

Manufacturing the Next Generation of Connected and Electrified Vehicle

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ABSTRACT

Increasing electrification of the vehicle as well as the demands of increased connectivity presents automotive manufacturers with formidable challenges. Automakers and suppliers likely will encounter three practices that will influence how they develop and manufacture highly connected vehicles and future e-mobility platforms: 1) hierarchical production processes in fixed footprints that do not share data freely; 2) lack of real-time, in-line quality inspection and correction processes for complex miniaturized electronic components; and 3) floor to enterprise resource and execution systems that can collect, analyze and respond to rapidly changing production needs.

While the automotive manufacturing industry has implemented sensors, robotics and computerized automation for decades, these systems largely are organized in a hierarchical fashion within individual data silos, and often in a closed, hard-wired network environment largely disconnected from IT and enterprise service-based networks. To complicate matters, automotive and industrial standard manufacturing equipment is still largely constrained by a large installed base of legacy workflow, equipment and standards.

This paper explores some possible directions how automakers and suppliers will need to change and what considerations they will need to account for with respect to data into order to manufacture the next generation of connected and electrified vehicles.

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INTRODUCTION

There is little question the drive to achieve sustainable and connected transportation has emerged as a vital mission in recent years. New Corporate Average Fuel Economy (CAFE) [1], National Highway Traffic and Safety Administration (NHTSA) [2] and Greenhouse Gas (GHG) [3] standards represent a dramatic change from previously announced policies. In addition, announcements from the Department of Transportation (DOT) [4] and by several automakers, suppliers and new entrants suggest significant government and private-sector interest into pursuing technology in this space [5].

While various stakeholders negotiate the rules of engagement for connected and self-driving vehicles [6,7], the marketplace is rapidly evolving and conventional models of vehicle ownership are being challenged. In addition to near-term technologies such as location awareness and collision mitigation, new usage frameworks are being created through concepts such as vehicle-to-infrastructure (V2I) communication, and vehicle-to-vehicle (V2V) communication [8,9].

These frameworks may be combined with "the Internet of Things" (IoT) [10], "the Internet of Things in Motion" (IoTM) [11], "the Industrial Internet of Things" (IIoT)¹ [12], and "the Internet of Everything" (IoE) [13] to exponentially increase innovation and

create new industries and products. Alongside these new industries and applications come the challenges associated with integrating new and old manufacturing processes, paradigms, and techniques.

While many of these initiatives are in their initial stages and the perspective of the consumer has yet to be tested, the impact on vehicle architecture is visible. The increased use of electronics, high voltage systems², and advanced electrochemical based energy storage systems such as Lithium-Ion based technology are set to play a large role in future vehicle applications. As the presence of on-board diagnostics, electronic modules, and electronic monitoring systems increases coupled with the increased focus on formalized functional safety procedures, such as ISO 26262 [14], the average vehicle continues to evolve into an ever complex computing system with over 40,000 plus individual parts and several million lines of code [15].

The majority of industry experts agree these innovations are not amenable to a one size fits all strategy and that the new manufacturing landscape needs more flexibility [16,17,18]. This reality has produced a new dynamic market relationship between automakers and suppliers changing the way data is used across the supply chain.

1. German Trade and Invest (GTAI) coined the term Industrie 4.0 - see <http://www.gtai.de/GTAI/Navigation/EN/Invest/Industries/Smarter-business/smart-products-industrie-4.0.t=industrie-40.did=589872.html> for more information

2. For the purpose of this paper, this includes electrical systems and components operating at or over 48VDC.

THE NEW MANUFACTURING MARKET DYNAMIC

During the Great Recession, automakers and suppliers reduced their liabilities, mitigated their regional exposure, and rationalized capacity [15]. Several Chinese and consumer technology suppliers, with systems and cash on hand, gained a significant foothold in the North America automotive component market [19,20]. Looking to gain new revenue, many traditional automakers and suppliers sought to reposition themselves as mobility solution providers rather than vehicle product providers [15]. These factors coupled with the changing consumer needs have resulted in new entrants and new business models that are fundamentally changing the North American automotive industry.

Optimizing Capacity

Automotive history in North America is a story of boom and bust - characterized by periods of rapid plant expansion as sales surged, followed by market downturns that left automakers and their suppliers with underused plants, idled thousands of workers, and burdened dealers with significant excess vehicle inventory. As the economy continues to recover from the 2008 downturn, automakers and automotive suppliers are still reluctant to expand to meet near-term industry demands. In fact, the average incremental increase in production capacity is only expected to grow between 2 to 4 percent over the next 10 years [21]. With higher levels of capacity utilization, many companies are now strategically investing in incremental capacity expansion both in the United States and abroad particularly in regions where aggregate cost (labor, quality, expertise) outweighs the cost of shipping product.

