Reaching Across Data Silos in The Electronics Supply Chain to Achieve Parts-Per-Billion Quality Levels

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Abstract

With the dramatic increase in connected devices in the IoT era, it is becoming imperative to do much more to ensure the quality of all electronic components, especially for devices in mission-critical applications. In this paper, we will discuss actual use cases where product quality and time-to-quality was dramatically improved through the use of a seamless big data infrastructure. The data infrastructure can collect data from across the global supply chain and analyze that data in near-real-time to quickly identify manufacturing issues than can negatively impact product quality and reliability, greatly reducing test costs and downstream Return Merchandise Authorizations (RMAs). By bringing together manufacturing data from Original Equipment Manufacturers (OEMs), system integrators and suppliers, overall time-to-quality for the entire supply chain can be reduced by a month or more, dramatically improving time-to-market and market share for all contributors to the supply chain.

Introduction

Electronic systems, from cars and smartphones to data center servers, increasingly use more semiconductor devices, which themselves are increasingly complex.The manufacturing and testing of each component, board and system introduce variability that leads to significant quality challenges. At the same time quality and reliability cannot be compromised. Whether due to mission criticality or the value of brand reputation, quality and reliability issues have huge implications on the cost and reputation of a brand owner.Figure 1 shows how certain vertical market segments are more sensitive to mission criticality, brand recognition, or both as in the case of the automotive industry.

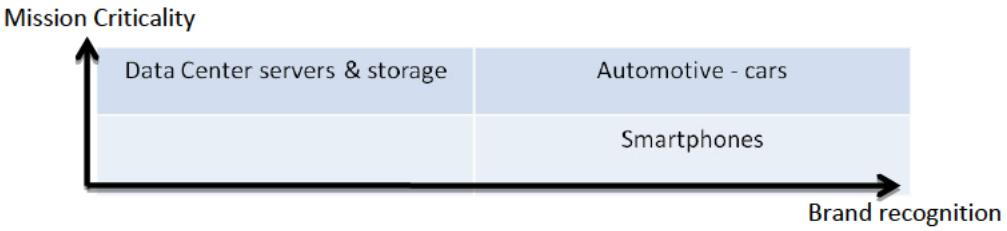

Figure 1 –Effects of mission criticality and brand recognition on specific market segments

A European car manufacturer, presented fascinating numbers that highlight the challenge[1]:

- There are 7,000 semiconductor devices in a premium car
- 1 DPPM (Defective Part Per Million) means 7 failures per 1,000 cars
- With 4,000 cars manufactured each day, this means 1 failure every hour

A key problem in improving the quality of electronic products is that OEMs and Original Component Manufacturers (OCMs) hardly use product analytics, and even those who do, do it in silos with no data sharing between them.Both sides operate in the dark. The main reason is reluctance, mainly on the OCM side, to share data with their customers, for fear of how they might use that data. However, there is real-life evidence that sharing data can actually lead to win-win scenarios for both sides.Sharing product data between OEMs and OCMs can help both during New Product Introduction (NPI) and during High Volume Manufacturing (HVM). The former affects time-to-market and time-to-revenue. The latter greatly affects brand reputation and product cost.

Many technical and business challenges need to be addressed in implementing a mutually-beneficial product data sharing system, including:

- Maintain data confidentiality, ensure only relevant insights are shared
- Perform data analytics effectively on all products in the value chain, from chips to systems
- Implement the necessary data management and security measures

This paper presents the business values of data sharing throughout the product life cycle and throughout its value chain. It then describes a model of a data sharing hub, managed by a trusted 3rd partythat can deliver the business values while overcoming all the challenges.

The Hidden Benefits of Product Data Sharing

An OEM Engineering team, working on the next generation of the company's flagship product, has completed the system debug and is excited to move to the next NPI phase - initial pre-production. They receive a batch of populated boards of the new system and eagerly start to test them.A few days into testing it becomes clear that something is not right. Some boards work well while others do not. A debug effort starts. Top management is watching closely, a marketing campaign is already in motion, and all the pressure is on the Engineering team to resolve the issues quickly.The team now faces the following questions:

- Is something wrong with our board design? Is it marginal?
- Is something wrong with one of the chips/components we use? To meet our system requirements, we chose some chips that were just recently introduced by the OCMs. Are there issues with those chips? Are they marginal? Are there coverage issues with the test programs of those chips that allow bad chips to ship?
- Are there specific combinations of chips in our systems (e.g. SoC and memory devices) that are marginal or sensitive?

Such a scenario is very common in the electronics industry.The problem is that while chips and systems continuously become more complex and are therefore more prone to issues, the way system and chip companies deal with them has not fundamentally changed.System designers test the system without much data on the chips beyond their data sheets, and OCMs test their chips without much data on the systems that use them.

Today's world, where chip and system companies need to introduce increasingly innovative products at a fast pace, and where time-to-market is crucial to gain a competitive advantage (or not lose one), calls for a much different approach for co-operation between OEMs and OCMs. It needs a value chain quality network that allows secure and trustworthy sharing of product data and product analytics.

The concept of sharing data between customers and suppliers is not new, and its business value is clear. Many industries have realized that once companies optimized their own operations the only way to continue to improve was through breaking silos in the supply chain. Any advanced supply chain management today includes sharing data about inventories, production schedules, and shipping status between customers and suppliers.

Sharing product data takes this concept to the next level. The impact of doing it is equivalent to adding product analytics to process analytics. For those not familiar with the differences between product and process analytics, Table 1 below provides a short summary.

Table 1 – Process versus Product Analytics

	Process Analytics	**Product Analytics**
The "things"	Machines	Products
Outcome	Smart preventive maintenance, improved asset management	Improved product quality, performance, brand protection
P&L impact	Higher profit	Higher revenue AND profit
Beneficiaries	Manufacturer	Brand owner AND manufacturer

This paper shows how a value chain quality network for sharing product data and product analytics can provide both OEMs and OCMs with significant business values throughout the product lifecycle:

- Improve quality and brand protection
- Reduce customer returns and warranty costs
- Improve NPI and shorten time to yield/quality
- Provide insights to design teams to improve current and future products
- Improve engineering efficiency
- Lower cost by enabling smart binning

How Does It Work?

Let us go back to the example above – an OEM Engineering team starts to test a batch of the main board of a new system, realizes something is wrong, and launches a debug effort. Typically, the team will run many tests on all the boards to see where they behave the same and where not, and will try to test the various chips on each board to seethe same. If the root cause cannot be found, or if certain chips may cause the board problems, the OEM notifies the respective OCMs. The OCMs try to replicate the issues in their labs or testers but often can not do it accurately and therefore report back that they did not find anything (a k.a. NTF – No Trouble Found).At best, the OCMs may send support personnel to the OEM site to help with the system debug, but often these situations lead to finger pointing, waste of time and resources, and frustration on both sides.Even with the best intentions of the OEM and the OCMs, who share

an interest in fast time-to-market/yield/quality since only then they all start to generate revenue from that design, it is very hard for them to make fast progress since they all operate in at least partial darkness.

Now assume the OEM and OCMs share product data and perform cross-product analytics. Such analytics can find answers to the following questions and many more:

- What is common and what is different among boards that work well and boards that do not?
- What is common and what is different among specific chips used in boards that work well and chips used in boards that do not?
- Are there correlations between chip behaviors and board behaviors?
- Are there correlations between combinations of chips (including from different OCMs) and board behaviors?
- Are there correlations between parameters of chips, combinations of chips, and boards (e.g. manufacturing dates or locations, test dates or locations, specific test results, functional or electrical parameters)?
- Which boards fail because of chip issues and which boards fail even though all their chips are good, indicating problems with the boards or the way they are tested?

This type of product analytics, only possible when board and chip data are shared, can findhidden systematic patterns and correlations in what otherwise seems like random problems. It helps both OEMs and OCMs improve NPI, save engineering time, and shorten time-to-market, time-to-yield, and time-to-quality.

High Volume Manufacturing (HVM)

The example above shows the value of sharing product data during NPI. But the value goes far beyond just the NPI phase. Think about all the cases,from smartphones to cars, where productswerealready in the market when customers started to complain about their performance or worse – started to return them.The technical challenges facing the OEM in these cases are similar but the implications much larger – damage to brand reputation and customer satisfaction and the financial impact of product recalls and lost revenue. Most OEMs, concerned about customer reaction and media coverage of their behavior, typically respond to such issues by completely stopping shipments of the affected products and issuing a broad recall of products already in the field.

Issues can arise during HVM, even if the NPI was done well, due to several reasons – a maverick lot of chips or boards, a minor change to the design of the board or a chip, or a minor change to manufacturing or test procedures.

First, it should be noted that sharing product data between OCMs and OEMs can prevent many of these issues from happening in the first place since higher quality is introduced into the design, NPI, and HVM phases. But when a problem does happen in the field after all, sharing data can minimize the damage considerably. Here too product data analytics that cover both OCMs and OEMs can quickly turn what may initially seem like random problems into insights of the root cause. Such analytics can shed light on questions like the following:

- What is unique about problematic products? How do they differ from the good ones?
- Has anything changed in the final product or in any of its components?
- Are there correlations between changes in chip or in chip combinations and board behaviors?
- Are changes related to manufacturing dates or locations, test dates or locations, specific test results, etc.?

Getting quick answers to these questions has a huge impact as they identify root cause and tell the OEM whether a recall is required or not, and even if it is – it can minimize the recall by identifying which specific products may be affected.

This type of product analytics, only possible when board and chip data are shared, can find hidden systematic patterns and correlations in what otherwise seems like random problems. As depicted in Figure 2 below, sharing data helps OEMs quickly find the root cause of issues (days versus weeks) by enabling them to perform more pinpoint troubleshooting. It thus improves customer satisfaction, protects brand reputation, and minimizes the financial impact of product issues and recalls.

