Pipeline Inspection Analytics

Learning from weak signals to predict the degradation risk level

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Disclaimer: Confidential information are not included in this report

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1 Abstract

Inline inspection and external inspection of oil and gas pipelines are crucial to detect various types of anomalies and degradation which can possibly yield failures with hazardous consequences, economic losses, and irreversible human and environmental damage. So far it is not possible to predict when and where a failure would occur.

Most of the existing models consider only a limited number of factors such as corrosion or fatigue wear and only a few attempts toward a comprehensive modeling of pipeline condition have been made in the past decade.

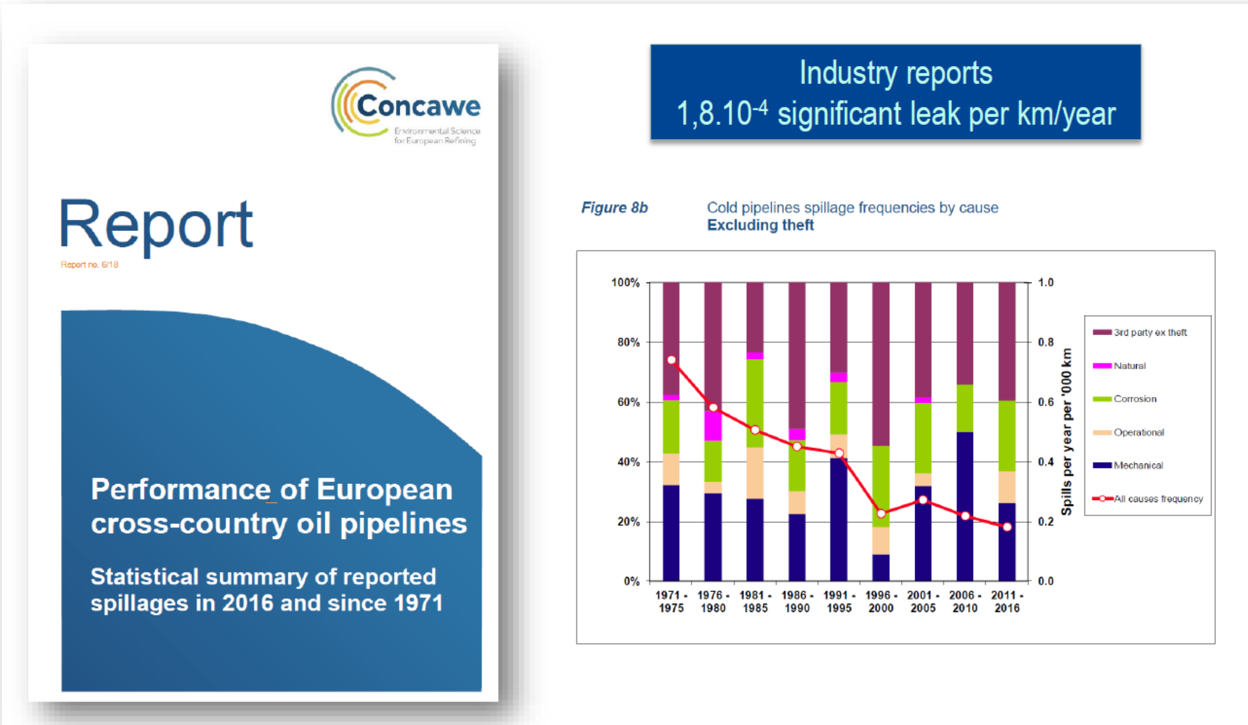
We tackle this problem with the data science methodology and tools applied to a major French oil pipeline. More specifically,

- We first perform a geospatial and temporal data fusion of relevant heterogeneous sources (pipe tally, inspection, weather, environment, …) yielding a multidimensional view of the pipeline hosted in a geographical information system.
- Then, we develop machine learning models to classify anomaly types and predict the degradation risk level at each pipeline segment or at singular tubes.

The outcome will help the pipeline stakeholders (inspection and operators) to prioritize their inspection efforts by highlighting significant likelihood of failure stemming from the correlation of weak signals that would otherwise remain unnoticed.

