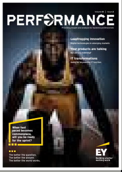

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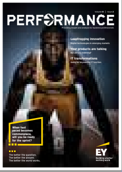
Your products are talking, are you listening?

The internet of things (IoT) is starting to revolutionize how automotive, aerospace and industrial equipment manufacturers design, manufacture and sustain their products. As these products become more intelligent and connected, it will be a competitive necessity for manufacturers to listen to them individually and collectively – anticipating product failures, improving their designs and avoiding costly repairs or damage to the brand.



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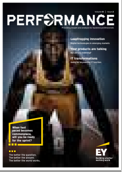
Authors

Kevin Reale
Senior Manager, Advisory Services, Performance Improvement, Supply Chain Management, Product Life Cycle Management, EY, US

Anton Bossenbroek
Manager, Advisory Services, Performance Improvement, Advanced Analytics, EY, US

Jake Darlington
Staff, Advisory Services, Performance Improvement, Advanced Analytics, EY, US



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The sensors that monitor systems inside digital products are generating vast amounts of diagnostic trouble codes[1] and operational machine data.[2] This data, which is communicated to manufacturers using telematics,[3] also provides information to its operators on machine health and status. Now, data scientists can use reliability-based advanced analytics to improve the detection, diagnoses and prediction of in-service product failures – that could reduce detection to correction (D2C) cycle times by months, or even years.

Most manufacturers are still using warranty-based submissions to detect and analyze failure events, which can result in the following challenges:

- Submissions can take 90 to 120 days to process for analysis.
- Specific in-service cycles, when the problem occurred, or operating conditions at the time of the issue are not represented.
- In-service failures that have the greatest negative impact to a product's reliability are not represented. Some failures that cause downtime may not generate a warranty or service call.
- Incident or failure rate analysis may not detect an emerging issue until it is reported on a Pareto chart.

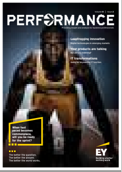
1. Diagnostic trouble codes (DTC) identify and communicate where and what onboard problems exist on a machine or vehicle.
2. Operational machine measures are the absolute value provided by machine and vehicle sensors (e.g., temperature, pressure and speed).
3. Telematics is the transmission of machine data to a remote data consumer. It has grown increasingly prevalent as telecommunication has become more reliable and less expensive.

Rio Tinto has approx. **900** heavy mobile equipment (HME) trucks.

Each truck has approx. **200** sensors.

The entire fleet provides approx. **4.9** terabytes of data per day.

Source: Rio Tinto, Internet of things world forum, 2014, http://www.riotinto.com/documents/141014_Presentation_Internet_of_Things_World_Forum_John_McGagh.pdf, accessed March 2016.



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The speed that manufacturers develop or improve their ability to listen to their intelligent products, generate insights and integrate this information into action will provide tangible benefits that, ultimately, increase shareholder value.

Increasing amounts of products are evolving from having sensors that simply inform operators, for example, the engine is overheating to communicating the health and status of an entire fleet of machines. In response, manufacturers need to be ready to manage and use this data to drive continuous improvements to existing and new products. Armed with this intelligence, engineering, manufacturing and after-sales service stakeholders can improve product quality and reliability, reduce costs, strengthen customer relationships and loyalty, and increase equipment and parts sales.

The speed that manufacturers develop or improve their ability to listen to their intelligent products, generate insights and integrate this information into action will provide tangible benefits that, ultimately, increase shareholder value.

The digital product and its digital twin

Machines with onboard controllers connected to remote data repositories via telematics are collectively called "digital products" and comprise what is referred to as the internet of things (IoT). Digital products have enabled comprehensive monitoring of a machine's health and operations, allowing companies and customers to track a product's operating characteristics, history and usage.

In the last decade, the concept of the "digital twin" has also emerged. As defined by Dr. Michael Grieves,[4] "The concept of a virtual, digital equivalent to a physical product is the digital twin." The model has three main elements:

4. Dr. M. Grieves, *Digital twin: manufacturing excellence through virtual factory replication*, 2014, http://innovate.fit.edu/plm/documents/doc_mgr/912/1411.0_Digital_Twin_White_Paper_Dr_Grieves.pdf, accessed April 2016.

