Quantification of PBA Quality, Test Coverage and Zero Hour Defect Rate

H&W Design - Meeting Point

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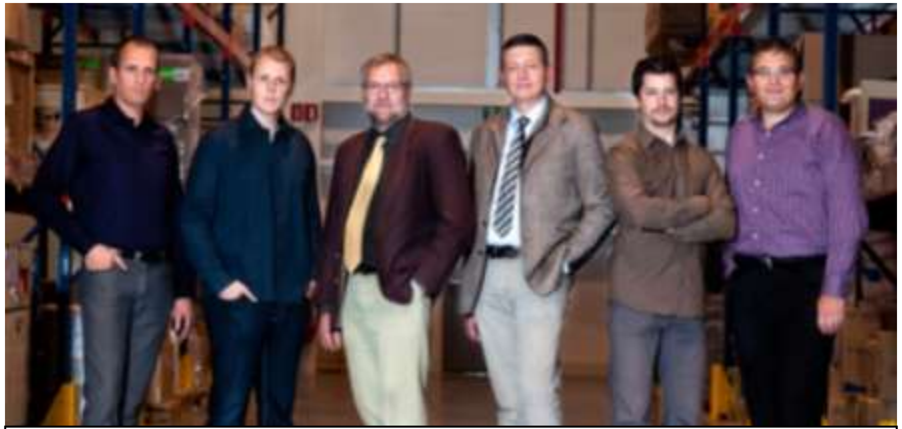
EDM
Electronic Design & Manufacturing

Electronics Design & Manufacturing



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>70 years industry
>20 years research
experience in electronics

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Better electronics
at
reduced cost
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Content

1. PBA Quality
2. BOM: PBA Quality versus component selection
3. Structural testing
4. Impact of test on PBA Quality (yield)
5. In practice
6. Modeling
7. Conclusions

1. PBA Quality

Quality

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

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

Specification/expectation:

- 100% functionality of PBA at customer → 100% quality
- P = Reliability(t=0)="Zero Hour Defect Rate" ZHDR
  Consumer electronics reference (product): P = R(t=0) = 3-6%
- How to quantify ZHDR and improve it by design and test?

1. PBA Quality

Quantified Quality:

- 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.

Properties:

→ Quality Q=Yield (first pass – after test)

→ ZHDR=P=R(t=0) = 1-Q (Q: as delivered quality)

→ Q decreases with increasing number of Defect Opportunities (complexity) and manufacturing processes.

→ Q improves by introducing test and repair.

Note: *In real life there is no such thing as "Zero Defect Manufacturing"*

1. PBA Quality

- Quality maximization:
  defect minimization, quantification, detection and repair.
- Categorization of assembly defects depends on the defect definition. Many possibilities.

- The complete supply-chain contributes and carries responsibility.
- Design is in the driver seat: **"Rubbish in is rubbish out"**
  1. BOM definition
  2. Layout

$$\frac{\partial Q}{\partial inputs} >> \frac{\partial Q}{\partial proces}$$

Every PBA represents a very large number of input variables

*→ **D-f-Assembly is mandatory***

1. PBA Quality

Quantified Quality:

- Started with IPC-7912 on PBA
- Expanded to complete mechatronic systems in MoVIP: *Modellering van de Voorspelbaarheid van Initiële Productkwaliteit.* (Point One – ASML & suppliers)

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**.
- Predictabillity of quality. Basis for **Design-for-Quality**.
- Basis for **a common quantified quality language** in the supply chain.

Predict Assembly Performance

Current Assembly Performance

1200 PCBA's/Machine

Assembly ZHDR 1%

20 Machines/Year

5h Repair time

12 disturbances/machine Build

1200h Loss electronics → 0.4 Machine not build

Profit

Interest

Space

………

1. PBA Quality

R&D behind Quantified Quality

- Development of quantification concept
  - PBA: Based on IPC-7912 defect opportunity
    component-placement-interconnection defects
  - Mechatronic systems:
    Parts – Virtual Connector Parts (connections)
- Failure probability models
- Test coverage models
- Tool

1. PBA Quality

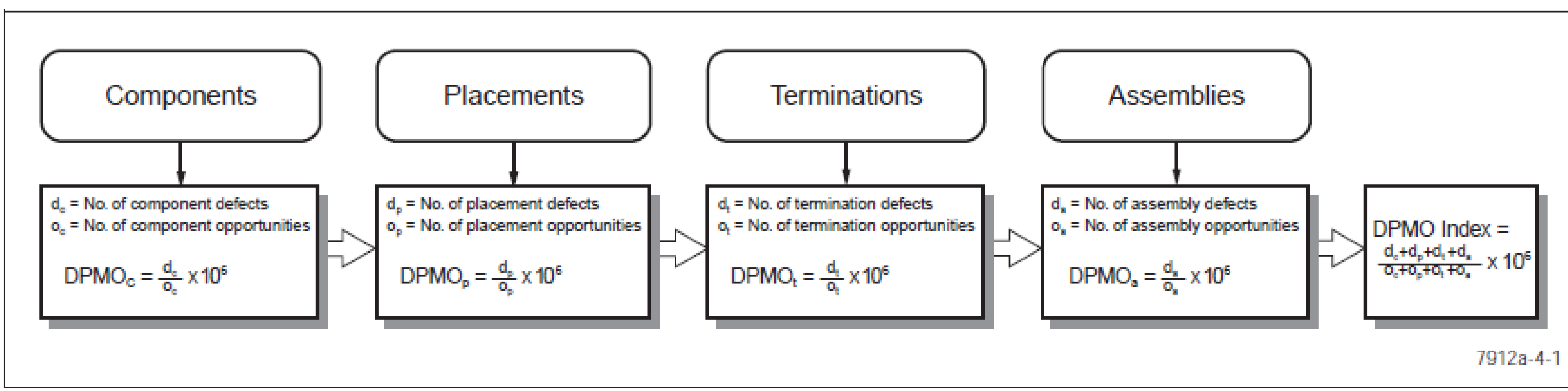
Definition of defect categories: *wish list*

- Related to physical defects (≠electrical)
- "As simple as possible but not simplier"
- Linked to industry standards:
  - Defect Opportunities of a PBA
    Component, placement, termination, PBA, PCB
  - Defects Per Million opportunities = DPMO
    - IPC-7912: measurement of defect rate– quality index
    - RISK: failure probability → PBA failure probability P/yield and test impact

IPC ASSOCIATION CONNECTING ELECTRONICS INDUSTRIES

IPC-7912A

End-Item DPMO for Printed Circuit Board Assemblies



1. PBA Quality

IPC-7912 Defect categories:

- Failing PCB: #DO=1
- Failing component: #DO = # components
- Wrongly placed component: #DO = # componenten
- Failing interconnection: #DO = # terminals
- Failure at PBA level: #DO = 1
- **#DO=1+1+2x #components + #terminals**

Stig Oresjo - Agilent

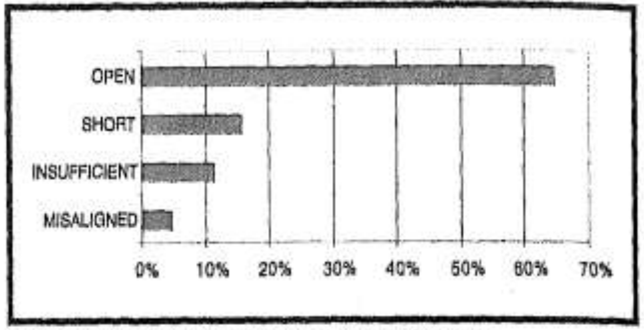
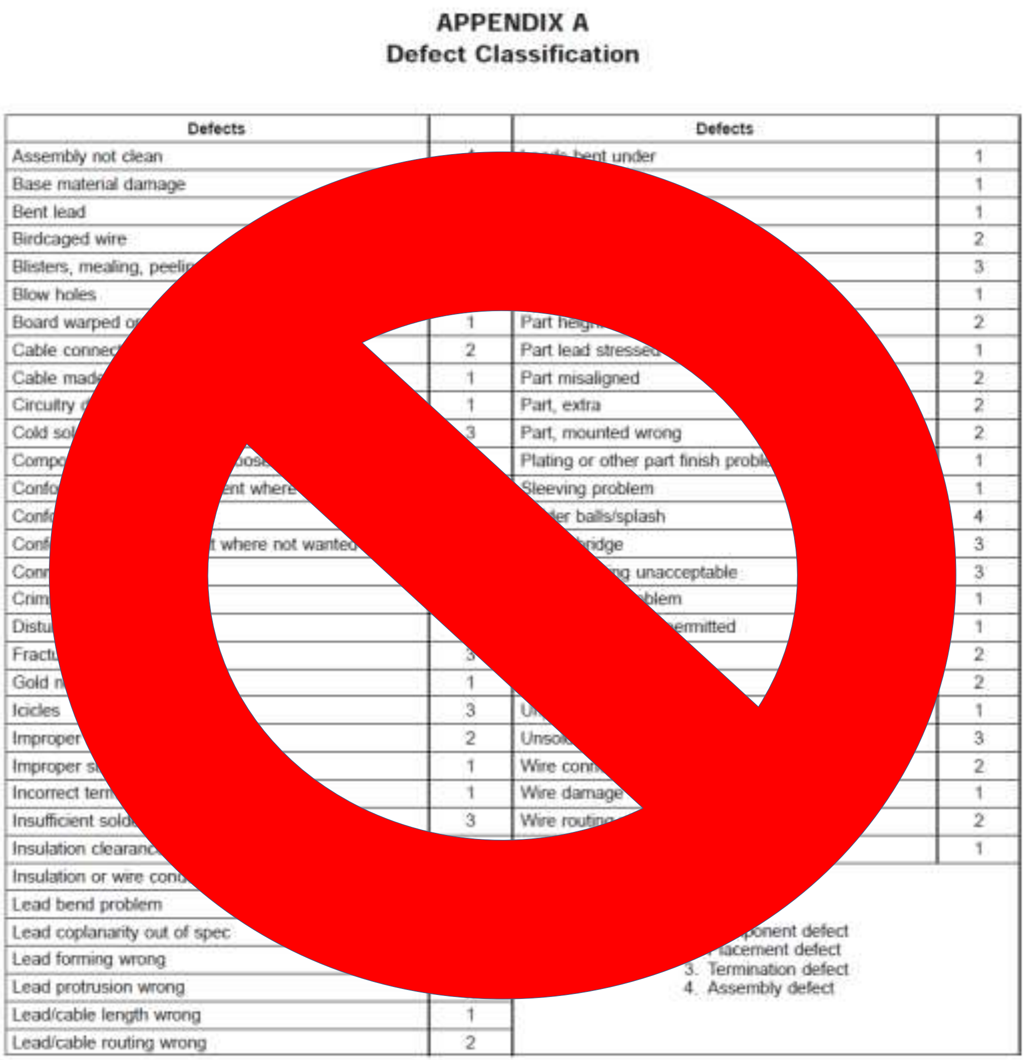


FIGURE 4: Fault spectrum of all gullwing solder joints.

Not enough detail (too simple):

- Different failure probability for different failure types: ex. short vs. open
- Test methods have a defect type dependent test coverage.
  Ex. AOI: missing vs. wrong component
- Definition of defect types for each main defect opportunity type.

