“Predict complex system behaviour within uncertain scenario”

alias

How to estimate, before the metal is cut, a critical system performance

Presented by:

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Carlo Leardi, graduated in electronic engineering in Genova Italy.

His professional background starts with quality assurance responsibility and evolved to full verification, validation and testing commitment within complex systems development deployment projects in the following areas: automotive, freight railways and packaging industry. As a passion before and today as a full job, he is dealing with Quantitative Systems Engineering on a day-to-day application and coaching of a full range of statistical and simulation methodologies supporting the decisional process. He published several articles in Engineering and Systems Engineering journals.

ESEP, TLI member, one of the founders and past President of the INCOSE Italian Chapter. founder of AISE, the Italian association of Systems Engineering.

He taught at the Systems Engineering Master, ForteMare and Strategos.

He is serving the Incose Italian Chapter for training and certification.

Agenda

The case
Context
System complexity aspects
Scenario un-predictability aspects
Simulation purpose
Rationales for the initial modelling choice
State of the “Art”
Opportunities for improvement and scope extension

The case

A **brownfield system** is under development in the **liquid food packaging industry**
Product protection is requested to more than double within an excellence baseline.
No models or specific rigs available to stress test the relevant aspects.
Severe reduction of the experts prediction capability: integration of AI driven automation with well established “traditional” technologies within a renewed architecture.

Context: Complex system in the liquid food packaging industry

Human being

Processed milk

Packaging material

Packaging Line

Package

Handling use and recycling

AI density

System’s complexity aspects

Complicated: scaled-up, dynamic interdependencies
Emergent: un-expected behaviours linked to AI
Difficult: sub-systems relationships, step increase of a key performance.
Uncertain: technologies efficiency integrated in the system’s architecture

INCOSE Systems Engineering Handbook, fifth edition 2023
SYSTEMS ENGINEERING INTRODUCTION
*“... SE is an integrative approach to help teams collaborate to **understand and manage** systems and their **complexity** and deliver successful systems”*

Scenario unpredictability aspects

Deployed into different products configurations

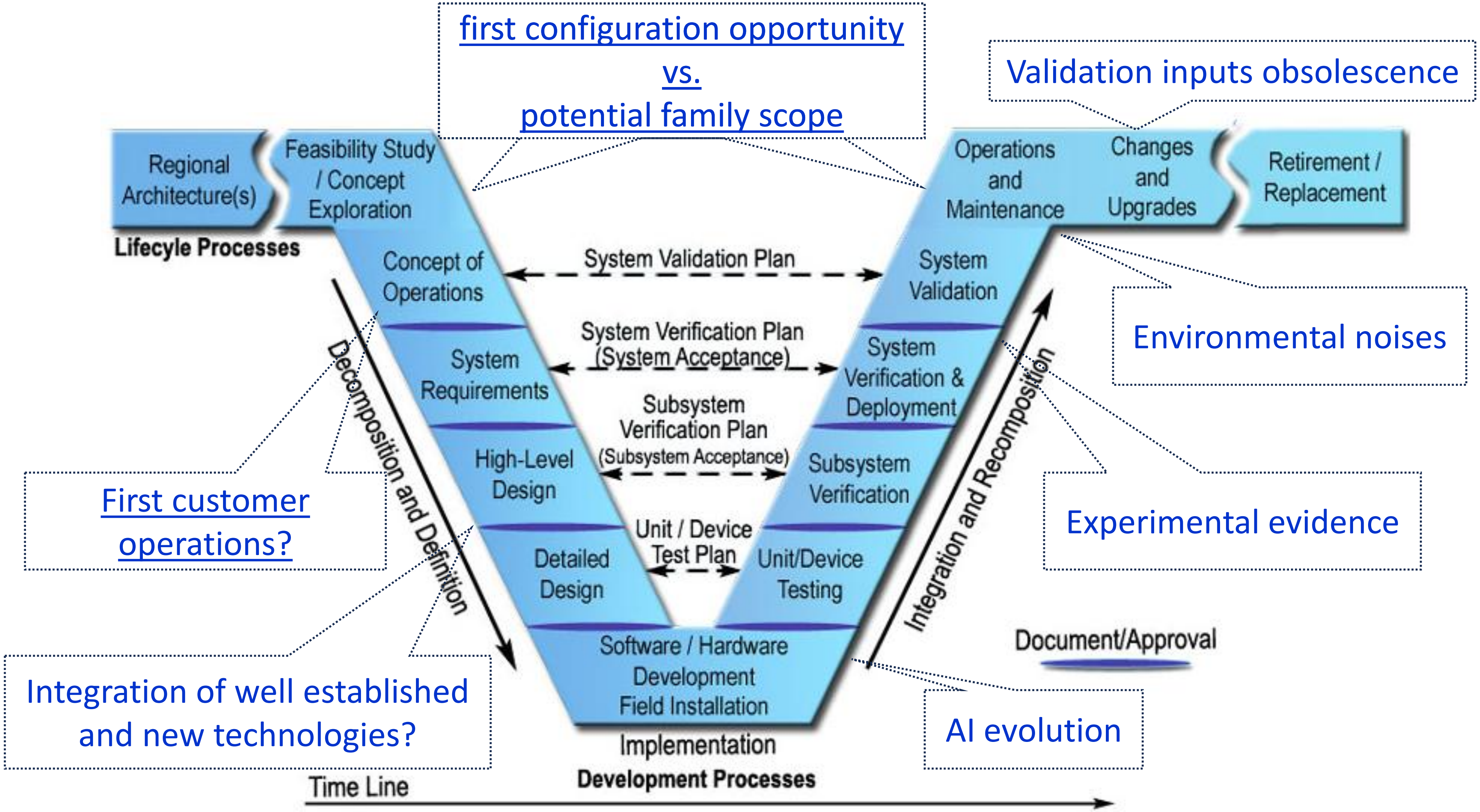
The products are intended to be installed and operated worldwide

Limited experience of so advanced and complex systems behaviour on the field

On-going field demonstration(s).

