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From Internal Combustion to Battery Electric Vehicles:
Enabling Digital Manufacturing

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The Center for Automotive Research is an independent non-profit that produces industry-driven research and fosters dialogue on critical issues facing the automotive industry and its impact on the U.S. economy and society. CAR researchers closely track current and future global automotive industry and technology trends and assess their impacts. CAR researchers also study international collaborations and stay abreast of changes in international trade and regulatory environments, the development of technology standards, and the deployment of new vehicle technologies.

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Executive Summary

Today's automotive industry faces a historical shift from internal combustion engine (ICE) vehicles to battery electric vehicles (BEV). This shift is profound, dramatically altering the structure of the automotive value chain and the vehicle manufacturing process. This conversion occurs as the industry undergoes a digital transformation. The ICE to BEV project builds a 2020 CAR project on digital transformation by considering the implications of a transition in propulsion technology and a digital transformation in manufacturing for the North American automotive sector.

The project begins to identify the "white spaces" in manufacturing enabled by a transition to BEV and digital manufacturing. For this project, the research team conducted long-form interviews to support a targeted technology survey of manufacturing (operations) and information technology decision-makers at five vehicle manufacturers. CAR researchers also conducted interviews with leading labor representatives. The gathered information provides a snapshot of how the North American automotive industry is digitally converting vehicle manufacturing and the critical role of BEVs in that conversion.

CAR considered three building blocks to help place structure around the digital transformation enabled by BEV manufacturing: technology (production and digital) process (scheduling, throughput, and quality assurance) and organizational (alignment and skills). CAR researchers also investigate the role of partners in the transition.

Perhaps the most challenging aspect of the ICE to BEV transformation is the sheer breadth of changes to the production process - from new BEV-specific parts, processes, and suppliers to new technology opportunities made possible via digital technologies. Survey results identified the production of the battery cell/module/pack and the selection of suppliers as the primary challenge of the new BEV manufacturing paradigm.

A common theme from the interviews was the uncertainty of demand for BEVs. Several manufacturers are pursuing dual-mode production lines, which will require more flexibility, specifically for ICE and BEV configurations. Digital tools are being implemented to support planning. Based on the survey results, improved supply chain integration and more timely data are the most common ingredients being leveraged for process improvements in production scheduling. Respondents indicated enhanced supplier integration would be needed as EV production increases to avoid disruption and fully leverage analytics to optimize production throughput rapidly.

OEM and Organized Labor respondents agreed that the rate of change in the automotive industry is driving the need for enhanced skills. However, a recurring theme from interviewees punctuated this point by pointing out that these skills were digital transformation-related, much more than being only BEV-related. In other words, skills associated with new digital technologies (i.e., data management requirements, advanced analytics, machine learning, and automation) remain a development priority. Still, they pertain equally to both BEV and ICE vehicles.

While automakers have specified the need to develop new digital transformation and production skills internally within their organizations, they also recognize that there are focused capabilities in which partners can most definitely enhance these efforts. The research concluded that product and service partners in the areas of hardware/software supply, business process consulting, technology consulting, and IT consulting were dispersed. However, “very important” (the very best significance level) rankings did appear at least somewhat in all three business process areas surveyed and across the different partner products and services. This is not entirely surprising, given the current marketplace’s high demand for digital transformation skills.

Introduction

Today’s automotive industry faces a historical shift from internal combustion engine (ICE) vehicles to battery electric vehicles (BEV). This shift is profound, dramatically altering the structure of the automotive propulsion system value chain and manufacturing process. The propulsion value chain is changing from one dominated by ICE-based OEMs and suppliers to a new BEV-based value chain comprising BEV offerings from existing OEMs and suppliers. Additionally, newly emergent “BEV-only” OEMs, e.g., Tesla, Rivian, Lucid, and suppliers, e.g., CATL LG Energy Solutions and American Battery Solutions (ABS), have added to a broad competitive landscape.

While much recent discussion has been about the new entrants, the shift in propulsion technologies has profoundly affected traditional manufacturers and propulsion suppliers. Delphi’s (renamed Aptiv) 2017 spin-out of its propulsion group Delphi Technologies (later acquired by BorgWarner) is an example of the change within the propulsion supply sector. Ford’s announcement to separate its ICE development and manufacturing into Ford Blue and its BEV development into Ford Model e is a recent example of remarkable change.

The BEV manufacturing conversion occurs as the industry undergoes a digital transformation. The digital transformation of automotive manufacturing is complex, massive, and rapidly evolving. CAR considered three building blocks to help place structure around the digital transformation: technology, process, and organizational, i.e., people and change. Many often approach digital transformation as a technology-driven challenge. However, technology is only one aspect determining success in digitally transforming manufacturing. Technology adoption often creates problems without a coherent process and organizational change plan. CAR published a report in 2020 that considered the importance of the strategic vision connecting the technology, process, and organization elements of digitally transforming vehicle manufacturing in the automotive sector.[1]

The ICE to BEV project follows the 2020 effort by considering the combined implications of a transition in propulsion and a digital transformation in manufacturing in the North American automotive sector. It also explores the opportunities the transition creates for rapidly advancing data-driven manufacturing. The project attempts to identify the "white spaces" in manufacturing enabled by a transition to BEV and digital manufacturing.

This research effort aims to view automotive industry-wide challenges and opportunities associated with the shift to BEV manufacturing. We do not seek to collect proprietary or confidential information driving competitive advantage among companies but rather to provide a mutually beneficial "2022 snapshot" of industry challenges and practices in managing the historical shift from ICE to BEV production.

The shift from ICE to BEV-based vehicles has important implications for automotive manufacturing - impacting people, processes, and technology opportunities across the automotive value chain. At this nascent and rapidly evolving point in BEV history, automotive OEMs and suppliers are charting new ground, often working independently and in isolation from similar efforts across the industry value chain. While this can sometimes be a source of competitive advantage, this often leads to missed opportunities for understanding mutual challenges and leveraging best practices in adapting to the new BEV reality. The CAR ICE to BEV project is a solid first step to understanding those challenges and creating a proactive stakeholder-led effort to address them.