1. PBA quality



APPENDIX A
Defect Classification

Defects		Defects	
Assembly not clean		ads bent under	1
Base material damage			1
Bent lead			1
Birdcaged wire			2
Blisters, mealing, peeli			3
Blow holes			1
Board warped o	1	Part heig	2
Cable connec	2	Part lead stressed	1
Cable mad	1	Part misaligned	2
Circuitry	1	Part, extra	2
Cold sol	3	Part, mounted wrong	2
Compo oose		Plating or other part finish proble	1
Confo ent where		Sleeving problem	1
Conf		der balls/splash	4
Conf t where not wanted		bridge	3
Conn		ng unacceptable	3
Crim		blem	1
Distu		ermitted	1
Fractu	3		2
Gold r	1		2
Icicles	3	U	1
Improper	2	Unso	3
Improper s	1	Wire conn	2
Incorrect term	1	Wire damage	1
Insufficient sold	3	Wire routing	2
Insulation clearanc			1
Insulation or wire cond			
Lead bend problem			
Lead coplanarity out of spec			
Lead forming wrong			
Lead protrusion wrong			
Lead/cable length wrong	1		
Lead/cable routing wrong	2		

ponent defect
lacement defect
3. Termination defect
4. Assembly defect

IPC-7912 classification

Not usable:

- No definitions
- No structure
- No hierarchy
- Outdated
- Tombstoning is not a placement defect

1. PBA Quality

IPC Defect Category	PBA-item	EDM Defect Type	Definition
Component (DT_{PCB} = 3)	PCB	PCB DEFECT	PCB manufacturing defect
		DELAMINATION	Delamination of PCB during heat treatment
		VIA CRACKING	Via cracking during heat treatment
		class 1-2-3	IPC class 1-2-3 quality defect as defined by IPC-A-600 standard
Component (DT_C = 3)	BoM	PHYSICAL OUT-OF-SPEC	A component is functional but some aspect of its physical properties does not adhere to specification
		ELECTRICAL OUT-OF-SPEC	A component is functional but some aspect of its electrical properties does not adhere to specification
		FATAL DEFECT	A component is not functional due to electrical malfunction (including data programming error e.g. wrong PROM code)
		class 1-2-3	IPC class 1-2-3 quality defect as defined by IPC-A-610 standard
Placement (DT_P = 4)	BoM	MISSING	A component is missing.
		WRONGLY EQUIPPED	A wrong component was placed or a component was placed on a not-equipped location of the PBA design/layout
		MISORIENTED	Component placed with incorrect orientation w.r.t. pin 1
		MISPLACED	Component placed at incorrect position (e.g. with X-Y offset) or small orientation offset to the correct position resulting in electrical defect
		class 1-2-3	IPC class 1-2-3 quality defect as defined by IPC-A-610 standard
Termination (DT_T = 2)	BoM	OPEN	The electrical contact between the component terminal and a pad is interrupted.
		SHORT	Undesired electrical connection between a component terminal and other terminal(s) or other electrically conductive PBA features.
		class 1-2-3	IPC class 1-2-3 quality defect as defined by IPC-A-610 standard
Assembly (DT_{PBA} = 4)	PBA	MECHANICAL	PBA mechanical defect (not component related)
		INTERCONNECTION	PBA interconnection defect (not component related)
		CLEANING	PBA cleanliness issue
		CONFORMAL COATING	Conformal coating does not adhere to its specification (pinholes, not coated/overcoated areas)
		class 1-2-3	IPC class 1-2-3 quality defect as defined by IPC-A-610 standard

EDM definitions

- As simple as possible
- FUNCTIONAL DEFECTS
- Acceptability defects
  IPC class 1-2-3
- Physical defects
- Independent of the failure cause
- Manufacturing not design defects

1. PBA Quality

EDM Definitions

Extension to non-electrical components

Defect Opportunity Category		Defect Type	Definition
PLACEMENT	ELECTRICAL $DT_{PLM-EL} = 4$	MISSING	An electrical component is missing.
		WRONG	A wrong electrical component was placed.
		MISORIENTED	Electrical component placed with incorrect orientation w.r.t. pin 1.
		MISPLACED	Electrical component placed at incorrect position e.g. with X-Y
		class 1-2-3	
	MECHANICAL $DT_{PLM-ME} = 4$	MISSING	
		WRONG	
		MISORIENTED	
		MISPLACED	
		quality	
	OPTICAL $DT_{PLM-OP} = 4$	MISSING	
		WRONG	
		MISORIENTED	
		MISPLACED	
		quality	

Defect Opportunity Category		Defect Type	Definition
TERMINATION	ELECTRICAL $DT_{TRM-EL} = 2$	OPEN	The electrical contact between the electrical component terminal and a pad is interrupted.
		SHORT	Undesired electrical contact between electrical component terminals or other electrically conductive PBA features.
		class 1-2-3	IPC class 1-2-3 quality defect as defined by IPC-A-610.
	MECHANICAL $DT_{TRM-ME} = 3$	FUNCTIONAL	The mechanical connection is not functional: e.g. uncured glue, damaged bolt, … Note: if subassembly parts are present this defect type depends on the mechanical connection defects, see Table 2.
		OUT-OF-SPEC	The mechanical connection is functional, but some of its properties do not adhere to specification. Same note as above.
		MOUNTING	Mounting issue with the mechanical connection: e.g. glue not dispensed, wrong bolt used, rivet placed at wrong location, … Same note as above.
		quality	Connection quality issue leading to non-acceptability of the assembly. Same note as above.
	OPTICAL $DT_{TRM-OP} = 3$	FUNCTIONAL	The optical connection is not functional: e.g. receiving or creating cross-talk from/to other optical connections.
		OUT-OF-SPEC	The optical connection is functional, but some of its properties does not adhere to specification: e.g. excessive loss
		MOUNTING	Mounting issue with the optical connection: e.g. missing connection
		quality	Connection quality issue leading to non-acceptability of the assembly.

1. PBA Quality

PBA Quality

IPC-7912 DPMO-index

- A measure for quality.
- DPMO Index ≈ average $DPMO_{av}$ over all *DO*

  $1\text{-}Y = P = 1-(1-DPMO_{av})^{DO} \approx DO \times \text{DPMO-index}$
  if DPMO & DPMO-index <0.01

4.3 DPMO Index The DPMO Index (see 1.3.2) for a completed assembly is a simple unweighted index as follows:

$$\text{DPMO Index} = \left[\frac{d_c + d_p + d_t + d_a}{o_c + o_p + o_t + o_a}\right] \times 10^6$$

The above DPMO index may also be applied to more than one assembly by summing the defects and opportunities across all assemblies as follows:

$$\text{DPMO Index} = \left[\frac{\Sigma d_c + \Sigma d_p + \Sigma d_t + \Sigma d_a}{\Sigma o_c + \Sigma o_p + \Sigma o_t + \Sigma o_a}\right] \times 10^6$$

IPC-7912 Overall Manufacturing Index

- OMI ≈ PBA failure probability *P*

  ≈ Non-quality *NQ=1-Q*

  if DPMO & $DPMO_{c,t,p,a}$-index <0.01
- Too crude for:
  - Correct failure probability calculation
  - Impact of test

OMI for a completed electronic assembly is as follows:

$$\text{OMI} = [1 - (p_c)(p_p)(p_t)(p_a)] \times 10^6$$

where:

$$p_c = 1 - \frac{d_c}{o_c} \qquad p_p = 1 - \frac{d_p}{o_p}$$

$$p_t = 1 - \frac{d_t}{o_t} \qquad p_a = 1 - \frac{d_a}{o_a}$$

IPC-7912: inspection oriented – counting of defects

1. PBA Quality: calculation

Quantified quality calculation:

$DPMO_i$ failure probability for DO_i ; $Q_i=1-DPMO_i$ quality of DO_i.

Quantified Quality Q = probability of a functional PBA

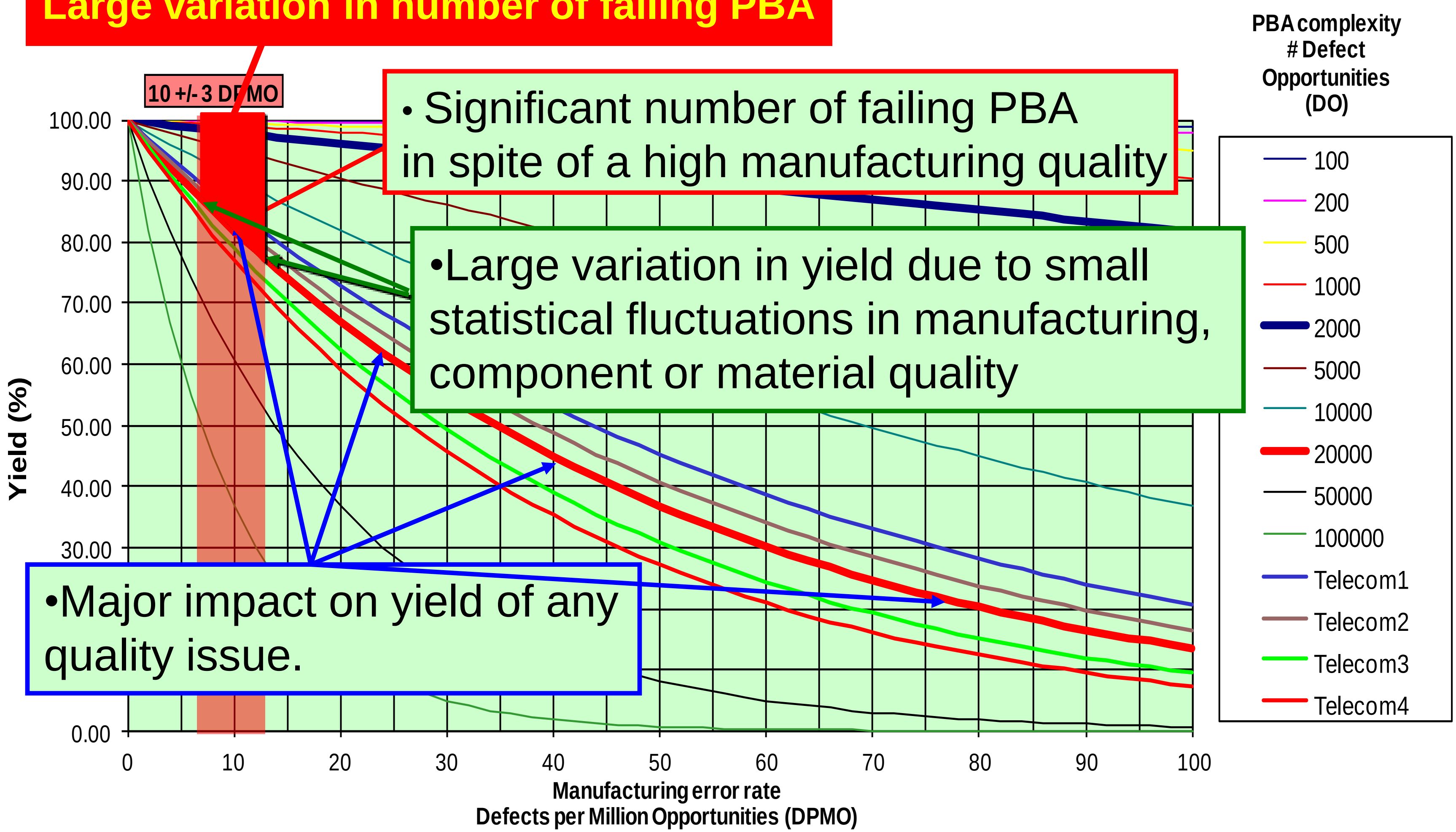
$$Q=\prod_{i=1}^{DO}[Q_i]=\prod_{i=1}^{DO}[1-DPMO_i]=1-P$$
$$=[1-DPMO_{av}]^{DO} \quad \text{(by definition)}$$
$$\approx 1-DO\cdot DPMO_{index}$$

Quality and PBA failure probability depend on:

- Assembly failure probabilities/quality: $DPMO_i$, Q_i
  DESIGN, components (BOM), PCB, assembly processes,...
- PBA complexity: DO
  DESIGN

1. PBA Quality

Significant number of failing PBA
Large variation in number of failing PBA



• Significant number of failing PBA in spite of a high manufacturing quality

•Large variation in yield due to small statistical fluctuations in manufacturing, component or material quality

•Major impact on yield of any quality issue.

