
# Smart Maintenance for Smart Mobility

## Experience, Perspectives & Challenges

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September 9, 2020

ALSTOM
• mobility by nature •

# AGENDA

## Smart Maintenance for Smart Mobility

- What is Smart Mobility ?
- Why does Smart Mobility require Smart Maintenance ?
- From single Asset to Complex System to Fleet
- Opportunities  and Challenges

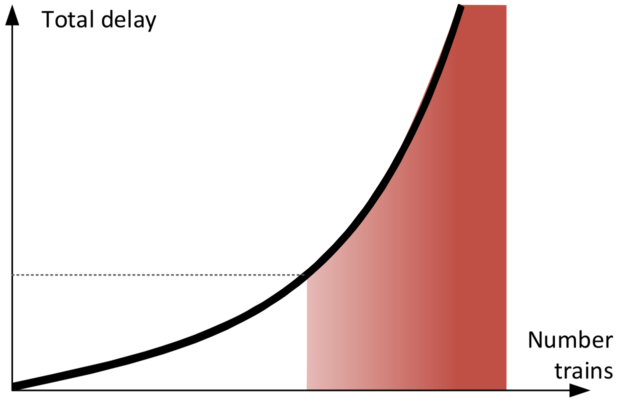
# Alstom Digital Mobility

## Alstom has evolved from rail equipment manufacturer to mobility solutions provider

# Smart and Sustainable Mobility for tomorrow's cities

A number of innovative cities around the world have a "Smart City" program. Example: Singapore (Land Transport Authority, LTA). Some challenges:

- **Alleviating Congestion** :
  - City population growth and ecological concern→ urban public transport demand expected to rise 50% by 2050
  - Today, most urban rail networks are saturated at peak hours→ knock-on delays




- **Multi-modality :**

  Today, switching from one mode to another in case of incident is not easy.
  Last mile usually a problem. Little offer for alternative connections

  → Seamless chain between pedestrians/ cycles/busses/trains
  → Inclusion of autonomous vehicles as complementary or alternative mode.

- **Sustainability**: optimizing life-cycle cost.

# What is Smart Mobility ?

Three desirable key characteristics:

- **Flexibility**: Multiple modes of transportation allow travellers to choose which ones work best for a given situation-> resilience

- **Efficiency:** The trip gets the travellers to their destination with minimal disruption and in as little time as possible→ punctuality

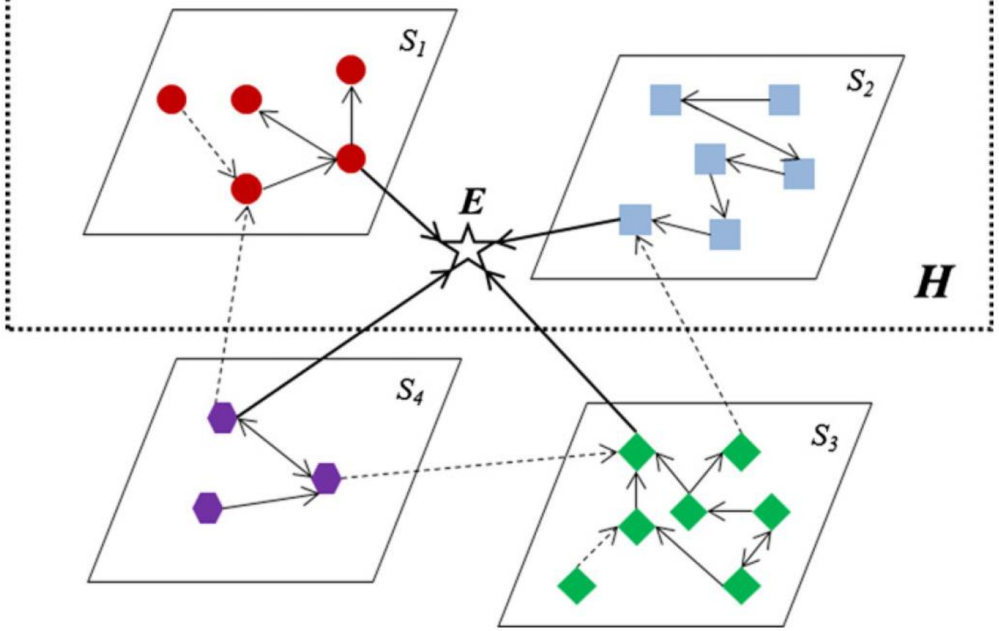
- **Integration**: The full route is planned door-to-door, regardless of which modes of transportation are used-> seamless multimodal transport

# Multi-modal transportation: a ‘System of Systems’

## Different systems are managed independently but must (or should) coordinate

Fleet of trains
(« Metro »)

Fleet of busses




Fleet of taxis

Fleet of bicycles ( e.g. Vélib)

Single Client:
the passenger

# Muli-modal Transportation: a ‘System of Systems’

## Five properties characterize a  System of Systems in general:

- Geographical distribution
- Heterogeneity
- Evolutionary Development
- Operational and managerial independence
- Emergent Behavior →Unintended consequences

Field of study since the 1980s ( defense industry) . Reliability, Safety, Maintenance implications still insufficiently understood ( IEEE Working Group)

# Why does Smart Mobility require Smart Maintenance ?

## Traditional Maintenance

- **Preventive**:  systematic, i.e. scheduled at predetermined  times or mileages

→  Rigid , fixed maintenance plans

- **Corrective:** post-factum, i.e. after the failure has occurred→ unscheduled (randomness)

→Maintenance teams may be overwhelmed…. or idle.
→Resources ( people, tools and parts) are dimensioned by averages or  worst case (peak and failures)
→Spare parts may be in excess…  or lacking
→Asset utilization is generally far from optimized
→Availability may be insufficient