Methodology

The research team conducted long-form interviews to support a targeted technology survey of manufacturing (operations) and information technology decision-makers at five vehicle manufacturers.

The combined inputs enabled the research team to gather a snapshot of how the North American automotive industry is digitally transforming vehicle manufacturing and the role BEVs play in that transformation. The industry participants included multiple representatives from FOUR traditional vehicle manufacturers and one new entrant. The respondents agreed to participate under the condition of no attribution. The report will compare and contrast the survey responses for each OEM but will not identify the company.

The number of companies participating is low and not necessarily representative of industry trends. However, three points are essential. First, the respondents hold positions at their companies' highest manufacturing and information technology groups. These individuals set the vision for their respective companies and demonstrated an impressive knowledge of the challenges

1. Smith, B., Dennis, E.P., Modi, S., and Nriagu, E (2020). The State of Industry X in Automotive, Center for Automotive Research, Ann Arbor, MI.

and opportunities. Second, the traditional companies selected have a long history of electrification and digital transformation. While identifying "leaders" is challenging, these companies have a proven track record in both areas. Finally, the interview discussions and survey responses strongly indicate that the process can serve as a foundation for future work to support the industry in the conversion. The research team believes the project is an outstanding first step in a much more comprehensive effort.

ICE to BEV Production - Most Critical Challenges

Perhaps the most challenging aspect of the ICE to BEV transformation is the sheer breadth of changes to the production process - from new BEV-specific parts, processes, and suppliers to new technology opportunities made possible via digital technologies.

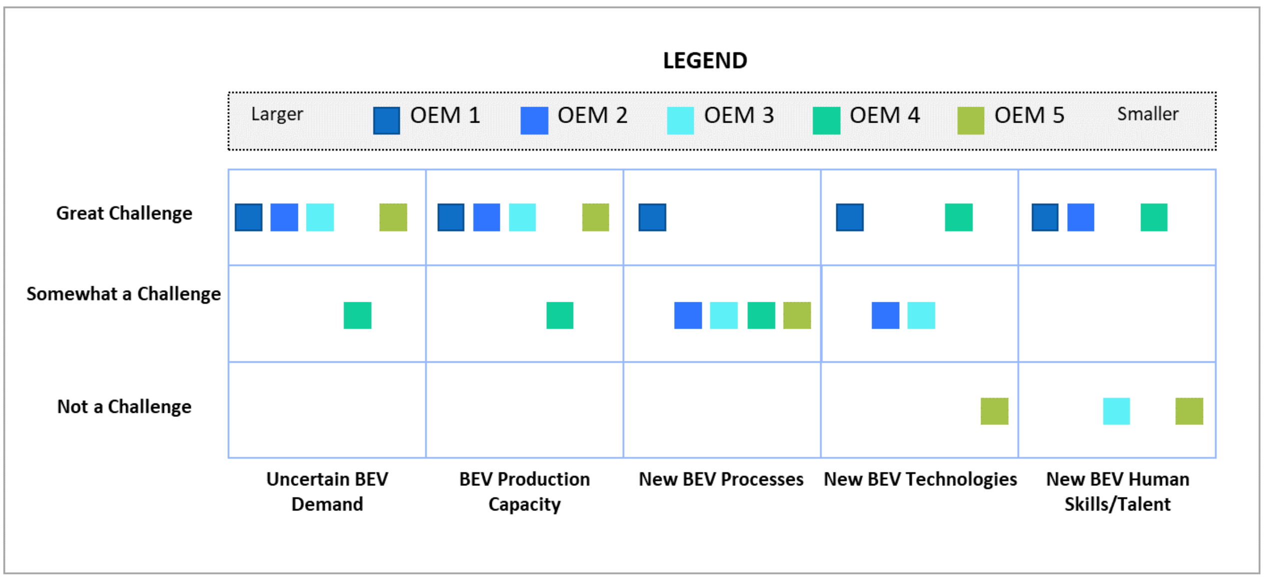

Figure 1: Greatest BEV Challenges

Against this backdrop, we asked survey respondents to outline their greatest BEV-related challenges. Figure 1 illustrates that survey responses reveal key similarities and differences between OEMs.

Key Highlights

First, respondents were nearly unanimous that two challenge areas rise among all others:

- Uncertain BEV Demand: Four of the five survey respondents rated demand uncertainty as a "great challenge," the highest level possible, with the remaining respondent indicating this as "somewhat a challenge." The interview phase of the project added additional color to this challenge, with interviewees consistently describing new BEV offerings and uncertainty regarding the ultimate rate of consumer acceptance. This concern was particularly acute for traditional OEMs, who expressed the necessity to "hedge bets" by flexibly altering the mix of ICE and BEV production wherever possible.

- Limited BEV production capacity. All respondents identified limited capacity as a "great challenge." This is not surprising given the current high levels of BEV demand with a limited supply of vehicles available. During the interviews, traditional OEMs quickly pointed out the need for flexible capacity in the short term to mitigate the risks of ICE/BEV demand fluctuations.

While new BEV labor skills were rated as a significant challenge by three OEMs, it was only rated as a moderate challenge for the remaining two. Interviews provided additional insights regarding skills, with respondents clarifying the skills surrounding digital transformation being the broader concern, incorporating many of the new skills required for modern BEV production.
Also evident from figure 1, respondents provided less correlated responses to the remaining challenge areas. While new BEV processes and new BEV technologies were both deemed as challenges, they did not rise to the highest level of importance.

Responding to the BEV challenges outlined above will involve significant changes to production processes, technologies, and people across the manufacturing enterprise. The remainder of this whitepaper considers changes to each of these areas.

Impact on Production Process

The shift from ICE to BEV manufacturing impacts many elements of the production process, requiring new vehicle components and systems, production processes, and resource requirements. This section of the report focuses on BEV impacts on the production process in greater detail.