1. PBA Quality: Definitions

EDM
Electronic Design & Manufacturing

imec

PBA manufacturing Quality (DPMO) and Test Coverage quantification

Project : VIS-PROSPERITA

V3.0
June 2012

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11 June 2012

<u>Q_{DO} = Quality at defect opportunity level:</u>

Q_{DO} is the probability of having <u>no</u> defect at a specific defect opportunity.

$$Q_{DO} = 1 - DPMO_{DO} \times 10^{-6} \qquad [2]$$

<u>NQ_{DO} = Non-Quality at defect opportunity level:</u>

NQ_{DO} is the probability of having a defect at a specific defect opportunity.

$$NQ_{DO} = 1 - Q_{DO} \qquad [3]$$

$$NQ_{DO} = DPMO_{DO} \times 10^{-6} \qquad [4]$$

<u>Compound Q_{SET} = Quality of</u>

Q_{SET} is the compound proba ... t
opportunities. Based on elem ... :

$$Q_{SET} = \prod_{DO=1}^{N_{SET}} Q_{DO} \qquad [5]$$

$$Q_{SET} = \prod_{DO=1}^{N_{SET}} Q_{DO}$$

From which the compound DPMO of a set of defect opportunities can be derived.

<u>Compound $DPMO_{SET}$ = DPMO of a set of defect opportunities:</u>

For a set of N_{SET} defect opportunities:

$$DPMO_{SET} = (1 - Q_{SET}) \times 10^{6} \qquad [6]$$

$$DPMO_{SET} = (1 - \prod_{DO=1}^{N_{SET}} (1 - DPMO_{DO} \times 10^{-6})) \times 10^{6} \qquad [7]$$

EDM imec

2. PBA Quality versus BOM

Failing PBA give rise to high non-quality costs and poor delivery performance:

- PBA trouble-shooting: time-consuming, high skilled job.
- PBA repair: time-consuming, high-skilled repair operator job.
- Cost of scrap-material: components, PCB, PBA.
- Limited trouble-shoot and repair capacity with potentially highly variable input: delivery performance, high Work-In-Progress (WIP)
- Customer satisfaction

Low Cost/high quality manufacturing = High Yield manufacturing

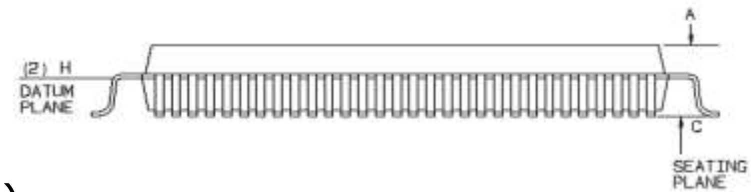
- Limit the degree of complexity: DO.
  Ex: Increase the integration level at component level.
- MINIMISE DPMO by DESIGN-FOR-MANUFACTURING
  - Layout
  - **Bill-of-Material (BOM)**
  - Acceptability criteria for components and PCB

2. PBA Quality versus BOM

Failure probability DPMO depends in first order on the components selected i.e. BOM

Failure probability increases with:

- Smaller terminals
- Smaller pitch
- Decreasing terminal coplanarity
- Extreme dimensions (very big/small)
- Low dimensional quality
- Low terminal quality (dimensions, shape, solderability,…)



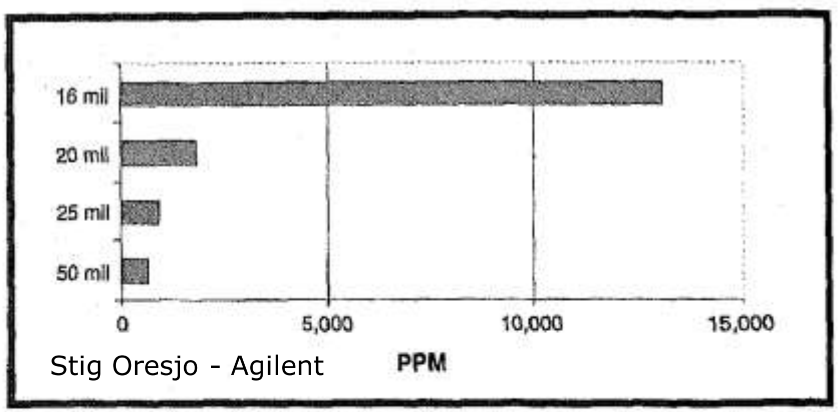
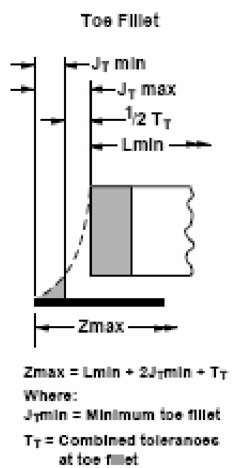


FIGURE 3: Defect levels for different pin pitches of QFP ICs.



COMBINATION!
- Small high density packages: µBGA, 0402, 0201,…
- Large components: DPAK, trafo, capacitors,…

2. PBA Quality versus BOM

Cost of a low quality/high DPMO depends on the repairability

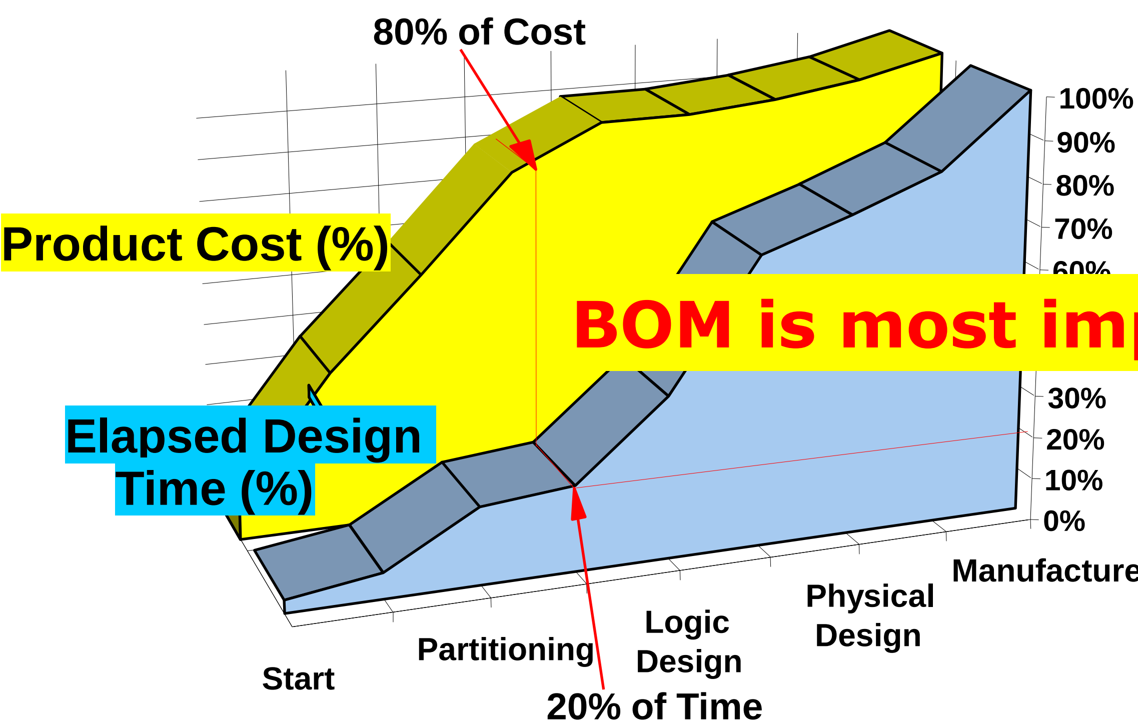
Low cost manufacturing: Avoid the red zone!

Rework / DPMO	**Easy**	**Difficult/costly** (component replacement)
Low	Leaded pitch>0.5mm Chip > 0402	BGA pitch > 0.75mm Leadless QFN pitch > 0.6mm
High	Leaded pitch<0.5mm Wave soldered SMD	CSP pitch<0.65mm Leadless QFN pitch < 0.6mm Chip < 0402

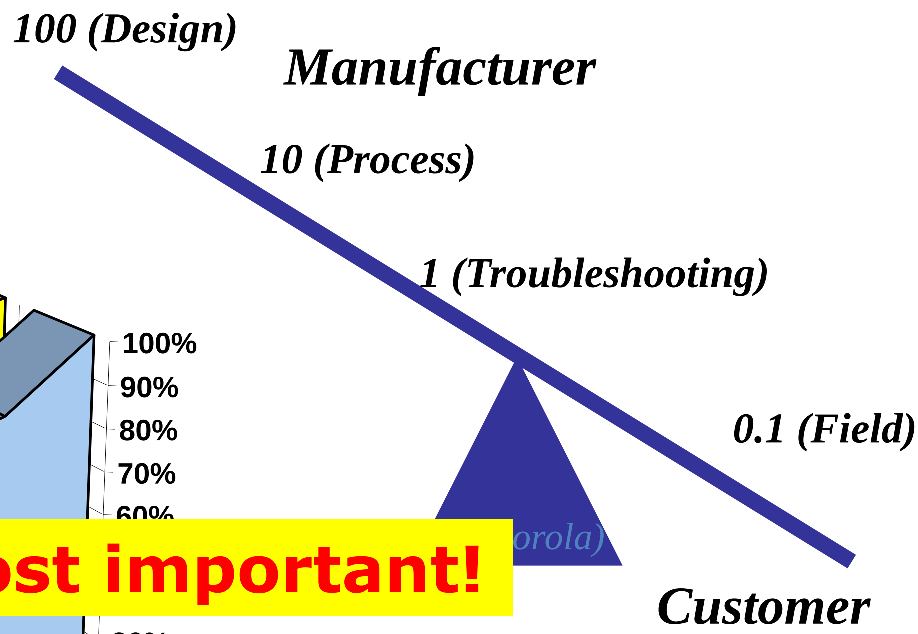
High quality

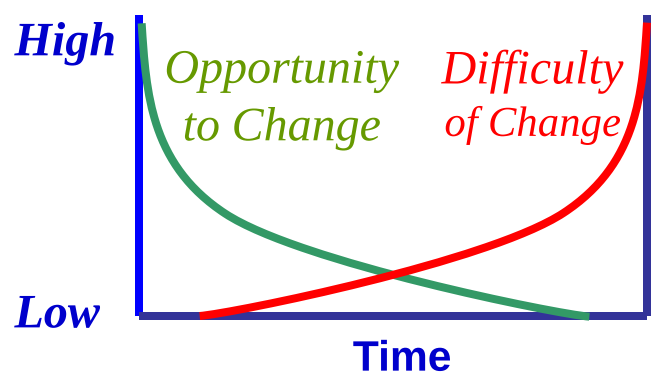
2. PBA Quality versus BOM Design-for-Assembly

DfM Rule #1: The sooner, the better!



BOM is most important!





3. Structural test

Production test methods

- Inspection methods
  - Visual inspection by operator
  - Automatic Optical inspection (AOI)
    - 2D-Xray inspection (manual/automatic)
      - 3D-Xray inspection

- Electrical test methods
  - Flying probe testing
  - In-Circuit Testing (ICT) with bed of nails (Manufacturing Defect Analysis (MDA): "passive ICT")
  - Boundary Scan testing (JTAG): virtual bed of nails
  - Functional testing

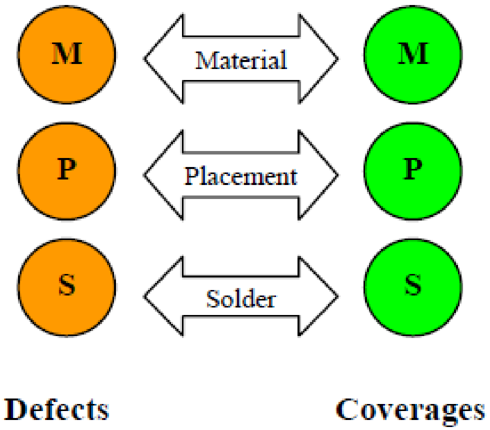
3. Structural test

Test coverage: what defects can tests detect?

