INFRALERT

RAMS & LCC Toolkit

1st Open Workshop
Brussel (Belgium) 16.11.16

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cemosa
Ingeniería y Control

Outline

Introduction
General Overview

RAMS
LCC

Use Case / some results
On-going conclusions

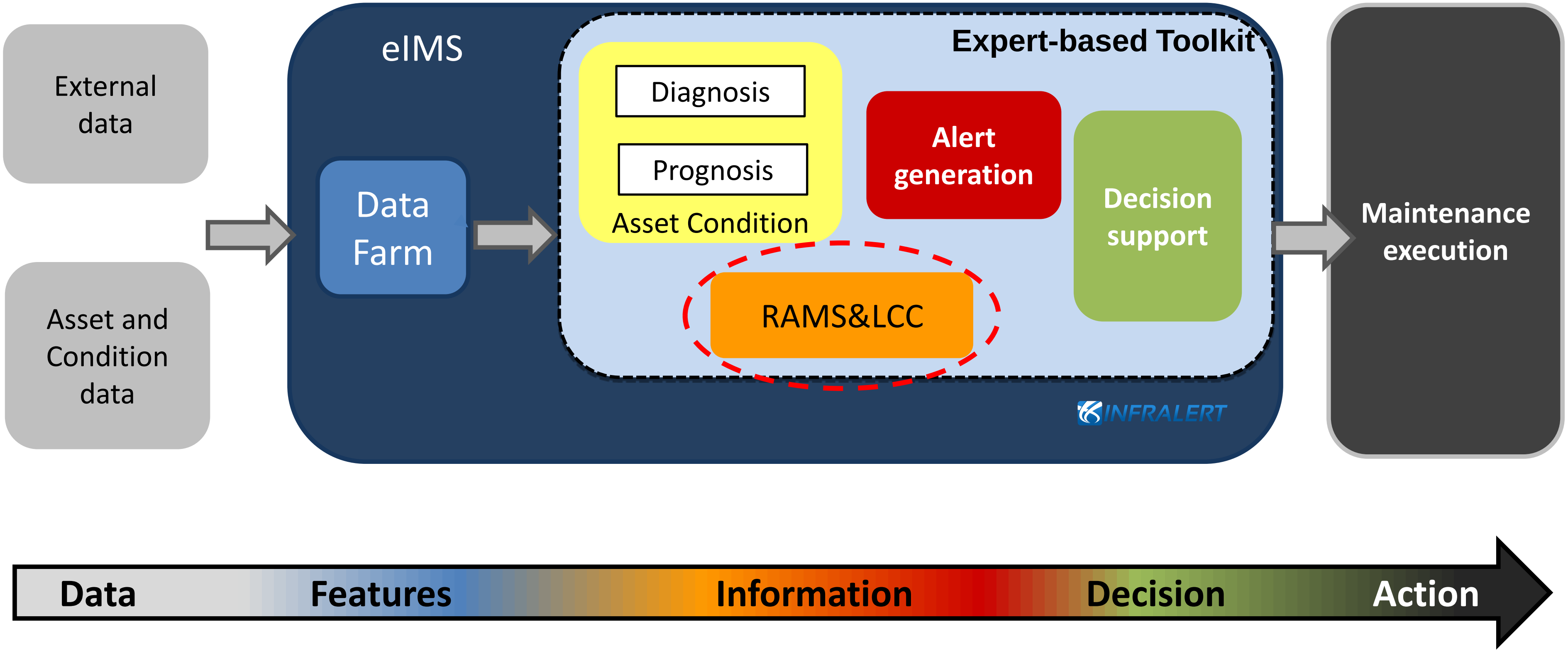
Introduction

- Rail & Road infrastructures are complex systems
  - Once they are installed it is very difficult to modify their initial design
- The performance of the infrastructure depends on
  - Maintenance and renewal activities during its life-cycle
- To guarantee optimal long-term results
  - The effects of maintenance decisions must be evaluated
- Infra managers' goal:
  - Optimize (maintenance) budget
  - Increase reliability and availability of the system
  - Keep predefined safety levels
- Aim of INFRALERT RAMS&LCC expert-toolkit:
  - System RAMS/LCC analysis in order to extract effective maintenance decisions
  - Assess LCC uncertainty : associated with stochastic RAMS and economic conditions

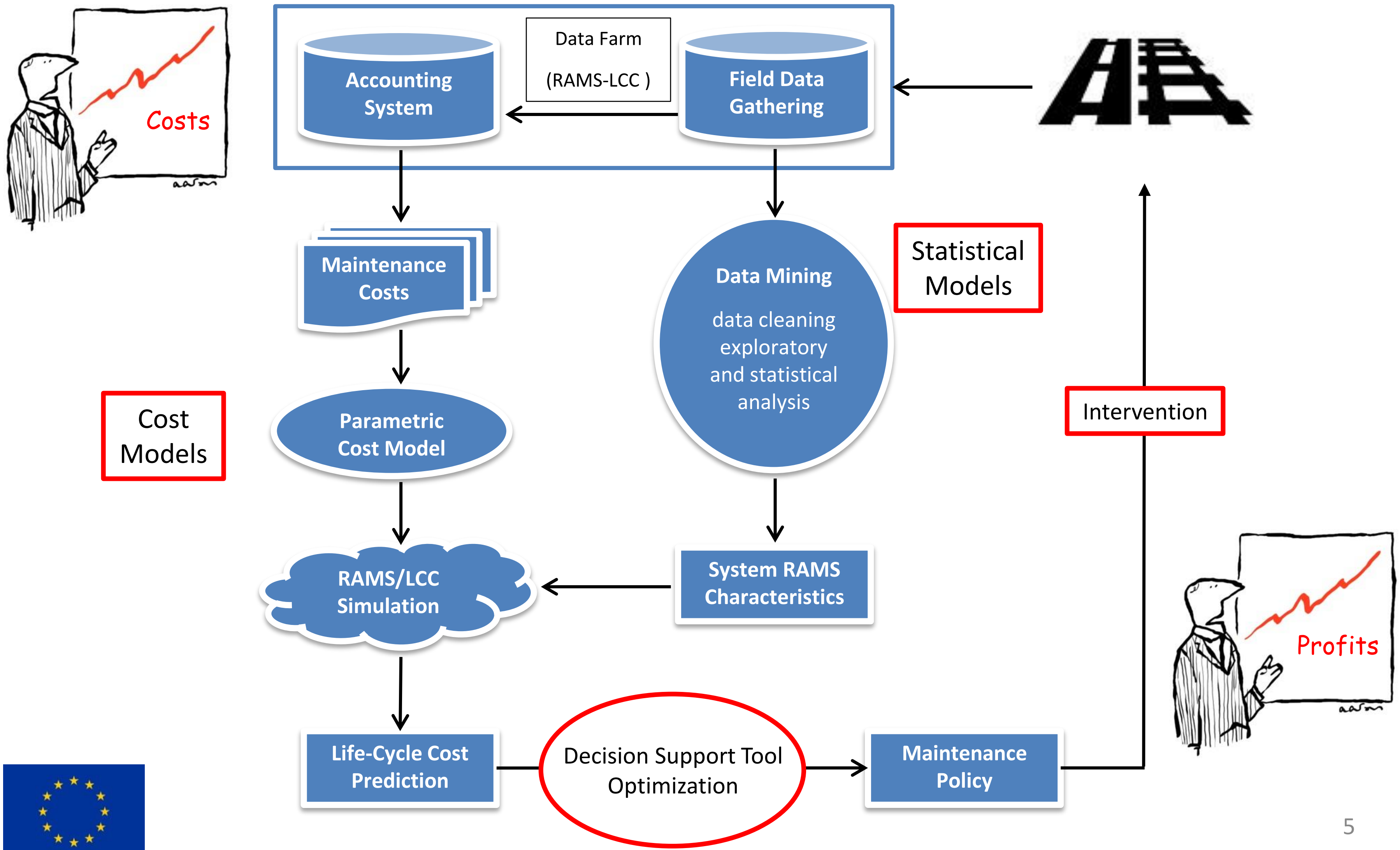
Context of INFRALERT

RAMS&LCC “intermediate step”:

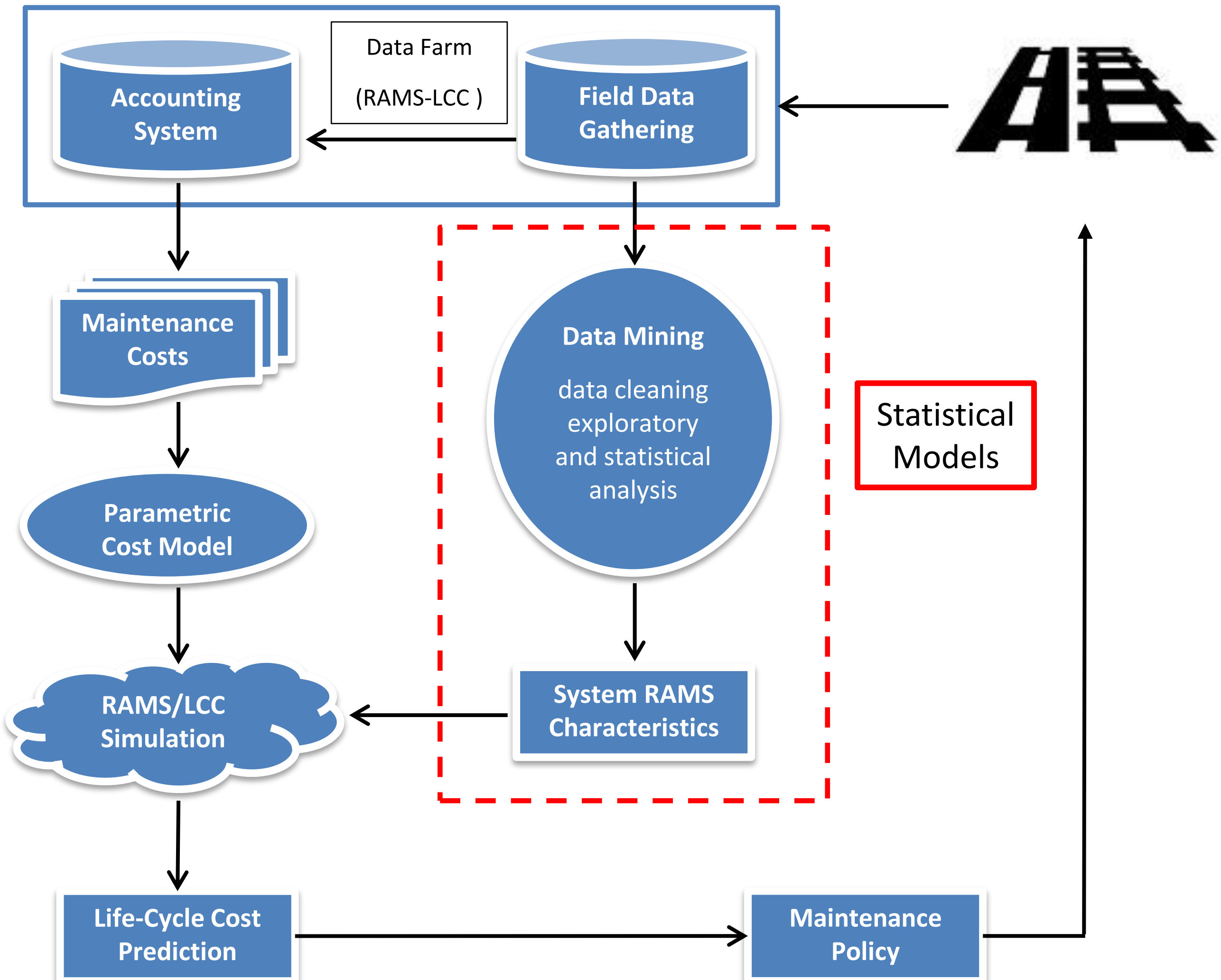
– Uses information from maintenance activities
– Provides inputs for decision support



RAMS/LCC Toolkit: The Big Picture



RAMS



Data Farm
(RAMS-LCC)
Accounting System
Field Data Gathering
Maintenance Costs
Data Mining
data cleaning exploratory and statistical analysis
Statistical Models
Parametric Cost Model
RAMS/LCC Simulation
System RAMS Characteristics
Life-Cycle Cost Prediction
Maintenance Policy

RAMS Definition

EN 50126 (1999)

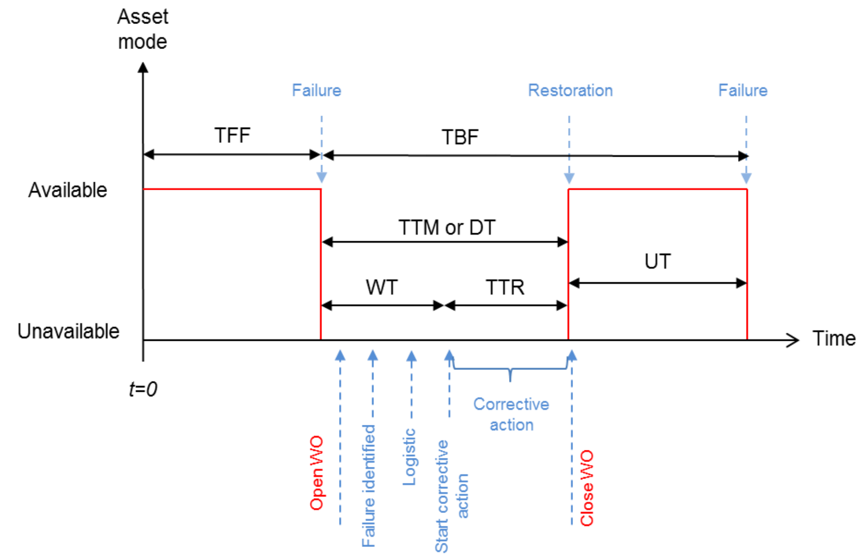
- *Reliability (R)*: probability that an item can perform a required function under given conditions for a given time interval.
- *Availability (A)*: ability of a product to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval assuming that the required external resources are provided.
- *Maintainability (M)*: probability that a given active maintenance action, for an item under given conditions of use, can be carried out within a stated time interval when the maintenance is performed under stated conditions and using stated procedures and resources.
- *Safety (S)*: the state of technical system freedom from unacceptable risk of harm.

Reliability	Availability	Maintainability	Safety
Reliability, R(t) Unreliability, 1 - R(t) Failure rate, λ(t) Mean Time Between Failures, MTBF Mean Time To Failure, MTTF	Mean Up Time, MUT Mean Down Time, MDT Availability, A(t) Unavailability, 1-A(t)	Maintainability, M(t) Repair rate, μ(t) Mean Time To Maintain, MTTM Mean Time To Restore, MTTR False Alarm Rate, FAR	Hazard Rate, H(t) Tolerable Hazard Rate, THR Mean Time Between Safety System Failure, MTBSF

RAMS Parameters

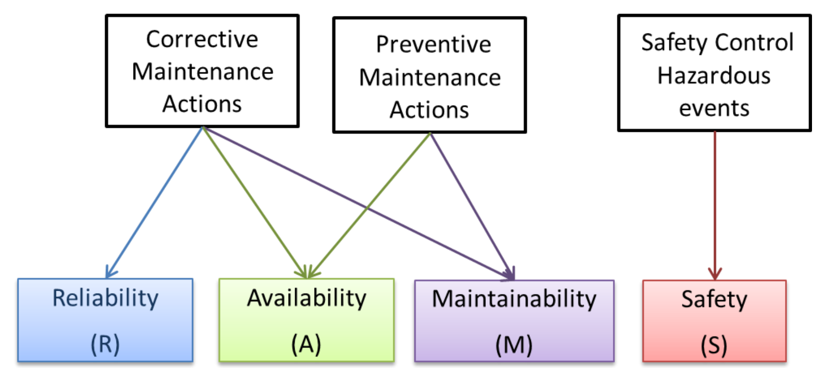
RAMS parameters are defined in base of failure events:

- TFF: Time to First Failure (non-repairable assets).
- TBF: Time Between Failures (repairable assets).
- TTM or DT: Time To Maintain or Down Time (asset not available).
- UT: Up Time or available state (system in full operation).
- WT: Waiting Time or logistic time (system waiting for correction).
- TTR: Time To Restore (corrective action is taking place).



