End-to-end data management essential to meet reliability requirements of **automotive electronics**

Automobile manufacturers need more robust electronic systems. Yet chip suppliers pursuing this opportunity face a dilemma: quality controls optimized for consumer electronics can't deliver in a sector where products must function for years, not months. Rudolph Technologies explains why advanced data management is key to future success.

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THE RAPIDLY INCREASING electronic content in automotive applications has revealed tremendous differences in reliability expectations between two industries. Car makers think of lifetimes in tens of years while electronics may become obsolete in tens of months. The automotive market will certainly not adopt the limited expectations of the electronics consumer and so the onus is on the electronics industry to improve reliability and extend product lifetimes.

Electronics manufacturers, who have grown up in an environment driven by process yield, must shift their focus to product reliability. For suppliers of inspection and metrology systems this shift will manifest in at least two important areas, system performance and data management. To tighten process control and reduce defects, measurement systems must be more precise and inspection systems more sensitive.

The increase in metrology and inspection required to improve reliability will generate a tsunami of data that must be collected, stored, and analyzed to extract actionable information. Most importantly, electronics manufacturers will require data management systems that provide die level traceability across an increasingly complex supply chain. Although semiconductor manufacturers have long collected large volumes of data, as much as 90% of it has typically lain dormant, never to be interrogated. Some projections of activity in an advanced datastore more than flip that number, estimating as much 99% of data will be actively mined. One of the biggest challenges may be cultural, persuading individual suppliers to interact and provide access to data on a “trusted source” basis.

For most of its history the automobile industry’s reliability concerns have focused primarily on mechanical systems. That focus is changing rapidly as the electronic content of cars comprises a rapidly increasing share of value, and the number of electronic components, each a potential point of failure, grows at an exponential rate. If devices are counted at the individual transistor level, the number quickly becomes astronomical. Device failure rates of one in a million are not adequate and even one in a billion can yield unacceptable levels of system failure. Though zero-defect quality control may not be achievable in a literal sense, the term captures the essential premise of a continuous improvement program in which no level of failure is acceptable.

The automotive industry has well-developed systems for testing and quality assurance. Components are expected to work for 18 years in a dirty, harsh environment with substantial vibration and wide temperature swings. In a mechanical system with hundreds or thousands of parts, failure rates in the parts-per-million range are not excessive. The electronics industry also has exacting requirements for quality and control, but historically it has focused on increasing the yield of functional devices at the end of the manufacturing process. Relatively short product lifetime requirements have put less emphasis on long-term reliability, and most electronic components are designed to operate in a relatively benign and well controlled environment.

Product liability is another important difference between the industries. Few consumer electronic products carry the significant risks to the health and safety of the user found in automotive applications. An

