SAP Predictive Maintenance and Service

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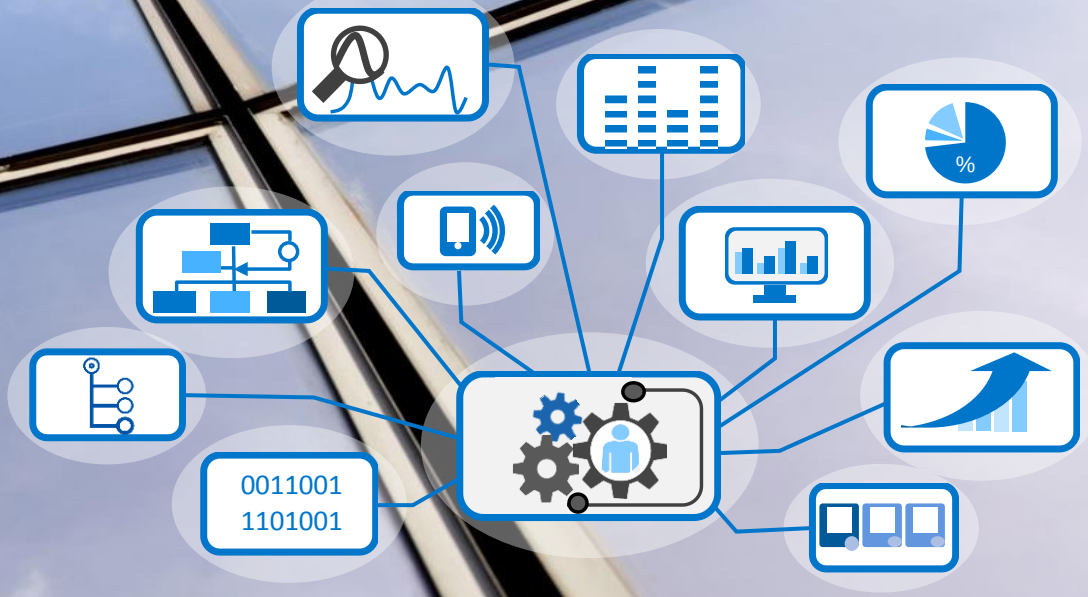

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Purpose of today's session

- Establish an overview of SAPs solution and vision on Predictive Maintenance & Services (PdMS)
- Understand the journey – Running a predictive maintenance project requires huge efforts but wields equally big potentials
- Case of Trenitalia

*) OT = operational technology

SAP Predictive Maintenance and Service solution

From sensor to outcome

Sensor

Connected assets

- Onboarding
- Connectivity
- Device management
- Security

Data

IT/OT* Convergence

- Big Data ingestion
- Big Data infrastructure
- Merging sensor data with business information

Insight

Data analysis

- Root cause analysis
- Asset health monitoring
- Machine learning
- Anomaly detection
- Triggering of corrective actions

Action

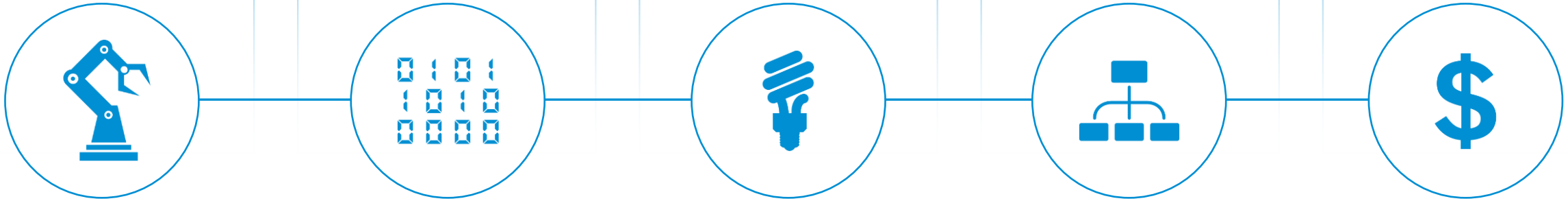
Maintenance activities

- Prioritized maintenance and service activities
- Optimized warranty and spare parts management
- Prescriptive Maintenance
- Quality improvements

Outcome

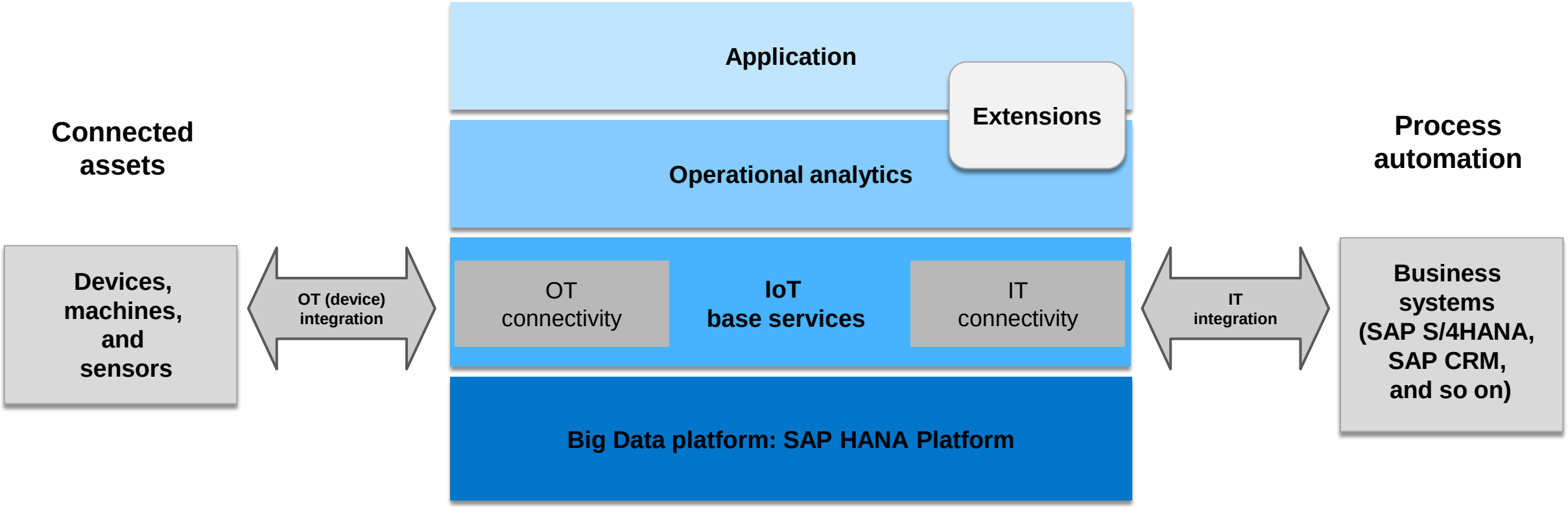
Business Value

- Customer experience
- Increased quality
- Lower costs
- Operational efficiency
- R&D effectiveness
- Material procurement



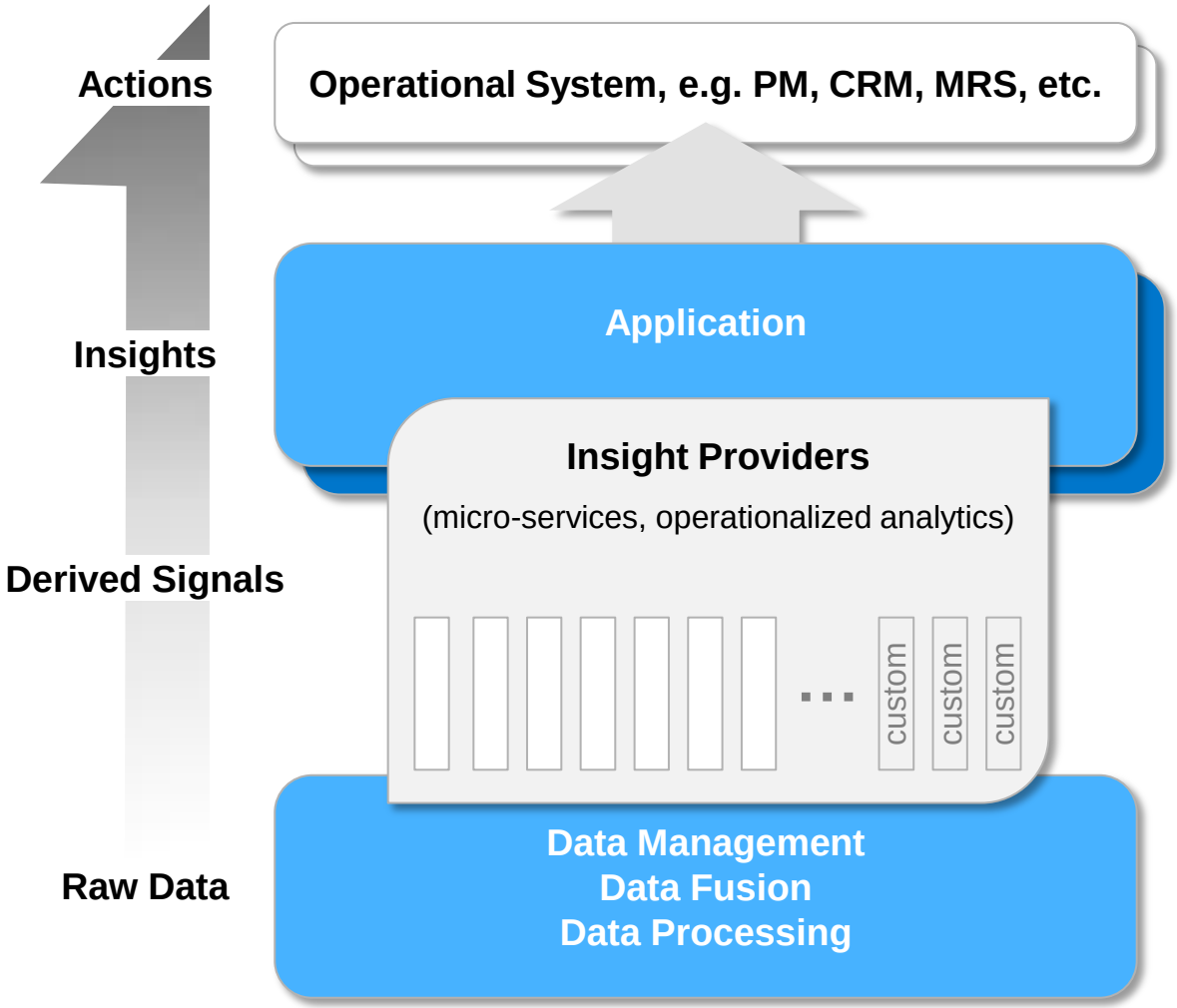
*) OT = operational technology

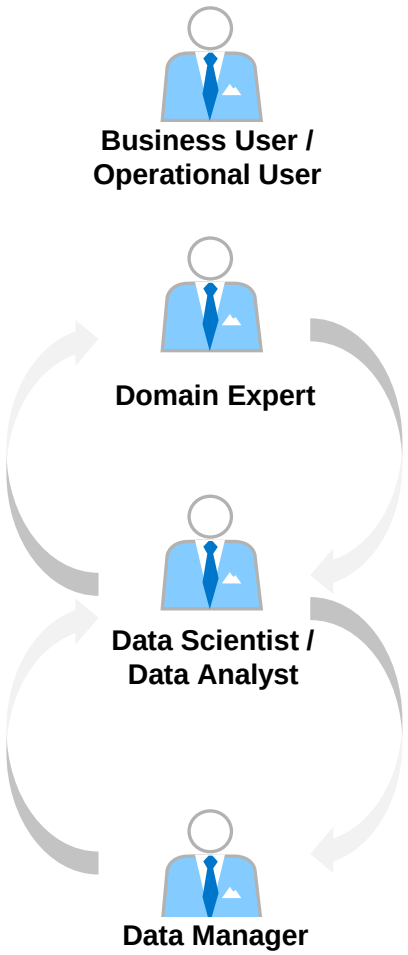
SAP Predictive Maintenance and Service Conceptual Architecture