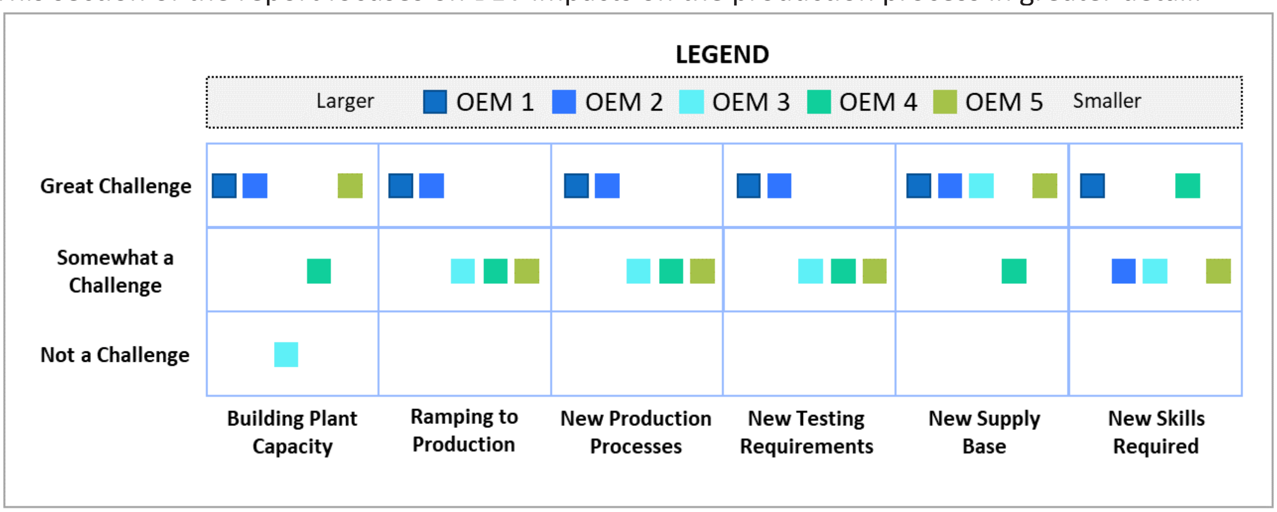

Figure 2: Greatest Production Challenges from ICE to BEV

Figure 2 presents responses to a survey question probing for the "greatest production-related challenges associated with the shift from ICE to BEV production." Several insights can be gleaned:

Key Highlights

Once again, while all challenge areas for this question were deemed important, two challenges stood out:

- New Supply Base: survey respondents were unanimous when describing the "great" level of challenges associated with developing a new supply base catering to BEV technologies. During the interviews, participants elaborated on the challenges ranging from difficulty identifying and selecting new suppliers, training new suppliers, to certifying new suppliers. One interviewee also described more stringent requirements for suppliers providing advanced in-vehicle software solutions, particularly in software configuration management (vehicle-level software version control). This participant pointed out that this is not necessarily a BEV-only requirement but a requirement for the "software-controlled vehicle" more generally, including ICE vehicles.
- Sufficient Plant Capacity: respondents were near-unanimous in rating this as a "great" challenge. One survey respondent dissented from this assessment, rating this as "somewhat" of a challenge. However, upon follow-up with this participant during an in-person interview, the respondent clarified that BEV capacity was indeed important. Still, flexible capacity was more important given the uncertainty of demand concerns outlined previously.

The remaining challenge areas in Figure 2 (ramping to production, new production processes, new testing requirements, and new skills required) were considered important to respondents. Still, the level of importance of each OEM relative to others was far more dispersed. To gain greater insights into these challenges, we will address each in greater detail later in this document.

New BEV Operations

While many production processes from ICE to BEV vehicles remain unchanged, several others (i.e., battery and electric powertrain operations) are entirely new. This section identifies new BEV production processes and assesses the relative challenges imposed by each.

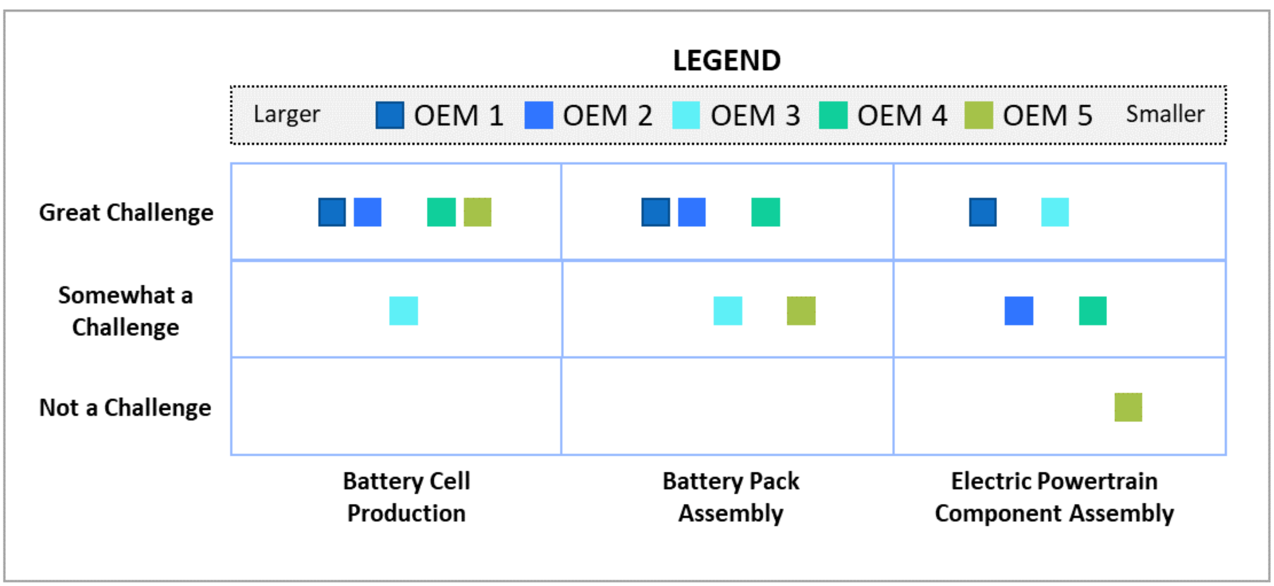

Figure 3. Most Challenging New BEV Operations

Figure 3 presents responses to a survey question asking participants to identify "which EV processes are particularly challenging." Several insights can be gleaned:

Key Highlights

Once again, while all challenge areas for this question were deemed important, two challenges stood out:

- While each process area is new and potentially challenging, battery cell production emerged as the greatest challenge. This is perhaps not surprising given the dramatic advancements in battery cell chemistry, form factor optimization, and supplier selection challenges. While survey respondents were near-unanimous on this assessment, there was one exception from OEM #3, who cited many years of working with an existing supplier to alleviate significant concerns.
- Closely trailing battery cell production as the primary challenge was battery pack assembly. While three respondents rated this as a "great" challenge, the remaining two rated this as "somewhat" of a challenge. Through insights gained in subsequent interviews, this diminished challenge level can be understood via two explanations. First, respondents cited prior battery pack assembly experience gleaned from manufacturing hybrid and BEV vehicles. Second, other respondents alleviate such challenges by outsourcing this process and purchasing fully assembled packs.
- An interesting observation in this area arises from OEM perceptions of potential competitive advantage driven by the battery "make versus buy" strategy. Based on interview discussions, several OEMs are pondering this question. Will the battery emerge as a source of competitive advantage (as defined by the customer)? Or will batteries devolve into commodity status items over time?

Focus: Optimizing Production Scheduling

BEV production also has implications for the production scheduling process. First, as previously discussed, demand uncertainty leads manufacturers to design increased flexibility into plant operations, particularly for dual-mode (ICE/BEV) production lines. At the same time, BEV demand is outstripping the supply of BEV vehicles on the market. This leads to, essentially, a demand-driven build-to-order (BTO) production process. This section focuses on production scheduling challenges and opportunities within this demand-driven production environment.

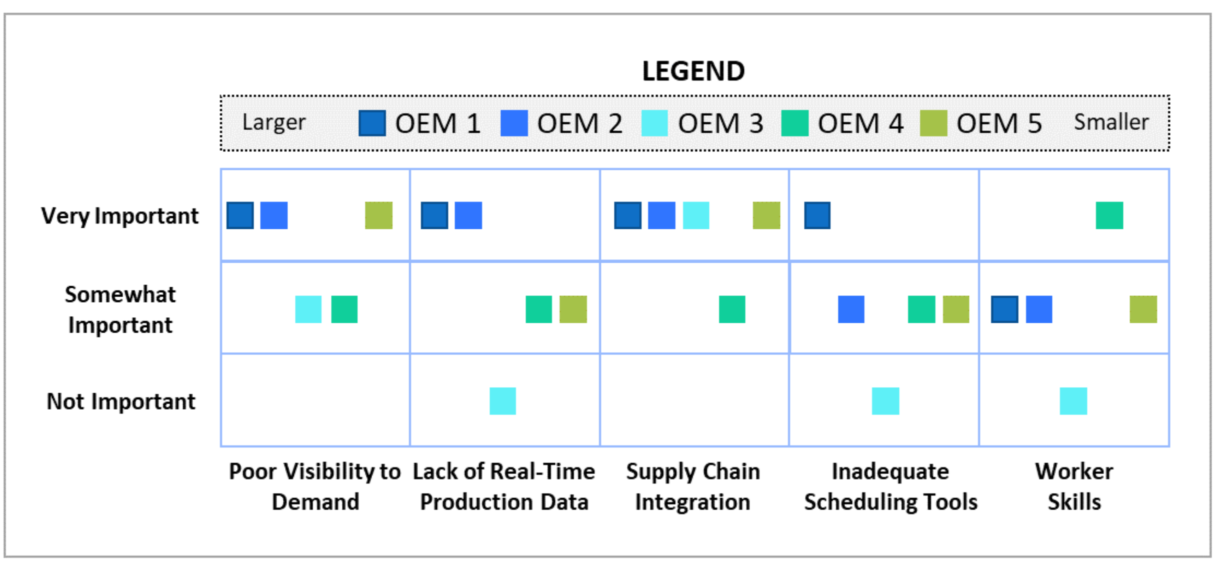

Figure 4: Production Scheduling Challenges

Figure 4 presents responses to a survey question asking respondents to identify "current challenges in optimizing production scheduling." Responses are analyzed below.

Key Highlights

Two of the five challenges presented to respondents were consistently mentioned as "very important" challenges.

- Immediately evident is that supply chain integration appears to be a "very important" production scheduling challenge to four of the five surveyed OEMs, with the remaining OEM ranking this as "somewhat important." From in-person interviews of respondents, the root cause of these challenges was almost universally associated with supply disruption risks stemming from global supply shortages (i.e., semiconductors, electronic modules) and limited supplier capacity for emerging technologies (batteries).
- Closely trailing supply chain integration as the primary challenge was poor visibility to demand, with all but two respondents rating this challenge as "very important." During the interview processes, however, we realized that this was, in fact, a unanimous consensus due to the vagueness surrounding the term "poor visibility of demand." When, instead, we refined the survey wording choice to being "uncertainty of demand," all respondents rated this as "very important," the highest level of challenge presented.
- The remaining challenge areas in Figure 4 (lack of real-time data, insufficiently advanced planning tools, and worker skills) were considered to be at least "somewhat important" to respondents. Still, the level of importance among respondents was far more dispersed. To gain greater insights into these challenges, we will address each in greater detail later in this document.

How are OEMs working to alleviate production scheduling concerns? Figure 5 (below) summarizes responses to the question, "in what areas are you investing in production scheduling in the future?"