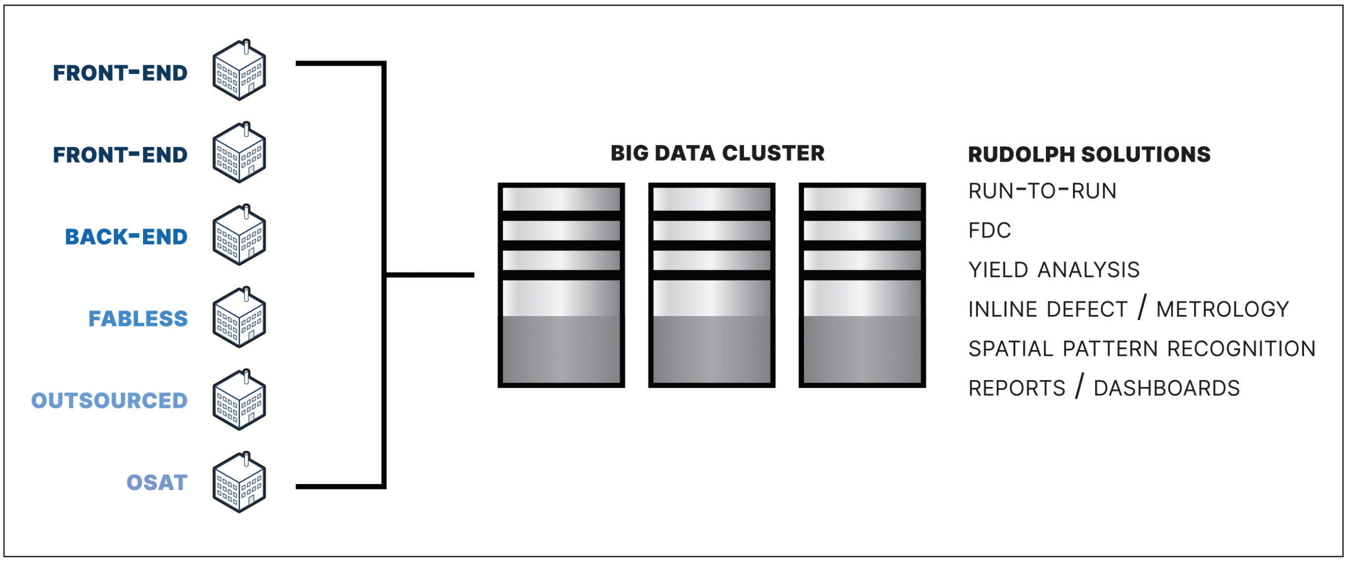