2 Introduction

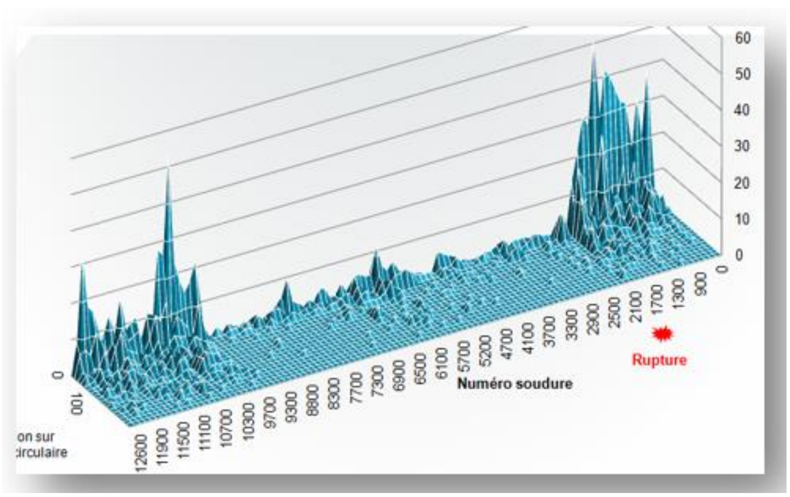
2.1 Context

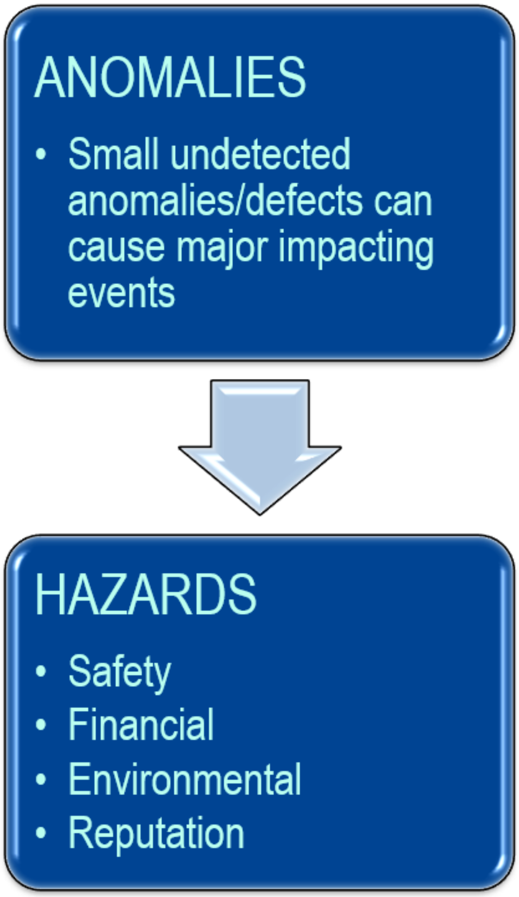


Industry reports
2.10^{-4} significant leak per km/year
due to corrosion

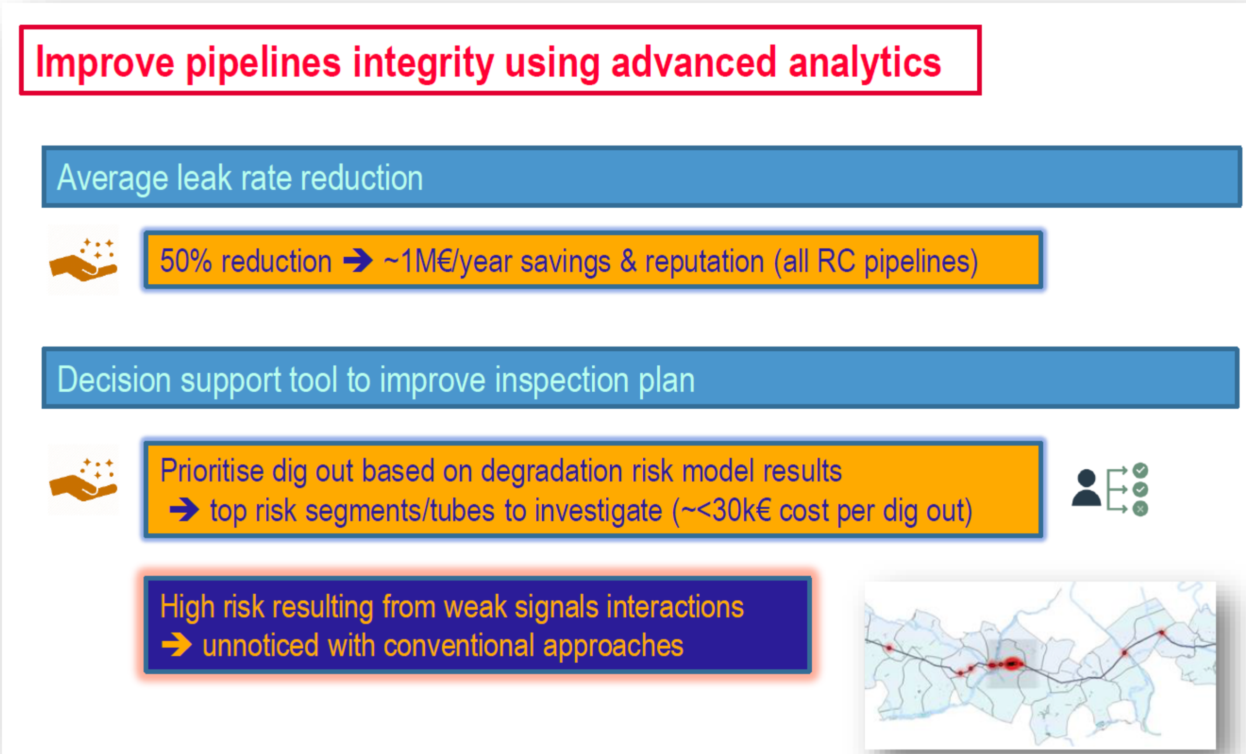
INSPECTION

- 3rd party inline inspection reports missed anomalies

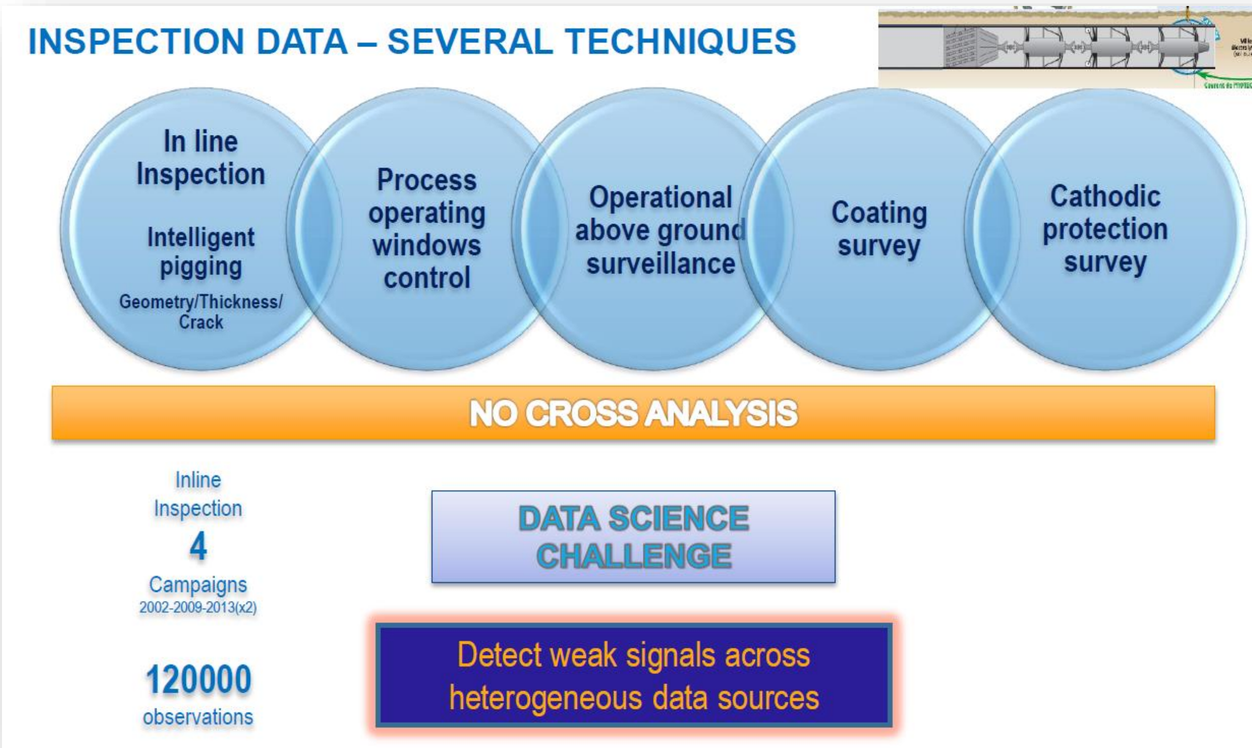


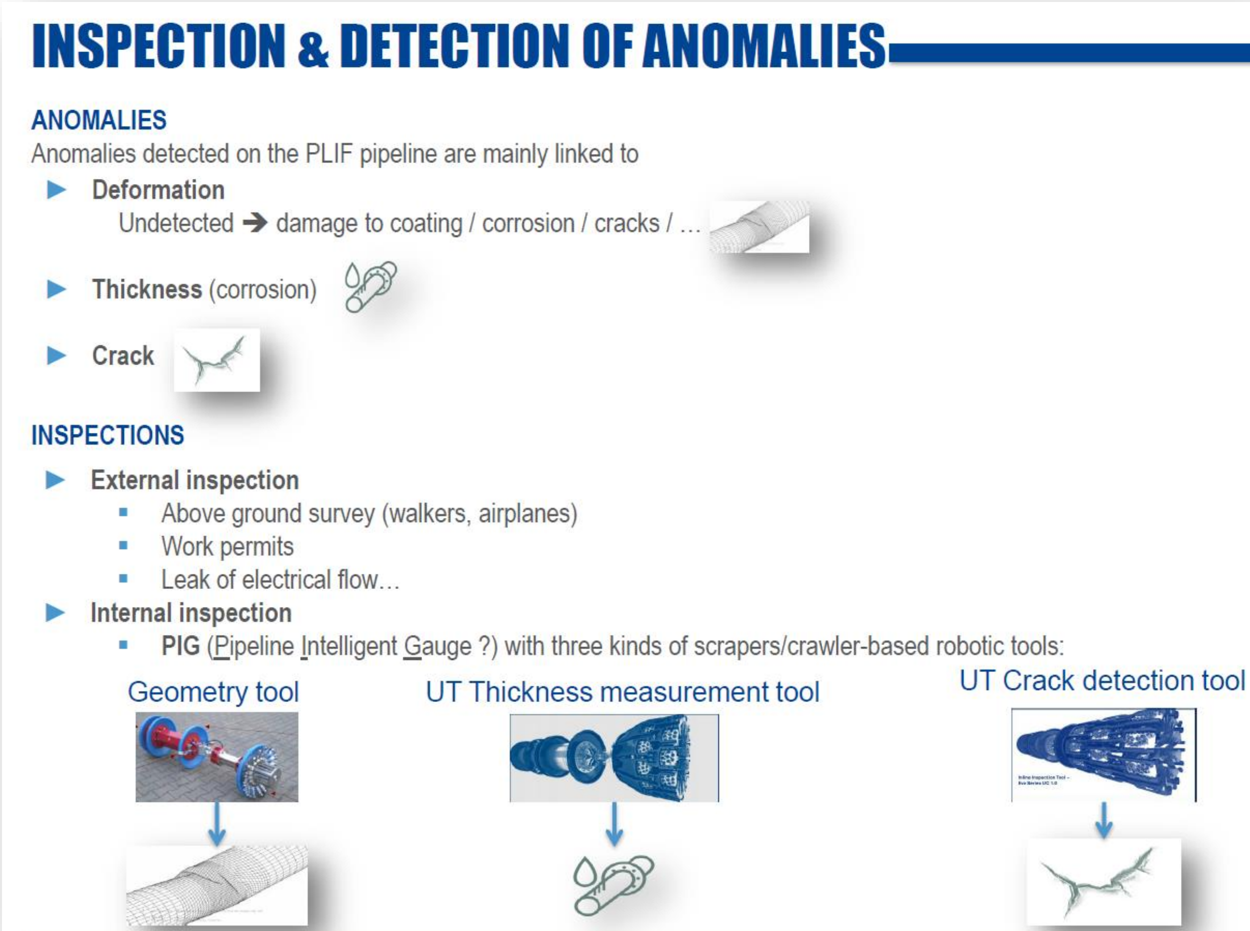

ANOMALIES
• Small undetected anomalies/defects can cause major impacting events
HAZARDS
• Safety
• Financial
• Environmental
• Reputation

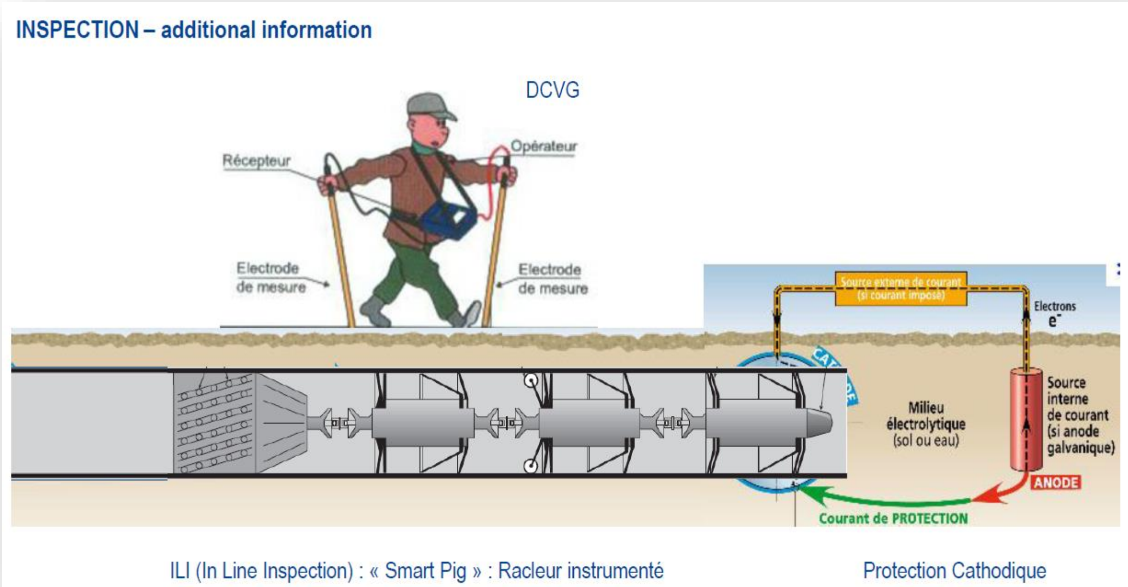
2.2 Objectives