RAMS obtained through Statistical Analysis of maintenance actions:

- Reliability/Survival Function R(t): info MTFF, MTBF, failure rate
- Maintainability M(t): info MTTM, MTTR, repair rate
- Inherent/Achieved/Operational Availability.
- Safety: hazardous events, MTBSF, hazard rate



Therefore a need for statistical models

RAMS (Statistical) Models

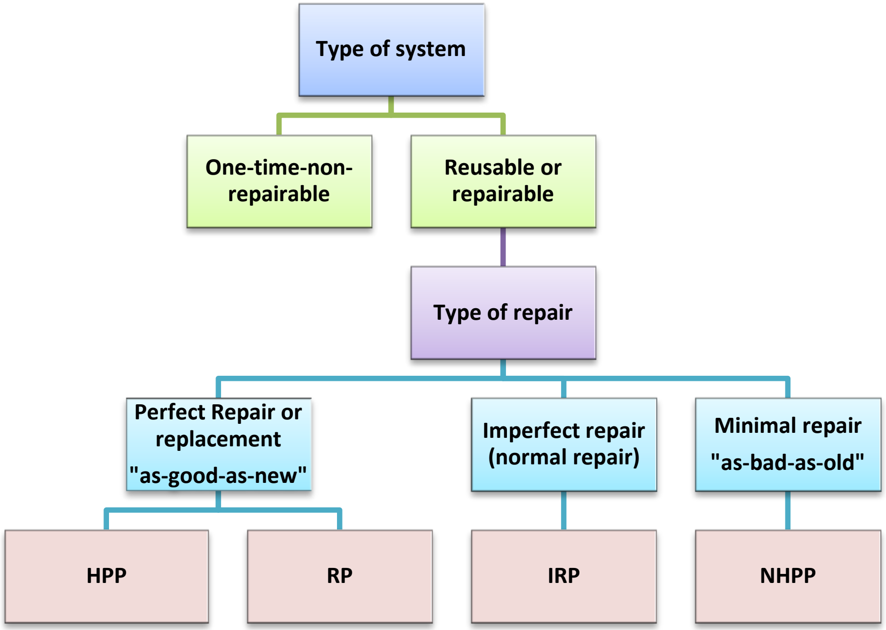
Time-to-event process in Survival Analysis:

- Items under study either suffer event (F) or are censored (C)
- Events are **non-recurrent**
- Subjects remain at risk until F or C
- No failure occurred until first failure
- Hazard defined in terms of $P(t<T<t+h|T>t)$
- Parametric Models (traditional): **Exp**, **Weibul**, **Log-normal**.
- Non-Parametric Models: **Nelson-Aalen**, **Kaplan-Meier**
- Proportional Hazard: **Cox PH model**

Repairable systems or **Recurrent Events**:

- Items suffer multiple failures (F)
- Items remain at risk until study is completed
- Non-Homogeneous Poisson Process (NHPP)
- Parametric Models (traditional): **power law**, **linear**, **log-linear**.
- Non-parametric estimators: **Peña-Hollander**, **Wang-Chang**
- Proportional Hazard: **Andersen-Gill** (extension of Cox's model)

Reliability models depend on type of system



RAMS (Statistical) Models

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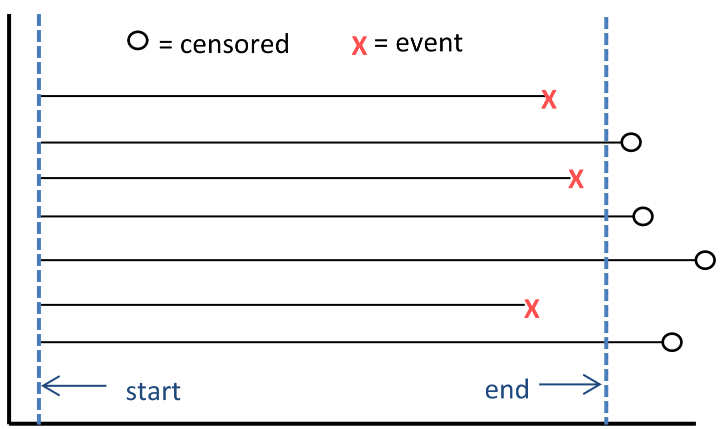
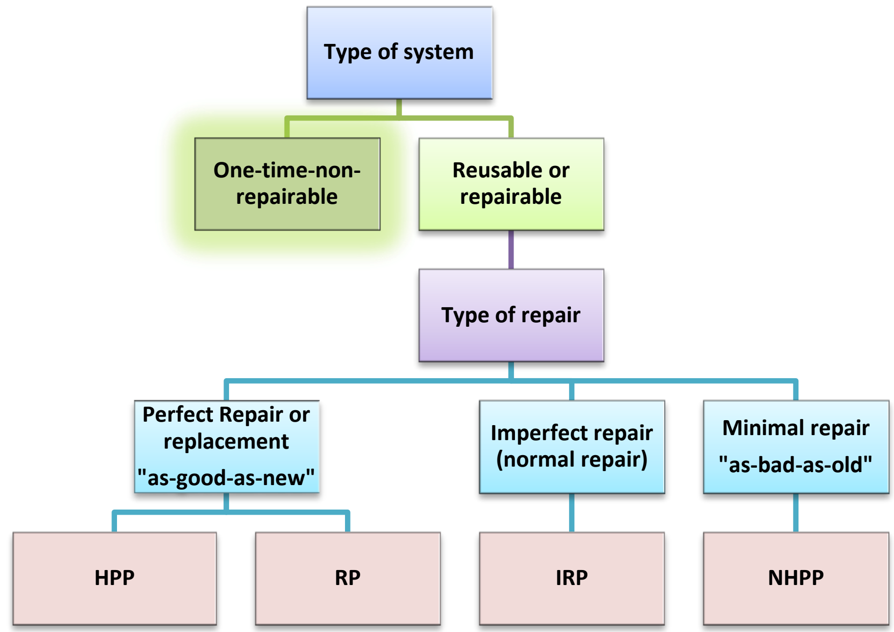


Reliability models depend on type of system



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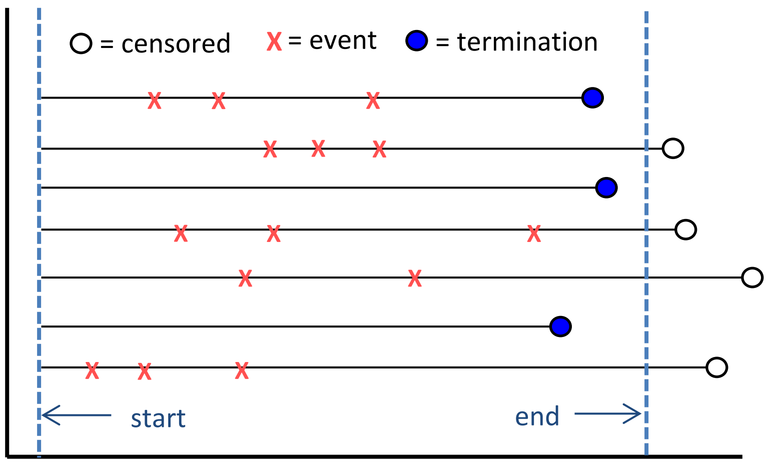