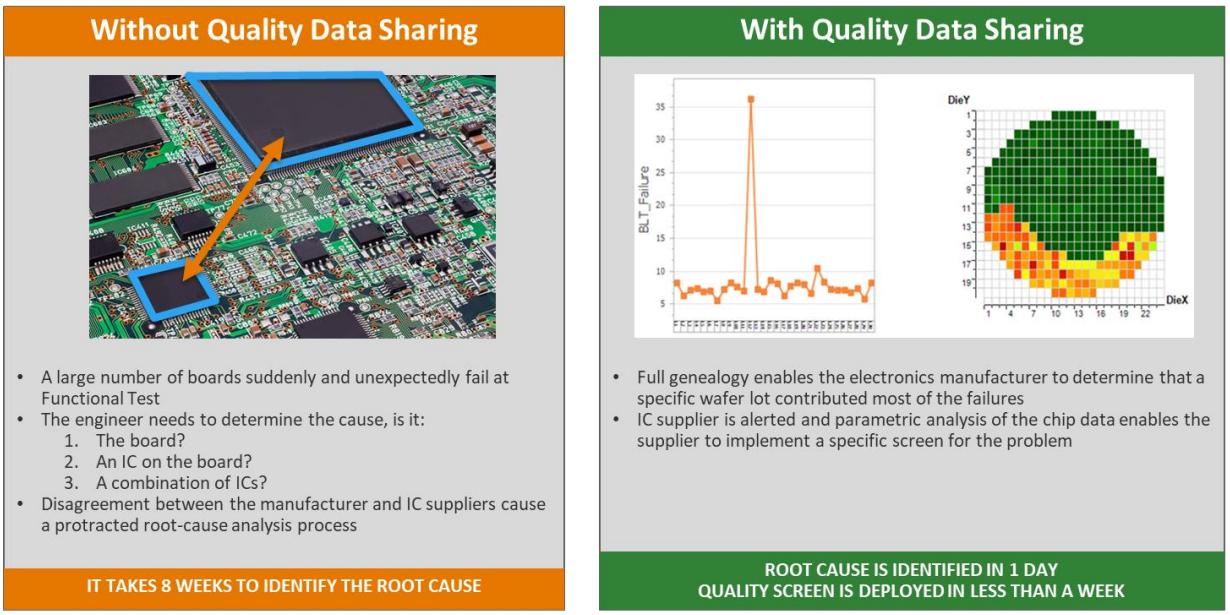

Figure 2 – Data sharing dramatically improving time to identify root cause of issues

Smart Binning

Sharing product data between OEMs and OCMs is not only valuable when issues are encountered. It can improve cost and efficiency in other ways too, such as smart binning.

Binning is a common practice in semiconductors – defining different part numbers with different prices based on chip test results.Today most binning is very coarse, based on just one or two parameters, such as clock frequency. In a high volume system, if the OEM and OCMs perform product analytics on shared data, binning can be "smarter" with significant benefits for both sides. Such analytics can identify the following:

- Chip parameters to which the system is sensitive, allowing the OEM to tune the system design or suggest to the OCM not to ship certain chips to the specific system.
- Chip parameters that do not affect the specific system, allowing shipping chips that would not be shipped otherwise, thus improving OCM yield.
- Chip tests that are irrelevant for the specific system, allowing lower cost through Test Time Reduction (TTR).

Design Improvements

The examples above show the value of sharing product data when the chips and systems are already available and are in NPI or HVM. But product analytics on chips and systems that use them also have great value in providing feedback to the design teams on how their products perform, allowing them to improve the design based on the insights the analytics provide. The design teams can use these insights for developing the next generation products or to create updated versions of the current products with higher performance, higher quality and reliability, or lower cost.

The Challenges of Product Data Sharing

While the benefits of product data sharing are clear, it also creates challenges, both technical and business, that must be addressed.

- How much data and what data should be shared? The more complete the data shared, the higher the likelihood of analytics finding insights effectively. But complete product data is often huge and in most cases (except an ASIC dedicated to a specific system) much of it may not be relevant to the need at hand.
- Who does the analytics and how?Suppose an OEM has all the data of all the chips used in his system. How does he know what analytics to run? They probably do not know the chips well enough to get any insights on them. The same applies for the OCMs as neither of them knows well enough the system or the other chips in the system.Cross-domain expertise is critical for extracting value from the cross-domain analytics.
- How will data be used?Product data can reveal things like yield, design sensitivities, and design margins, and is therefore very sensitive. OEMs are reluctant to provide such information to their OCMs, and even more so - OCMs are reluctant to provide such visibility to their customers for fear of what they may use it for.
- Will data be secure?The natural and obvious concern about any data leaving the company premise.

- How to address many-to-many scenarios?When data sharing is prevalent, there will be many-to-many scenarios since an OEM uses chips from many OCMs and an OCM sells chips to many OEMs. Managing all the data flows and analytics becomes very complex.

A Proposed Solution

A hub that connects OEMs and OCMs, managed and operated by a trusted 3rd party which manages data, performs analytics, and provides a quality protection service to both sides, can deliver the values of sharing product data while addressing the associated challenges.

The 3rd party, with data scientists with the relevant domain expertise and access to the necessary data can manage the data sharing operation as follows:

- By having domain expertise in both semiconductors and systems the 3rd party can perform analytics for both the OEMs and OCMs, eliminating the need for either to develop expertise in the other domain or to hire data scientists who are hard to find.
- By working with many OCMs and OEMs the 3rd party has visibility into which chips are used by which systems (genealogy) and can ensure analytics are done on all the relevant products, and only on them.
- Through clear Service Level Agreements with both OEMs and OCMs the 3rd party can guarantee to all parties what will be shared, alleviating the concern about OEMs getting sensitive data from the OCMs and vice versa. For example, the 3rd party can guarantee that only insights based on specific analytics are shared, with no data at all moving between OCM and OEM.
- The 3rd party can implement state-of-the-art security measures to ensure data in the hub is properly secure, relieving the OEMs and OCMs from the need to address security if they received sensitive data from the other party.

Figure 3 below shows the high-level architecture of such a solution.

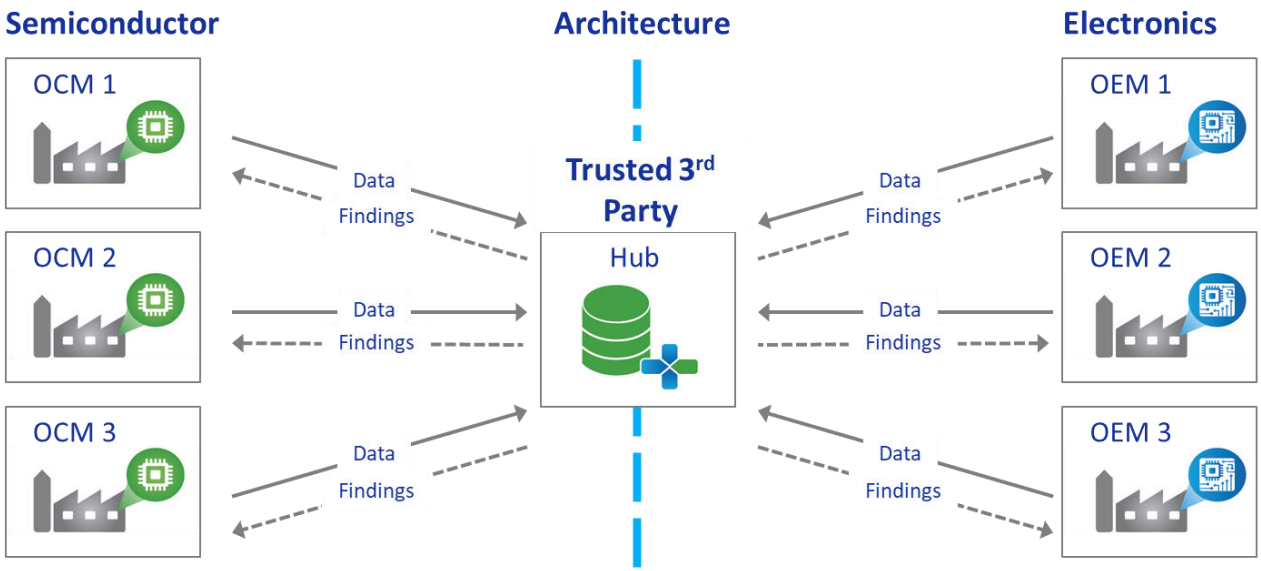

Figure 3 – Concept of a quality protection service 3rd party solution

Quality sharing across the supply chain will help both the supplier and the customer. As shown in Figure 4, the OCM (or chip supplier) will lose 0.7% yield when doing blind outlier detection across 100 tests. When the customer, or OEM, shares data with the OCM, they are able to relay the meaningful tests that truly impact their quality. This allows the OCM to focus their outlier detection on the ten relevant tests, improving their yield loss to 0.4%. Additionally, they can reduce the customer's yield loss from 1% to 0.5% by tightening even further the outlier detection on those ten tests while still improving their yield loss from 0.7% to 0.5%. In this case, both the OEM and the OCM win.

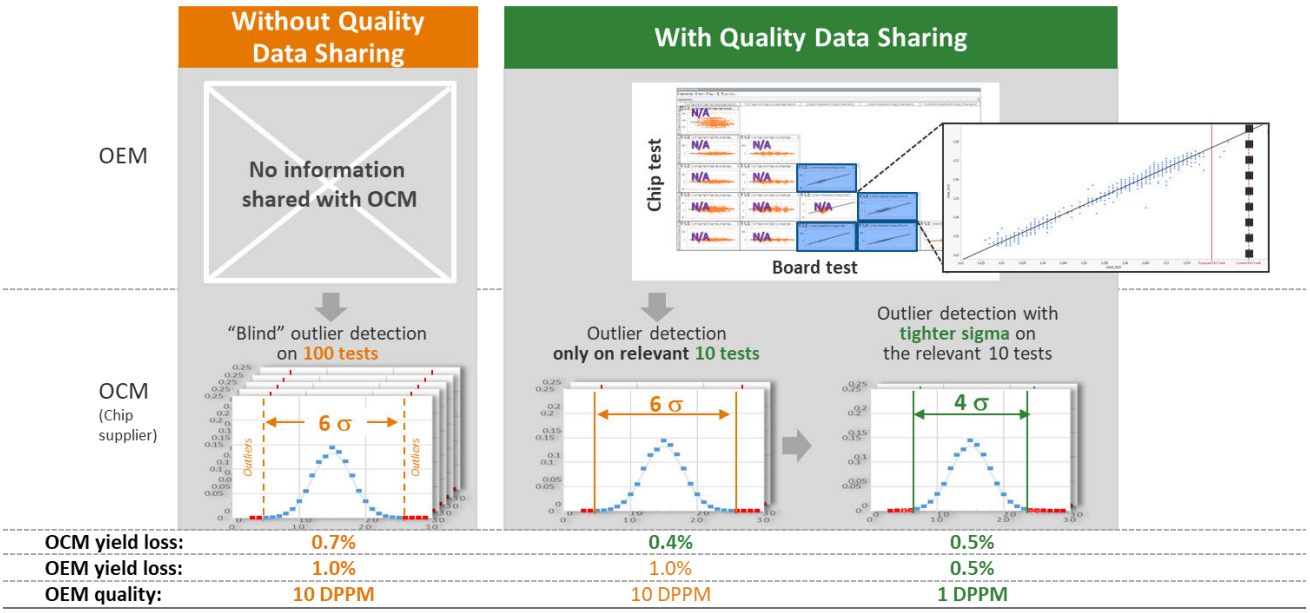

Figure 4 – Win-Win for Supplier and Customer →<u>Single</u> Board Type per IC

It is not all the time that a single chip will go into a single board at a single OEM. However, the same fundamentals remain true. When quality data is shared, a win-win can be created for both OCM and OEM in terms of yield and quality. The OCM can do product-specific outlier detection and improve their overall yield for one product and if another product has either a subset of tests or a completely different set of tests then, depending on volume, it may be advantageous to modify the outlier detection for that second product, as shown below in Figure 5.