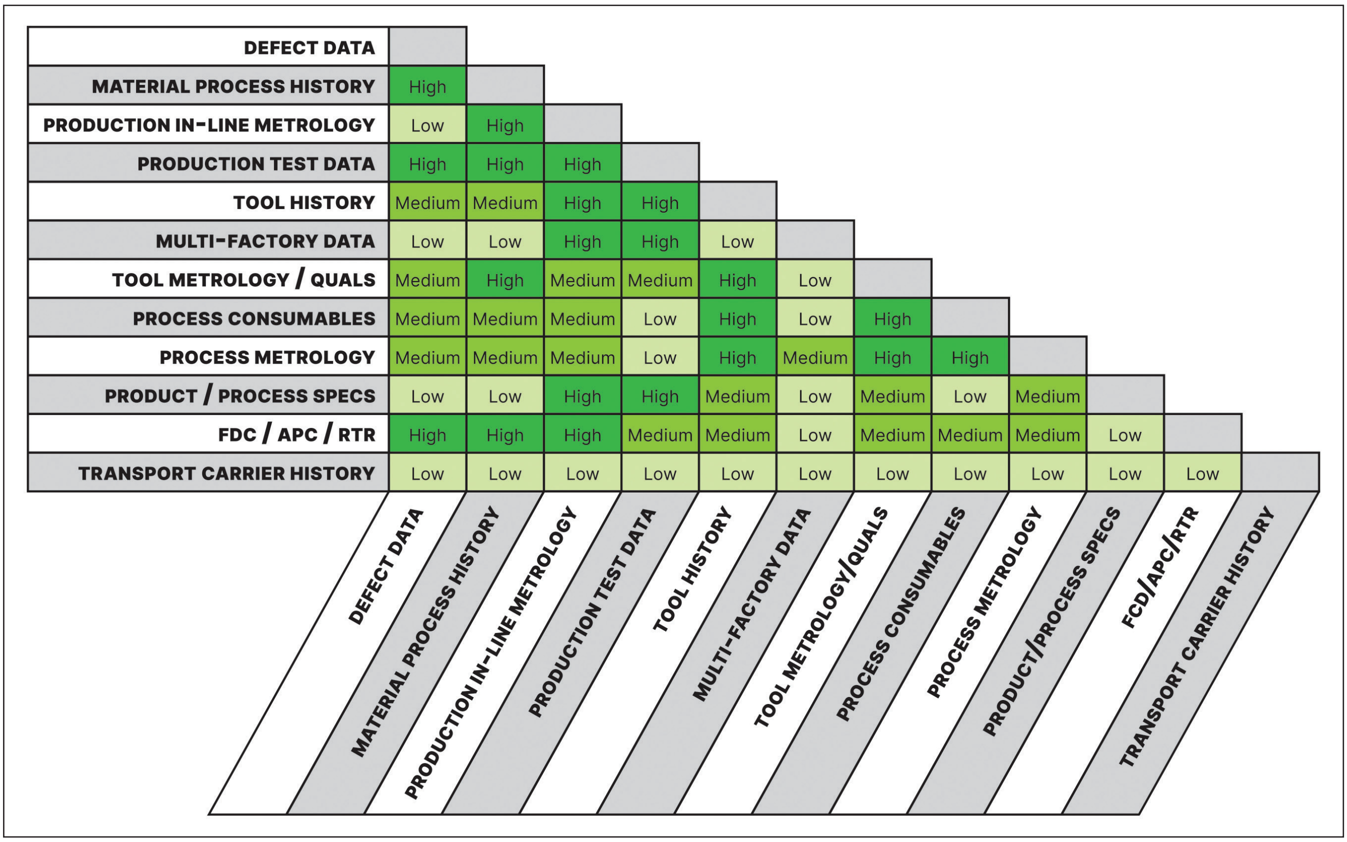