Figure 1: Perceived risks from the internet of things

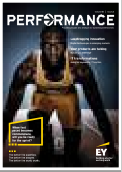
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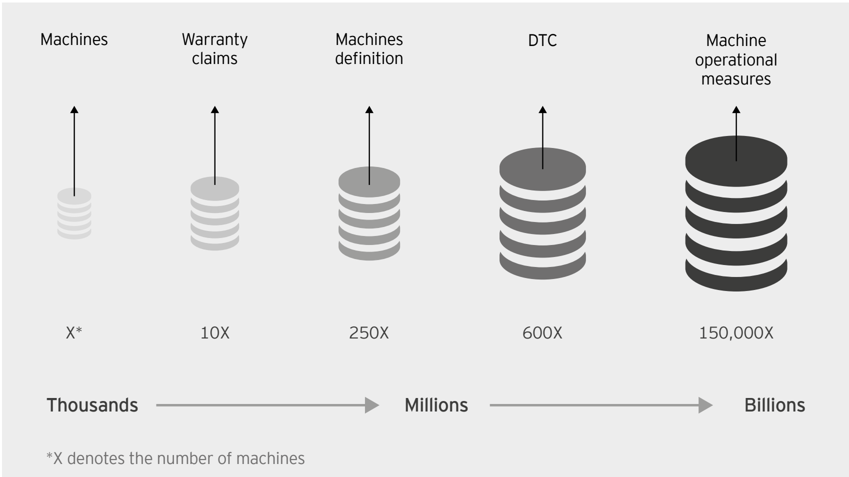
Figure 2: Relative sizes of data types



1. Physical products in real space
2. Virtual products in virtual space
3. The connections of data and information that tie the virtual and real products together

The unified repository (UR) provides the link between the physical in-service world of the product and its digital twin, operating in a virtual, data-driven environment. Figure 3 shows all the potential interconnections between the UR, the product and the digital twin via data from the various internal enterprise systems, external sources and that generated by the digital product itself.

Data sources

The primary content for the digital twin is the data generated by the digital product over its life cycle. Figure 2 provides a relative comparison of some of the data sources. This data will be in a variety of formats:

- **Transmitted data** – digital products transmit two major types of data:
  - **Health status** – machines communicate health status through diagnostic trouble codes (DTCs). A DTC is a stored location- and time-stamped response to an issue in a machine or vehicle. It occurs when there is a violation of control limit thresholds. These codes can be specific to a manufacturer or generic, as in the case of the automotive industry's common onboard diagnostic classification (OBD-II).
  - **Operational machine measures** – these provide a detailed, time-ordered view of specific machine conditions, such as oil pressure, flow rates or temperatures. When combined with health status data, operational measures can deliver critical information to diagnose the cause of a specific failure, or provide additional insights to a warranty or service submission. Transmitted data will account for the majority of data managed in the UR.
- **Enterprise data** – in addition to broadcasting health and operating data, a digital product generates a vast amount of metadata during its life cycle. Connecting all of these data sources together defines the product's DNA for the "digital twin."

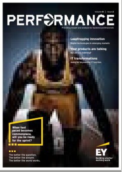


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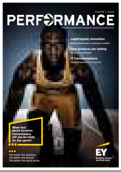
Figure 3: The unified repository and the digital twin



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> By leveraging the data generated by digital products, a manufacturer can reduce the overall detection to correction cycle time by 50%–90%.

- **External data** – these sources provide additional attributes that can be used to augment understanding of a machine's health status and operational measures. Some examples of external data sources include weather, temperature, social media feeds, traffic patterns, geographical terrain and sustainment inventories. External data can help aid in answering questions such as whether moisture affects operation or terrain impedes performance.

