QUANTIFIED QUALITY AND RELIABILITY

A NEW WAY TO LOOK AT PRODUCT QUALITY

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Electronics Design & Manufacturing

Met steun van:

AGENTSCHAP INNOVEREN & ONDERNEMEN

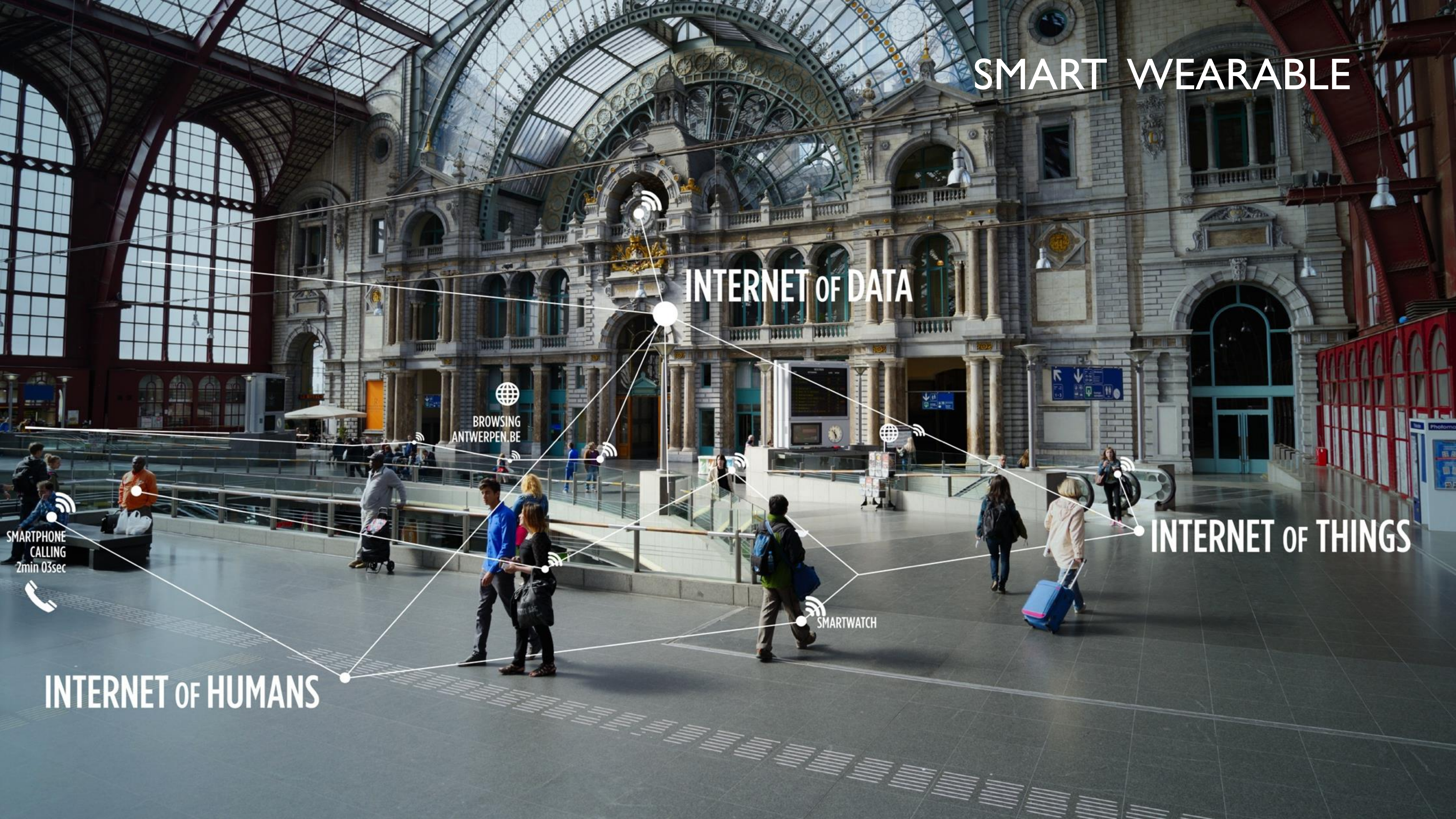
CHALLENGES OF 21st CENTURY PRODUCTS

21^{st} CENTURY PRODUCTS
KEYWORDS

- "Smart"
- Digitalization
- Internet of Things (IoT)
- Industry 4.0
- Artificial Intelligence
- Data science
- Wearable
- Connected
- Mobile
- Wireless
- …


Article
June 2015
Manufacturing's next act
By Cornelius Baur and Dominik Wee

SMART WEARABLE




SMART CAR
Knowledge base
&
Deep learning
in the Cloud
Real-time execution

SMART CITY


15 min BEFORE RAIN APPROACHES YOU
05min 37sec BEFORE ARRIVAL
08min 07sec SINCE DEPARTURE
1,214 KWH GAINED
1,358 KWH GAINED
04 TABLES LEFT
FULLY BOOKED
23 WATT USED
432 METER TO THE CHEAPEST DIESEL
ENERGY SAVING MEDAL UNLOCKED
04 RED LIGHTS ON YOUR WAY
YOU WALKED 1894 METER SO FAR
YOUR PACKAGE WILL ARRIVE IN 15 MIN
17 HOURS PARKING LEFT
235 METER UNTIL BIKE PARKING
124 PEOPLE FAVORISED

THE "SMART WORLD"

WHAT IS NEW ABOUT "SMART WORLD"?

- Closing the loop between control and operation: towards continuous, real-time feedback
- Exploitation of an increasing amount of information
- (Self-)Learning, dynamic, adaptable systems

Why now?

It has become affordable: low-cost, high-performance electronics.

SMART SYSTEM STRUCTURE

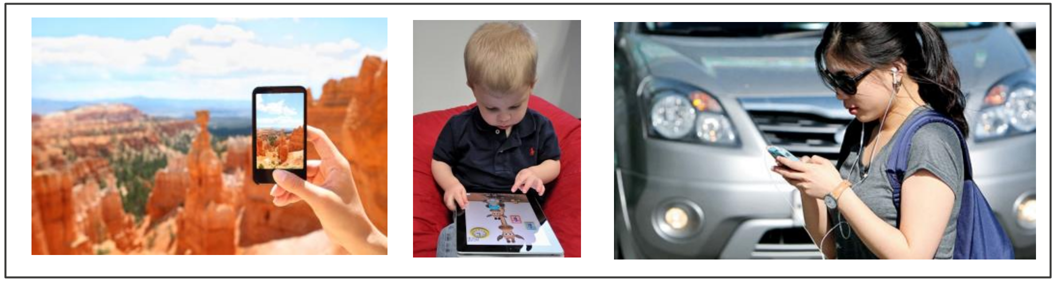
APPLICATION LAYER

FUNCTIONAL LAYER

PHYSICAL LAYER

USER, BUSINESS, LEGAL TOPICS

"FUNCTIONAL" VIEW



SMART SYSTEM STRUCTURE

"SMART WORLD" SYSTEM CHARACTERISTICS

@ Application level:

Software (AI) using

@ functional level:

A high number of (wireless) **interconnected & distributed electronic hardware** modules (sensing, computing, communication, power).

@ physical level:

- New electronic devices in all kinds of "environments": wearables, vehicles, machinery, building, infrastructure...
- Often hard-to-reach and/or harsh environment.
- Integration of electronics in new environments.

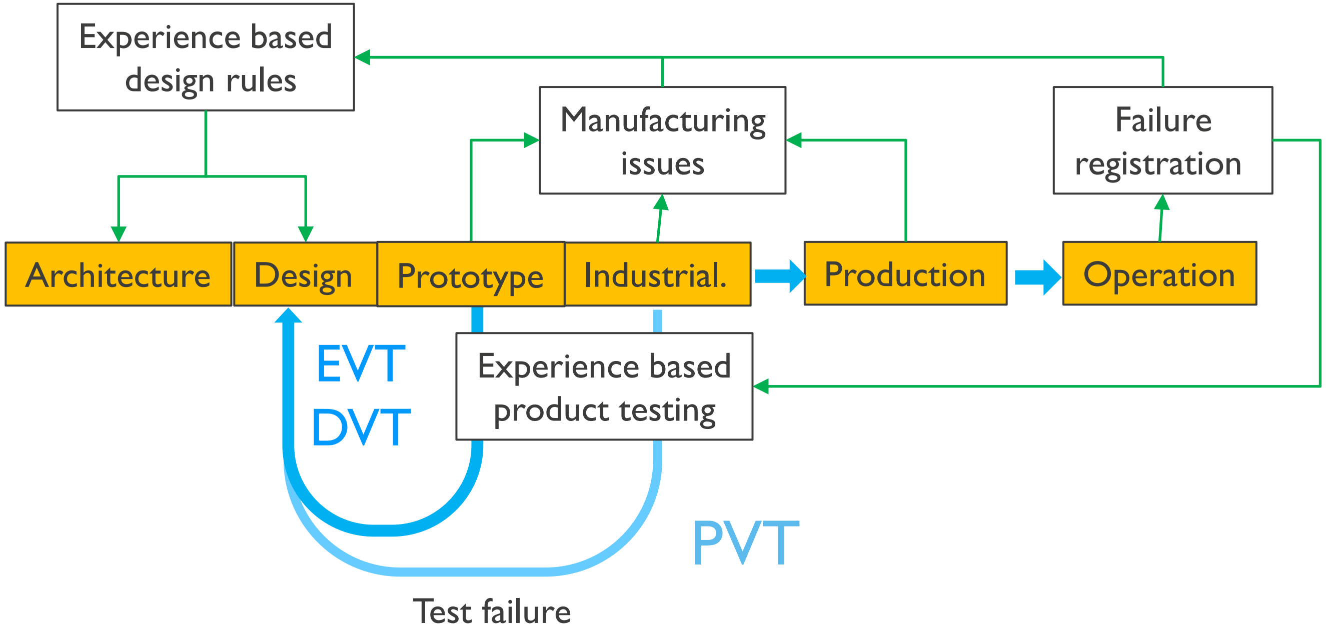
SMART SYSTEM STRUCTURE

PRODUCT DEVELOPMENT REQUIREMENTS FOR THE "SMART WORLD"

- System adaptable to
  - Different applications
  - Different environments and mission profiles
  - Different volumes, markets (consumer, professional, safety critical)
  - Different product life cycles
  - All this may be variable over time for the same product
- Use of new electronic devices with little use history
- High quality, high reliability, low maintenance.
- Short time-to-market: fast development, scale-up and deployment
- Lowest possible cost

NEW PRODUCT INTRODUCTION

THE TRADITIONAL DESIGN-BUILD-TEST APPROACH



- New devices, environments, way of use: no experience!
- Hardware iteration: Time consuming, cost of builds
- Not suitable for smart products

NEW PRODUCT INTRODUCTION FOR THE SMART WORLD

WHAT DO WE NEED?

