WP 5

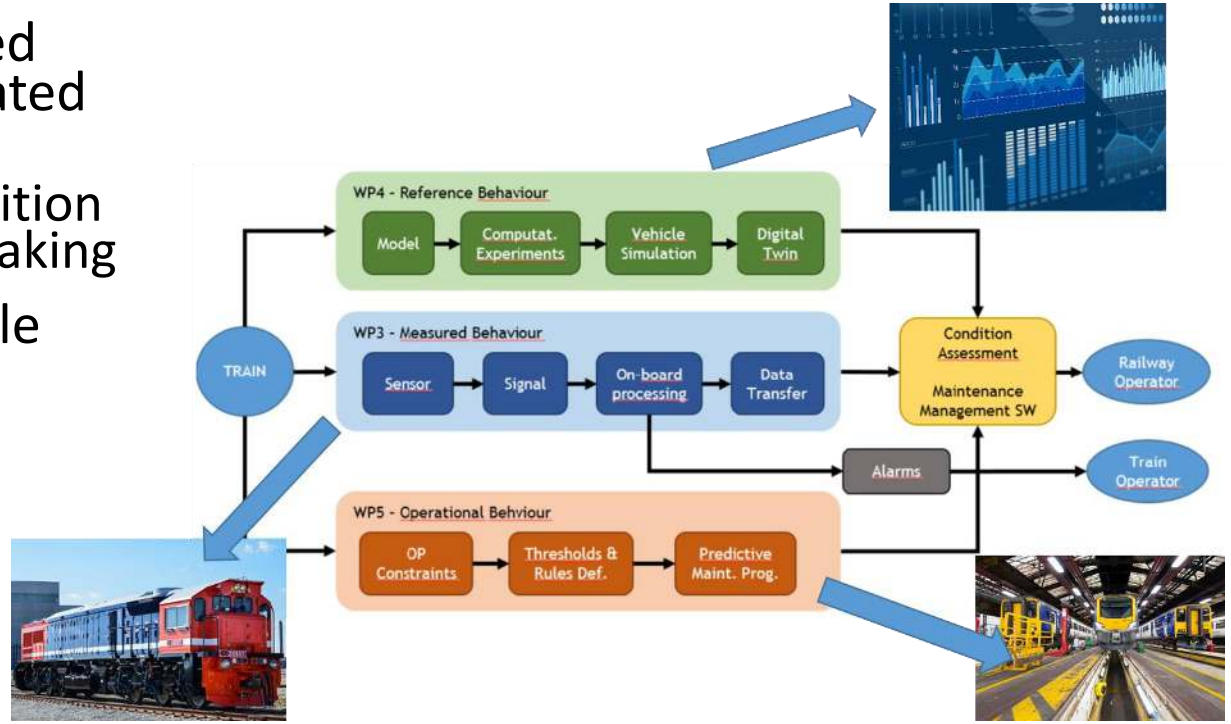
Operational Behavior

Grant 881805

Locomotive bOgie Condition mAinTEnance (LOCATE)

- Technologies for sustainable and attractive European rail freight (IP5)
- Set-up a complete procedure for condition-based maintenance of a locomotive bogie (and associated sub-systems)
  - Provide reliable information about its condition allowing effective maintenance decision-making
- Implementation and evaluation through full-scale demonstration on FGC Series 254 locomotive
- Three key objectives:

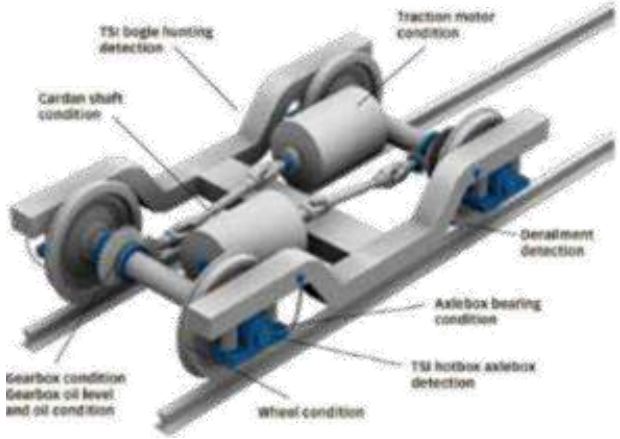
1. Measured behaviour: set-up a complete measurement scheme of the bogie sub-system (WP3)
2. Reference behaviour: threshold values and reference condition criteria (WP4)
3. Operational behaviour: framework for predictive maintenance based on condition/reference behaviour, optimised maintenance schedule and operational constraints (WP5)



