Review of Side-Channel and Machine-Vision Based Counterfeit Detection Techniques

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University of Maryland

- Flagship campus of the University System of Maryland – Founded in 1856 (Engineering in 1894). It is a global campus with 41,000 student from 50 states in the US and 118 countries and the leadership of the University, the College of Engineering, and the Research Laboratory are enthusiastic participants in global collaborations in research, education, and publication with strong track record.
- Its faculty includes two Nobel laureates, three Pulitzer Prize winners, 60 members of the national academies and scores of Fulbright scholars
- The University is ranked No. 22 among public research institution and No. 15 in most innovative schools by U.S. News & World Report among US Universities. Globally, it is ranked 51 with several subject areas in the top 25
- The College of Engineering is ranked in top 25 in both Undergraduate and Graduate categories with four departments in top 25 in the graduate programs showing strength in research funding, research outcomes, student achievements, and publications. In the QS World ranking, it is at number 126 with the Mechanical Engineering department in the 101-150 range.

- According to The Princeton Review and Entrepreneur Magazine, UMD is ranked No. 8 overall for undergraduate entrepreneurship programs. In 2018, UMD had 5 new start-ups, 35 US patents, 181 new discoveries and award and license income exceed 2.3 million dollars

CALCE Overview

- The Center for Advanced Life Cycle Engineering (CALCE) formally started in 1984, as a NSF Center of Excellence in systems reliability
- Founder and driving force behind the development and implementation of physics-of-failure (PoF) approaches to reliability
- Internationally recognized leader in reliability assessment of electronics based on PoF analysis and prognostics and health management (PHM)
- One of the world's most advanced and comprehensive testing and failure analysis laboratories
- Funded by over 150 of the world's leading companies
- Supported by over 100 faculty, visiting scientists and research assistants
- Received NSF Innovation Award and NDIA Systems Engineering Excellence Award in 2009 and IEEE Standards Education Award in 2013

CALCE Mission and Thrust Areas

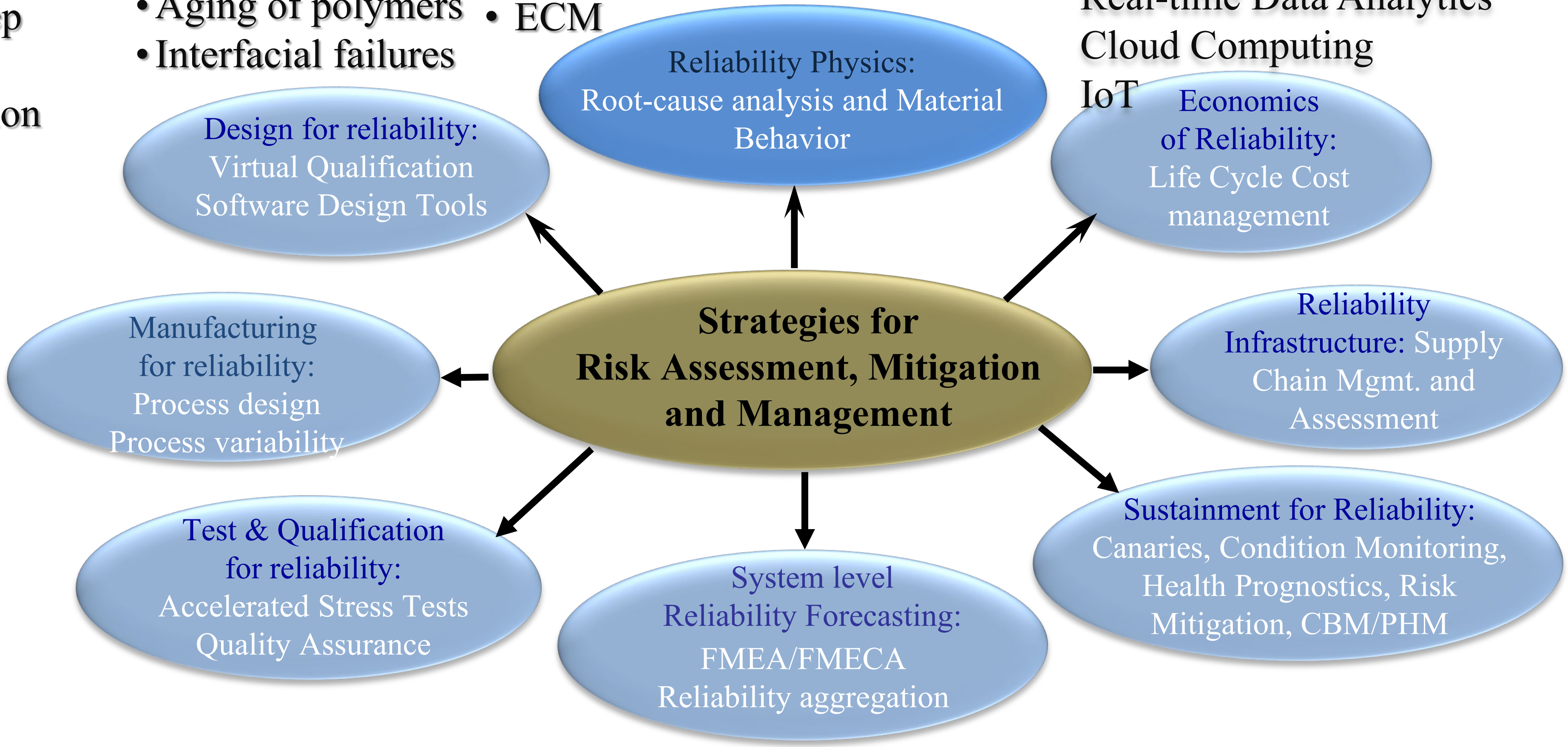
Providing a knowledge and resource base to support the development and sustainment of competitive electronic products