Product:

- Dynamical
- High Quality
- High Reliability
- Low Cost
- Time-to-market

Trustworthy PREDICTION of all Product Life Cycle aspects

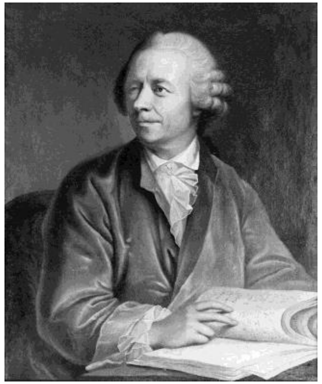
without costly, time-consuming prototyping, testing and design iterations

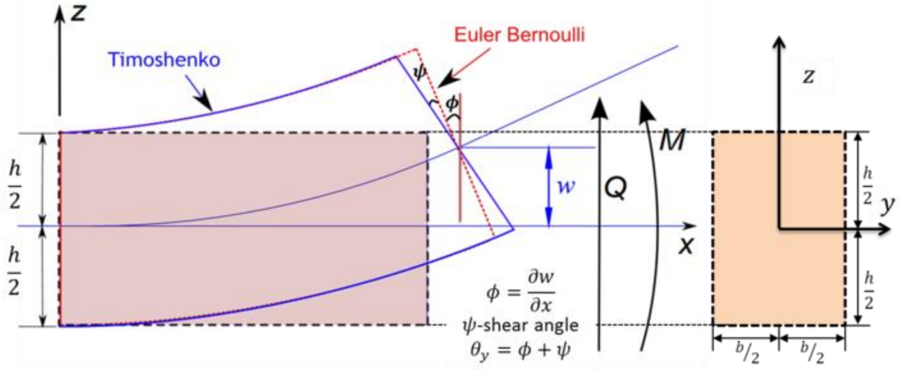
How do we do that?

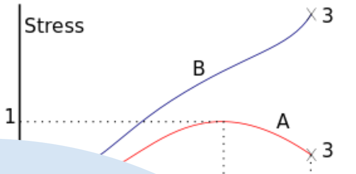
NPI FOR THE SMART WORLD

A PRACTICAL WAY



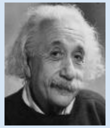




SCIENCE

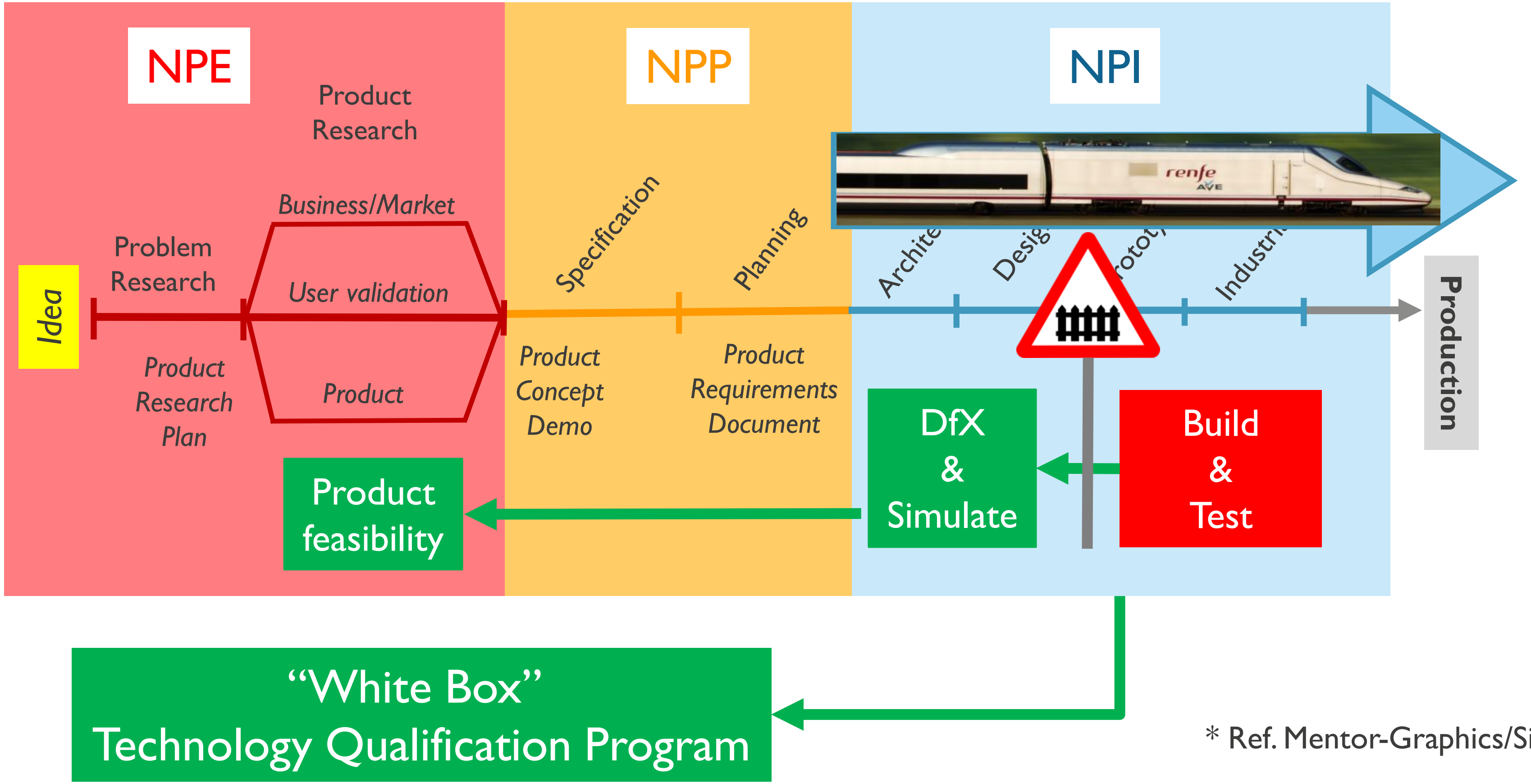
The next best thing to a crystal ball



The Mechanics of Electronics

NEW PRODUCT INTRODUCTION

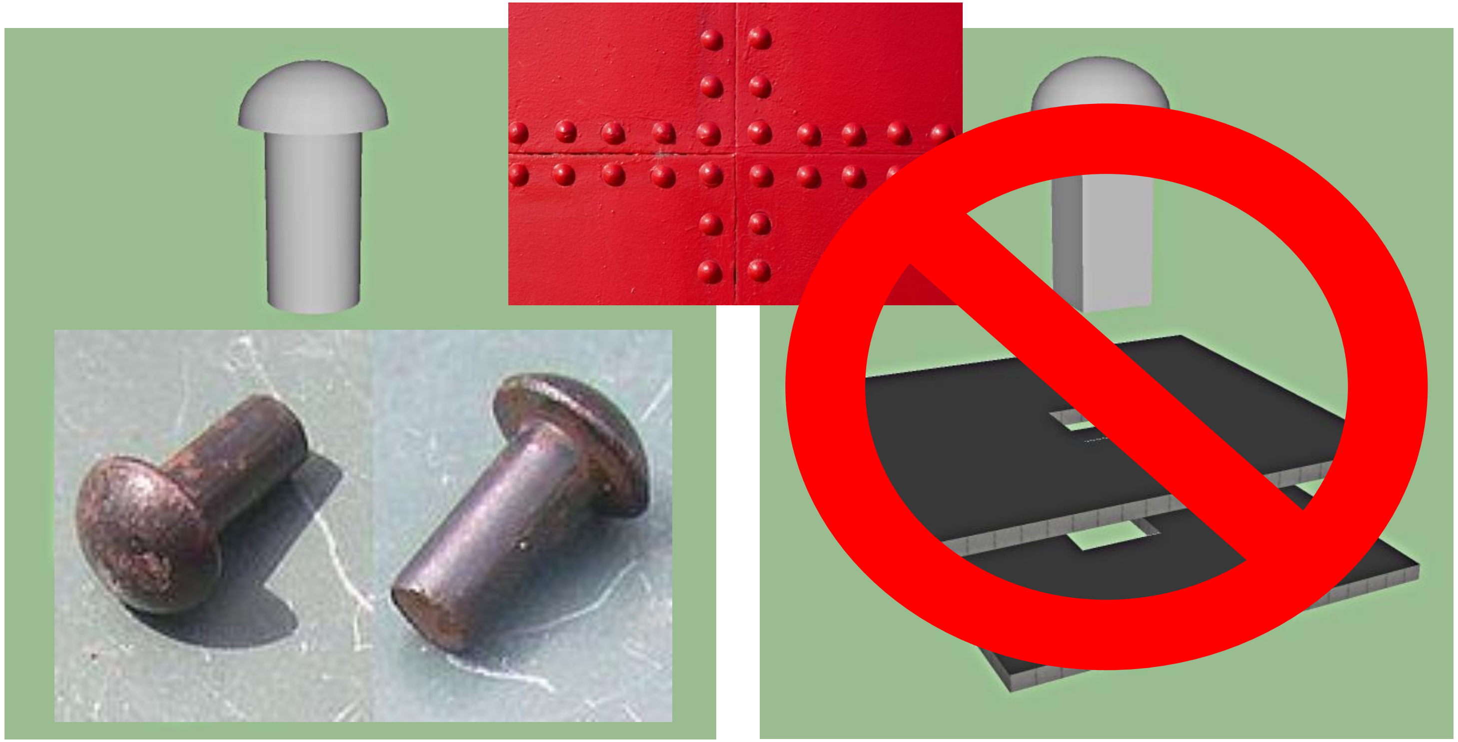
"SHIFT LEFT" *



* Ref. Mentor-Graphics/Siemens

DESIGN-FOR-MANUFACTURING

UIT DE OUDE DOOS: KLINKNAGELVERBINDING



De beste kwaliteit tegen de laagste kost?

WELKE KENNIS?

MAAKKENNIS!