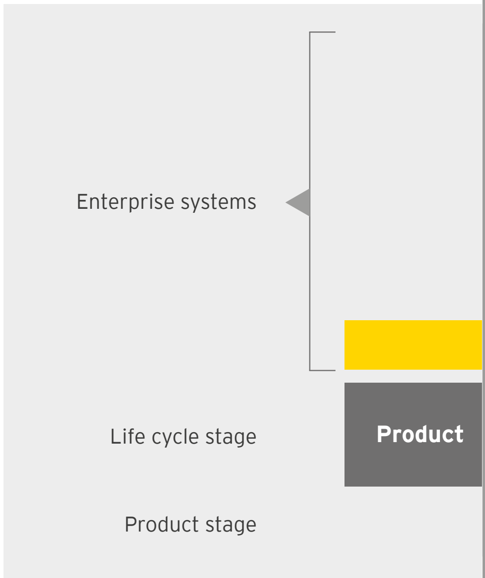
But the sheer volume of data generated makes analysis a major challenge. According to one North American vehicle manufacturer, a vehicle operating 6 to 10 hours can generate up to a petabyte of data per day.

There are several ways to address this issue. Some organizations store telematics data in inadequate conventional repositories – resulting in data being lost because it will not fit in the available space. Others try to reduce the data volume by recording it in units of hours instead of minutes, or even seconds. Often, despite these efforts, databases still grow at unmanageable rates and struggle to provide the responsiveness required to analyze fleet data. Many manufacturers have, simply, yet to determine what to do with their machine data.

Detection to correction

Because of the data warehousing challenge, as well as inadequate analytical tools and technical expertise, many digital product manufacturers still use traditional means, such as warranty submission analysis, to detect and diagnose product issues. This leads to significant D2C cycle times. One North American automotive manufacturer indicated that just one day on a major product issue can equate to US$1m in warranty and recall related costs. As demonstrated in Figure 5, the time associated to detect, analyze and communicate a product issue, using IoT-enabled processes, could be significant.

By leveraging the data generated by digital products, a manufacturer can reduce the overall D2C cycle time by 50%–90%. This means that a problem with a machine is addressed within the warranty submission process, effectively bypassing the associated delays. Instead of a warranty claim signaling that a problem has occurred, reliability-based predictive analytics provide the signal by which a failure can be detected and prioritized.



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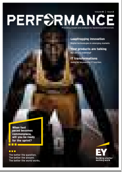