Absolutely not in line with flexibility requirements of Smart Mobility
→  Need  for 'smart, adaptive maintenance'

# What are the requirements for Smart Maintenance ?

Ideally, Maintenance must make the Assets available for when they are needed, and achieve that goal cost-effectively

--"when they are needed": depends on variable passenger demand→ need to monitor and anticipate demand

-- "make assets available":→ need to monitor assets and anticipate failures

→ **condition-based / predictive maintenance**

**PHM ( Prognostics & Health Management)**

Maintenance cannot be managed separately from Operations

Dynamic Maintenance of a Fleet of Assets
Predictive Traffic Management

# Enabler : Digitalisation is changing the world of maintenance

**FROM**

- **Communication**
- **Silos**
- **Information accessibility**
- **No Added value**

## Digitalisation

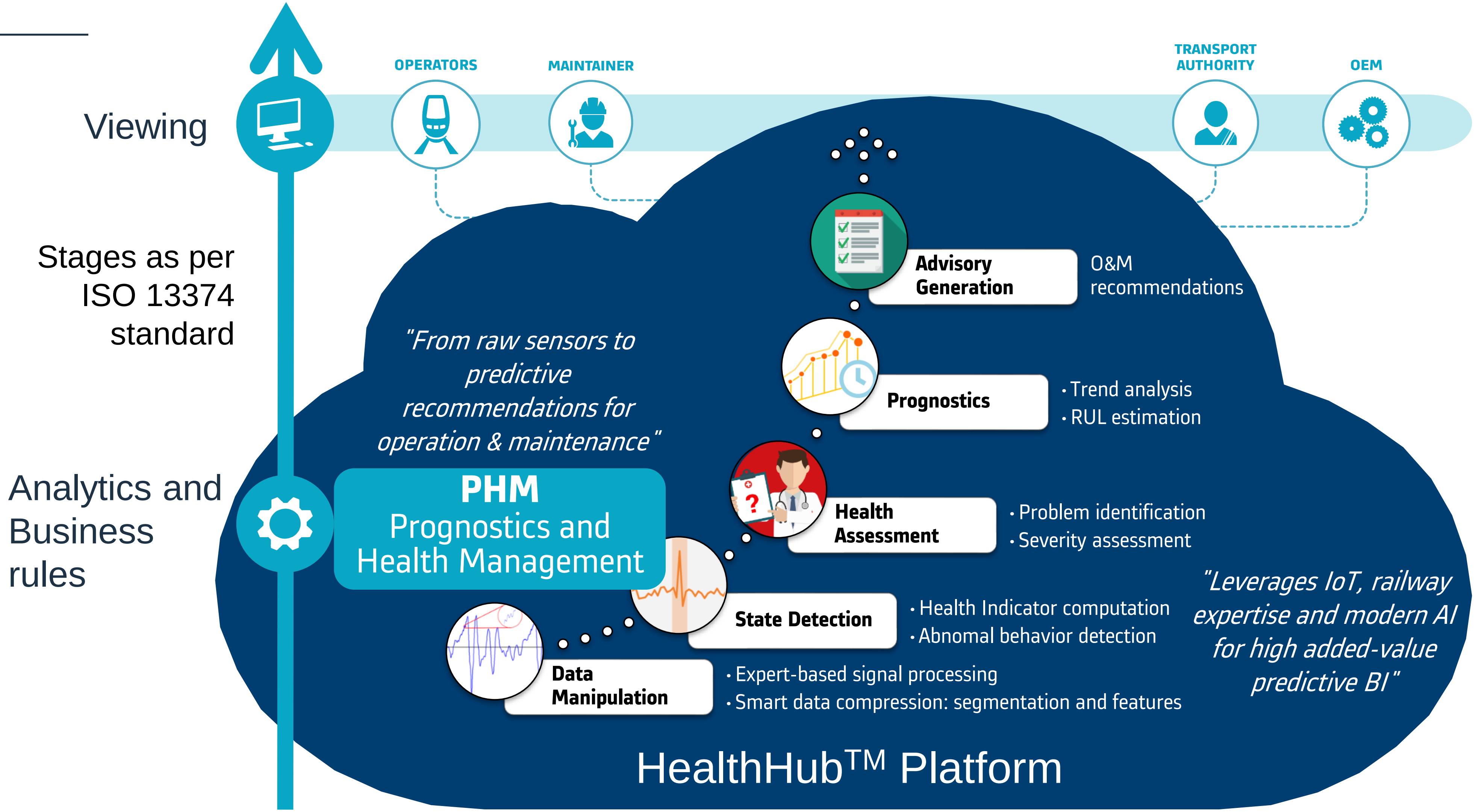
**Accessibility of data**
**Management of information**
**Interface with other systems**
**Maintainer feedback**

**TO:**

- **Availability needs, operation load, KPIs**
- **Health of assets, notifications**
- **Depot resources in real time**
- **Training for everyone anywhere**
- **Optimisation of global productivity**