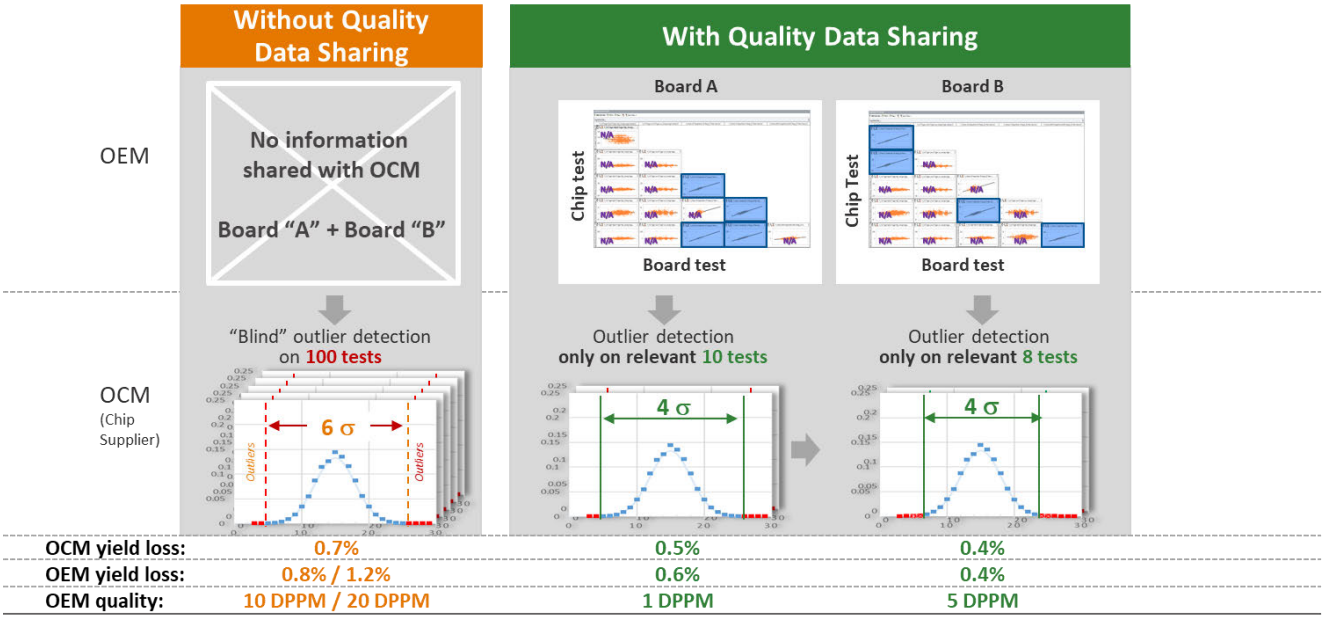

Figure 5 – Win-Win for Supplier and Customer →<u>Several</u> Board Types per IC

Summary

Sharing product data can provide both OEMs and OCMs with significant business values throughout the product lifecycle. It enables insights not possible if analytics on OCM and OEM products are done in silos, thus turns what seems like random issues into meaningful patterns and correlations.

Sharing product data delivers many business values:

- Improve quality and brand protection
- Reduce customer returns and warranty costs
- Improve NPI and shorten time to yield/quality
- Provide insights to design teams to improve current and future products
- Improve engineering efficiency
- Lower cost by enabling smart binning

Sharing product data between OEMs and OCMs creates technical and business challenges. A hub that connects them, managed and operated by a trusted 3rd party can provide the values of data sharing while addressing the challenges.The data in the hub is managed and secured, confidentiality is maintained, and analytics for both sides is performed by the 3rd party who provides insights as a service.

References

1. Audi – SEMICON Europa 2015, Dresden presentation.

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Reaching Across Data Silos in The Electronics Supply Chain to Achieve Parts-Per-Billion Quality Levels

Mark Moyer, Optimal Plus

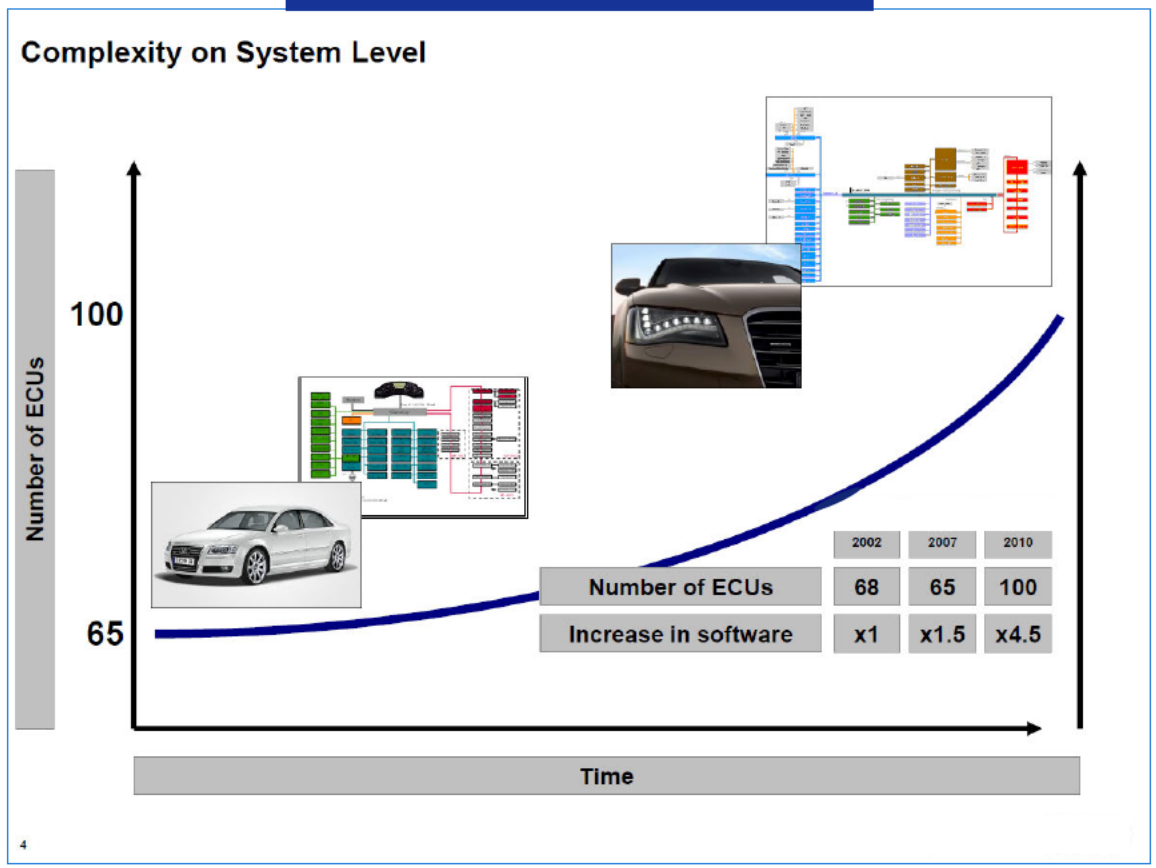
Agenda

- The Problem
- A Solution
- Examples
- Closing

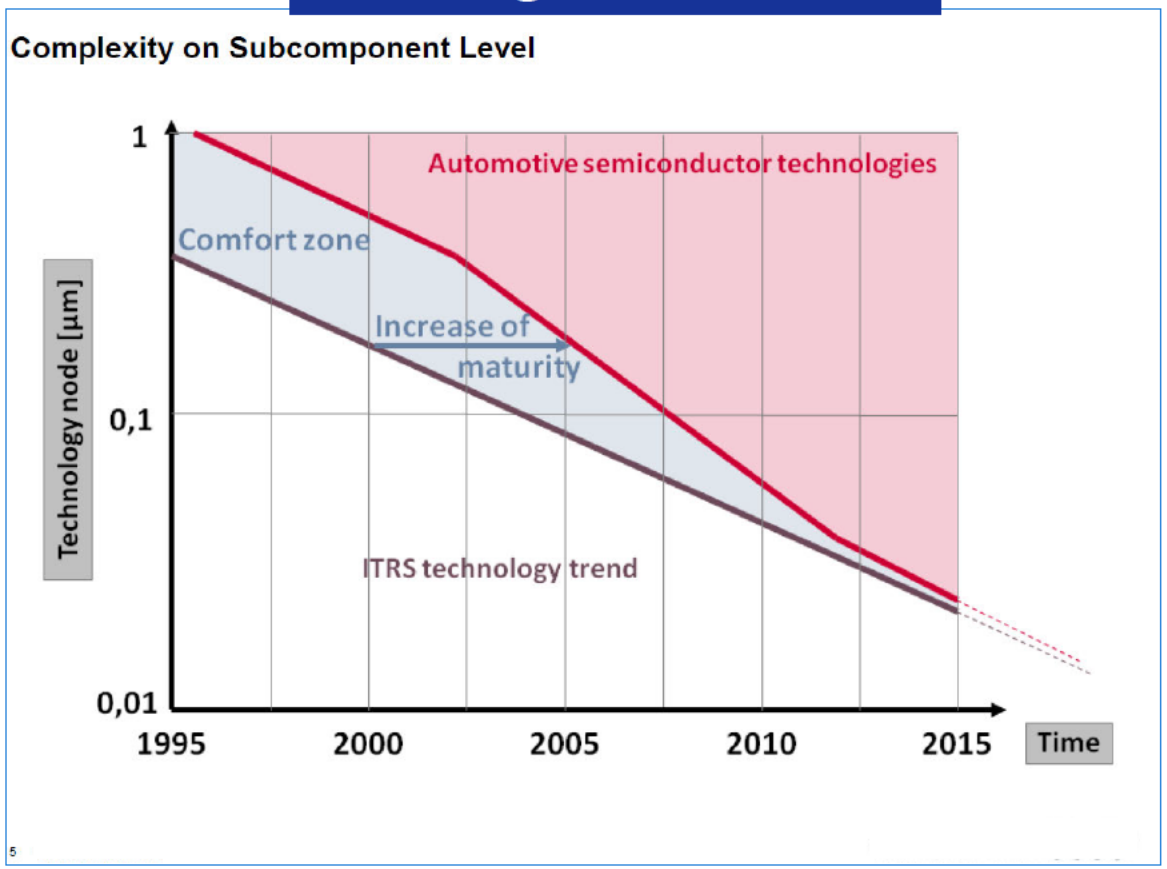
The Problem: Trends Affecting Quality

Chip → Board → System → Car

More Semiconductors…



Stretching the Tech Limits



[1]