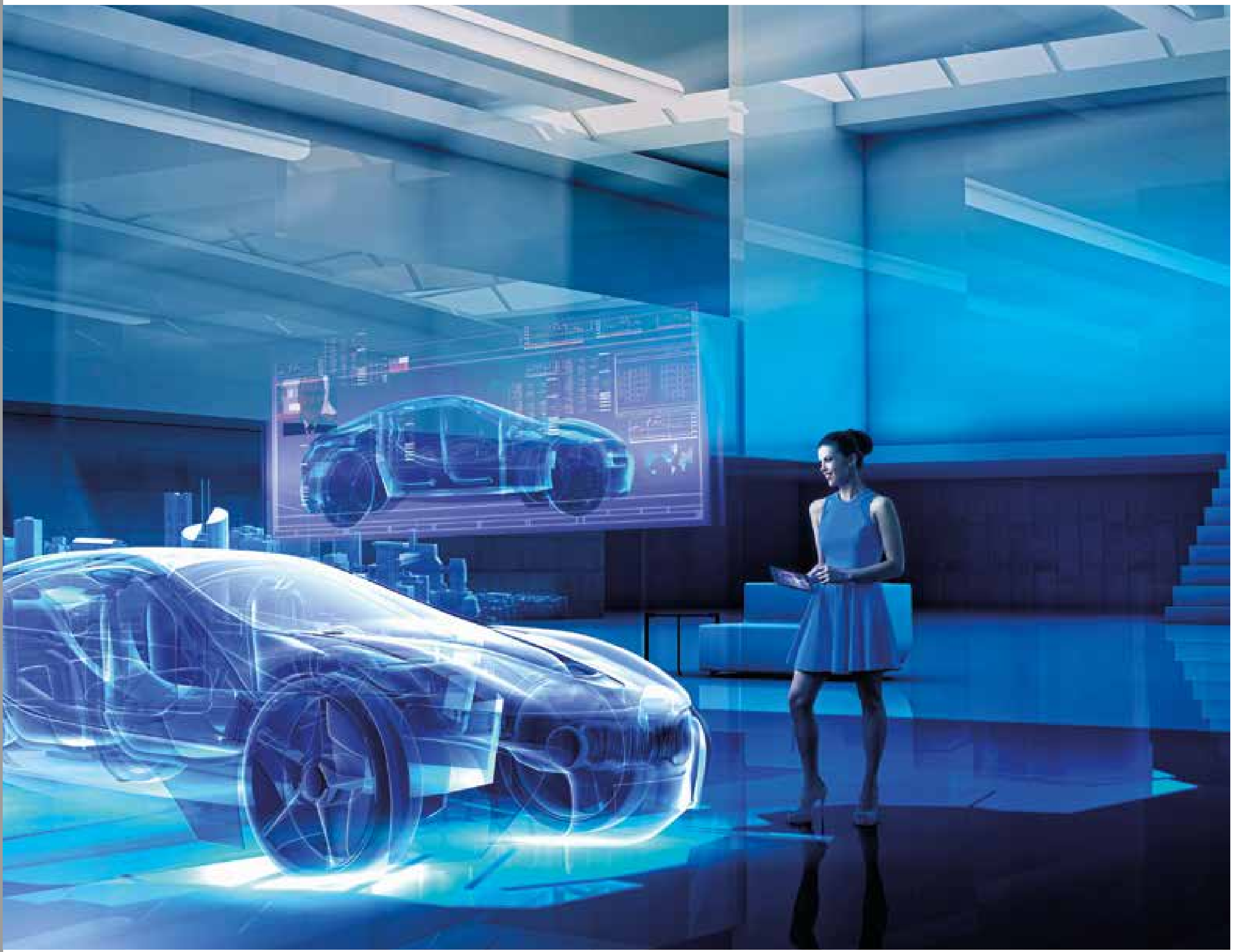
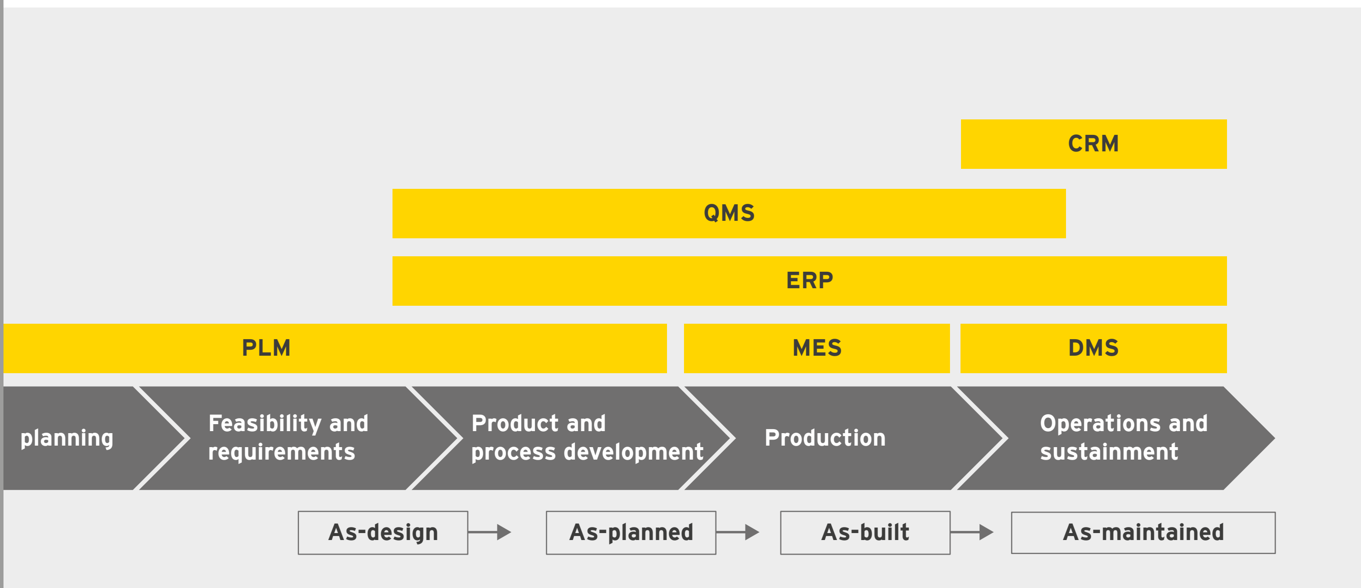