Fig 1. Data collection and management across an increasingly complex electronics manufacturing supply chain requires warehousing of data in a central integrated database where disparate data structures are pre-aligned to permit fast, thorough analysis and extraction of actionable data.



	DEFECT DATA	MATERIAL PROCESS HISTORY	PRODUCTION IN-LINE METROLOGY	PRODUCTION TEST DATA	TOOL HISTORY	MULTI-FACTORY DATA	TOOL METROLOGY/QUALS	PROCESS CONSUMABLES	PROCESS METROLOGY	PRODUCT/PROCESS SPECS	FCD/APC/RTR	TRANSPORT CARRIER HISTORY
DEFECT DATA												
MATERIAL PROCESS HISTORY	High											
PRODUCTION IN-LINE METROLOGY	Low	High										
PRODUCTION TEST DATA	High	High	High									
TOOL HISTORY	Medium	Medium	High	High								
MULTI-FACTORY DATA	Low	Low	High	High	Low							
TOOL METROLOGY / QUALS	Medium	High	Medium	Medium	High	Low						
PROCESS CONSUMABLES	Medium	Medium	Medium	Low	High	Low	High					
PROCESS METROLOGY	Medium	Medium	Medium	Low	High	Medium	High	High				
PRODUCT / PROCESS SPECS	Low	Low	High	High	Medium	Low	Medium	Low	Medium			
FDC / APC / RTR	High	High	High	Medium	Medium	Low	Medium	Medium	Medium	Low		
TRANSPORT CARRIER HISTORY	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	

Fig 2. The importance of integrated access to pre-aligned data from a variety of sources is emphasized by this chart which shows the likelihood – high, medium, or low – that data from any two sources will interact in a fab-wide problem-solving scenario.

aspect of product liability more unique to electronic assemblies derives from the somewhat monolithic nature of the finished component. The assembly may consist of multiple die and millions of transistors that are not individually repairable. If the assembly fails all these components are lost. The financial liability for the failure passes upstream, so that a supplier of a defective die may ultimately be held liable for the cost of the entire assembly. This model may work for a phone or smart watch but will not work for an automobile.

Current trends will only increase emphasis on reliability. While the number of electronic components and their share of value are increasing rapidly, experts also point to changing patterns of usage. Today an automobile typically spends most of its time parked, unused. If we move to an era of autonomous vehicles summoned on-demand from a shared pool, usage may approach 100%, with vehicles travelling hundreds of thousands of miles in a year.

To meet these challenges the electronics industry will have to make a fundamental shift in focus from process yield to product reliability. In an environment where the cost of reliability failure far exceeds the cost of yield loss, reliability and testing approaches that scrap nominally acceptable parts may be adopted more widely. Examples include guard-banding, where devices are scraped simply because they are located near a known defect, and part-averaging, which rejects statistical outliers even if they fall within process control limits. Process engineers and inspection and measurement system suppliers must focus on understanding the underlying causes of reliability failures with ever tighter process control, more precise measurements and more sensitive inspection. In addition, electronics manufacturers will need end-to-end process control with data management tools that provide detailed visibility across a supply chain that will certainly grow more complex.