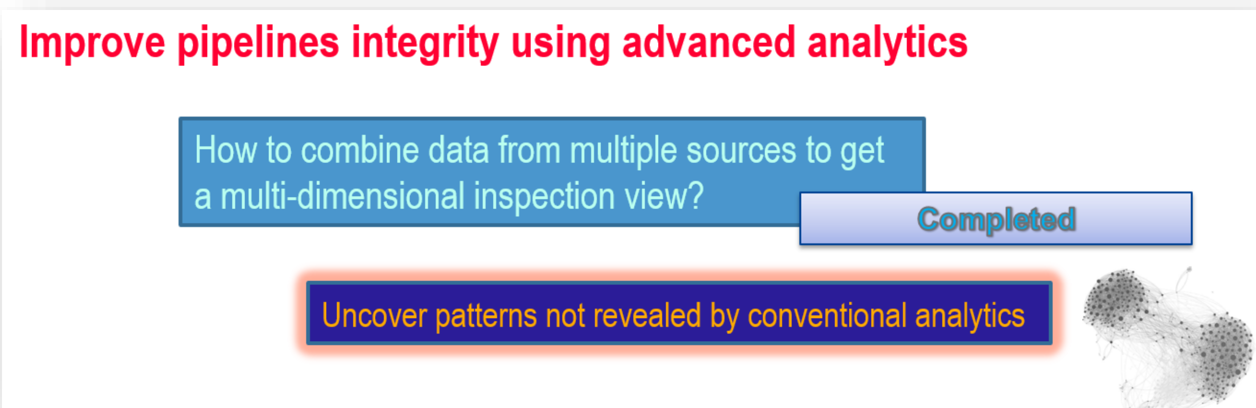
2.3 Inspection data – Techniques

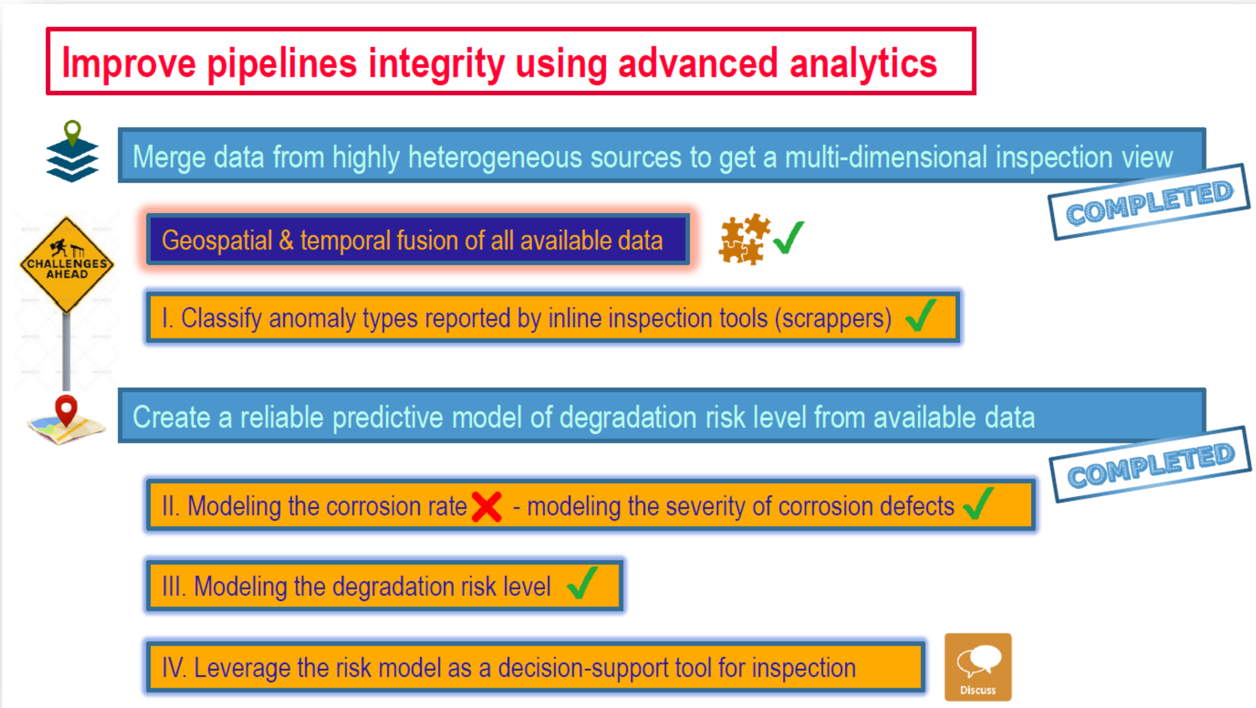



INSPECTION & DETECTION OF ANOMALIES
ANOMALIES
Anomalies detected on the PLIF pipeline are mainly linked to
Deformation
Undetected ➔ damage to coating / corrosion / cracks / …
Thickness (corrosion)
Crack
INSPECTIONS
External inspection
Above ground survey (walkers, airplanes)
Work permits
Leak of electrical flow…
Internal inspection
PIG (Pipeline Intelligent Gauge ?) with three kinds of scrapers/crawler-based robotic tools:
Geometry tool
UT Thickness measurement tool
UT Crack detection tool



