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Remote diagnostics and optimization of the machine maintenance service

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Executive summary

- **It is demonstrated on a case with "connected" Océ printers how**
  - Optimal maintenance attributes/features can be obtained by applying a data mining process
  - Maintenance thresholds can be optimally set
  - Predictive maintenance can be implemented

Overview

- Remote connectivity platform
- What can data mining do for you?
- Data mining methodology for optimal maintenance
- Case study: Océ printers
- Conclusions

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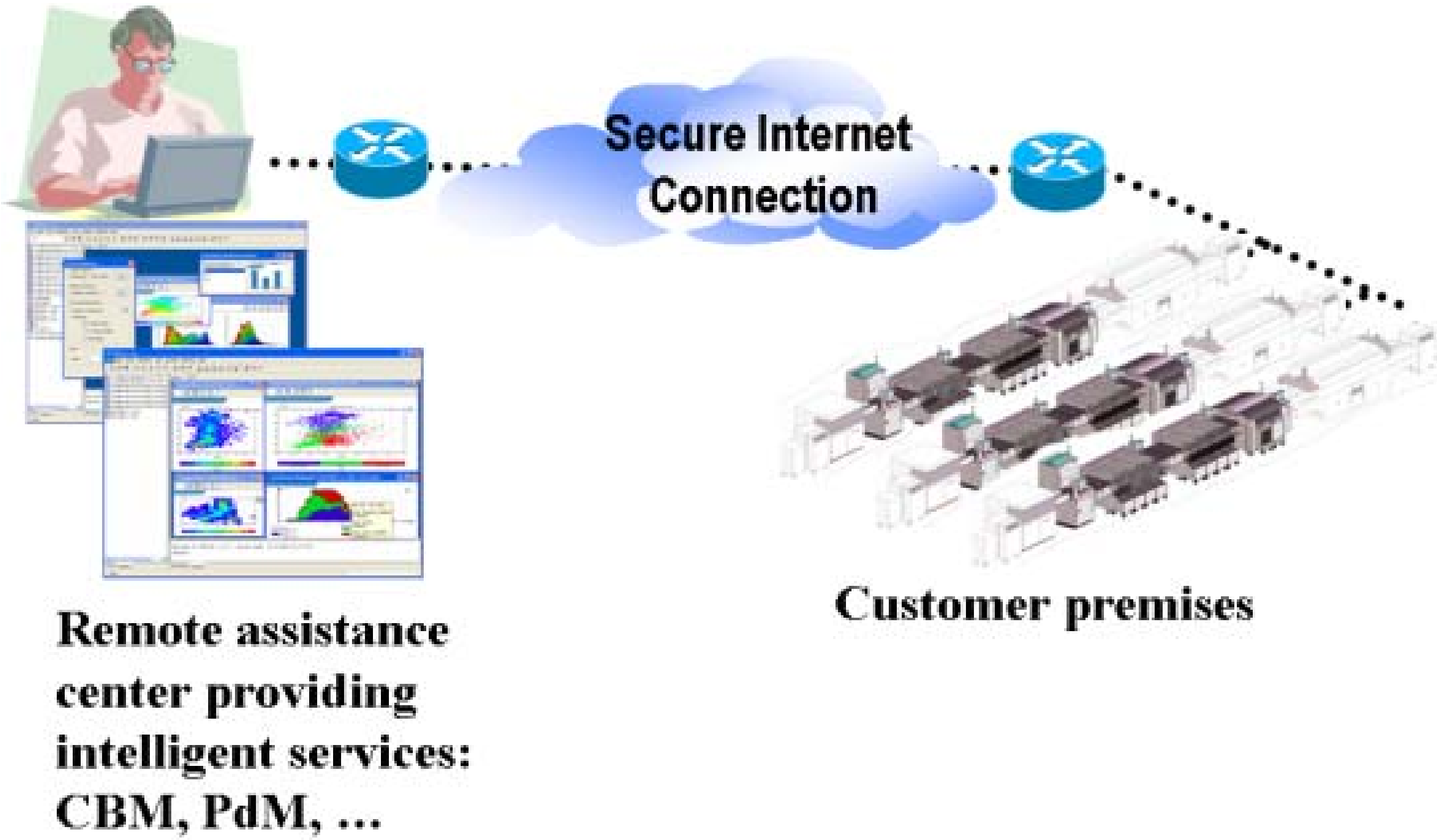
Remote connectivity platform



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Goal of the data mining process

The industrial problem → **Companies need insight in the operational behavior of their products.**

Why?

- **Preventive/Predictive maintenance:**

  Cost optimization = Trade-off preventive / corrective

  - When will next failure occur?
  - What will this failure be?
  - Coordinated maintenance of groups useful?

- **Diagnostics:**
  - Why does my machine fail earlier than expected?
  - What are my most common root causes?

Goal of the data mining process

- **Increase insight in machine behavior**
  - Analyze currently available data and extract factual information.
  - Provide indications for missing data.
  - Qualify currently used maintenance criteria.

  → Data mining

- **Provide a starting point for making reliable maintenance predictions**

  → Prognostics

- ***Data mining* and *prognostics* in combination with *the remote connectivity platform*:**

  → Remote diagnostics and remote optimization of maintenance actions

Data mining, prognostics, what is it?

- **Data mining (DM)**

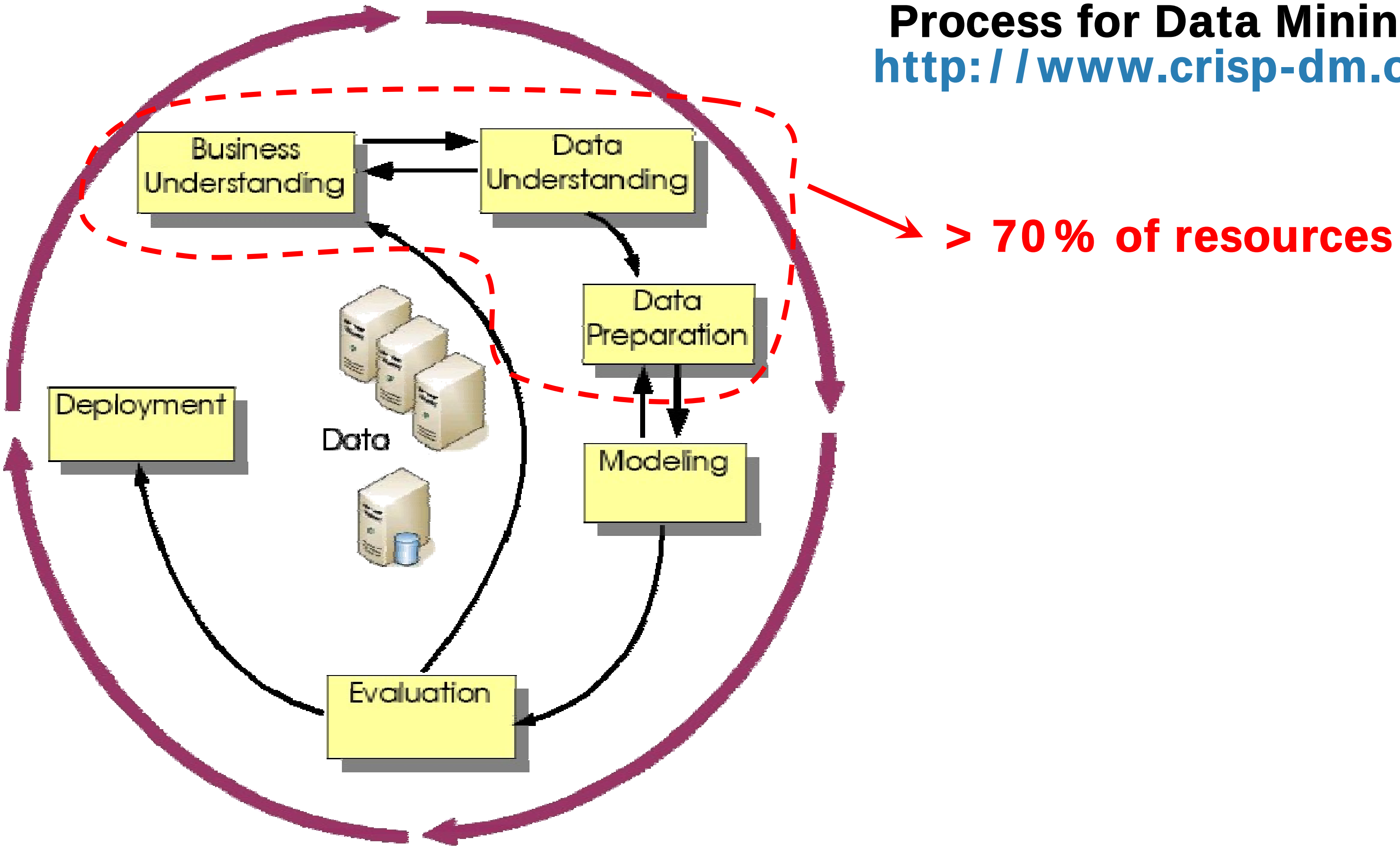
  Discovering meaningful new correlations, patterns and trends by sifting through large amounts of data stored in repositories, using pattern recognition technologies as well as statistical and mathematical techniques