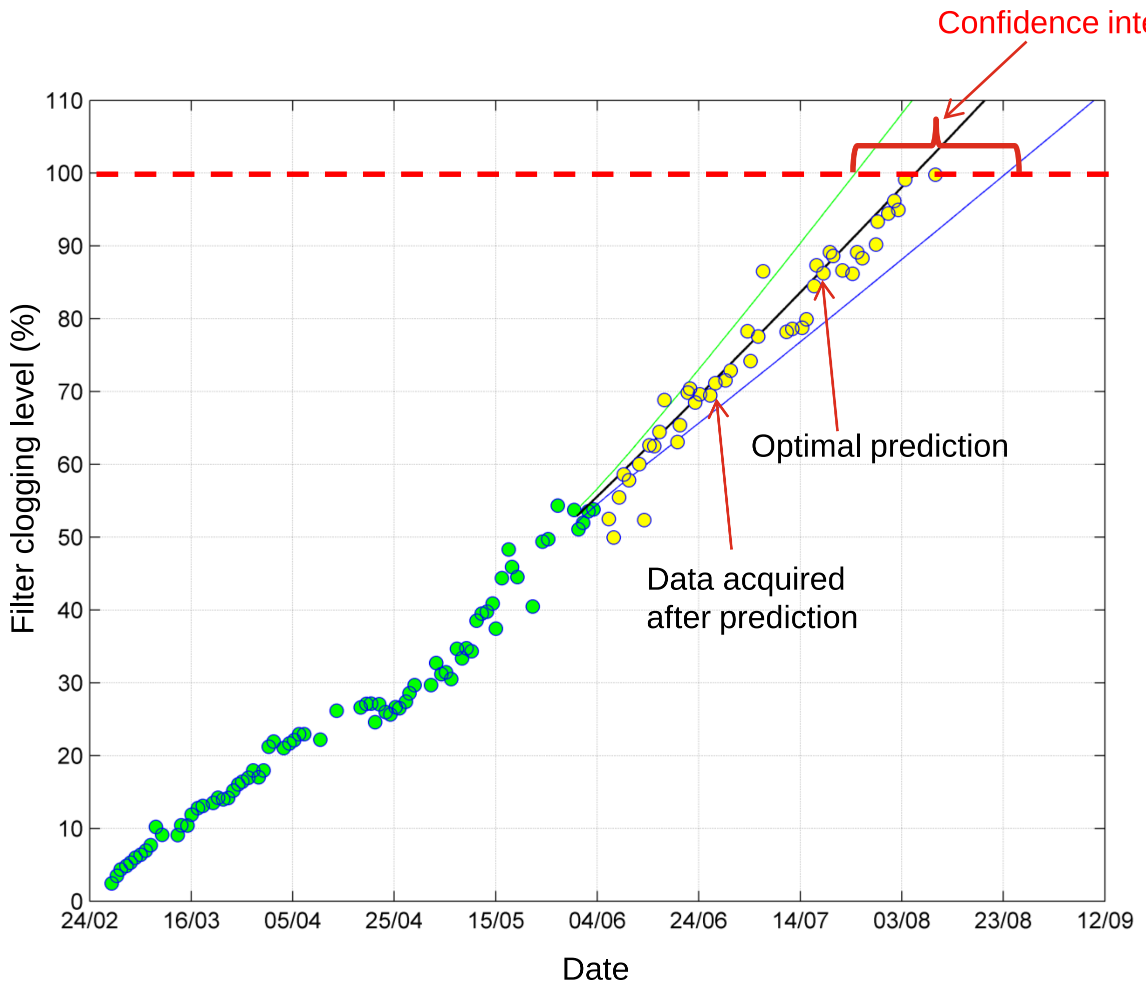
**Digitalisation enables interaction between different maintenance actors and operations**

# Alstom’s CBM and PHM (Prognostics & Health Management) Framework



# RUL ( Remaining Useful Life)

Example:
HVAC filter




RUL is a *random variable*

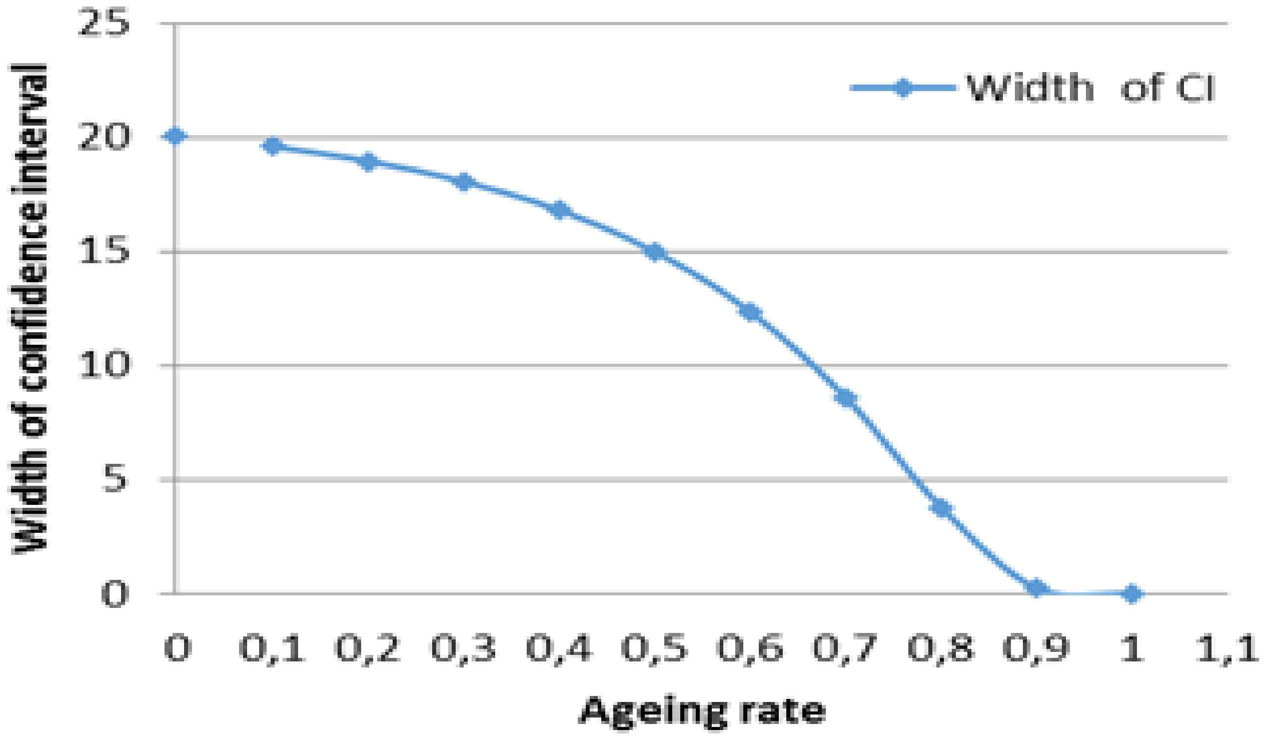
Need to deal with *uncertainty and quantify it if possible*:

-- model (epistemic)
-- data (measurement)
-- future load

Otherwise, meaningless

# Confidence interval for RUL : influence of ageing rate

- The higher the “RUL Loss rate per unit of time”, or ageing rate (k), the narrower the confidence interval
- In the limit of k → 1 ( deterministic ageing), confidence interval shrinks to 0.
- In the opposite limit k=0 ( exponential distribution for RUL), confidence interval width is maximal:

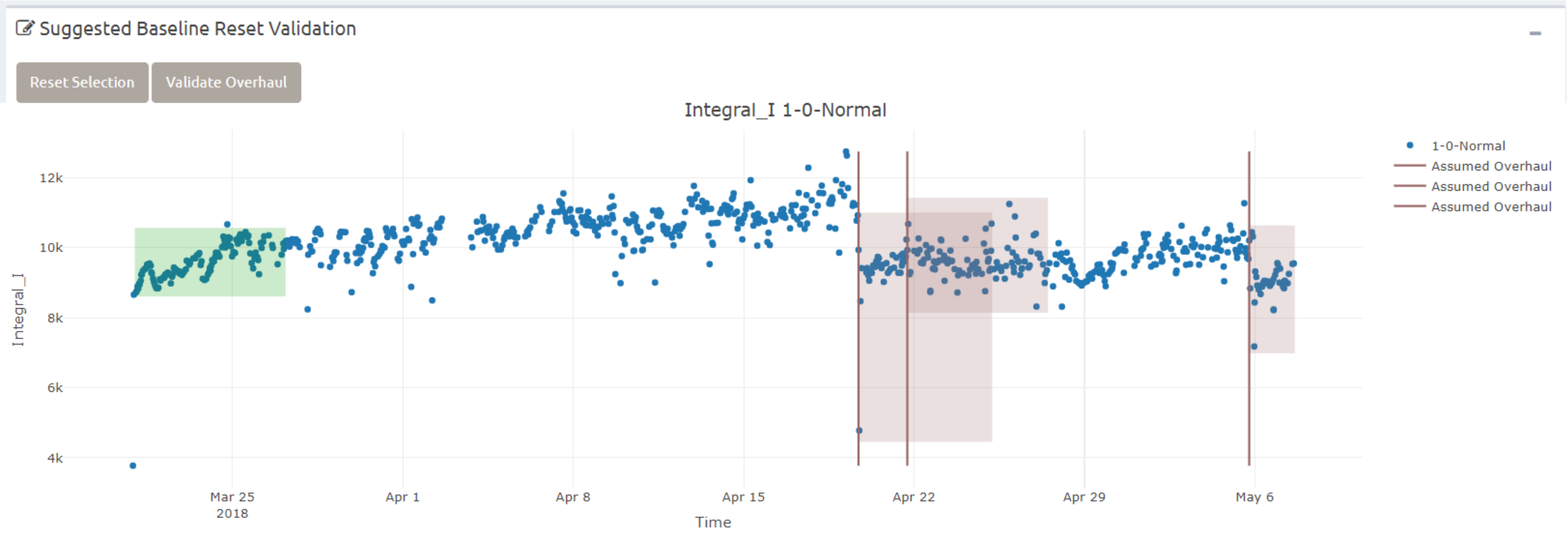



For family of distributions with MRL linear in time

From ESREL2018 (P.Dersin, the class of lifetime distributions with a mean residual life linear in time)

# When  to reset baseline ?  Context evolution

When changes in context ( environment but also maintenance operations) occur , algorithm has to be retrained



# Key Performance Indicators

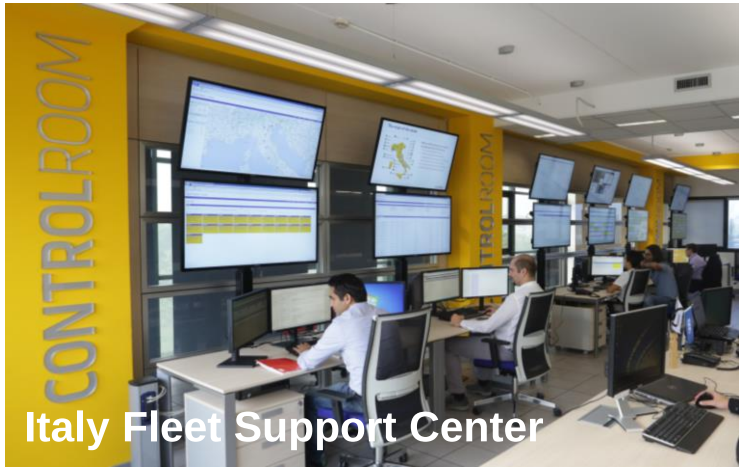
If Railway operators are to trust predictive maintenance, it is key to guarantee performance levels in terms of

- Detection ( detection rate, false alarm)
- Diagnostics ( true diagnostics rate)
- Prognostics ( accuracy of RUL estimation.)

