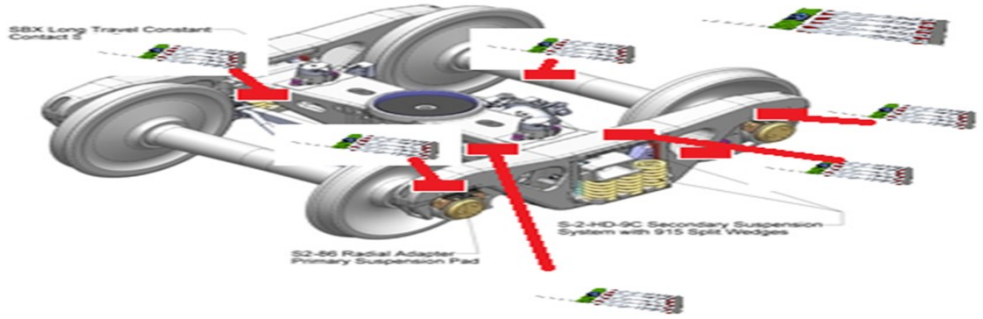
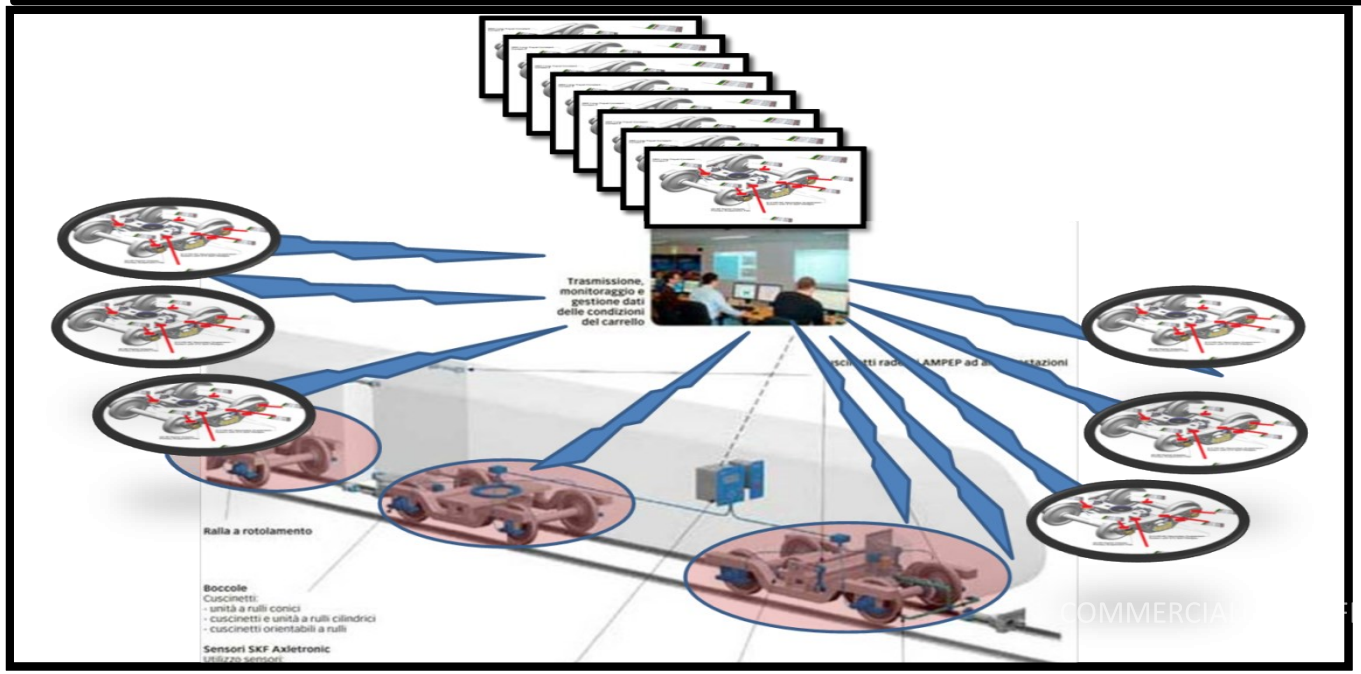


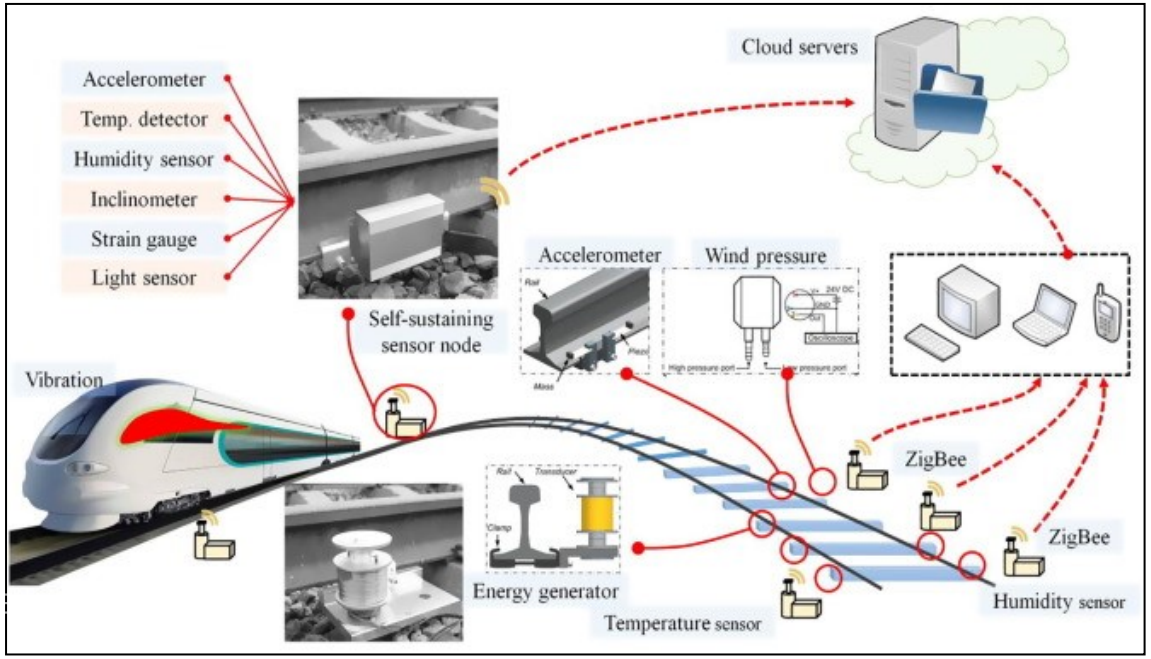
The Fatigue Critical HOT SPOTS in BOGIES and the applications of Smart fatigue damage sensors in order to monitor the RESIDUAL FATIGUE STRENGTH or Fatigue Lifetime.

IN RAILWAY STRUCTURES, Specific and Fatigue sensitive regions, locations under high loads, predetermined and formerly known-experienced spots.

- **DO MAINTENANCE BASED ON THE STATE OF THE STRUCTURE AS NEED ARISES**
- **INCREASES AVAILABILITY**
- **REDUCES MAINTENANCE COSTS**
- **INCREASES RELIABILITY**

Wireless Enabled INTELLIGENT Damage Sensor Network and Health Monitoring Center for BOGIES





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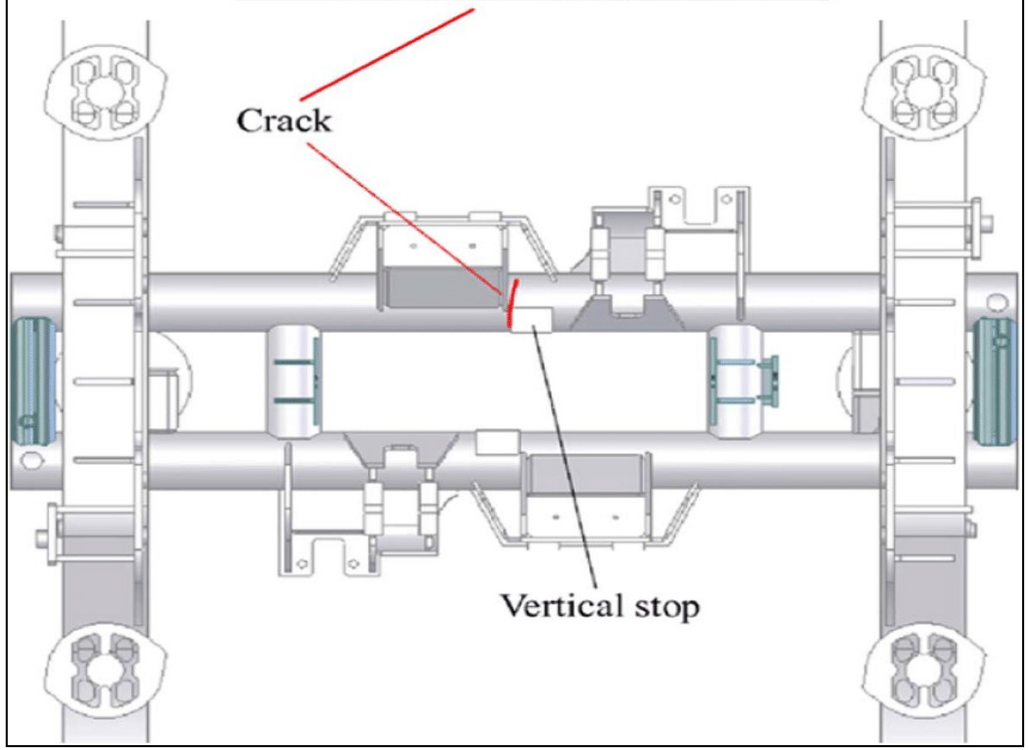
THE LIST OF RFID CHIPS STORED DATA INFORMATION OF EACH MAINTENENCE CRITICAL PART OF RAIL STRUCTURES

A) THE OPERATIONAL HISTORY OF EACH CRITICAL COMPONENT
B) THE MAINTENANCE OR FATIGUE MAINTENANCE HISTORY OF EACH COMPONENT
C) THE INFORMATION RELATED TO THE CONFIGURATION OF THE RAIL PART IN WHICH THE COMPONENT IS INSTALLED
D) THE DATE THE COMPONENT MANUFACTURED
E) THE NAME OF THE SUPPLIER OF THE COMPONENT
F) THE SERIAL NUMBER OF THE COMPONENT
G) THE PART NUMBER OF THE COMPONENT.
G) THE PART EXPECTED SCHEDULED REPAIR TIME
H) THE PART MATERIAL PROPERTIES
I) THE PART REDESIGNS NEEDS AND DESIGN MODIFICATION OR REVISION
K) THE PART CONNECTION PROPERTIES (RIVET, WELDED ETC...)
L) THE PART REPAIRED OR REPLACED
M) THE PART EXPECTED SERVICE LIFETIME
N) THE PART .....

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS



The fatigue strength reliability, one of the important study themes is the strength or fatigue characteristic of each railway system component that is subject to repeated cycling loads during use.