- **Prognostics**

  Predicting the future condition of a machine/component. It can be used to predict remaining component lifetime and perform condition based maintenance

CRISP-DM standard

Cross Industry Standard Process for Data Mining
http://www.crisp-dm.org/



Data modeling step

Technique	Description	Method(s)
Clustering	Unsupervised machine learning to group objects in different classes	K-Means, AutoClass
Classification	Assign unknown objects to well established classes	Neural Networks, K-NN, SVM
Conceptual clustering	Qualitative language to describe the knowledge used for clustering	Decision Tree
Dependency modeling	Describes the dependency between variables	Bayesian Networks PCA, Dendrogram
Summarization	Provides a compact description of a subset of data	Statistical reporting Visualization
Regression	Determines functions that links a given continuous variable to other	ANN, Regression Tree, ML Regression
Rules based modeling	Generate rules that describe tendency of data	Association rules

Criteria for selection of data modelling method

- Interpretability: how well the model helps to understand the data
- Predictive accuracy: how well the model can predict unseen situations
- Computational efficiency: how fast the algorithm is and how well it scales to very large databases

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- **FMTC data mining methodology for optimizing maintenance**
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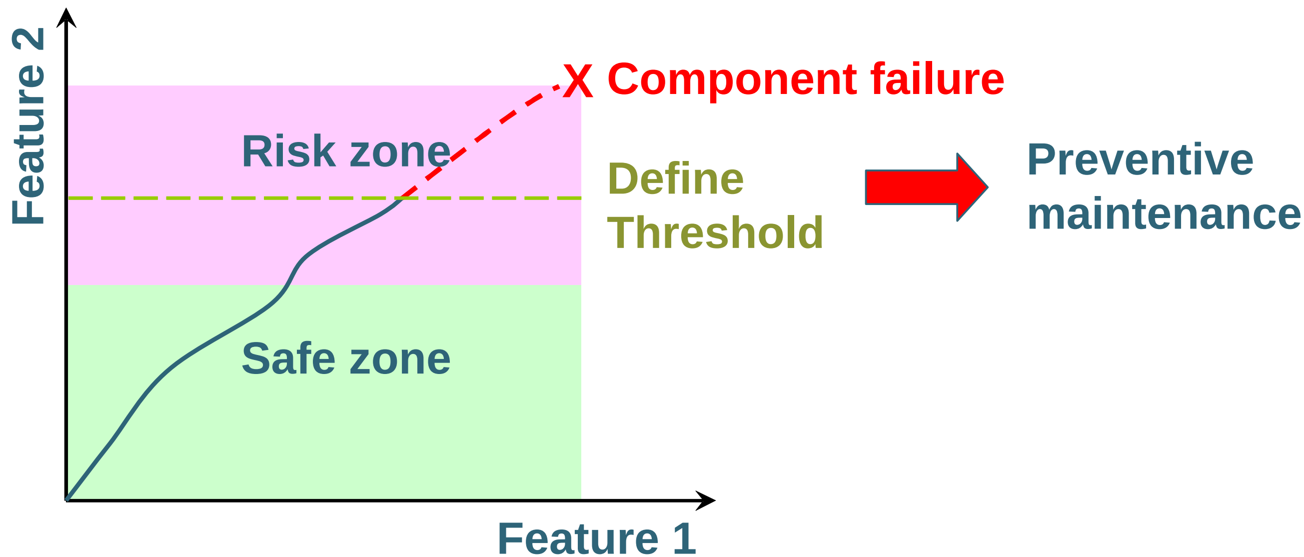
Feature selection

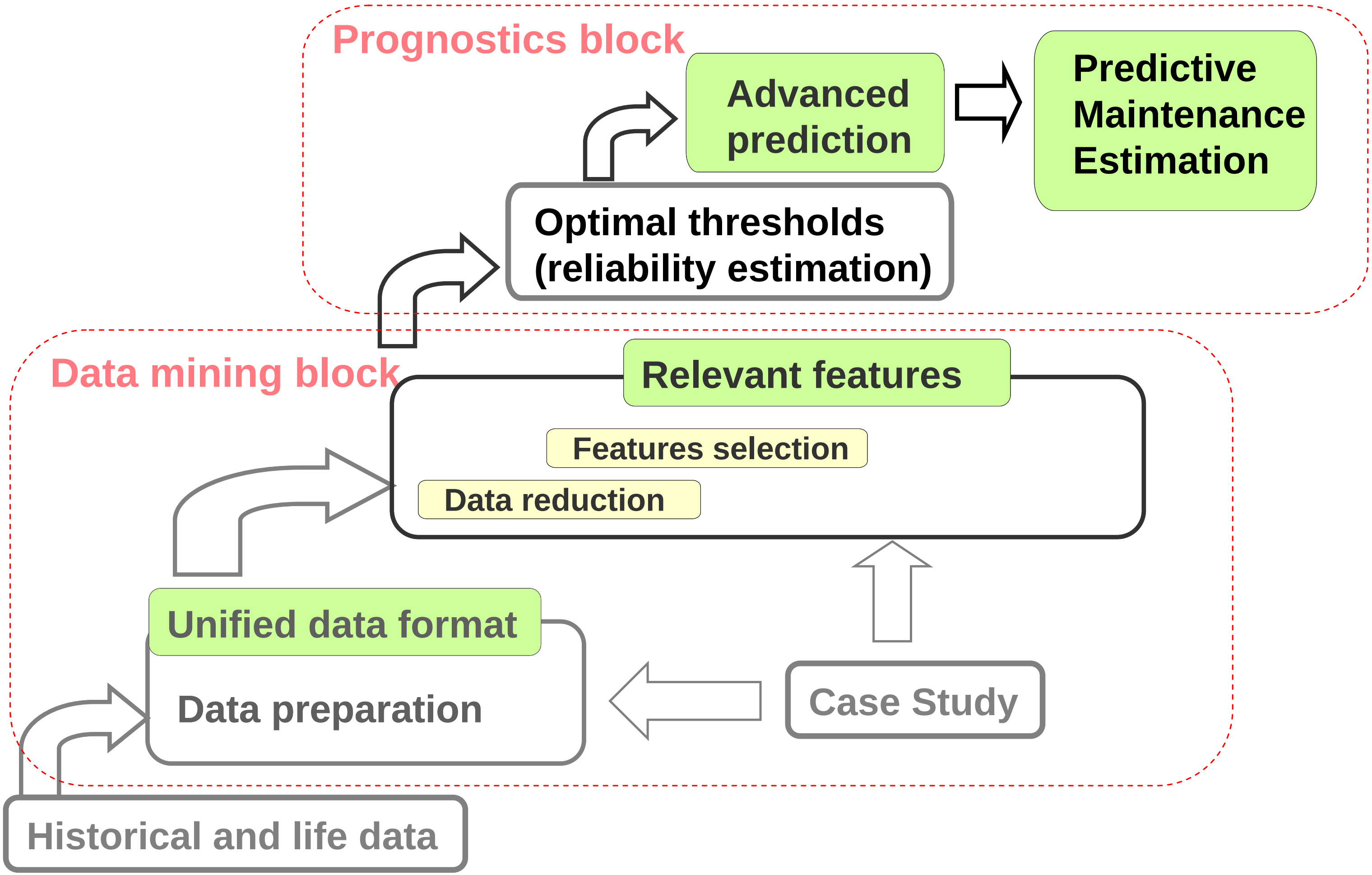
Use Data mining to find features linked to component failure