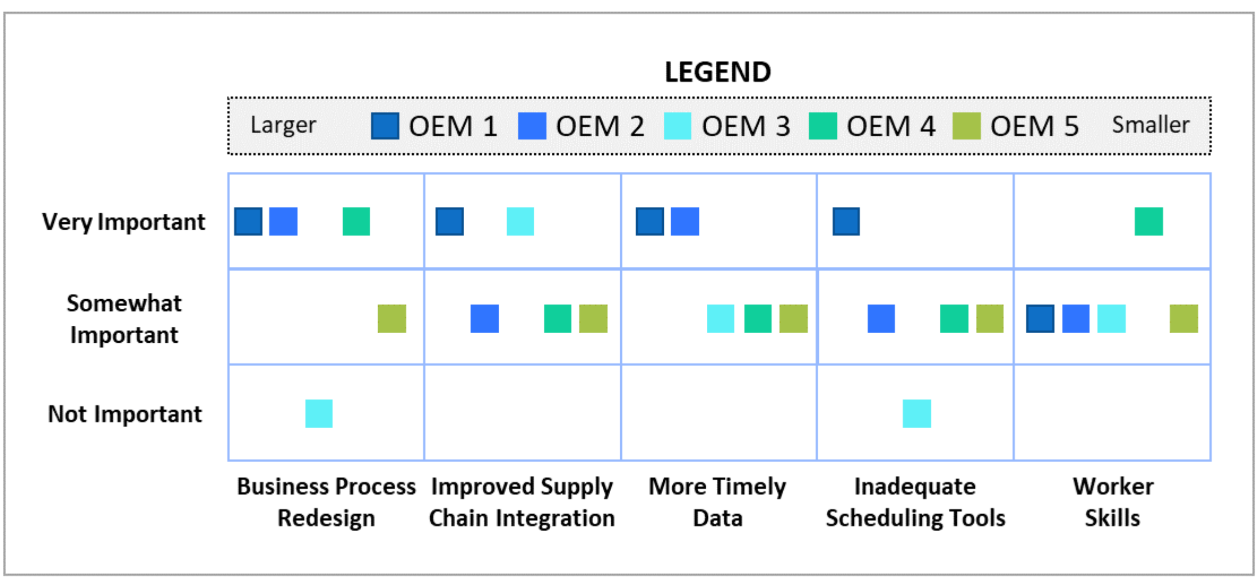

Figure 5: Investments in Production Scheduling

Figure 4 presents responses to a survey question asking respondents to identify "current challenges in optimizing production scheduling." Responses are analyzed below.

Key Highlights

Overall, it appears that OEMs are embarking on various investment priorities when tackling the challenge of production scheduling. That said, it appears as though improved supply chain integration and more timely data are the most common ingredients being leveraged for process improvements in this area. This was reinforced during the interview process, with participants stressing the need for "rapid communication" and "timely responses" regarding changing production conditions.

Focus: Optimizing Production Throughput

In 2022, the biggest EV production challenge may be scaling up to higher production levels and as such, optimizing production throughput in plants is a goal shared by many automakers. This section considers challenges and opportunities in this area, investigating key production constraints and strategies to alleviate these constraints.

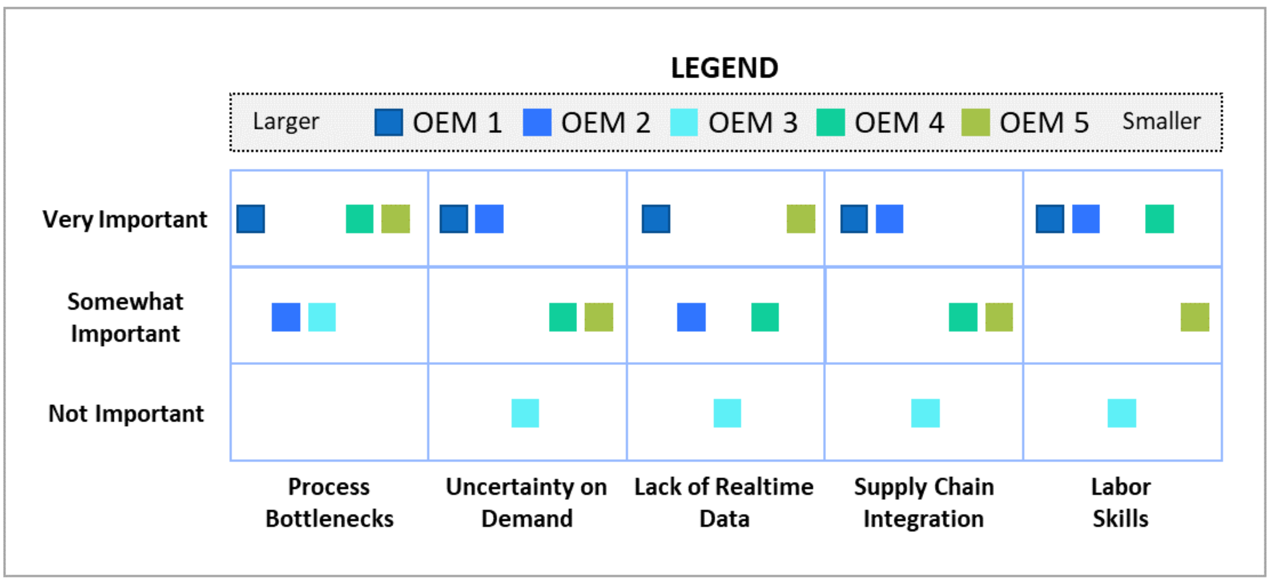

Figure 6: Production Throughput Challenges

Figure 6 presents responses to a survey question asking respondents to "identify current challenges in optimizing production throughput." Analysis of these responses, in addition to follow-up interviews with participants, provide interesting observations.

Key Highlights

- Not surprisingly, process bottlenecks represented a significant challenge to optimizing production throughput. Interestingly, these challenges were evaluated as being "very important" to three OEMs with distinctly different characteristics – two being large traditional OEMs. At the same time, the other respondent was a much smaller new entrant OEM. As expected, interviews with participants confirmed that battery-related constraints constituted the great majority of BEV bottlenecks. However, the complexities of mixed-mode (ICE and BEV) production on single production lines has the potential to add constraints as well. BEV-specific constraints will be examined in greater detail in the next section of the report.