Figure 4: Data systems used throughout a product's life cycle



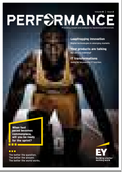


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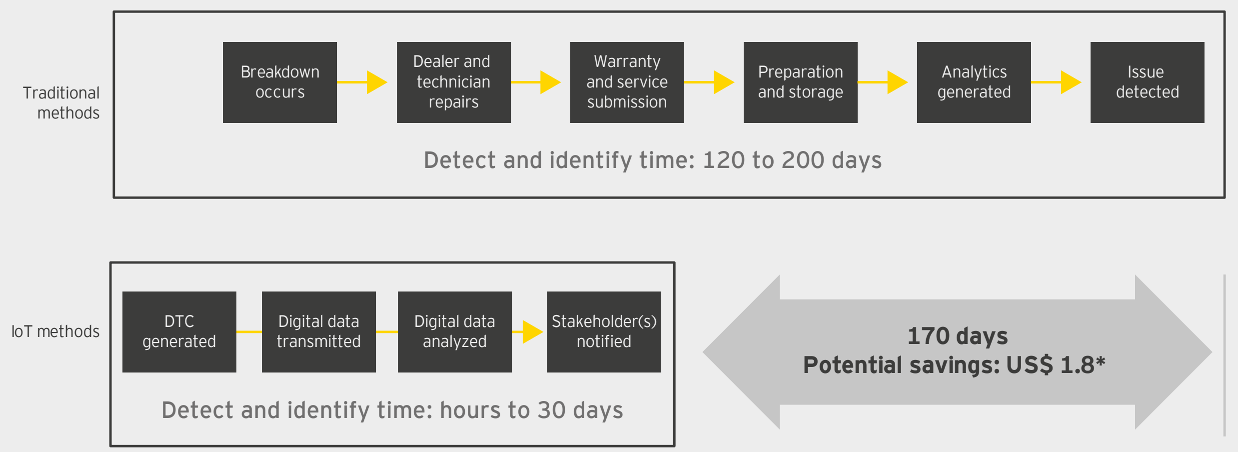
Figure 5: Improvement in D2C cycle times

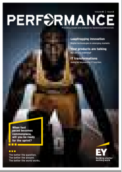


*Savings calculation assumes daily production volume of 100, average claim cost of US$225 and failure rate of 50%, i.e., 100 x 50% x US$225 x 164 = US$1.845m.

Three key components enable a digital product manufacturer to harness its data and deliver insights:

- **Data repositories and infrastructure** – by far the largest innovation in big data storage has been Apache Hadoop, an open source, Java-based software framework designed to sit above a server farm of commodity computers. Hadoop enables quick processing of large amounts of data by distributing data storage and processing activity across the network. While the software is free, implementation requires expertise and physical space for servers. To quickly mine insights from the entirety of a manufacturer's digital product data, a Hadoop implementation, or some similar framework, is essential.
- **Advanced analytics** – turning the data in the UR into actionable insights requires advanced analytic techniques. Figure 3 provides an overview of the various techniques used to improve reliability and quality, and for reducing costs relating to nonconformance.
- **Reliability engineering analysis** – manufacturers require the right tools for converting the various data sources into actionable insights. The primary tool for assessing the potential impact and criticality of failures is product reliability analysis, i.e., the probability that a device will perform its required function, subject to stated conditions, for a specific period of time. It is quantified as "mean time between failures" for a repairable product and "mean time to failure" for non-repairable products.

Product reliability analysis involves determining the rate or speed at which a product reaches the end of its estimated useful life. This type of analysis is referred to accelerated failure



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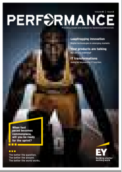
> Intelligent digital products can drive actionable insights if the information is integrated across the value chain of stakeholders responsible for developing, manufacturing and sustaining those products.

time (AFT). In AFT models, the speed of failure can be accelerated or decelerated by accounting for time-dependent and time-independent covariates:

- **Time-independent** – the characteristics of a product (such as build configuration) that result in an AFT.
- **Time-dependent** – the operating conditions (such as temperature or hydraulics pressure) that result in an AFT.