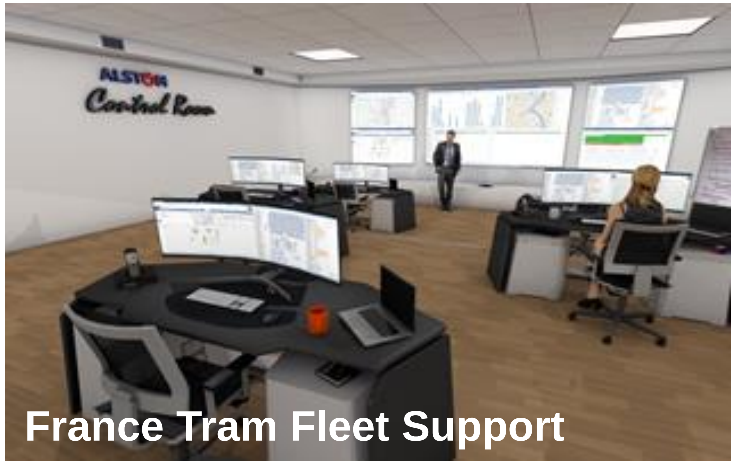
- → In spite of multiple uncertainties

# HealthHub™ Fleet Support Centers

UK Fleet Support Center



Italy Fleet Support Center



France Tram Fleet Support


Benelux Fleet Support Center

France Data Center


Santiago (Chile) Fleet Support Center

# Monitoring not just individual items of equipment but complex systems

## Example: Detecting, Diagnosing, Anticipating Radio Communication Issues

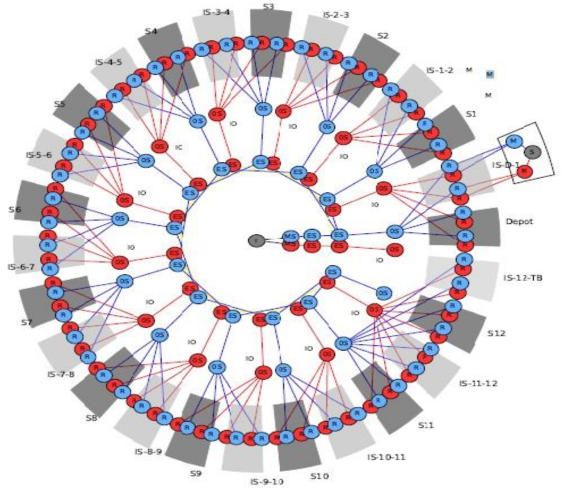
- ***Problem:***

In CBTC ( Communication Based Train Control) as well as ETCS (European Train Control System), data communication system is operations critical**.**

A number of degradations linked to radio signal quality occur, which lead to disruptions in operations, and delays:
→Loss or delays of packets→ movement authority not received on time →unwanted emergency brakes→**delays.**

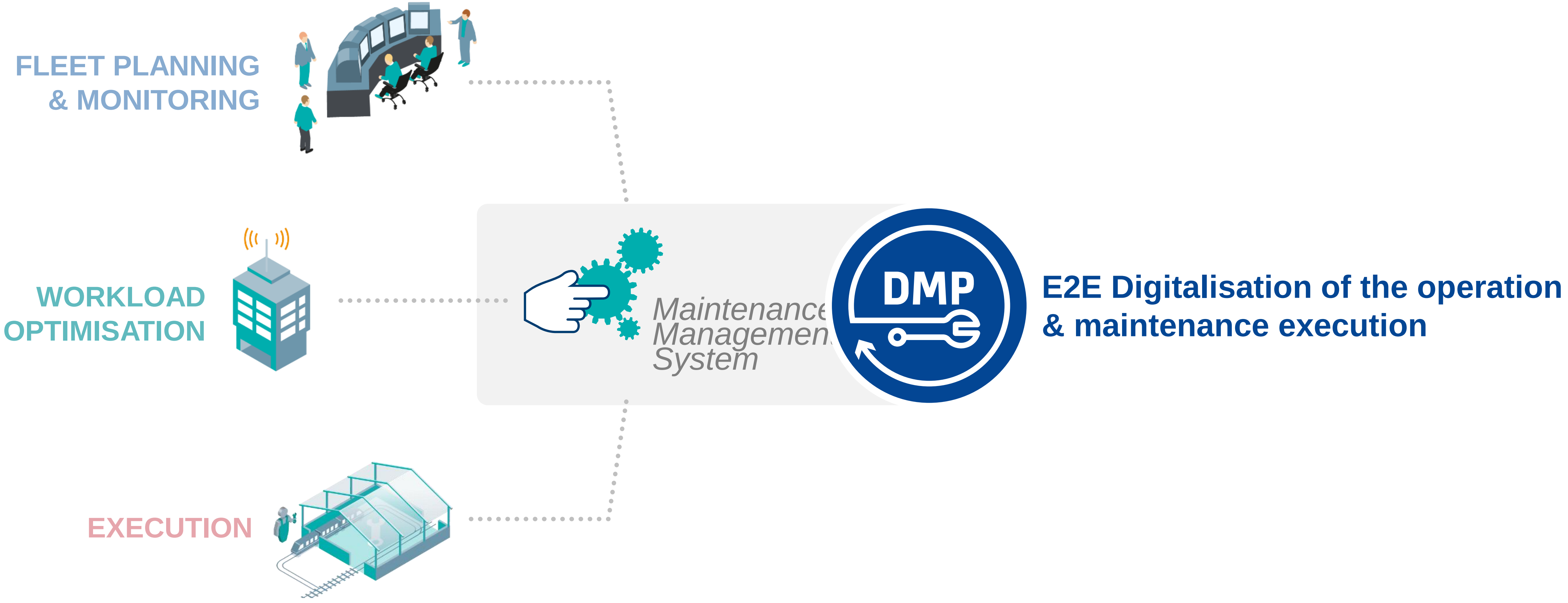
- ***AI/Machine learning based Solution***