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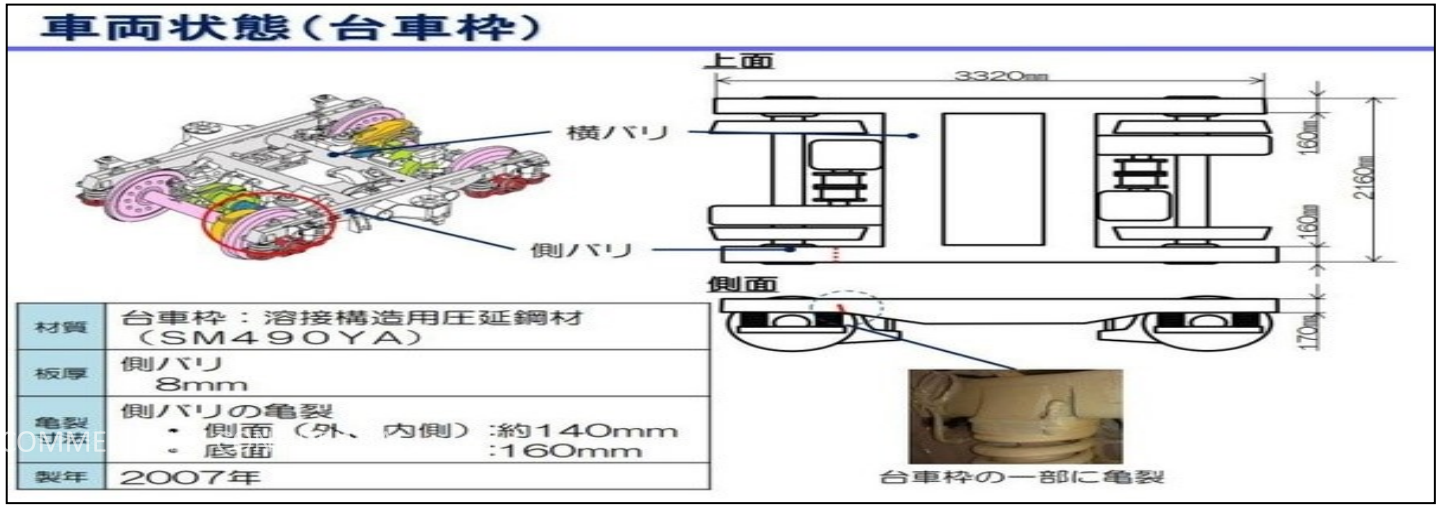
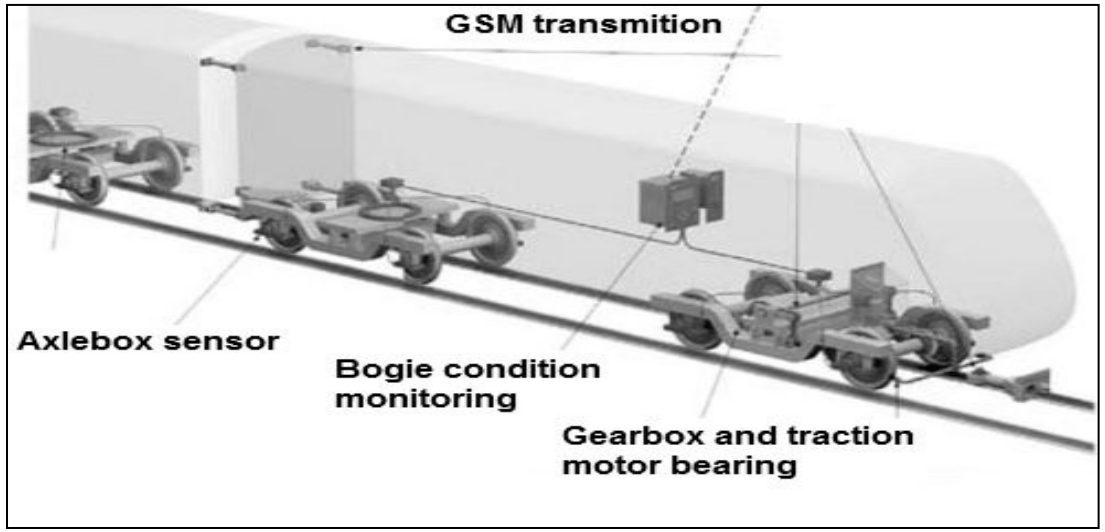
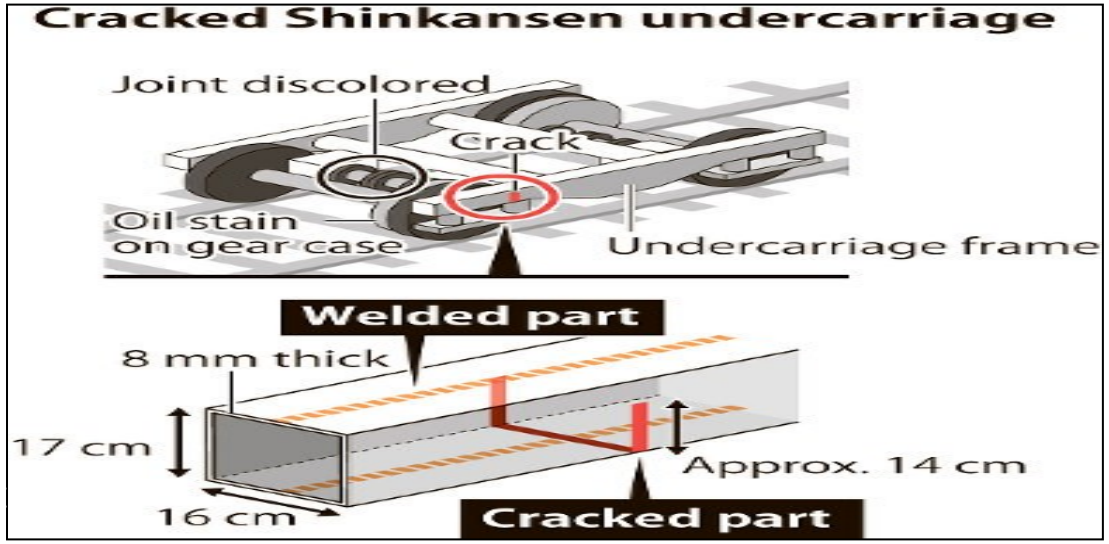


TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

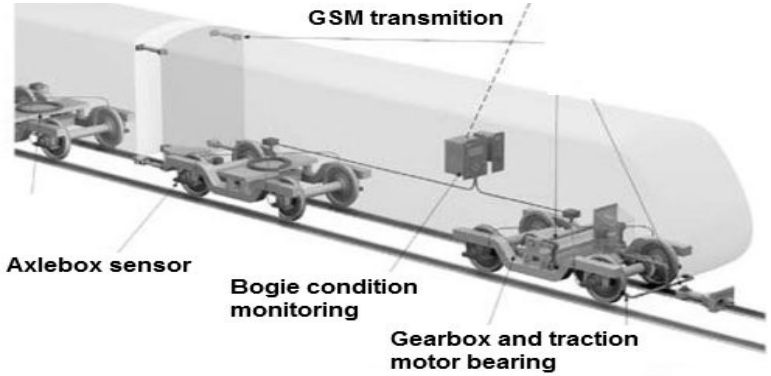
- **The starting point for car body fatigue analysis is the prediction of dynamic response of the car body structure, which is usually expressed as a stress or strain time history.**
- **A quasi-static stress analysis method is one of standard time domain approaches used to obtain the dynamic stress for fatigue life assessment.**
- **It is a linear elastic analysis that is associated with external load variations.**
- **The main idea behinds this method is that the external load history acting on the structure can be replaced by a static unit load acting on the same location in the same direction as the load history. The quasi-static stress analysis is then performed for each individual unit loads.**

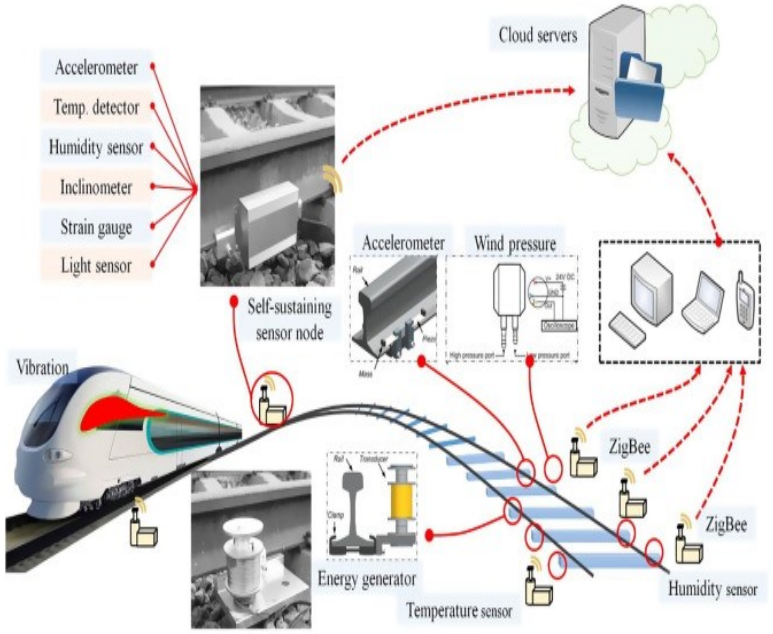




TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

- The developments in RAIL TECNOLOGIES are estimated at an industrial level to perform the cost benefit analysis. The impact on traction costs is assessed by the railway undertaking involved in the project and by the operator of a fleet of wagons for new car transport.
- This assessment enables to select the most efficient investments to reach a real step change in competitiveness, reliability and renewed attractiveness of rail freight transport.
- A specific attention is dedicated to the impact on a possible wagonload activity if the study on the couple of wagons logistics concludes positively.
- In order to monitor the future progress the economic analysis identifies significant characterizing fundamental factors like reliability, cost reduction and network capacity. For a global analysis these assessments integrate the progress made in terminals studied in other parts.