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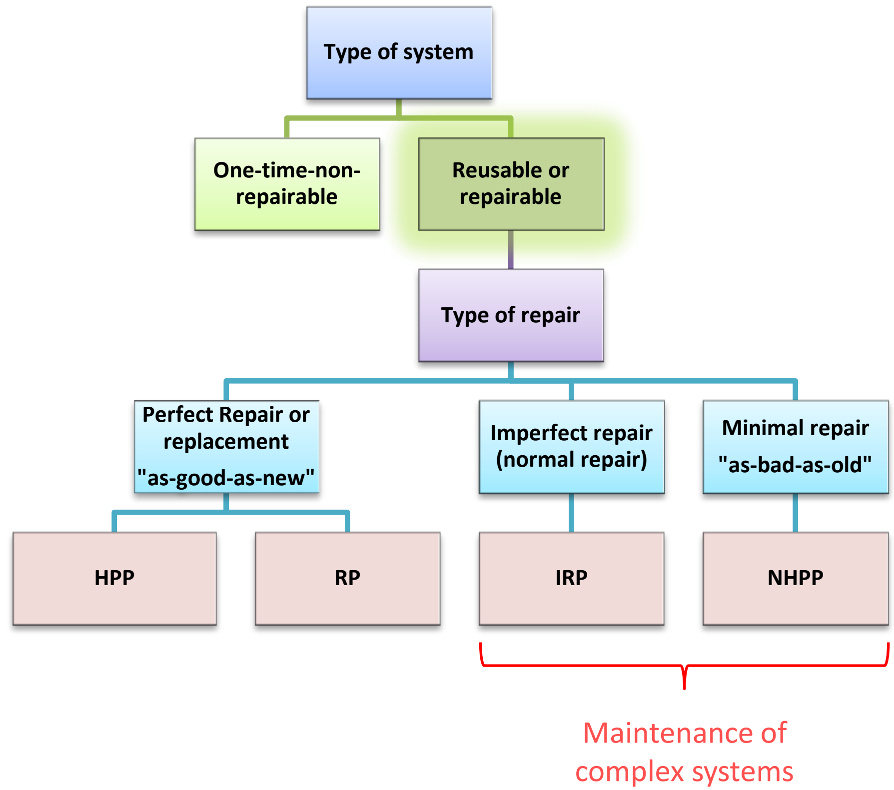

Enhanced RAMS: *Covariates*

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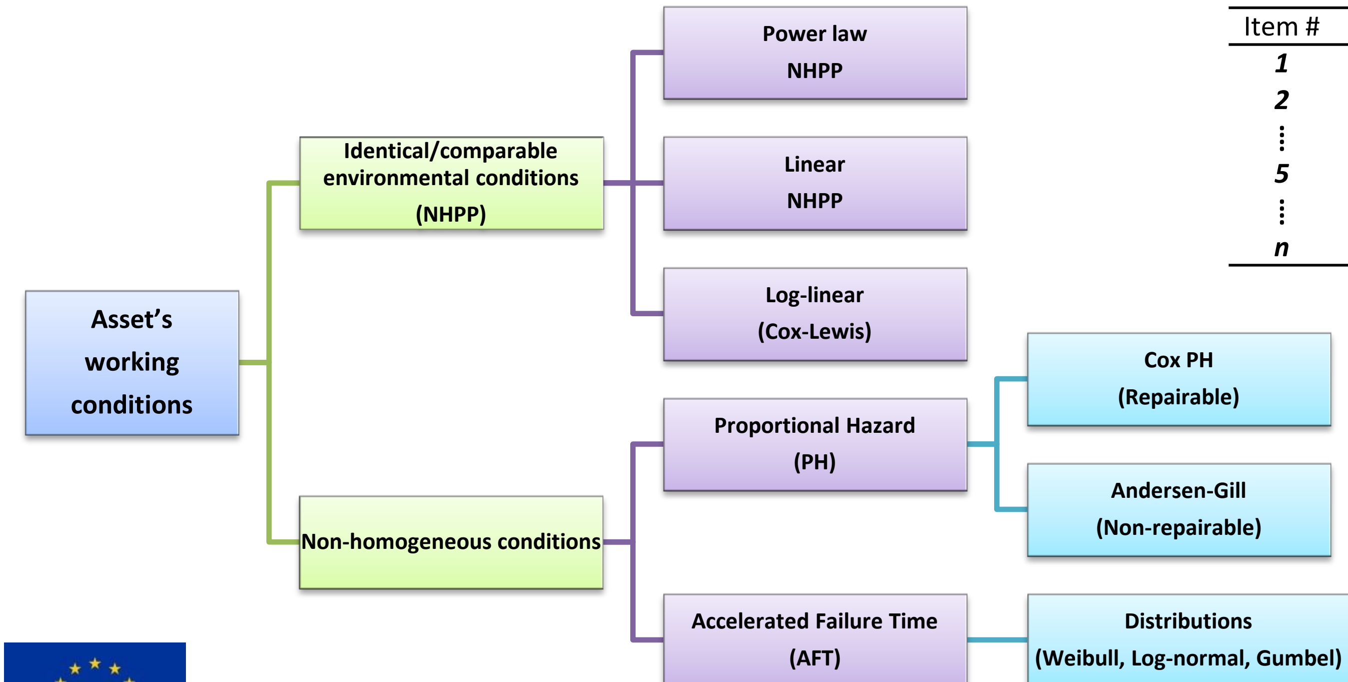
Remember by definition [EN 50126 (1999)]

Reliability (R): probability … perform function ***under given conditions*** …
Availability (A): ability … to be in a state to perform function ***under given conditions*** …
Maintainability (M): probability … active maintenance can be carried out ***under given conditions of use*** …

In Statistics the ***"given conditions"*** that influence RAMS characteristics are called **COVARIATES** [In the ROOF $w(t)$ *or RR* $\mu(t)$]
These may include: *weather, locations, maintenance staff skills, asset characteristics (e.g. S&C or rail type, age, etc …)*.



Item #	t	δ	X_1	X_2	…	X_p
1	t_1	d_1	x_{11}	x_{12}	…	x_{1p}
2	t_2	d_2	x_{21}	x_{22}	…	x_{2p}
⋮	⋮	⋮	⋮	⋮		⋮
5	t_5	d_5	x_{51}	x_{52}	…	x_{5p}
⋮	⋮	⋮	⋮	⋮		⋮
n	t_n	d_n	x_{n1}	x_{n2}	…	x_{np}