→Continuous or periodic Monitoring of radio signal strength
→Preventive maintenance measures to avoid traffic disruptions



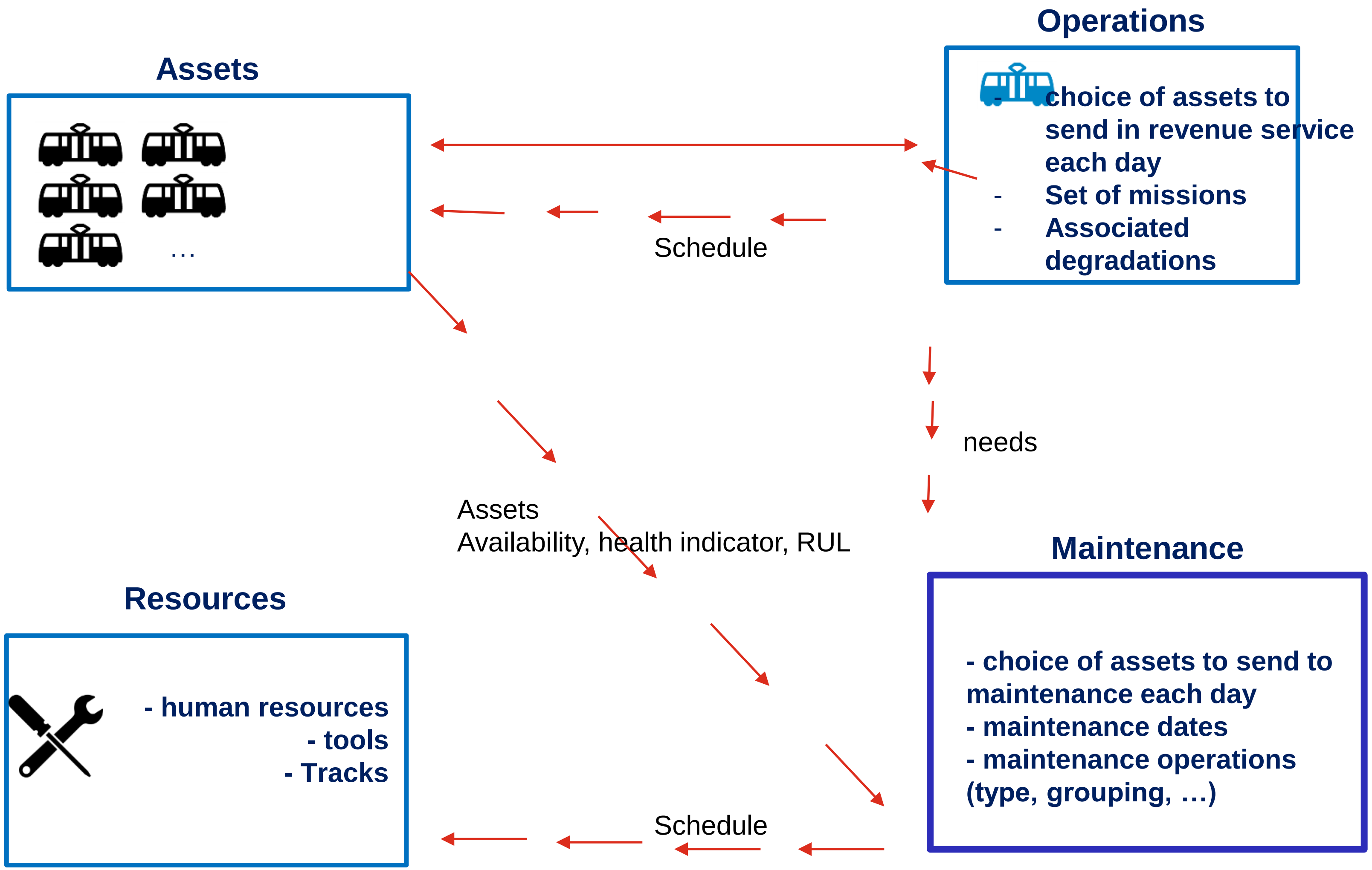
# What is dynamic Maintenance Planning ?