3 Challenges

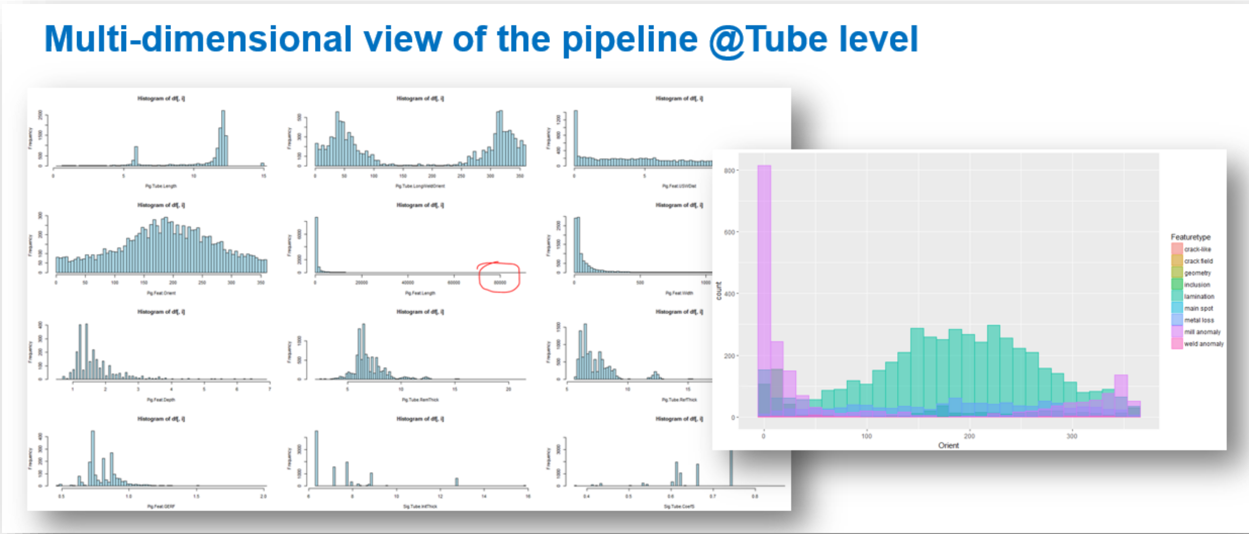




4 Data science approach

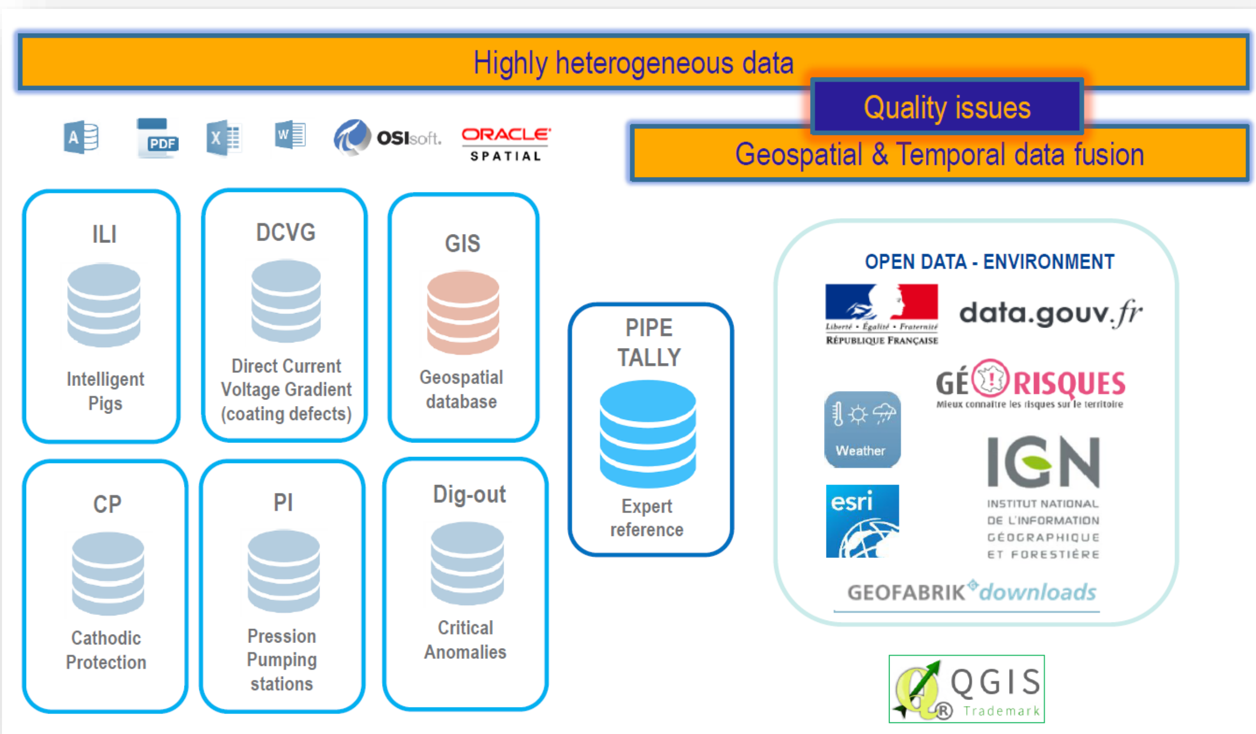
4.1 Audit and descriptive statistics

Inline inspection



Evolution of individual anomalies and analysis with domain experts.

4.2 Data fusion



4.3 Data enrichment

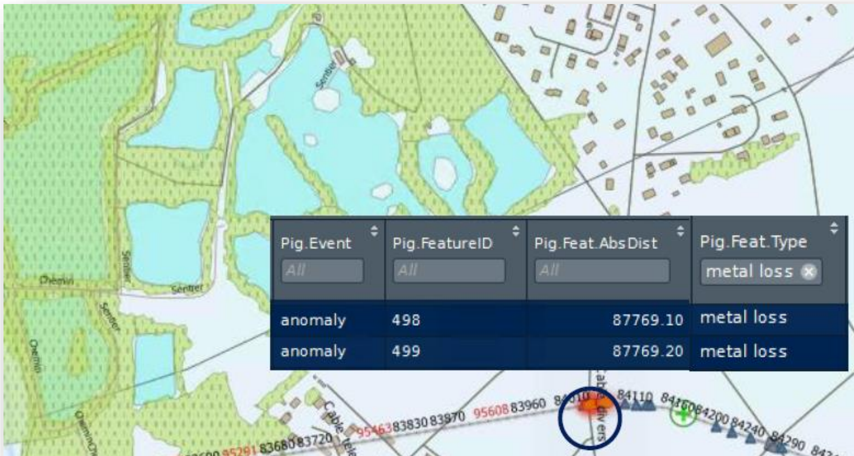
How to combine data from multiple sources to get a multi-dimensional inspection view?