SAP Products and Capabilities

How SAP Approaches Predictive Maintenance and Service





Take specific actions utilizing existing business systems

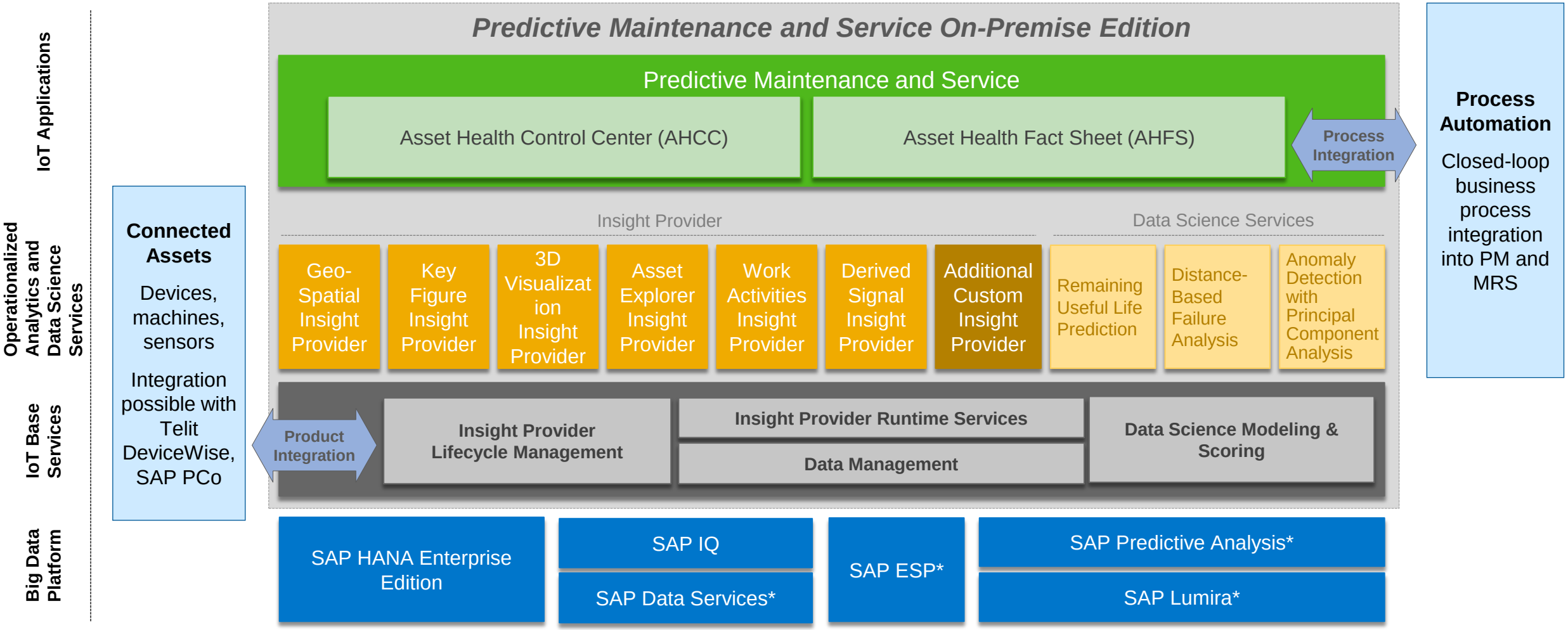
Deliver insights to the domain expert from interpreted signals

Translate the OT data into consumable signals

Capture operations technology (OT) data through scalable and cost-effective process

Predictive Maintenance and Service On-Premise Edition (PdMS OPE)

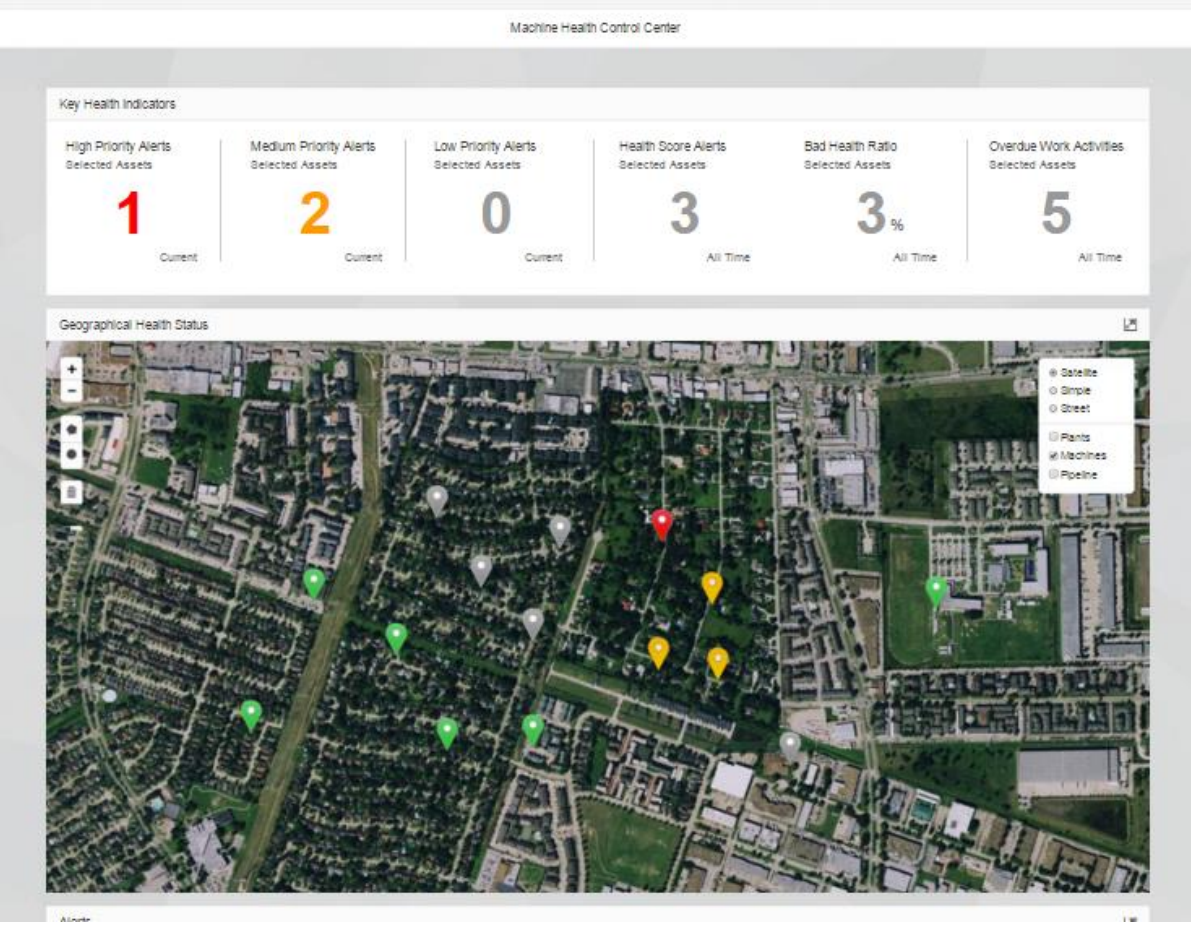
Business Applications built on Modular Analytics



*Optional components

SAP Products and Capabilities

Asset Health Control Center: Supervise Machine Health and Act on Issues



Health status at a glance

- Health status of the complete fleet
- Aggregated from component health scores
- Based on out-of-the-box machine learning
- Derived Signals Management

Personal and extensible

- Flexibly composed by insight providers
- Drill-down into 1 machine

Integrated into operational processes

- E.g. close-loop integration for services
- via Multi-Resource Scheduling (MRS)

Maintenance Innovation in Context Railway Case

Trenitalia at a Glance

❑ Fully owned by the FS Group, 100% controlled by the Ministry of Treasury	
❑ Staff	31.082 employees
❑ Fleet	1.580 locos 112 EMUs (electro-trains) 1.547 MUs (light trains) 25.896 coaches and freight cars 498 shunting locos
❑ Passengers	38,6 Bn of passenger / km per year
❑ Tons	14,7 Bn of tons / km per year
❑ Trains	7.263 / day
❑ Revenue	5.577 M€

The Business Value of Maintenance Innovation

Perform ALL the required interventions, and ONLY the required interventions, at the RIGHT TIME, ensuring availability of the RIGHT RESOURCES

Reduce Costs of Operations

- Avoid any unnecessary activity
- Plan in advance and in detail for any intervention, ensuring availability of spare parts, facilities, tools and trained resources

Reduce Unplanned Downtime

- Prevent breakdowns while trains are in operations
- Prevent extended maintenance downtime due to unforeseen activities

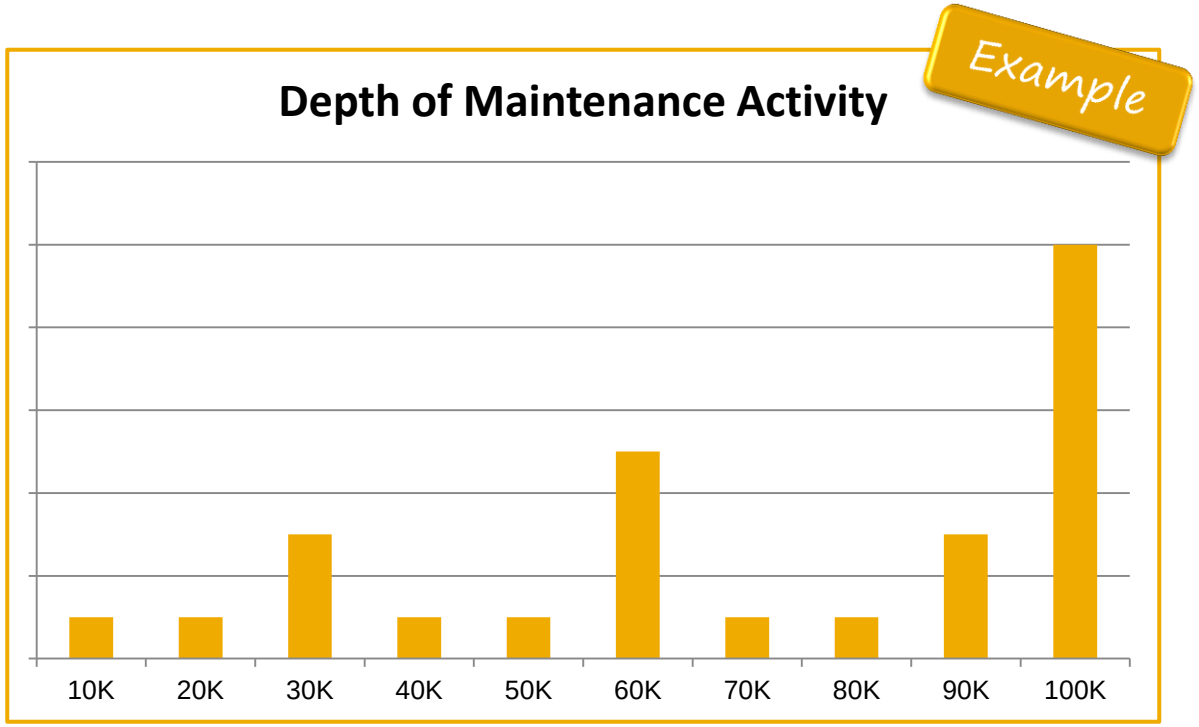
- >8-10% of direct savings on impacted maintenance costs
- >5-8% increase in asset availability
- >x% of reduction of breakdowns of trains in operations

Ground diagnostic

On board diagnostic

Dynamic Maintenance Management System

The Problem with Preventative Maintenance Planning



- Work done by simple assets can be described by a simple indicator such as time of operations or units of throughput, but if we consider a complex machine like a train, **the specific operational conditions have a huge impact on how its various components wear out**
- These operational conditions are not known a priori by the manufacturer of the machine, and can change dramatically in the day-by-day work – **this creates the need of operating under extremely conservative assumptions**
- The only real value of these plans is that they are logistically very simple to execute and don't require much information

Increase Planning Efficiency and Relevance With Life and Health Indicators

Life

Measure as precisely as possible the expected wear of the part by counting and projecting a set of relevant parameter (e.g. cycles, hours of operation, kilometers, energy etc.)