WP5 Aims & objectives

- To develop a framework for condition-based and predictive maintenance of bogies which can be effectively integrated into current fleet maintenance programs

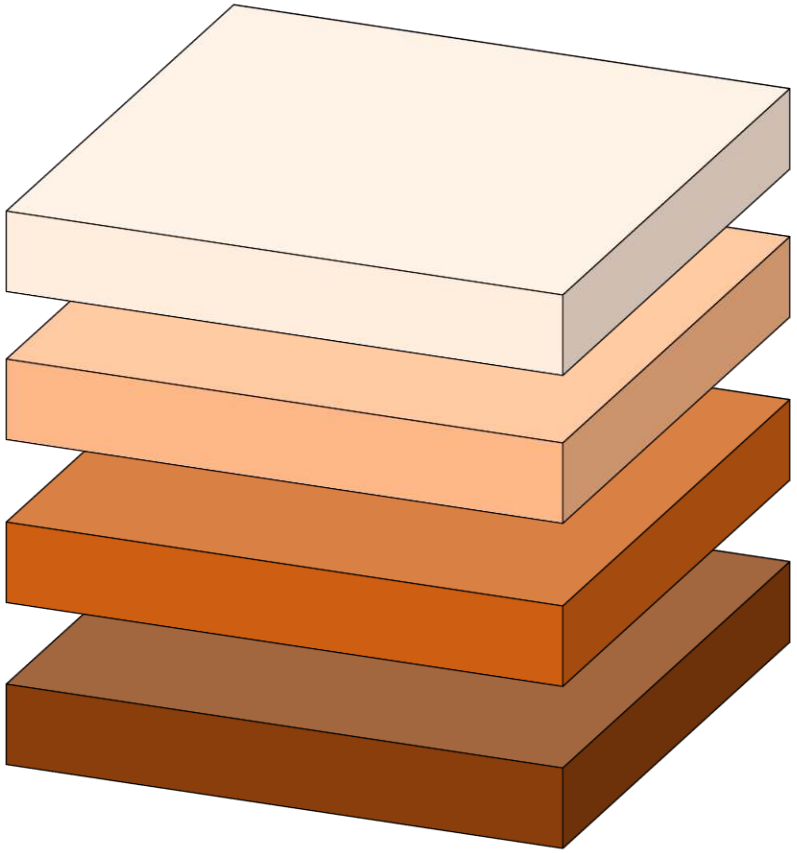
1. Comprehensive understanding of common failure mechanisms of a bogie, including:
   - degradation process and safety/risk profile
   - indicators of health condition (e.g. parameters and limit values)
   - maintenance actions and procedures
   - constraints of these maintenance procedures
2. Definition of decision-making framework for locomotive bogie maintenance and an understanding of the technical and operational constraints and opportunities for optimisation
3. To produce a sound knowledge-map for applying various optimisation methods and tools in practical maintenance programs of bogies
4. To develop a prototype of a software tool to support the decision making and optimisation of maintenance plans



Digital maintenance strategies

Prescriptive Maintenance
- Dynamic condition
- Agile and responsive
- Low cost (PdM ROI)
- Highly disruptive

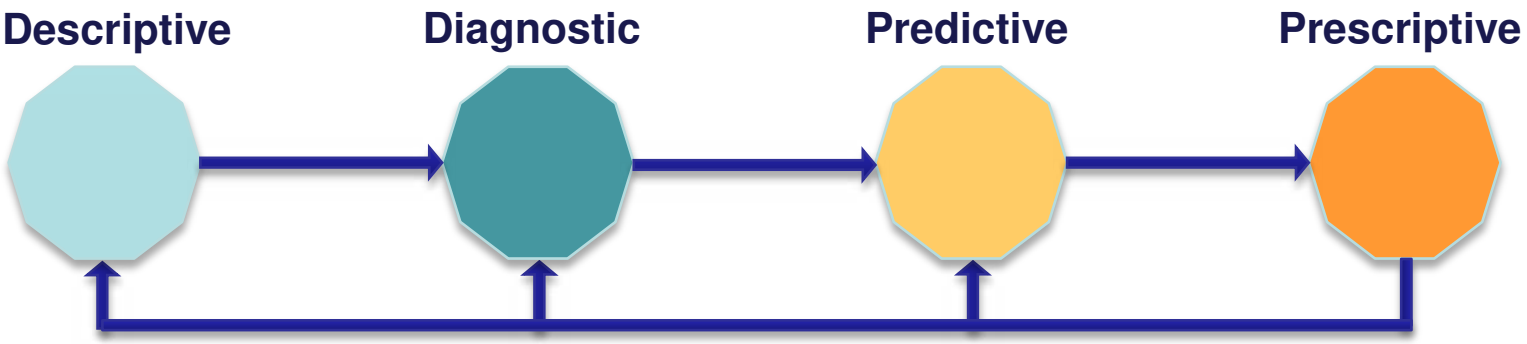
Preventative Maintenance
- Time \ distance based
- Safety implications
- Loss of time
- Low cost
- Reliable
- High Maintenance costs
- Loss of availability