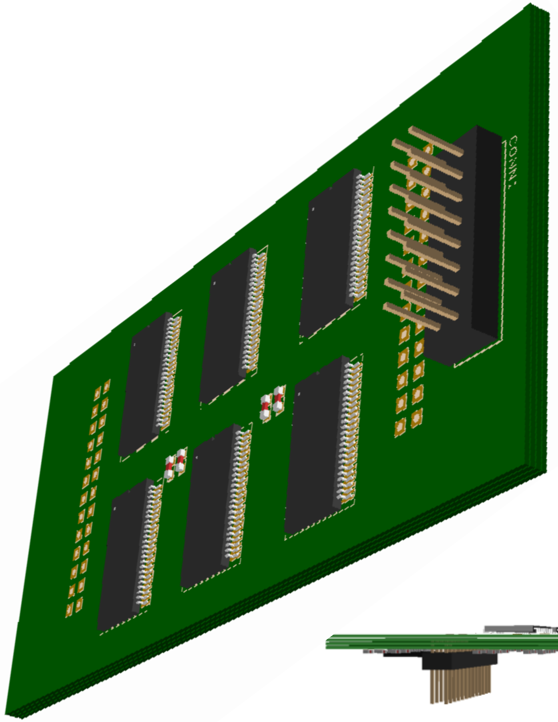
Bewerkingstechnieken

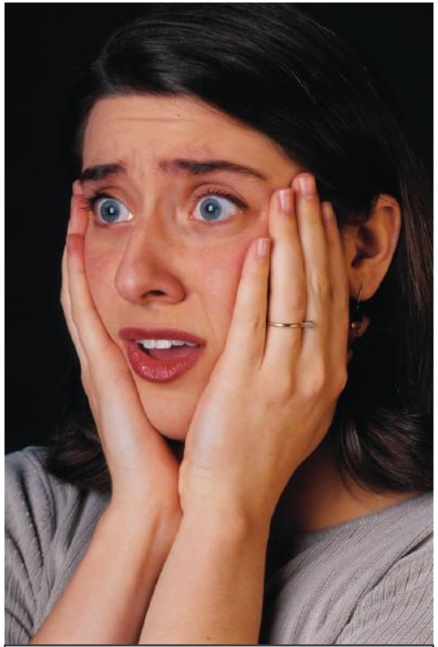
Assemblagetechnieken

EN NU ELEKTRONICA

Welke van de twee is het equivalent van de “vierkante klinknagel”?

EN NU ELEKTRONICA





M. Janssens – *Uw-EMS*
Productievoorbereiding

Een draak van een PBA!

DESIGN-FOR-MANUFACTURING

Why Printed Circuit Board Design Matters to the Executive:

How PCBs Are a Strategic Asset for Cost Reduction and Faster Time-to-Market

Aberdeen Group
A Harte-Hanks Company

February 2010

Michelle Boucher

Onze ervaring

DfM impact op **productie**kost:
20% tot 75% kostreductie!

VIEW ON (SMART) PRODUCT DEVELOPMENT CHALLENGES


RR

BEST PRACTICES FOR ELECTRONICS DESIGN EXECUTIVES

November 2018

Greg Cline
Research Analyst, Manufacturing and Product Innovation & Engineering

ABERDEEN

https://www.mentor.com/pcb/resources/

NEW PRODUCT INTRODUCTION

PRODUCT COMPLEXITY

Table 1: Increasingly Complex Products Demand a Multi-Domain Product Development Solution

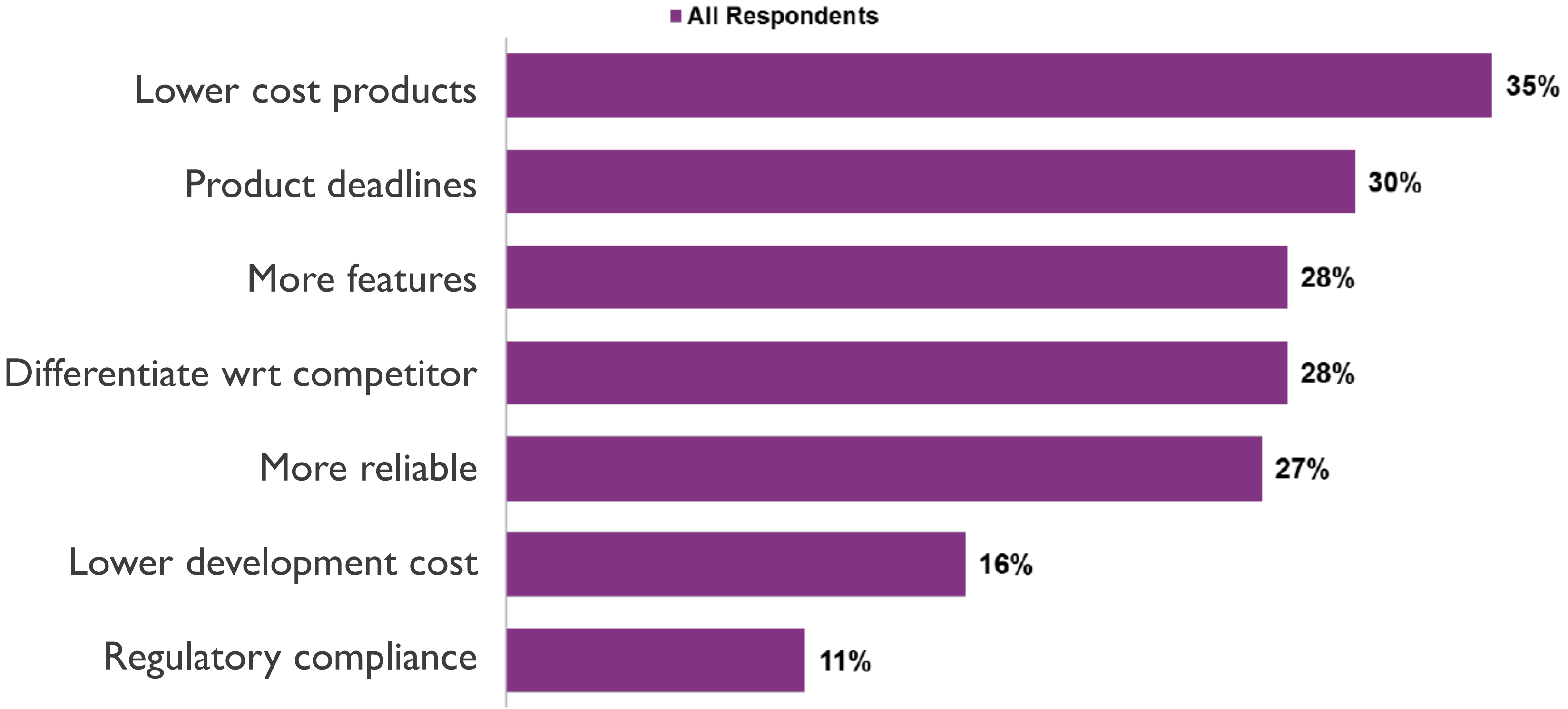
Product Element	% Increase — Past Two Years
Number of mechanical components	14%
Lines of software code	34%
Number of electrical components	21%

Source: Aberdeen, November 2018

NEW PRODUCT INTRODUCTION

EXTERNAL CHALLENGES

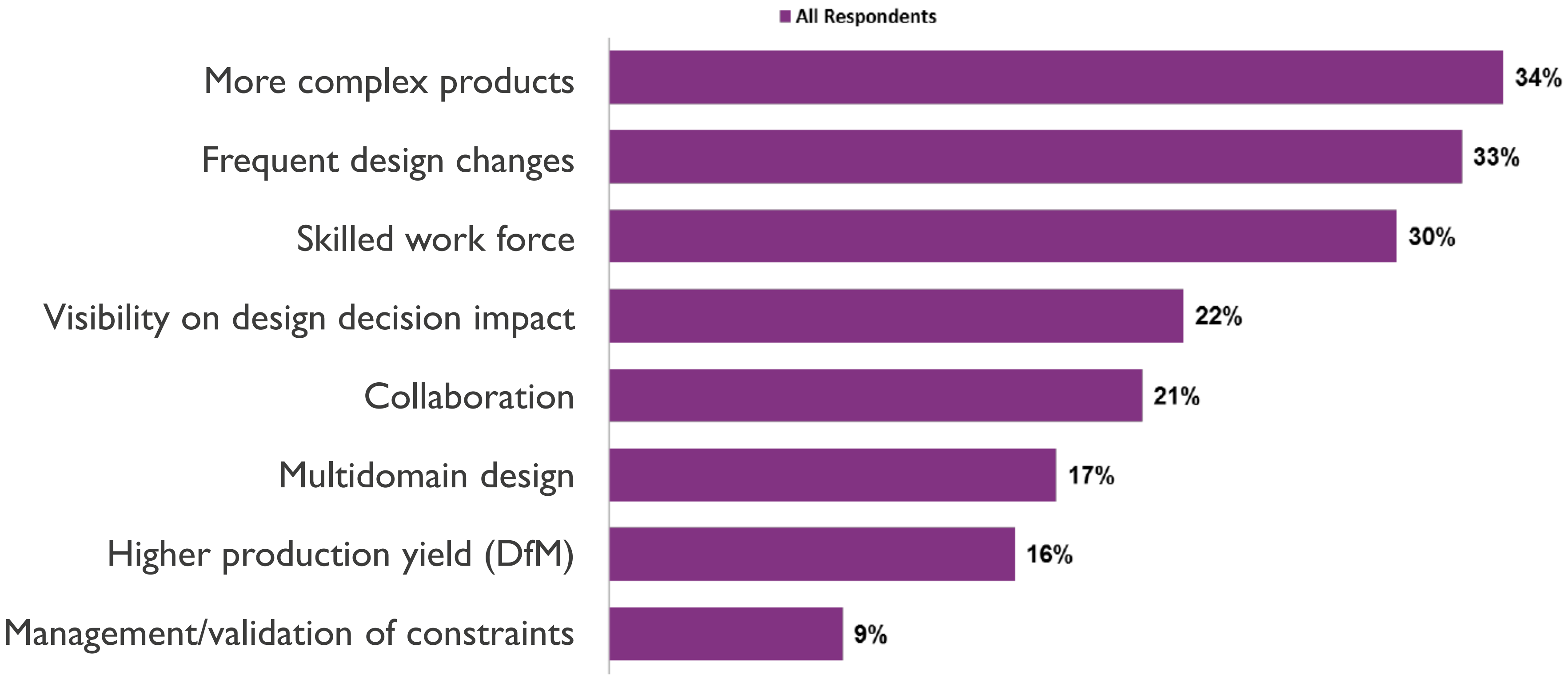
Figure 1: External Business Pressures of Electronics Design