- Fatigue and Fracture
- Plasticity, creep
- Wear/fretting
- Electromigration
- ESD/EOS
- TDDB

- Whiskers
- Aging of polymers
- Interfacial failures

- Corrosion
- ECM

Machine Learning and Artificial Intelligence
Real-time Data Analytics
Cloud Computing
IoT



Convergence of Reliability-Physics (RP) and Artificial Intelligence (AI)

Purpose

- Section 843 of the 2019 National Defense Authorization Act (NDAA) tasked the Defense Microelectronics Activity (DMEA) with coordinating the establishment of a pilot program to evaluate Machine Vision technologies in the field of counterfeit microelectronic detection.
- DMEA contracted CALCE to perform a blinded study of the effectiveness of techniques for counterfeit detection and part authentication.
- The results are being used to assess the readiness and accuracy of side channel and machine vision methods for part authentication, and to improve standards for counterfeit testing.

Outline

- Introduction
- Side Channel Methods
- Machine Vision Methods
- Standards-Based Methods
- Risk-Based Test Plans
- Conclusions

Introduction

- CALCE performed a study in 2019-20 for DMEA that included a review of emerging counterfeit detection systems and technologies and comparison with SAE AS6171 standards-based testing, with a blind study of effectiveness with real counterfeits including clones.
- Labs were provided mixed sets of 20 parts for each part number. Each mixed set contained parts from two date codes: one date code was counterfeit while the other was authentic.
- CALCE, in partnership with SMT Corp., worked with eight technology organizations to assess their technologies and their ability to detect counterfeit parts.
- The study provided a set of long and short term recommendations to the US DoD regarding the adoption of these technologies.

Participating Parties

DMEA

SMT Corporation → calce

Machine Vision

- Creative Electron
- COVISUS
- ALITHEON

Standards-Based

- INTEGRA TECHNOLOGIES
- micross — one source. one solution.™

Side Channel

- Sandia National Laboratories
- BATTELLE
- PFP CYBERSECURITY

Categories of Counterfeit Parts

- Counterfeit parts, based on AS6171, include:[1]
  - **Recycled:** Reclaimed/recovered then misrepresented as new.
  - **Remarked:** Part markings replaced with forged markings.
  - **Overproduced:** Authorized part from contracted facility fabricated outside of contract.
  - **Out-of-Specification/Defective:** Identified nonconforming part represented as conforming.
  - **Provided with forged documentation:** Associated documents modified.
  - **Cloned:** A reproduction of an authorized part without approva
  - **Tampered:** Modified for sabotage or malfunction.

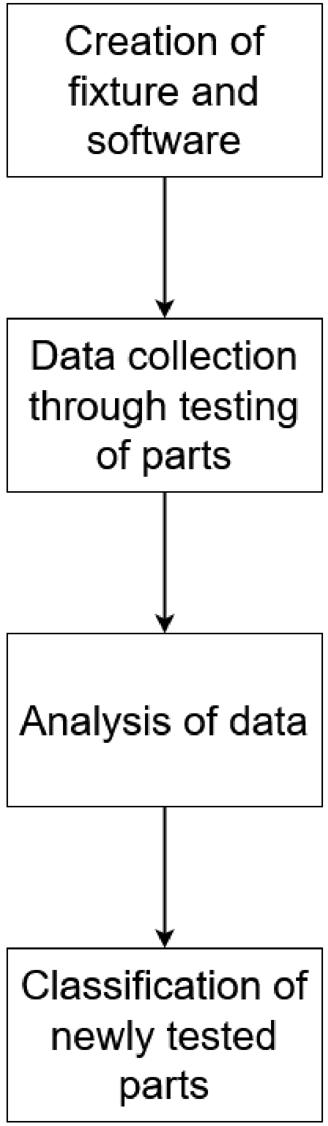
Conventional (Recycled, Remarked, Overproduced, Out-of-Specification/Defective, Provided with forged documentation)

Advanced Counterfeits (Cloned, Tampered)

[1] SAE AS6171 Test Methods Standard; General Requirements, Suspect/Counterfeit, Electrical, Electronic, and Electromechanical Parts, 2016.