Returns containment

Once a failed part returned from the field has been analyzed to determine the cause of the failure, automotive manufacturers must quickly determine what other vehicles contain parts likely to fail for the same or related causes. Die-level traceability, sometimes called genealogy, allows engineers to look back throughout the production process to find die with similar characteristics or history. These may include common material lots, processing equipment, events, timing, location, manufacturing plant, shipper, and more – the list is nearly endless.

Data sources may include defect detection, yield analysis, automated process control, and fault detection and classification systems, all from different manufacturers. Engineers are confronted by numerous challenges, including the amount of data, differences in data formats, and access to the data at different entities in the supply chain. An efficient solution requires an integrated database

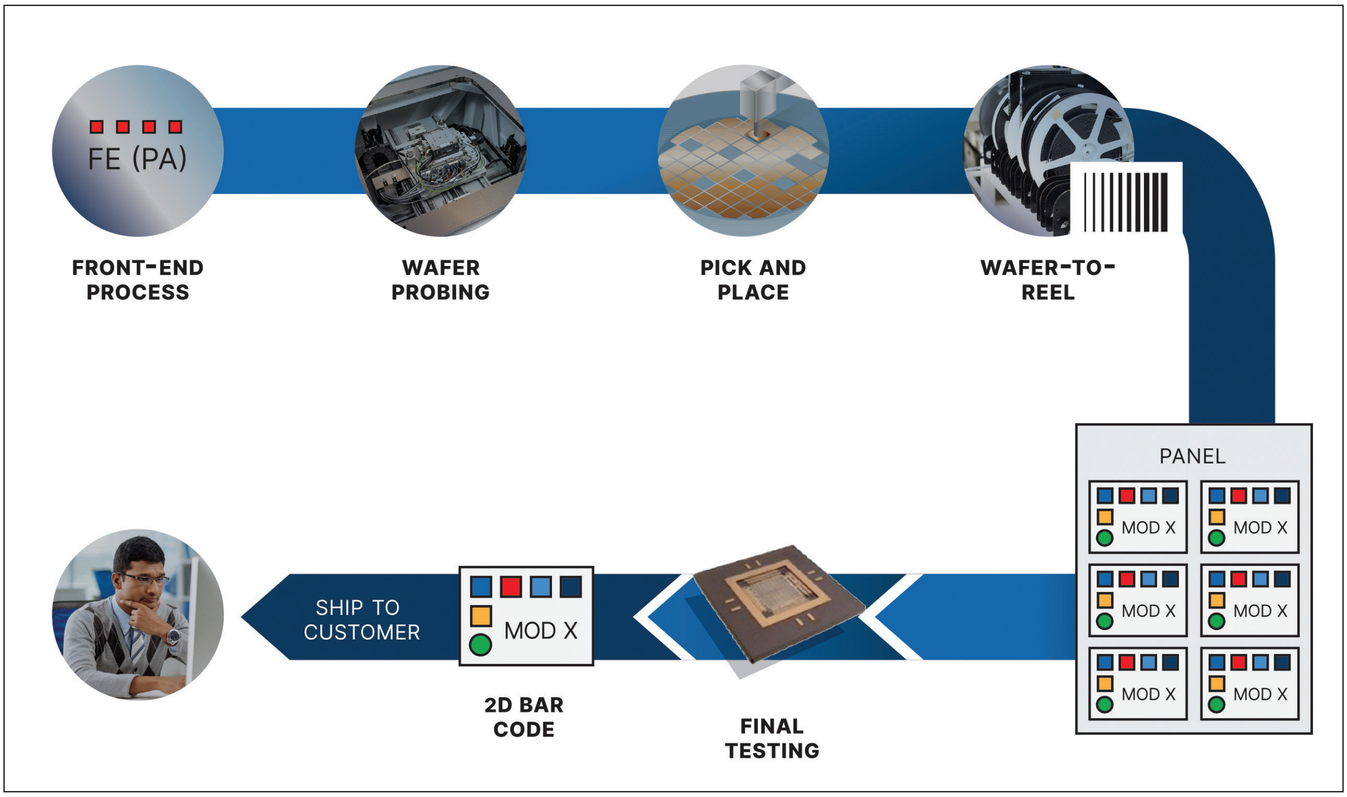


Figure 3. Die level traceability requires tracking of individual die as they are configured and reconfigured at various steps in the manufacturing process – from wafer to reel to panel to module – with each reconfiguration often occurring at a different supplier.

with high speed and large capacity and the ability to pre-align data from disparate sources to facilitate algorithmic searches for significant correlations. When common factors are found and at-risk die identified, manufacturers can minimize their costs and liability by issuing a recall for those vehicles and only those vehicles likely to be affected.

Corner case identification

Engineers routinely test products and processes to determine acceptable limits for variables. A variable near the limit is known as an edge case. The problem becomes more challenging when there are multiple interacting variables. Extending the edge metaphor to multivariate analysis, cases where variables in multiple dimensions are near their limits are known as corner cases. In low risk applications, corner cases may receive less attention, on the presumption that the likelihood that a component will encounter a situation where multiple conditions are near their limits is low.

In automotive applications, where the cost of failure can be high because of risks to the health and safety of the operator, corner cases are much more important. For every failure, engineers will want to know if this is a corner case they have not seen before. While the analogy of a two-dimensional corner is easy to appreciate, finding a "corner" as the number of variables/dimensions increases becomes more challenging. The ability to recognize when a part or module fails at a never validated corner in a multivariate parameter space is essential in preventing escapes.

Guard banding

In conventional engineering, guard banding refers to establishing a zone around a specification limit equal to some proportion of the measurement system's precision. For this reason, the capabilities of measurement and inspection systems must be well