% of Respondents, n = 122, Source: Aberdeen 2018, November 2018

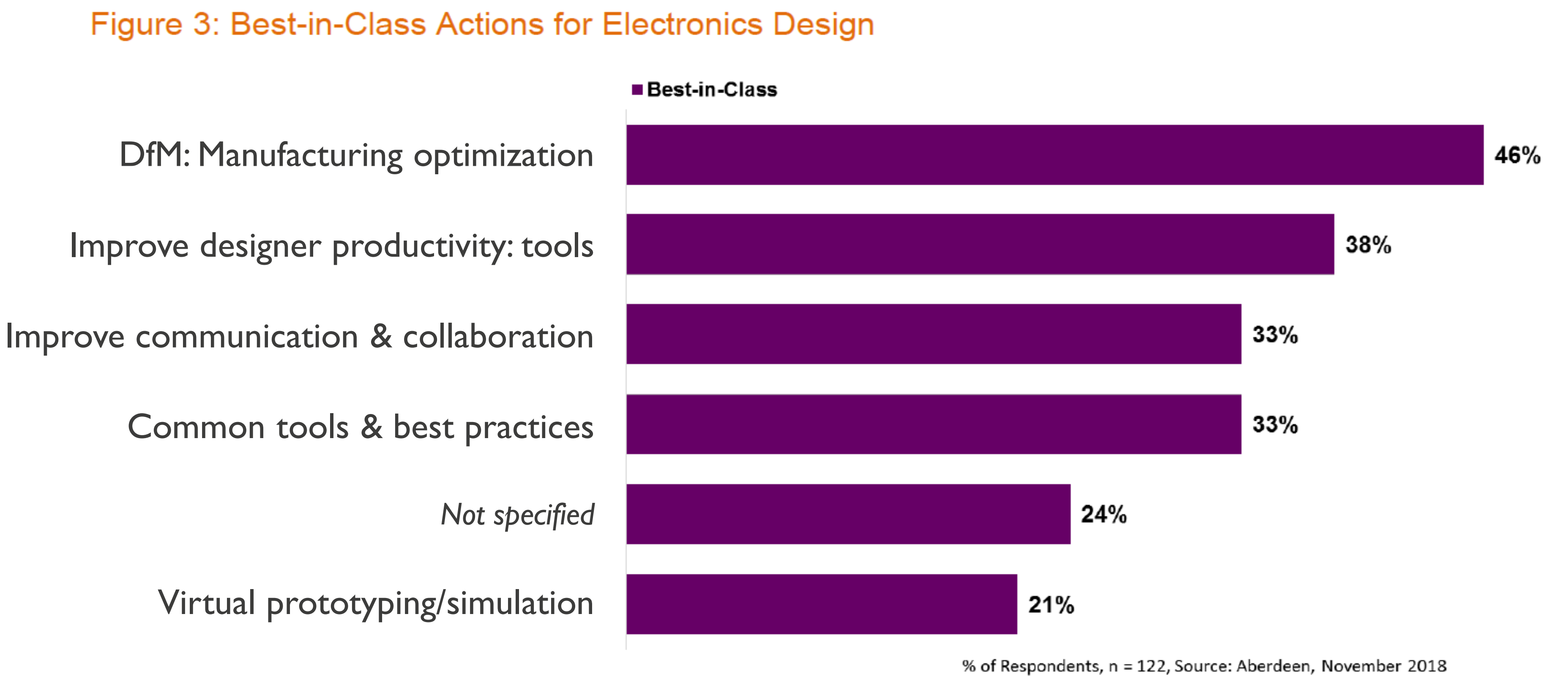
NEW PRODUCT INTRODUCTION
INTERNAL CHALLENGES

Figure 2: Internal Challenges of Electronics Design



% of Respondents, n = 122, Source: Aberdeen, November 2018

NEW PRODUCT INTRODUCTION
FACING THE CHALLENGES

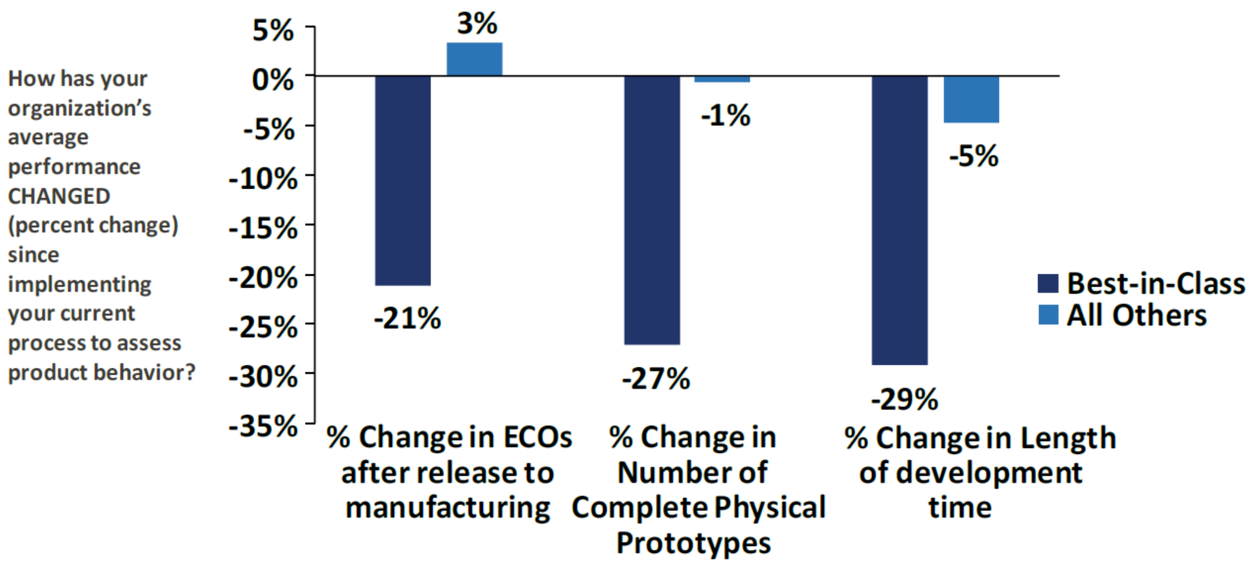


NEW PRODUCT INTRODUCTION

THE SHIFT LEFT

Instead of waiting until a design is completed, the "Shift Left" methodology integrates manufacturing and performance validation in the design process.

Figure 4: Simulation-Driven Design Boosts Performance



Shift Left is a major advance in electronics design, allowing users to ultimately eliminate many of the iterations used for manufacturability and performance analysis today, thus making the overall flow more efficient.

NEW PRODUCT INTRODUCTION

THE SHIFT LEFT

Table 2: Who Are the Best-in-Class?

Best-in-Class Metric	Best-in-Class	Industry Average	Laggard
Product cost targets met	85%	67%	38%
Product launch dates met	86%	66%	35%
Product quality targets met at release date	90%	73%	39%
Product revenue targets met	81%	66%	45%
Length of development cycle (two years)	+3%	+18%	+18%

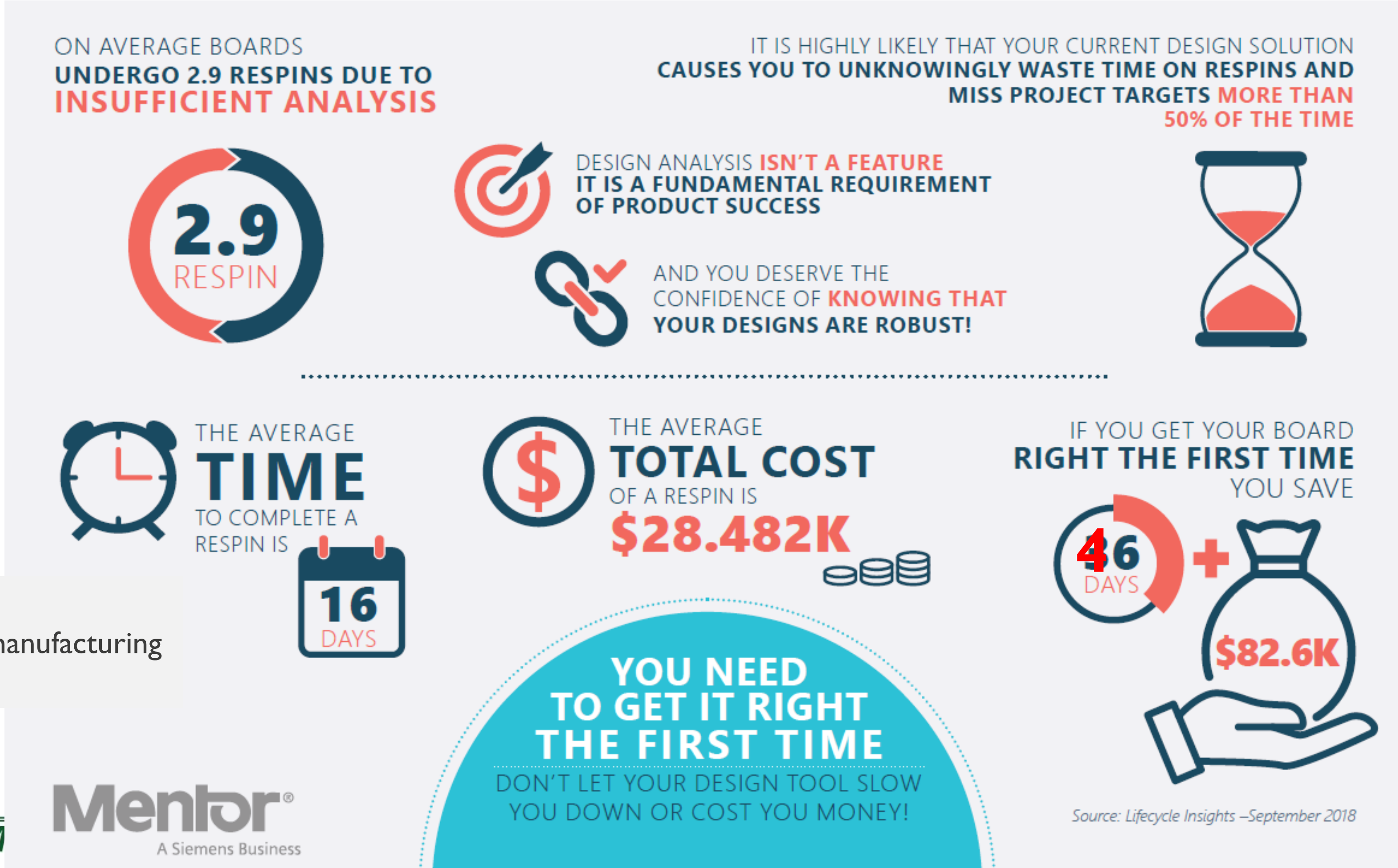
% of Products Meeting Target = 122, Source: Aberdeen, March 2018

Best-in-Class organizations perform much better compared to Laggards across cycle time, cost, and quality metrics:

- **Cycle time:** 2.5x better performance on meeting product launch date targets (6x better on holding the line on length of development cycles over the past two years).
- **Cost:** 2.2x better performance on meeting product cost targets.
- **Quality:** 2.3x better performance on meeting product quality targets at release date.

NEW PRODUCT INTRODUCTION

DEVELOPMENT STRATEGY: AVERAGE COST/TIME OF A PBA BUILD



Note:
Ordering and manufacturing not included.