The Problem: Auto Industry Shift from Warranty to Liability

European Car Manufacturer

7,000 semiconductor devices per premium car

1ppm failure rate = 7 failures for 1,000 cars

4,000 cars manufactured each day = **1** failure each hour!

production failures
long-term in-use electronic reliability failures

"Audio, Communication, Entertainment and Navigation or **ACEN is now the most problematic area** on most vehicles and is the cause of the industry's **3% year-over-year decline in vehicle dependability**."

[2]

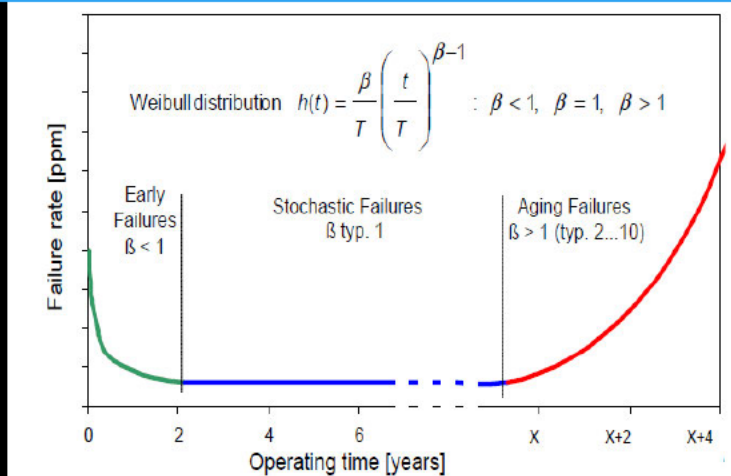
The Problem: ECU Reliability and Component Performance

Car manufacturers are asked to commit to 0 km + field failure rates < 10 PPM / Year

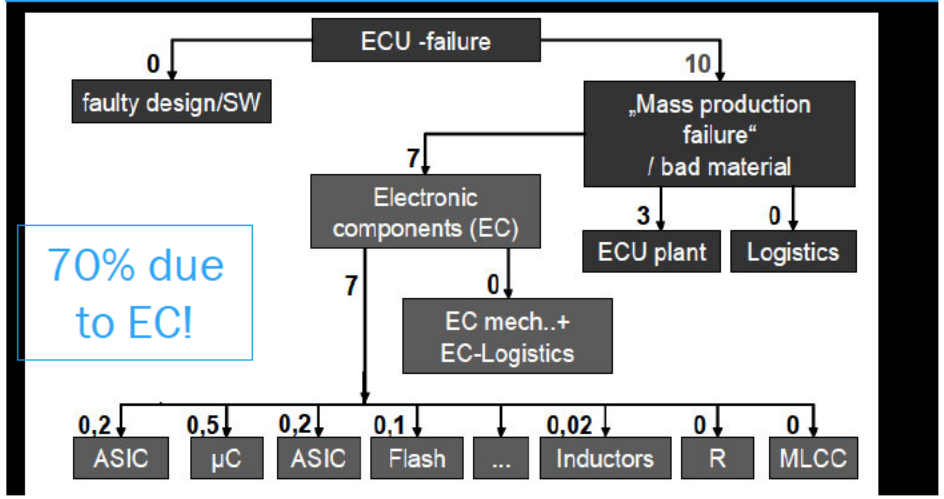
The majority of of ECU EFRs are caused by defects of supplied components

To achieve 10 PPM, each component must be << 1 PPM (equivalent to ZD)

Typical Reliability Failure Profile (Bathtub Curve)



Typical ECU Failure Contributions

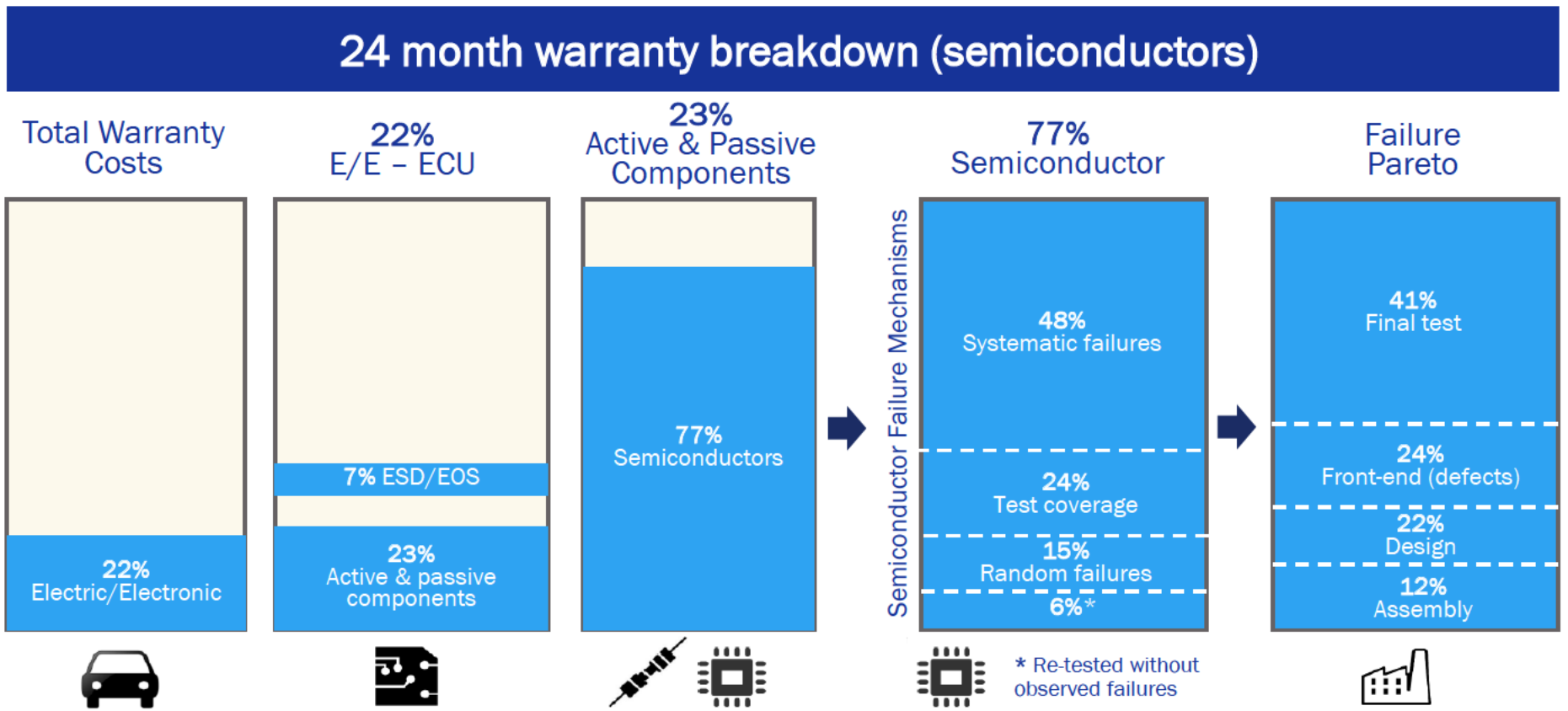


[3]

The Problem: Where do the Field Failures Come From?

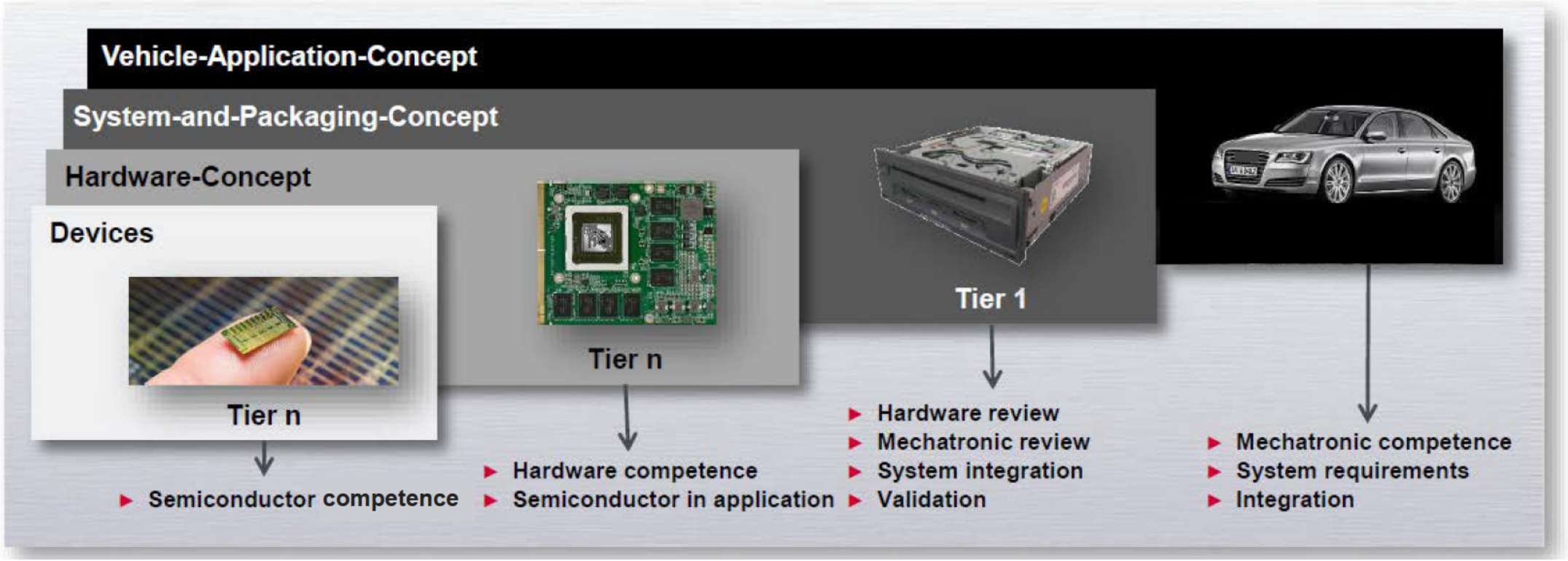
1. A significant part of the electric/electronic failures is related to semiconductors
2. Pareto of semiconductor failures in ECUs highlights issues related to design, test and defectivity

The Problem: Superior Semiconductor Quality is Critical!