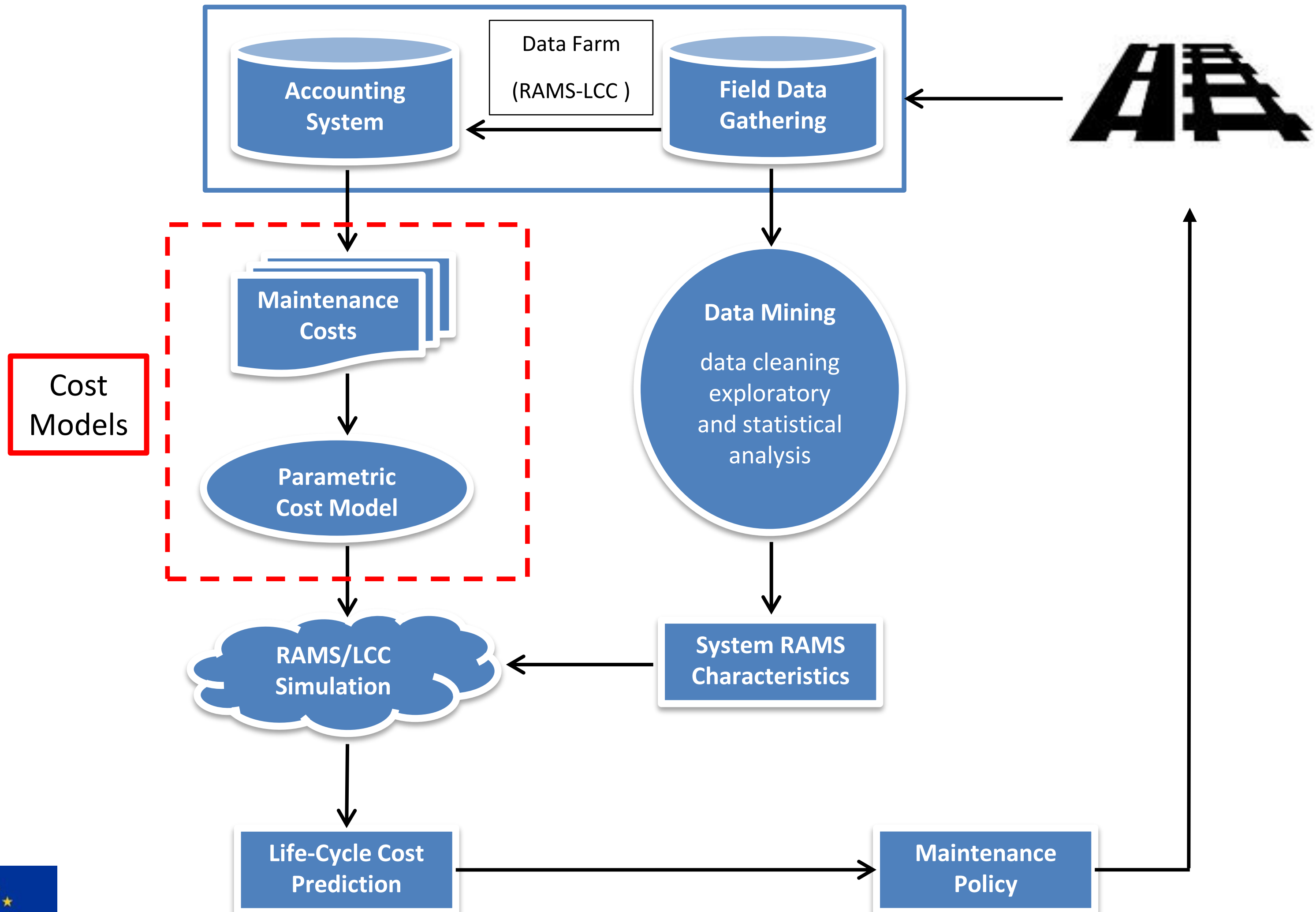
$$\omega(t;X) = \lambda_0(t)\, exp(X^T \boldsymbol{\beta})$$
$$\mu(t;X) = \mu_0(t)\, exp(X^T \boldsymbol{\beta})$$

Baseline (non-)parametric

Time (in)dependent X / X(t)

Technical

LCC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Life-Cycle Cost (LCC) Analysis

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- LCC analysis associates costs to the different Life-Cycles of an asset
- *Availability* and *Maintainability* are the most significant cost drivers in LCC analysis
- Wide range of impact on operational cost elements
- Very important to properly model system availability and maintainability

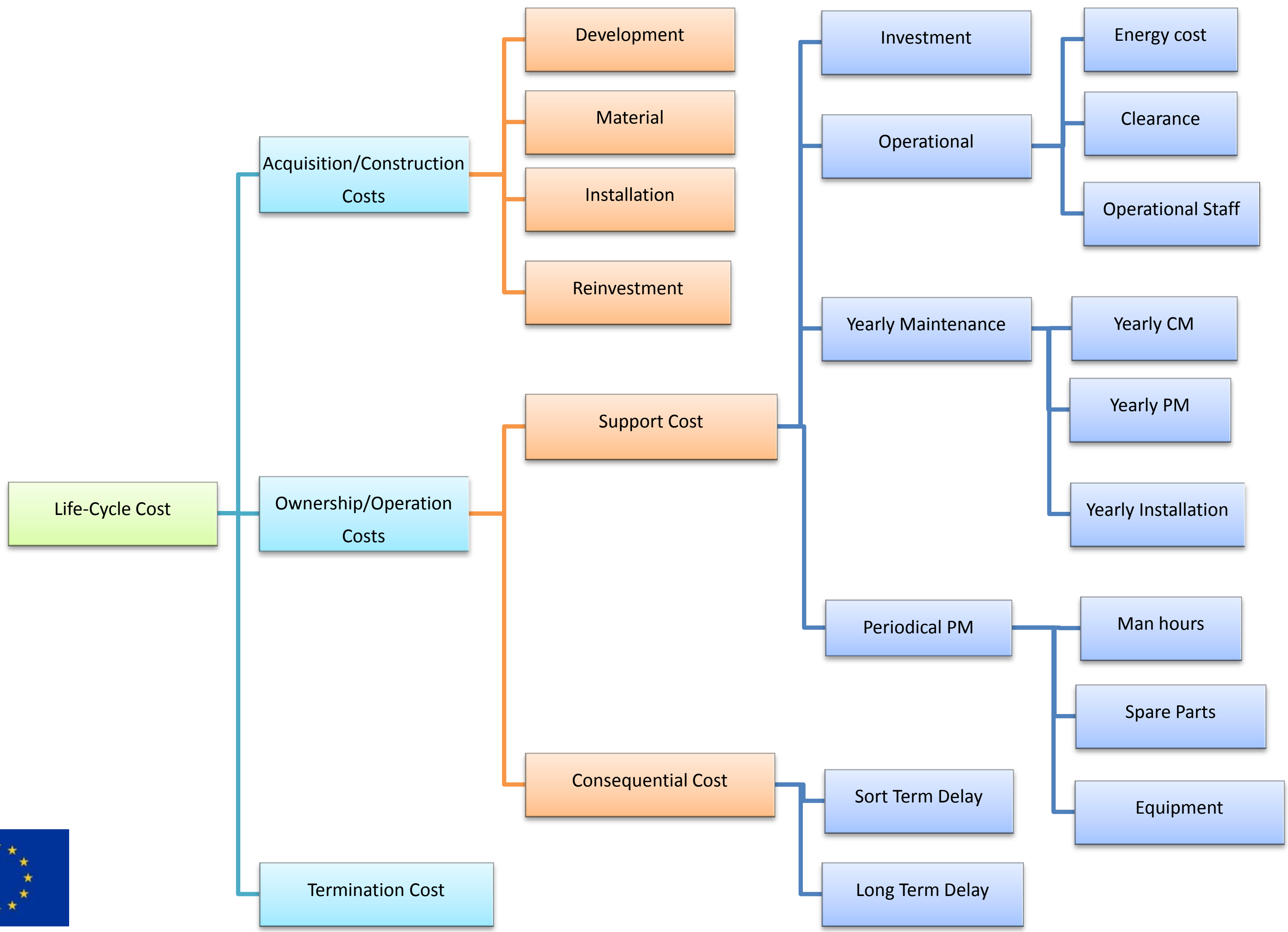
Steps in LCC Analysis:

- Identify cost drivers (elements)
- Develop a CBS
- Implement cost model
- Quantify uncertainties

Life-Cycle Phases (IEC 60300-3-3)	Life-Cycle Costs	Nature
- Concept and definition - Design and development - Manufacturing - Installation	Acquisition	Fixed
- Operation - Maintenance	Ownership	Variable
- Disposal	Termination	Fixed

Modelled through Data Analysis of Work Orders

LCC - Cost Breakdown Structure (CBS)