DESIGN-FOR-MANUFACTURING

WHY?

Low-Cost manufacturing = High Yield manufacturing

- Limit the complexity level: less Defect Opportunities
  Increased integration at component level.
- MINIMIZE DEFECT RATE BY PROPER DESIGN-FOR-MANUFACTURING
  - Layout
  - Bill-of-Material
  - Acceptability criteria for components and PCB

QUALITY
QUANTIFICATION AND PREDICTION

QUALITY QUANTIFICATION
DO YOU RECOGNIZE THIS?

We are a bit more expensive,
but our quality is so much better!

QUALITY QUANTIFICATION
BETTER QUALITY?

Better performance

Less failures at start!

Longer lifetime!

Tested!

MORE ROBUST!

MIL Qualified!

Certified

IPC class 3

Cleaned!

Metal i.s.o. plastic

Screwed i.s.o. glued

Less damage!

Metal finish i.s.o. paint

GREEN PRODUCT!

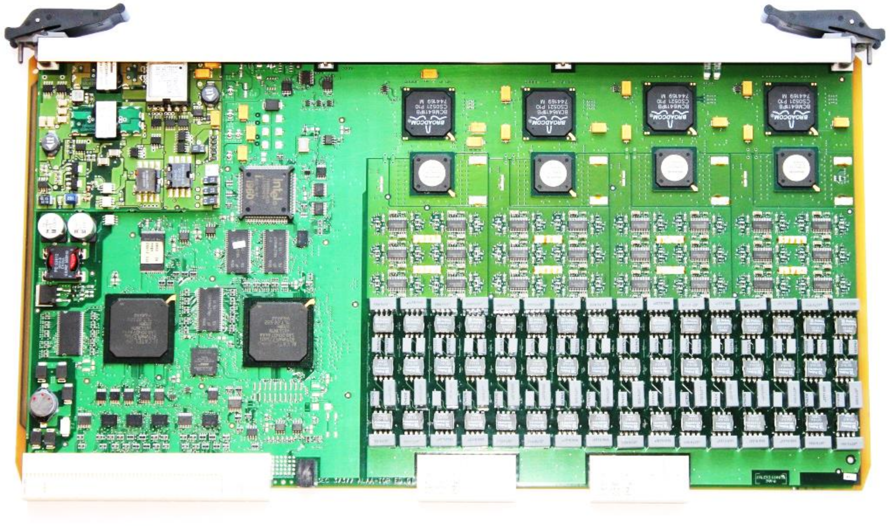
RoHS

Low energy consumption!

Vintage design

And all you can imagine to be related to quality …

QUALITY QUANTIFICATION
ELECTRONICS



Top Quality!

50% lower assembly cost!

QUANTIFIED QUALITY

QUALITY DEFINITION

The properties of the product – whatever they may be – agree to or exceed specifications or expectations.

A non-quality issue is any property of the product that does not satisfy specifications or expectations.

Quantified Quality (cEDM – EDM-D-007 & Pred-X)

- The **Quantified Quality Q** of a part/product is the probability of having **no defect**.
- A **defect** is any property that does not meet expectations.

QUALITY PHYSICS (Craig Hillman, DfR Solutions 2018)

QUANTIFIED QUALITY
QUALITY PREREQUISITE

A **defect** is any property that does not meet expectations.

Quality starts with proper specification

WYSIWYG

What You Specify Is What You (may) Get (at best)

For every unspecified item you will receive the cheapest version that will fulfill what is specified.

QUANTIFIED QUALITY

Quality calculation

- Determine the Defect Opportunities DO
- Determine no-defect probability Q_i per DO
- Defect-free PBA → no defective DO
- The probability Q of a defect-free PBA:

$$Q = \prod_{i=1}^{DO} Q_i$$

QUALITY QUANTIFICATION
QUANTIFIED QUALITY

Properties of Quality Q:

- Q=Yield (first pass – after test)
- Zero Hour Defect Rate (ZHDR) = 1-Q
- Q decreases with:
  - Increasing number of DO (complexity)
  - Increasing assembly failure rate: $DPMO_i.10^{-6} = 1-Q_i$
- Q improves by introducing test and repair.

$$Q = \prod_{i=1}^{DO} Q_i$$

In real life there is no such thing as

“Zero Defect Manufacturing”

Be realistic:

Deal with manufacturing failure risks

Tests are required!

QUALITY QUANTIFICATION
QUANTIFIED QUALITY

Added value of Quantified Quality concept:

- **Quality** becomes measurable and quantifiable.
  One can assign **an objective value** to it.
- **Test -** perceived as an overhead cost **-** transforms into a quality improving therefore **a value adding process**.
- Predictability of quality: Basis for **Design-for-Quality**.
- Basis for **a common quantified quality language** in the supply chain.

QUALITY QUANTIFICATION

COST OF "LOW QUALITY"

Top quality!

- Q = 99.5%
- BOM = €450
- Assembly = €50
- Price = €550

50% lower assembly cost!

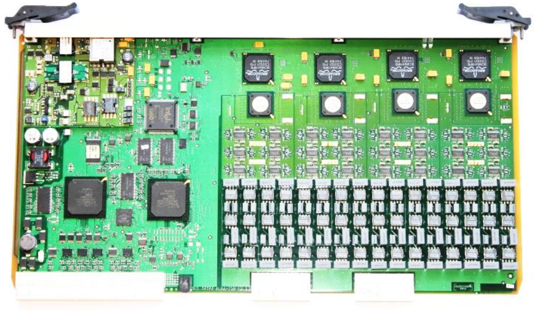
- Q = 98%
- BOM = €425
- Assembly = €25
- Price = €525

QUALITY QUANTIFICATION

COST OF "LOW QUALITY"

Volume
10000/year

Non-quality cost: €2500 per failure at customer



Q=99.5%

Cost: M€5 NQ-cost: 2500 x 0.5% x 10000=**K€ 125**
Sales: M€5.5 Margin: **K€ 375** or **€37.5/PBA**

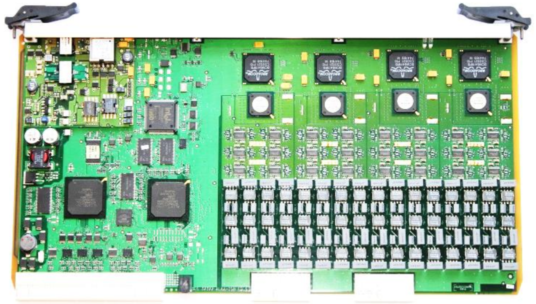
Q=98 %

Cost: M€4.5 NQ-cost: 2500 x 2% x 10000=**K€ 500**
Sales: M€5.25 Margin: **K€ 250** or **€25/PBA**

QUALITY QUANTIFICATION
COST OF "LOW QUALITY"

Volume
10000/year

Non-quality cost: €5000 per failure at customer



Q=99.5%

Cost: M€5.0 NQ-cost: 5000 x 0.5%x 10000=**K€ 250**
Sales: M€5.5 Margin: **K€ 250** or **€25/PBA**

Q=98 %

Cost: M€4.5 NQ-cost: 5000 x 2% x 10000=**M€ 1**
Sales: M€5.25 Margin: **-K€ 250** or **-€25/PBA**

QUALITY QUANTIFICATION

QUALITY AFTER TEST

DO
=
20000

Top quality!

- Q=99.5%
- DPMO=10
- AOI QTC=40%
- ICT QTC=50%
- FT QTC=90%

50% lower assembly cost!

- Q=98%
- DPMO=20
- AOI QTC=40%
- FT QTC=88%

QUALITY QUANTIFICATION

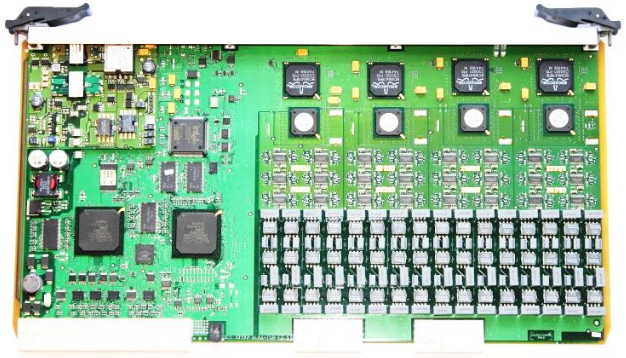
QUALITY AFTER TEST

DO = 20000

$DPMO = 10ppm \rightarrow$ **Q_{FP} = 81.9%**

$\Delta Q_{AOI} = 7.2\%$ $\Delta Q_{ICT} = 5.5\%$ $\Delta Q_{FT} = 4.9\%$

17.6% repair → Q = 99.5%

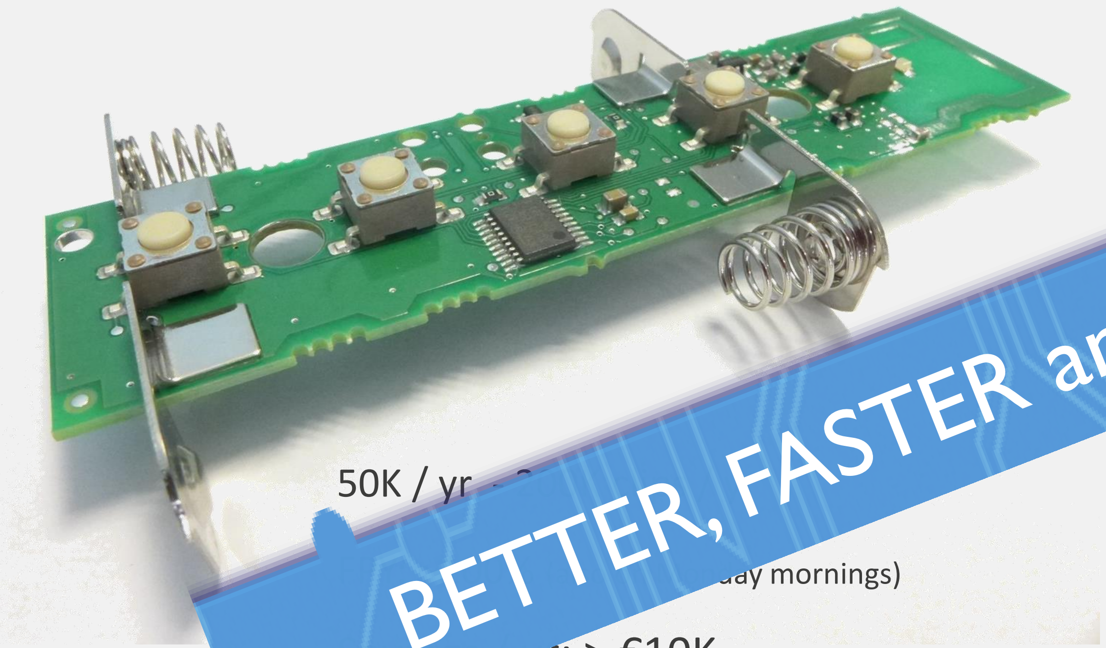


$DPMO = 20ppm \rightarrow$ **Q_{FP} = 67%**

$\Delta Q_{AOI} = 16.5\%$ $\Delta Q_{FT} = 14.5\%$

***31% repair* → Q = 98%**

DFM RESULTS IN LOW-COST MANUFACTURING



50K / yr

ay mornings)

/ yr: > €10K

Automation & Design-for

- New and St ry
- on component level
- ity remarks: reduction 10x!
- Lead times prototypes (and series)

→ reduction of 65%

BETTER, FASTER and LOWER COST!

ref.: Gert D'Handschotter, ED&A, cEDM event 2015, www.cedm.be

DESIGN-FOR-MANUFACTURING

Door maakkennis wordt DfM ook:

DESIGN

for

Mon€y!