Depends on the defect type → defect models required

Industry defect models (≠IPC-7912 – test oriented)

- PCOLA/SOQ (Agilent)
  Presence, Correctness, Orientation, Live, Alignment
  Short, Open, Quality
- PCOLA/SOQ/FA(I)M (iNEMI):
  \+ Feature, At-Speed, (In-parallel), Measurement
- MPS (Philips)
  Material, Placement, Solder
- PPVS (Aster – Testway)
  Presence, Polarity, Value, Solder



Issues:

- Not standardised –not in line with IPC-7912
  IPC-7912: Component – Placement – Termination – PCB/PBA
- Variable level of detail: grouping of certain defect types
- Definition of defect categories - test coverage – structure?

What can tests detect?

iNEMI

Strengths of tests:

AOI: optical inspection

- Missing components
- Orientation of components

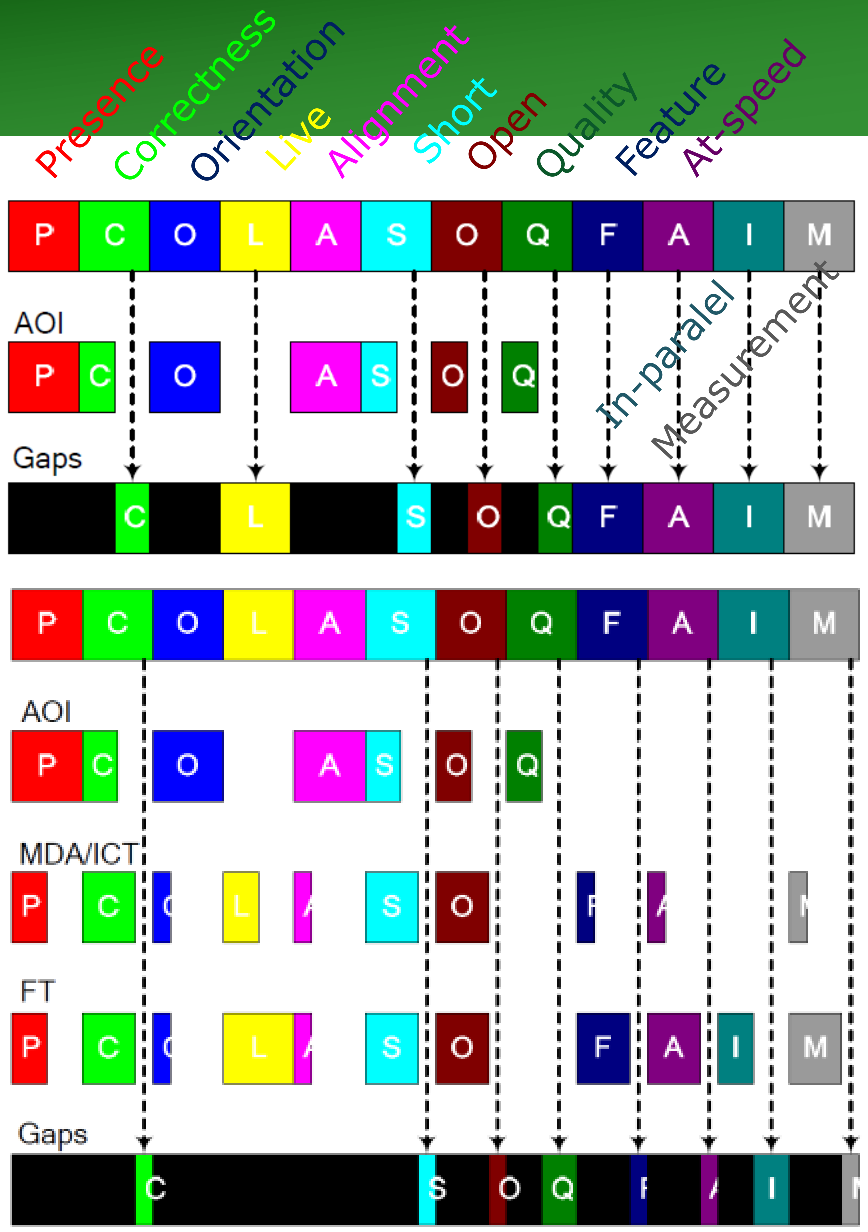
ICT: electrical

- Shorts
- Opens (false contact!)
- Correctness component

Functional test:

- Shorts
- Opens (false contact!)
- Correctness component
- **Defect component**

TEST STRATEGY: “Fill the gaps”



4. Impact of test on quality

Manufacturing Test Strategy Cost Model

NEMI

Board Assembly Technical Integration Group

Test Strategy Project

March 2003

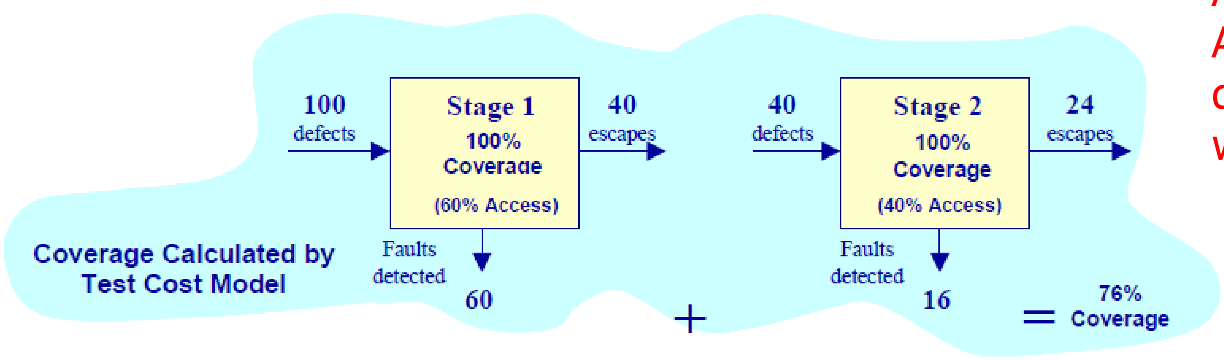
Defect spectrum:

Joint – Component structural – Component electrical

Test Coverage T_C= Test Access T_A x Test Effectiveness T_E

Defects found $D_f = T_C \times D$

Multiple tests $D_f = T_{C1} \times T_{C2} \ldots T_{Cn} \times D$



The model was constructed this way in order to simplify computations. The computations when test coverage is complementary would be beyond the scope of the team that constructed this model. Users of the model need to understand these limitations in multi-machine test strategies with complementary coverage.

Criticism:

→ Wrong!

A test is not random!

A test eliminates defects in a systematic way (D: defect group)

Over simplified

→ Unnecessary simplifications

4. Impact of test on quality cEDM approach

Defect model in line with IPC-7912 plus:

- Defect Types for each Defect Opportunity Do_i (N_i):
  - Termination
  - Component
  - Placement
  - Assembly
- Can be matched with other industry models: PCOLA, MVS, PPVS,...

IPC Defect Category	PBA-item	EDM Defect Type	Definition
Component (DT_{PCB} = 3)	PCB	PCB DEFECT	PCB manufacturing defect
		DELAMINATION	Delamination of PCB during heat treatment
		VIA CRACKING	Via cracking during heat treatment
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Termination (DT_T = 2)	BoM	OPEN	The electrical contact between the component terminal and a pad is interrupted.
		SHORT	Undesired electrical connection between a component terminal and other terminal(s) or other electrically conductive PBA features.
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		INTERCONNECTION	PBA interconnection defect (not component related)
		CLEANING	PBA cleanliness issue
		CONFORMAL COATING	Conformal coating does not adhere to its specification (pinholes, not coated/overcoated areas)
		class 1-2-3	IPC class 1-2-3 quality defect as defined by IPC-A-610 standard

Unambiguous description of defects and test coverage:

- At defect type level Do_i (N_i): highest level of detail
- Bottom-up calculation of quality (yield) and failure probabilities

4. Impact of test on quality cEDM approach

- For each Defect Type *k* belonging to a certain Defect Opportunity DO_i:
  - A test access value: TA_i^k
  - A test efficiency value: TE_i^k
  - A test coverage value: $TC_i^k = TA_i^k TE_i^k$
  - A DPMO value before test: $DPMO_i^k$
  - A DPMO value after test: ${}^a DPMO_i^k = (1 - TC_i^k)\ DPMO_i^k$
- Test access TA_i^k: Can a defect type *k* of opportunity i be measured?
  - All circuit and test information available: TA=0/1
  - Limited information (ex. BOM): TA = probability
- Test efficiency TE_i^k: Probability that a defect can be detected when having access
- Effect of a test:
  - **Interpretation 1**: Reduction of failure probability → 0 (perfect repair)
  - Interpretation 2: Elimination of a Defect Opportuniteit
  - **NOT (!)**: reduction with fraction *TC* of the number of defects in a group of defects D.

4. Impact of test on quality cEDM approach

- a Test Access value: TA_{DT} [12]

  or: can defect type *DT* belonging to defect opportunity *DO* be measured?
  TA value: - in case all circuit and test data is available: *TA*=0/1 (binary value)
  - in case limited data is available: *TA*=probability (*TA*=0...1)

- a Test Efficiency value: TE_{DT} [13]

  or: the probability that the defect can be identified
  TE value: *TE*=0...1 (fractional value)

- a Test Coverage value: $TC_{DT} = TA_{DT} \times TE_{DT}$ [14]

  TC value: *TC*=0...1 (fractional value)

- a Test Slip-through value: $TS_{DT} = 1 - TC_{DT}$ [15]

  TS value: *TS*=0...1 (fractional value)

4. Impact of test on quality
cEDM approach

DPMO and Quality at defect type level

Since a defect type level defect opportunity is in itself a defect opportunity, for each defect type *DT* belonging to a defect opportunity *DO* we can assign:

- DPMO value before test : $DPMO_{DT}$ [16]

  Quality value before test : $Q_{DT} = 1 - DPMO_{DT} \times 10^{-6}$ [17]

  Non-Quality value before test : $NQ_{DT} = 1 - Q_{DT}$ [18]

- DPMO value after test : ${}^{a}DPMO_{DT} = TS_{DT} \times DPMO_{DT}$

  Quality value after test : ${}^{a}Q_{DT} = 1 - {}^{a}DPMO_{DT} \times 10^{-6}$

  Non-Quality value after test : ${}^{a}NQ_{DT} = 1 - {}^{a}Q_{DT}$

In case of multiple tests with t=test-id and T=number of tests:

$${}^{a}NQ_{DT} = \prod_{t=1}^{T} TS_{DT}^{t} \times NQ_{DT}$$

TS_{DT}^{t} is TS_{DT} (see paragraph 3.6.2) for test t

$${}^{a}Q_{DT} = 1 - \prod_{t=1}^{T} TS_{DT}^{t} \times NQ_{DT}$$

$${}^{a}Q_{DT} = 1 - \prod_{t=1}^{T} (1 - TC_{DT}^{t}) \times (1 - Q_{DT})$$

4. Impact of test on quality cEDM approach

DPMO and Quality at defect opportunity level

The compound Quality (compound DPMO) for a defect opportunity *DO* is the probability of having no defects (at least one defect) of the underlying defect type level defect opportunities N_{DO}, and is calculated as follows.