Highly heterogeneous data

Sig.Tube.Length	Sig.Tube.Nuance	Sig.Tube.WeldUS	Sig.Tube.WeldDS	Sig.Tube.Ref
All	All	All	All	All
11.67	X60	4875	4876	1603
11.67	X60	4875	4876	1603

Sig.Tube.Crossing	Sig.Tube.Compens
All	All
rue des tritons	Dalle BA Longueur : 14 2m*2m Epaisseur : 15cm .

Geospatial & Temporal data fusion

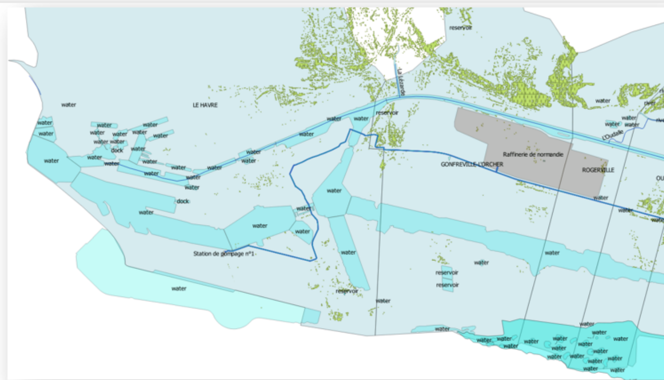


GEOSPATIAL DATA FUSION

+ Data enrichment

Geospatial merge of heterogeneous data

Pipe Tally + GIS + Inspection (Pig, DCVG, PC)
+ geographic data (roads, waterways, …)
+ weather conditions (local stations)
+ soil condition (clay, sand, …)
+ pressure



+ Feature engineering

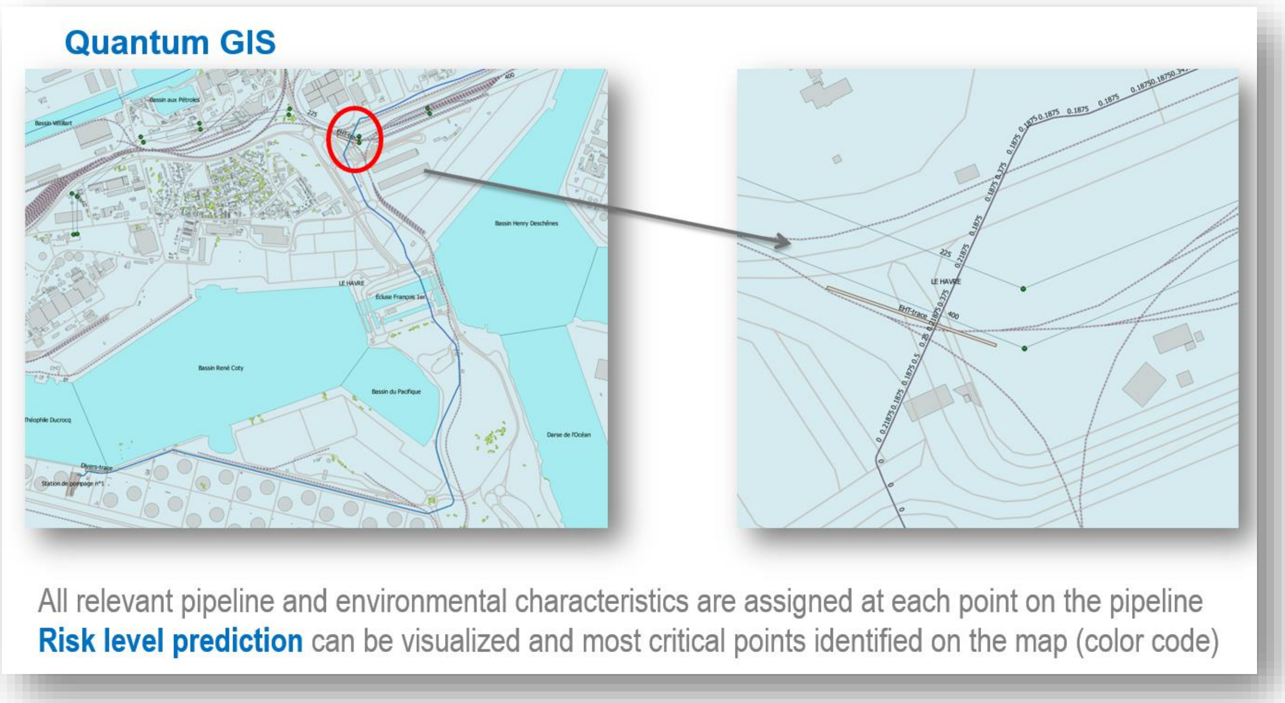
Density and evolution of anomalies

Short- and long-term corrosion rates – Dent – Cathodic protection – Coating defects - …

Result = input dataset for machine learning modeling

Pipeline/Tube characteristics + Inspection data + Environment data

4.4 Geospatial visualisation of results



4.5 Machine learning modelling

4.5.1 Segments and singular tubes

Definition of granularity for the degradation risk level

Focus on segment
Homogeneous segmentation based on statistical clustering combined with domain expert knowledge or arbitrary split every 100m

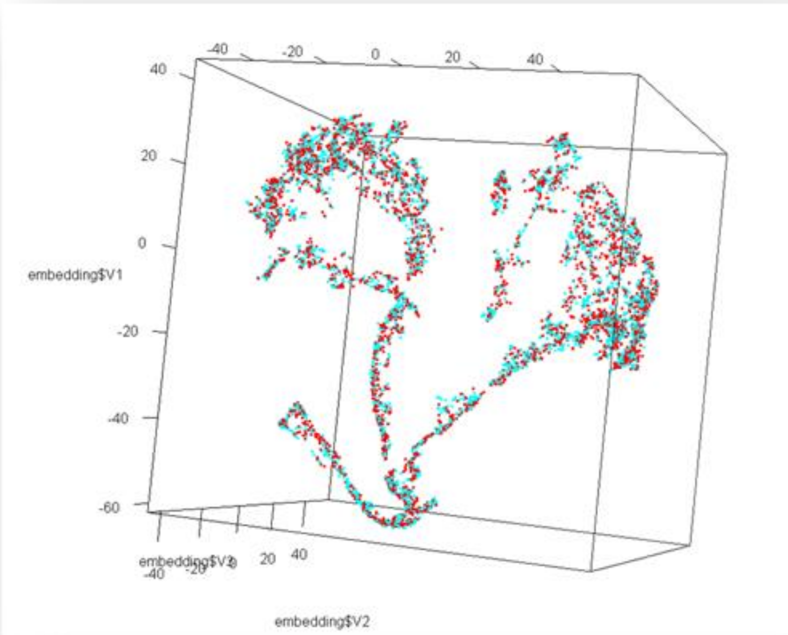
Focus on singular point
Tube with at least one “crossing” of influencing environmental element (river, electric line, railways, ...) ~20% tubes

4.5.2 Unsupervised learning

Unsupervised learning – Clustering tubes in homogeneous families (***segments***)

Inspection data – Unsupervised learning

Exploratory
PCA – t-SNE

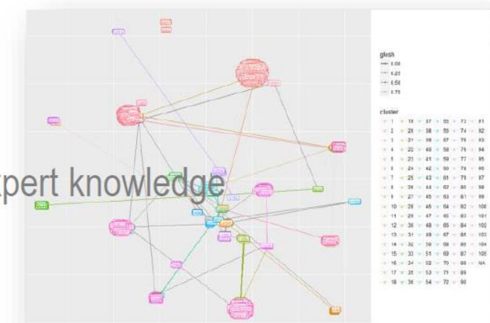


Segment

Homogeneous segmentation based either on

- dynamic cut
- statistical clustering combined with domain expert knowledge

➔ segment as extra tube attribute



LargeVis & HDBScan algorithms

4.5.3 Classification of anomaly types

Classify anomaly types reported by ILI

Multi-class classification on 2013 campaign

Extreme gradient boosting (trees) – xgboost

Almost perfect classification of anomaly types

➔ Consistency of anomaly reporting (ILI owner) based on interpreted data above reporting threshold