The advantage of AFT, compared with other types of analysis, is that the resulting conclusions have close ties to engineering. However, because of the



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large amounts of data, the challenge is identifying the covariates that significantly impact the failure rate. Data mining permits identification of the covariates that accelerate or decelerate the life of a machine in an automatic fashion, allowing unique insights from the extremely large volume of data collected by machines, through the IoT, across their lives.

By making monitoring of machines more accessible, the IoT not only enables manufacturers to detect which operating conditions lead a product to reach the end of its life sooner, it also enables more parts within a product to be monitored. This results in an increase in the amount of data that must be digested in the D2C processes. It therefore becomes essential to offer D2C experts an insightful view that permits prioritization of part failures.

RAAK algorithm

The RAAK algorithm offers a unique approach to help identify and prioritize failures across a large number. It aggregates metrics from the AFT models, as well as other data, presenting each failure as a bubble in a chart – the size of the bubble indicates how critical the failure is. The metrics comprise impact, importance, predictive likelihood and propagation frequency of failures. Implementing the RAAK algorithm opens the wealth of information that is available from leveraging the IoT to a much wider audience and far more quickly than many other methods, as no training in AFT is required.

The volume of the product being monitored drives the frequency of how often the data is updated. Because the data is continuously flowing in from the in-service digital products, it can be assessed daily. Typically, a more frequent analysis is done at product launch to identify early life failures and emerging issues.

The RAAK algorithm visualization has two primary benefits. First, it allows deep in-service failure analysis. As a result of the fact it can utilize the full fleet dataset, it displays patterns in aggregate failures as well as having the capability for in-depth, single-machine analysis. However, if the data is collected and analyzed in near-real time, the algorithm provides insights into emerging and developing failures. This enables manufacturers to initiate corrective action, such as part replacement, before the issue becomes a costly problem.

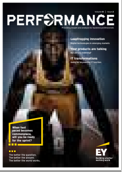
The future is now

Intelligent digital products can drive actionable insights if the information is integrated across the value chain of stakeholders responsible for developing, manufacturing and sustaining those products.

As more connected objects or "things" are embedded in industrial, automotive and aerospace products, the management and use of machine diagnostic data will be critical to improving the reliability of existing and future products, while reducing the cost of nonconformance.

Listening to your products and interpreting what they are saying will introduce technology, process and organizational challenges that can seem overwhelming. Here are some actions that can help make this journey manageable:

- **Establish a business-driven unified data environment to enable the digital twin –** start by preparing a list of measurable questions that the organization is trying to answer: what systems have the greatest negative impact on product reliability within the first 100 hours in service? What sequence of events lead up to or follow a product failure? Is there anything unique about the product's configuration, manufacturing location, component supplier, build date or operating conditions that could have caused the failure? Manufacturers



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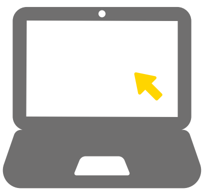
Intelligent

Products generating large volumes of operational and environmental data



Insight

Advanced analytics and data mining using data generated by digital products and processes

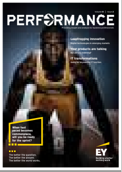
Integration

Synchronized information across the value chain

should avoid the costly and time-consuming endeavor of integrating millions or billions of records prior to understanding the questions they really need to answer.

- **Reach functional alignment on product reliability** – some manufacturers may use different data sources to establish product reliability-related metrics. For example, one organization might use warranty data to calculate failures per machine, while another may use DTCs to determine mean time between failures (MTBF) or mean time to fail (MTTF). The manufacturer uses these measures and others to detect, select and prioritize the failures that require corrective actions. Both approaches may be necessary, depending on the type of failure and the relationships established by the systems and quality engineers. The key for manufacturers is to establish product reliability metric(s) across various functions, ensuring a holistic approach to reducing D2C.
- **Embrace systems engineering-based product reliability analysis** – leading manufacturers have tools and processes that systemically create and manage the relationships between a machine's systems, components, software, service parts and onboard diagnostics used to measure and detect a system fault. For example, several manufacturers have been able to detect an issue, as a result of DTCs, months before the problem emerging as a detectable warranty claim.