[4]

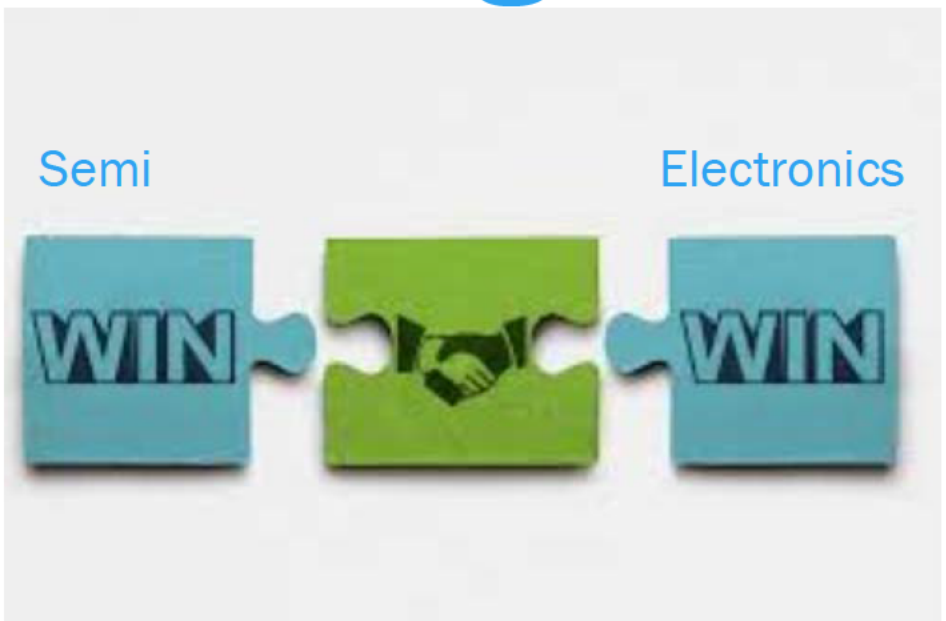
The Problem: Silos are Not an Option Anymore



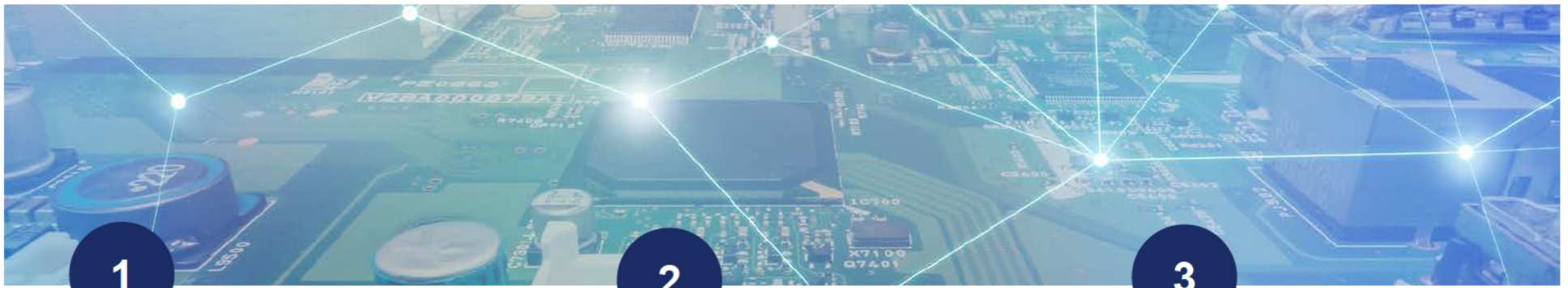
[1]

The Solution: A Trusted 3rd Party Data Sharing Platform

Sharing Data



The Solution: Understanding How to Share Data



1

IP Protection

- **Exposing IP** to potential competitors
- **Data** can be **leveraged against** the **other party**
- **Benefit for customer is clear**, but what about the supplier? (**"Win-Lose"**)

2

Technical Challenges

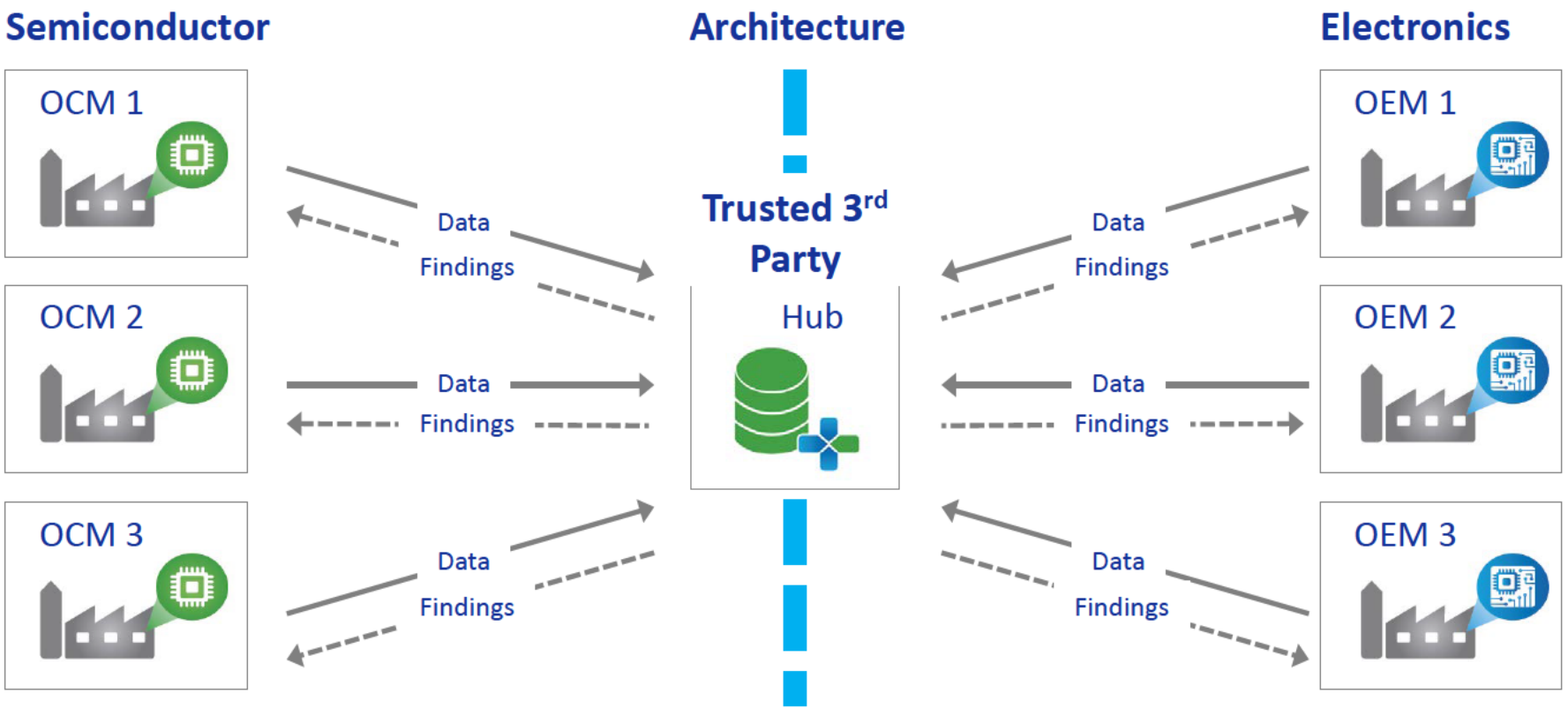
- **Data** flow / management
- **Security**
- Integration
- **Complex** many-to-many scenarios
- Lack of traceability

3

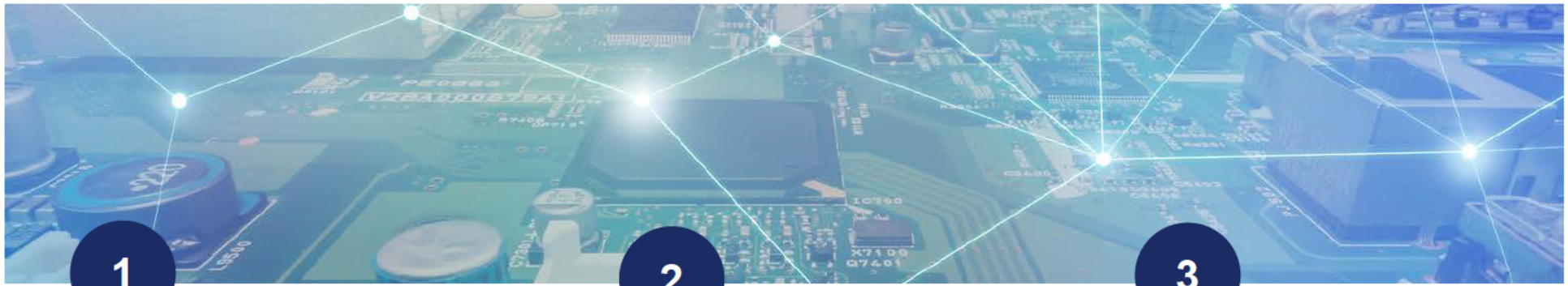
Expertise

- **Complex** correlations and **analytics**
- **Cross-domain expertise** is required