Side Channel Based Counterfeit Detection Methods

- Side channel refers to methods for extracting part functional information that are external to the part.
- Power consumption analysis
  - Idle or in operation
  - Examples: Battelle, PFP Cybersecurity
- Analysis of emitted electromagnetic radiation
  - Example: Nokomis
- Side channel methods are meant to be non-destructive while also being relatively fast.
- The study asked participating labs to perform clustering on the parts.



Confusion Matrix for Side Channel Analysis of Clustering Results

TP: Correctly placed part in the counterfeit cluster.	FP: Placed authentic part in counterfeit cluster.
FN: Placed counterfeit part in authentic cluster.	TN: Correctly placed part in the authentic cluster.

$$\text{Accuracy} = \frac{TP+TN}{TP+TN+FP+FN}$$

TP: True positive; FP: False positive; FN: False negative; TN: True negative

Side Channel: Overall Results

Number of Parts		Percentage	
TP 142	FP 0	TP 0.93	FP 0.00
FN 10	TN 150	FN 0.07	TN 1.00
Accuracy=0.97			

- These results represent the misclassification of one clone by one participant.
- Although the clustering accuracy is high, the ability to identify a counterfeit part depends on the availability of an authentic part of the same vintage.

Side Channel: Clone Results

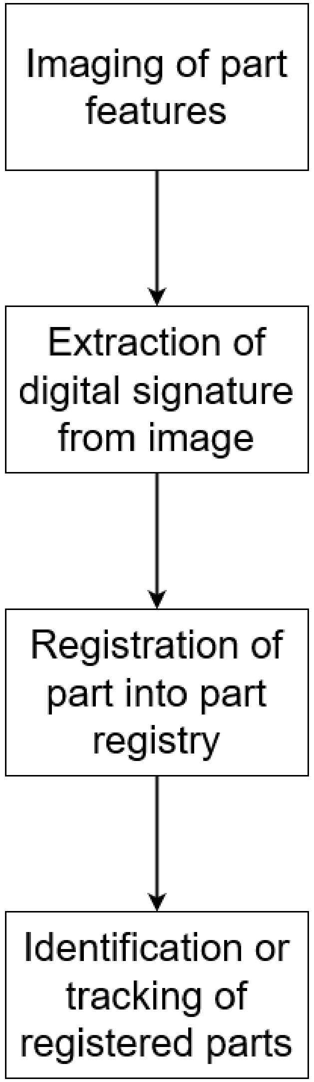
Number of Parts		Percentage	
TP 132	FP 0	TP 0.93	FP 0.00
FN 10	TN 140	FN 0.07	TN 1.00
Accuracy=0.96			

Side Channel: Conventional Counterfeit Results

Number of Parts		Percentage	
TP 10	FP 0	TP 1.00	FP 0.00
FN 0	TN 10	FN 0.00	TN 1.00
Accuracy=1.00			

Machine Vision Based Counterfeit Detection Methods

- Machine vision involves the collection and analysis of images such as those from cameras, microscopes, or other forms of electromagnetic radiation (e.g., X-rays).
- Machine vision can be used to identify and “track” a registered part.
  - Registered parts are those that have been added to a system or part registry (i.e., database).
  - Registration methods are sometimes referred to as tracking, as they do not distinguish or compare parts, but rather identify those that have been seen previously.
- Machine vision is being explored for detection of counterfeits by comparison to an exemplar, defect identification, or lack of consistency within a lot.



Part Classification Using Machine Vision

- Registration was performed using each lab's own proprietary method on a subset of the parts.
- Parts were returned after registration for selective surface modification.
- Once surface modification was complete, on both previously registered and unregistered parts, parts were returned to the lab for testing.
- Labs were tasked to identify which parts were registered.

Confusion Matrix for Machine Vision Analysis of Tracking Results

TP: Unregistered part correctly identified as unregistered.	FP: Registered part identified as unregistered -or- registered part identified as incorrect registered part.
FN: Unregistered part identified as registered.	TN: Registered part correctly identified as registered.