Predictive Maintenance (PdM)
- Condition based
- Timely intervention
- Lower cost
- Initial high cost

Corrective Maintenance
- Run to failure
- Safety implications
- Loss of time
- Costly implications
- Unreliable

Digital maintenance strategies



Digital Asset Representation

Digital Decision Support

Digital Performance Monitoring

Digital Technology Enablement

Foundations

Analytical

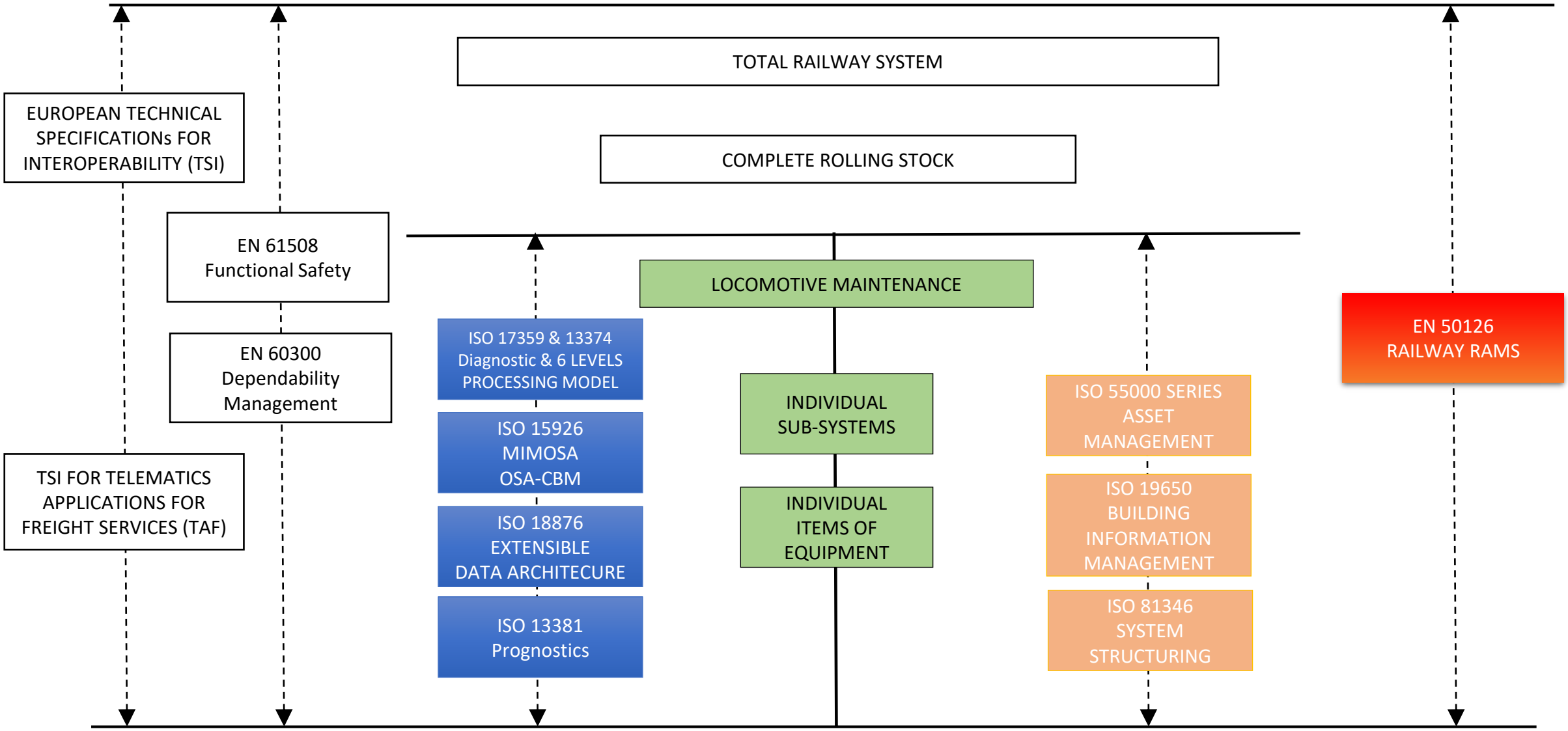
- - - - - - -

Technological

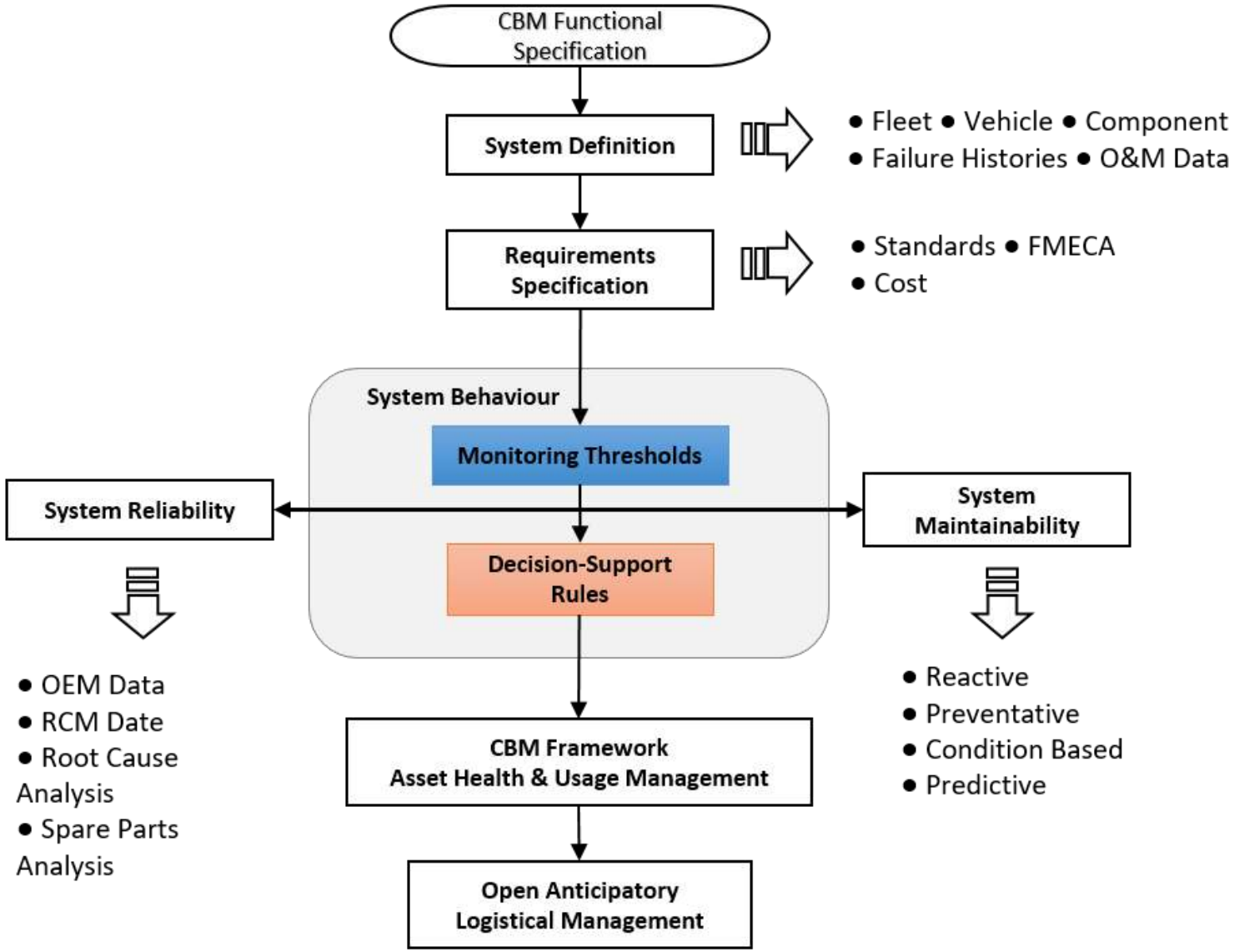
- - - - - - -

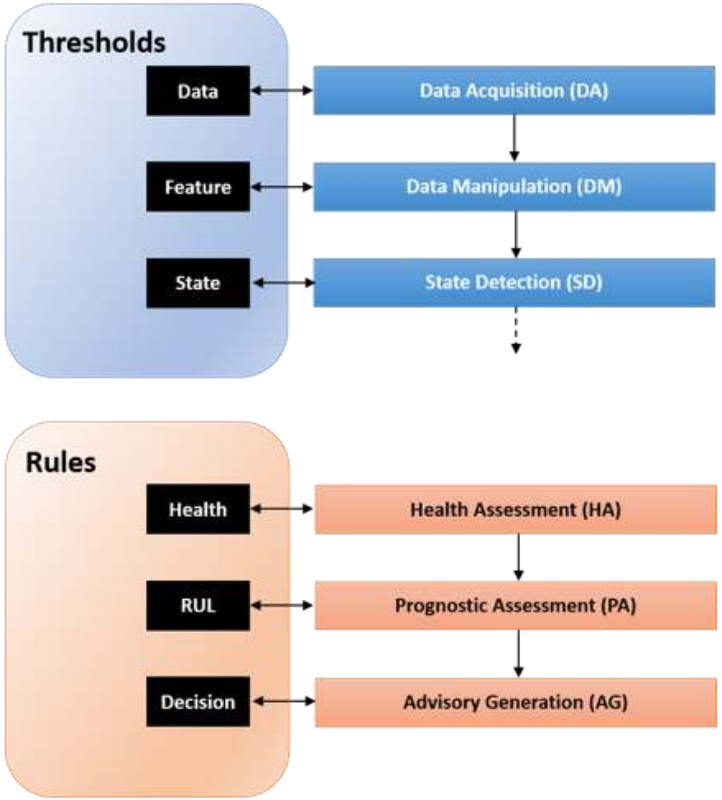