- Define Threshold
- Regression model to predict feature evolution

→ Predictive maintenance action

FMTC data mining methodology
A generic approach for industrial applications



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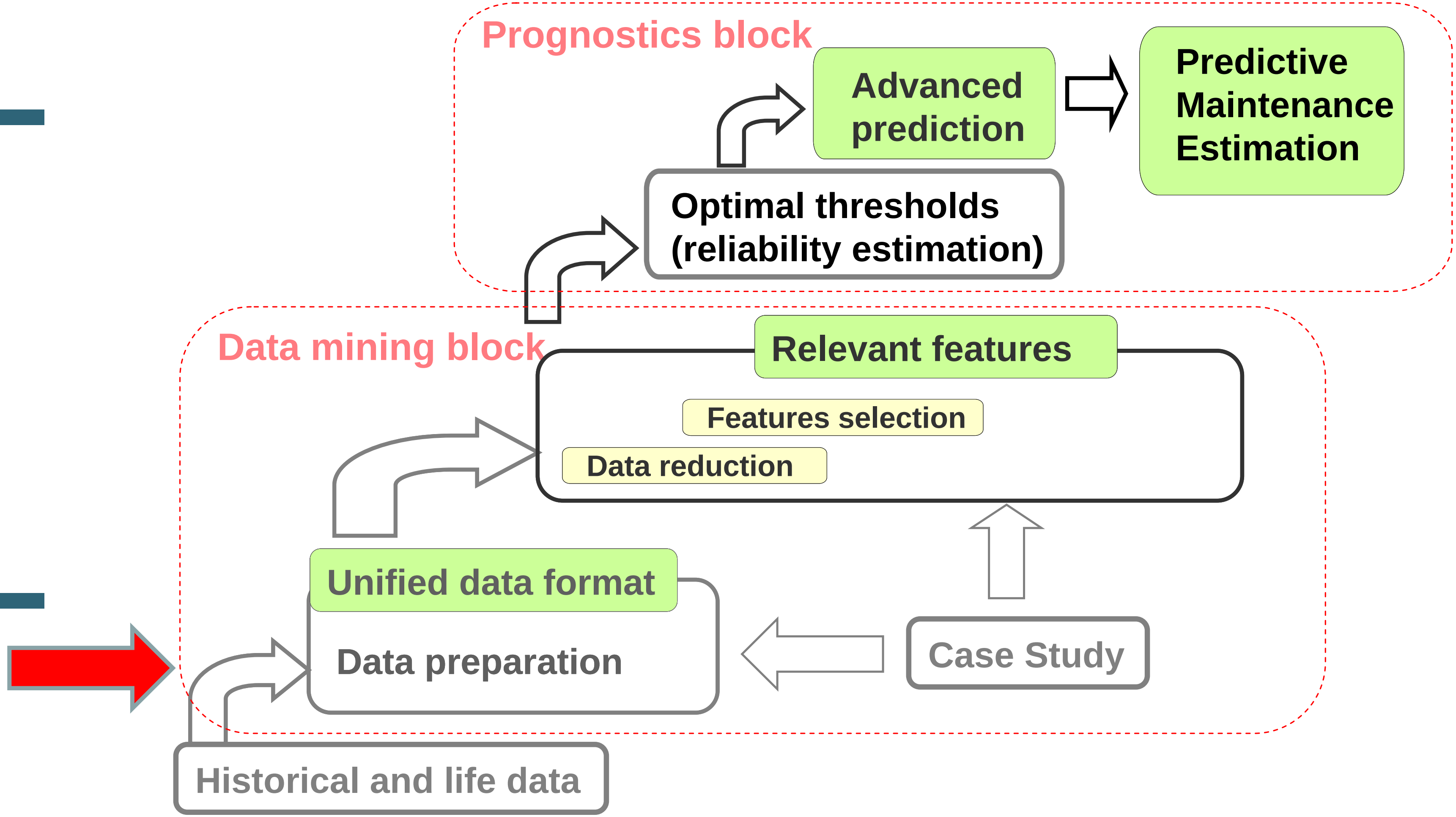
Current situation for specific printer

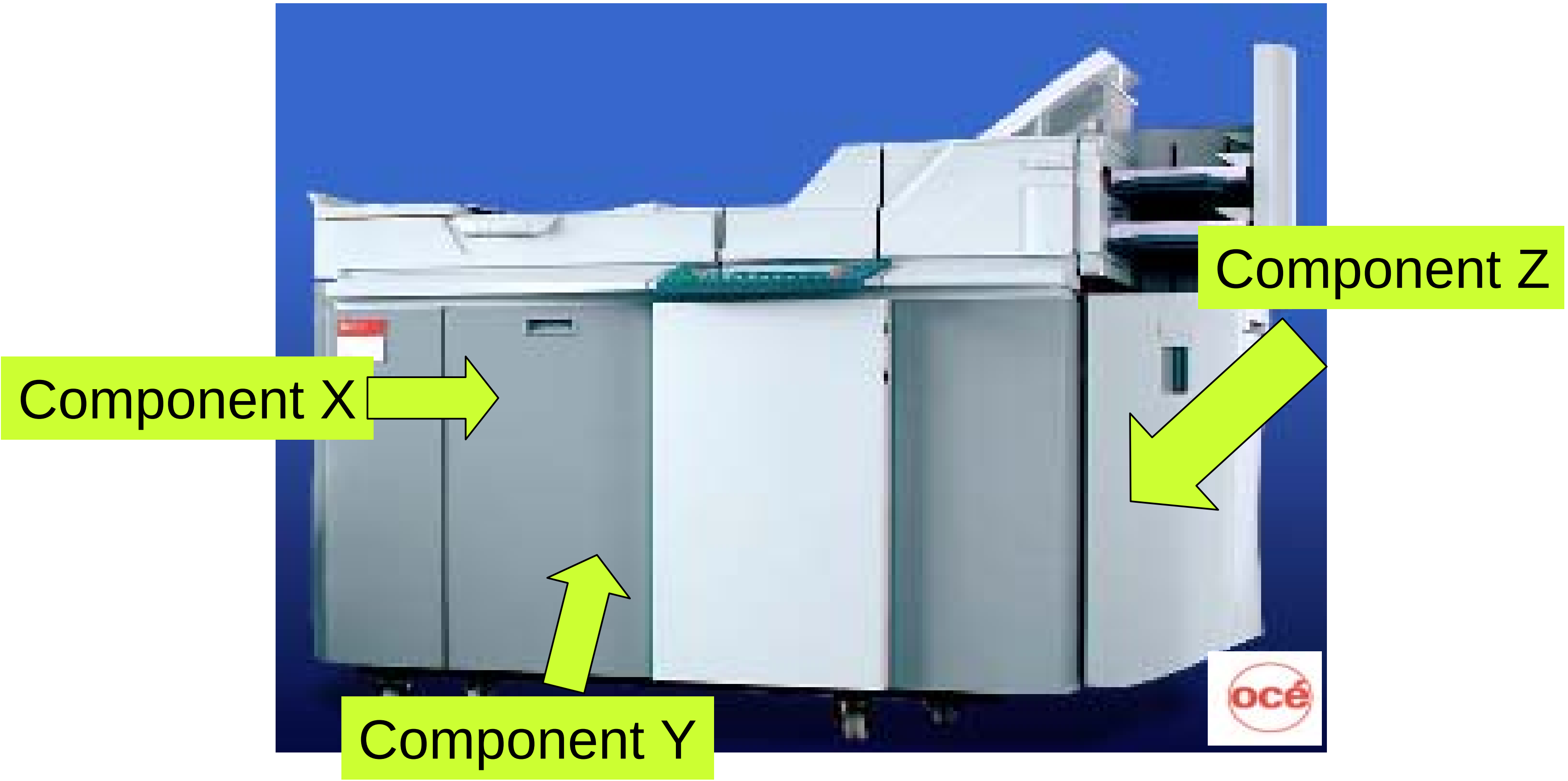
- Preventive maintenance is possible when technician is on-site.
- It is based on technician experience and "historical" guidelines. The origin or reason of guideline is established by field experience