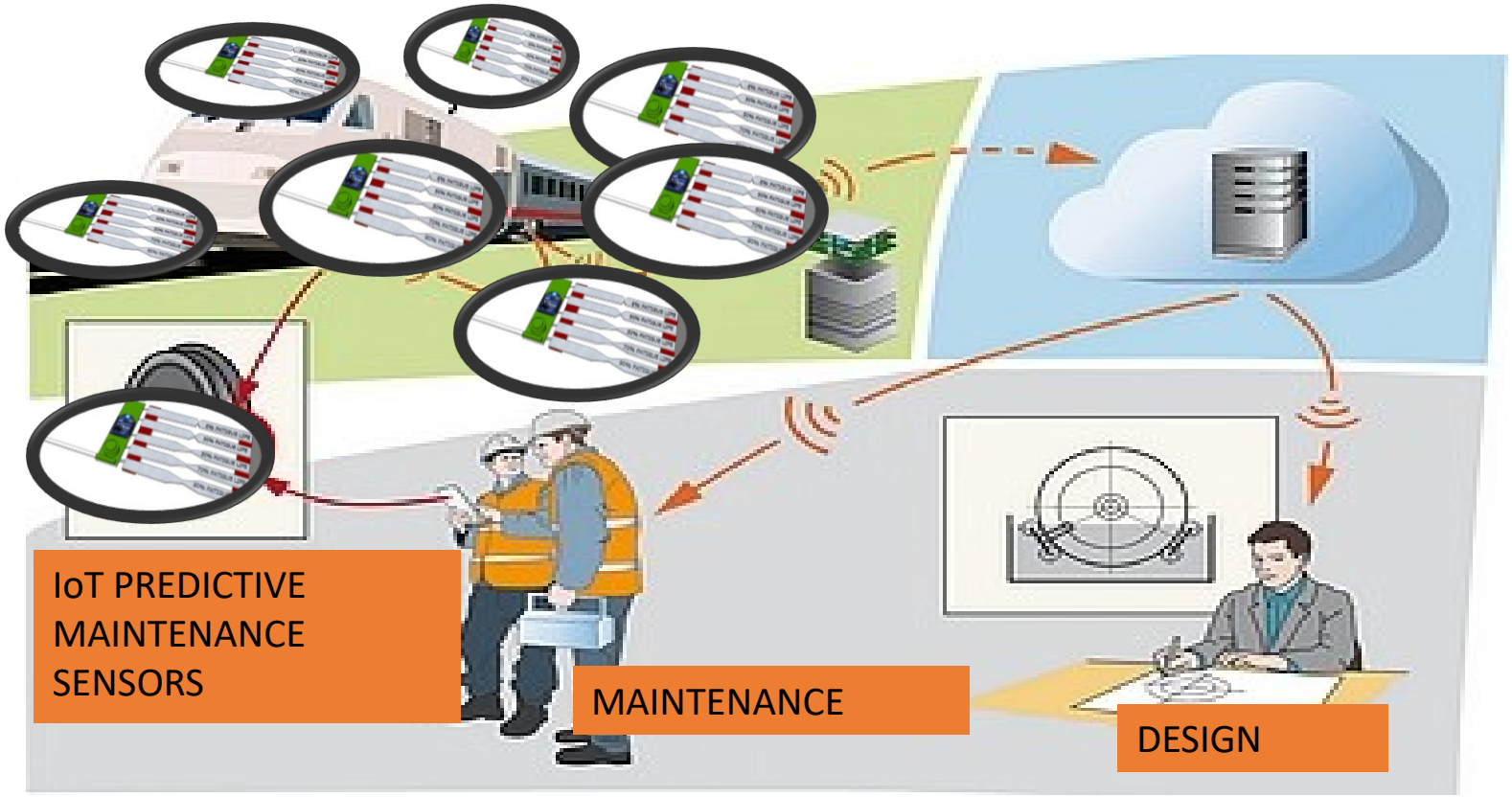




TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

- **High strength steels in railway vehicle applications Potential applications: structural parts (bogie and vehicle frames, vehicle body, etc.); Potential mass reduction: 30-35%; Recyclability: 100%; Price: above traditional structural steels, however, convenient. Drawback: gaps in manufacturing, lack of standard acceptance norms. frames, **
- **Polymer composites in railway vehicles applications Focus and successful applications so far - in passenger vehicles; Potential applications: bodyshells, tanks, support elements, etc.; Potential mass reduction: 50-75%; Flexibility in manufacturing of 3D complex shaped parts - significant advantage leading to reduction of no. of parts, labour time, etc.; Major barriers: the lack of relevant standards to take into account composite intrinsic properties; different inner structures and failure mechanisms compared to metallic materials (e.g., FRPs are sensitive to impact loads).**

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS



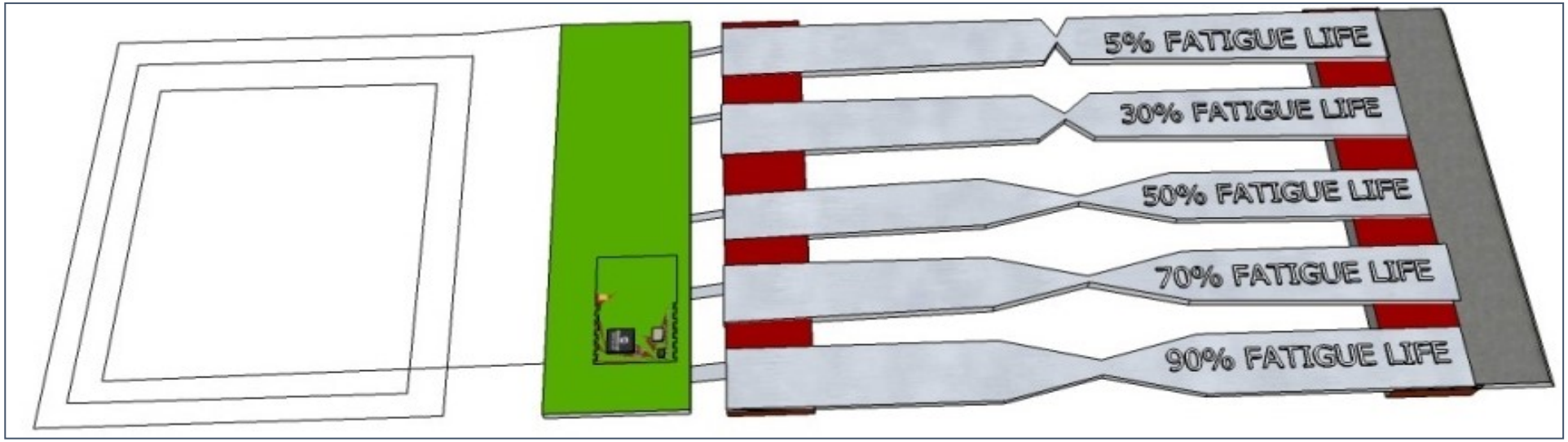
WIRELESS INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS NETWORK

STRUCTURAL FATIGUE DAMAGE MONITORING, MAINTENANCE AND DESIGN in different components of RAIL SYSTEMS (bogies, car body frames or fatigue specific-sensitive elements) during normal service.

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

- **A Novel Smart RFID Fatigue Damage Sensor aiming to the prediction of fatigue residual strength of critical mechanical and structural components for Structural Health Monitoring has been DEVELOPED and PATENTED (PATENT N0. US 8,746,077 B2).**
- **The proposed smart sensor system is designed for early detection and estimation of the structural health cumulative fatigue damage level and wirelessly transferring the information using an active or passive RFID integrated system.**
- **The developed RFID fatigue sensor system has a specially designed geometry with multiple parallel oriented unidirectional, bidirectional or multi directional breakable C, U or V type notched beams having different fatigue lifetimes to predict not only unidirectional or bidirectional fatigue damage but also multidimensional cumulative fatigue damage level of structural or mechanical elements including composite structures.**
- **It is foreseen that the proposed RFID-IoT Smart Fatigue Sensor will revolutionize the concept of fatigue design and also will revolutionize the fatigue inspection and maintenance management methodologies by using the RFID-IoT Smart Fatigue Sensor Network Data.**

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS



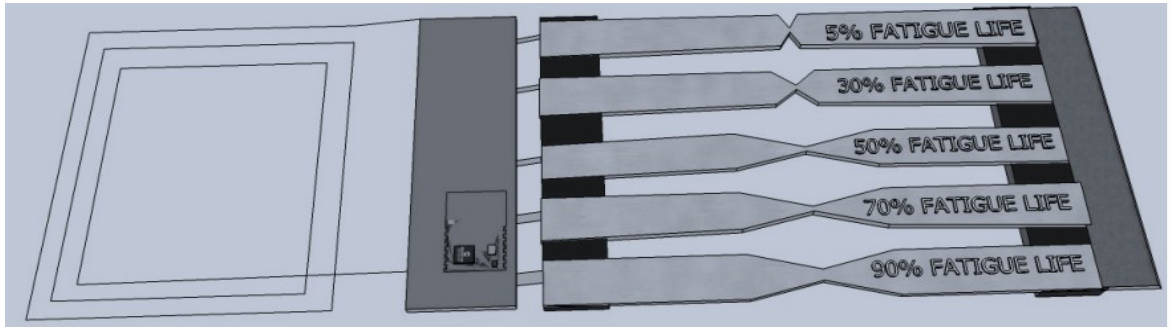
FATIGUE SENSOR (PATENT N0. US 8,746,077 B2)

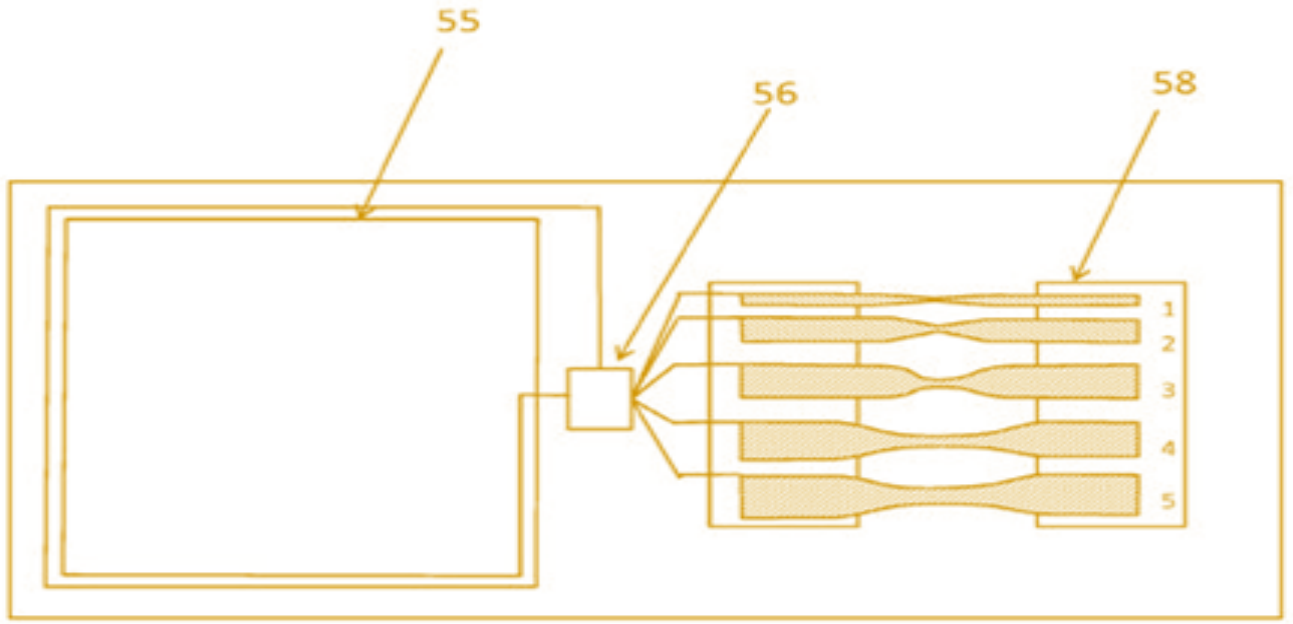
The sensor with no battery is shown in figure. This type is powered by RF power emitted by the interrogation wand. Interrogation distance of RFID type devices depend on both transmitter power and the coil size of the receiver.