- Quality value before test : $$Q_{DO} = \prod_{DT=1}^{N_{DO}} Q_{DT}$$ [22]

  DPMO value before test : $$DPMO_{DO} = (1 - Q_{DO}) \times 10^6$$ [23]

  Non-Quality value before test : $$NQ_{DO} = 1 - Q_{DO}$$ [24]

- Quality value after test : $${}^{a}Q_{DO} = \prod_{DT=1}^{N_{DO}} {}^{a}Q_{DT}$$ [25]

  DPMO value after test : $${}^{a}DPMO_{DO} = (1 - {}^{a}Q_{DO}) \times 10^6$$ [26]

  Non-Quality value after test : $${}^{a}NQ_{DO} = 1 - {}^{a}Q_{DO}$$ [27]

with: N_{DO} = number of defect types of defect opportunity *DO* (see paragraph 3.5)

PBA Quality after test (and repair):

$${}^{a}Q_{PBA} = \prod_{DO=1}^{N} {}^{a}Q_{DO}$$

Failure probabilities (Q=Y,P) calculated after determination of test impact at Defect type level. Test impact correctly covered without unnecessary and erroneous approximations!

4. Impact of test on quality
cEDM approach– Test coverage

Test coverage per defect category: ex. component, termination,...

- **Absolute Test Coverage** per defect category: is the ratio of the defect opportunities of a certain defect category covered by the test to the total number of defect opportunities in the defect category. It is a measure for the effectivity of the test to cover a certain set of defect opportunities. It is independent of the manufacturing error rate.

$$ATC_{category} = \frac{\sum_{i=1}^{DO_{category}} \sum_{k=1}^{N_i} TC_i^k}{\sum_{i=1}^{DO_{category}} N_i}$$

For complete PBA

- **Absolute Test coverage** (complete PBA)

$$ATC = \frac{\sum_{i=1}^{DO} \sum_{k=1}^{N_i} TC_i^k}{\sum_{i=1}^{DO} N_i}$$

ABSOLUTE TESTCOVERAGE
Measure for the effectivity of a test to detect certain set of defect opportunities/types.

4. Impact of test on quality
cEDM approach– Test coverage

Test coverage per defect category: ex. component, termination,...

- Ponderated Test Coverage per category:

$$PTC_{category} = 1 - \sum_{i=1}^{DO_{category}} \sum_{k=1}^{N_i} (1 - TC_i^k) \frac{DPMO_i^k}{\sum_{i=1}^{DO_{category}} \sum_{k=1}^{N_i} DPMO_i^k}$$

or: $$PTC_{category} = \frac{\sum_{i=1}^{DO_{category}} \sum_{k=1}^{N_i} TC_i^k DPMO_i^k}{\sum_{i=1}^{DO_{category}} \sum_{k=1}^{N_i} DPMO_i^k} = \frac{\sum_{i=1}^{DO_{category}} \sum_{k=1}^{N_i} \Delta DPMO_i^k}{\sum_{i=1}^{DO_{category}} \sum_{k=1}^{N_i} DPMO_i^k}$$

PONDERATED TESTCOVERAGE
Measure for the effectivity of a test method to detect actual defects

For complete PBA

$$PTC = \frac{\Delta DPMO_{tot} DO}{DPMO_{tot} DO} = \frac{\sum_{i=1}^{DO} \sum_{k=1}^{N} DPMO_i^k - \sum_{i=1}^{DO} \sum_{k=1}^{N} (1 - TC_i^k) DPMO_i^k}{\sum_{i=1}^{DO} \sum_{k=1}^{N} DPMO_i^k}$$

5.1.3 Equivalent Test Coverage (per defect opportunity): ***ETC*** $_{DO}$

The equivalent test coverage ETC_{DO} gives the test coverage of the test methodology for the defect opportunity *DO* and its impact on the compound DPMO value for this defect opportunity. It relates the compound DPMO values for defect opportunity *DO* before and after test.

$$ETC_{DO} = \frac{\Delta DPMO_{DO}}{DPMO_{DO}} = \frac{\Delta NQ_{DO}}{NQ_{DO}}$$

or:

$$ETC_{DO} = \frac{NQ_{DO} - {}^{a}NQ_{DO}}{NQ_{DO}}$$

or:

$$ETC_{DO} = \frac{{}^{a}Q_{DO} - Q_{DO}}{NQ_{DO}}$$

for ${}^{a}Q_{DO}$, Q_{DO} and NQ_{DO} see 4.1.2

Note: for small DPMO values PTC and ETC will become numerically equal.

EQUIVALENT TESTCOVERAGE
Test impact on the compound DPMO/quality of a set of defect opportunities

4. Impact of test on quality
cEDM approach– Test coverage

5.5.3 PBA Quality Test Coverage: QTC_{PBA}

The quality test coverage QTC_{PBA} is defined as the ratio between the amount of defective PBA that are successfully identified as failing PBA and the total amount of defective PBA before test.
It is a measure for the impact of the test(s) on the PBA Quality (or First-Pass Yield).

$$QTC_{PBA} = \frac{\Delta Q_{PBA}}{{}^{0}NQ_{PBA}}$$

$$QTC_{PBA} = \frac{{}^{a}Q_{PBA} - {}^{0}Q_{PBA}}{{}^{0}NQ_{PBA}}$$

with:

$${}^{a}Q_{PBA} = 1 - {}^{a}NQ_{PBA}$$

$${}^{a}NQ_{PBA} = QTS_{PBA} \times {}^{0}NQ_{PBA}$$

$$QTS_{PBA} = 1 - QTC_{PBA}$$

QTS_{PBA} is the PBA Quality Test Slip-through

by which for the Quality after test holds:

$${}^{a}Q_{PBA} = 1 - (QTS_{PBA} \times {}^{0}NQ_{PBA})$$

PBA Quality TESTCOVERAGE
Test impact on the quality/yield of the PBA
=
Equivalent Test Coverage for complete PBA

Several Test Coverage definitions are possible: unambiguous definition is mandatory for correct interpretation!

4. Impact of test on quality cEDM approach– Test strategy

- No test provides 100% test coverage
- Test coverage depends on:
  - Defect category (ex.interconnection) and defect type (ex. Open)
  - Test method ex. AOI vs. ICT
- Defect identification (trouble-shoot) depends on the test. From simple and low-cost to difficult and expensive:
  1. AOI
  2. In-Circuit test (MDA/ICT) – flying probe
  3. Boundary Scan
  4. Functional test
- Good practice: start with the test that provides the lowest cost trouble-shoot.
- An effective test strategy requires proper DPMO estimation, correct test coverage and PBA quality *Q* quantification.

4. Impact of test on quality
cEDM approach - Component packing naming

All modeling and PBA manufacturing preparation requires:

- A unique and complete identification of component packing
- Component properties: dimensions, material, process parameters,...

Different industrial naming conventions:

- Non-standardized package naming
  - Common Package Designation
    e.g. PLCC-44, BGA-256, SOIC-16
  - Descriptive Information
    e.g. “SMD Tant 100µF 10V SIZE D 10% very low ESR”
- “Standardized” package naming
  - JEDEC Descriptive Package Designation (JESD30E)
    e.g. PBGA-252(256)/17x17-1.00
  - IPC Descriptive Package Designation (IPC-7351)
    e.g. RESMELF34x14
  - VALOR Descriptive Package Designation (is based on JEDEC)
    e.g. PBGA-B252(256)/PM-L170W170T18
- Detailed standardized description
  - JEDEC Outline Number (JEP95)
    e.g. MO-153

NO COMPLETE STANDARDISATION!

4. Impact of test on quality
cEDM approach - Component packing naming

<EDM Prefix> <EDM Body> <EDM Suffix>

JESD30 | VALOR | JESD30 | VALOR | JESD30 JEP95

<**AF**> <**MSH**> <**TP**> <**O**> - <**PBM**> <**TP**> <**POS**> - <**TS**> <**TC**> <**TD**> / <**TP**> <**S**> - <**OL**> <**OW**> <**OH**> - <**SC**> / suppl. info

EDM Prefix

AF = Added Feature

MSH = Maximum Seated Height

TP = Terminal Pitch

O = Other

EDM Body

PBM = Package Body Material

TP = Terminal Position

POS = Package Outline Style

TS = Terminal Shape

EDM Suffix

TC = Terminal Count

TD = Terminal Diameter

TP = Terminal Pitch

S = Subtype

OL = Overall Length

OW = Overall Width

OH = Overall Height

SC = Serial Character

Supplementary information

e.g. JESD30 Nominal Package Dimensions, JEP95 Outline Number, Packaging Technology/Mounting (e.g. WLCSP)

Basic BOM input for : Pred-X

4. Impact of test on quality Summary

EDM approach

- In line with IPC-7912
- Oriented to identification of physical failures
- Description of defect spectrum and test at DO level results in a correct method for the calculation of the impact of test on the PBA failure probability or quality.
- No intermediate approximations.
  Using a PC this as easy as using approximate, erroneous methods
  ex. iNEMI.
- Unambiguous definitions are essential:
  defect types – test access – test efficency – test coverage.

Goal:

Objective, universally applicable and in-principle correct approach to failure probability and test coverage calculations.

5. In practice

Objective

Talk the same language OEM – EMS

- Use the same defect model
- Use the same test coverage definitions

- EDM approach provides a science-based, mathematically correct, universally applicable methodology

- Challenge: agreements
  - OEM – EMS
  - EMS – EMS

5. In practice

Quality measurement and characterisation

PBA Quality

First Pass Yield Y_{FP} and failure probability $P_{FP}=1-Y_{FP}\approx OMI$

- Quantified quality of PBA prior to test (product)
- Is not a quality parameter for design or assembly (EMS). PBA complexity is integrated.

Quality of design-assembly operation

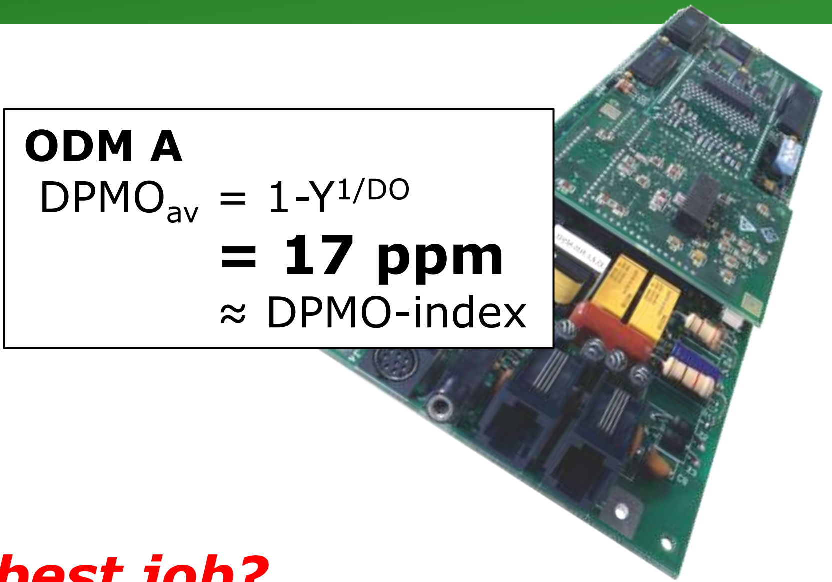
Average $DPMO_{av} \approx$ DPMO-index (counting defects)

- $DPMO_{av}= 1-Y^{1/DO}$ (obtainable from production test results)
- Basis for quality evaluation of design (DfM) and assembly operation

5. In practice

Medium complexity:

- ODM A (design+assembly)
- 500 components
- 5000 DO/PBA
- Q=Y=92%

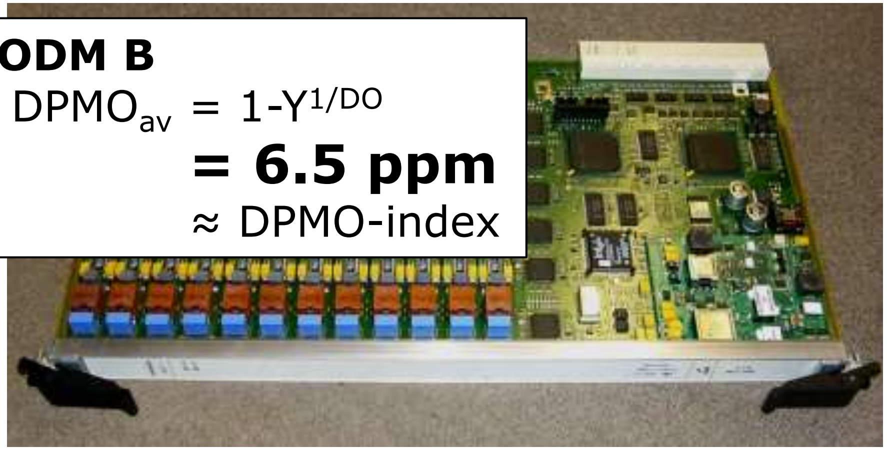


ODM A
$DPMO_{av} = 1\text{-}Y^{1/DO}$
= 17 ppm
≈ DPMO-index

Which ODM delivers the best job?