➔ Possible improvement (real added value): classification model based on raw ILI data

➔ challenging the results of ILI reports

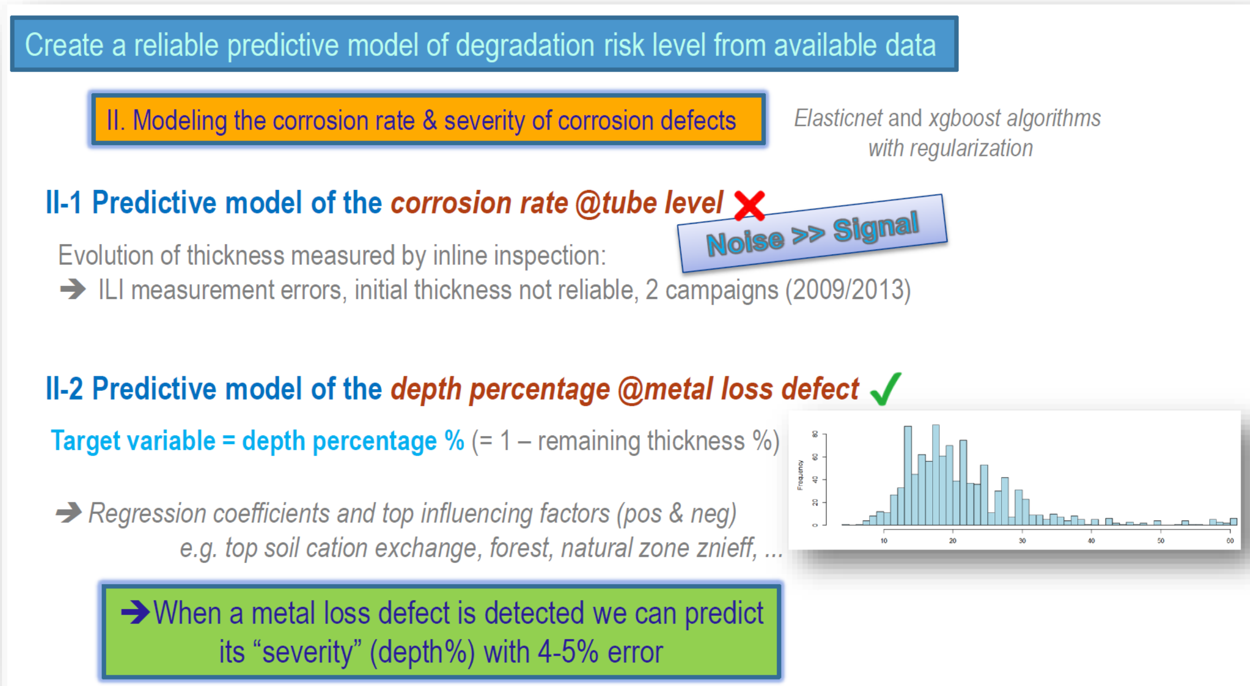
```
Confusion Matrix and Statistics

            Reference
Prediction   dent geometry inclusion lamination main.spot metal.loss
  dent         45        0         0          0         0          0
  geometry      0       68         0          0         0          0
  inclusion     0        0        86          1         0          0
  lamination    0        0         0       1480         1          0
  main.spot     0        0         0          0         7          0
  metal.loss    0        0         0          0         0        480

Overall Statistics

               Accuracy : 0.9991
                 95% CI : (0.9967, 0.9999)
    No Information Rate : 0.6831
    P-Value [Acc > NIR] : < 2.2e-16

                  Kappa : 0.9981
 Mcnemar's Test P-Value : NA
```

Influencing factors

Tube/anomaly characteristics (thickness, radial position, ...)

No external variables

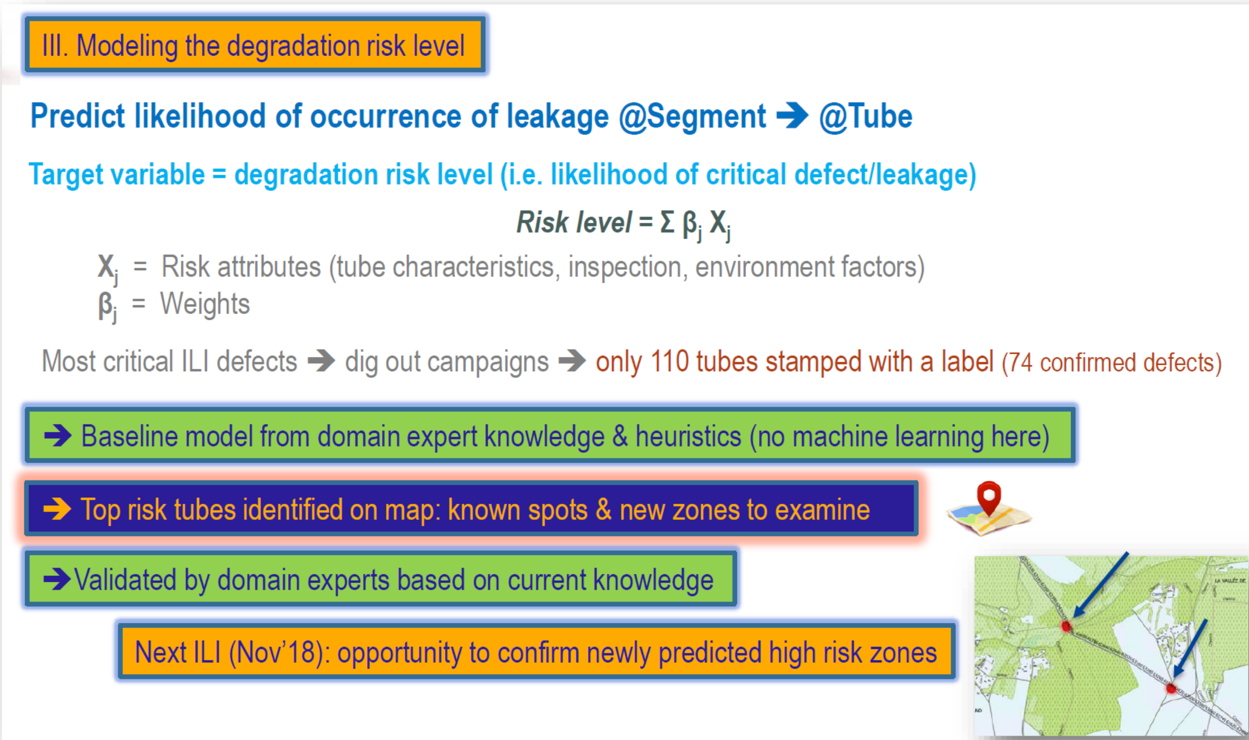
4.5.4 Predictive model of the corrosion rate