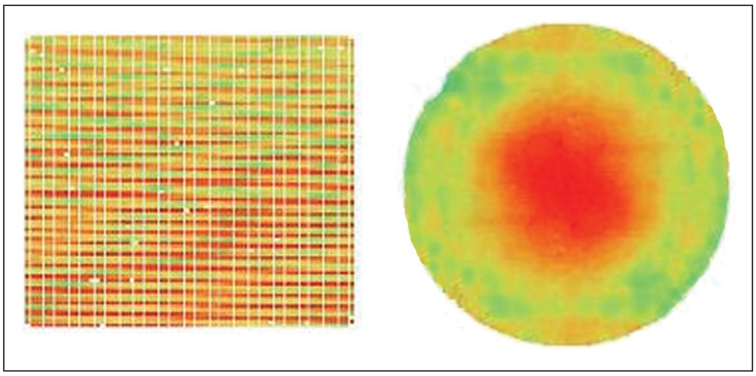
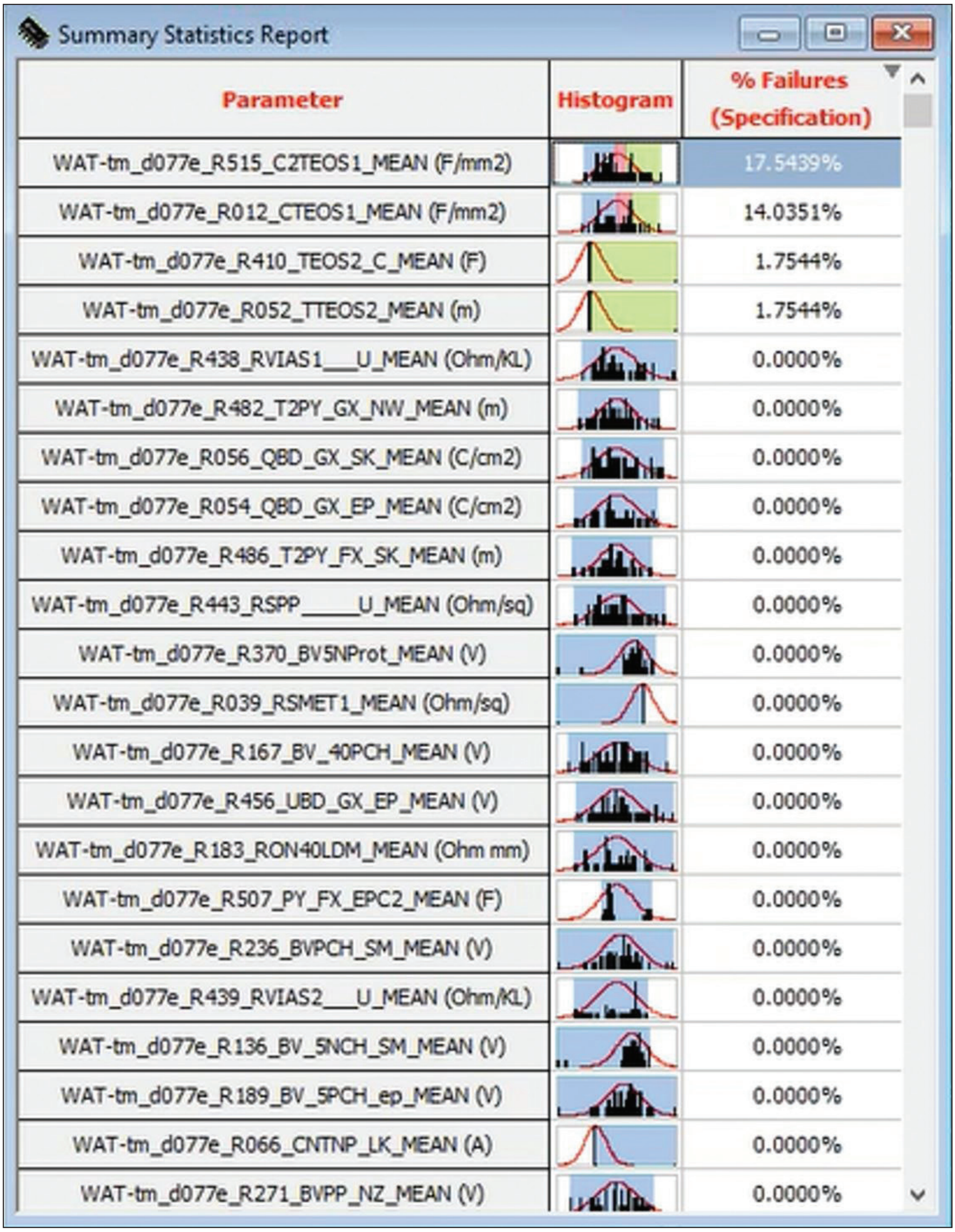


Figure 4. Back mapping can reveal spatial relationships that are not obvious. Engineers observed a characteristic striped pattern in visual displays of test results from panel die. Back mapping results showed original wafer die locations that revealed a front-end process issue. A similar approach can identify die at risk of failure.