- Supply chain integration again rose to a high level of importance, with two of five OEMs considering this a "very important" challenge. Interview insights pointed to challenges associated with developing new supplier relationships based on new EV technologies and ensuring sufficient and reliable supplier capacity.
- The remaining challenges in Figure 6 (uncertainty of demand, lack of real-time data, and labor skills) all represented significant, though somewhat lower, levels of challenges. Future sections of this report will examine many of these factors in greater detail.

As discussed previously, according to our research, battery-related bottlenecks constitute a large portion of BEV production constraints. We will now consider these constraints in greater detail.

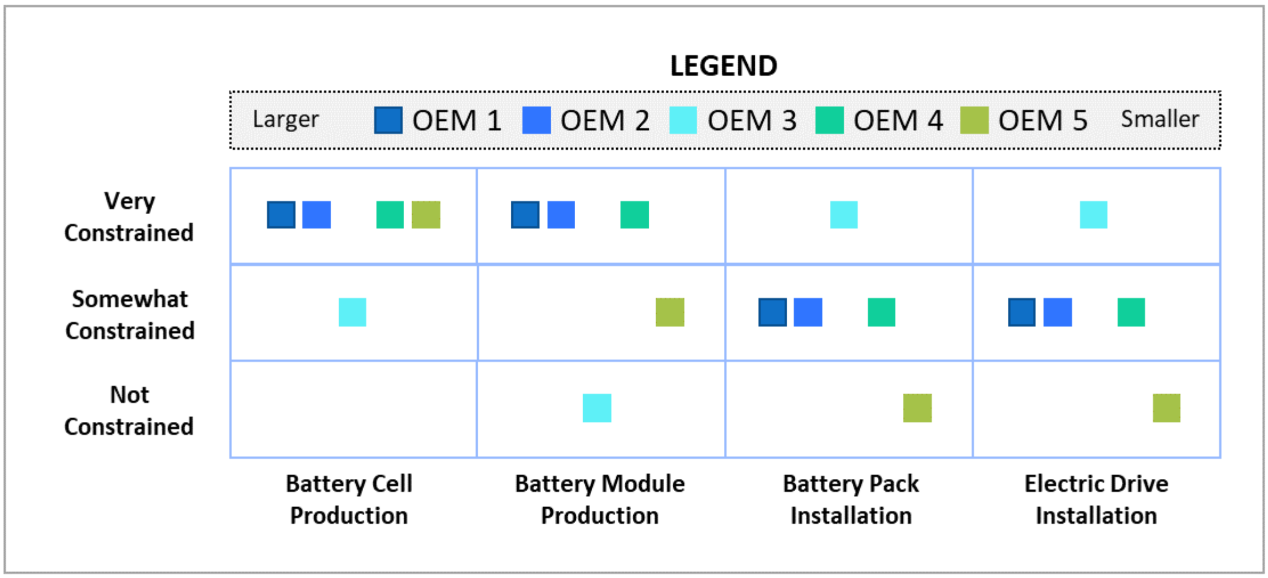

Figure 7: BEV Areas with Greatest Constraints

Figure 7 presents responses to a survey question asking respondents to "identify areas in which you are experiencing the greatest production constraints."

Key Highlights

- The survey identified battery cell production as the primary BEV production constraint, with four respondents rating these constraints as "very constrained." The lone dissenter (OEM #3) rated this constraint less severely, describing the battery cell production as "somewhat constrained." In a subsequent follow-up interview, probing for an explanation for this, we learned that the "somewhat constrained" characterization was based primarily on historical battery supply experiences with existing hybrid vehicles, adding that as the company pivots to full BEV production in the future, battery cell production constraints are a "real concern."
- Battery module production provided more varied survey responses, with three OEMs rating this as "very constrained." As gleaned in subsequent interviews, responses to this question correlate closely to whether the OEM manages the module assembly processes "in-house" or whether this process is outsourced to suppliers.

The research shows that BEV-related production constraints can represent a significant source of production throughput concerns. This raises interesting questions regarding OEM strategies to

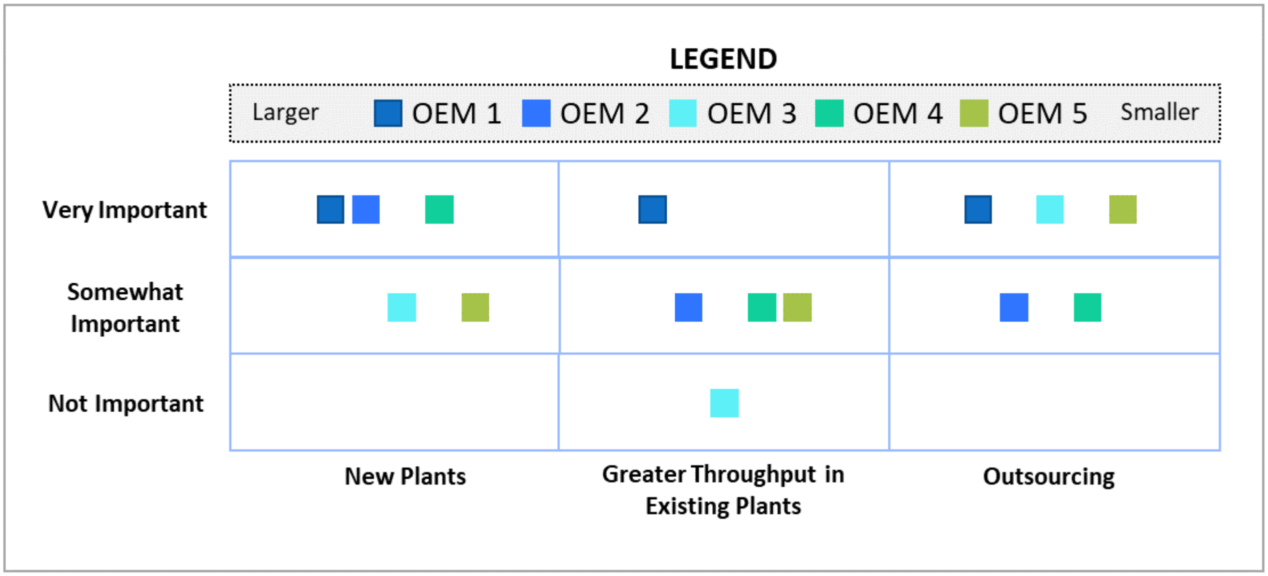

Figure 8: Strategies to Alleviate Production Constraints

Figure 8 presents responses to a survey question asking respondents to "identify your strategy to alleviate BEV production constraints."