TP: True positive; FP: False positive; FN: False negative; TN: True negative

Machine Vision: Overall Results

Number of Parts		Percentage	
TP 156	FP 17	TP 0.87	FP 0.09
FN 24	TN 163	FN 0.13	TN 0.91
Accuracy=0.89			

- One of the labs used two independent methods; both methods are included in these results.
- One of the three labs achieved close to 100% accuracy.

Machine Vision: Clone Results

Number of Parts		Percentage	
TP 145	FP 17	TP 0.91	FP 0.11
FN 15	TN 143	FN 0.09	TN 0.89
Accuracy=0.90			

Machine Vision: Conventional Counterfeit Results

Number of Parts		Percentage	
TP 11	FP 0	TP 0.55	FP 0.00
FN 9	TN 20	FN 0.45	TN 1.00
Accuracy=0.78			

Standards-Based Testing

- This testing refers to the use of well-established characterization and measurement tools based on SAE AS6171 (such as external visual inspection, X-ray imaging, and electrical testing) to identify defects.
- In this context, a defect is an indicator that a part may be counterfeit. Defects are features or characteristics that are not consistent with expectations for a part produced by an original component manufacturer.
- Three labs, besides CALCE, were involved in the standards-based portion of the blind study. The labs are designated as labs A through D. Results from lab D have not been included in this presentation.

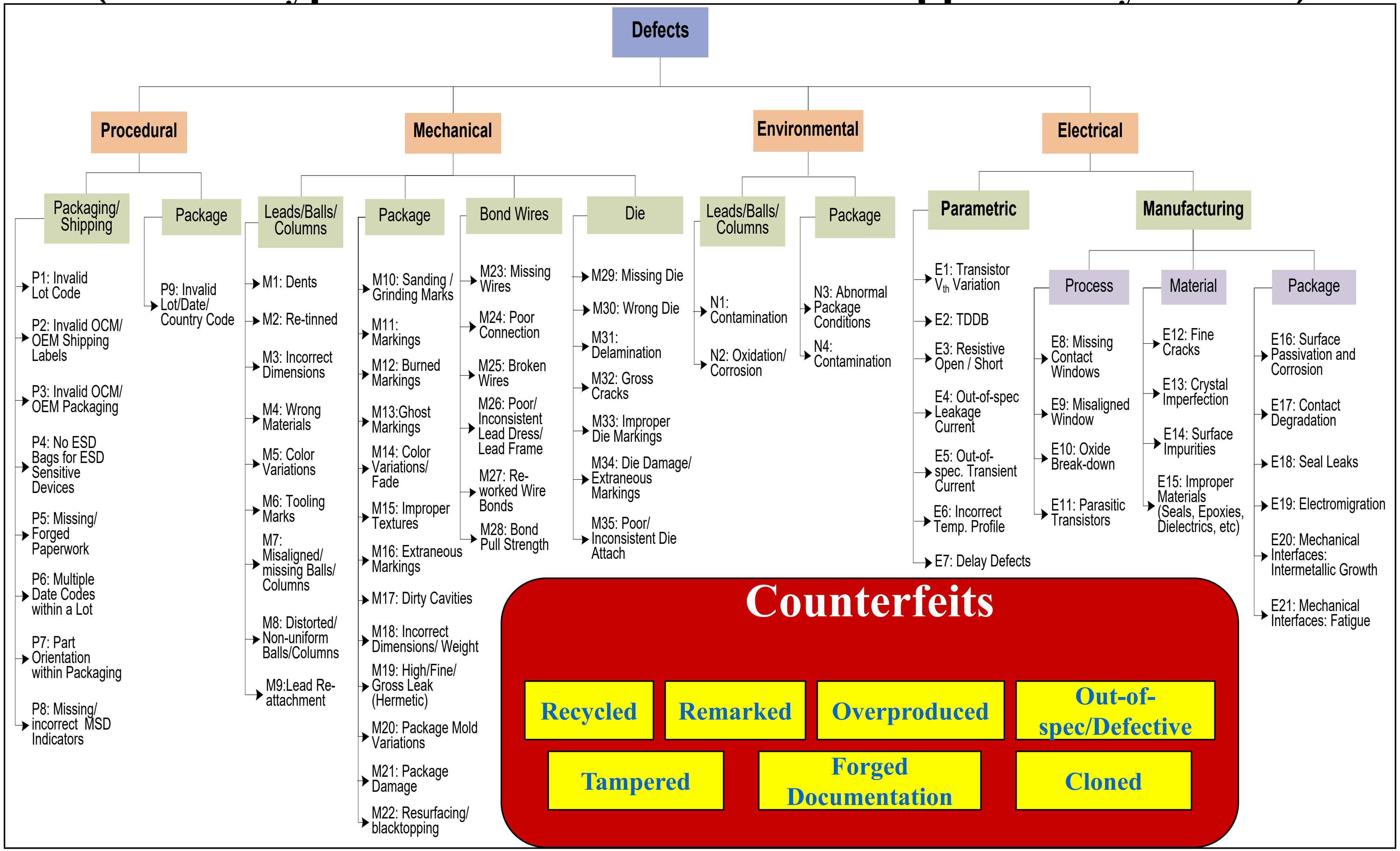
Standards Based Test Methods Included in Study