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

- **Identify all the Fatigue Critical HOT SPOTS in STRUCTURES for the applications of Smart fatigue damage sensors in order to monitor the RESIDUAL FATIGUE STRENGTH or Fatigue Lifetime. Specific and Fatigue sensitive regions, locations under high loads, predetermined and formerly known-experienced spots on the structures and mechanical components such as Riveted, Bolted and Hole Type Connections etc..**
- **Determine of maximum critical STRESSES in all the Fatigue Critical HOT SPOTS in STRUCTURES(Bolted and Welded Joints) by using FEA numerical model of the structure for the applications of smart fatigue damage sensors in order to monitor the RESIDUAL FATIGUE STRENGTH or Fatigue Lifetime Monitoring.**
- **Development of Fatigue Model or Models of the selected FATIGUE SENSITIVE HOT SPOTS and Virtual FEA-Numerical Modeling and Analysis of the whole structure.**
- **Determine also the multi axial stresses acting locations and Find the principle stresses and directions for the applications of the sensors.**

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS





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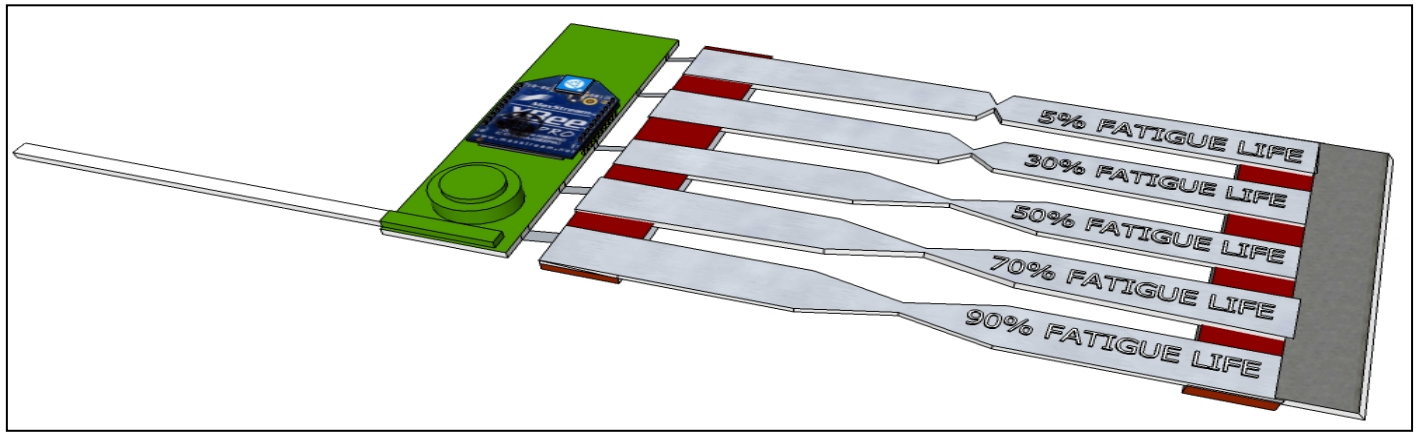


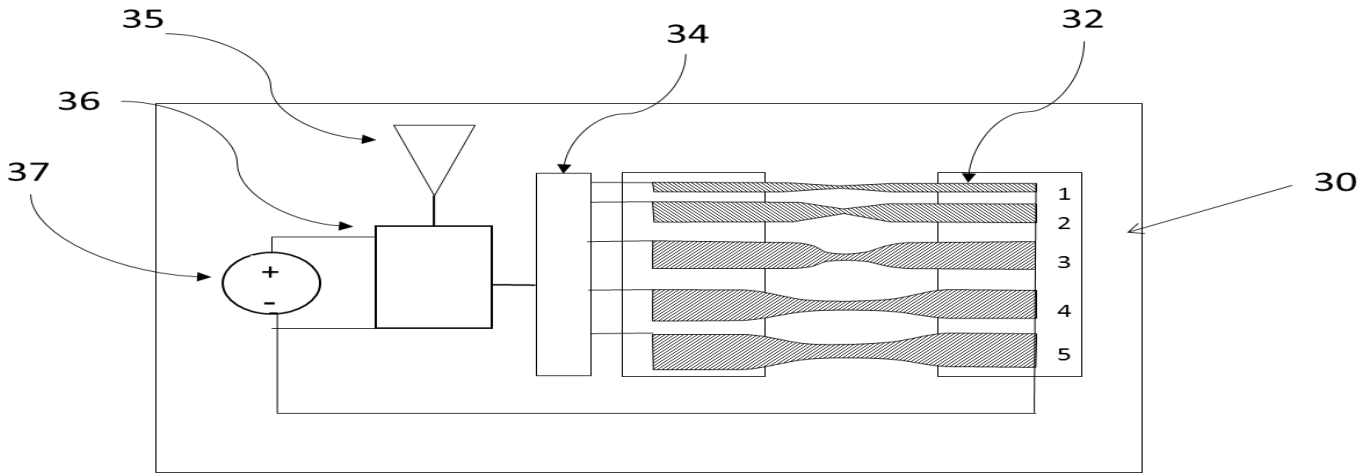
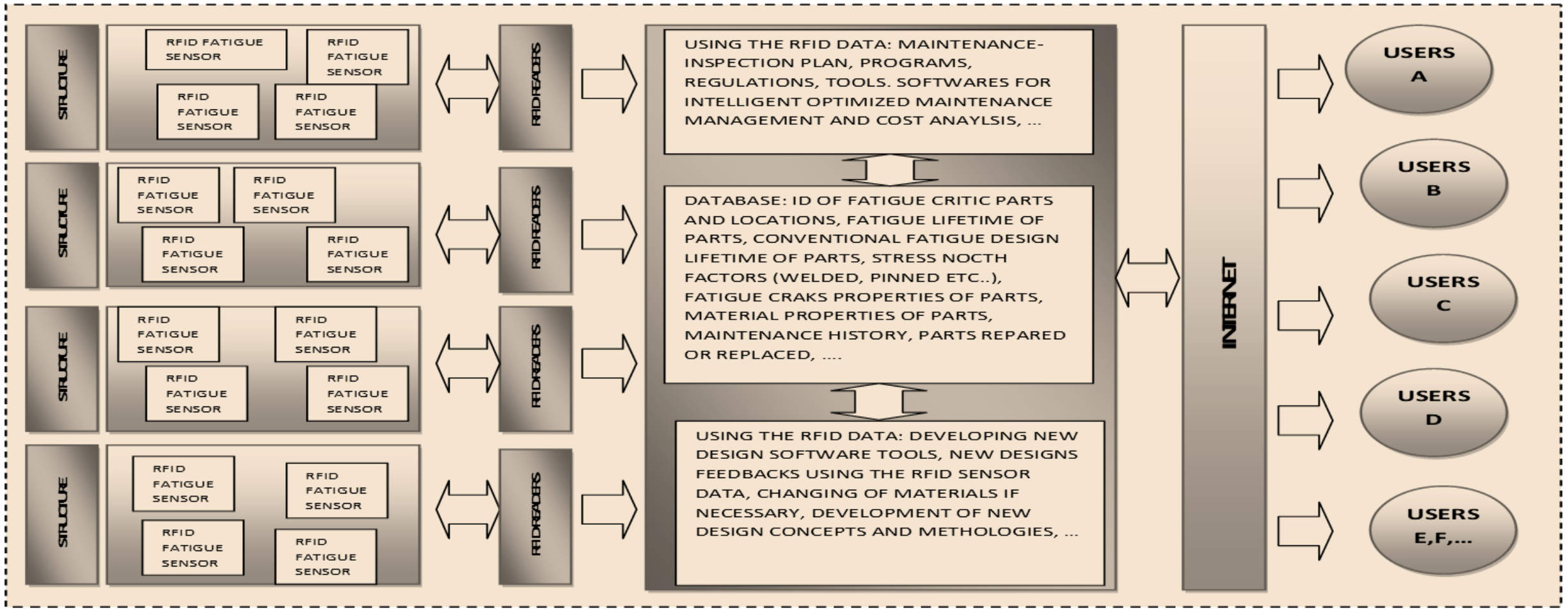


FIG 2.

There are two versions of the fatigue sensor, one with a battery version and another one which works with RF power. The one with the battery uses Zigbee or similar low power sensor networking to interrogate the sensor about the state of breakable fingers. The sensor nodes relay information from one node to the other to communicate with the master node.

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS



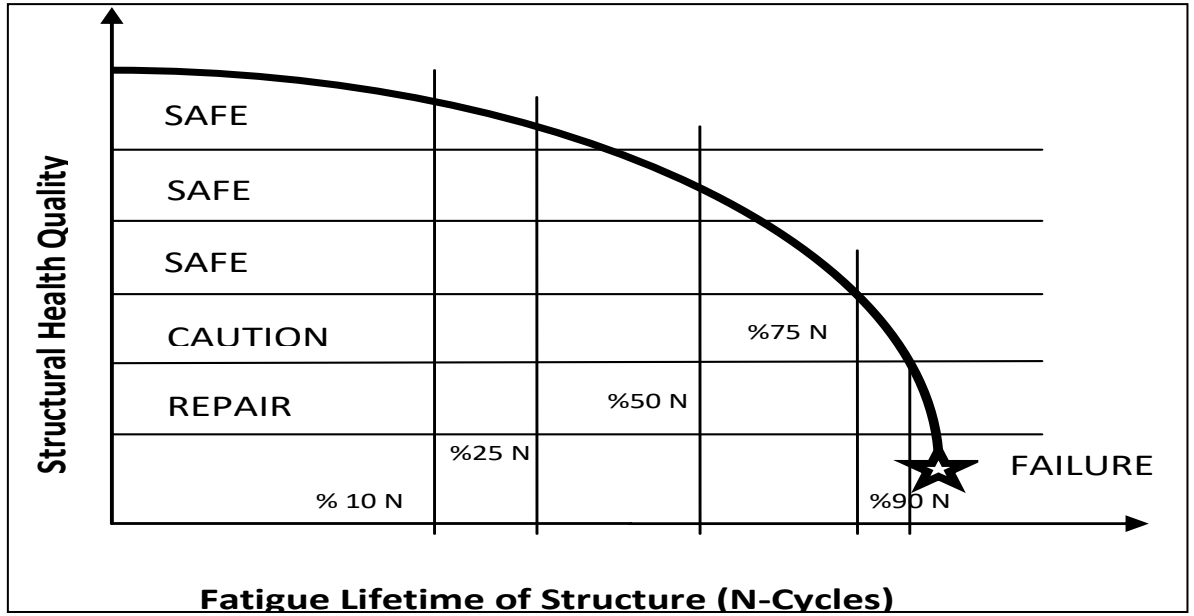
TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

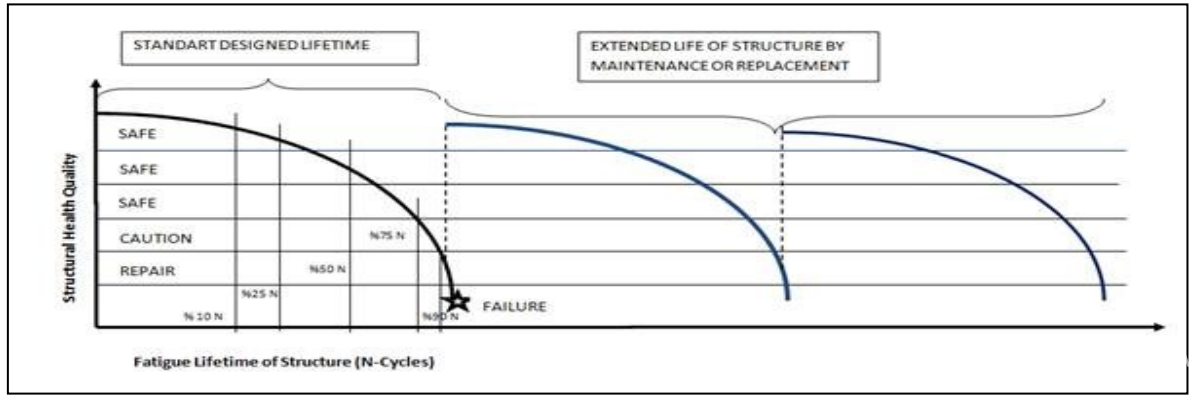
DATABASE:

The RFID Fatigue Sensor System collects;

The operational lifetime history of each fatigue critical component or location, the fatigue properties of the critical part, the type of fatigue cracks, the maintenance history, the fatigue maintenance history of each critical location or component, the fatigue sensitive details of the structure, the component manufactured time, the manufacturer of the part, the ID number of the component, the part and critical connections., the part expected scheduled repair time, the part material properties, the part redesign needs and design modification or revision, the part connection properties(rivet, welded, lap joints etc..), the parts repaired or replaced, the parts expected service lifetime, the parts crack lengths and many more useful information of structures.