Maintenance is performed when predefined thresholds are reached

Health

Takes into account the actual status of operation by measuring physical parameters (e.g. closing time for a door, temperatures of cooling systems) or relevant combinations of indicators

Maintenance is performed when the parameter goes out of the normal range, indicating a probable deterioration of condition

Planning Engine
Improving the Relevance of Maintenance Activities

Planning based on Km / Time of operations

- Current model, standard in the industry
- Easy to operate because all the components in the material share the same driver
- Sub-optimal for the same reason

Planning based on Life Indicators

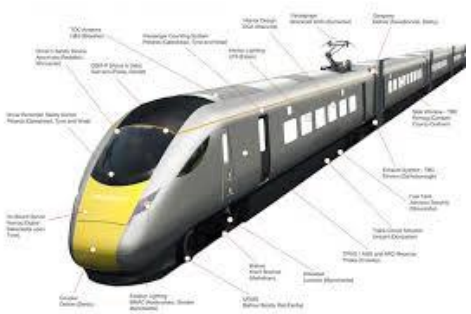
- Based on more relevant drivers and indicators that better represent the effective current and expected usage of every single component
- Increased precision is directly connected with the quality and precision of the planning for the materials
- Requires optimization methods in order to produce a plan, due to the fact that every component in a material can have different life situation

Planning based on Life and Health Indicators

- Further increase the relevance of the plan, considering the future effects that the evolution of life indicators will have on the ability of every component to perform, and on its risk of failure
- Requires sophisticated mathematical methods to predict the behavioral patterns of health indicator based on the expected usage of the materials
- Health indicators can in any case used to trigger short term maintenance activities

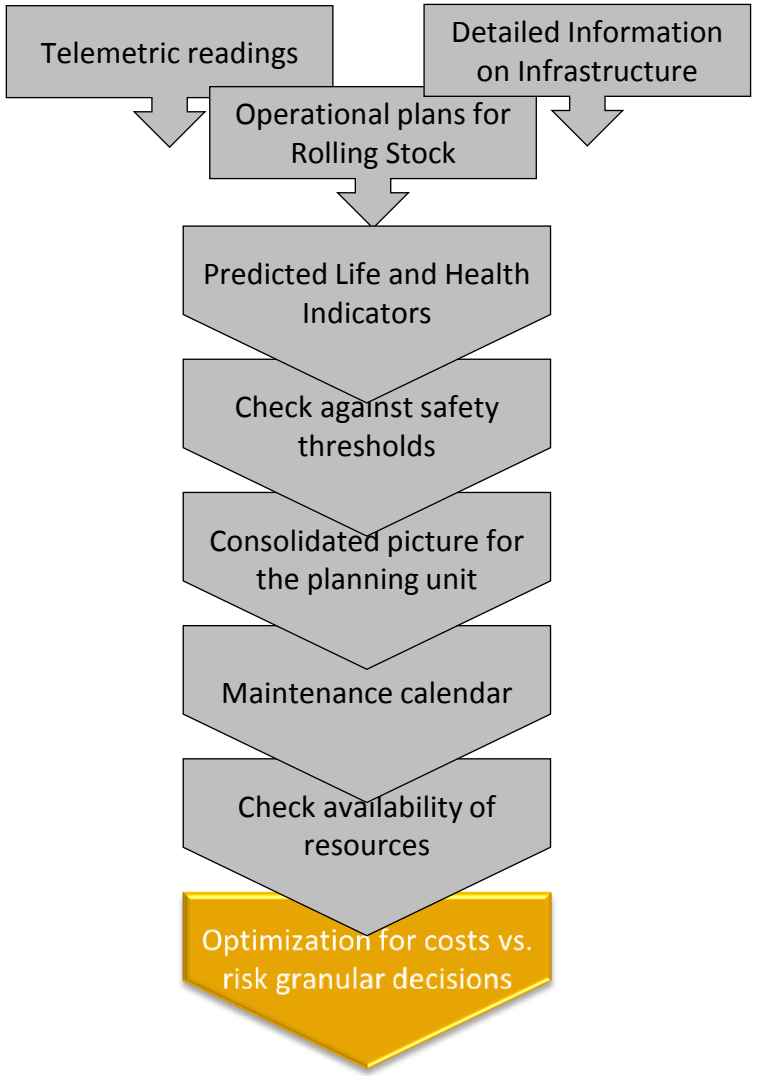
Life and Health Indicators in Action

SIMPLIFIED

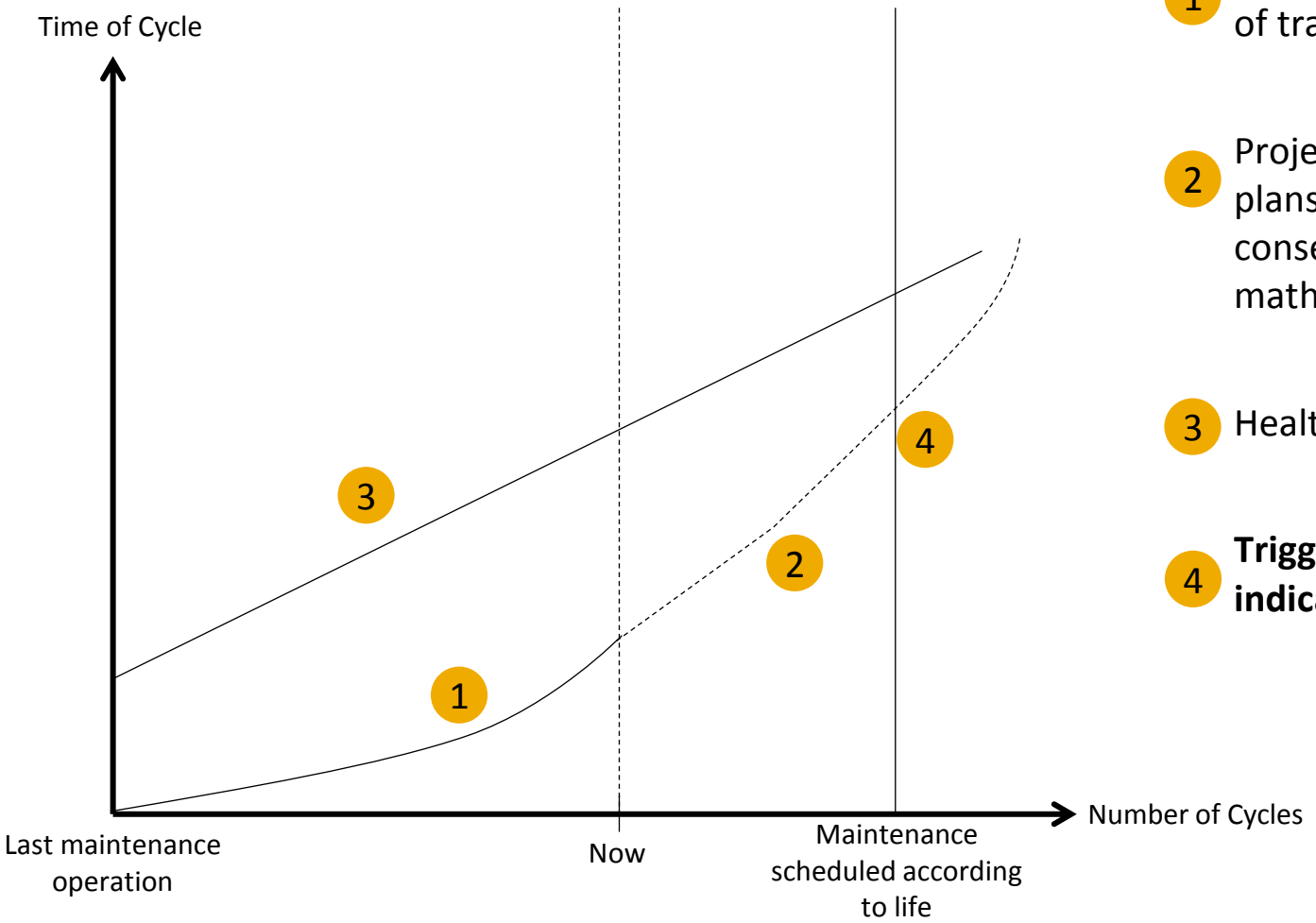


	Life Ind.	Health Ind.
Bearings	f(Km, radios, weight)	Vibration pattern
Wheels	f(Km, exchanges, radios, weight)	Edge shape
Engine	f(Km, weight)	f(power gen, power absrbd)
Doors	Open / close cycles	Open / close time
Pantograph	Up / down cycles	Up / down time
A/C	f(hours, ext temp, int temp)	f(Delta int temp)
…		

- "Real" Big Data in action: hundreds of TB, huge number of sources and entities involved
- Complex algorithms to predict indicators and optimize the outcome across multiple dimensions
- Huge transformational value and financial impact