1. External visual inspection (EVI) (general and detailed) *[AS6171/2A]*
2. X-ray imaging *[AS6171/5]*
3. Electrical testing (curve tracing minimum) *[AS6171/7]*
4. Dimensional measurement *[AS6171/2A]*
5. Weight measurement *[AS6171/2A]*
6. External X-ray fluorescence spectroscopy (XRF) of leads *[AS6171/3]*
7. Fourier-transform infrared spectroscopy (FTIR) *[AS6171/9]*
8. Scanning electron microscopy (SEM) *[AS6171/2A]*
9. Scanning acoustic microscopy (SAM) *[AS6171/6]*
10. Remarking *[AS6171/2A]*
11. Resurfacing *[AS6171/2A]*
12. Internal inspection using optical microscopy *[AS6171/4]*

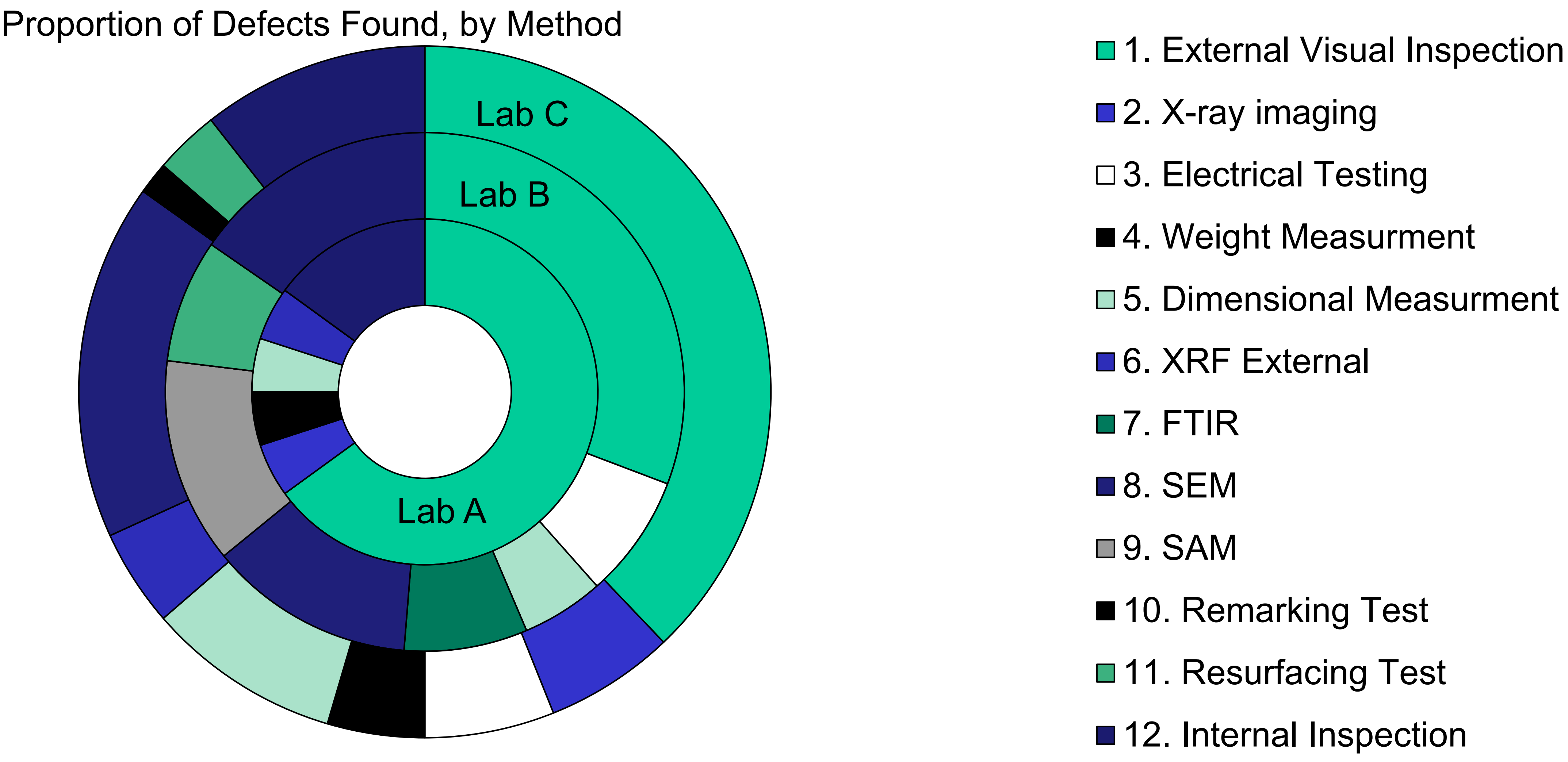
Taxonomy of Defects (Device Types Identified in the AS6171)