The Solution: A "Quality Protection Service"



The Solution: Trusted 3rd Party Hub Solution



1

IP protection

- **Data is hidden** from other parties
- **Only info relevant** to resolving identified issues **is shared**

2

Technical

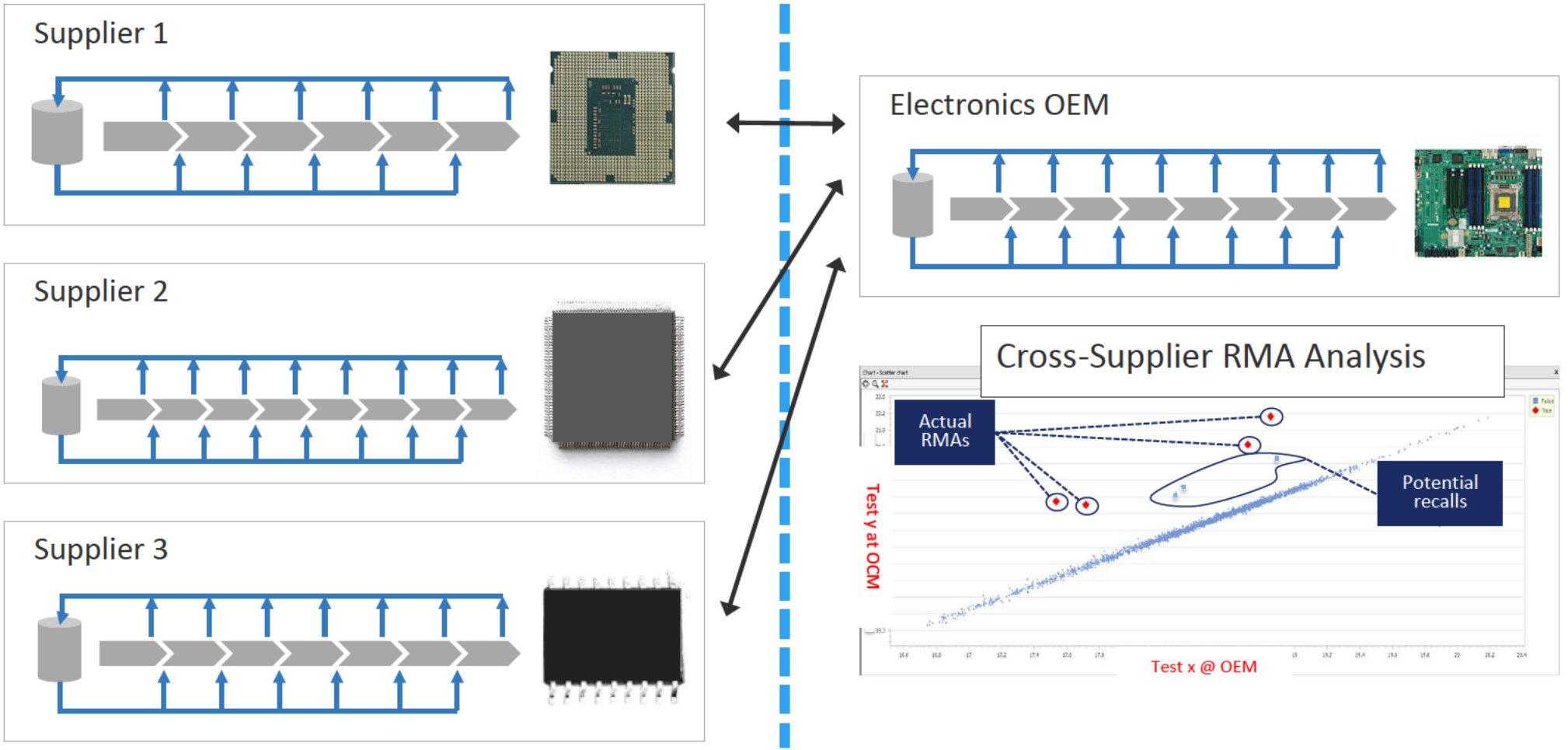
- The hub is **responsible for** the bulk of the **implementation and applications**
- The hub has **more options to maintain traceability**

3

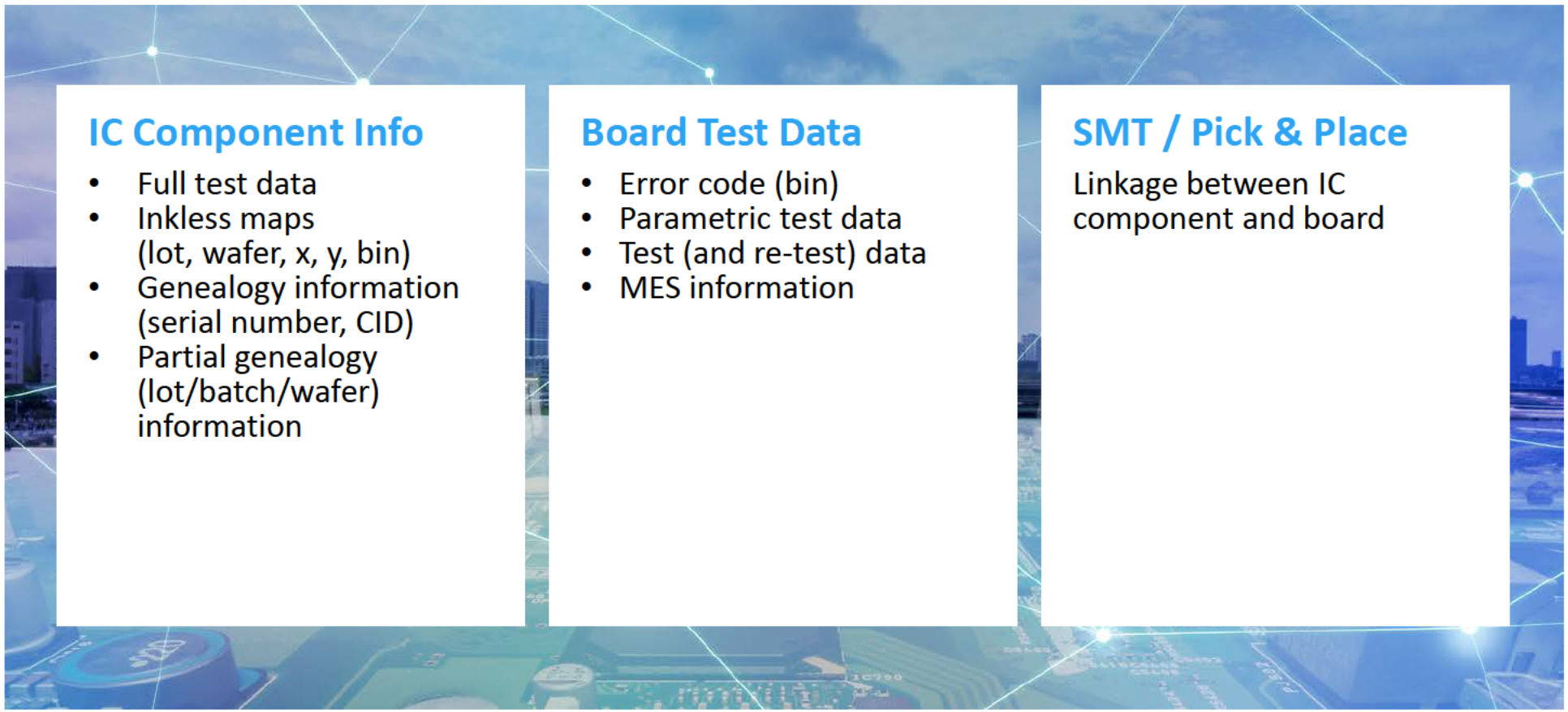
Expertise

- The hub **provides** the **analytics expertise**
- **Each party leverages its own expertise** when evaluating the issues identified by the hub

The Solution: Sharing Data *Across* the Supply Chain



The Solution: Quality Data Sources



IC Component Info

- Full test data
- Inkless maps (lot, wafer, x, y, bin)
- Genealogy information (serial number, CID)
- Partial genealogy (lot/batch/wafer) information

Board Test Data

- Error code (bin)
- Parametric test data
- Test (and re-test) data
- MES information

SMT / Pick & Place

Linkage between IC component and board

The Solution: What Quality Data Sharing Can Achieve

Lower RMA costs

- **Board-to-chip correlations**
- **Rapid** root cause **analysis**
- On-line **RMA Prevention Rules**
- Reduced NTF Rates
- **Proactive** targeted **recalls**

Improved quality and time-to-quality

- Reduced time to reach **board-level DPPM goals**
- On-line **quality link** between **chips and boards**
- Escape Prevention and Outlier Detection
- **Enhanced** Functional **Safety** (ISO 26262)

More efficient test processes

Adaptive Test

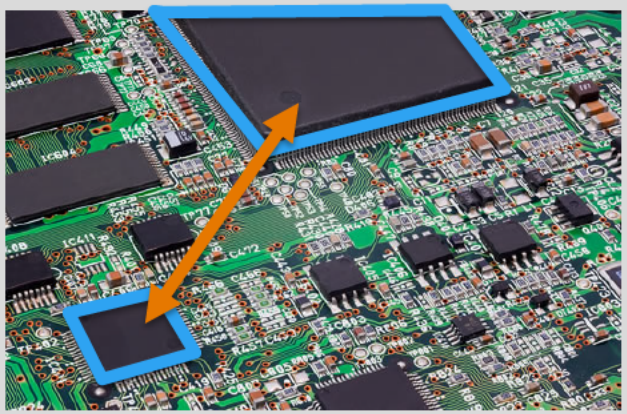
- Test "suspect" parts more
- Test "perfect" parts less

Better system performance

- **Avoid** in-Spec Chips with **marginal performance** at board
- **Smart Pairing** – Select the right chips for the right system board

Scenario: Reducing Time-to-Quality (RCA and CA/PA)