Key Highlights

The survey responses indicate several interesting findings:

- In general, all OEM respondents appear to be leveraging the full menu of options to alleviate production constraints: new plants, greater throughput in existing plants, and outsourcing.
- Larger OEM respondents are more likely to leverage new plants and greater throughput in existing plants as strategies to alleviate production constraints.
- In interviews, larger OEMs indicated a greater propensity to bring battery manufacturing (both cells and modules) "in-house" to alleviate potential constraints.
- In both the survey and subsequent interviews, one OEM highlighted greater throughput in existing plants to alleviate production constraints and indicated the importance of improved analytics as a mechanism to achieve this goal (figure 9).

As evidenced above, automakers are expending significant efforts to optimize BEV production throughput. The following section examines the types of investments OEMs are undertaking to achieve this goal.

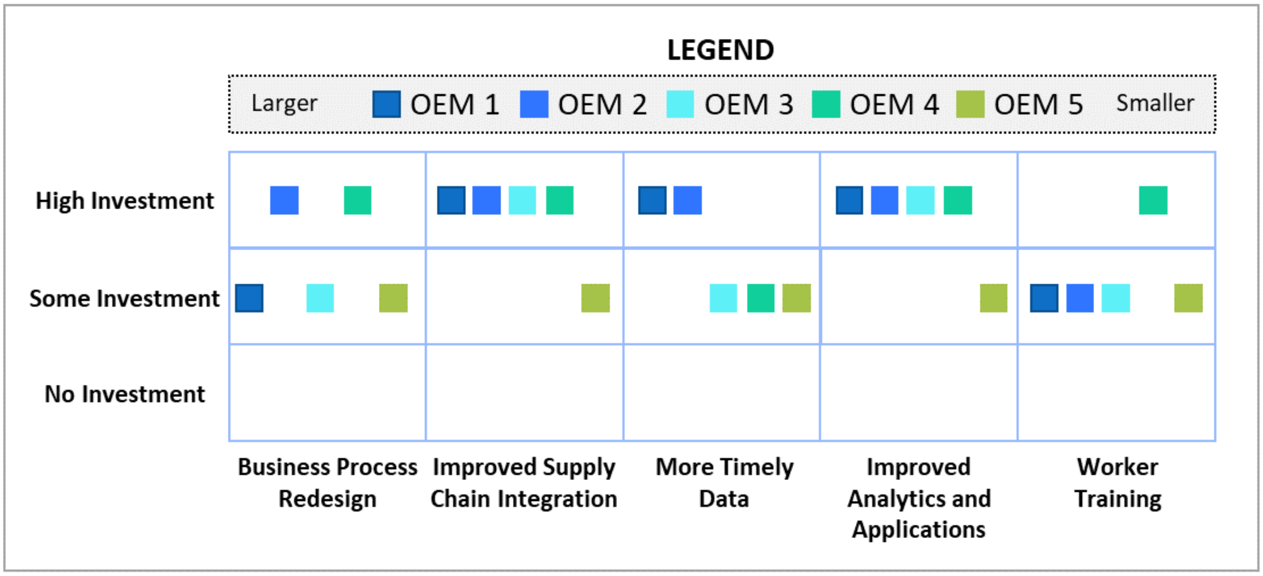

Figure 9: Investments to Improve Production Throughput

Figure 9 presents responses to a survey question asking respondents to “identify areas in which you are making investments to optimize production throughput in the future.”

Key Highlights

- Judging from the survey results, improved supply chain integration is a critical tool to improve production throughput, with four respondents indicating a “ high investment “ in this area. Such investments include more rigorous supplier selection processes to reduce supplier risk and improved supplier communications initiatives to avoid supply disruptions.
- Investments to improve analytics and applications were also highlighted as opportunities to optimize production throughput, with four respondents indicating “high investment” levels for these initiatives. Interview results from one large OEM indicated big data analytics initiatives to dynamically identify production constraints and prioritize corrective actions to the constraints most negatively impacting production.

Focus: Optimizing Quality Assurance

Over the last several decades, automakers have continuously been striving to improve product quality. Industry 4.0 (connected manufacturing, machine learning, and analytics) has provided new capabilities to continue this effort. Against this backdrop, this section investigates current BEV production quality assurance challenges and opportunities and strategies to continuously improve BEV quality in the future.