FMTC data mining methodology
A generic approach for industrial applications



Selection of most maintenance intensive components

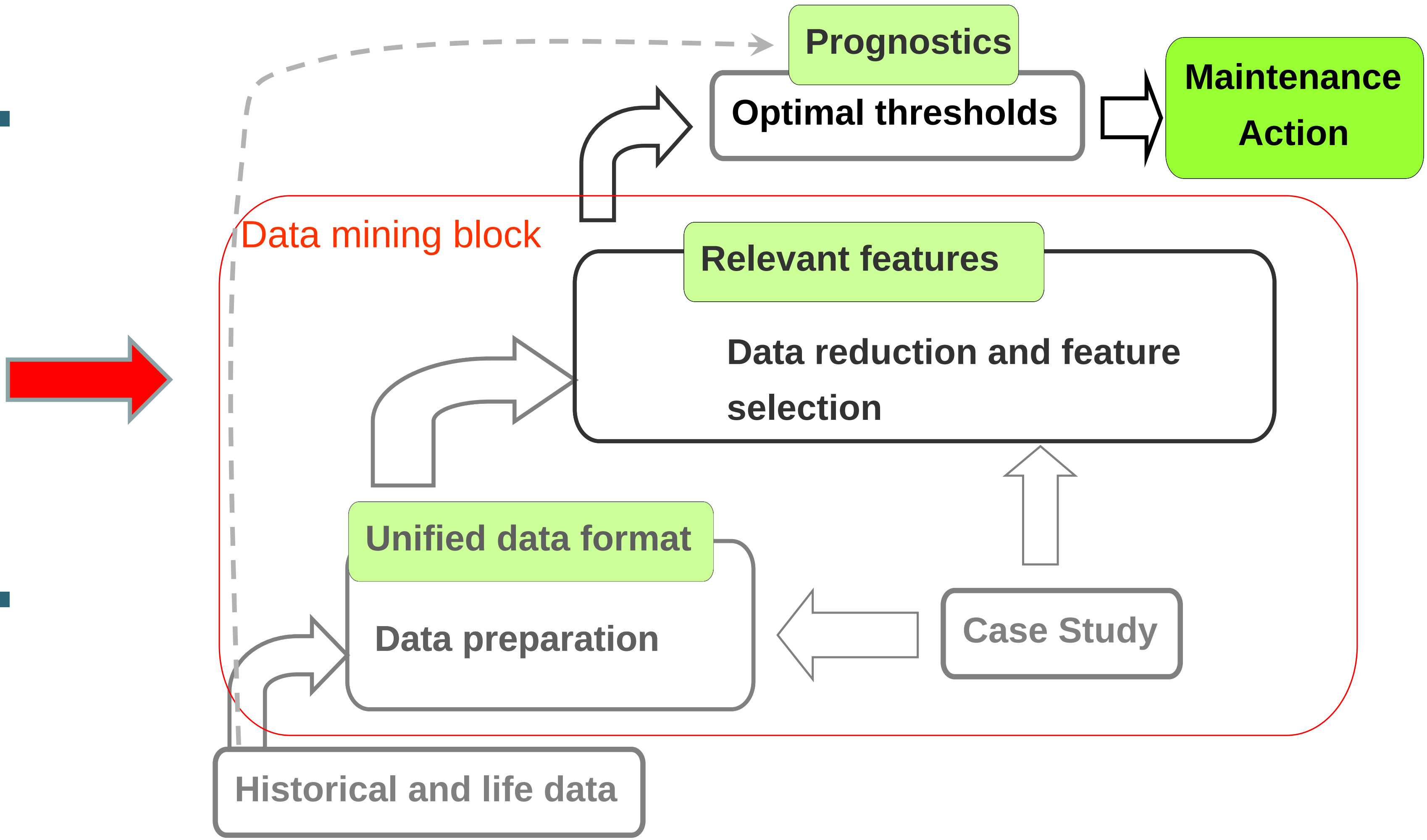
- From historical database maintenance intensive components are selected and a ranking is made



Unified data format (1)

$Attribute_1$	$Attribute_2$	…	…	$Attribute_N$	$Output_1$
$Object_{F11}$	$Object_{F21}$			$Object_{FN1}$	Part not replaced
$Object_{F12}$	$Object_{F22}$			$Object_{FN2}$	Part replaced
$Object_{F13}$	$Object_{F23}$			$Object_{FN3}$	Part not replaced
…	…			…	
…	…			…	
…	…			…	
$Object_{F1M}$	$Object_{F2M}$			$Object_{FNM}$	Part replaced

Case study 1
Feature selection



Identify the top features using the replacement information as an output

	Speed	Accuracy	Numerical Output	Categorical Output	optimization
ISF	++	-	N	Y (2 classes)	N
Spearman	+	+	Y	Y	N
Entropy	-	+	N	Y	N
DT	--	+	N	Y	local

Feature Ranking	Attribute
1	Error code XXX
2	ID_XYZ
3	…..

Define new maintenance action depending on results on 1

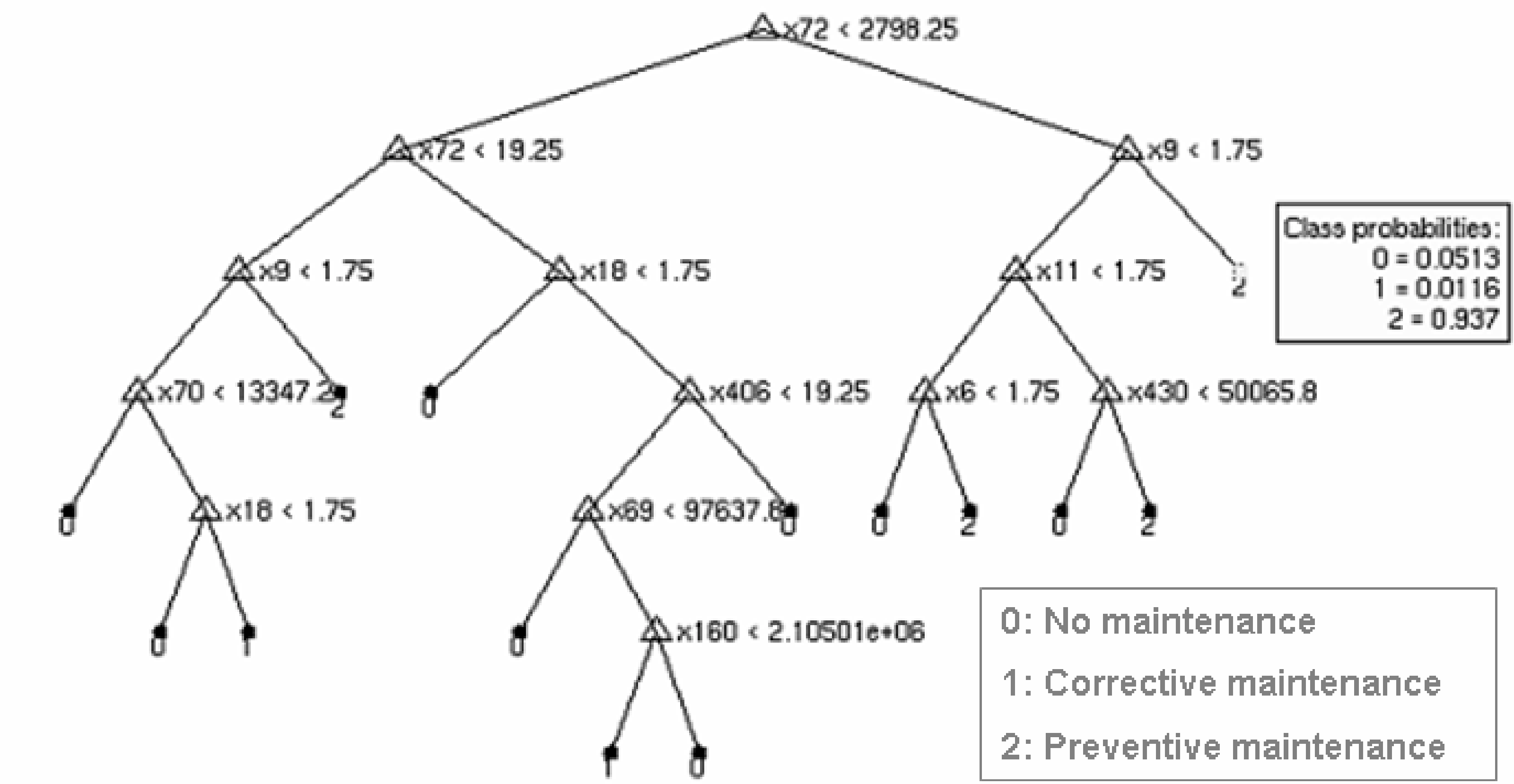
- New maintenance definition seemed more accurate than information in historical database