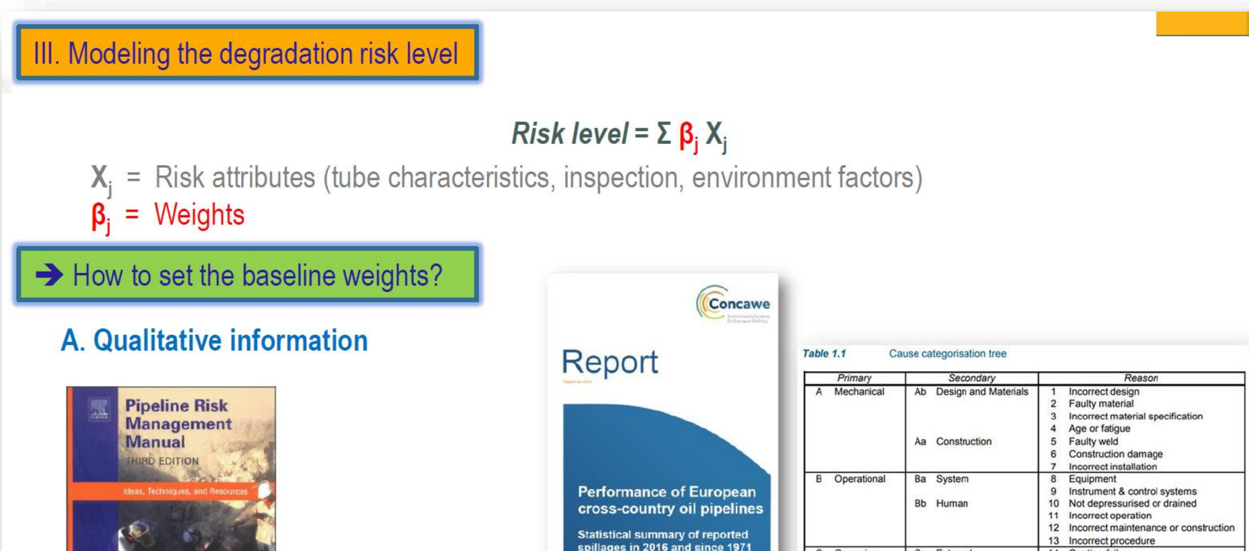
4.6 Degradation risk level model

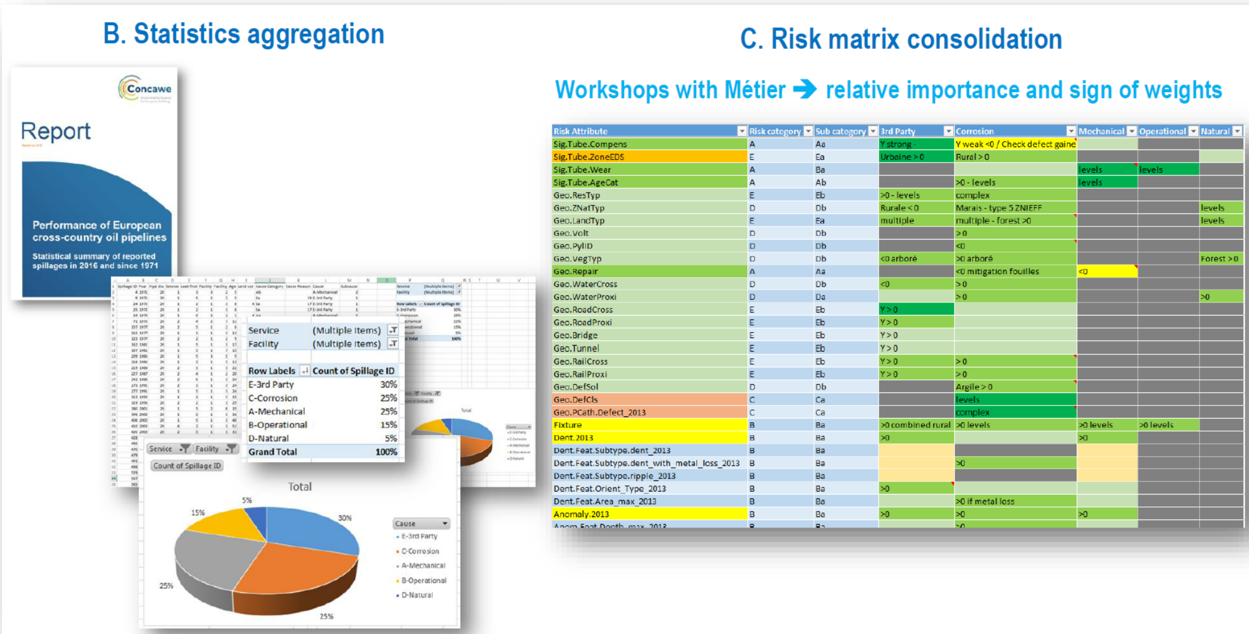
Data-driven + Domain expertise + Heuristics