From individual asset to fleet

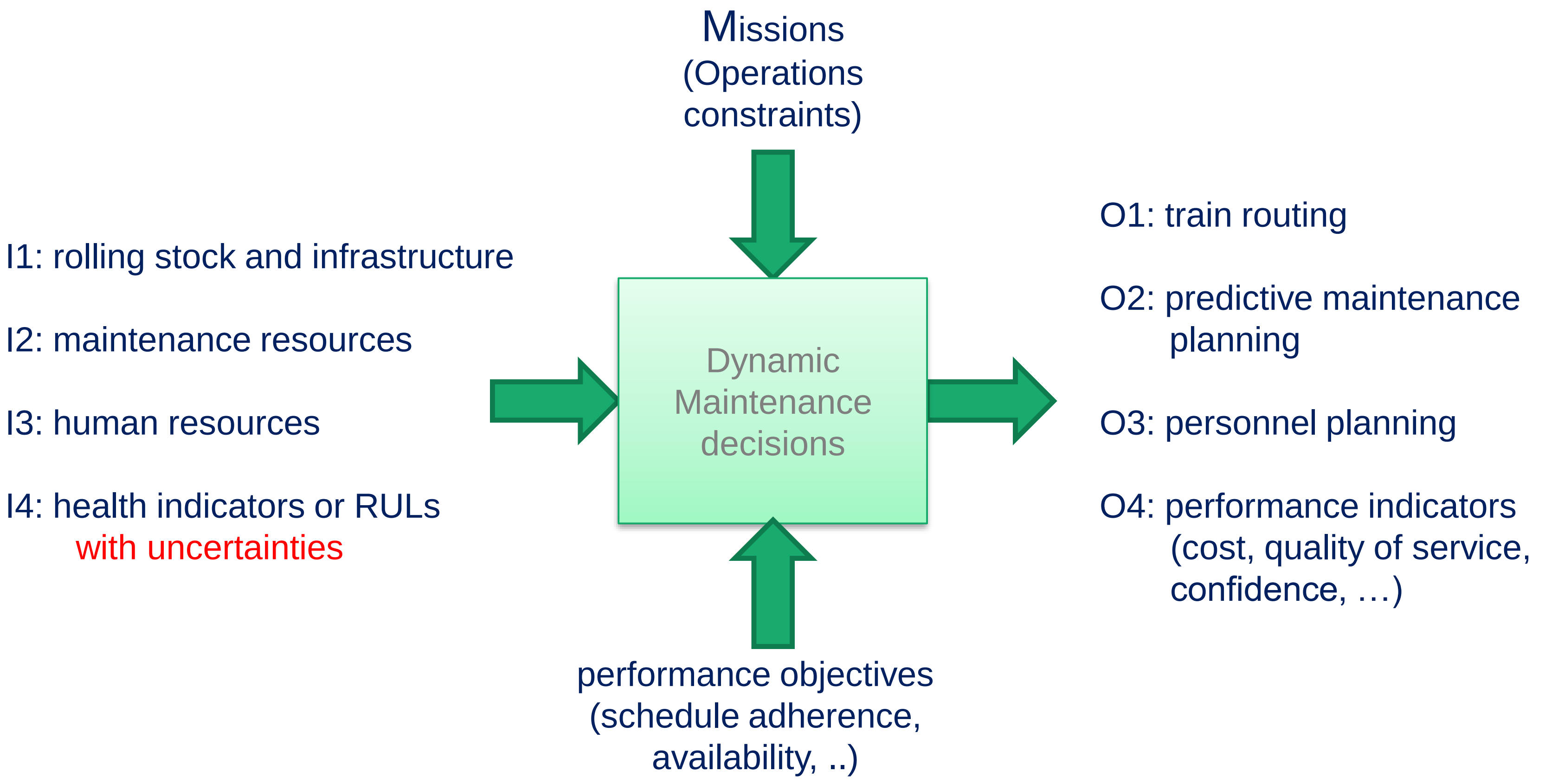


# Fleet Level:Maintenance and Operations

## Multi-agent System



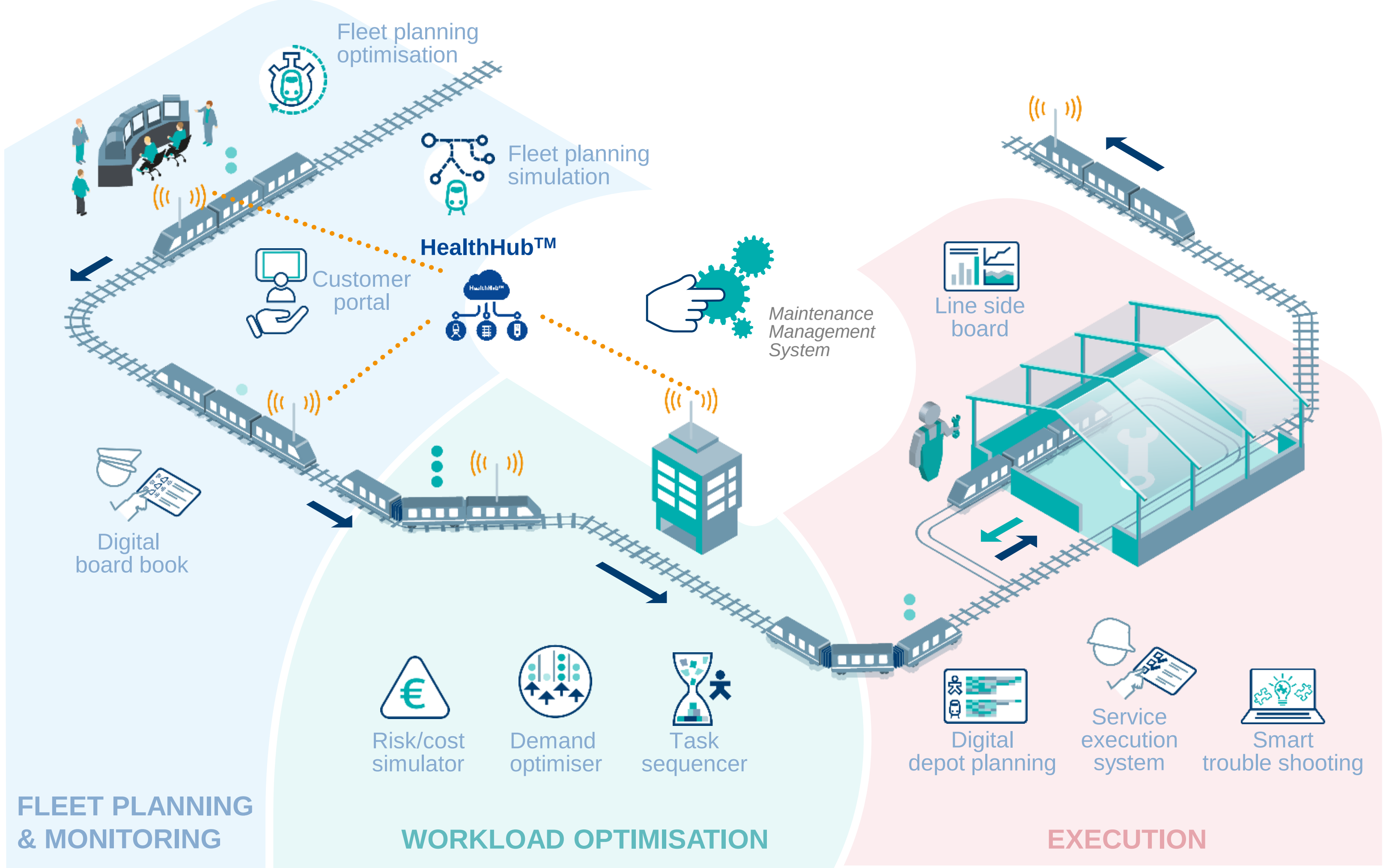
# Maintenance and Operations Decisions




**Predictive maintenance for a fleet of assets with material and human resource constraints**

# The Dynamic maintenance planning journey

## Dynamic Optimization with Uncertainty



# Enabler: Digitalisation is changing the world of Operations.

# the MASTRIA® mobility platform

**Multimodal coordination:** all modes of transportation

**Operation supervision:** **alternative solutions** in case of incident

**Predictive analytics:** **plan and optimize** the mobility **based on the demand**

**Facilitate** **MaaS (‘Mobility as a Service”)** implementation

Public Tranport

Roads

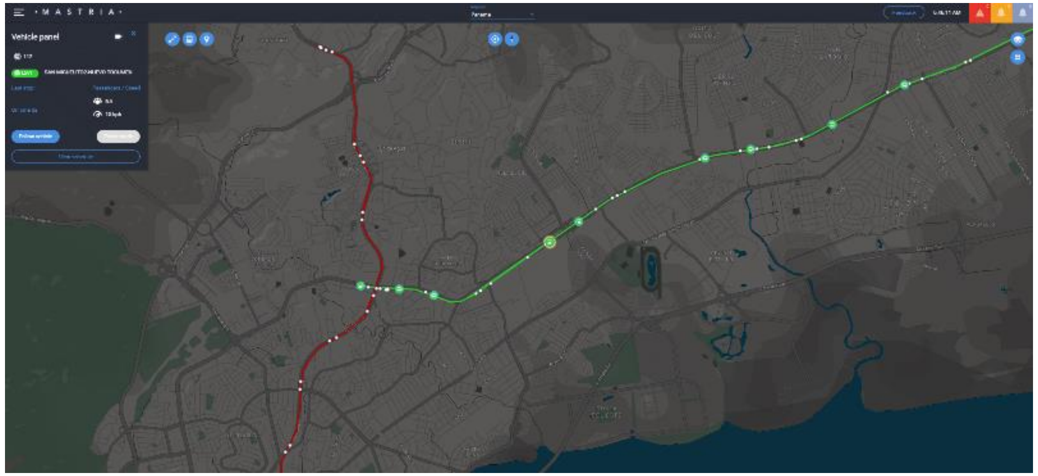
City

Telecom

# Example of Results: network capacity optimization ( Panama City)

**Max ¨Fail to Board¨ from 70% to 40%**


- Prediction 30 minutes in advance of ¨Fail to Board¨ alert (50%)
- Activating ¨direct trains¨ to the right stations
  - Immediate results in December 2019 – January 2020




*Real-time monitoring of the trains and their load*


*¨Fail to Board¨ at San Miguelito*

**3 minutes less waiting time for 30 000 passengers during peak hours**
**1500 hours per day -> equivalent 3M$ GDP / year**

## Existing Data

**Rolling stock & Signalling**
- Coach, train weight & position
- Doors events & technical data

**Tickets**
- Validations
- People counting

**Smartphone Apps**
- Trip planning
- Crowd sourcing

**Cameras**
- Video flows
- Temperature & behavior

**Telecom**
- Origin-destination matrix
- Density information

« AI Powered »:

Deep reinforcement learning