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS





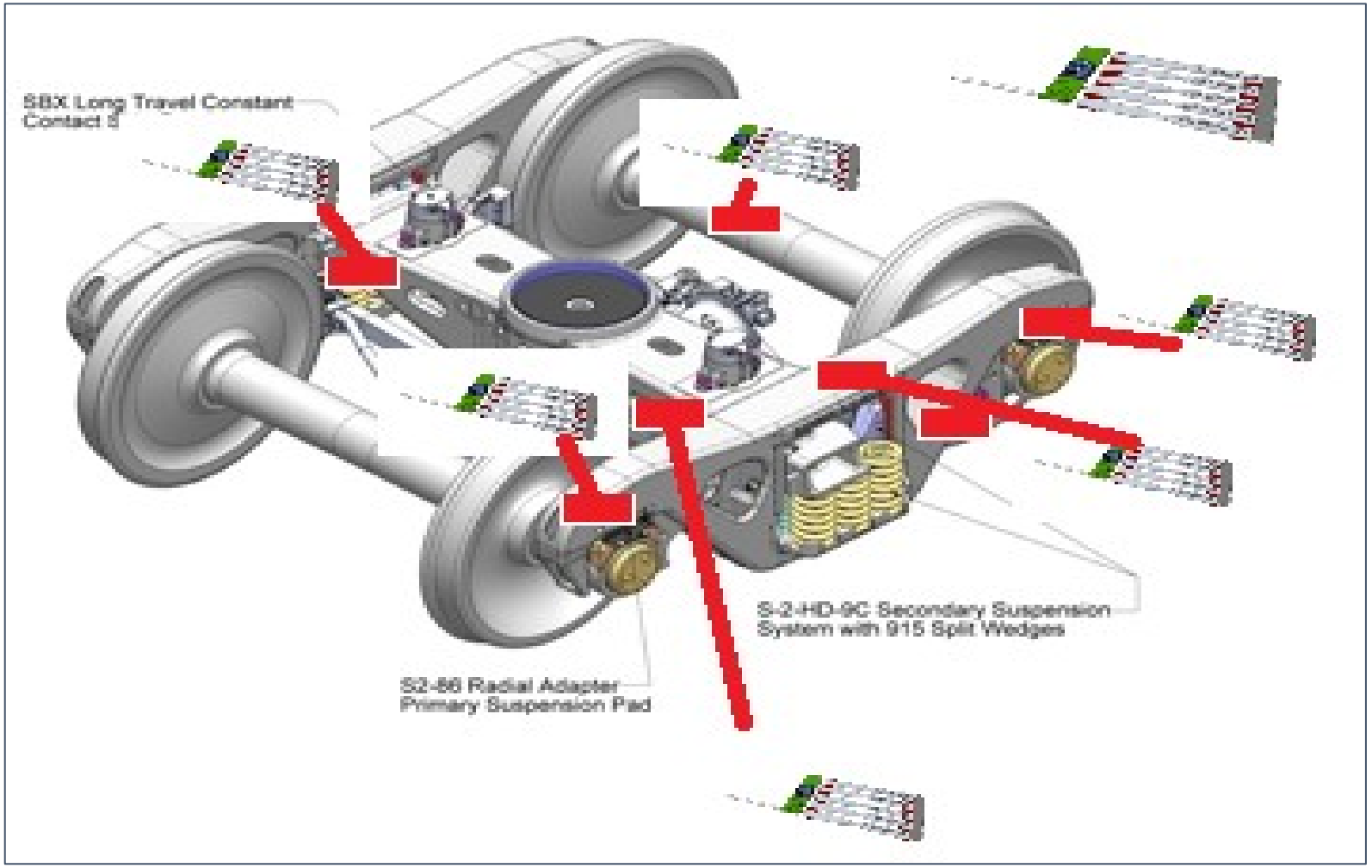
Failing or Degrading System Model and Remaining Usefulful Life for PdM

- **The required maintenance decisions and the health state of critical parts of structures are given according to the RFID Fatigue Sensor Network data.**
- **The RFID Fatigue Sensor network information is mandating, the time of the fatigue damaged parts or locations should be repaired or replaced.**
- **Therefore, the proposed RFID Fatigue Sensor based Intelligent Predictive-Condition Based Maintenance Model is very efficient and effective strategic system since it increases service life and reliability and reduces maintenance and operations expenses.**

RAILWAY COMPONENT BASED ACCIDENTS:

- According to a database, established by the Federal Railroad Administration (FRA), showing degradation/damage to mechanical parts that caused accidents/incidents from the years 2004 to 2007 in the United States (Federal Railroad Administration Office of Safety Analysis 2008). This database reveals that mechanical parts can be separated into three groups in terms of contributions to train accidents.
- Wheelsets (wheel, axles and journal bearings) comprised the largest group, with a 44.7% contribution in terms of total accidents caused.
- The second largest group included the brakes, coupler and body, with a 36.7% contribution, followed by a rate of 18.6% for the group including the pantograph, underframe and door. This analysis underscores the increasing need for wheelset damage detection techniques.

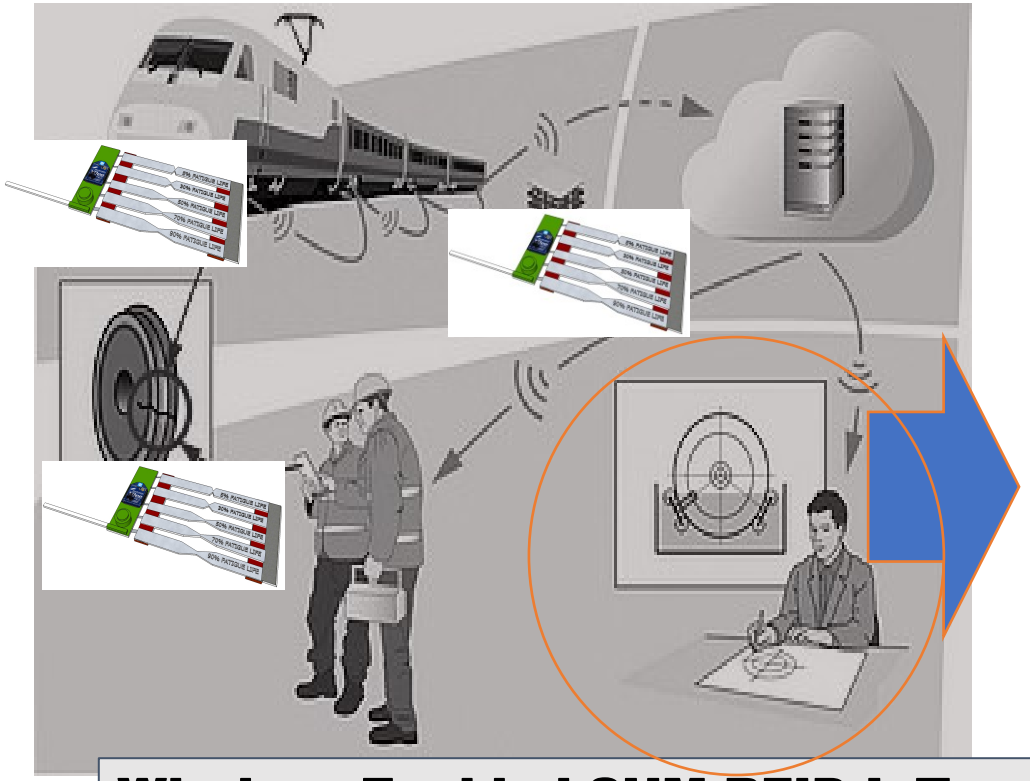
TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS



The Fatigue Critical HOT SPOTS in BOGIES and the applications of Smart fatigue damage sensors in order to monitor the RESIDUAL FATIGUE STRENGTH or Fatigue Lifetime.

IN RAILWAY STRUCTURES, Specific and Fatigue sensitive regions, locations under high loads, predetermined and formerly known-experienced spots.