4.6.1 Likelihood of leak occurrence



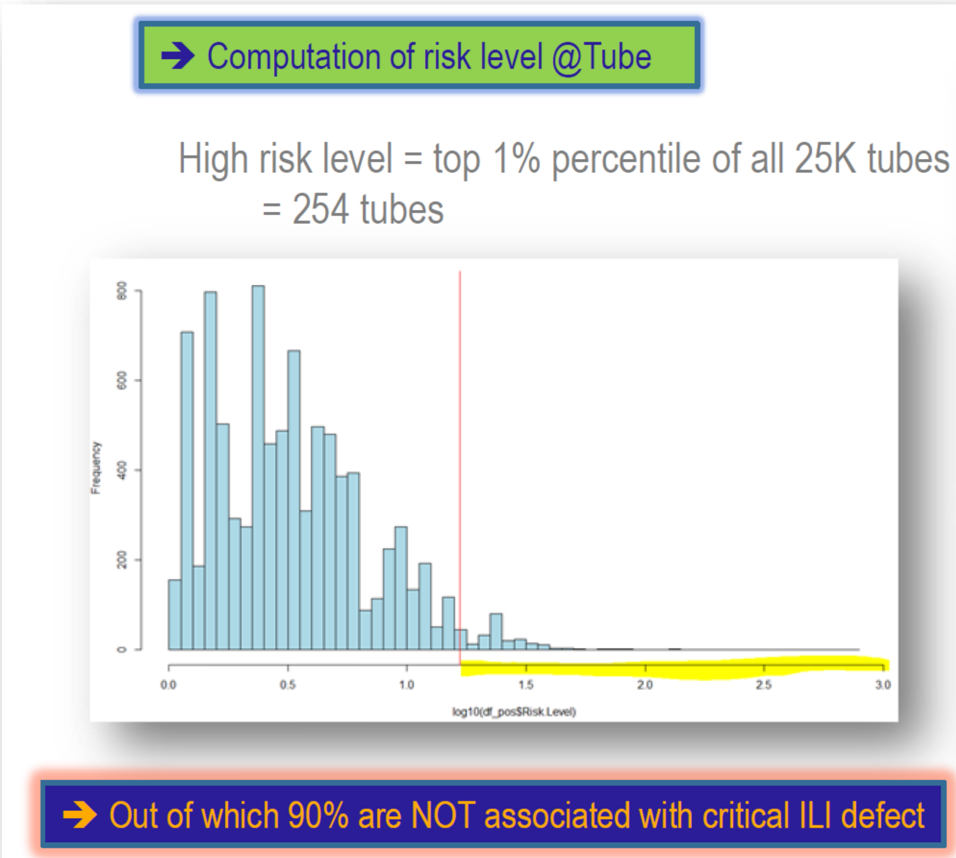
4.6.2 Baseline weights

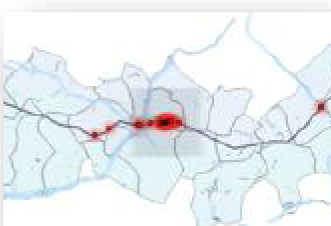




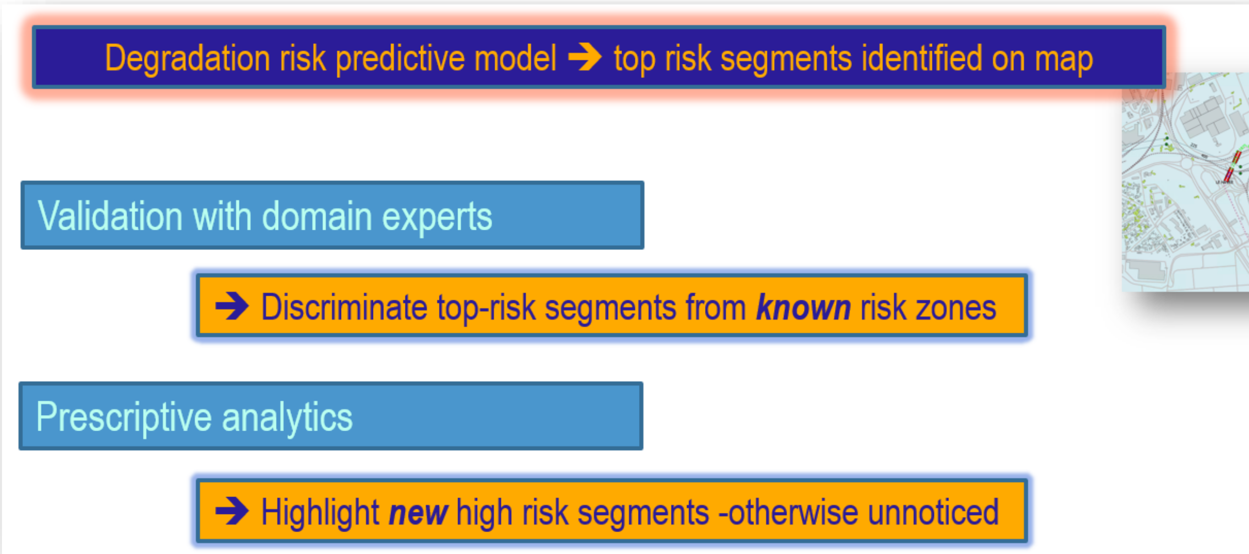
Risk Attribute	Risk category	Sub category	3rd Party	Corrosion	Mechanical	Operational	Natural
Sig.Tube.Compens	A	Aa	Y strong -	Y weak <0 / Check defect gaine			
Sig.Tube.ZoneEDS	E	Ea	Urbaine > 0	Rural > 0			
Sig.Tube.Wear	A	Ba			levels	levels	
Sig.Tube.AgeCat	A	Ab		>0 - levels	levels		
Geo.ResTyp	E	Eb	>0 - levels	complex			
Geo.ZNatTyp	D	Db	Rurale < 0	Marais - type 5 ZNIEFF			levels
Geo.LandTyp	E	Ea	multiple	multiple - forest >0			levels
Geo.Volt	D	Db		> 0			
Geo.PylID	D	Db		<0			
Geo.VegTyp	D	Db	<0 arboré	>0 arboré			Forest > 0
Geo.Repair	A	Aa		<0 mitigation fouilles	<0		
Geo.WaterCross	D	Db	<0	> 0			
Geo.WaterProxi	D	Da		> 0			>0
Geo.RoadCross	E	Eb	Y > 0				
Geo.RoadProxi	E	Eb	Y > 0				
Geo.Bridge	E	Eb	Y > 0				
Geo.Tunnel	E	Eb	Y > 0				
Geo.RailCross	E	Eb	Y > 0	> 0			
Geo.RailProxi	E	Eb	Y > 0	> 0			
Geo.DefSol	D	Db		Argile > 0			
Geo.DefCls	C	Ca		levels			
Geo.PCath.Defect_2013	C	Ca		complex			
Fixture	B	Ba	>0 combined rural	>0 levels	>0 levels	>0 levels	
Dent.2013	B	Ba	>0		>0		
Dent.Feat.Subtype.dent_2013	B	Ba					
Dent.Feat.Subtype.dent_with_metal_loss_2013	B	Ba		>0			
Dent.Feat.Subtype.ripple_2013	B	Ba					
Dent.Feat.Orient_Type_2013	B	Ba	>0				
Dent.Feat.Area_max_2013	B	Ba		>0 if metal loss			
Anomaly.2013	B	Ba	>0	>0	>0		
Anom.Feat.Depth_max_2013	B	Ba		>0			

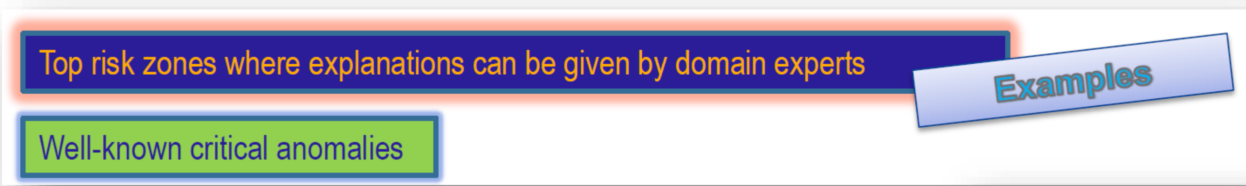
4.6.3 Computation of risk level

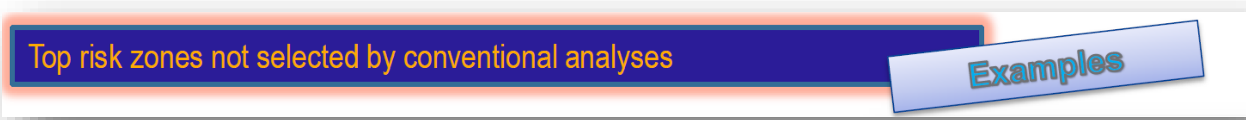




4.6.4 Domain expert analysis





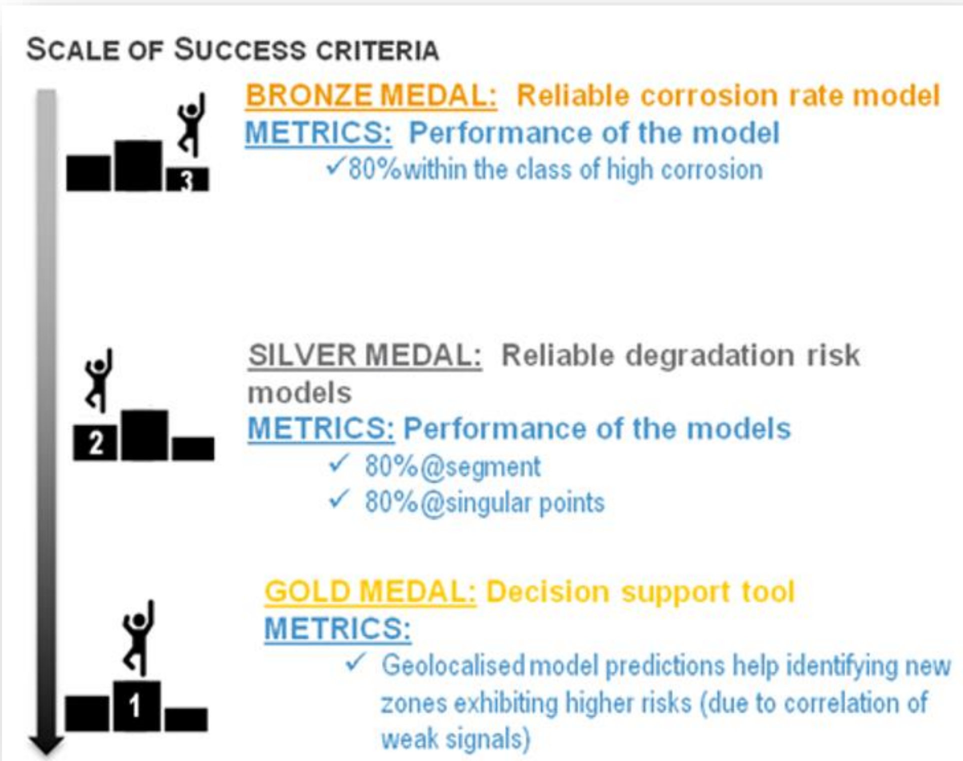


Example of risk factors:

- Metal loss defects
- Weaker cathodic protection
- Singular tube
- gaine/pipe contact

The result details are confidential and can't be disclosed in this report.

4.7 Key Success Factors



5 Decision-support tool for inspection