Smart Maintenance for Smart Mobility

Experience, Perspectives & Challenges

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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 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
- Operational and managerial independence
- Emergent Behavior
- Evolutionary Development → 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

**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

Accessibility of data
- Management of information
- Interface with other systems
- Maintainer feedback
Alstom’s CBM and PHM (Prognostics & Health Management) Framework

Stages as per ISO 13374 standard

Viewing

Analytics and Business rules

PHM
Prognostics and Health Management

"From raw sensors to predictive recommendations for operation & maintenance"

Prognostics
- Trend analysis
- RUL estimation

Health Assessment
- Problem identification
- Severity assessment

State Detection
- Health Indicator computation
- Abnormal behavior detection

Data Manipulation
- Expert-based signal processing
- Smart data compression: segmentation and features

Advisory Generation
- O&M recommendations

HealthHub™ Platform

"Leverages IoT, railway expertise and modern AI for high added-value predictive BI"
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 $k \to 1$ (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 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 PLANNING & MONITORING

WORKLOAD OPTIMISATION

EXECUTION

E2E Digitalisation of the operation & maintenance execution
Fleet Level: Maintenance and Operations

Multi-agent System

**Assets**
- Choice of assets to send in revenue service each day
  - Set of missions
  - Associated degradations

**Operations**

**Maintenance**
- Choice of assets to send to maintenance each day
  - Maintenance dates
  - Maintenance operations (type, grouping, …)

**Resources**
- Human resources
- Tools
- Tracks

**Schedule**

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

Missions (Operations constraints)

I1: rolling stock and infrastructure
I2: maintenance resources
I3: human resources
I4: health indicators or RULs with uncertainties

O1: train routing
O2: predictive maintenance planning
O3: personnel planning
O4: performance indicators (cost, quality of service, confidence, …)

Dynamic Maintenance decisions

Performance objectives (schedule adherence, availability, ..)
The Dynamic maintenance planning journey

Dynamic Optimization with Uncertainty

Fleet planning optimisation
Fleet planning simulation
Customer portal
HealthHub™
Maintenance Management System
Digital board book

Risk/cost simulator
Demand optimiser
Task sequencer

Digital depot planning
Service execution system
Smart trouble shooting

FLEET PLANNING & MONITORING
WORKLOAD OPTIMISATION
EXECUTION
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
Example of Results: network capacity optimization (Panama City)

- 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

Max “Fail to Board” from 70% to 40%

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

[Image of a crowded station]

[Graph showing failed to board rates over time]
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

Informing Passengers
- Info trains & stations
- Apps
- Open data
Conclusion: Global Vision

**SUPPLY**
- Dynamic prediction of Asset Health *(uncertainty)*
  - Single item
  - Complex system
- From single asset to entire Fleet

**DEMAND**
- Dynamic prediction of Passenger Demand *(uncertainty)*

**OPTIMIZATION**
- Maintenance
- Operations

Rail

SoS

Other modes

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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 \( \rightarrow \) 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
Some Bibliographical References


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