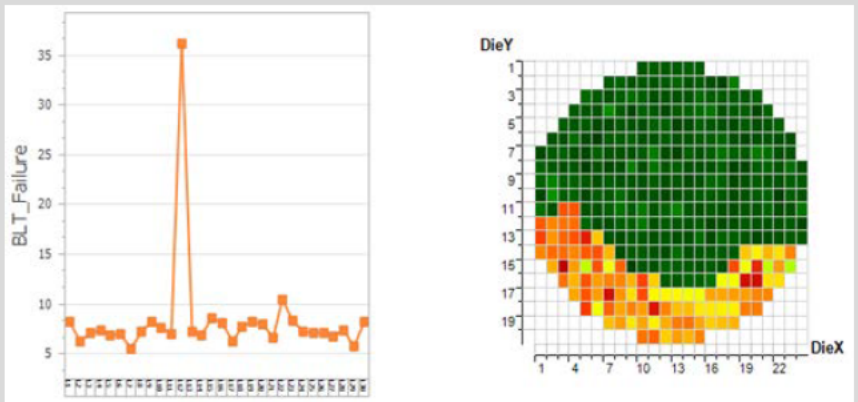
Without Quality Data Sharing



- A large number of boards suddenly and unexpectedly fail at Functional Test
- The engineer needs to determine the cause, is it:
  1. The board?
  2. An IC on the board?
  3. A combination of ICs?
- Disagreement between the manufacturer and IC suppliers cause a protracted root-cause analysis process

IT TAKES 8 WEEKS TO IDENTIFY THE ROOT CAUSE

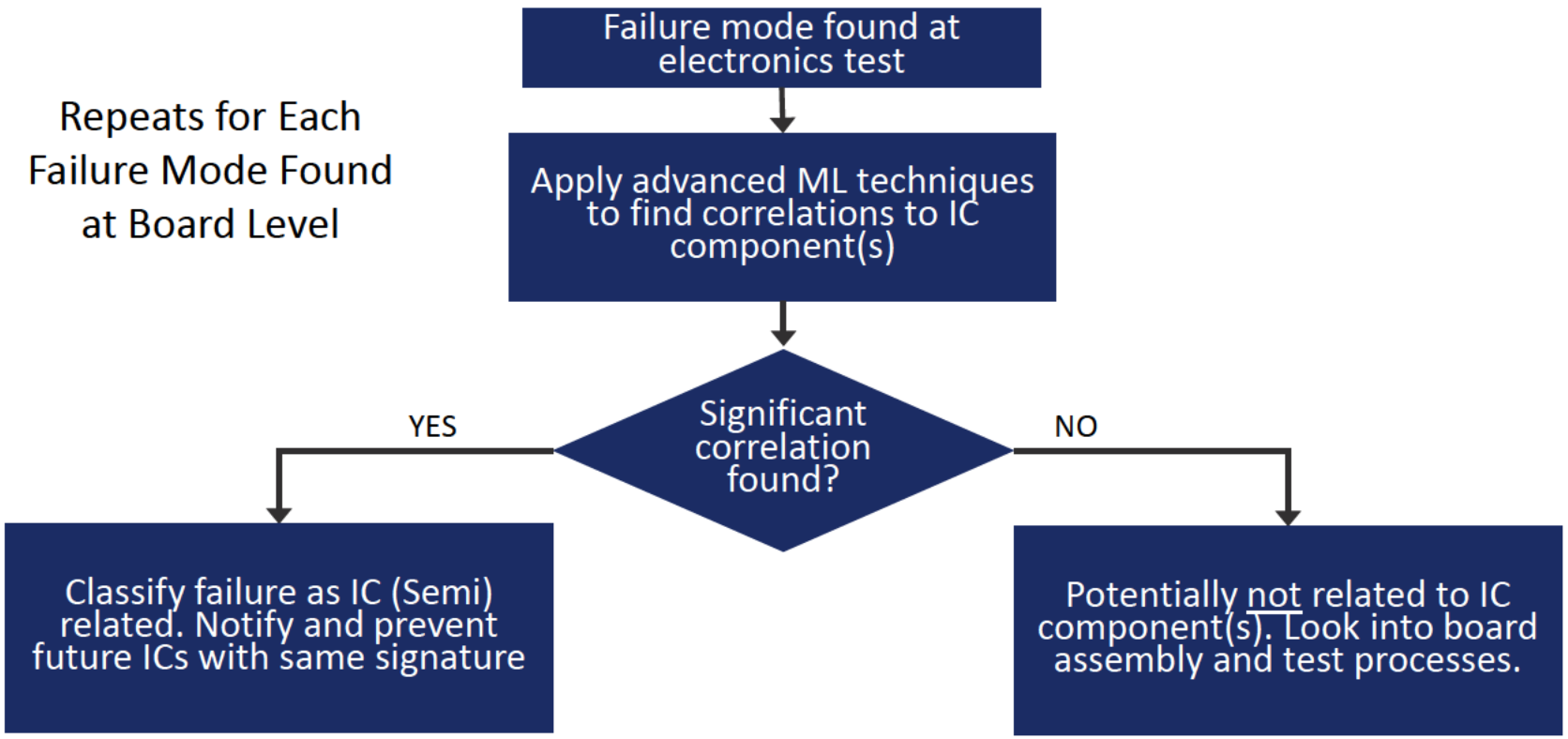
With Quality Data Sharing



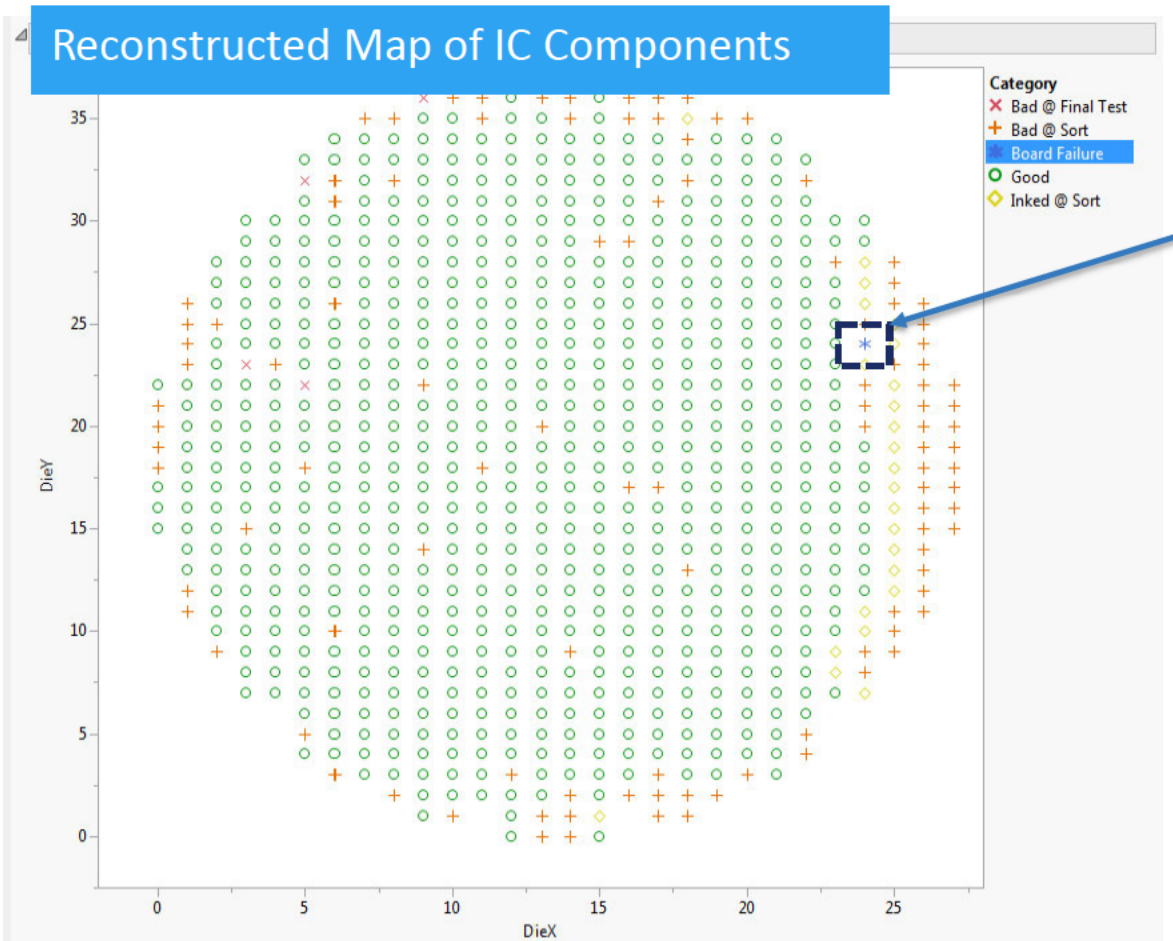
- Full genealogy enables the electronics manufacturer to determine that a specific wafer lot contributed most of the failures
- IC supplier is alerted and parametric analysis of the chip data enables the supplier to implement a specific screen for the problem

ROOT CAUSE IS IDENTIFIED IN 1 DAY
QUALITY SCREEN IS DEPLOYED IN LESS THAN A WEEK

High-Level Example of Automated Analysis Flow



Test Case # 1 – Geographic Analysis

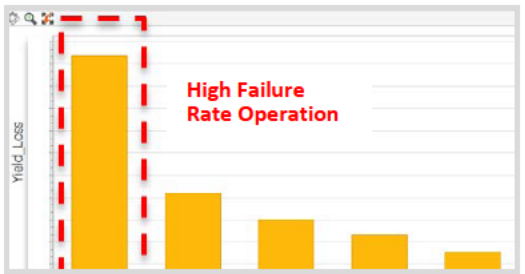


Board failure found adjacent to failing cluster at WS

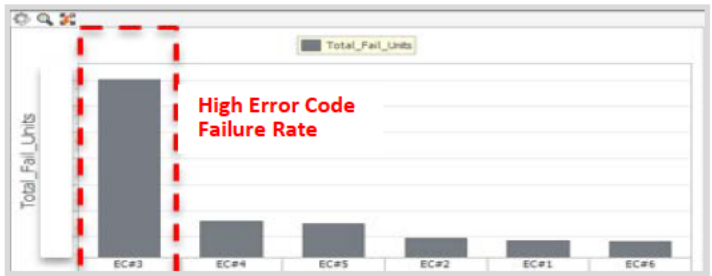
Learning can be fed back to improve future GDBN/Cluster settings

Test Case #2 – Systematic Analysis

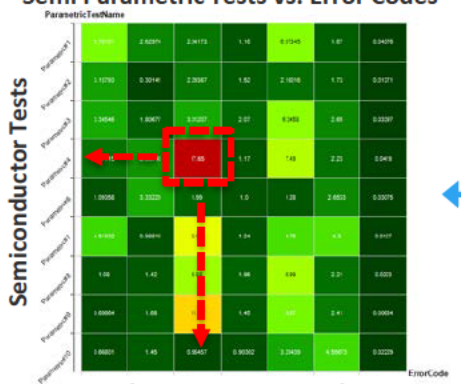
1 Electronics Yield Loss per Test Operation