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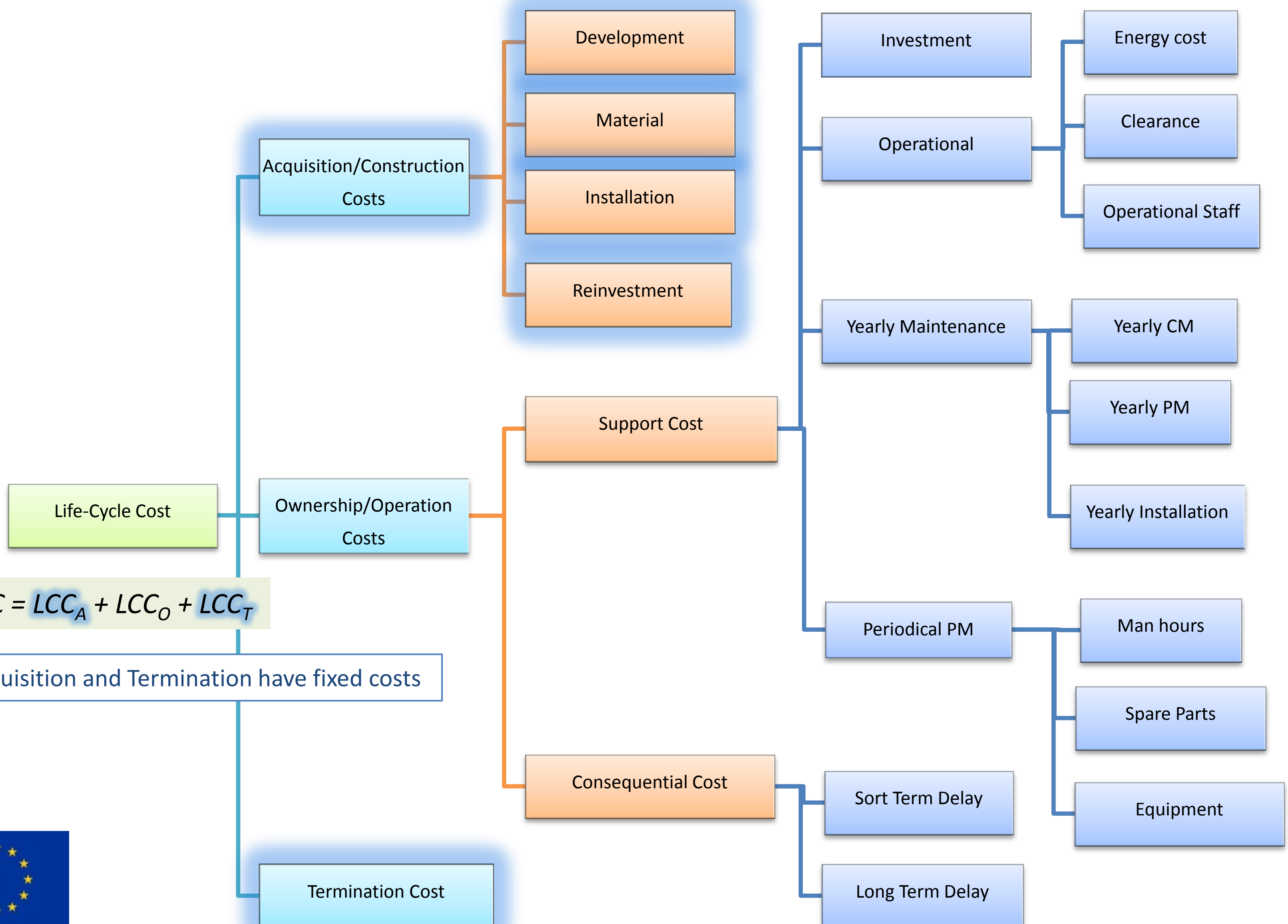
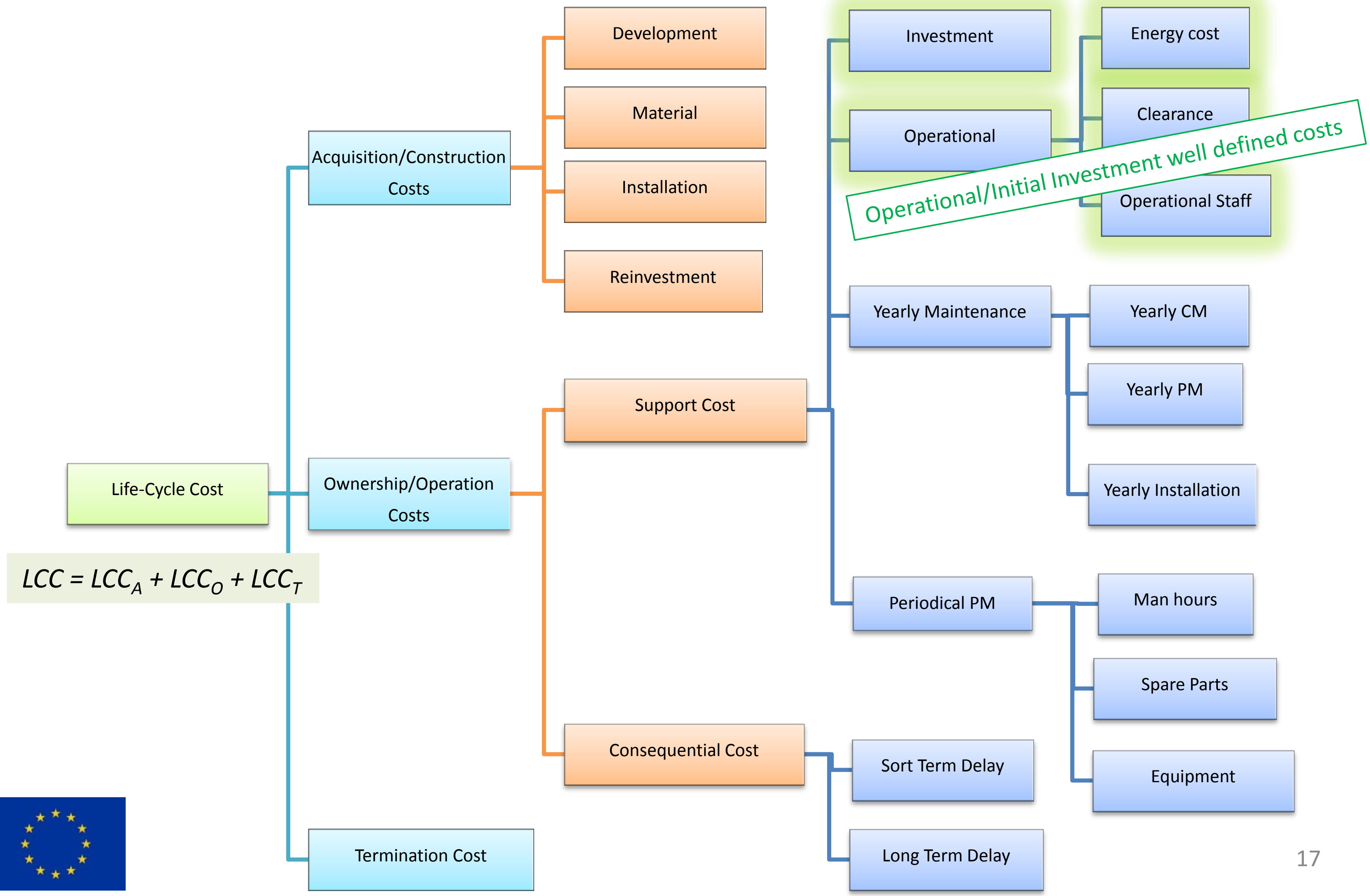


$$LCC = LCC_A + LCC_O + LCC_T$$

Acquisition and Termination have fixed costs

LCC - Cost Breakdown Structure (CBS)



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LCC - Cost Breakdown Structure (CBS)