Parameter	Histogram	% Failures (Specification)
WAT-tm_d077e_R515_C2TEOS1_MEAN (F/mm2)		17.5439%
WAT-tm_d077e_R012_CTEOS1_MEAN (F/mm2)		14.0351%
WAT-tm_d077e_R410_TEOS2_C_MEAN (F)		1.7544%
WAT-tm_d077e_R052_TTEOS2_MEAN (m)		1.7544%
WAT-tm_d077e_R438_RVIAS1___U_MEAN (Ohm/KL)		0.0000%
WAT-tm_d077e_R482_T2PY_GX_NW_MEAN (m)		0.0000%
WAT-tm_d077e_R056_QBD_GX_SK_MEAN (C/cm2)		0.0000%
WAT-tm_d077e_R054_QBD_GX_EP_MEAN (C/cm2)		0.0000%
WAT-tm_d077e_R486_T2PY_FX_SK_MEAN (m)		0.0000%
WAT-tm_d077e_R443_RSPP_____U_MEAN (Ohm/sq)		0.0000%
WAT-tm_d077e_R370_BV5NProt_MEAN (V)		0.0000%
WAT-tm_d077e_R039_RSMET1_MEAN (Ohm/sq)		0.0000%
WAT-tm_d077e_R167_BV_40PCH_MEAN (V)		0.0000%
WAT-tm_d077e_R456_UBD_GX_EP_MEAN (V)		0.0000%
WAT-tm_d077e_R183_RON40LDM_MEAN (Ohm mm)		0.0000%
WAT-tm_d077e_R507_PY_FX_EPC2_MEAN (F)		0.0000%
WAT-tm_d077e_R236_BVPCH_SM_MEAN (V)		0.0000%
WAT-tm_d077e_R439_RVIAS2___U_MEAN (Ohm/KL)		0.0000%
WAT-tm_d077e_R136_BV_5NCH_SM_MEAN (V)		0.0000%
WAT-tm_d077e_R189_BV_5PCH_ep_MEAN (V)		0.0000%
WAT-tm_d077e_R066_CNTNP_LK_MEAN (A)		0.0000%
WAT-tm_d077e_R271_BVPP_NZ_MEAN (V)		0.0000%

Figure 5.
This list is an example of the large number of variables that must be monitored. Automated routines can constantly mine an integrated datastore to find new corners.

characterized, with error bars or some other graphic representation of precision included in all results. Guard banding has also been used in semiconductor engineering to refer to the practice of including additional, redundant circuitry to ensure that failure of a single device does not cause failure of the whole circuit. More relevant to this discussion is geometric guard banding, where a die may be scrapped simply because it is located near a detected defect on a wafer. For example, die immediately adjacent to a scratch or several die in the extended direction of a scratch may be rejected on the presumption that they are more likely to fail. In these cases, the potential cost of failure is judged to be higher than the cost of yield loss.

Adaptive sampling

There is a constant tension between throughput and measurement/inspection requirements. Time spent on these functions is, in the strictest sense, non-

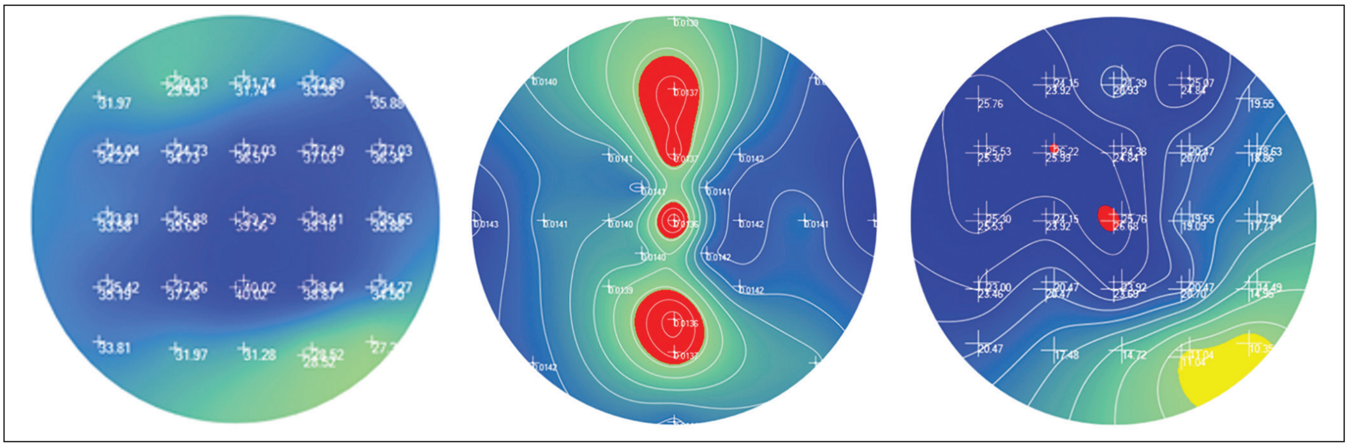


Figure 6. Adaptive sampling adjusts sampling rates in response to measured values to optimize the trade-off between measurement and throughput.