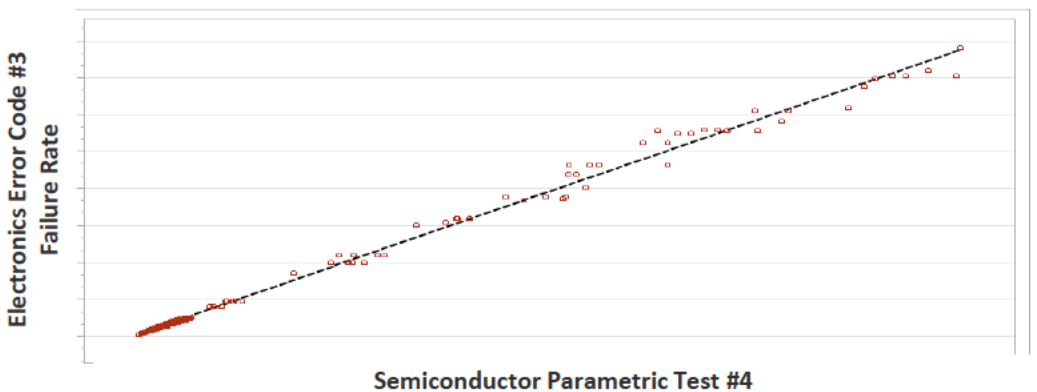
2 Failures per Error Code (EC) at low yielding operation



3 Correlation Heat Map
Semi Parametric Tests vs. Error Codes



4 Electronics Error Code #3 Failure Rate vs. Semi Parametric Test #4

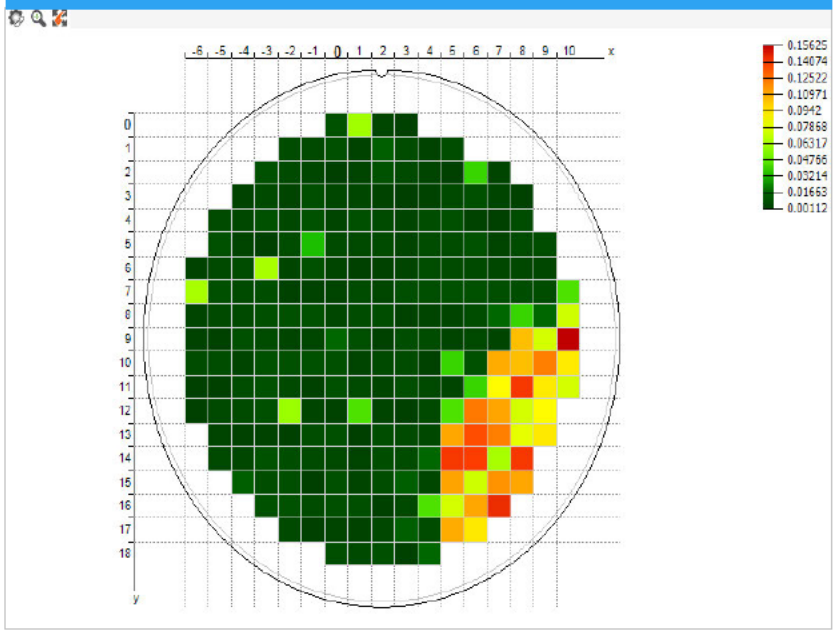


Test Case #2 – Systematic Analysis (cont.)

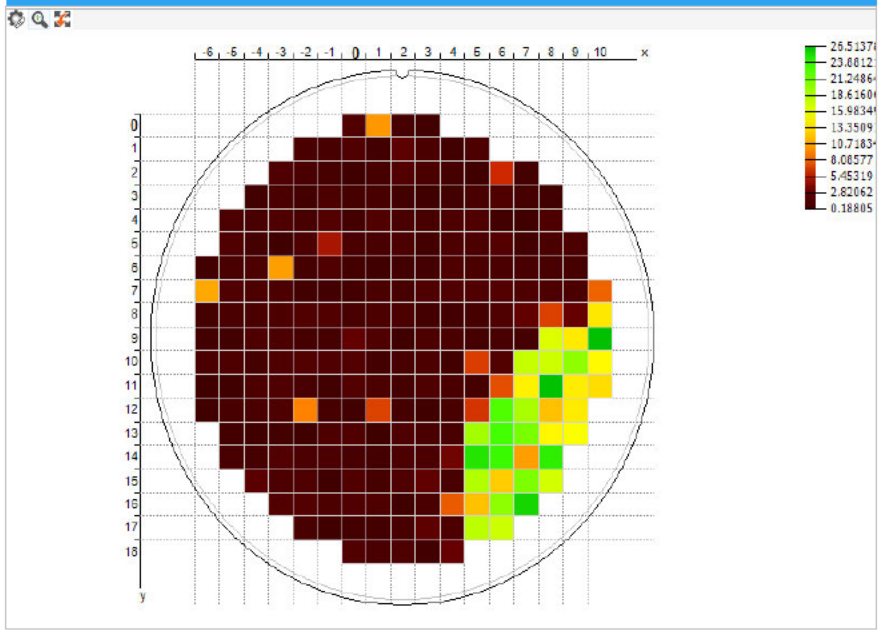
- EC #3 @ BLT correlates to Semi Parametric Test #4
- Reconstructed maps show bad lower right quadrant related to Error-Code #3 & higher Test Parameter #4

Spatial Signature indicates possible wafer process problem!

Reconstructed Map of EC #3 Fail Rate

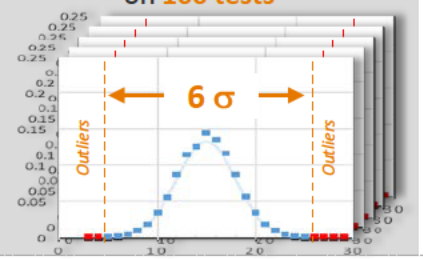


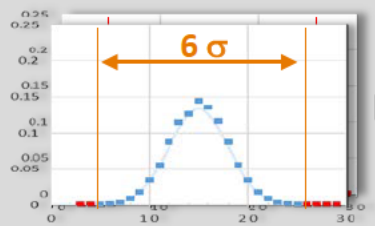
Stacked Wafer Map of Parametric Test #4 Medians

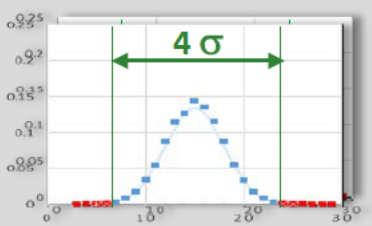


Win-Win for Supplier and Customer → Single Board Type per IC

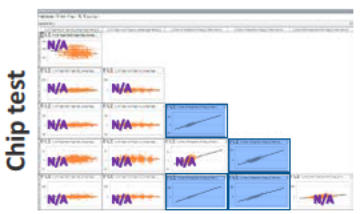
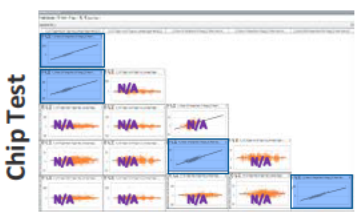
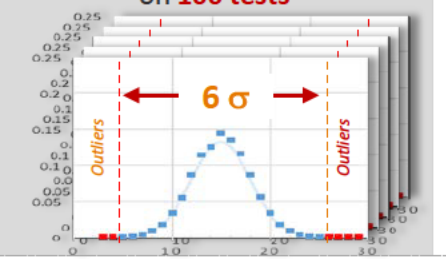
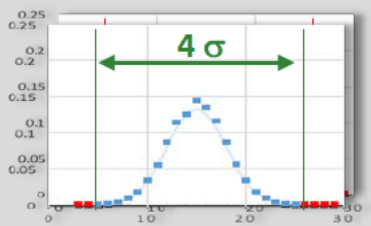
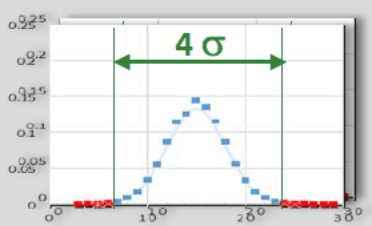
	Without Quality Data Sharing	With Quality Data Sharing	
OEM	No information shared with OCM	Chip test → Board test	
OCM (Chip supplier)	"Blind" outlier detection on 100 tests	Outlier detection only on relevant 10 tests	Outlier detection with tighter sigma on the relevant 10 tests
OCM yield loss:	0.7%	0.4%	0.5%
OEM yield loss:	1.0%	1.0%	0.5%
OEM quality:	10 DPPM	10 DPPM	1 DPPM







Win-Win for Supplier and Customer → Several Board Types per IC

	Without Quality Data Sharing	With Quality Data Sharing	
		Board A	Board B
OEM	No information shared with OCM Board "A" + Board "B"		
OCM (Chip Supplier)	"Blind" outlier detection on 100 tests 	Outlier detection only on relevant 10 tests 	Outlier detection only on relevant 8 tests 
OCM yield loss:	0.7%	0.5%	0.4%
OEM yield loss:	0.8% / 1.2%	0.6%	0.4%
OEM quality:	10 DPPM / 20 DPPM	1 DPPM	5 DPPM

Key Takeaways – The Quality Data Sharing Solution

1. **Electronics** are becoming **more pervasive** and **mission-critical**.

   Lower tolerance for **failures**.

2. The **supply chain** is becoming more **complex**

3. The next level of quality can only be achieved by **data sharing and analytics** that will enable **learning across Semi & Electronics**

4. **A cloud service**, run by a **trusted 3rd party**, **addresses** the data sharing **concerns** that have prevented this from happening so far

5. The **quality data sharing service** creates a **WIN-WIN** situation for the **entire supply chain**

References

[1] Audi – SEMICON Europa 2015, Dresden

[2] J.D. Power 2016 U.S. Vehicle Dependability Study A Solution

[3] Bosch – Trends in Automotive Electronics, Journal of Electrical Engineering, 2007

[4] BMW – SEMICONDUCTOR MANAGEMENT, April 2017

Thank You!