Digital

Structured approach to CBM

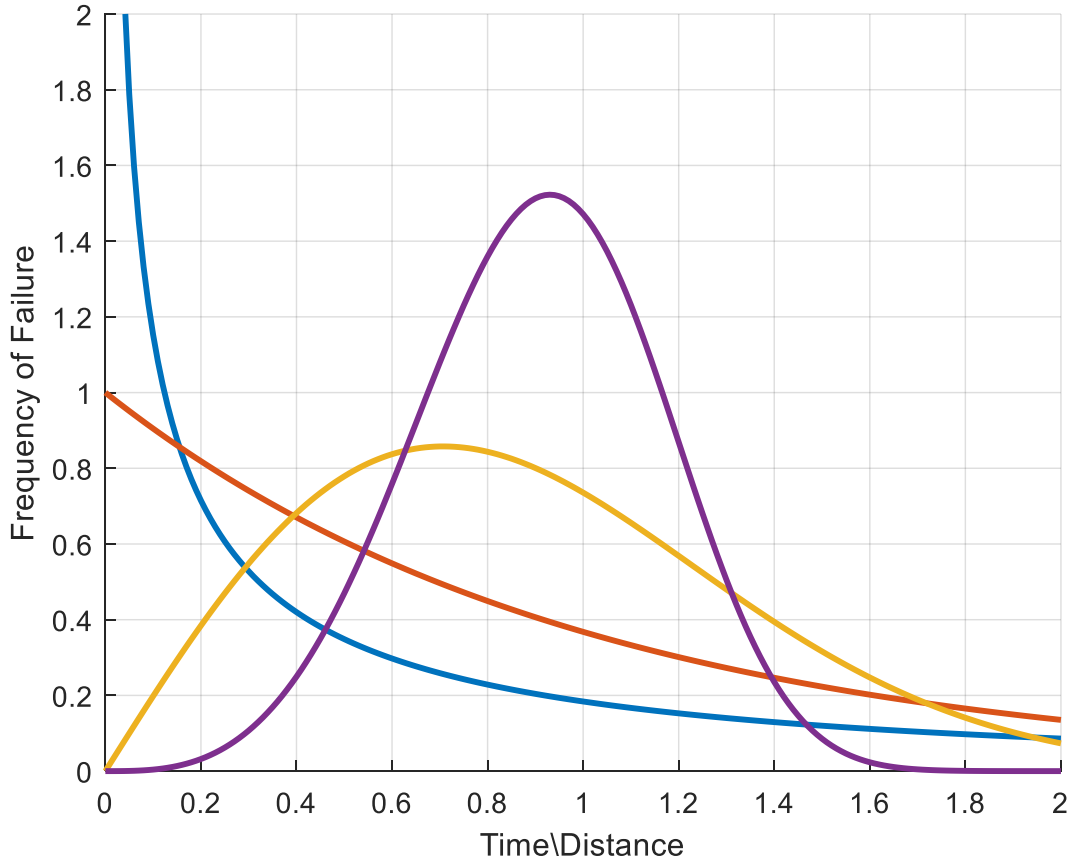


CBM Functional Specification

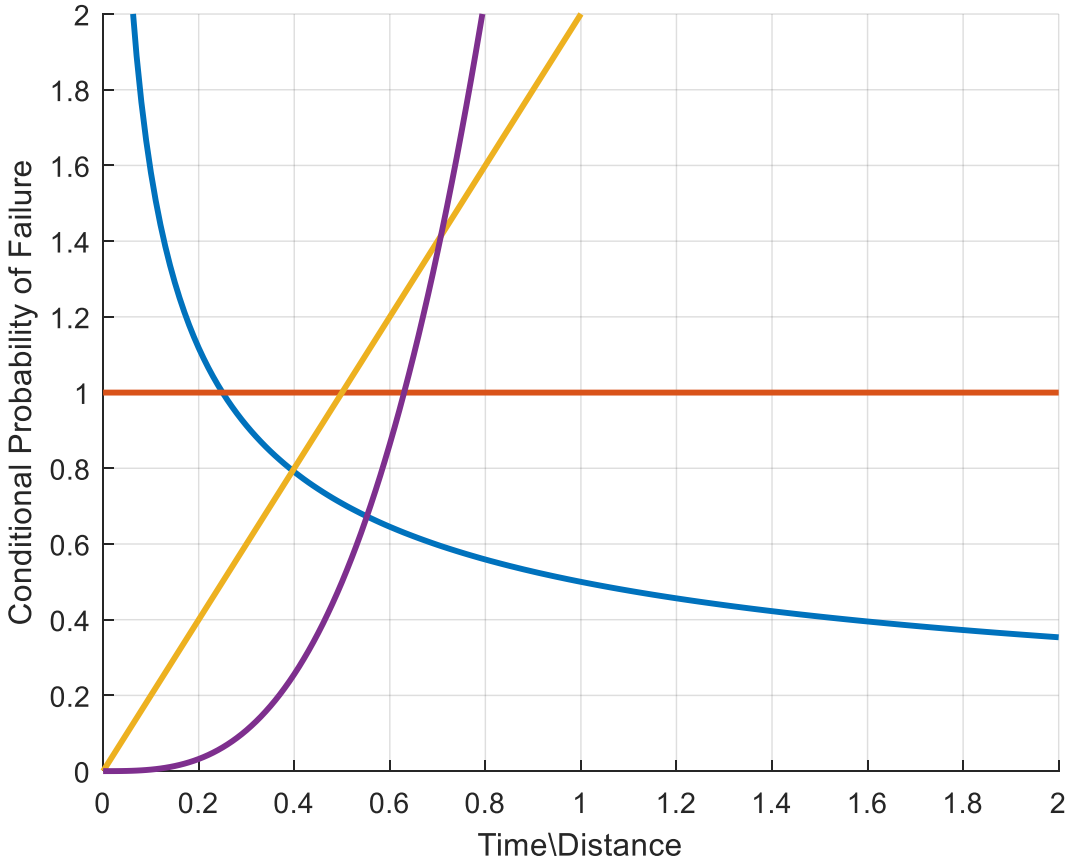




Reliability Engineering



(a)