Error code XXX	Replacement	Maintenance type
Generated	Yes	Preventive
Generated	No	No replacement
Not generated	Yes	Corrective ?
Not generated	No	No replacement

Unified data format (2)

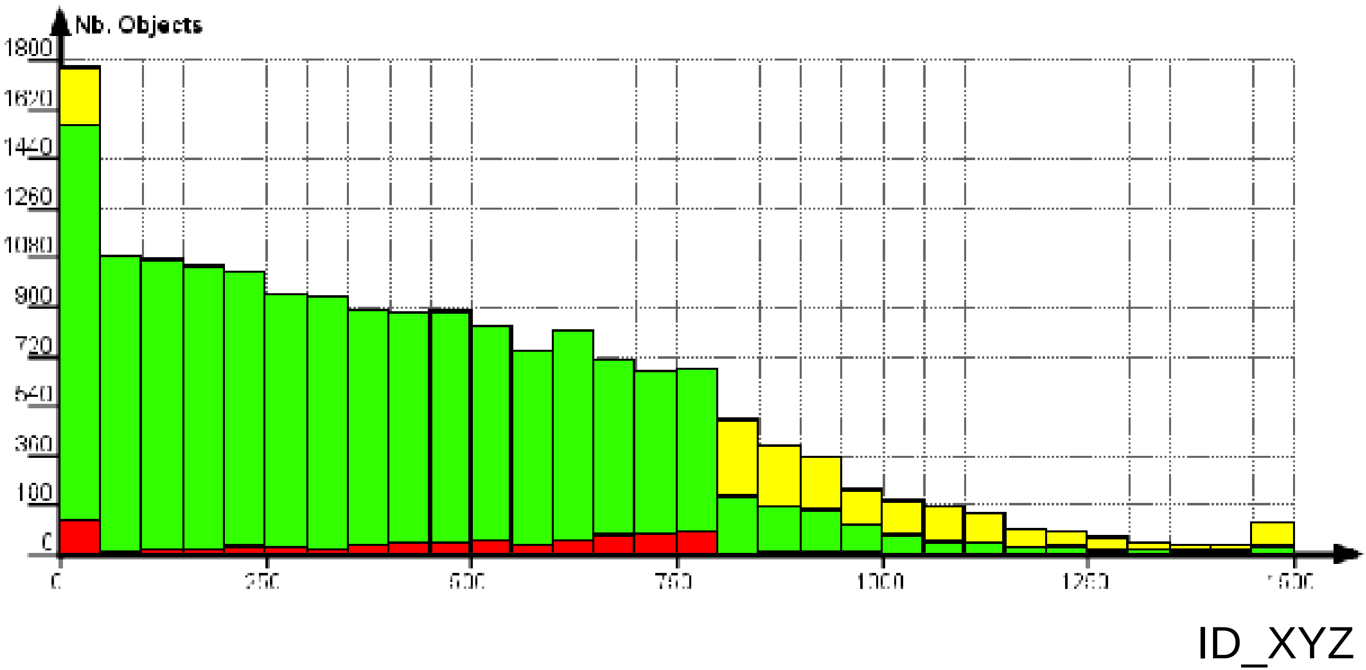
$Attribute_1$	$Attribute_2$	…	…	$Attribute_N$	$Output_1$	$Output_2$
$Object_{F11}$	$Object_{F21}$			$Object_{FN1}$	Part not replaced	No maintenance
$Object_{F12}$	$Object_{F22}$			$Object_{FN2}$	Part replaced	Corrective maintenance
$Object_{F13}$	$Object_{F23}$			$Object_{FN3}$	Part not replaced	No maintenance
…	…			…		
…	…			…		
…	…			…		
$Object_{F1M}$	$Object_{F2M}$			$Object_{FNM}$	Part replaced	Preventive maintenance