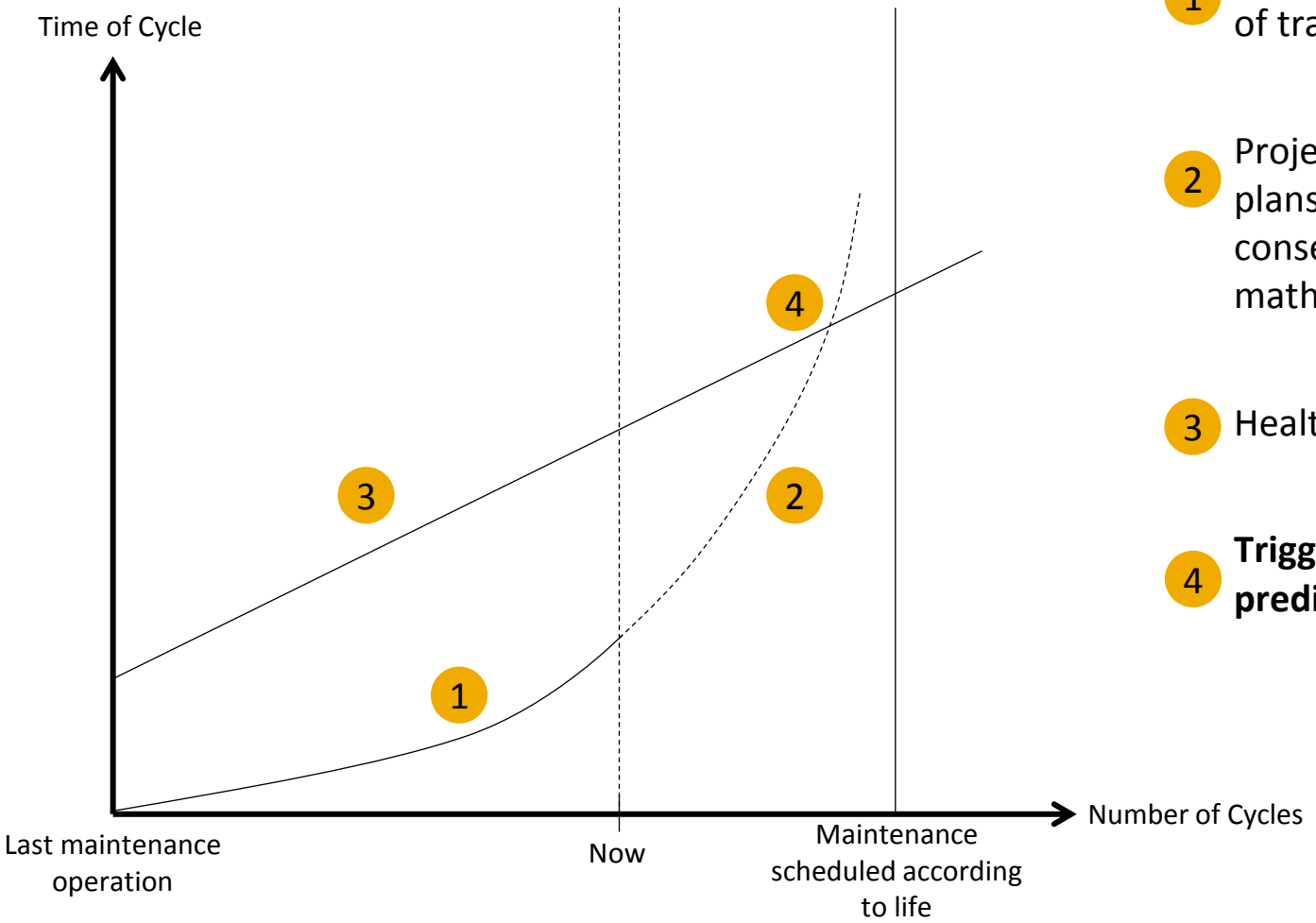


Life and Health Indicators for Trains Doors



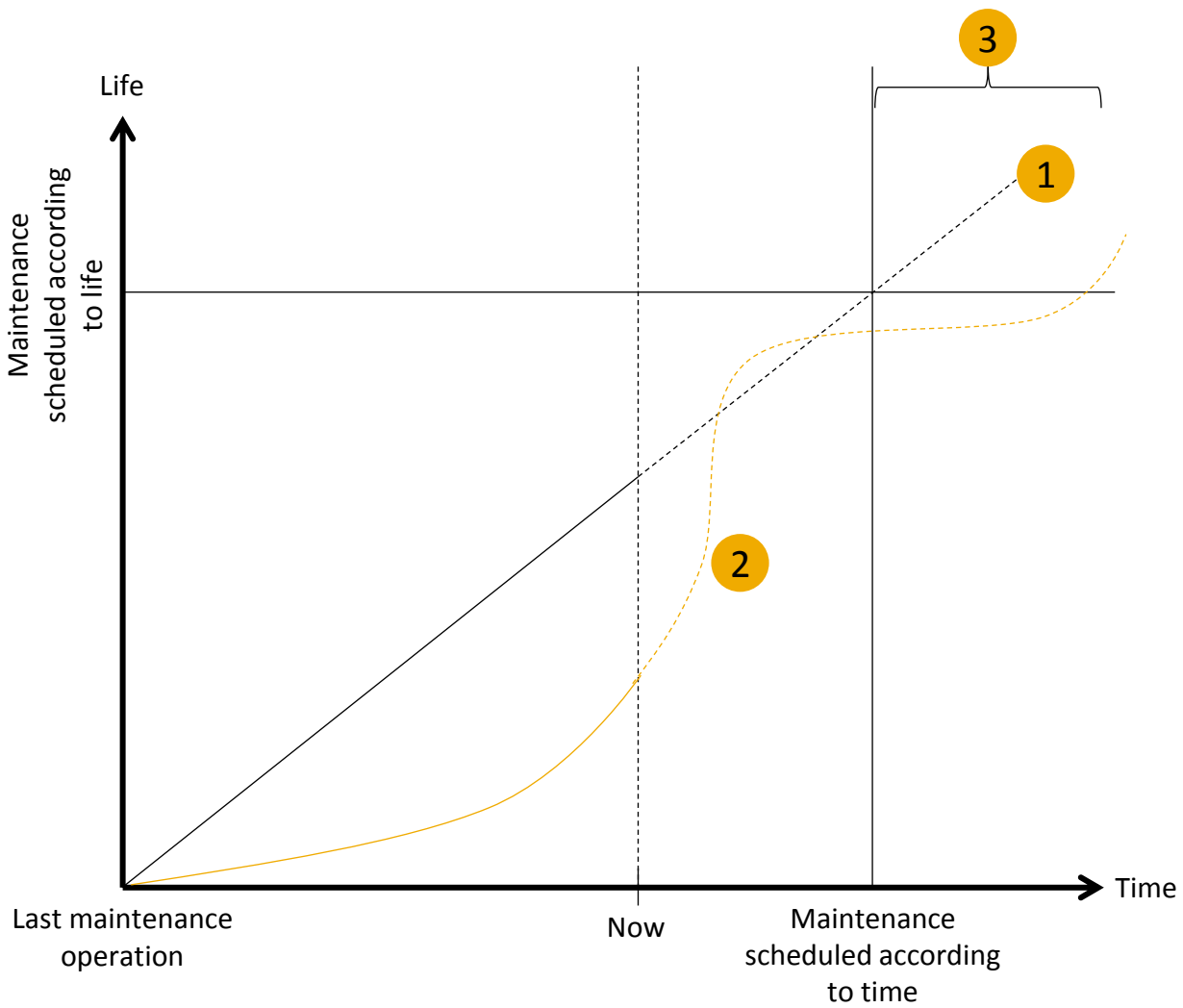
1. Past values are monitored by sensors on board of trains
2. Projection of life indicator considering the plans for the material, prediction of the consequence on the health indicator using mathematical methods
3. Health safety threshold – function of life
4. **Trigger of maintenance request due to the life indicator reaching risk threshold**

Life and Health Indicators for Trains Doors



1. Past values are monitored by sensors on board of trains
2. Projection of life indicator considering the plans for the material, prediction of the consequence on the health indicator using mathematical methods
3. Health safety threshold – function of life
4. **Trigger of maintenance request due to predicted health issues**

Life Indicator / Time Relationship – Example L1

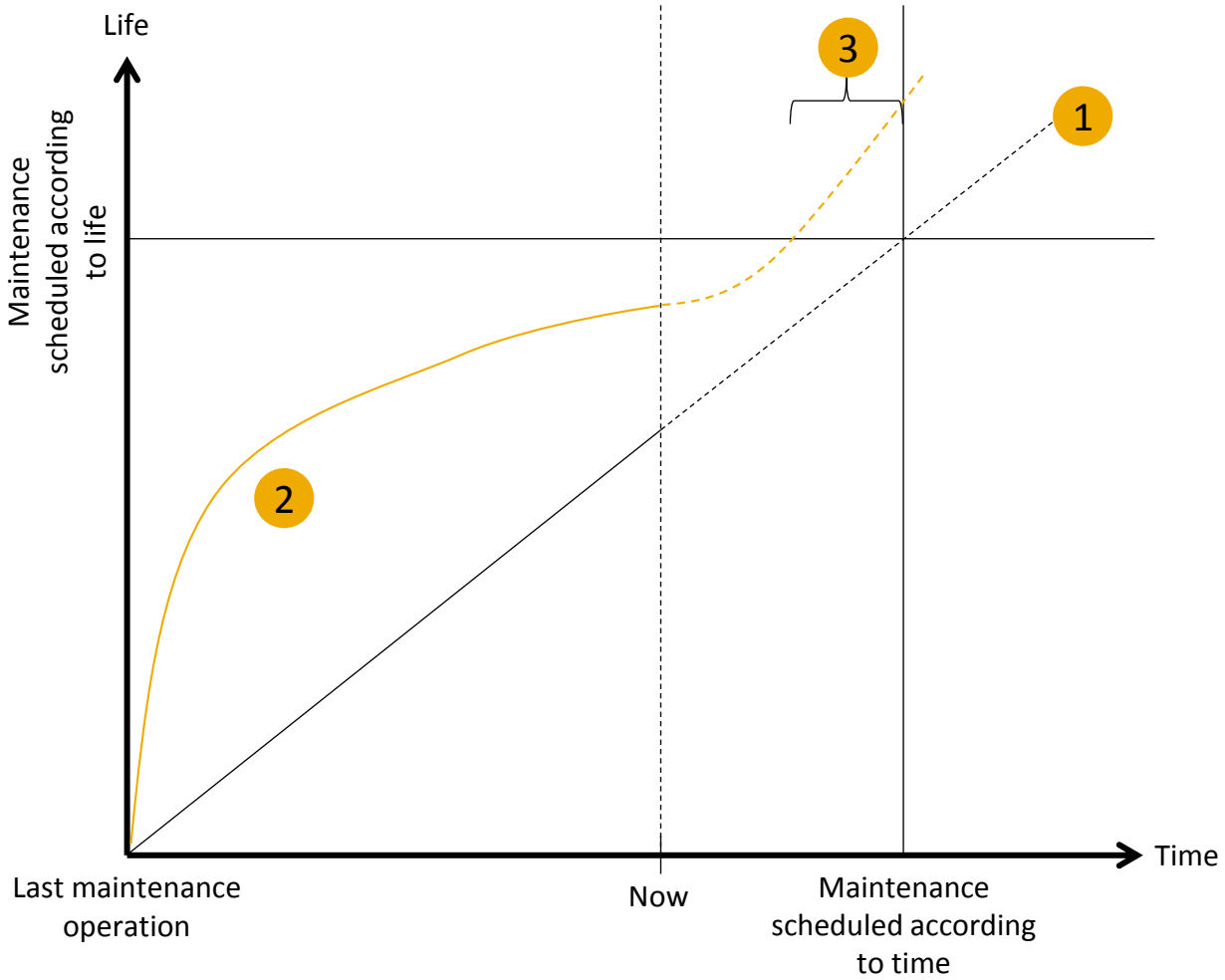


1. Line describing the expected aging of the component based on a linear relationship with time (and KM), which is the basis of current maintenance scheduling

2. Curve describing the effective evolution and projection of the synthetic function of life indicators

3. Time for which the maintenance can be postponed based on life indicators, compared to time / km based planning

Life Indicator / Time Relationship – Example L2



1. Line describing the expected aging of the component based on a linear relationship with time (and KM), which is the basis of current maintenance scheduling

2. Curve describing the effective evolution and projection of the synthetic function of life indicators

3. Area of risk of failure, because of the component likely wearing out faster than foreseen in the standard maintenance plan