Simulation purpose: Product Protection

probability of success ~~failure~~ during system’s life-cycle:



Rationales for the initial modelling choice

<u>Fault Tree Analysis simulation:</u>

The great majority of the non-homogeneous inputs of the FTA basic events derive from:

- FMEA items
- Legacy values and Experts opinions
- Empirical evidences from preliminary tests
- Experimental evidence from the field test installation
- <u>Available SW licenses and expertise</u>

The architecture and the process flow drives the FTA tree structure

	FMEA **Failure modes and Effects Analysis**	**FTA** **Fault Tree Analysis**
Results	Heterogeneous impacts given defined causes	Unique top event as an effect of internal and external events
Unit of measure	RPN = SeverityxOccurrencexDetection	Equalized frequence → 1 out <...> pkgs at 90% c.l.
Objective	Prioritize risk management effort	Identify main offenders, estimate top event failure frequency
Objective	Overall life-cycle, at all system's levels	Preventive estimates, estimating alternatives, sustaining root cause analysis
Approach	Bottom-up, inductive	Top down, deductive
Structure	Table, independent rows	Logic Diagram, tree suitable for simulations

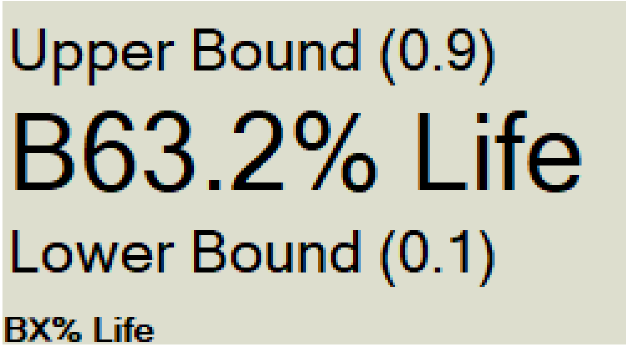
Initial modelling choice

Fault Tree Analysis

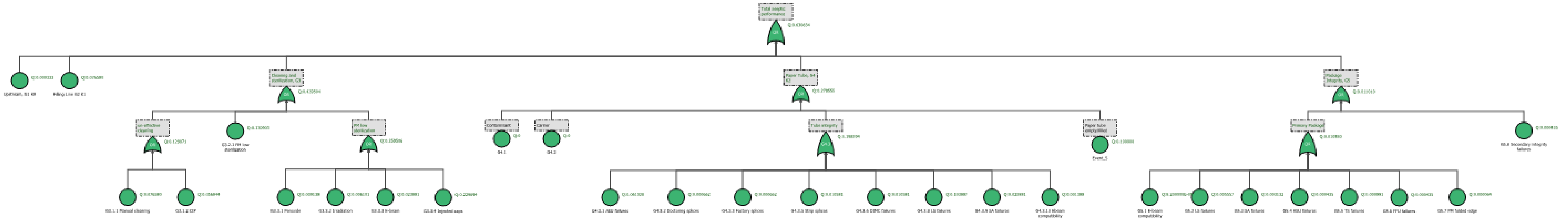
Full model: >300 basic events, >50 logic gates, 7 levels: operational although too complex and difficult to maintain

Over-simplified model for communication: 5 events, one gate, one level.

<u>Two-levels manageable model:</u>



Scope	Scope	structure	levels	Gates	Events	Values	Visualization
Initial approach	System	full	9	>50	>300	standardized	13 sub-pages
Focused on	External demonstration	full	5	29	90	standardized	One page <10%
Generalized to	High level system	reduced	2	7	25	Not standardized	One page 27%
Estimations by	Each of them	resume	1	1	5	Not standardized	One page 100%



State of the “Art”

FTA inputs evolution:

- FMEA quality and experimental estimates evolution
- Empirical evidences from physical robustness testing and Root Analyses outputs
- Huge availability of ancillary data from sensors, cameras, AI driven control from prototype(s)

Strengths:

- It is possible to update the estimate according to the original approach
- First experimental evidence confirms the estimation

Limits:

- FTA estimate decreases by adding basic events, increases by single evidences reduction
- Dependencies, apart duplications, pass through logic operators, no events phasing
- What is the operational scenario
- Model complexity un-manageable ➔ reduce model complexity: # of levels, basic events, and statistical models
- Difficulty of communication/review linked to visualization
- Lack of flexibility to support/describe root cause analysis

Opportunities for improvement and scope extension

<u>Same approach to simulation</u>:

- Maintain, simplify and update initial simulation
- Reduce complexity without loosing relevance
- Generalize the approach for another type of performance and metrics

<u>Simulation alternatives to address bi-directional change propagation</u>:

- Neural networks plus Bayesian desirability objective
- Design Structure Matrices plus Bayesian propagation
- Bayesian networks: R-prototype
- MCMC expert systems

References, How to Contact us

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