- Defects are broken down into six categories [each with their own code]:
  1. Packaging [P1-P12]
  2. Physical (Extensive Properties) [ME1-ME2]
  3. Physical (Terminations) [MT1-MT9]
  4. Physical (Surface) [MS1-MS14]
  5. Physical (Internal) [MP1-MP23]
  6. Electrical [E1-E9]

Taxonomy: Defects for Applicable Parts and Devices (Device Types Identified in the AS6171 Applicability Matrix)

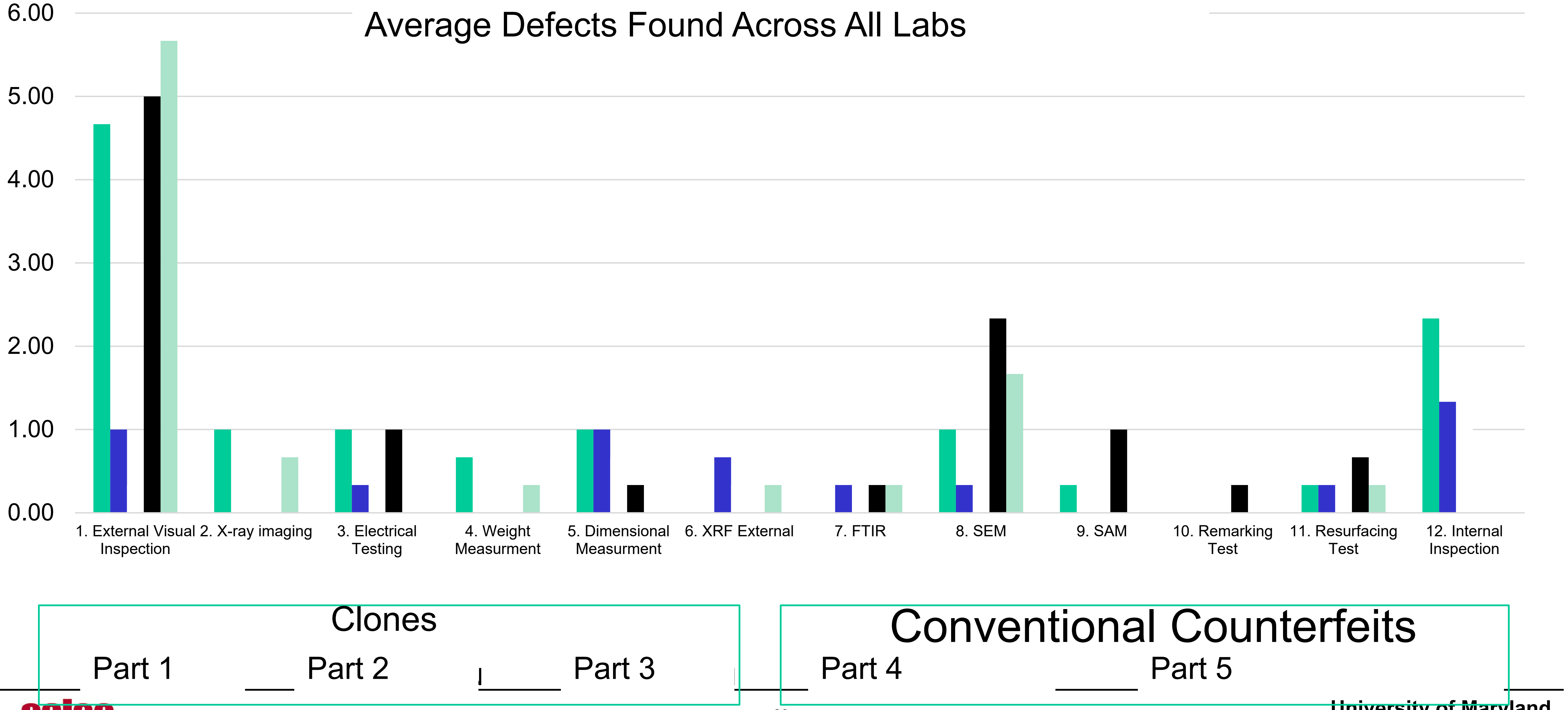


Average Defects Found by Each Lab



Averaged across five part numbers.