Life Indicators in Action: Braking System

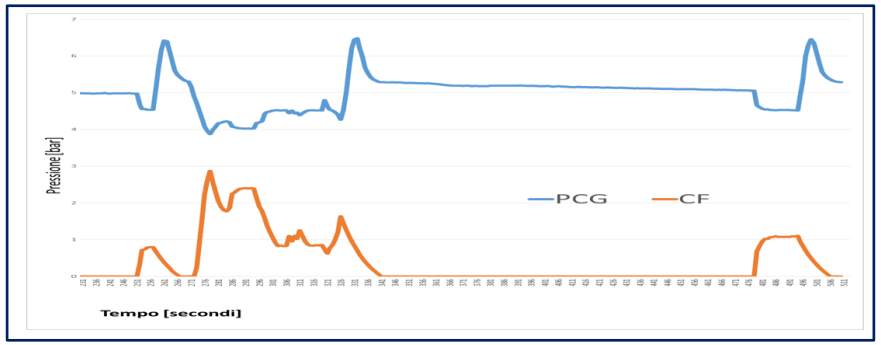
Objective and Approach

- Calculation of the life indicator → **energy dissipation** by friction braking systems, with separated analysis for locomotives and coaches
- Development and test of calculation algorithms for all the possible cases identified

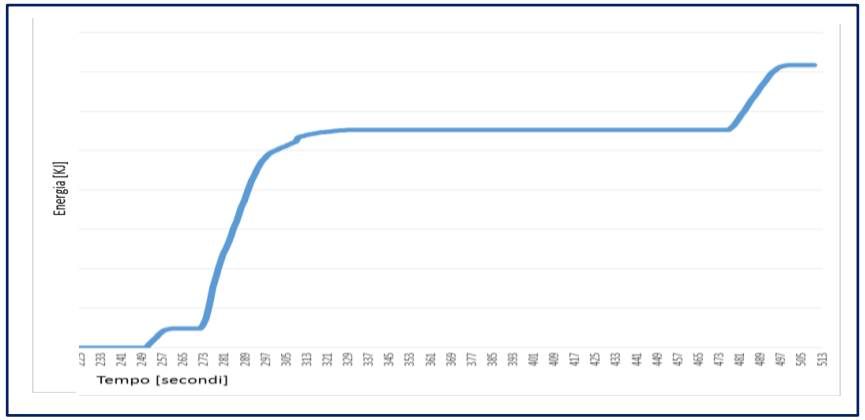
Results Achieved

- Monitoring of the effective usage and level of wear-out for every single component of the braking system against the risk thresholds identified

Pressione in Condotta Generale e Cilindro Freno

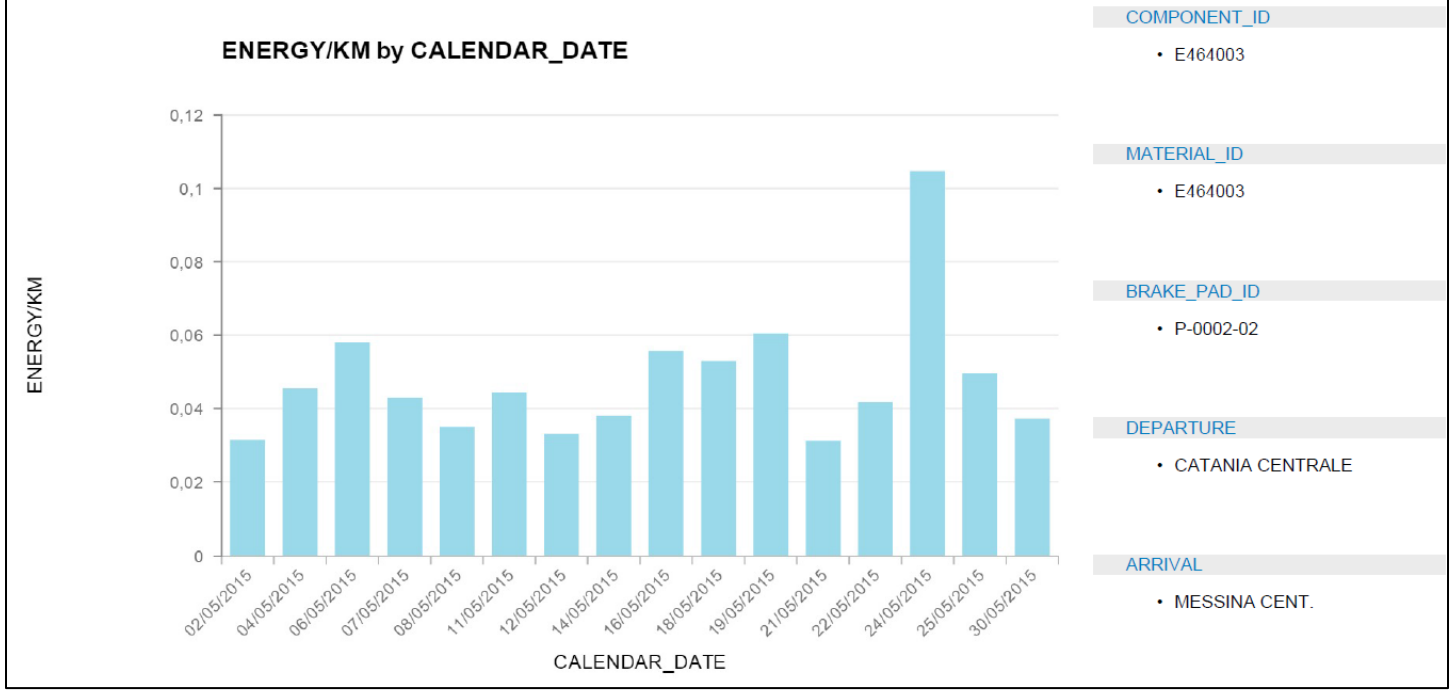


Energia dissipata cumulata per le carrozze



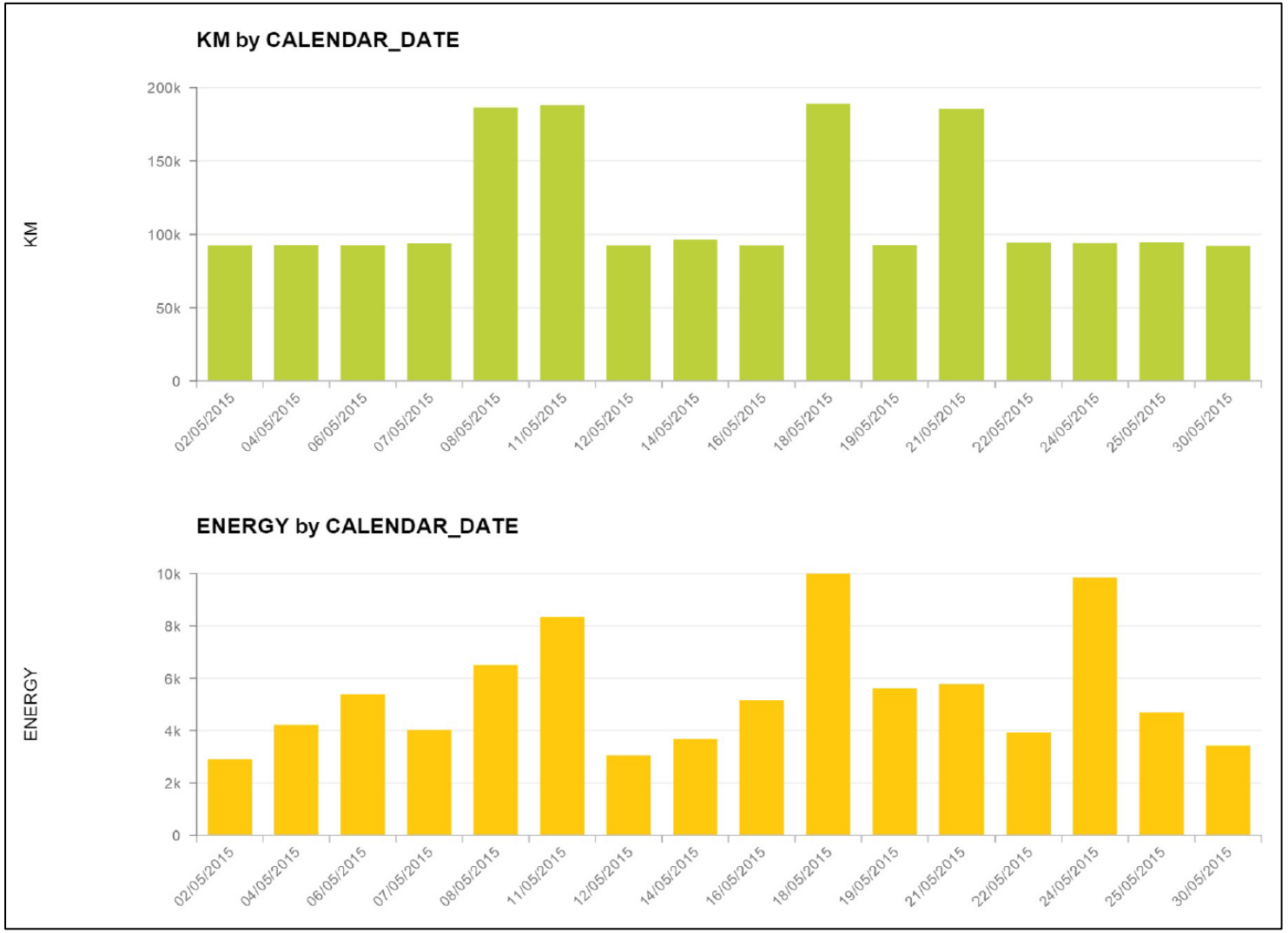
Life Indicators in Action: Braking System

MATERIAL_ID	CALENDAR_DATE	DEPARTURE	ARRIVAL	Measures		
				ENERGY/KM	KM	ENERGY
E464003	02/05/2015	CATANIA CENTRALE	MESSINA CENT.	0,03	92.597,35	2.912,53
	04/05/2015	CATANIA CENTRALE	MESSINA CENT.	0,05	92.839,25	4.221,51
	06/05/2015	CATANIA CENTRALE	MESSINA CENT.	0,06	92.713,60	5.382,53
	07/05/2015	CATANIA CENTRALE	MESSINA CENT.	0,04	93.789,17	4.022,59



- High variability of the energy dissipated per km clearly indicates that distance is not a good indicator of consumption for braking systems
- Comparison between traditional indicators such as km and more precise life indicators highlights the significant opportunity for optimization of maintenance operations

Life Indicators in Action: Braking System



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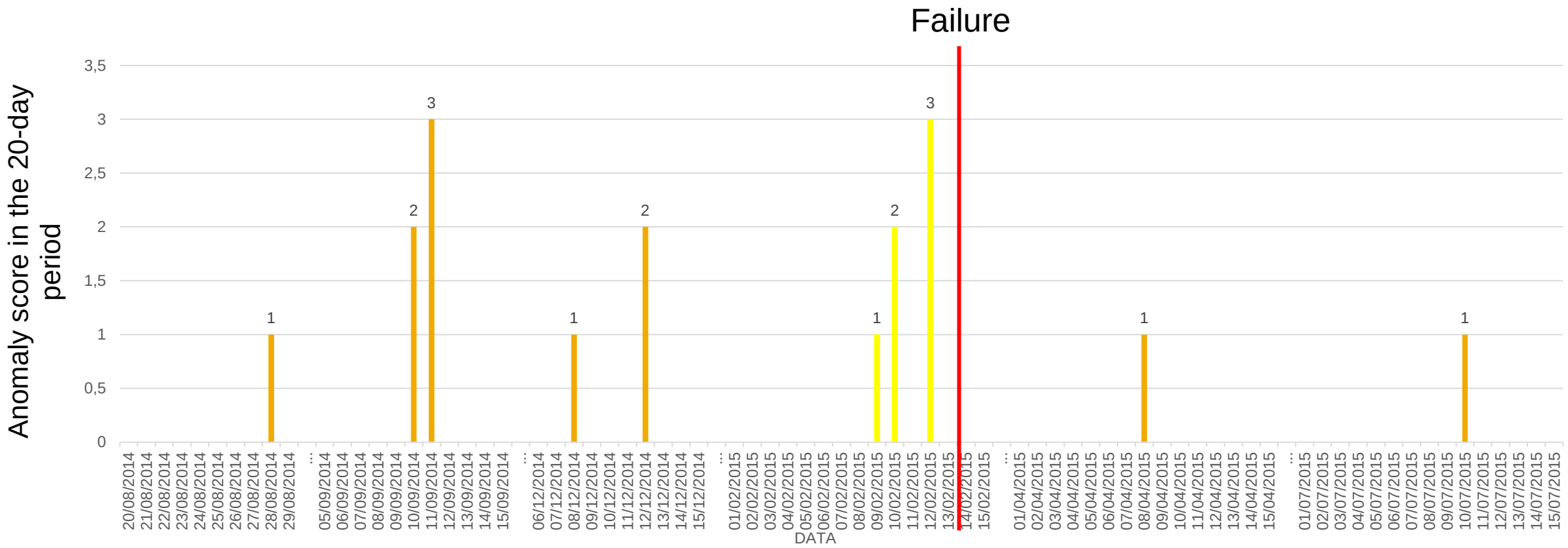
Anomaly Detection Analysis on Turnouts