In fact, many automotive manufacturing companies also are looking to re-shore jobs, bringing previously outsourced jobs back to the United States. A major reason for reshoring jobs is that the wages in formerly low-cost countries have increased while real wages have seen little growth in the United States. New trade agreements [22], port infrastructure on the East Coast [23], and improved logistics [24] have allowed manufacturers from high cost areas such as Western Europe to look to North America as a viable manufacturing alternative to displace manufacturing back home. The Nissan Murano, Lexus ES and Honda Fit all once were imported for domestic sale from Japan but now are produced in North America [25]. Likewise, Mercedes-Benz now makes the C class in Alabama and has cut back production of that vehicle in Germany, arguably where labor costs are higher [25].

Advent of the Specialist

Along with this re-evaluation of manufacturing locations are also expansion and shifting of the skills needed to manufacture increasingly complicated and varying vehicle technologies. Given the sheer number and diversity of parts within a vehicle, making high-quality components at scale requires a lot of in-depth process knowledge and on-going research and development [26]. With current market pressures, automotive manufacturers are investigating whether they should concentrate on product management and marketing while contracting design, development, and production to specialists in much the way the semiconductor industry operates

today [27,28]. Having specific high-impact components and subsystems made by specialist companies with expertise in their respective fields allows an automaker to ensure high-quality without developing the in-house skills and expertise required for producing these new electrified and connected technologies. This approach also allows for resource sharing amongst several neighboring products and projects, optimizing their output.

Although increasing specialist suppliers is an overall trend [29], vehicle manufacturers and their suppliers are also beginning to consider certain new components part of their "core capabilities" and thus, are working to enhance their own capabilities to create a competitive advantage. Several commercial software and technology companies have started to build vehicles [5,30], while mergers and acquisitions around core material, process, or design competencies within the traditional vehicle supplier framework have become a common place. As a result, many suppliers can no longer be adequately described through the legacy tier system, but as specialists with wide and distributed roots.

Regulatory and Compliance

Adopting connected and electrified technologies requires a robust manufacturing control and assessment strategy consisting of electronics, software, features, and components not traditionally ascribed to the vehicle platform. 2015 may prove to be a record year for recalls, eclipsing 2014 where an almost 64 million vehicles were recalled for safety design related issues [31]. Potential applications where connected and smart electronics may provide solutions are staggering; particularly where connected and fail safe operation is desired.

Proactive safety technologies and sound governance are critical to reducing fatalities and injuries [32]. At the manufacturing level, the Occupational Safety and Health Administration (OSHA) has recently launched a Regional Emphasis Program (REP) focused on enforcement on automotive suppliers in the southeast that supply engines, airbags, trim, or any other automotive products [33]. The stakes are very high as fines and negative publicity readily equate to lost sales.

In addition to safety compliance, automakers must follow regulated operational practices as defined in the U.S. Sarbanes-Oxley³ [34], European End-of-Life Vehicle (ELV)⁴ [35], and U.S. Dodd-Frank Act Conflict Minerals rule⁵ [36]. Automakers and their suppliers also must follow increasingly regulated practices for hazardous substances. Regulations such as Restriction of Hazardous Substances

3. U.S. companies are held responsible for actions taken on company behalf by contractors, lawyers, and consultants, regardless of whether they are acting on specific company direction.

4. Automakers (and suppliers) are responsible for heavy metals in a vehicle through reclamation of the vehicle, and may incur penalties whether aware of these materials or not.

5. U.S. companies are required to trace the origin of common, non-hazardous materials back to the smelter where created and the ores from which they were produced.

(RoHS)⁶ [37], Waste Electrical and Electronic Equipment (WEEE)⁷ [38], and Registration, Evaluation, Authorization and Restriction of Chemicals (REACH)⁸ [39] are increasingly being enforced globally.

As a result, automakers and their suppliers are automating and embracing enterprise-wide supply chain tracking and identification not only to facilitate inventory, but also to ensure compliance [40]. Over the past 10 years, this primarily has been a task of data capture and storage; however as supply chains and automotive parts become more sophisticated, the need for data processing down to the manufacturing floor level has become paramount. Manufacturers are looking for new ways to ensure granular traceability and accountability. This has led to an increased interest in tracking, vision and measurement technologies on the production floor.