RELIABILITY
QUANTIFICATION AND PREDICTION

RELIABILITY ASSESSMENT
DEFINITION

Reliability:

Probability that a product will perform its required function under stated conditions for a specific period of time.

“cEDM definition of reliability”:

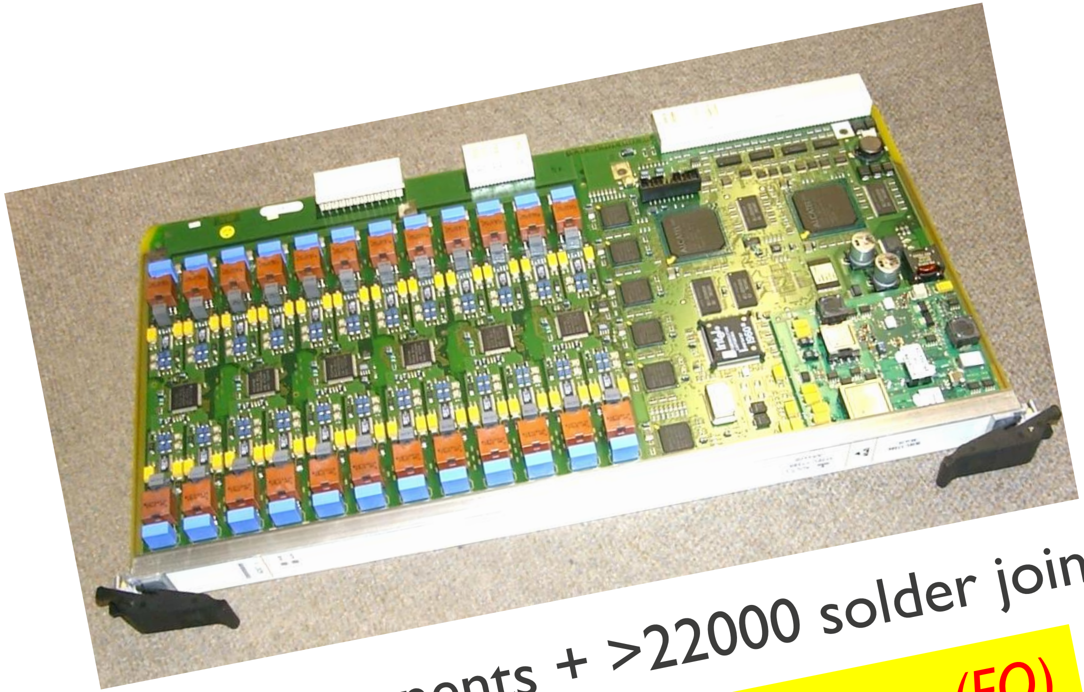
Reliability is the ability of the product to maintain it’s (Quantified) Quality under stated conditions for a specific period of time.

Reliability starts with Quality

Early failures are quality issues that have slipped through production tests

RELIABILITY ASSESSMENT

SO MANY THINGS CAN FAIL ...



2500 components + >22000 solder joints

= >40000 failure opportunities (FO)

Components

Solder joints

PCB

PBA

1 PBA =(1K to 100K FO)
x *n* failure mechanisms/FO

RELIABILITY ASSESSMENT

TRADITIONAL APPROACH: RELIABILITY PREDICTION STANDARDS

MIL-HDBK-217 - *the oldest, best-known most outdated (1995)*

Telcordia SR-332 - *previously Bellcore, telecommunication, US.*

IEC-61709/SN 29500 - *Siemens, industrial, Germany.*

IEC-TR-62380/Fides 2009 - *French industry, industrial-avionics, France.*

217plus – *Quanterion, commercial MIL-HDBK-217 update, US.*

GJB/Z 299C – *China.*

Describe how to determine the reliability of a **system of** electronic **components** using **constant failure rate statistics** and field failure data.

Basic principle: $\lambda_{sys} = \lambda_1 + \lambda_2 + \lambda_3 + \ldots + \lambda_n + \lambda_{PCB}$

RELIABILITY ASSESSMENT

CONSTANT FAILURE RATE: WHAT DOES IT MEAN?

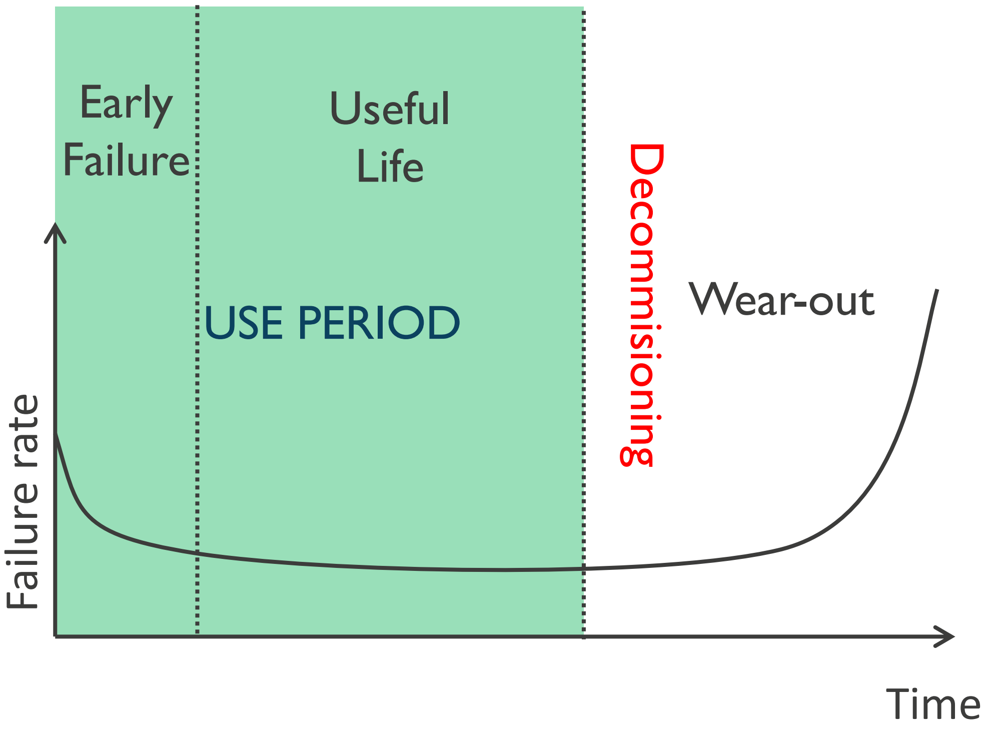
Buy NEW

Buy USED

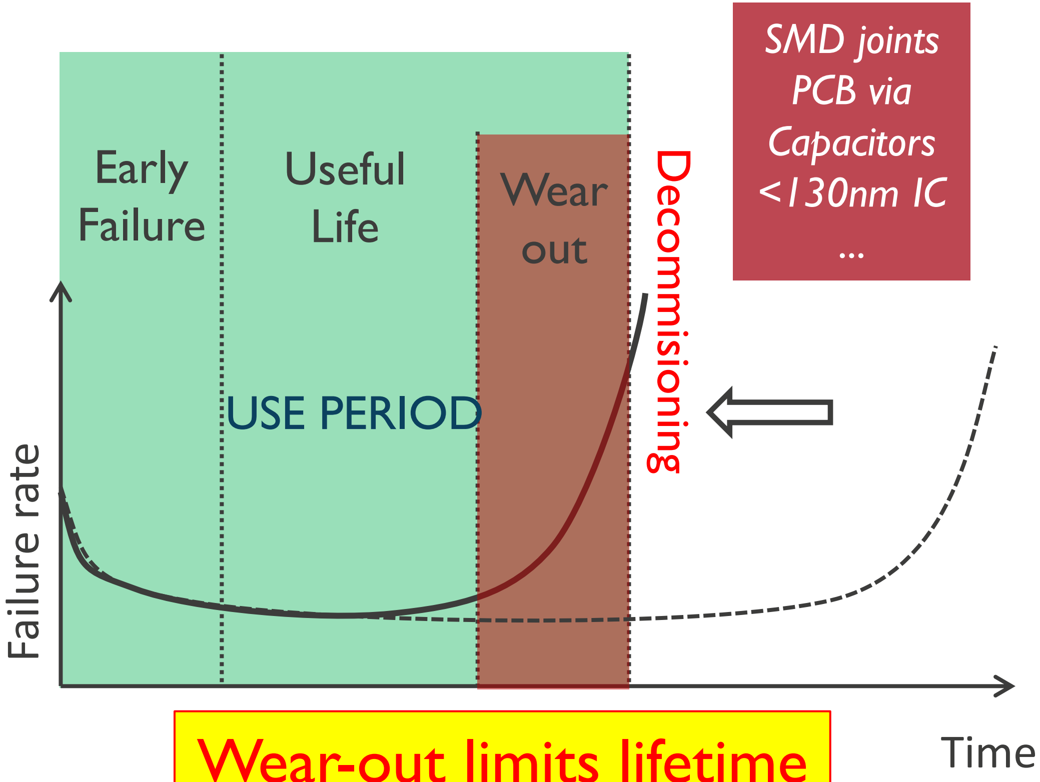
Do you expect the same failure rate for a used car as for a new one?

RELIABILITY ASSESSMENT
THE REAL WORLD

What it was (before the '80s)



What it is now!



Wear-out limits lifetime

Army 1995 Memo Prohibiting Further Use of MIL-HDBK-217 Actuarial Reliability Prediction Methods

DEPARTMENT OF THE ARMY
OFFICE OF THE ASSISTANT SECRETARY
RESEARCH DEVELOPMENT AND ACQUISITION

General Motors Reliability Policy

"... GM concurs and will comply with the findings and policy revisions of Feb. 15, 1996 by the Assistant Secretary of the U.S. Army for Research, Development and Acquisition. … Therefore: Mil-Hdbk 217, or a similar component reliability assessment method such as SAE PREL, **SHALL NOT BE USED**."