- 19 turnouts analyzed over a period of around 17 months
- Diagnostic equipment records tension and current of the actions
- Over the period there were only 11 actual failures, corresponding to an MTBF (Mean Time Between Failures) of around 21,000 hours
- Turnouts are inspected on the average once a month

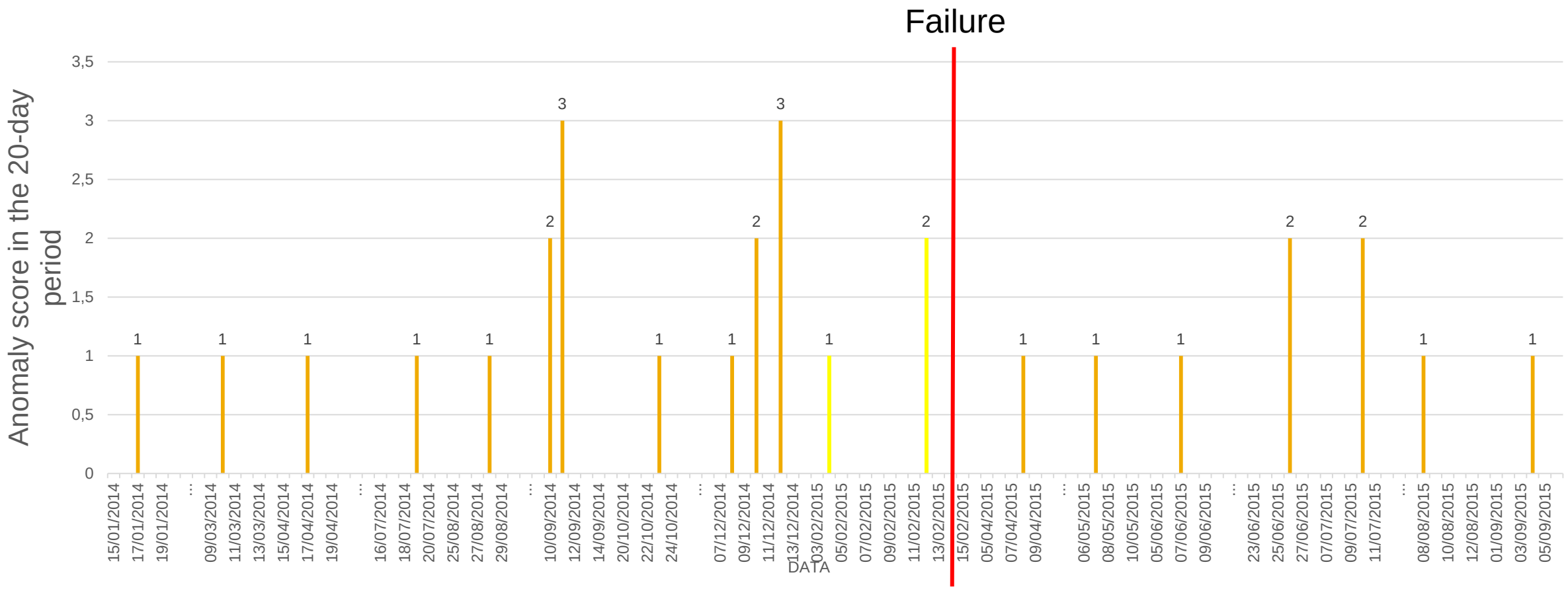
Data seem to indicate a situation of over-maintenance, driven by the strong priority of avoiding failures almost at any cost. This is typical of critical assets where failures come with big penalties

Analysis on Turnout 1

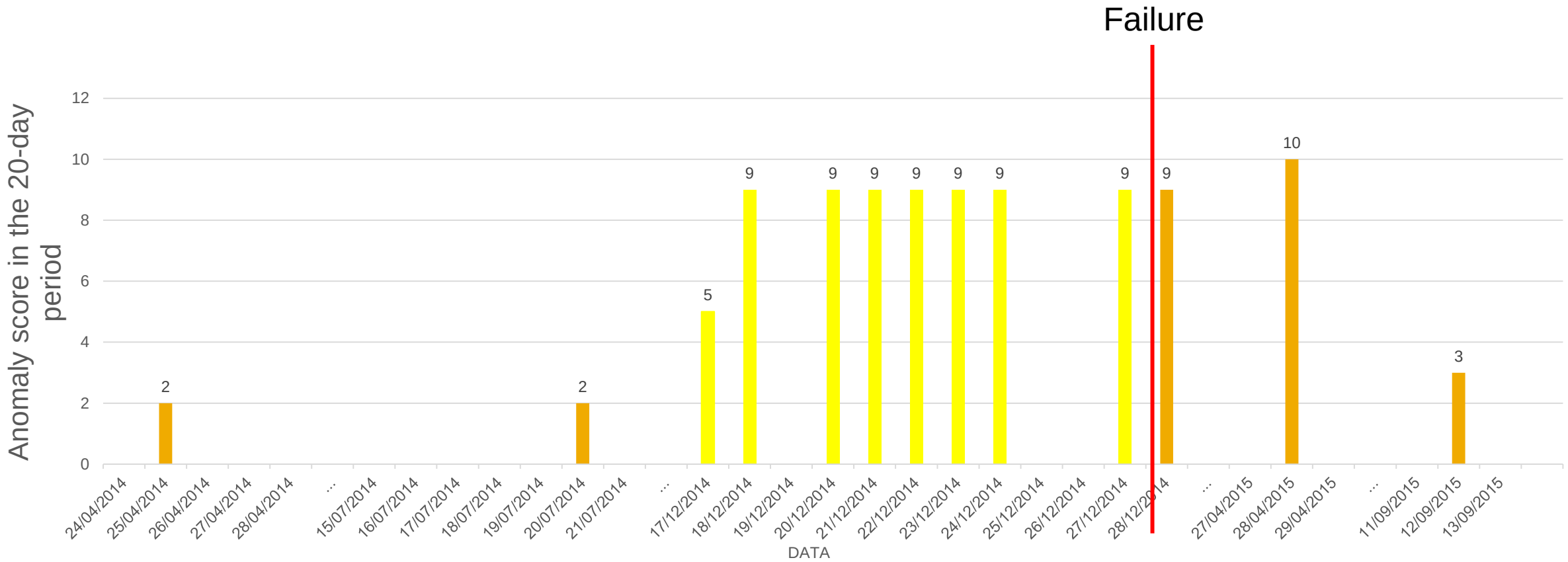
Thresholds on anomalies defined as a combination of severity and number of instances in a rolling period, and tuned to match violations and prevalence of failures, at least in terms of order of magnitude



Analysis on Turnout 2



Analysis on Turnout 3



Results of Anomaly Detection Analysis on Turnouts

		Predicted		
		YES	NO	
Actual	YES	5	6	11
	NO	69	1276	1345
		74	1282	1356

- 5 out of the 11 failures were predicted by the algorithm a few days in advance
- 6 failures were not predicted, best hypothesis is that around half could be identified with better diagnostic equipment, half is highly intractable from a data science perspective
- 69 false positives were also generated

Accuracy	94%	(TP + TN) / Total
Misclassification	6%	(FP + FN) / Total
True Positive Rate	45%	TP / Actual Yes - AKA Sensitivity / Recall
False Positive Rate	5%	FP / Actual No
Specificity	95%	TN / Actual No
Precision	7%	TP / Predicted Yes
Prevalence	0,8%	Actual Yes / Total
Negative Predictive Value	99,53%	TN/Predicted No

→ Very high accuracy and specificity

→ Very low precision

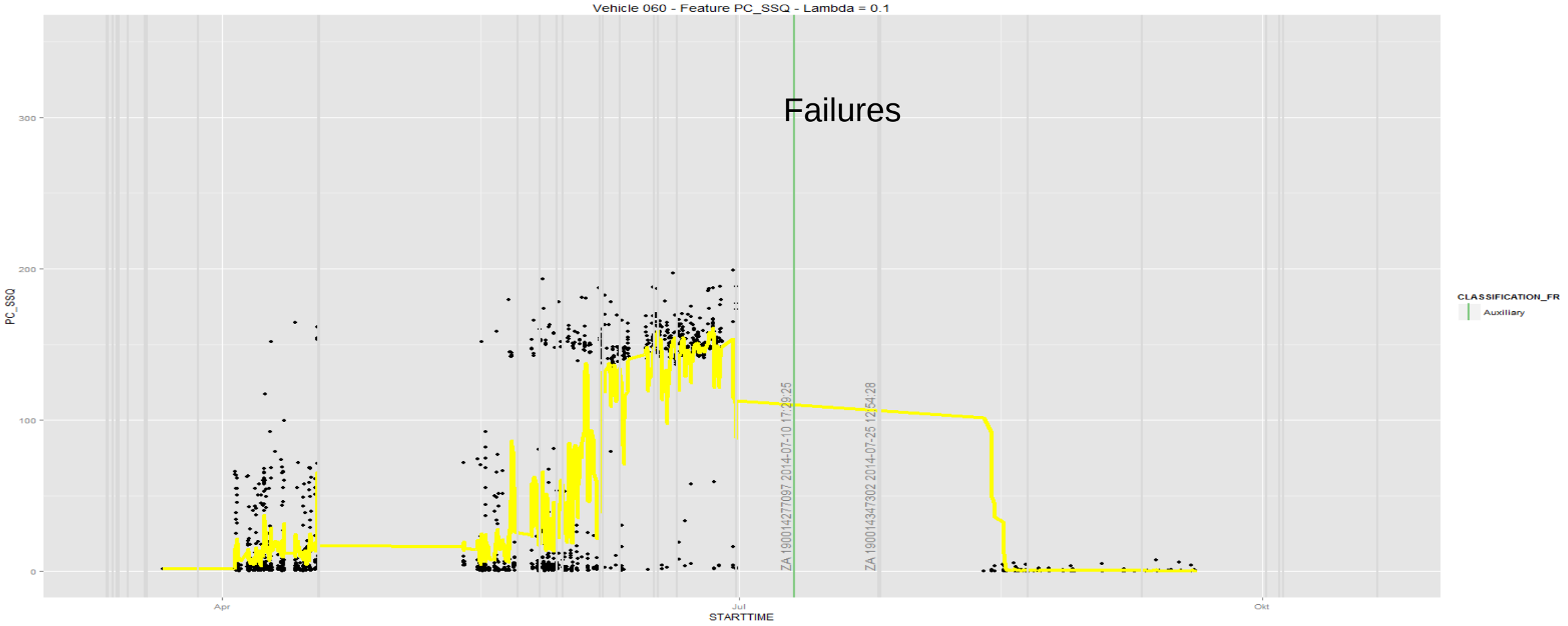
→ Prevalence (number of weeks in which a failure happens / total number of weeks analyzed) is below 1%