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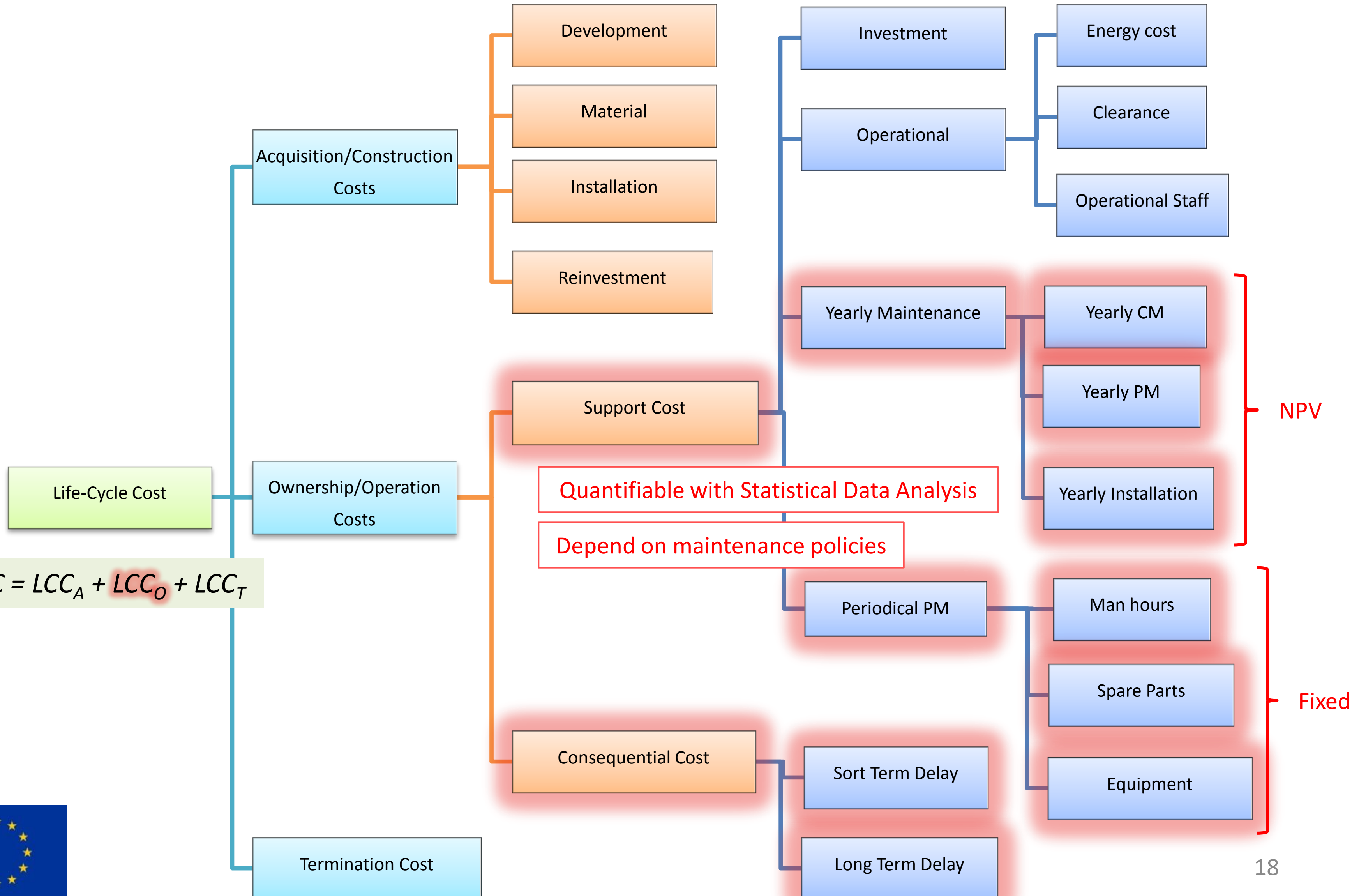

$LCC = LCC_A + LCC_O + LCC_T$

(Maintenance) LCC Models

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- Cost models highly dependent on the system under study
- The more information the more precise our cost model will be
- Annual Corrective Maintenance (CM) Cost (failures)

$$
\begin{aligned}
CY_{CM} &= Man\ Hours + Spare\ Parts + Equipment \\
&= \sum_{i=1}^{m}\sum_{j=1}^{n} \lambda_{ij}\left[C_L\, n_L\, (MRT_{ij} + MLT_{CM}) + C_{Pij} + C_{Eij}\right]
\end{aligned}
$$

- Annual Preventive Maintenance Cost

$$
\begin{aligned}
CY_{PM} &= Man\ Hours + Spare\ Parts + Equipment \\
&= \sum_{i=1}^{m}\sum_{j=1}^{n} \mu_{ij}\left[C_L\, n_L\, (MAT_{ij} + MLT_{PM}) + C_{Pij} + C_{Eij}\right]
\end{aligned}
$$

- Periodical Preventive Maintenance Cost

$$
\begin{aligned}
CP_{PM} &= Man\ Hours + Spare\ Parts + Equipment \\
&= \sum_{i=1}^{m}\sum_{j=1}^{n} \eta_{ij}\left[C_L\, n_L\, (MAT_{ij} + MLT_{PM}) + C_{Pij} + C_{Eij}\right]
\end{aligned}
$$

- Consequential or Unavailability Cost (LUC)

$$
LUC = \sum_{i=1}^{m}\sum_{j=1}^{n} \lambda_{ij}\, p_{ij}\, C_{Delay}\, MDT_j
$$

- Further cost decomposition can be included depending on specific maintenance actions in road/railway

Technical

(Maintenance) LCC Models

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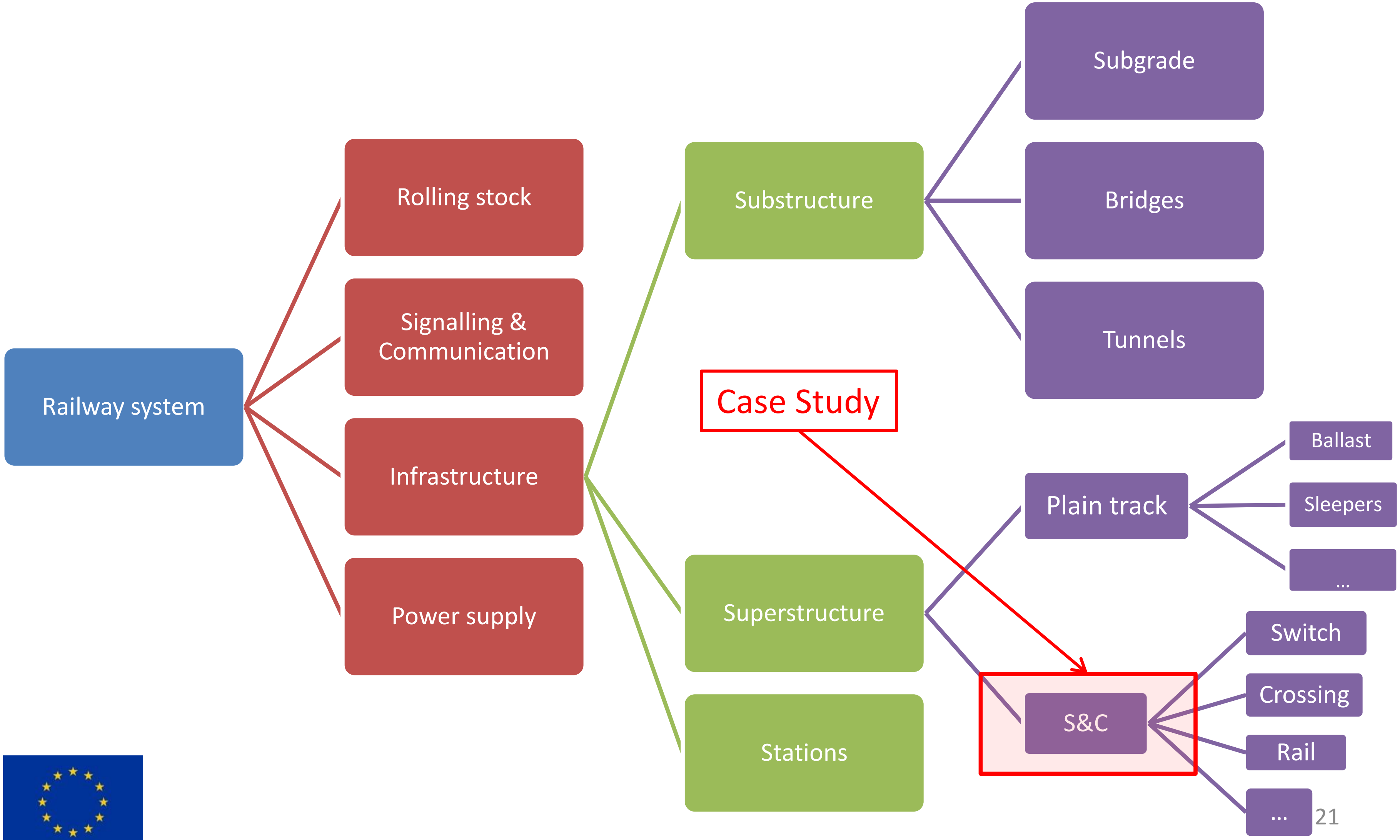
- Further cost decomposition can be included depending on maintenance actions (road/rail specific)