## Cross-data Analytics

## Simulating & Planning

**Analyze people flow**
**In trains and at stations**
**Anticipate demand evolution**

**Simulate access restriction**
**Measure impact on people flow**

## Monitoring & Predicting

**Real-time people flow monitoring**
**In trains and stations**
**Predict demand evolution**

**React to demand spike / incidents**
**Activate actions at the right time**

OPERATIONS CONTROL CENTERS

## Informing Passengers

**Info trains & stations** **Apps** **Open data**

# Conclusion:Global Vision

SUPPLY

DEMAND

Rail

SoS

Other modes

Dynamic prediction of Asset Health *(uncertainty)*

Single item
Complex system

From single asset to  entire Fleet

Dynamic prediction of Passenger Demand *(uncertainty)*

OPTIMIZATION

- Maintenance
- Operations

# Challenges and Opportunities

## Opportunities

- Leverage AI/ Machine Learning and combine with traditional optimization
- Context-adaptive maintenance and operations policies
- Reconfiguration algorithms learning from past experience
- Deep Learning for PHM

-Model more explicitly the “negotiation process” between Operations and Maintenance agents→ game-theoretic approach ?

# Challenges and Opportunities

## Challenges

-Large –scale real time optimization of distributed systems with multiple decision makers

-Dealing with ‘Systems-of-Systems’ issues ( Multimodality) : committing to performance (availability, cost) despite emergent behaviour→ Resilience

-Dealing with uncertainty, and uncertainty propagation (health indicators, RUL)

-Should decisions be
centralized : upload all health raw data to the cloud ?
or decentralized: bring intelligence (AI) down to the assets ?

-Assuring Cybersecurity and Safety

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# Acknowledgement

The author is grateful to Alstom and LTU colleagues for enriching discussions.

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