In rare event prediction case, achieving high accuracy, precision and sensitivity at the same time is extremely challenging

The real actionable insight often sits in the Negative Predictive Value

Data are analyzed in time series, but presented discretized by week

Anomaly Detection on Electric Engines of Locomotives



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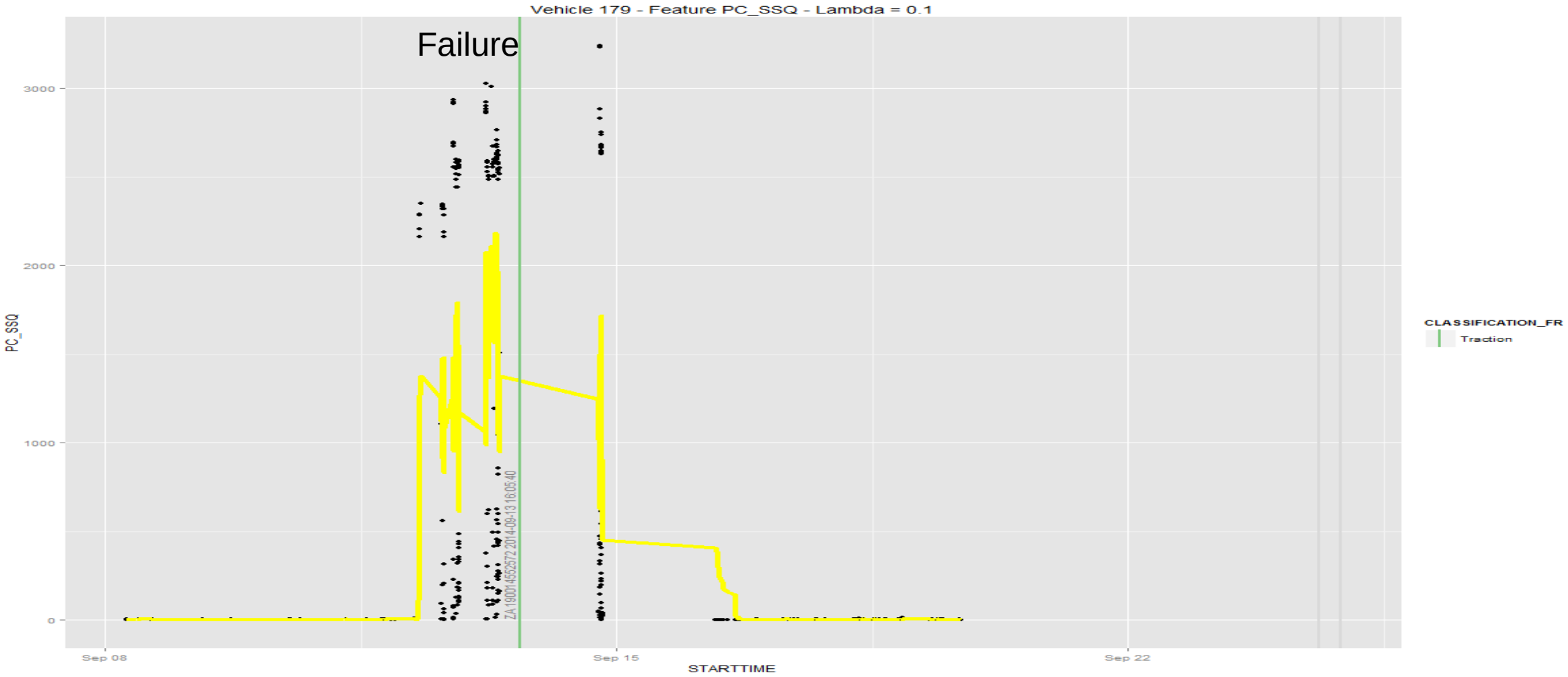

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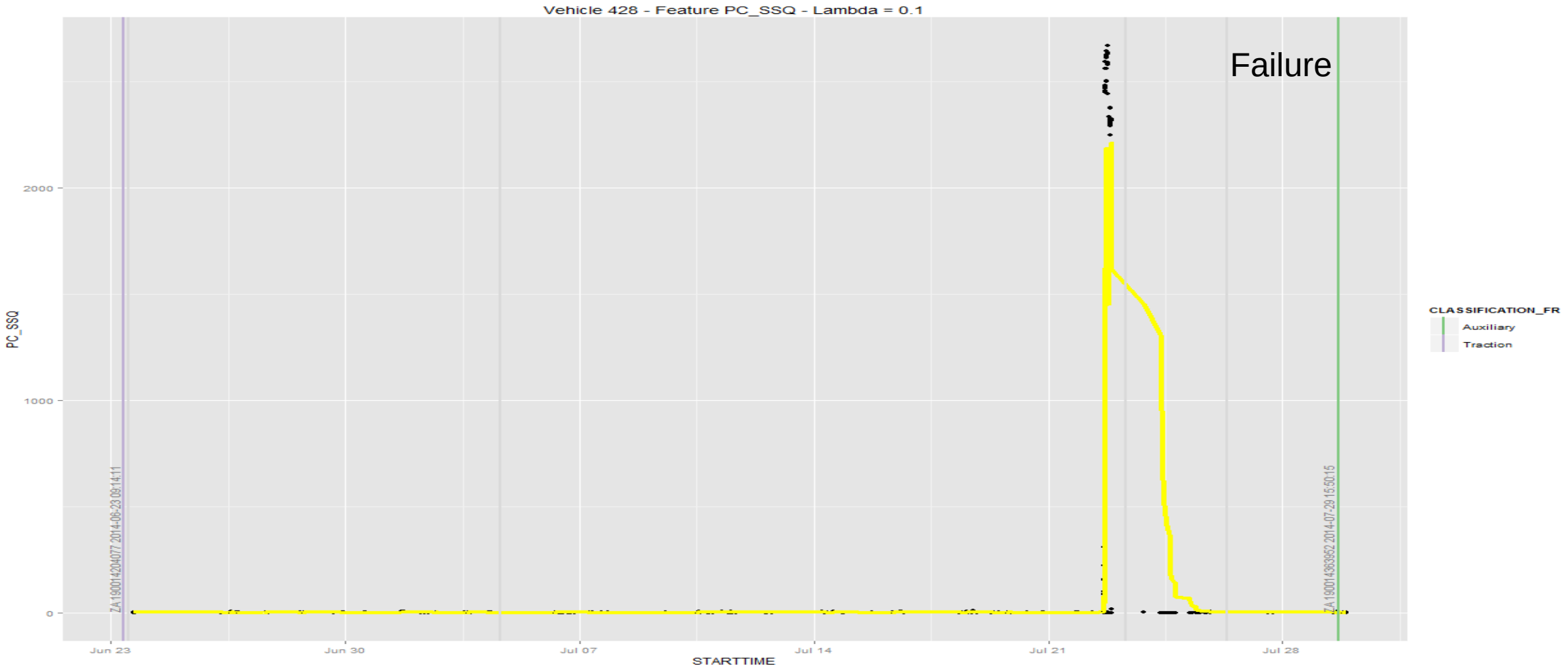
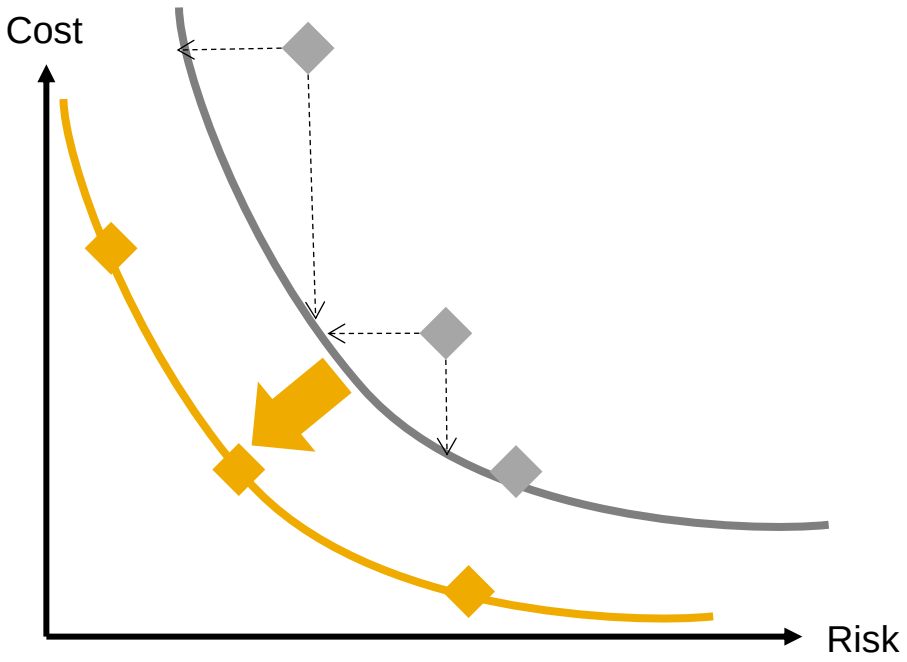


Conclusions

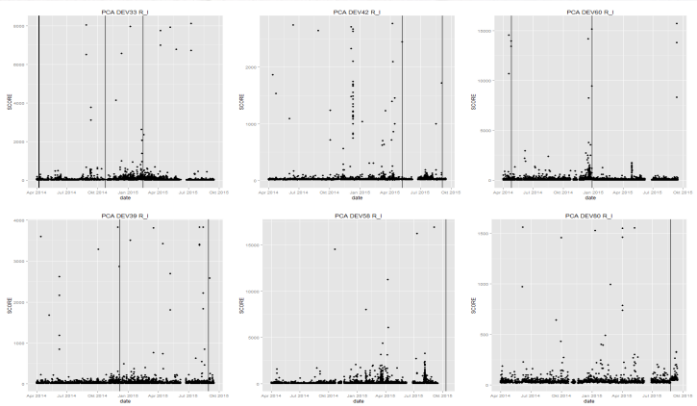
Transforming the Game in Maintenance Operations



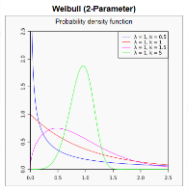
Definition of maintenance policies can be seen as the management of the **tension and trade-off between costs and risks.** Most of the efficiency efforts are aimed at making sure that the right balance is reached

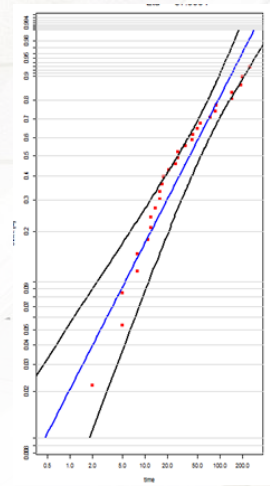
Internet of Things-based maintenance innovation represents the opportunity of **transforming structurally the system** and **reach a new level of balance between costs and risks**

Remember all the sofisticated models….