Comparison of Test Methods and Counterfeit Part Types



Standards-Based Test Findings

- External visual inspection found the largest number of defects.
- Defect counts varied widely between parts of the same counterfeit part category across most test methods. EVI defect counts for conventional counterfeits were more consistent than for clones.
- The effectiveness of some methods, such as FTIR, depends on the availability of an authentic part or documentation of part material composition.
  - Multiple labs observed differences when comparing parts with two different date codes.

Purpose of Risk Assessment

- Purpose: determine the recommended level of testing that should be utilized to manage the risk associated with the use of a part procured through an unauthorized supplier.
- Section 3.1 of AS6171 General Requirements provides a model for guidance to the User/Requester.

Risk-Based Testing

- A test sequence is a series of tests designed to achieve a certain level of confidence that a counterfeit part will be detected.
- The coverage of counterfeit defects (Counterfeit Defect Coverage (CDC)) and counterfeit part types (Counterfeit Type Coverage (CTC)) can be quantified for each test sequence.
- The target coverage levels are determined by the risk level assigned to the part, making risk assessment a cornerstone of test planning.

Risk Tier Level	Target Confidence (TC)
Critical	0.90
High	0.8
Moderate	0.65
Low	0.5
Very Low	0.35

Risk Assessment

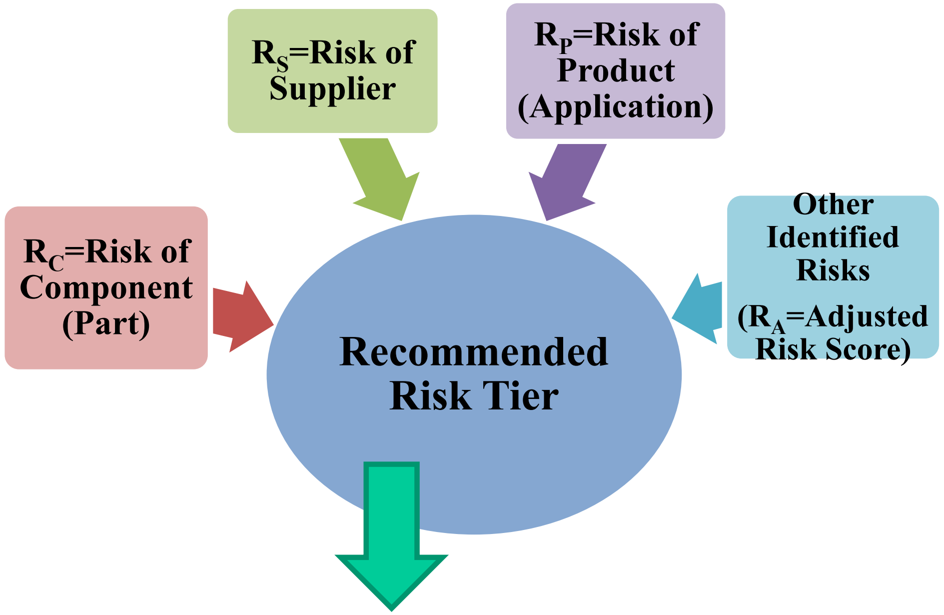
- Risk and recommended tier level of testing are based on:

❖ Rc: Effect of part failure on the product

❖ R_s: Risk of receiving a counterfeit part from the supplier

❖ R_p: Criticality of the product

❖ Other risk factors: availability of part, amount of product testing performed, redundancy, testability, supply chain



Risk Tier Level	Target Confidence (TC)
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Very Low	0.35