productive, but it is essential in maximizing the yield of good devices and their reliability. Adaptive sampling seeks to optimize the trade-off by dynamically adapting the sampling rate or density in response to highly variable measurement results. Figure 6 shows an example where the sampling density would be changed from one wafer to the next based on the variability of sample measurements. As demonstrated in Figure 6, these wafer maps utilize continuous color to show the actual variation of the measured parameter (unknown to the measurement system.) The white numbers show sampled values measured at specific locations. Given the underlying uniformity of the left wafer, the measurements would show little variability, providing high confidence that they are representative of all points on the wafer. On the middle and right wafer, the sampled measurements show greater variability, suggesting the need for increased sampling density to completely characterize the full wafer and provide confidence that all points fall within acceptable limits.

Part average testing

Part average testing (PAT) is a technique developed by automotive manufacturers. It is another example of a practice that discards nominally good parts judged to be at higher risk of failure. In part average testing, die that meet specification but fall outside the normal distribution of their cohort population are rejected.

Conclusion

Electronic and automotive manufacturers have historically had different expectations for product reliability. The increasing electronic content of automobiles will require electronics manufacturers to dramatically increase product lifetimes and reliability in much more demanding environments. Key to their ability to do so will be the intelligent use of process data. Major challenges that must be addressed include accommodating massive data volumes, aligning disparate data structures in an integrated datastore, and developing trusted relationships with data sources across a complex supply chain. We have described several examples of the use of advanced data analysis and data mining to address the reliability needs of the automotive market, including return containment, corner case identification, adaptive sampling and part average testing. All these techniques and more will be necessary to drive automotive electronics into the quality and reliability space required by car manufacturers and their customers.

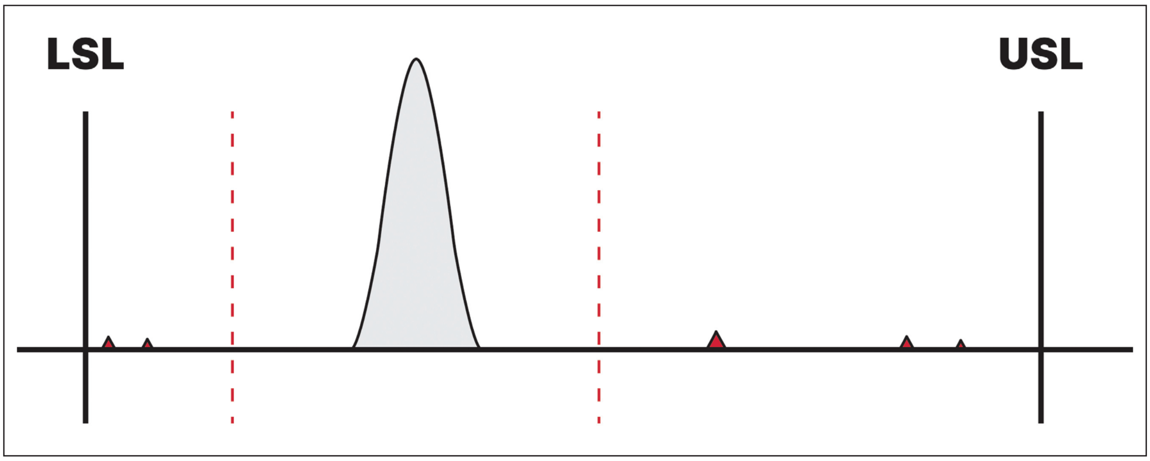


Figure 7 For static part average testing (PAT) the normal distribution is taken from a representative sample spanning several lots and is refreshed periodically. For dynamic PAT the normal distribution is calculated from a rolling sample of recently tested parts.