Identify the top features using the maintenance action as an output

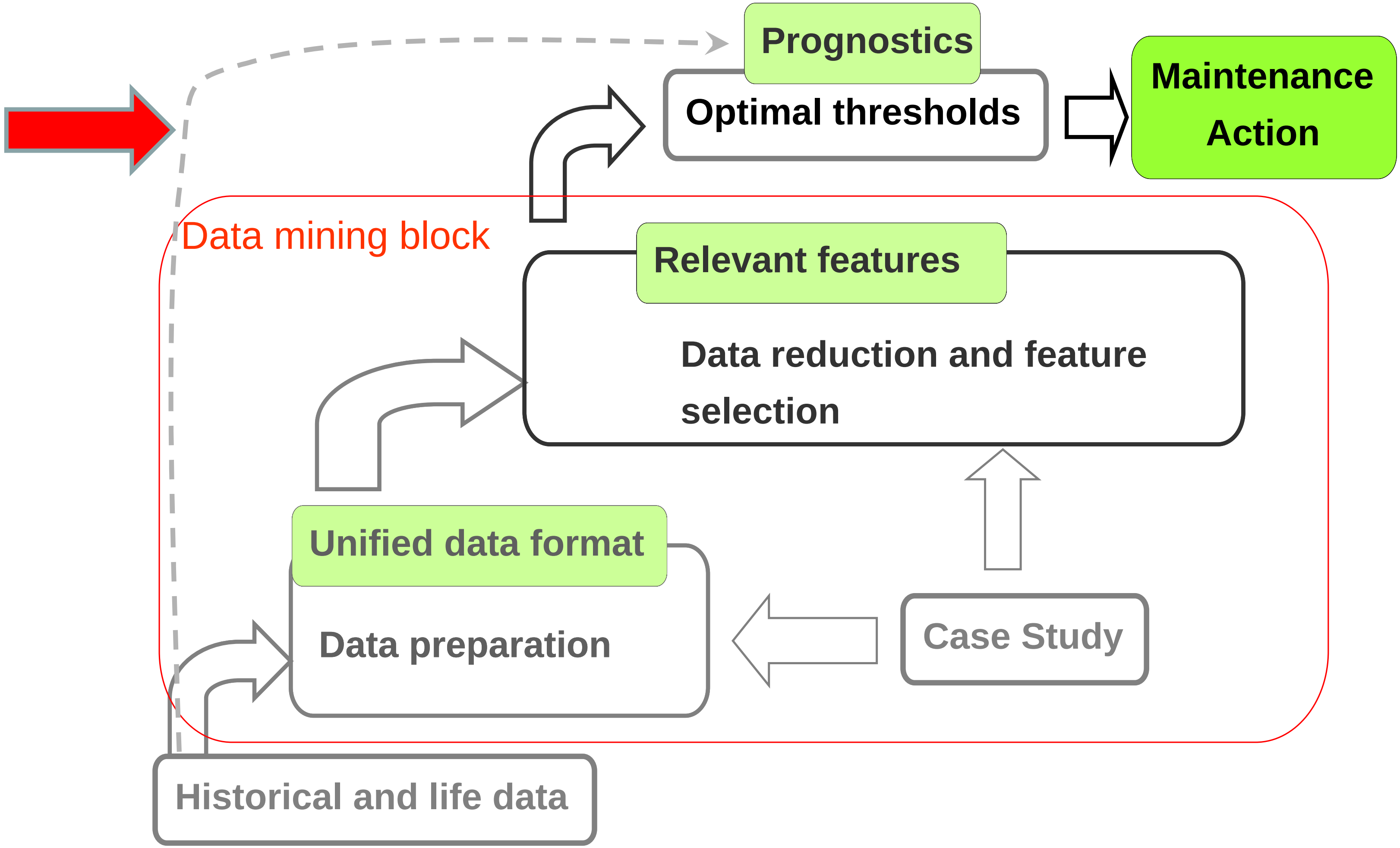


Histogram in function of ID_XYZ

ID_XYZ comes out as top-feature



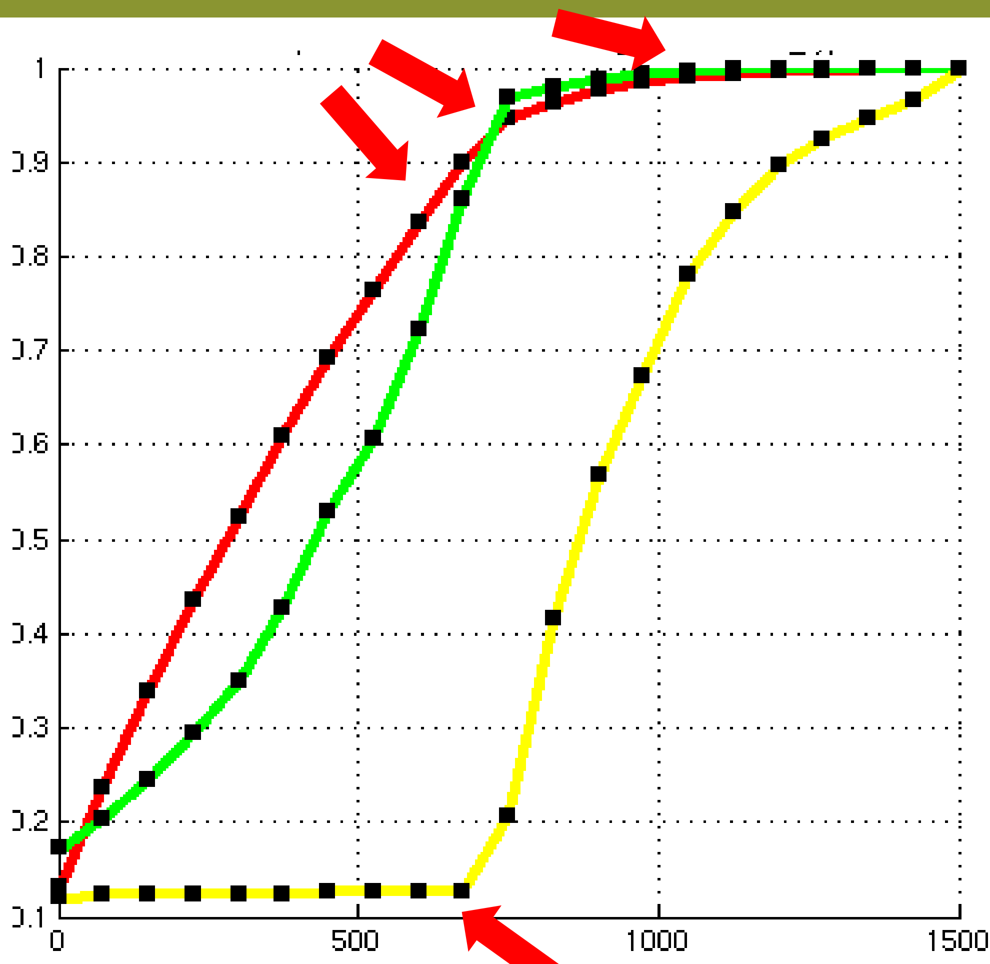
Case study 1
Determine threshold



Optimal threshold

Threshold can be chosen based on acceptable failure probability

Error code XXX	Replacement	Maintenance type
Generated	Yes	Preventive
Generated	No	No replacement
Not generated	Yes	Corrective ?
Not generated	No	No replacement

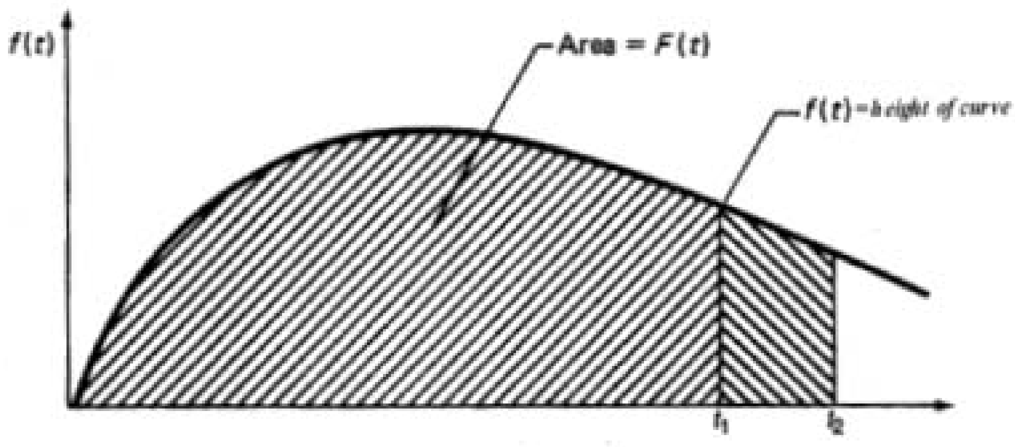


ID_XYZ

Threshold based on experience

Life Time Distribution

- **In order to define the optimal threshold in a statistical way, survival analyses are used**
  - Probability density functions are fitted to the failure data (in our case corrective maintenance data).



f(t): probability density function (PDF)

Area F(t): cumulative density function (CDF)

- **The shaded area between t_1 and t_2 represents the proportion of the population that fails between times t_1 and t_2.**

Distribution Models

- **Weibull distribution model**

The Weibull is a very flexible life distribution model with two parameters.

CDF: $F(t)=1-e^{-\left(\frac{t}{\alpha}\right)^{\gamma}}$

RELIABILITY: $e^{-\left(\frac{t}{\alpha}\right)^{\gamma}}$

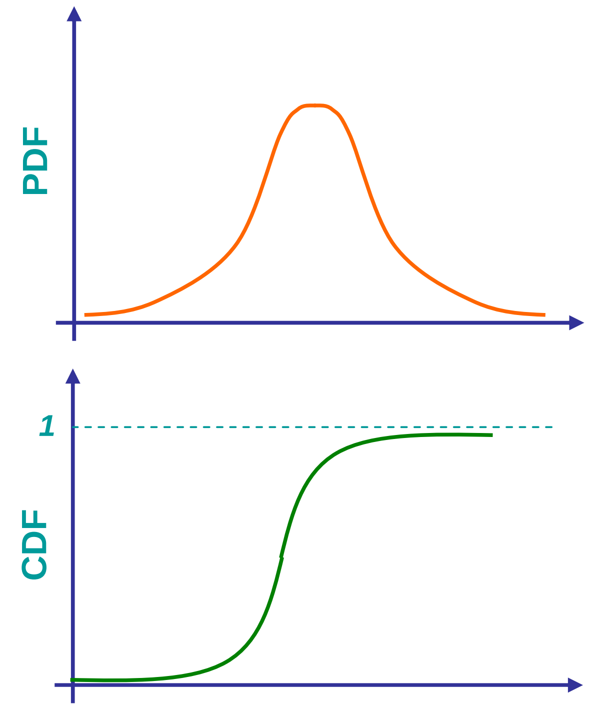
PDF: $f(t)=\frac{\gamma}{t}\left(\frac{t}{\alpha}\right)^{\gamma} e^{-\left(\frac{t}{\alpha}\right)^{\gamma}}$

FAILURE RATE: $\frac{\gamma}{\alpha}\left(\frac{t}{\alpha}\right)^{\gamma-1}$

MEAN: $\alpha\Gamma\left(1+\frac{1}{\gamma}\right)$

MEDIAN: $\alpha\,(\ln 2)^{\frac{1}{\gamma}}$

VARIANCE: $\alpha^{2}\Gamma\left(1+\frac{2}{\gamma}\right)-\left[\alpha\Gamma\left(1+\frac{1}{\gamma}\right)\right]^{2}$