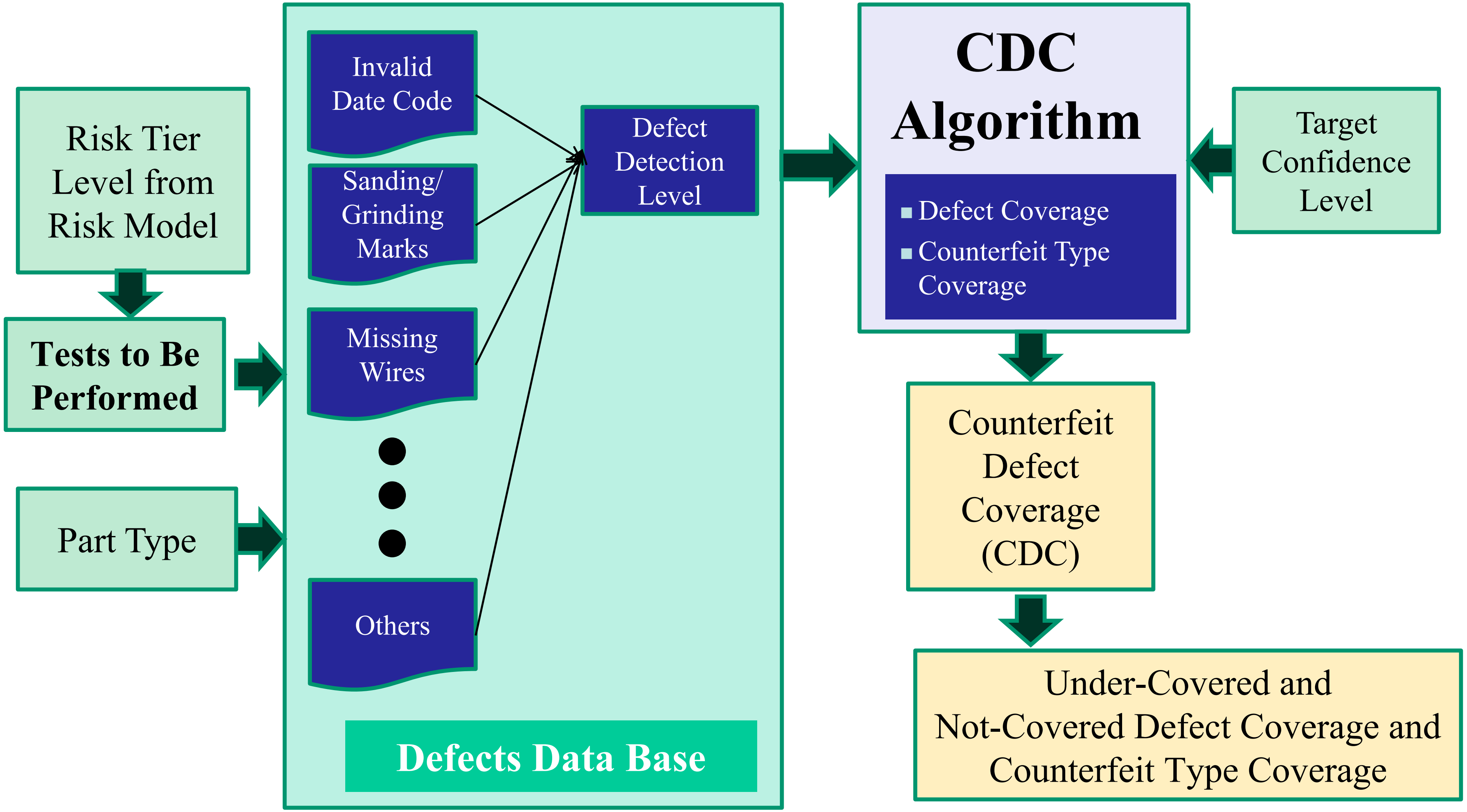
Risk Assessment Model

$R_A = R_P + R_C + R_S + A_P + A_C + A_S + A_G$

- R_A: Adjusted risk score
- A_i: Adjustment Factors
  - A_P: based on product level testing, and like/unlike redundancy
  - A_C: based on testability/complexity of part
  - A_S: based on risk associated with supplier
  - A_G: based on additional factors such as part availability and problem reports

SAE Counterfeit Defect Coverage (CDC) Tool: Analysis of Test Coverage

The web-based **CDC tool is being made available by SAE**



Sample Test Sequence for Moderate Risk

Active Parts, Complex, Example 2

Moderate Risk Target Confidence: 65%

Test #	Test Method
1	EVI, General (Full Lot)
2	EVI, Detailed (Sample)
3	EVI, Remarking
4	EVI, Resurfacing
5	EVI, Part Dimensions
7	XRF, Lead Finish Analysis
9	XRF, Material Composition
10	DDPA, Internal Inspection
13	Radiological, 2D
19	Electrical, DC Test at ambient temp.

G-19A Test Laboratory Standards Development Committee Update

Conclusions

- Standards-based testing for counterfeit detection remains the most effective tool and is widely available and accepted.
- While more defects were found using EVI, without other test methods defect coverage would not be sufficient. Clones present a challenge because of the variability observed for different test methods for different parts.
- Both side channel and machine vision technology based counterfeit detection tools have shown potential to classify components into groups with a high degree of accuracy.
- Side channel accuracy can suffer if training data is collected using parts, fixtures, software, or hardware that differ from the test platform.
- Whereas recognition of previously registered parts has been demonstrated for machine vision, its ability to classify parts with accuracy is unproven.

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