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

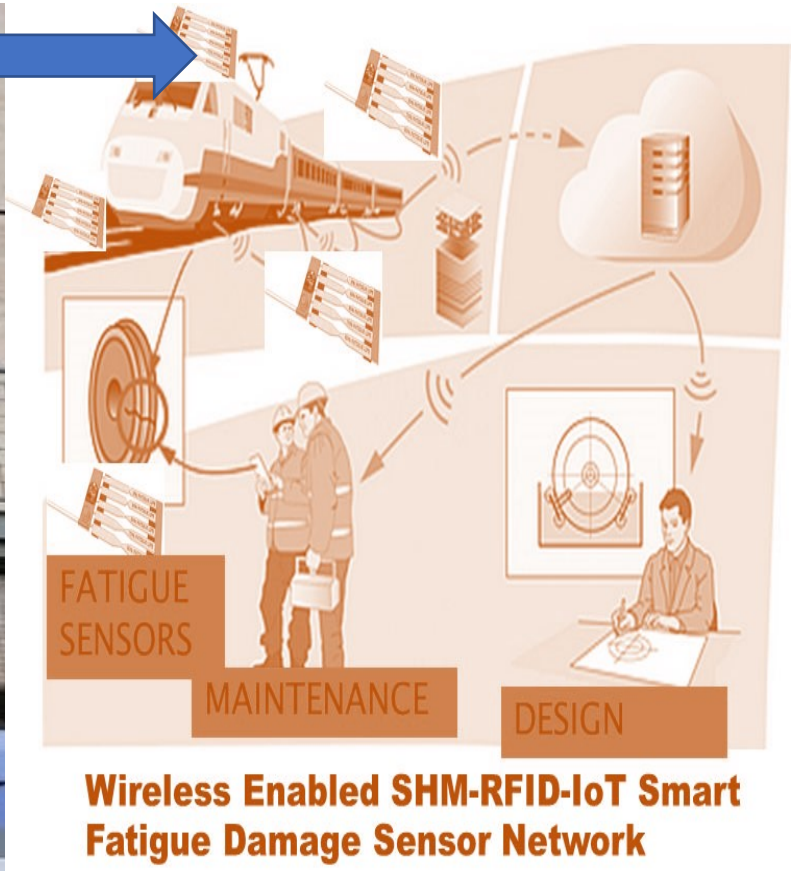


Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network

INTELLIGENT DESIGN SOFTWARE BY USING THE RFID FATIGUE DAMAGE SENSOR DATA FOR FATIGUE STRUCTURAL HEALTH MONITORING

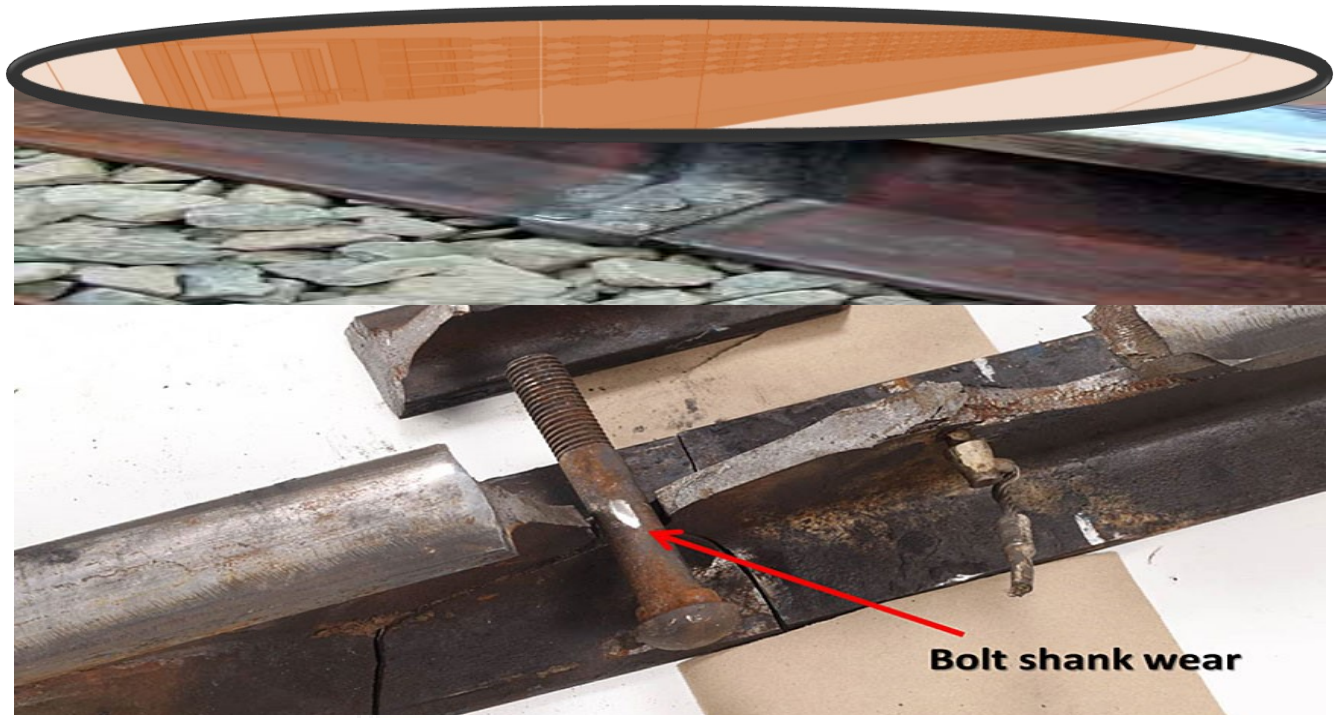
The structural fatigue health conditions of critical parts of structures are given according to the RFID Fatigue Sensor Network data. These data also provide a lot of information for new fatigue design improvements and also new design concepts. For this reason, the sensor data could affect the fatigue design regulations and methodologies since it is representing an extended periodic or real lifetime fatigue data for a unit and fleet of structures with SHM system.

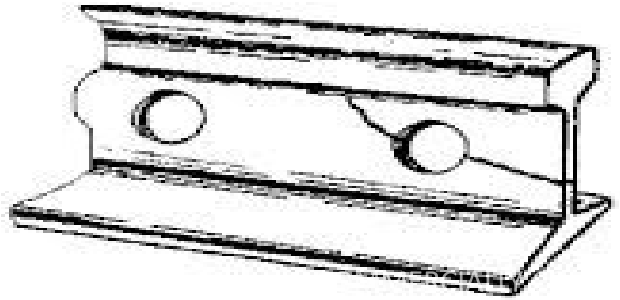
TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

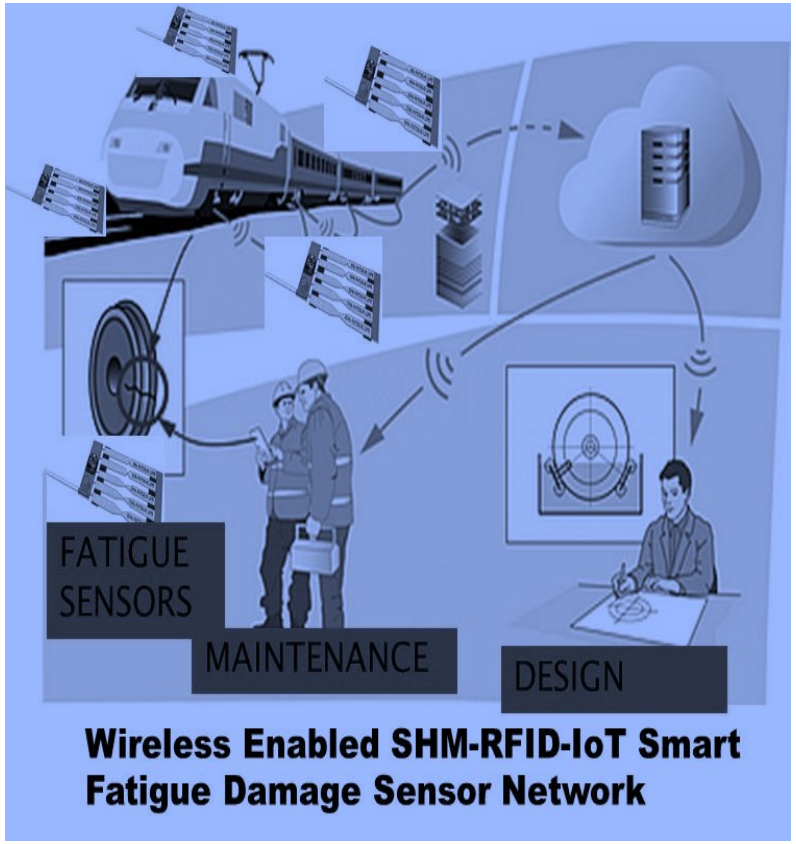


Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS







Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network

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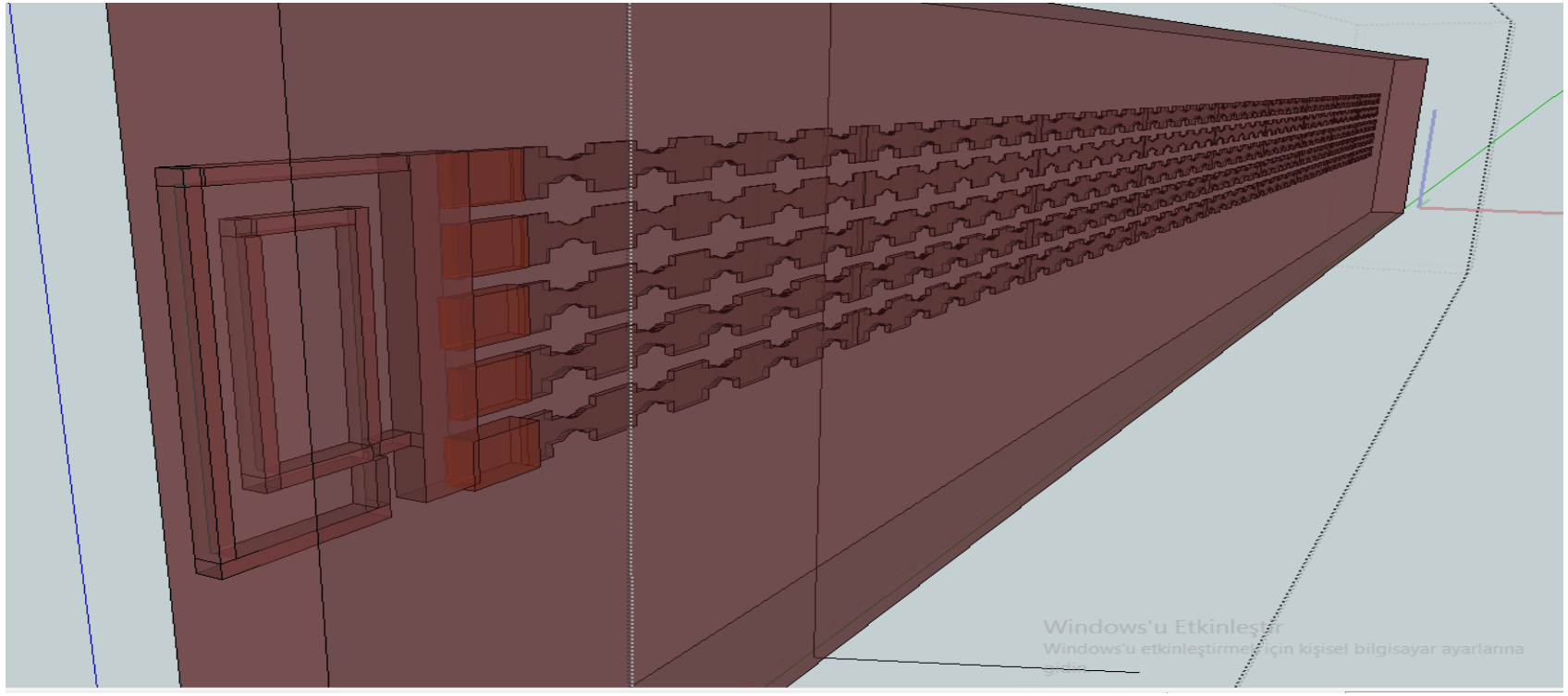
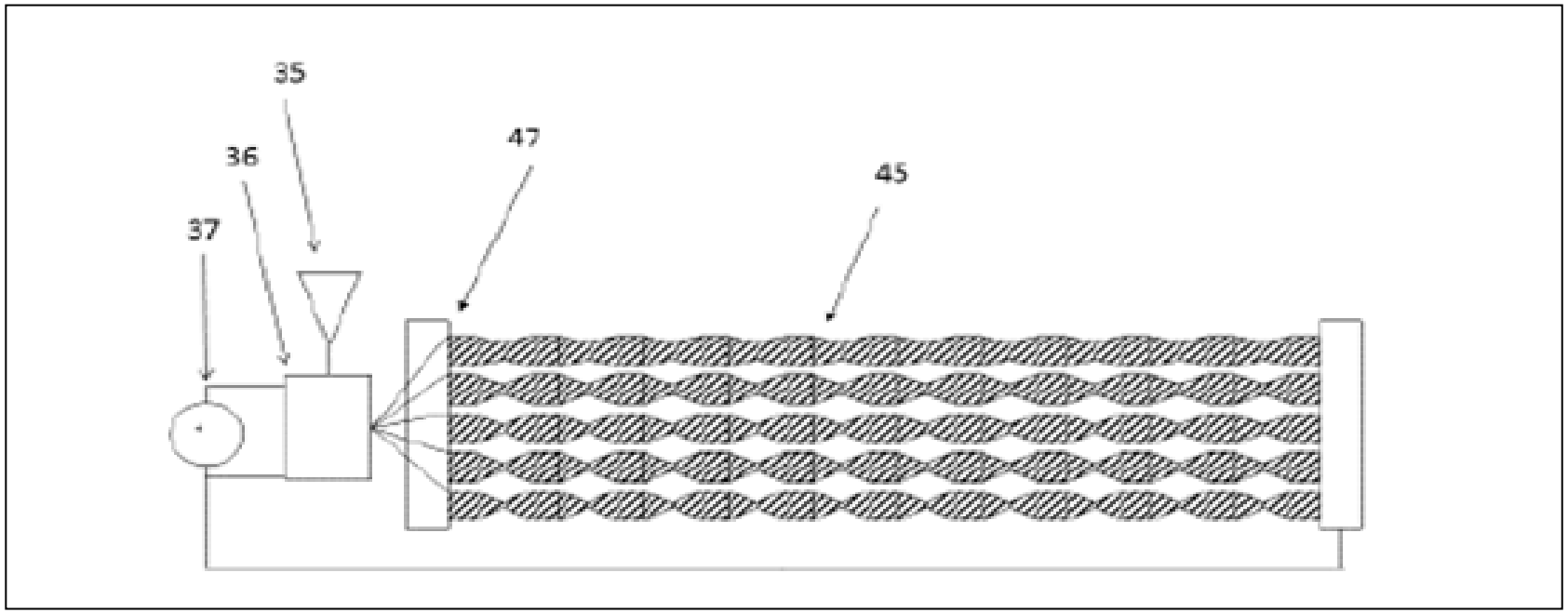