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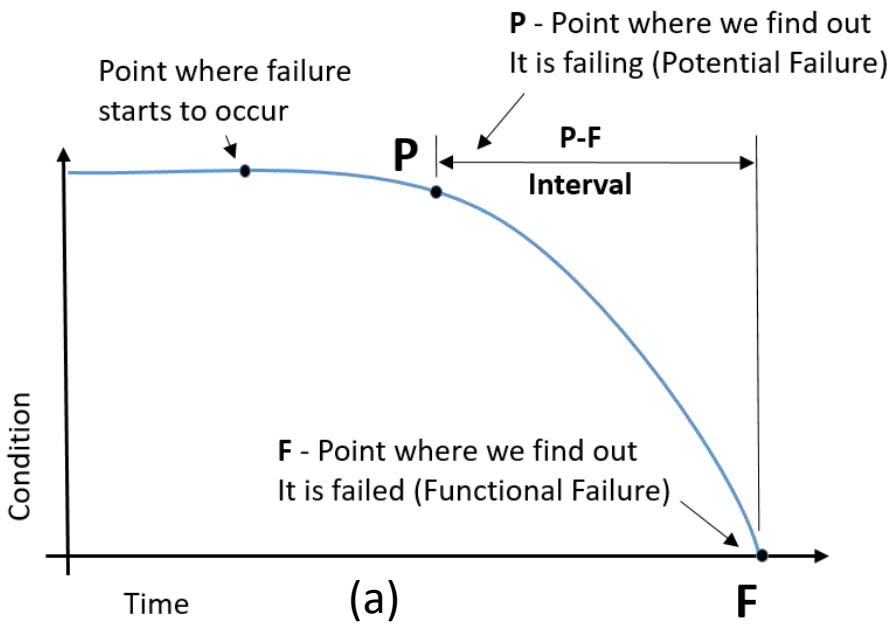
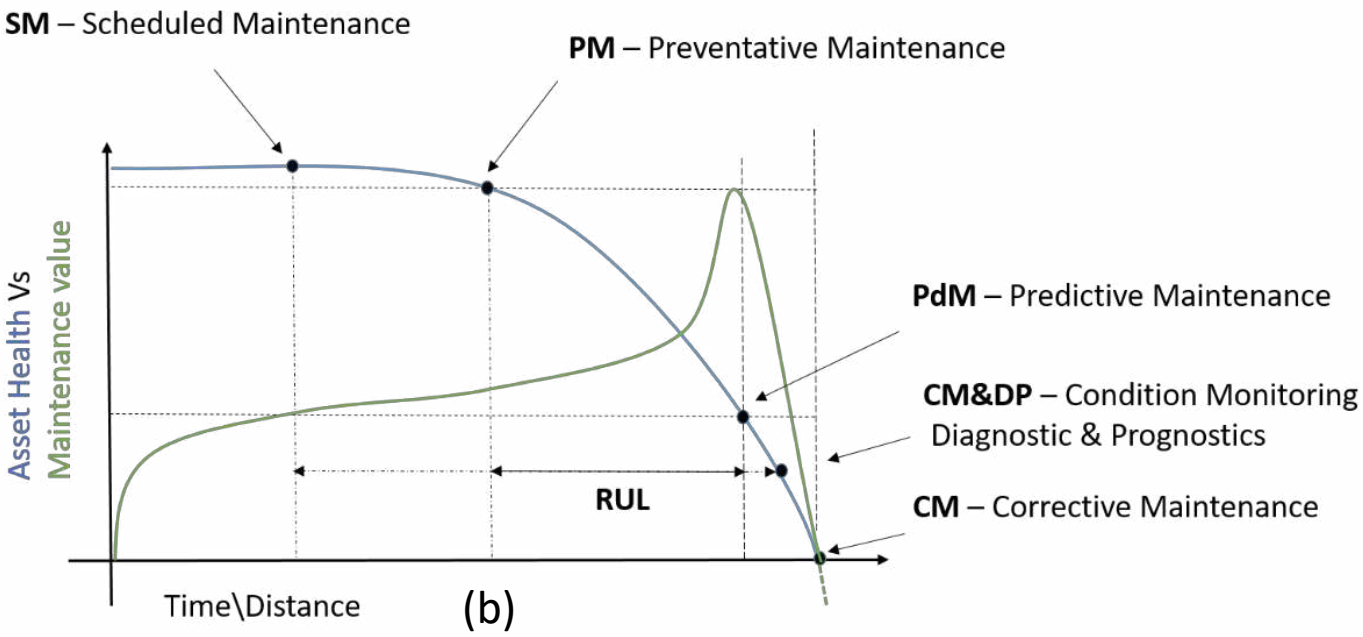
Predictive Maintenance





Integrated Framework

FMECA + Expert Judgment

- Selection of critical subsystems and components
- Failure Modes listing and prioritisation
- Estimation of failure rates

Sensor Data

- Integration of predictive maintenance for selected components
- Estimation of Remaining Useful Life

Optimisation Framework

- Mixed-Integer Linear Programming Scheduling Algorithm
- Capacity and Operational constraints set according to FGC's maintenance plan

Optimisation Framework

Table 23: Critical components based on the consolidated FMEA with Expert Judgment

Subsystem ID	Subsystem	Component	Component ID	Failure Mode	Severity	Failure rate (1/h))	Source
1	Wheelset	Axle	1.1	Axle Crack	10	1.5E-05	Expert Judgment
		Wheels					
		Bearings					
2	Axle Box	Axle Box					
		Axle Box					
		Axle Box					
3	Bogie Frame	Frame					
		Brake					

subsystem	component	failure mode
wheelset	axle	visible impacts
wheelset	axle	fatigue cracks
wheelset	axle	fatigue cracks
wheelset	wheels	cracks and notches on the wheel tread
wheelset	wheels	flats
wheelset	wheels	build up od material in case of CBB
wheelset	wheels	wheel out of round
wheelset	wheels	wear of the profile over threshold equivalent conicity exceeds
wheelset	wheels	wheel diameter < minimum
wheelset	wheels	internal distance between wheels too important
wheelset	wheelset	