GM North American Operation,
Technical Specification Number: 10288874, June 4, 1996.

U. S. Military View of Mil-Hdbk-217

"… Mil-Hdbk-217, Reliability Prediction of Electronic Equipment, **and progeny**, is not to be used as it has been shown to be unreliable and its use can lead to erroneous and misleading reliability predictions."

October 1994

Decker, Assistant Secretary of the Army (Research, Development, and Acquisition), Memorandum for Commander, U.S. Army Material Command, Program Executive Officers, and Program Managers

More than 20 years ago!

define the quantitative reliability requirements. The extent to which failures and usage conditions are defined should be determined on an acquisition-specific basis.

Predictions Methods in the 1990s.

RELIABILITY ASSESSMENT

TRADITIONAL APPROACH: WHY IS IT STILL USED?

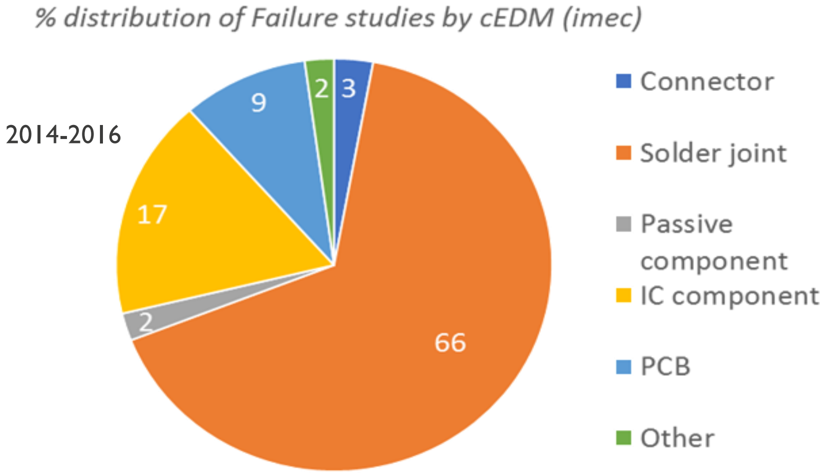
- *“We have always done it that way.”*
- The method is (still) accepted in industry.
- It is more or less comprehensive.
- It always gives a number.
- It is relatively simple to use (summation).
- Provides a lot of stretch… (1 – 8000)
- Lack of Physics-of-Failure know-how

RELIABILITY QUANTIFICATION
"THE RIGHT WAY"

RELIABILITY QUANTIFICATION
SYSTEM RELIABILITY

$$\lambda_{sys} = \lambda_1 + \lambda_2 + \lambda_3 + \ldots + \lambda_n + \lambda_{PCB}$$

is not valid.



How to handle?

- Identify all failure opportunities (EDM-D-100 – www.cedm.be)
- Reliability Physics based reliability function $R_i(t)$ *per FO*.

  $R_i(t)$: Probability that no failure has occurred at time *t* at failure opportunity *i*.

- For a system without redundancy: $R_{sys}(t) = \prod_{\forall \text{ Fail.Opp.}} R_i(t)$

RELIABILITY QUANTIFICATION
FAILURE OPPORTUNITIES

- System = PBA
  = {defect opportunities in manufacturing with quality} = $\{D_i(Q_i)\}$
  = {failure opportunities in operation with reliability} = $\{F_i(R_i(t))\}$
- Quality = probability of no defect in manufacturing
  Reliability = probability of no failure in operation
- PBA quality = $\prod_i(Q_i)$
  PBA reliability = $\prod_i(R_i(t))$ (simplest form: no redundancy)

RELIABILITY QUANTIFICATION

RELIABILITY CONTRIBUTIONS – NON-QUALITY SLIP-THROUGH

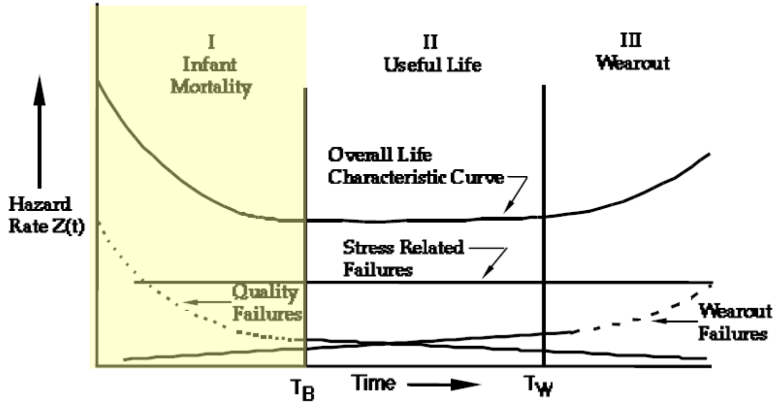
$$Q_i + NQ_i^{\text{pat}} + NQ_i^{\text{lat}} = 1$$

1. **Early failure** due to patent defect slip through:
   - TS_i = Test Slip of defect opportunity *i*
   - NQ_i^{pat} = patent non-quality = defect probability at defect opportunity *i*
   - u = use rate of functionality containing defect opportunity *i*

$$R_i^{\text{TS}}(t) = TS_i NQ_i^{\text{pat}} \exp[-ut]$$

2. **"Classic" Early failure** due to latent defects:
   - TS_i^{SS} = Stress Screening test slip of defect opportunity *i*
   - NQ_i^{lat} = latent non-quality
     = latent defect probability at defect opportunity *i*

$$R_i^{\text{lat}}(t) = TS_i^{\text{SS}} NQ_i^{\text{lat}} \exp\left[-\left(\frac{t}{\theta_{\text{lat}}}\right)^{\beta_{\text{lat}}}\right] \text{ with } \beta_{\text{lat}} < 1$$

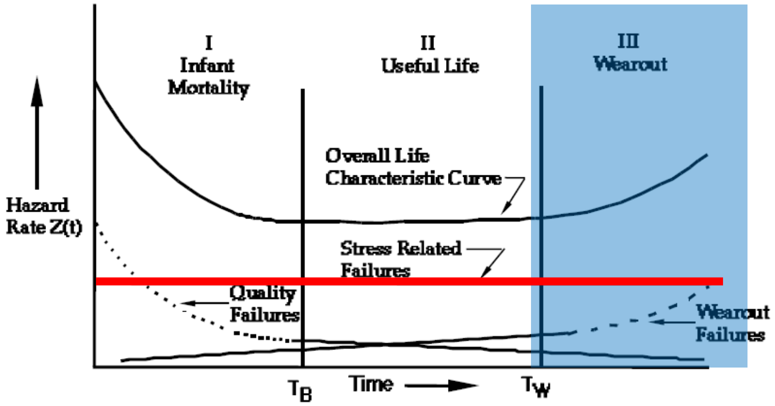


RELIABILITY QUANTIFICATION

RELIABILITY CONTRIBUTIONS: WEAR-OUT AND RANDOM OVERSTRESS

3. **Wear-out** failure of failure opportunity with quality Q_i:
   - γ = failure free period

$$R_i^{\mathrm{wo}}(t) = Q_i\{H(\gamma - t) + H(t-\gamma)\exp\left[-\left(\frac{t-\gamma}{\theta_{\mathrm{wo}}}\right)^{\beta_{\mathrm{wo}}}\right]\} \text{ with } \beta_{\mathrm{wo}} > 1$$



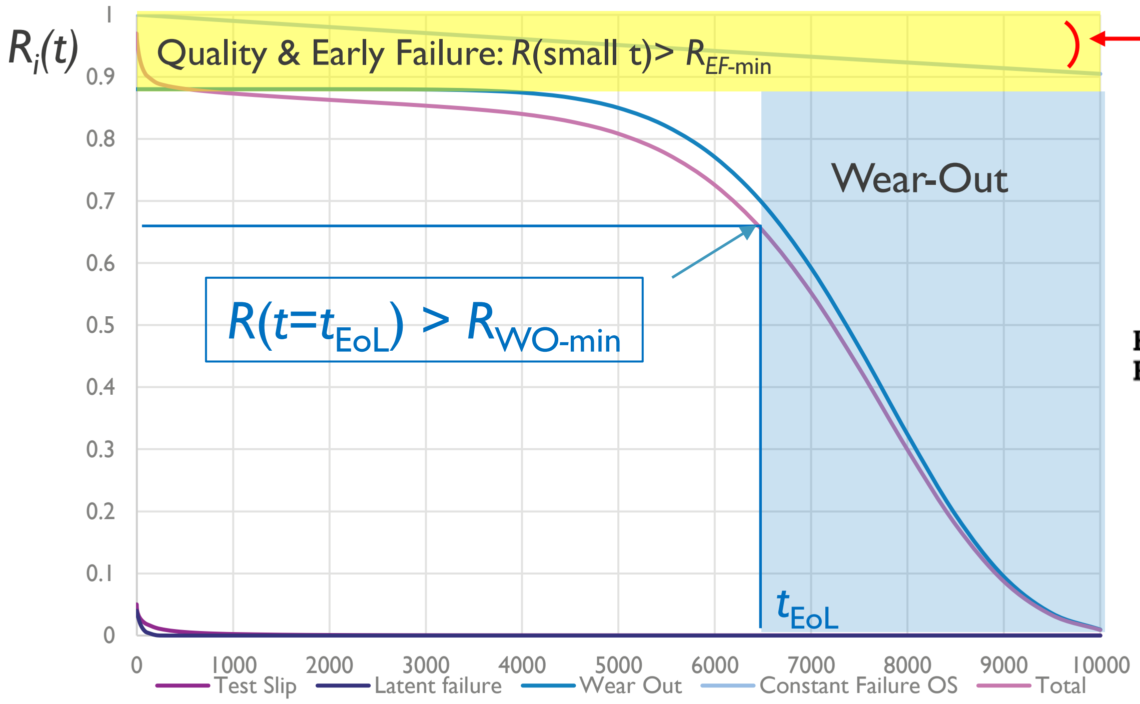
4. **Over-stress** constant failure rate contribution:
   - θ_i^{s} = over-stress rate at failure opportunity *i*
   - *n* = # of over-stress incidents to failure.
   - $n\theta_i^{\mathrm{s}}$= constant failure rate MTTF