LONG SERIAL STRUCTURAL FATIGUE DAMAGE SENSOR

LONG SERIAL STRUCTURAL FATIGUE DAMAGE SENSOR AND APPLICATIONS FOR MONITORING, MAINTENANCE AND DESIGN in different components of RAIL SYSTEMS (bogies, car body frames or fatigue specific-sensitive elements) during normal service.

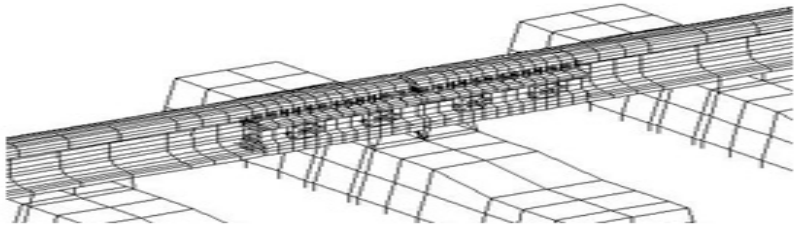
TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS



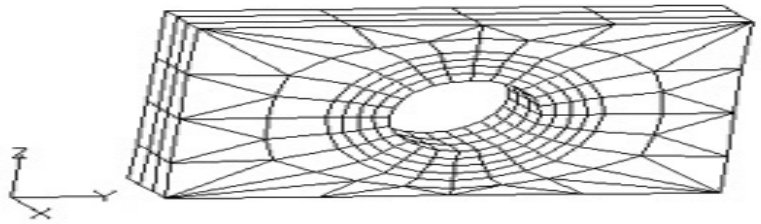
LONG SERIAL CONTINOUS STRUCTURAL FATIGUE DAMAGE SENSOR

LONG SERIAL STRUCTURAL FATIGUE DAMAGE SENSOR AND APPLICATIONS FOR MONITORING, MAINTENANCE AND DESIGN in different components of RAIL SYSTEMS (bogies, car body frames or fatigue specific-sensitive elements) during normal service.

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS



(a) Whole model



(b) Fine model around bolt hole

Fig. 1. Bolted rail joint components

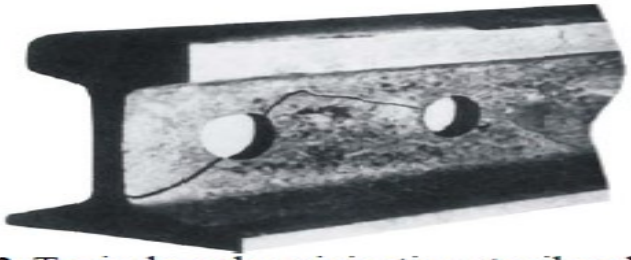


Fig. 2. Typical cracks originating at rail-end-bolt hole

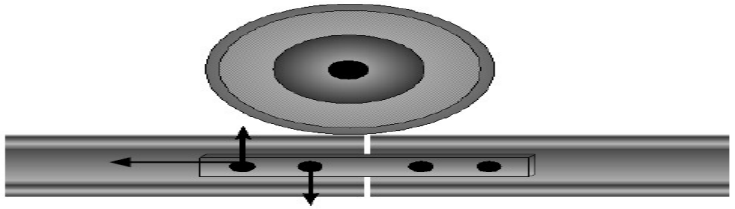


Figure 1. Fatigue Loading of Typical Rail Joint

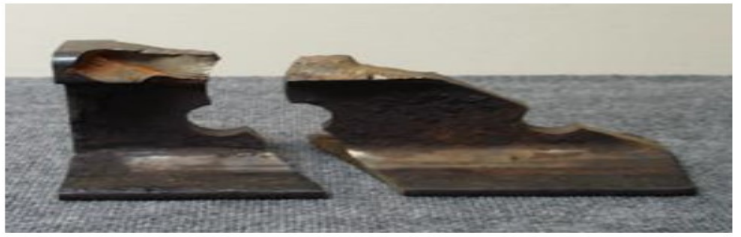
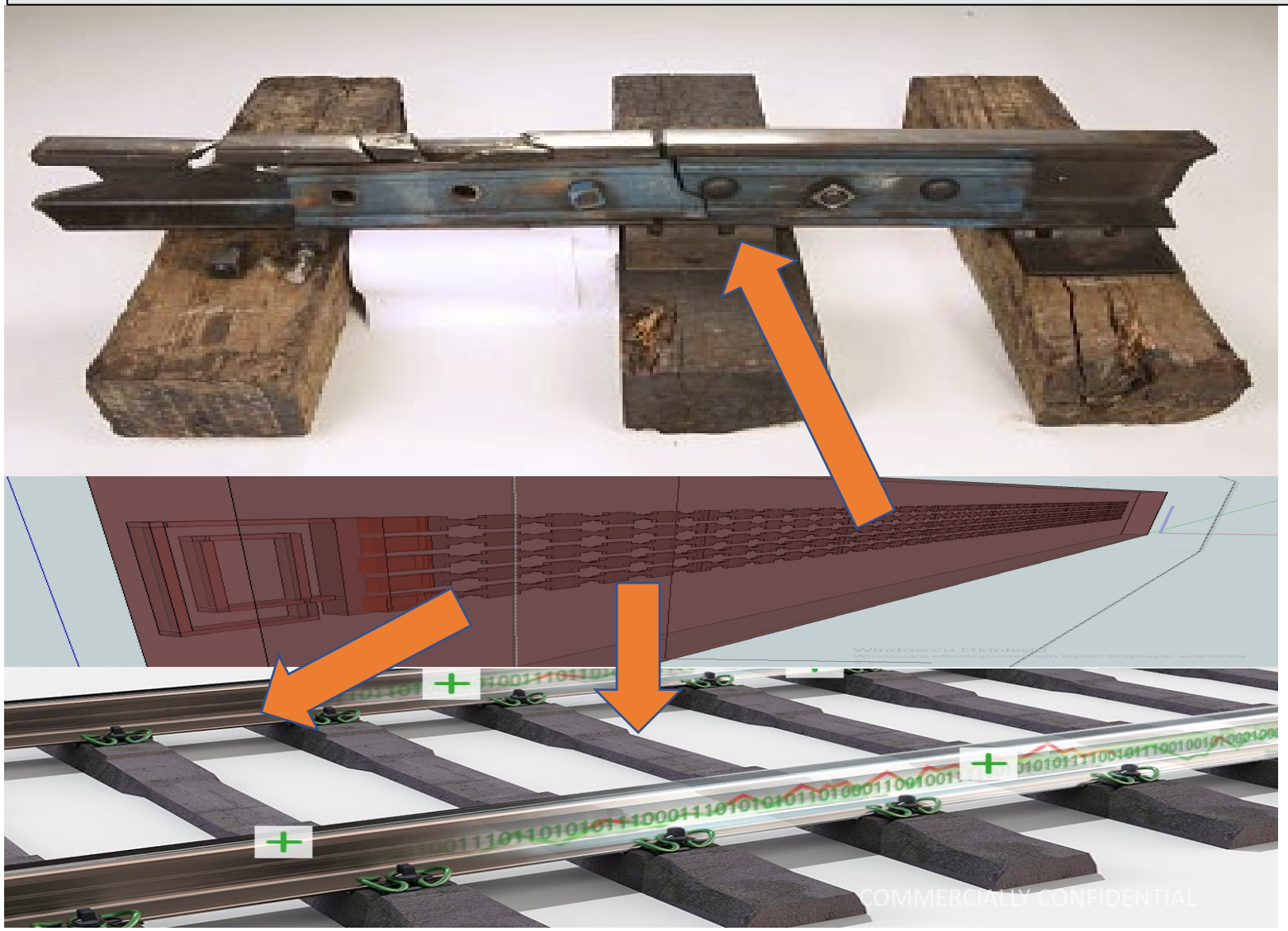


Figure 2. Example of Separated Piece Track End

LONG SERIAL STRUCTURAL FATIGUE DAMAGE SENSOR AND APPLICATIONS FOR MONITORING, MAINTENANCE AND DESIGN in different components of RAIL SYSTEMS (bogies, car body frames or fatigue specific-sensitive elements) during normal service.