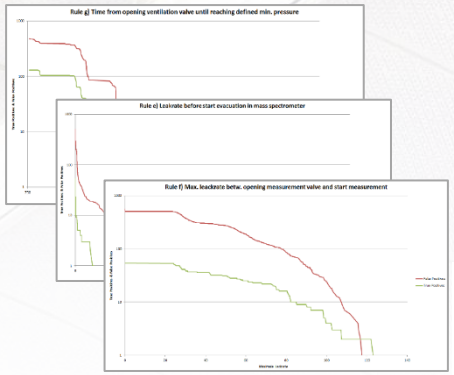
Principal Component Analysis of Switches



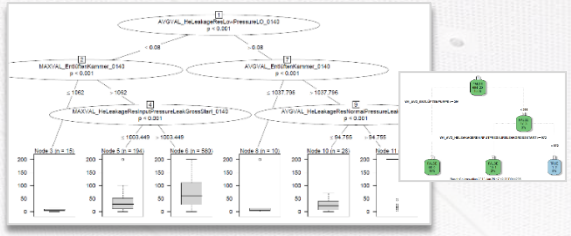


Weibull Remaining Useful Life Estimation

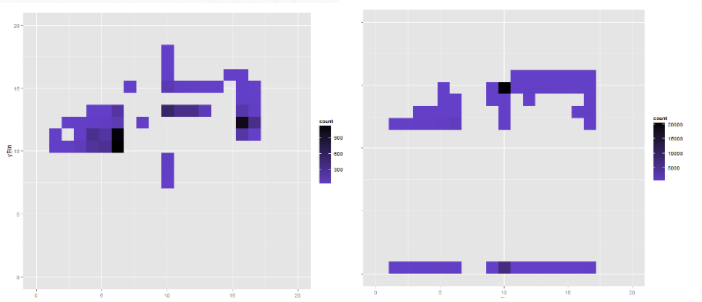
$$f(x;\lambda,k) = \begin{cases} \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-(x/\lambda)^k} & x \geq 0, \\ 0 & x < 0, \end{cases}$$

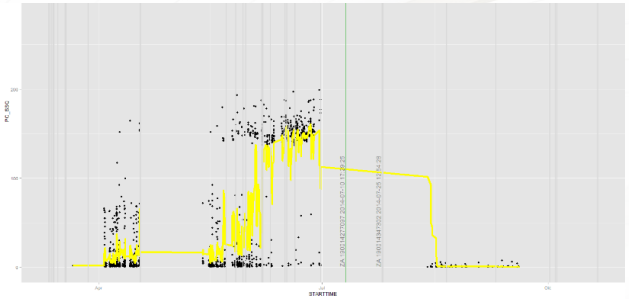


Expert Rule Validation



Automatic Rule Extraction with Decision Trees





Anomaly Detection with Principal Component Analysis scores

$$\mathrm{Var}[a^T X] = \frac{1}{n}\sum_{i=1}^{n}\left\{a^T\left(X_i - \frac{1}{n}\sum_{j=1}^{n} X_j\right)\right\}^2 = a^T V_{XX}\, a.$$

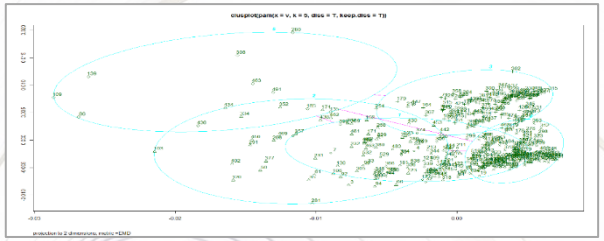
where

$$V_{XX} = \frac{1}{n}\sum_{i=1}^{n}\left(X_i - \frac{1}{n}\sum_{j=1}^{n} X_j\right)\left(X_i - \frac{1}{n}\sum_{j=1}^{n} X_j\right)^T$$

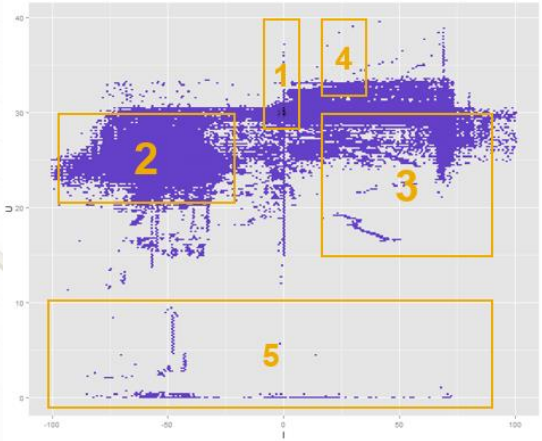
PCA

$$W(P,Q) = \min\left\{\sum_{x\in M,\, y\in M} dist(x,y)\cdot T(x,y) \,\middle|\, T: M\times M \to [0,1] \text{ with } \sum_{y\in M} T(x,y) = P(x),\ \sum_{x\in M} T(x,y) = Q(y)\right\}$$

Wasserstein Metric for battery performance analysis



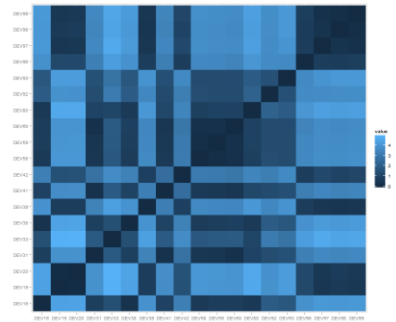
K-Mediod cluster analysis to partition the population into classes of similar devices

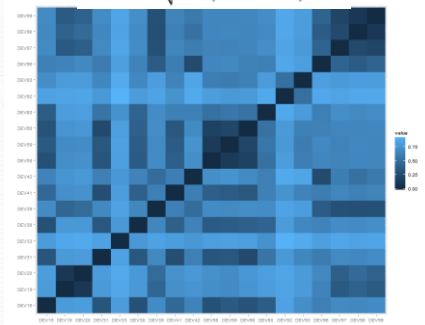


Battery behavioural groupings

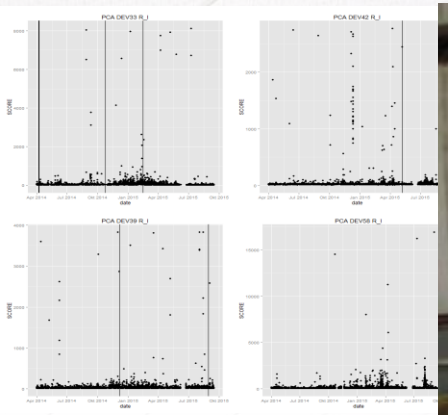
$$W_p(\mu,\nu) := \left(\inf_{\gamma\in\Gamma(\mu,\nu)} \int_{M\times M} d(x,y)^p \,\mathrm{d}\gamma(x,y)\right)^{1/p}$$

$$H(P,Q) := \sqrt{\frac{1}{2}\int\left(\sqrt{\frac{dP}{d\lambda}} - \sqrt{\frac{dQ}{d\lambda}}\right)^2 d\lambda}$$

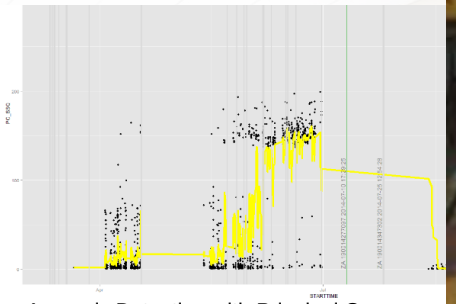




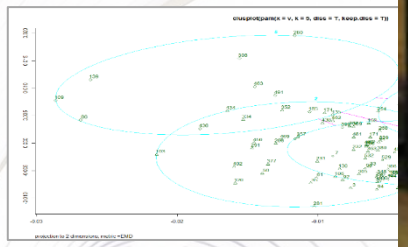
….need to work under the conditions of the “real world” eventually!



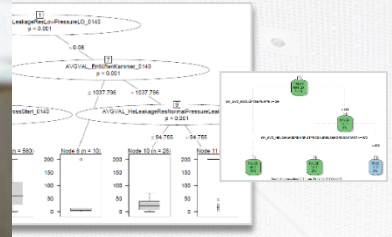
Principal Component Analys



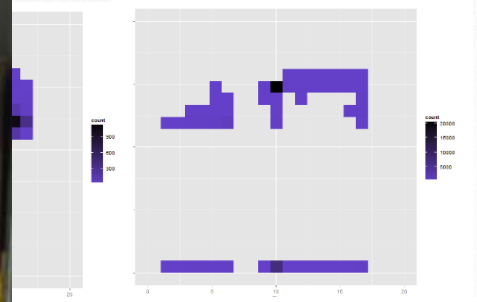
Anomaly Detection with Principal Componen



K-Mediod cluster analysis to partition the popu



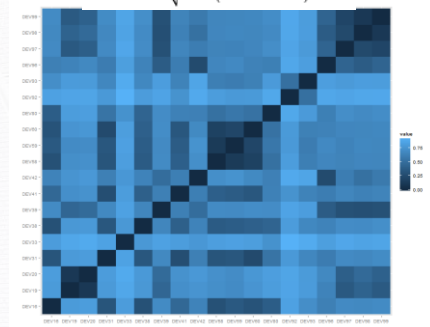
Rule Extraction with Decision Trees



$$\{T: M \times M \to [0,1] \text{ with } \sum_{y \in M} T(x,y) = P(x),\ \sum_{x \in M} T(x,y) = Q(y)\}$$

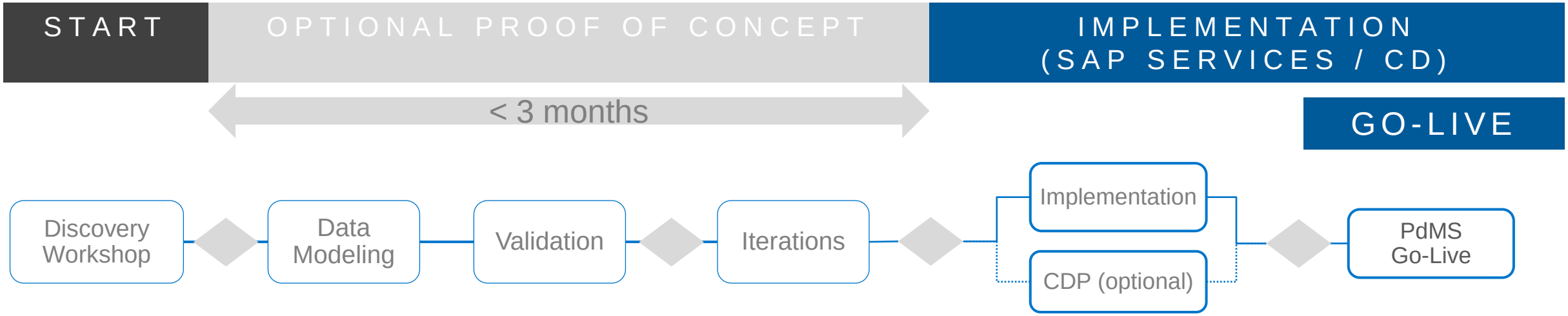
for battery performance analysis

$$H(P,Q) := \sqrt{\frac{1}{2}\int\left(\sqrt{\frac{dP}{d\lambda}} - \sqrt{\frac{dQ}{d\lambda}}\right)^2 d\lambda}$$



Extending to Meet Business Needs

Optional PoC is an opportunity to increase customer value proposition



- Understand and reframe the problem(s)
- Ideate possible solutions
- Ensure technical feasibility

- Prepare data
- Model data
- Generate derived signal models

- Determine standard out-of-the-box fit
- Evaluate technical feasibility

- Weekly iterations to collect feedback
- Pass acceptance tests and/or success criteria

- Standard Implementation
- Based on SAP standard PdMS product
- Custom development of new functionality

- Go-Live Support
- Standard Support
- SAP CD Support (optional)
- Application Management Service (AMS) (optional)

Thank you

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