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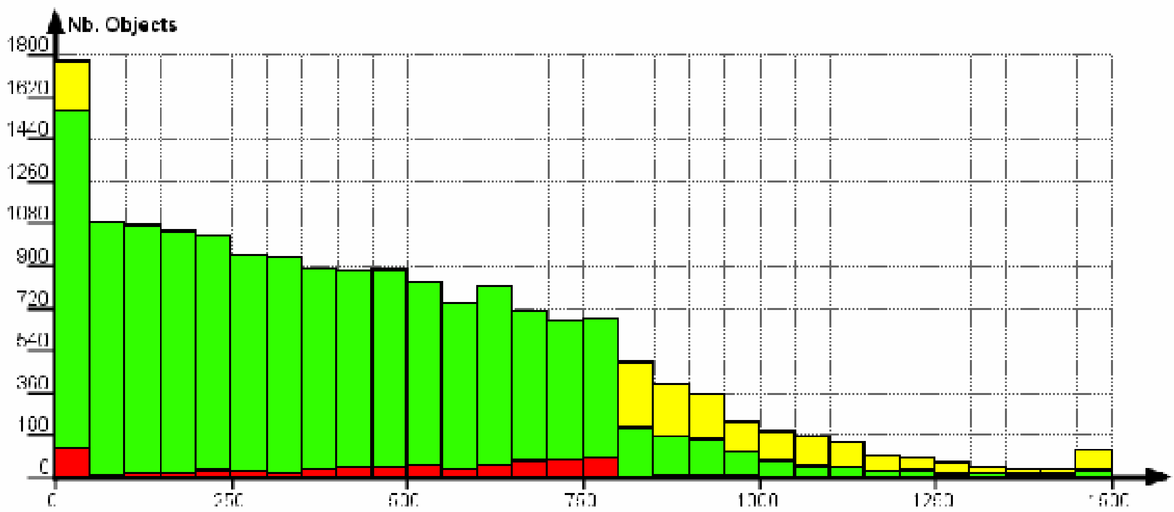
Reliability Data of OCÉ Case

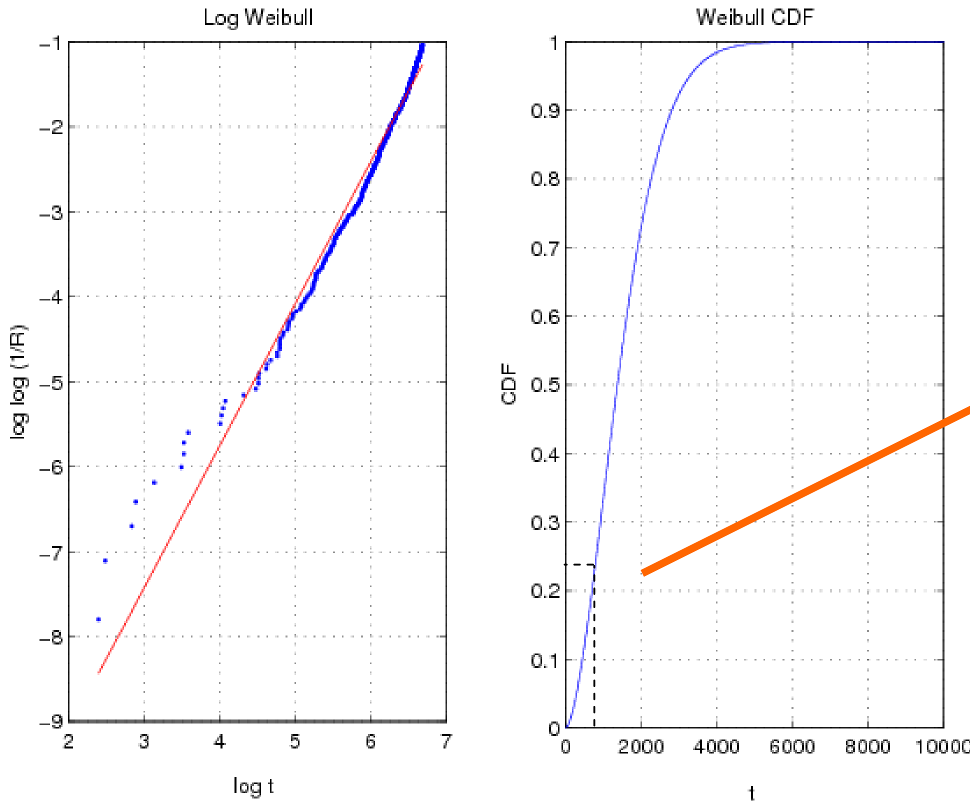
Data of 10 < ID_XYZ < 800 is considered, with the following reasons:

- ❑ID_XYZ < 10 contains suspicious data: high level of corrective maintenance
- ❑ID_XYZ> 800 contains no corrective maintenance: absence of failure data