Realistic

Based on FGC's maintenance and standards

Flexible

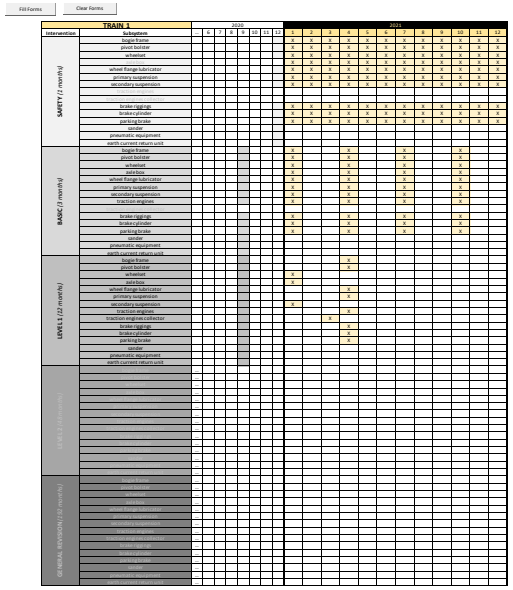
Piecewise hazard rate curves, easy to add/remove components

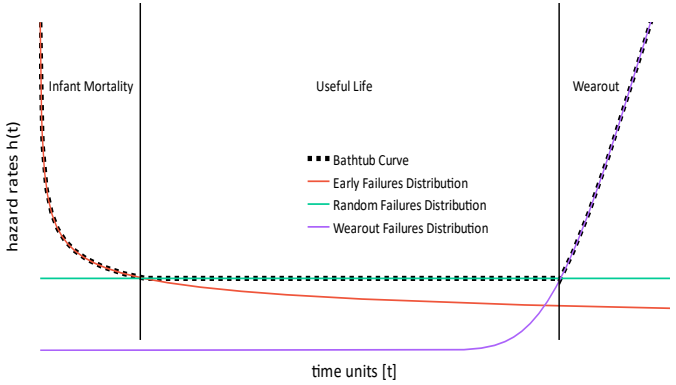
Fast

Running times: < 10 sec for commercial, about 20min for open source solvers

Effective

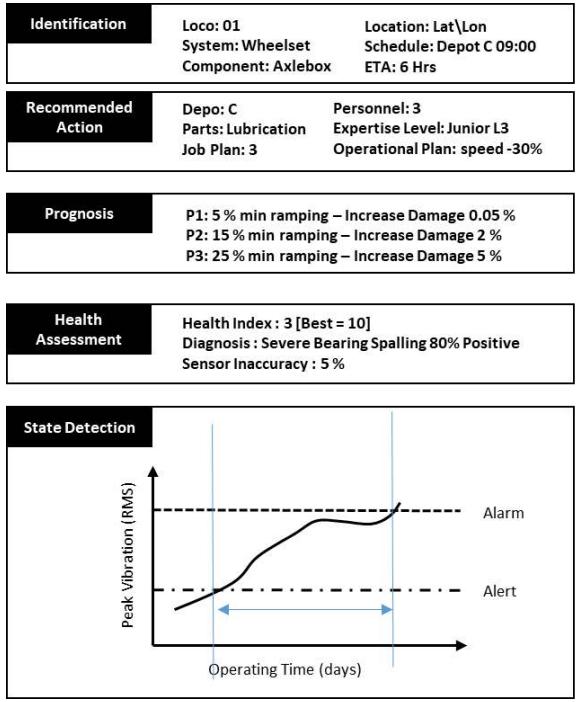
Delivers a maintenance plan within <0.5% of optimal solution in terms of expected maintenance costs





LOCATE – WP5 outputs and next steps

- CBM framework has been developed based on FMECA
  - Condition monitoring, diagnostics and prognostics approach has been adopted
- LOCATE CBM framework includes:
  - MSG3\RCM approach to development of functional failures modes
  - Failure frequency distribution and conditional probability of failure
  - P-F interval linked to maintenance task interval
  - Proportional hazard model linked to condition data for prognostics
  - Safety, environmental, operational and economic concerns observed to meet asset life cycle costs
- Next steps:
  - Complete demonstrator on FGC locomotive
  - Validation of ‘digital twins’ and P-F intervals
  - Linear piecewise approx. model for scheduling optimisation based on demonstrator



- Current Records
- Historical Records
- Operating cost
- Maintenance cost
- Spares Availability
- Load cycle
- Vehicle Speed
- RUL
- Root Cause Analysis
- Real-time asset status