Demand for Autonomous Intelligence

Since the “Industrie 4.0” term was coined over 30 years ago [5] and since IoT was first defined over 25 years ago [9], manufacturers have worked to implement basic and connected manufacturing concepts in a manner that grants return on investment (ROI). The automotive business is primarily a capital intensive business with high financial and regulatory barriers to entry. Automotive component and vehicle assembly lines are some of the most complex and complicated production systems in the world [10]. Line and process design and optimization are principal factors in developing and sustaining every manufacturing system - whether job, batch, cellular, mass, or line [11]. These are often dictated by legacy - either tradition or by investment.

Automotive manufacturers have continued to reduce waste and variability in their production processes while improving product quality and yield (the amount of output per unit of input) by implementing lean manufacturing and Six Sigma programs [41,42]. While success varied from manufacturer to manufacturer, it gradually became clear that to achieve peak efficiency, another method was required. In capital intensive processing environments with high barriers to entry (automotive, semiconductor, pharmaceuticals, chemicals, and mining), extreme swings in product demand and variability are facts of life. Being lean with one model may not necessarily benefit the next. Some manufacturers have defaulted to a pseudo - Just-in-Case (JIC) philosophy to complement the Just-In-Time (JIT) methodology [43] to compensate; however, this becomes prohibitively expensive when applied to all manufacturing processes within a plant.

Given the complexity of production activities that influence yield, automotive manufacturers and their suppliers have begun to seek a more granular approach to diagnosing and correcting process flaws. For success, it must be proactive and expandable. Advanced analytics provides just such an approach. However, to be sufficiently successful with analytics, one needs data, preferably automated data available in

real-time that is adaptable to technological changes. Capturing this data can be quite difficult for a manufacturer encumbered by legacy systems as it demands autonomous intelligence.

THE CHANGING VEHICLE LANDSCAPE

The vehicle landscape is changing. Like the legacy automotive production line, many different applications and devices will need to work with a range of stakeholders that is evolving at a pace unseen in the past [44]. Non-traditional devices will need to be connected in new ways, and smart sensors will create new opportunities. Data will need to have an ROI and will require aggregation, organization, connectivity and accessibility in the greater ecosystem.

Automotive R&D spending and requirements are changing to meet connectivity and electrification demands. Areas of particular focus are powertrain, materials, infotainment, and electronics. Powertrain improvements and new material processes comprise strategies for automakers to achieve greater performance and utility while meeting regulatory targets. Automakers now spend an average of \$1,200 for R&D per vehicle manufactured [45]. At the same time, technology specialist suppliers are slowly starting to take over the design process for particular components [29]. Improved fuel economy and emissions targets continue to drive improvements in propulsion, light weighting, aerodynamics, and attributes like steering and braking. Proactive safety devices are gaining traction with automakers, consumers and regulators alike. Consumer preferences, increasing congestion, and more mobility choices mean that vehicles contain more technologies to attract buyers.

Most vehicle architecture changes have been driven by improvements in semiconductor technology over the last 50 to 60 years. Today, it is the single largest driver of change with nearly every automotive design innovation arising from developments in electronics, and connectivity is viewed as the must have luxury feature. Innovations that were once restricted to luxury brands are being implemented in more standard vehicles as costs continue to fall and innovation accelerates [46]. Research data suggests that semiconductor content per vehicle is likely to grow from \$315 million USD in 2012 to near \$410 million USD by 2017 [47]. The overall cost of electronics in vehicle is expected to reach more than 32 percent by 2017 [48].

The Vehicle as a Supercomputer

In many aspects, the vehicle has become the new supercomputer. At the 2015 Consumer Electronics Show (CES) in Las Vegas, Nevada, Nvidia introduced two new computers for the vehicle - one designed for cockpit (in dash driver) information and the other targeted at autopilot or autonomous driving functions [49]. These innovations were powered by Nvidia's Tegra X1 processor, which can process data at 2.3 teraflops - twice the computing power of the most powerful supercomputer in the world in the year 2000 [50]. Supplementing this computing power is software.

Advances in software are powering rapid changes. This trend is accelerating innovation as more of the vehicle architecture is based on software, either implicitly or explicitly. Digital ecosystems, whether in-vehicle or in manufacturing, make it possible to replicate

6. RoHS in electrical and electronic equipment is similar to ELV, but applies to virtually all products sold in the E.U., and other regions are quickly adopting variations.

7. WEEE is the partner to RoHS, and sets collection, recycling and recovery targets for all types of electrical and electronic goods in the E.U.

8. REACH restricts use of over 150 different, common manufacturing chemicals, and applies to all goods sold or manufactured in the E.U., again with variations occurring elsewhere.