$$OS_i(t) = \exp\left[-\frac{t}{n\theta_i^{\mathrm{s}}}\right]$$

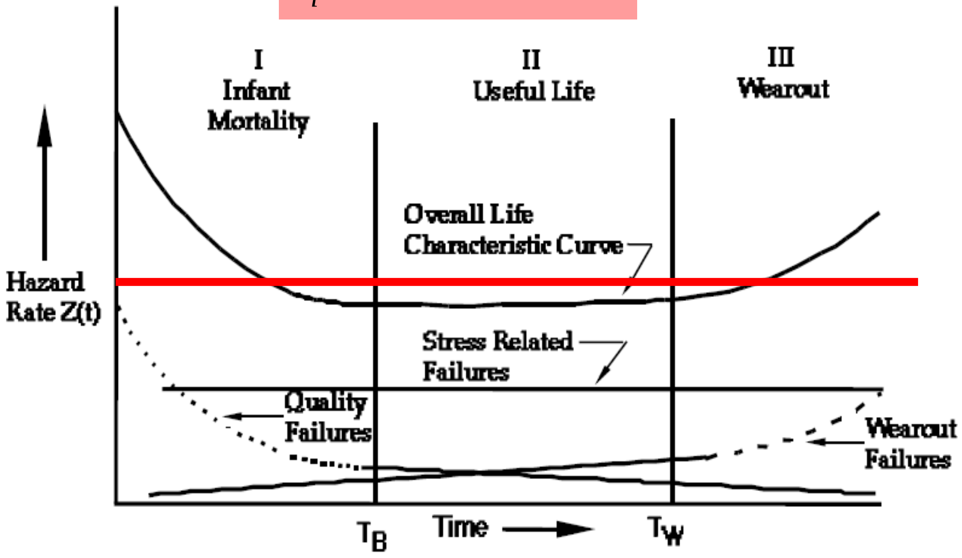
RELIABILITY QUANTIFICATION

RELIABILITY PER FAILURE OPPORTUNITY

$$R_i(t) = \left[R_i^{\mathrm{TS}}(t) + R_i^{\mathrm{lat}}(t) + R_i^{\mathrm{wo}}(t)\right] \cdot OS_i(t)$$



$\theta_i^{\,s} > \min.\ \mathrm{MTTF}$



TEN SLOTTE

DESIGN-FOR-EXCELLENCE
EDM FORUM: DFX GUIDELINES

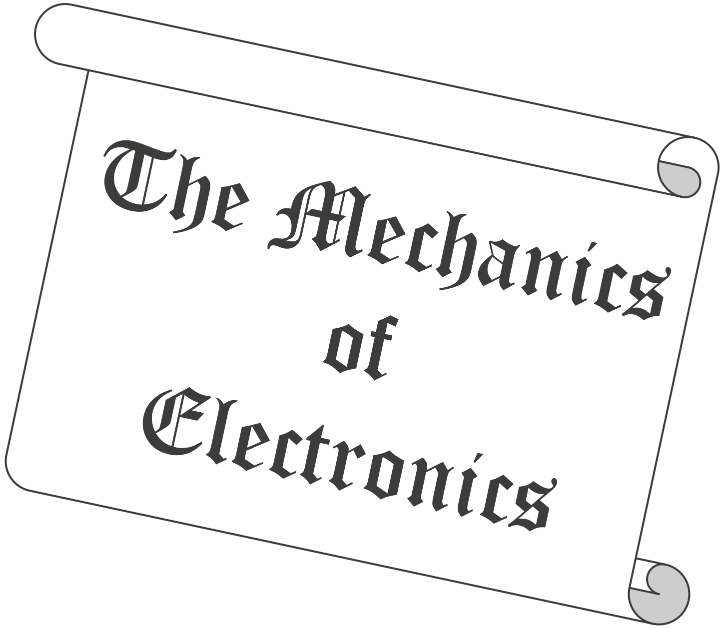
Electronics Design & Manufacturing

Purpose, goal

- Quality, reliability, compliancy ... at low(est) cost

Support physical design: electronics as a physical object

- Design-for-Manufacturing (PCB)
- Design-for-Assembly (PBA)
- Design-for-Test
- Design-for-Reliability
- Design-for-Compliancy (RoHS, CE, medical)



QUALITY QUANTIFICATION
PBA DFX TOOL

- Generic DfX supporting tool
- Can be used very early in design phase (concept)
- Quantified prediction of PBA DfX properties
- V1.0: Quality and test coverage prediction
- V2.0: Assembly capacity use and DfA analysis
- https://www.cedm.be/calculators/pred-x/product-information

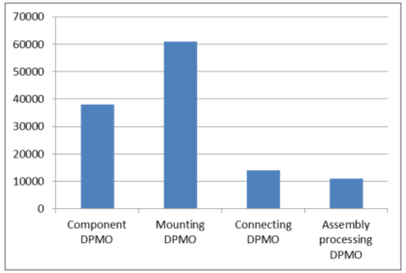
WORKING WITH IMEC'S CEDM
"QUALITY PREDICTION AND IMPROVEMENT"

LE
OEM

ASML

New Quality method achievements

- 4 to 6 times better PCBA quality in 3 years
- Manufacturing Risks have become transparent



CEDM Workshop 20, December 9, 2014

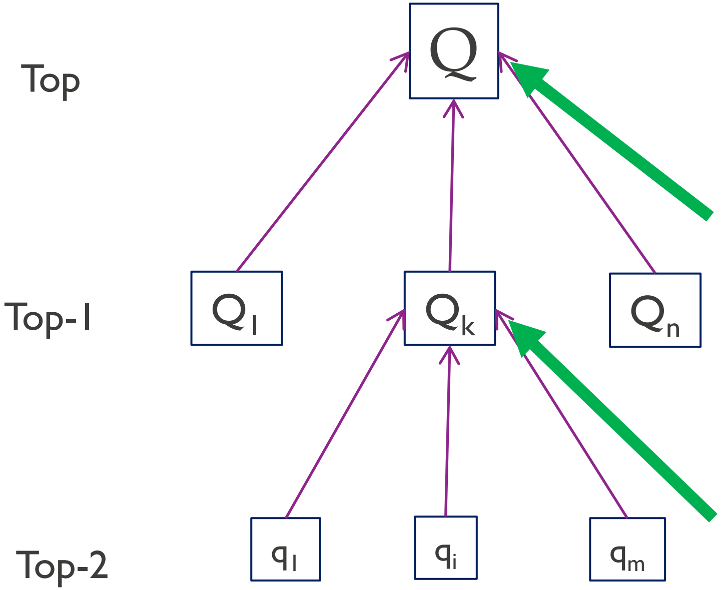
*After decades of constant PCBA quality we have been able to improve it at our suppliers by a factor 4 to 6 in 3 years time by deploying the new Quality Quantification methodology embedded in imec's **Pred-X** tool in **ASML**'s New Product Introduction process. Further quality improvement using this method at system level is the aim of ASML's ZHDR project.*

www.movip.nl – www.cedm.be

QUALITY QUANTIFICATION

MECHATRONIC SYSTEMS

Hierarchical levels – Qualities Q, Q_k, q_i



$$Q = \prod_{k=1}^{n} [Q_k]$$

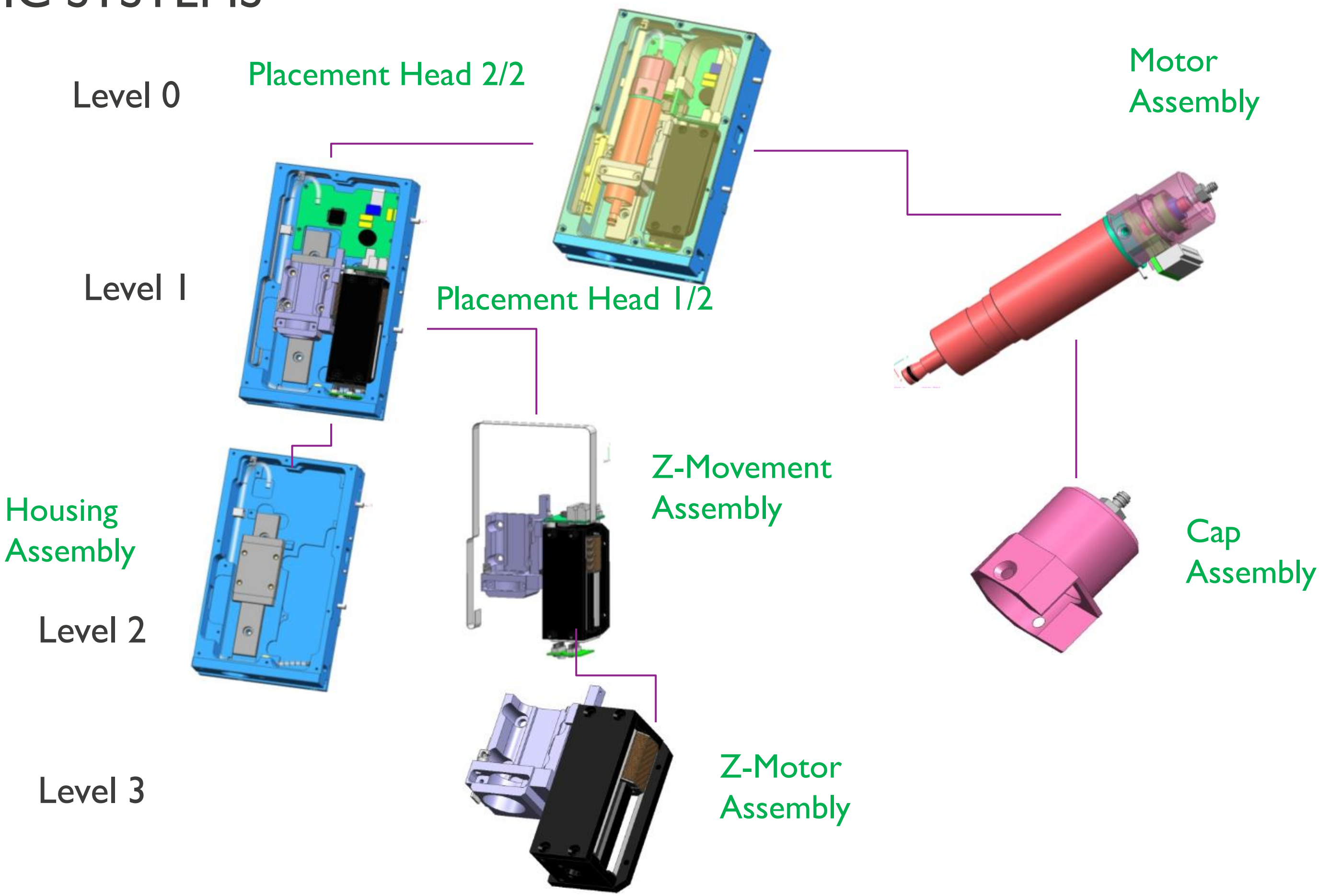
$$Q_k = \prod_{i=1}^{m} [q_i]$$

INDEPENDENT QUALITIES AT EACH LEVEL!

DEFINE HIERARCHICAL LEVEL

QUALITY QUANTIFICATION

MECHATRONIC SYSTEMS



THANK YOU

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