Estimated reliability

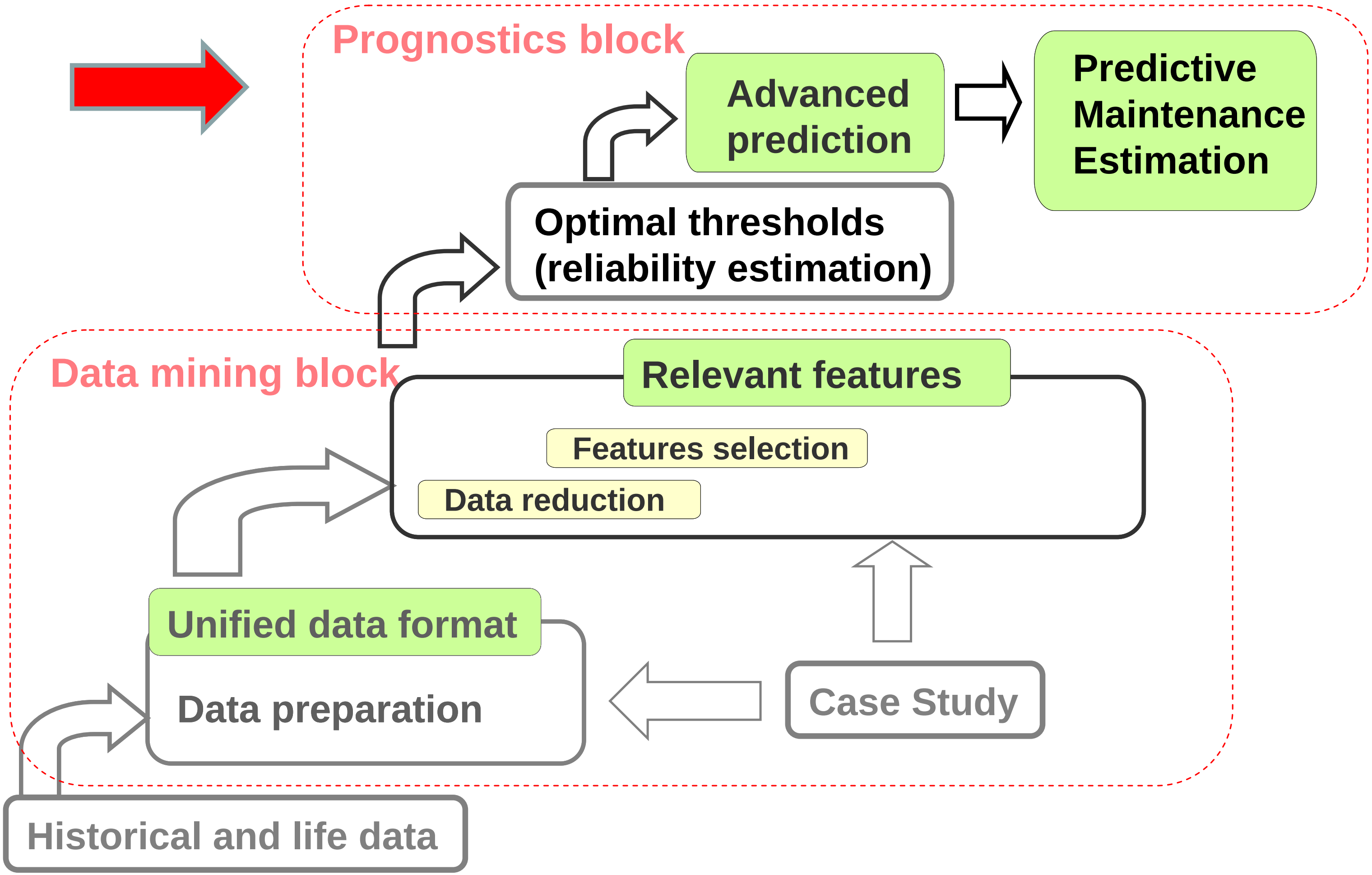
- **Weibull**



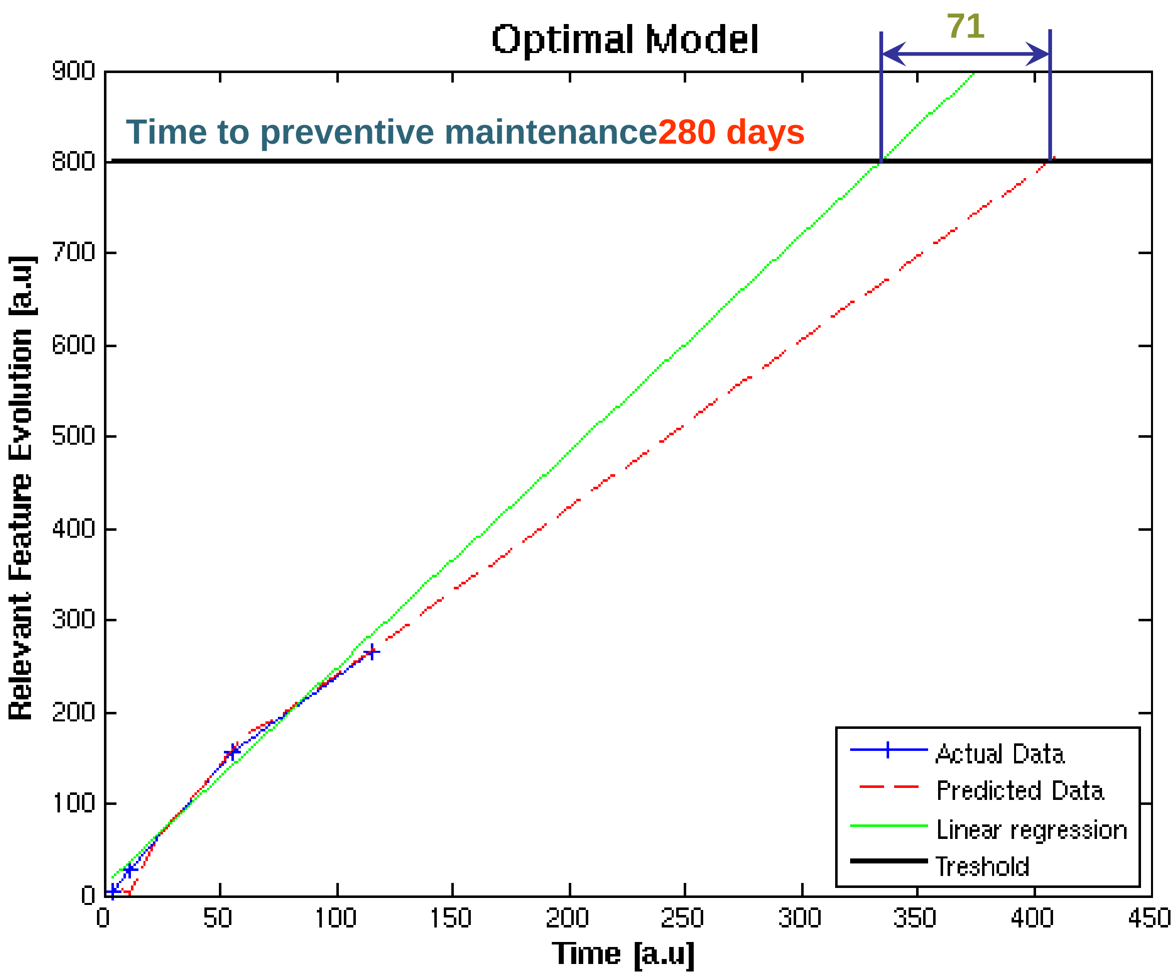
There is a probability of 24% that the component will fail by unit of ID_XYZ (800)

By analysis of business case it can be checked if threshold at 24% of failure is optimal

FMTC data mining methodology
A generic approach for industrial applications



Case study 1
Prognostics



Prognostics on-going

➢ **Different prediction algorithms have been checked**

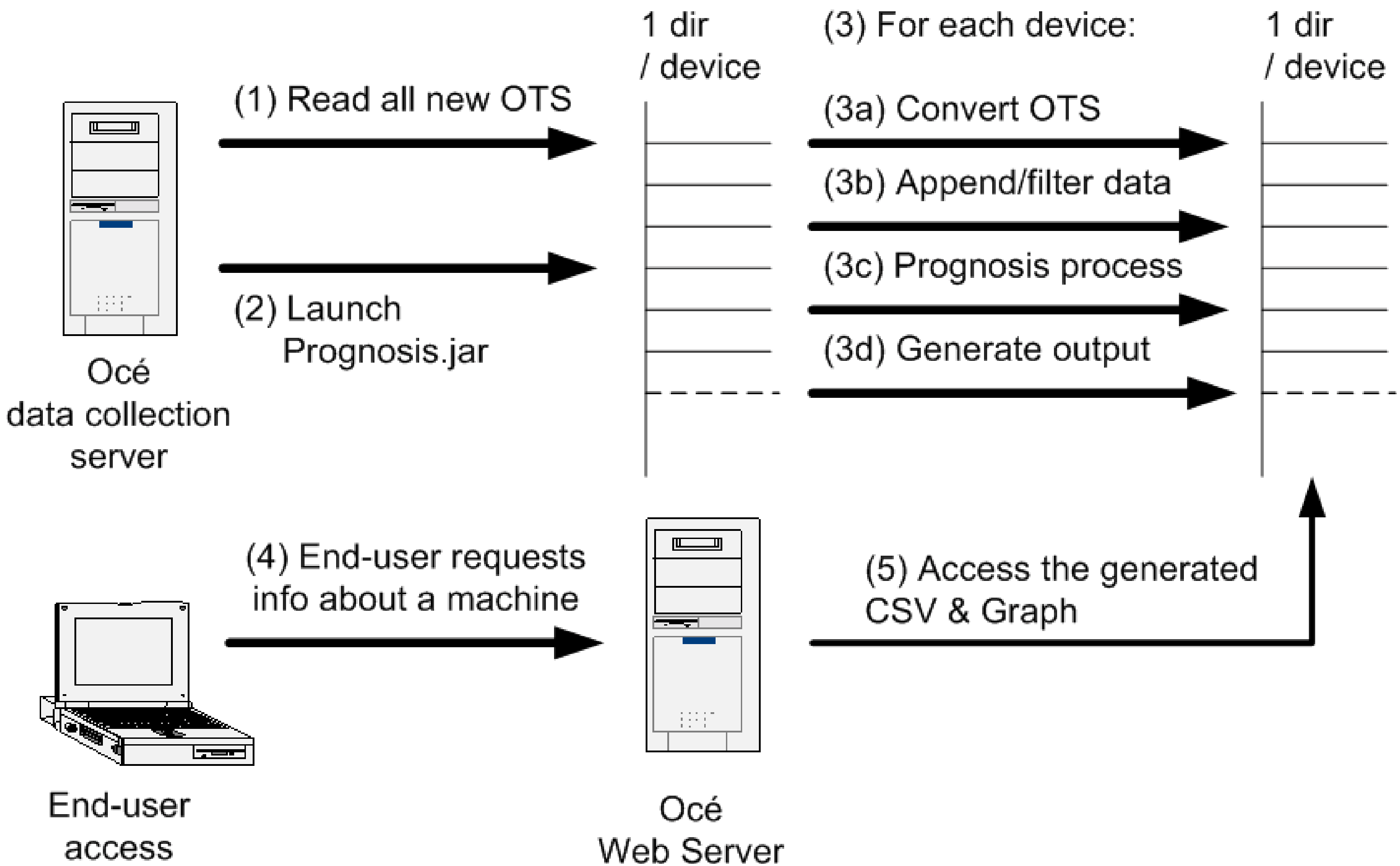
	Minimum data needed	Forecast horizon	Robust-ness	Interpretability	Experience needed	Standard software
Regression	+	-	-	+	++	+
Exponential smoothing	+	-	+	+	+	+
ARMA	+	+	+	+/-	-	+
ANN	--	++	+(+)	-	--	+
SVR	-	++	+(+)	-	-	?/-

➢ **Improvement of prediction algorithm**

❑ Prediction algorithm should deal with the fact that machines are switched off during certain periods

➢ **Implementation of demo on-going**

Implementation is on-going



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Conclusions

- **FMTC data mining approach was successfully applied to several components**
- **Data mining results proved useful to optimally find features of interest, better specify the maintenance thresholds, and perform predictive maintenance.**
- **FMTC and the partner are actively processing the results:**
  - Implementation in the machine device manager is on-going.
  - New business cases are being defined in the context of predictive maintenance.

Acknowledgments

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Proposed discussion topics

- Remote servicing is a journey, not a destination
- Can service maintenance also be optimized in your organization by application of this method?
- Where could data mining be successful for you?
- …