- **Close the loop** – the corrective action insights developed from advanced analytics need to drive the allocation of resources and investments required to mitigate a product issue – whether in the design, manufacture or sustainment of the product. The root cause and corrective actions need to be fed back into the system, design and



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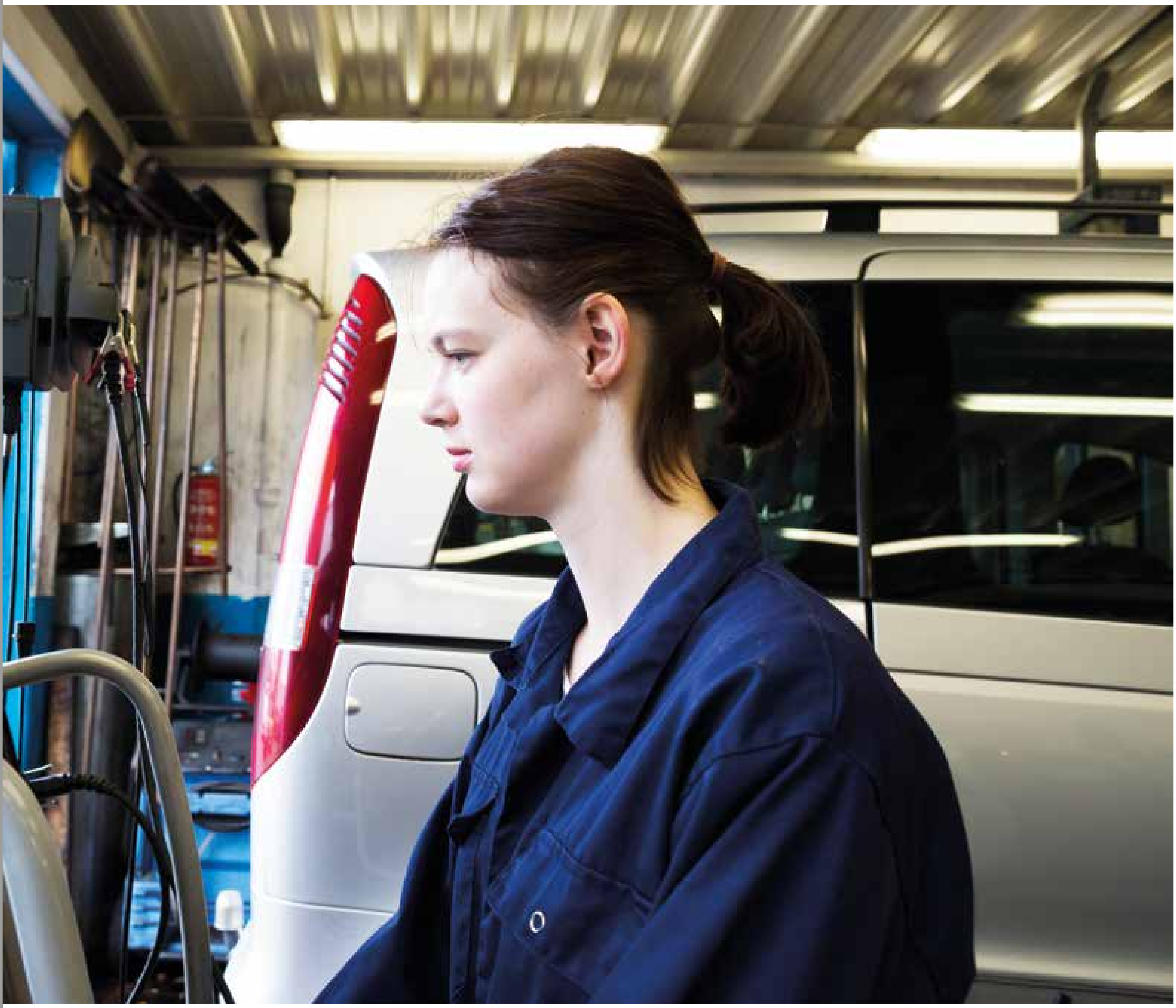

process FMEAs[5] to prevent future problems, and improve the design and processes for next-generation products, as well as manufacturing improvements.

- **Don't go it alone** – the process, technology and organizational changes required comprise a journey for which you might be best served by having someone to help show you the way.

Many leading manufacturers have had early success in this area by engaging various partners to assist them in the development and deployment of parts of or, sometimes, the entire strategy. ■

5. Failure mode effects analysis (FMEAs).