High complexity:

- ODM B
- 2500 components
- 25000 DO/PBA
- Q=Y=85%



ODM B
$DPMO_{av} = 1\text{-}Y^{1/DO}$
= 6.5 ppm
≈ DPMO-index

5. In practice

EMS

- Mapping of assembly failure probabilities
  - Report production test results according to standard defect model.
  - Translate internal defect codes to standard defect defnitions
  - Analyse and create DPMO model for design/production combinations.
  - Challenge:
    - At low volumes and low failure probability it is difficult to obtain statistically relevant amount of data.
    - Alternative: use a "universal" defect model tunable to designs and assembly operation at hand.
- Quantify the test coverage according to the standard physical defect model.
  - AOI: relatively straight forward
  - Electrical testing: more difficult
- Develop a quantitative test strategy methodology
- Use a standardized PBA description based on a universal, unambiguous component nomenclature

5. In practice

EMS: more applications using BOM and DO’s

Assign assembly time, cost,...

- Predict production time, WIP flow,...
- Predict capacity requirements ex. test and repair
- Failing PBA, scrap, delivery risk,...
- Quotations
- Logistical risk
- DfM quality evalution

Future modules of Pred-X

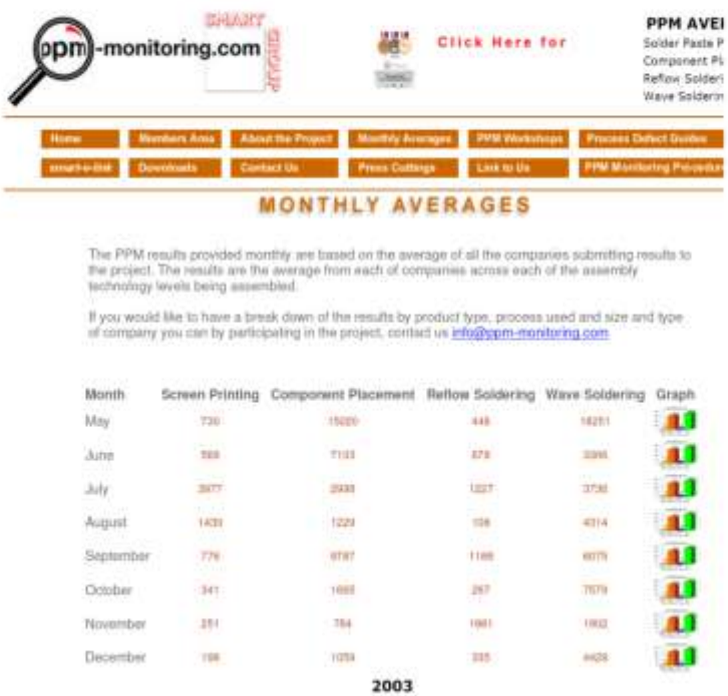
5. In practice

OEM

- Use a standardized PBA description based on a universal, unambiguous component nomenclature. Is required to quantify risks (manufacturability, quality, reliability,...).
- Introduce a quantified DfA methodology based on a standardised defect model, "universal" DPMO and test coverage models.
- Take DfTest measures (ex. provide test pads) for complex and/or failure critical PBA.
- Determine design guidelines related to DfA, DfTest en DfReliability. Evaluate Design-for-X quality.
- Innovate the design culture:
  - Physical realisation and physical robustness and reliability is as important as functionality
  - High density packages and PCB layout are not universal solutions.
  - Professional electronics require different design than consumer products: ex. large "pitch" components and through-hole connectors for quality, robustness and reliability reasons.
  - BOM design: compatibility of components? Do we really need to put everything on the same PBA?

DPMO modeling: industry-publically available

www.ppm-monitoring.com



- old data
- high ppm numbers

One billion Solder Joint study (Agilent/1999-2002)

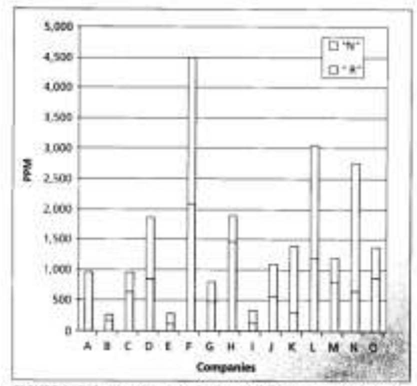


FIGURE 1: Defect levels in ppm for the 15 different companies in the study.

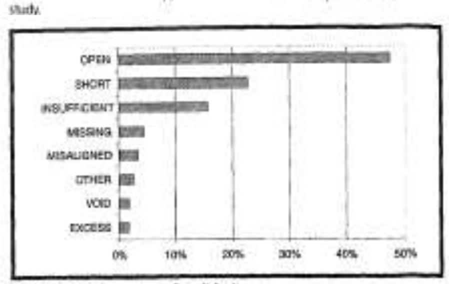


FIGURE 2: Fault spectrum for all faults.

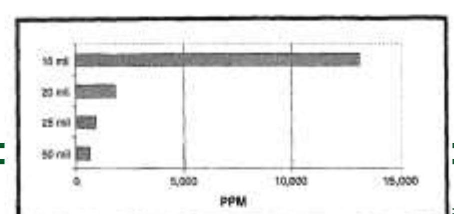


FIGURE 3: Defect levels for different pin pitches of QFP ICs.

iNEMI

	Component Package Types → DPMO	Defaults for structural DPMO Joint & Component → Structural DPMOJ	Defaults for structural DPMO Joint & Component → Structural DPMOC	Defaults for electrical DPMO component → Electrical DPMOC
4	Leaded (Gullwing)	200	100	100
5	Leaded (Gullwing)	500	100	100
6	Leaded (Gullwing)	700	100	100
7	Leaded (Gullwing)	1000	100	100
8	Leaded (Gullwing)	10000	100	100
9	Leaded (Gullwing)	15000	100	100
10	Jlead	300	100	100
11	Eutectic BGA	100	100	100
12	Eutectic BGA	150	100	100
13	NonEutectic BGA	150	100	100
14	CSP	100	100	100
15	Column Grid	100	100	100
16	1206 SMT	400	200	100
17	0805 SMT	150	300	100
18	0402 SMT	150	400	100
19	0201 SMT	200	400	100
20	1206 Wave	400	500	100
21	0805 Wave	150	1000	100
22	0402 Wave	150	2000	100
23	SMT Connector 1	2000	100	100
24	SMT Connector 2	2000	100	100
25	Res/Cap Pack 1	100	200	100
26	Res/Cap Pack 2	100	200	100
27	PTH/Wave 1	2000	200	100
28	PTH/Wave 2	2000	200	100
29	PTH/Wave 3	2000	200	100
30	PTH/Wave 4	2000	200	100

6. Modeling
EDM approach

Raw information		Knowledge description
• Data - physics • Relationships - graphs	→	• Algorithms • Look-up tables

Structuring the approximation levels

EDM: design support
Model development

- 0-order (default) models
  - Use only BOM information
  - Typical use: concept and early design stage, production: non-PBA specific questions
- 1a-order models
  - 0-order + electrical schematics (netlist e.a.) information
  - Typical use: intermediate design stage, production: electrical test, yield
- 1b-order models
  - 0-order + CAD (layout e.a) information
  - Typical use: intermediate design stage, production: proces, inspection, yield
- 2-order models
  - 0-order + CAD + electrical schematics information
  - Typical use: PBA specific generic analysis

Industrial tools
Relationship with physical defects

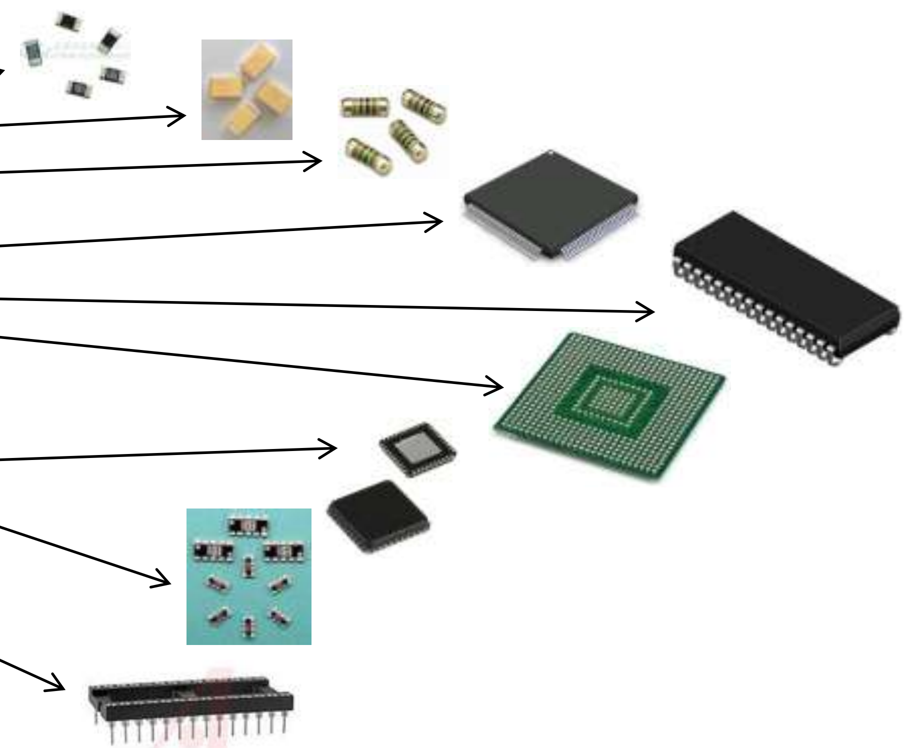
- *3-order models*
  - *2-order + hardware configuration info (FPGA configuration e.a.)*
  - *Typical use: PBA specific generic analysis for PBA with customised components*
- *4-order models*
  - *3-order + embedded software info*
  - *Typical use: Functional test development, production: test coverage of functional test.*

6. Modeling
DPMO modeling

- Component defects: 11 categories
- Termination defects & placement defects: 16 categories

As a function of Package Outline Style / Terminal Shape / Terminal Position

SMT 2 leaded Chip
SMT 2 leaded C,L bend (Ta, diode)
SMT 2 Leaded Melf
SMT 2 Leaded Other
Gullwing
J-Leaded
BGA
CGA
LGA
No leaded QFN
No leaded Chiparray
SMD Other
TH Press Fit
TH Connectors
TH Other
All Other