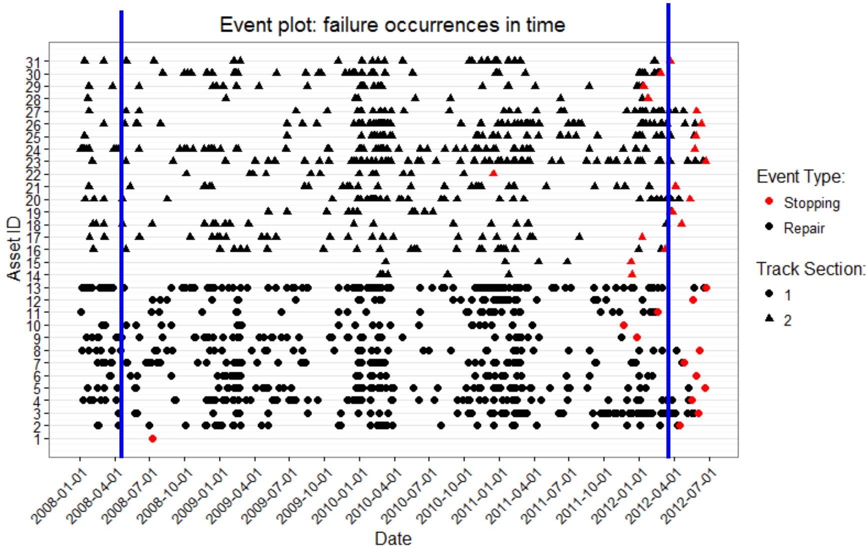
Stochastic RAMS

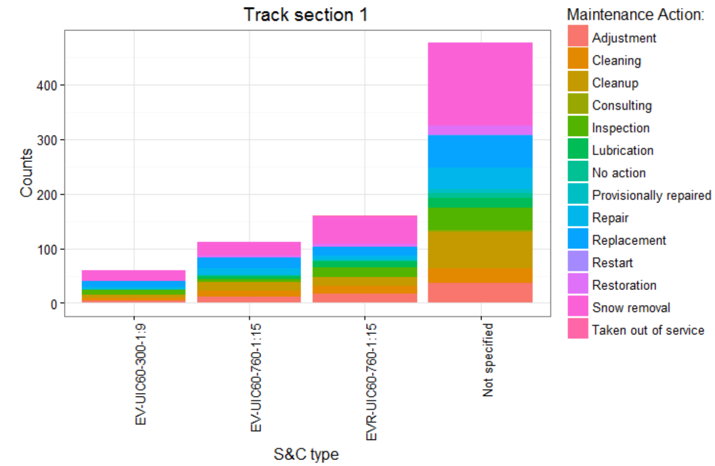
Stochastic LCC

A Case Study (LTU Database - S&Cs)

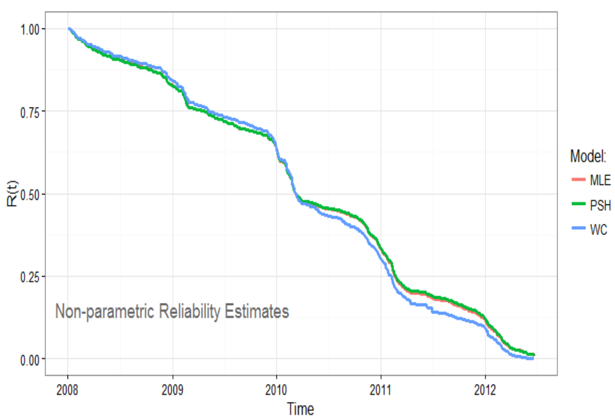


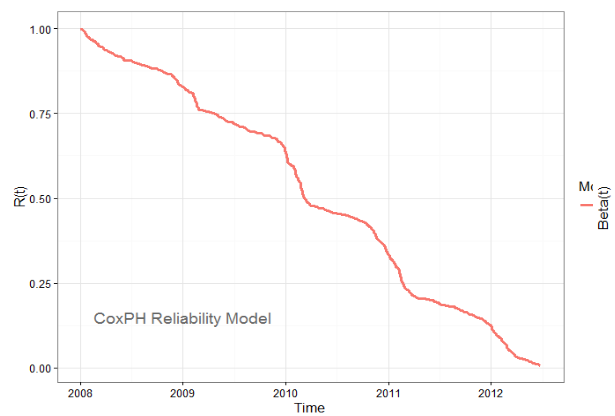
Case Study: Analysis of S&Cs

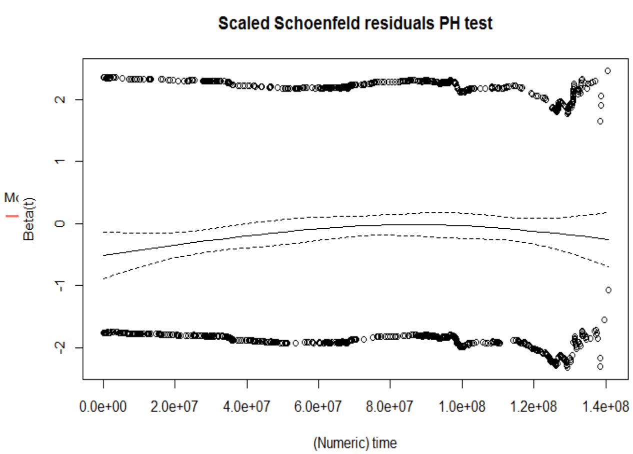




$$\omega(t; SEC) = \lambda_0(t)\, exp(\boldsymbol{\beta}_1 + \boldsymbol{\beta}_2 SEC)$$







RAMS&LCC
On-going work/conclusions

On-going conclusions

- Rail & Road combined **RAMS/LCC** analysis is being carried out using modern statistics tools
- System structure **needs to be split** in order to apply appropriate reliability models to subsystems
- Costs models applied to each particular sub-system: **PM & CM data** determine the inputs
- A **holistic approach** is being implemented for Rail and Road infrastructures
- Extension to road case **straightforward** although less variety of data is at hand

On-going work

- **Look for patterns /trends** in failure data: TTT-based plots and other SL techniques
- Possibility of including **physical information** (degradation) of individual assets
- Consider **mode and intensity of usage**, **environmental conditions**, other characteristics
- Improve quality and variety of data.

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Road Case Study (IP Database)