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS



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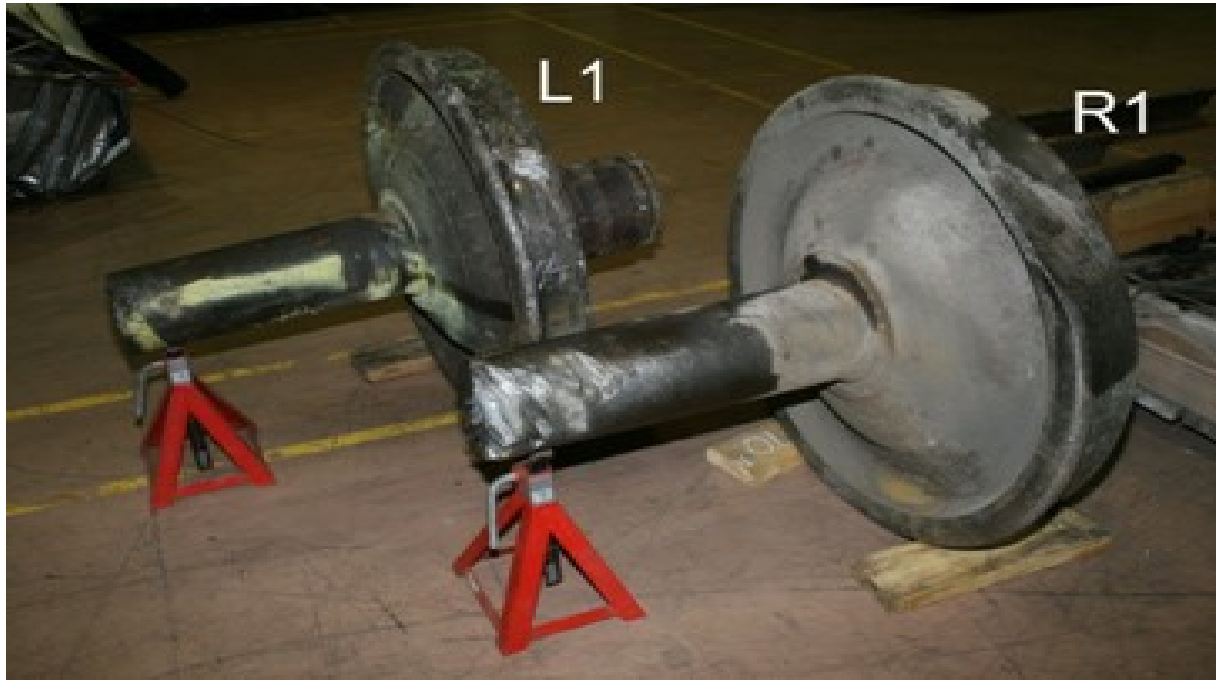


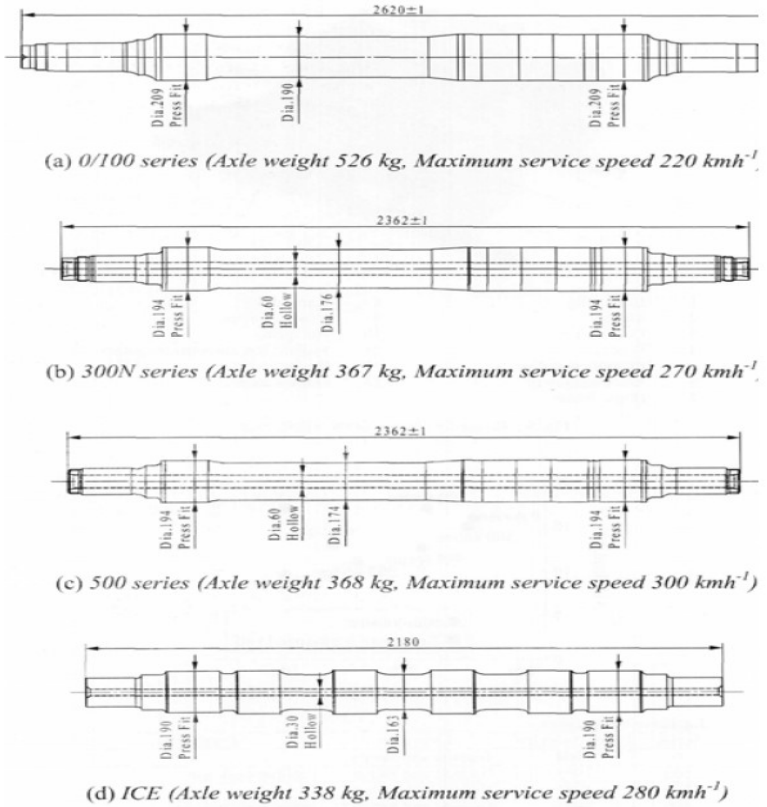


Figure 1. Change in the Shinkansen axle with increasing maximum operation speed [7].

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

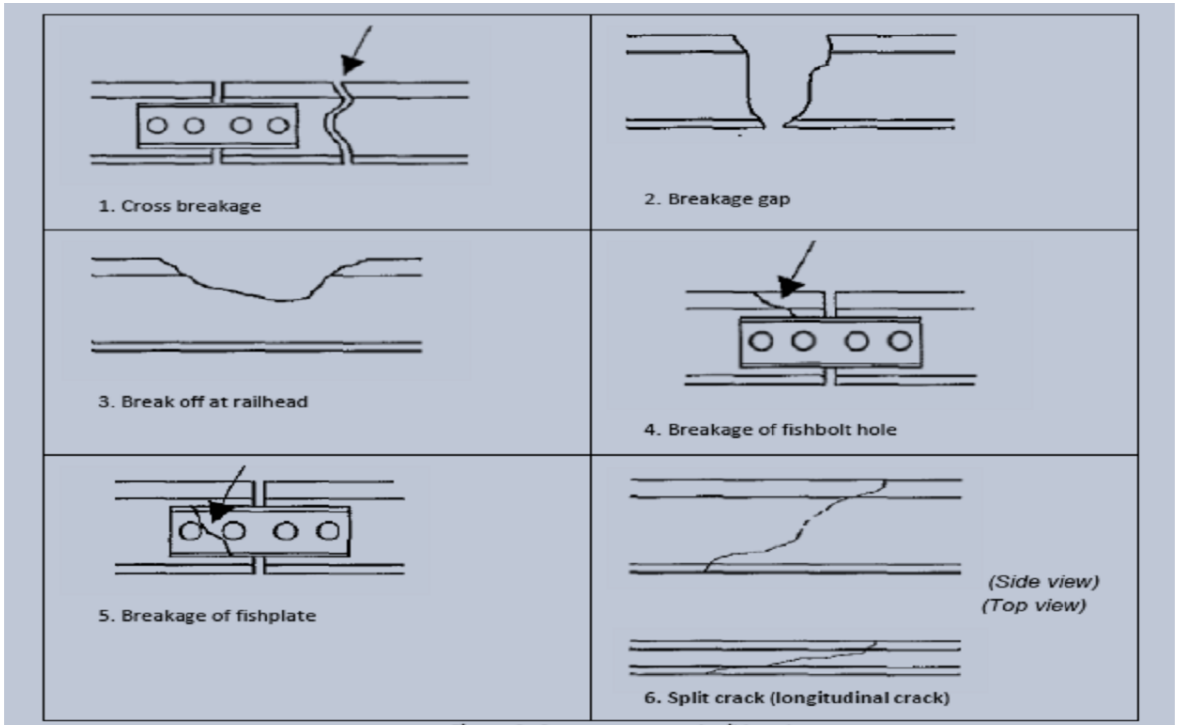
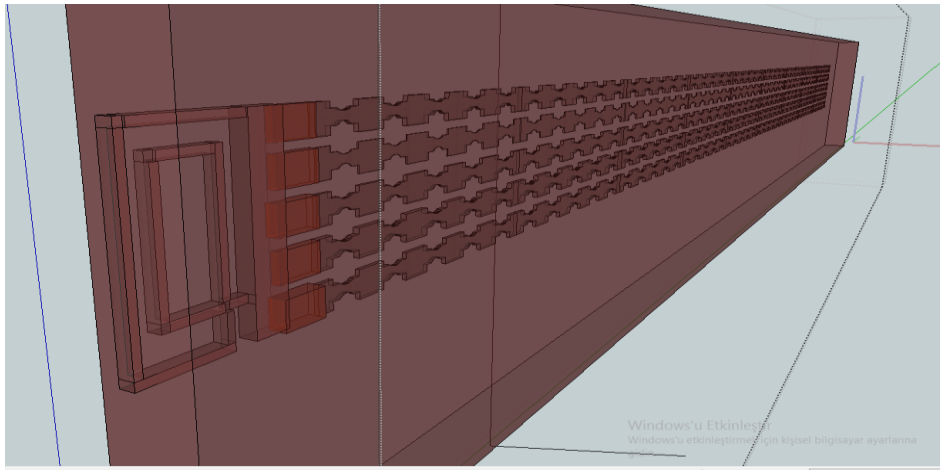


Figure 2: Common types of rail breaks
Source: Taylor 2011



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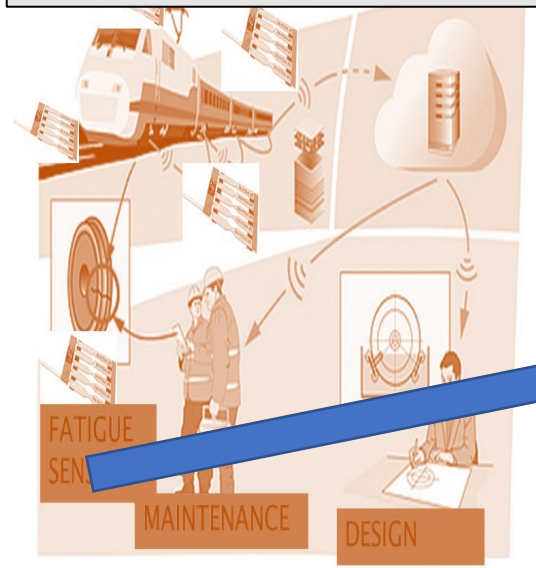
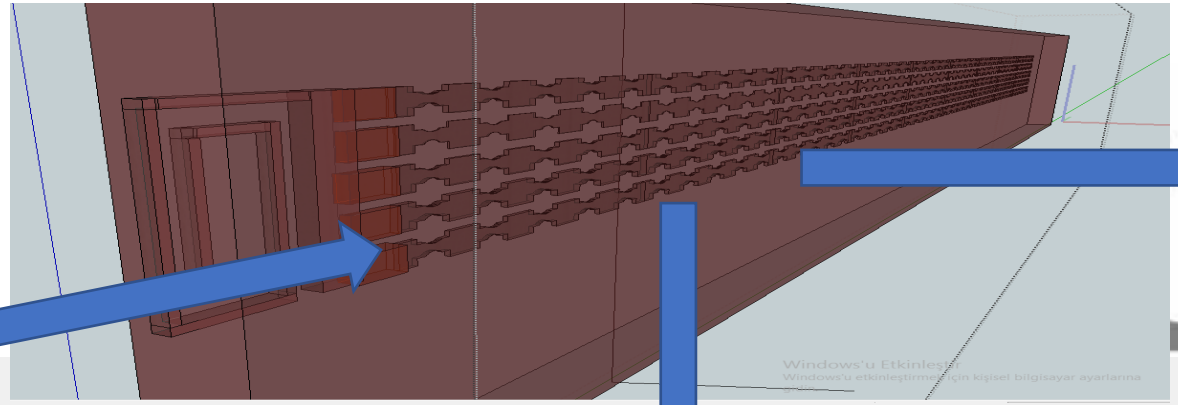


Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network



Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

The Fatigue Critical HOT SPOTS in RAILWAY BRIDGES and the applications of Smart fatigue damage sensors in order to monitor the RESIDUAL FATIGUE STRENGTH or Fatigue Lifetime.

IN RAILWAY BRIDGE STRUCTURES, Specific and Fatigue sensitive regions, locations under high loads, predetermined and formerly known-experienced spots

TRANSPORTATION APPLICATIONS OF NOVEL INTELLIGENT IoT PREDICTIVE MAINTENANCE SENSORS AND SENSOR NETWORKS FOR SMART MAINTENANCE DESIGN AND MANAGEMENT TROUGH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING ALGORITHMS

Wireless Enabled SHM-RFID-IoT Smart Fatigue Damage Sensor Network