In collaboration with cEDM partners

20000 PBA – 500.000.000 DO

production data

source A → pre-processing → data analysis → post-processing
source B → pre-processing

⋮

keep relation with assembly process data (SnPb/Pb-free, solder process, ...) + top/bottom

map source ‘fault codes’ towards Defect Types per IPC Defect Category

Defect Types
- Component (4)
- Placement(4)
- Termination(2)
- Assembly(4)

count #DO and #defects per source component code (top/bottom)

Defect Opportunities
components
terminals
PBAs

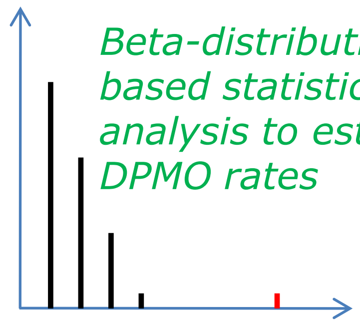
parsing of source package codes + translate to EDM Descriptive Package Designator

||

PDXD-C2/XH-L60W33T25

remove systematic assembly issues

- poor design
- quality issues
- outliers (batch related)

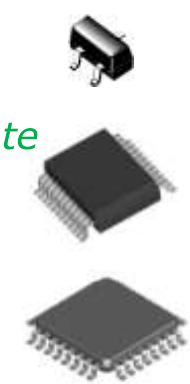


Beta-distribution based statistical analysis to estimate DPMO rates

structuring of DPMO data into ≠ package categories

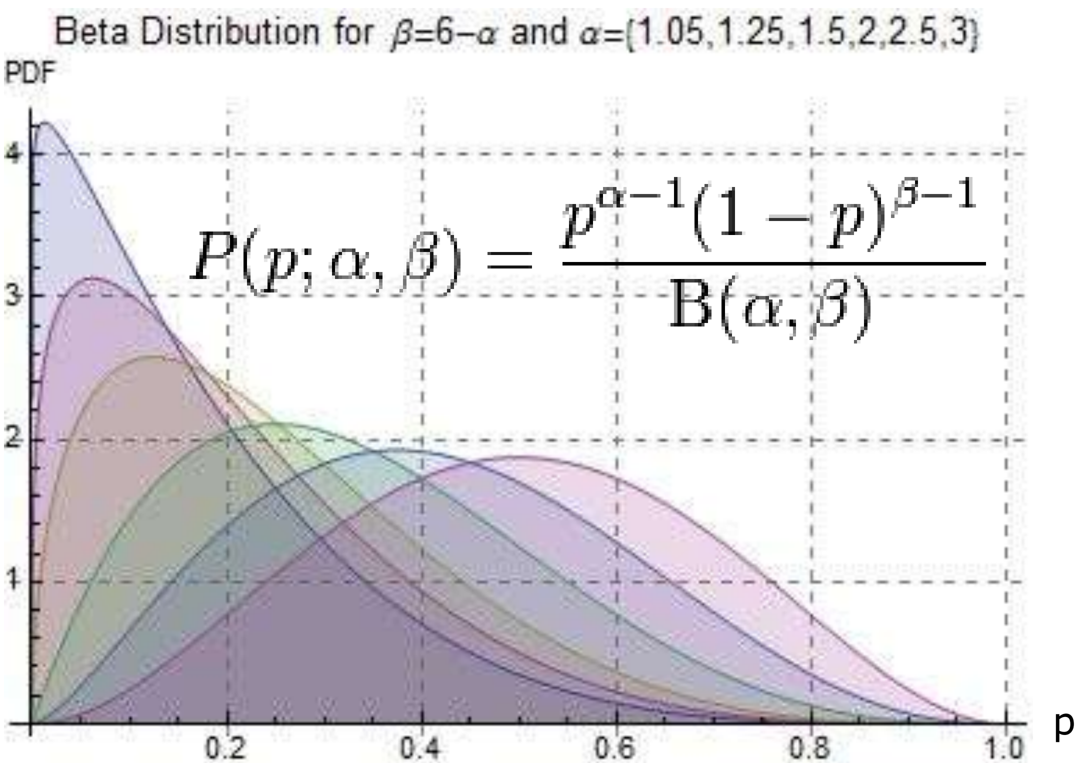
e.g. Gull-Wing packages

outline style



lead pitch
0.40 mm
0.50 mm
0.65 mm
0.80 mm
1.00 mm
1.27 mm

Estimating low probability DPMO: Beta distribution statistics



$$P(p;\alpha,\beta) = \frac{p^{\alpha-1}(1-p)^{\beta-1}}{B(\alpha,\beta)}$$

p=DPMO?

Estimate median, upper and lower confidence boundaries (90%) from testing:

d: defects obtained on DO opportunities

α=d+1

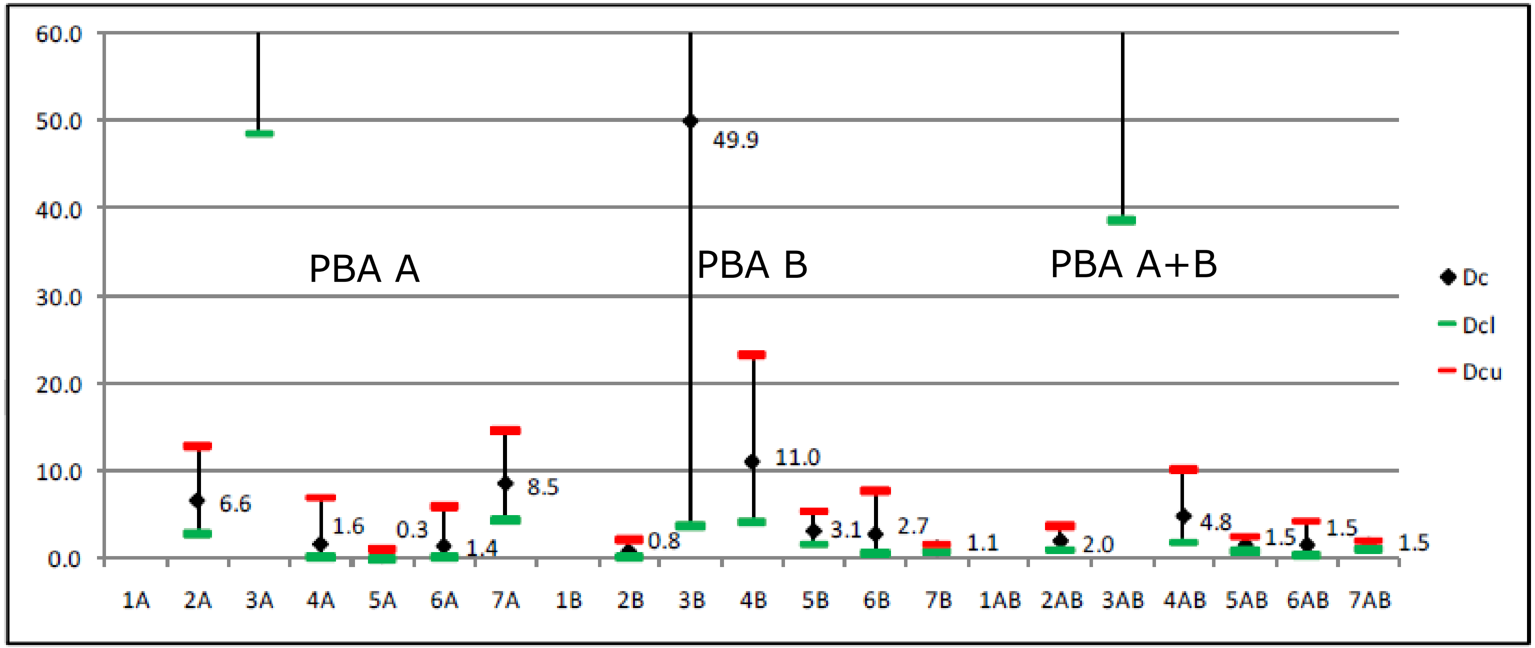
β=DO-d+1

$$B(\alpha,\beta) = \int_0^1 x^{\alpha-1}(1-x)^{\beta-1}\, dx$$

6. Modeling
DPMO Modeling

Defect type = Open
Component = Gull wing

OPEN – Top – Reflow : A=B=AB=150µm



Challenges:

- Low failure probabilities (1<DPMO<100ppm) requires large amounts of data and non-Gaussian statistical analysis.
- Relation between defect – # tested PBA – processes – circuit reference
- Search for relationships: physical basis

6. Modeling
DPMO Modeling

Electronic Design & Manufacturing

imec

PBA DPMO models

Project : VIS-PROSPERITA

V1.2
November 2012

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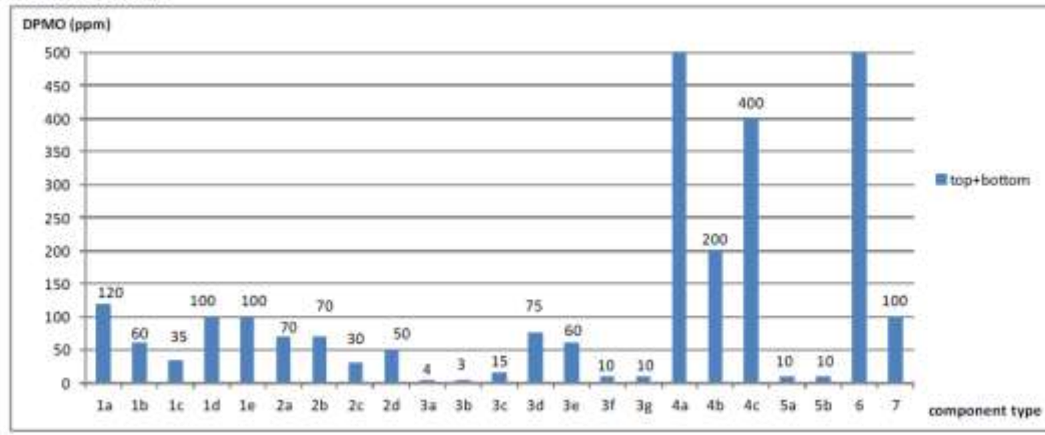
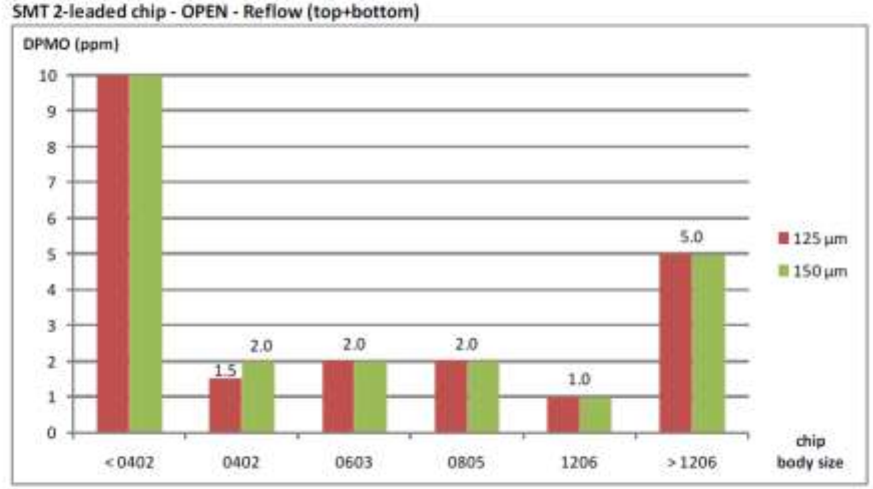
26 November 2012

Zero order model: BOM based

FUNCTIONAL defect



SMT 2-leaded chip - OPEN - Reflow (top+bottom)



IPC Category	Defect Type	Test Access	Test Efficiency
Termination (BOM)	Open	IF Terminal visible: TA = 1 ELSE: TA = 0	IF TH or leads Axial/Radial + 2 side inspection: TE = 0,5 ELSE: TE = 0
	Short	IF Terminal visible: TA = 1 ELSE: TA = 0	IF TH or Gullwing: TE = 1 ELSE: TE = 0
Placement (BOM)	Missing	TA = 1	TE = 1
	Wrongly equipped	TA = 1	Component has distinctive features such as label: TE = 0,95 ELSE: TE = 0,05
	Misoriented	TA = 1	Component has no orientation: TE = - Component has orientation mark: TE = 1 ELSE: TE = 0
	Misplaced	TA = 1	PCB provides position reference (e.g. silk screen): TE = 1 ELSE: TE = 0
Component (BOM)	Physical Out-of-spec	TA = 1	TE = 0,5
	Electrical Out-of-Spec	TA = 0	TE = -
	Fatal defect	TA = 0	TE = -
Component (PCB)	Design	TA = 0	TE = -
	PCB Defect	TA = 0	TE = -
	Delamination	TA = 0	TE = -
	Via cracking	TA = 0	TE = -
Assembly (PBA)	Mechanical	TA = 1	TE = 0
	Interconnection	TA = 1	TE = 0
	Cleaning	TA = 0	TE = -
	Conformal coating	TA = 1	TE = 0

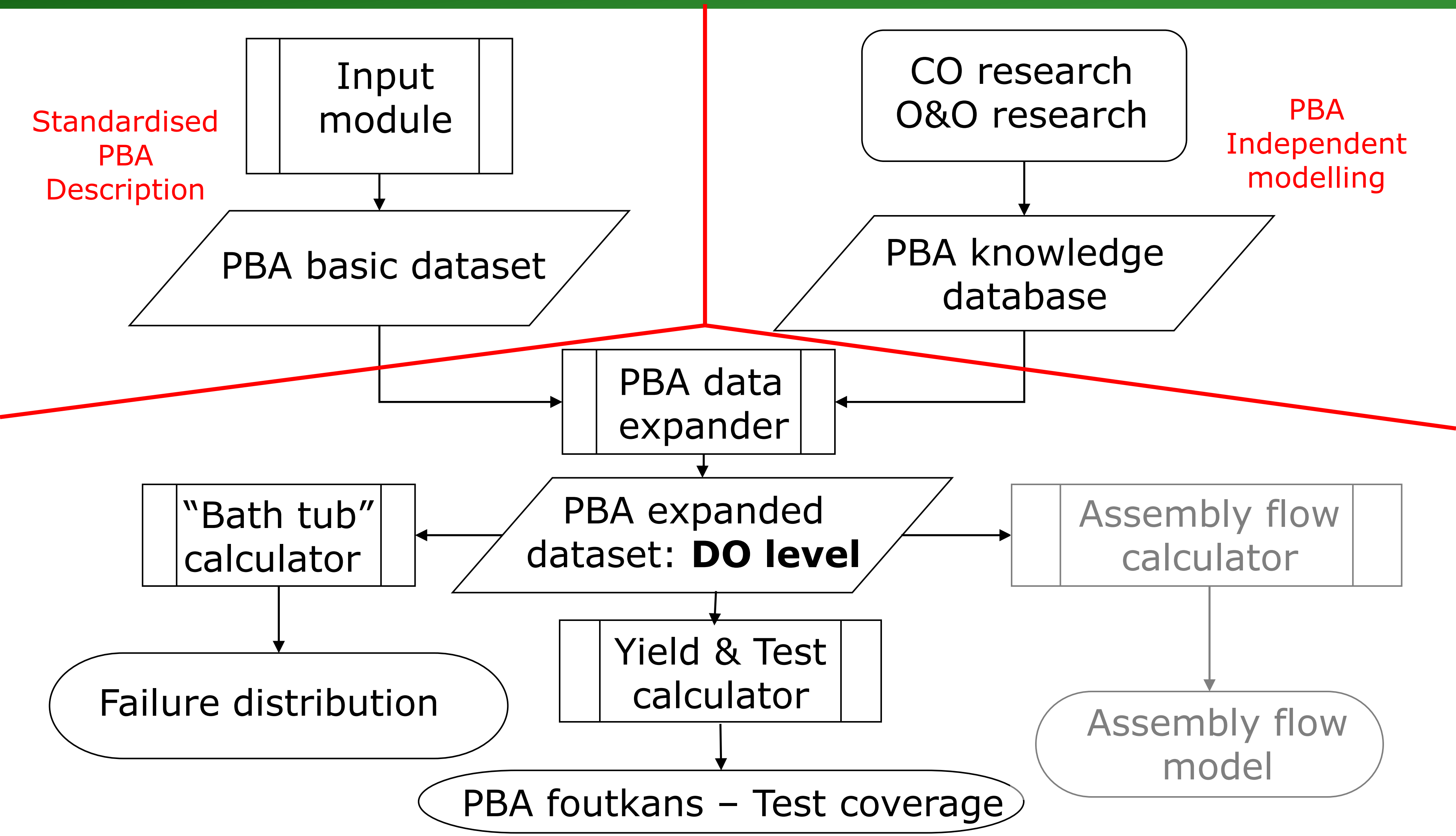
AOI model
Algorithm based

- POS ϵ {AT, CC, GA, FP, SO, CY, IP, FM}
- POS ϵ {XD, LF} AND TC = 2 AND S ϵ {R, F, H, E} AND Max(L,W) ≥ 1,6 mm
- POS ϵ {XD,LF} AND TC = 2 AND S ϵ {C,F,I,J,L,N,O,P,Q,R}
- POS ϵ {AT,CC,GA,FP,SO,CY,IP,FM} OR (POS ϵ {XD,LF} AND TC=2 AND S NOT ϵ {C,F,I,J,L,N,O,P,Q,R}
- = SMD AND (POS ϵ {CC,GA} OR (POS ϵ {FP,SO,FM} AND TC ≥ 8 AND (TS ="N" OR TP ϵ {D,T})))

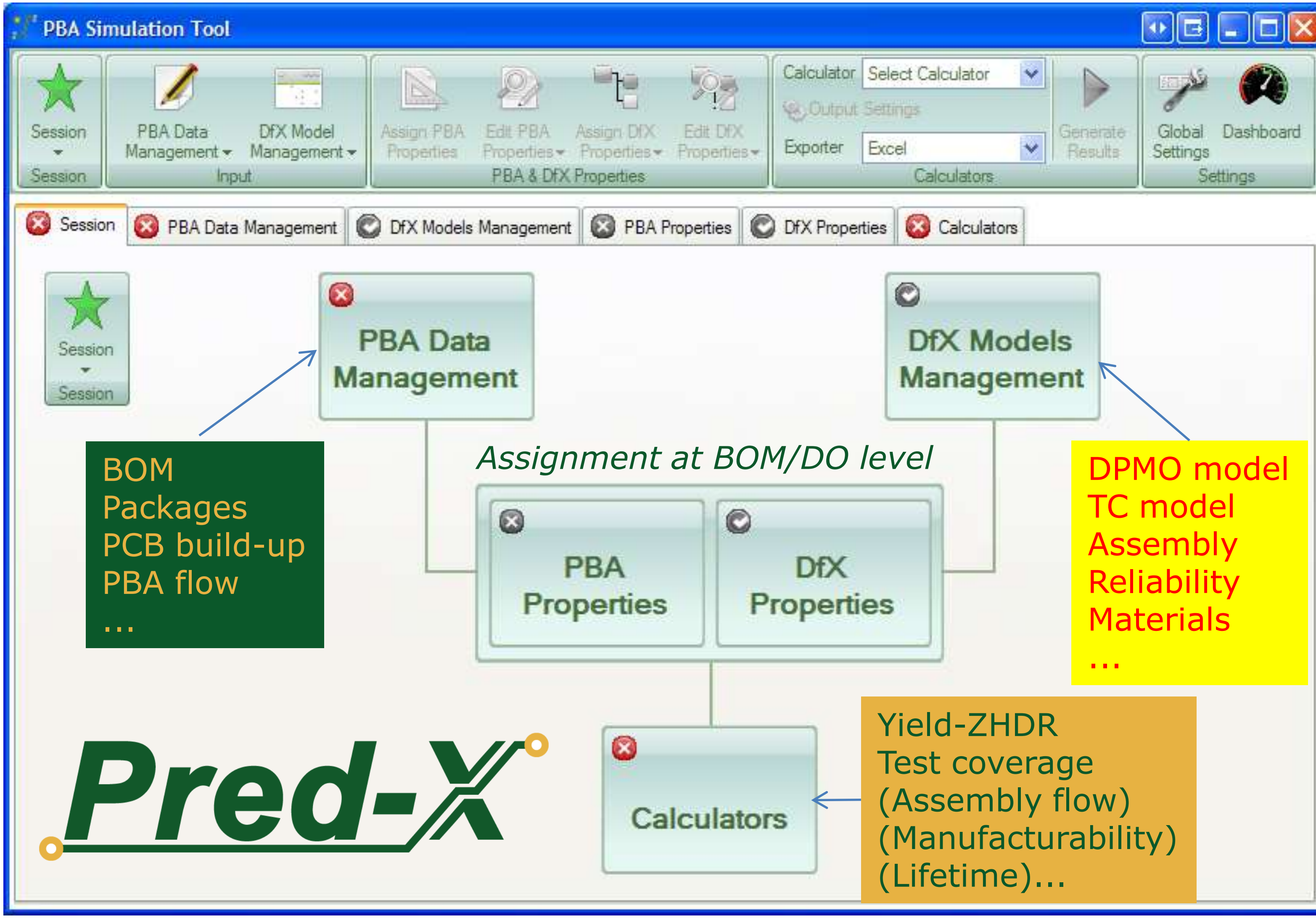
6. Pred-X

- Generic DfX supporting tool
- Can be used very early in design phase (concept phase)
- Quantified prediction of PBA DfX properties
- V1.0: Yield and test coverage prediction (2013)

6. Pred-X


Standardised PBA Description
Input module
PBA basic dataset
CO research
O&O research
PBA Independent modelling
PBA knowledge database
PBA data expander
"Bath tub" calculator
PBA expanded dataset: DO level
Assembly flow calculator
Failure distribution
Yield & Test calculator
Assembly flow model
PBA foutkans – Test coverage

6. Pred-X



PBA Simulation Tool
Session
PBA Data Management
DfX Model Management
Input
Assign PBA Properties
Edit PBA Properties
Assign DfX Properties
Edit DfX Properties
PBA & DfX Properties
Calculator
Select Calculator
Output Settings
Exporter
Excel
Calculators
Generate Results
Global Settings
Dashboard
Settings
Session
PBA Data Management
DfX Models Management
PBA Properties
DfX Properties
Calculators
PBA Data Management
DfX Models Management
Assignment at BOM/DO level
PBA Properties
DfX Properties
Calculators
BOM
Packages
PCB build-up
PBA flow
...
DPMO model
TC model
Assembly
Reliability
Materials
...
Yield-ZHDR
Test coverage
(Assembly flow)
(Manufacturability)
(Lifetime)...
Pred-X

7. Conclusions

- PBA quality and test coverage quantification require a science based, mathematically correct approach.
- Actual industrial approach can be improved considerably:
  - Different defect models: poor structure, mixed level of details
  - Poor quality/ambiguous definitions, no standardisation
  - Approximate, erroneous calculation methods
- EDM approach: Talk the same language
  - In line with IPC-7912 standaard
  - Standardisation of PBA/BOM description
  - Exact calculation of compound PBA failure probability and Quality Q
  - Exact calculation of impact of test by calculation at defect opportunity level.
  - BOM based modeling of DPMO, test coverage, e.a., to support PBA design, production and test.
- Basis for a systematic, standardised description of PBA quality, test coverage and time zero failure risk.

Vragen?

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