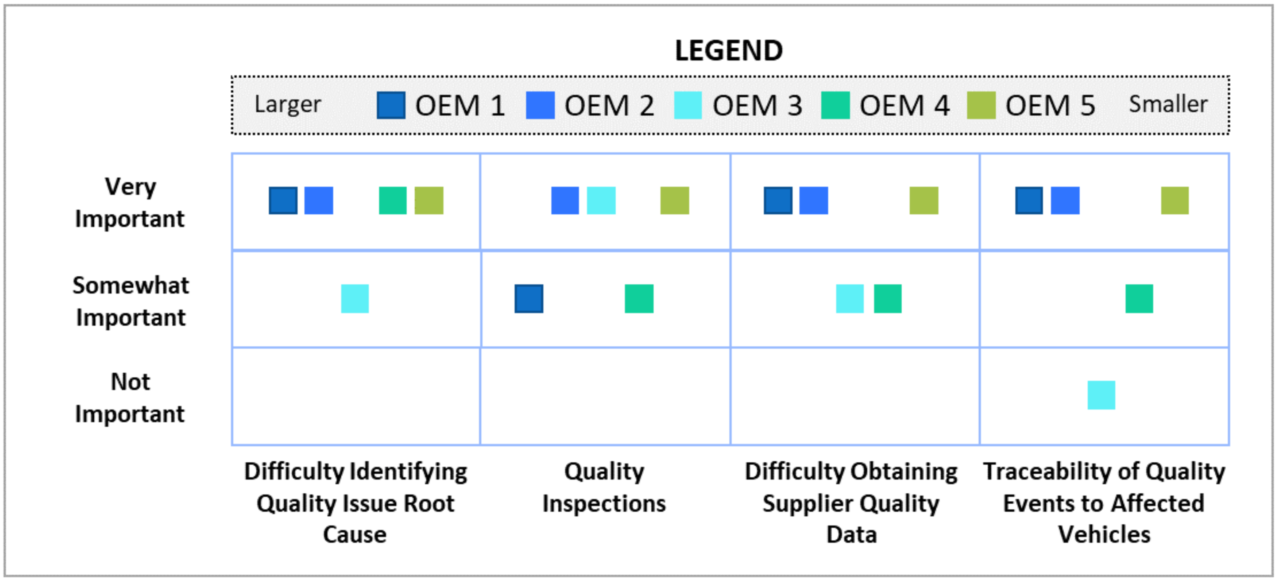

Figure 10: Production Quality Control Challenges

Figure 10 presents responses to a survey question asking respondents to "identify your current challenges surrounding production quality control."

Key Highlights

- Based on the survey results, respondents face "across the board" challenges (incorporating all surveyed challenge areas) in their efforts to optimize production quality.
- Within the interviews, three companies stressed that the current trend towards "software-defined vehicles" is creating heightened requirements to accurately "trace" the versions of software components installed within the vehicle (also known as software configuration management). Furthermore, this information should be captured within the OEM's manufacturing execution system (MES) for future traceability.
- Within the interviews, the increasing use of computer vision for quality inspections was a recurrent theme.

OEM respondents pointed out that many quality control challenges above apply equally to BEV and ICE vehicle production. The next question considers quality control challenges in the context of BEV-specific processes.

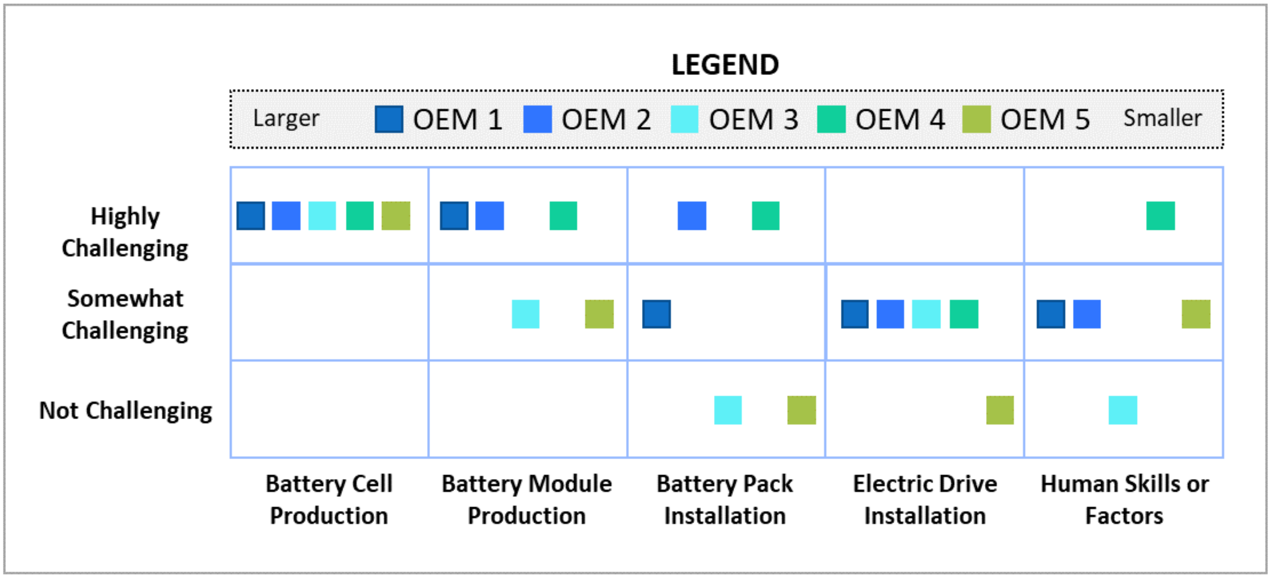

Figure 11: BEV Processes Presenting Challenges from Quality Perspective

Figure 11 presents responses to a survey question asking respondents to "identify which BEV production processes present challenges from a quality assurance perspective."

Key Highlights

- Battery cell production was unanimously deemed a "highly challenging" BEV-specific process area from a quality control perspective. Subsequent interviews explained both the importance of maintaining battery cell quality and the "newness" of this process from an OEM perspective.
- Battery module production was raised as a "highly challenging" quality control challenge by three OEM respondents, while two others rated it as "somewhat challenging." Interviews of those rating this as "highly challenging" revealed that battery pack "testing at scale" represented a significant challenge. In contrast, those rating module quality control as only "somewhat challenging" either had previous experience producing battery modules or outsourced this function altogether.
- Three survey respondents saw battery pack installations as only "somewhat challenging," while two considered this "highly challenging." Asked for clarification during subsequent interviews, these respondents pointed out significant challenges associated with battery pack functional and leakage tests.
- Electric drive component installation was only "somewhat challenging" based on survey responses. Interviews clarified that the quality control processes for this function were very similar to powertrain installation processes in ICE vehicles.
- Human skills or factors were seen as "highly challenging" by one OEM respondent but only "somewhat challenging" by the remaining four respondents. In a subsequent interview, OEM #4, who rated human skills as "highly challenging," identified high voltage component handling and testing as a critical new BEV skill. Other interview participants stated that overall, quality control skills for BEV production were broadly similar to those required for ICE production. Human skills will be considered in greater detail in the later "Impact to the Organization" section of this report.

Given the broad adoption of Industry 4.0 technologies (connected manufacturing, analytics, and machine learning) by manufacturers in general, we now consider how these technologies are being utilized to support quality assurance functions within BEV production organizations.

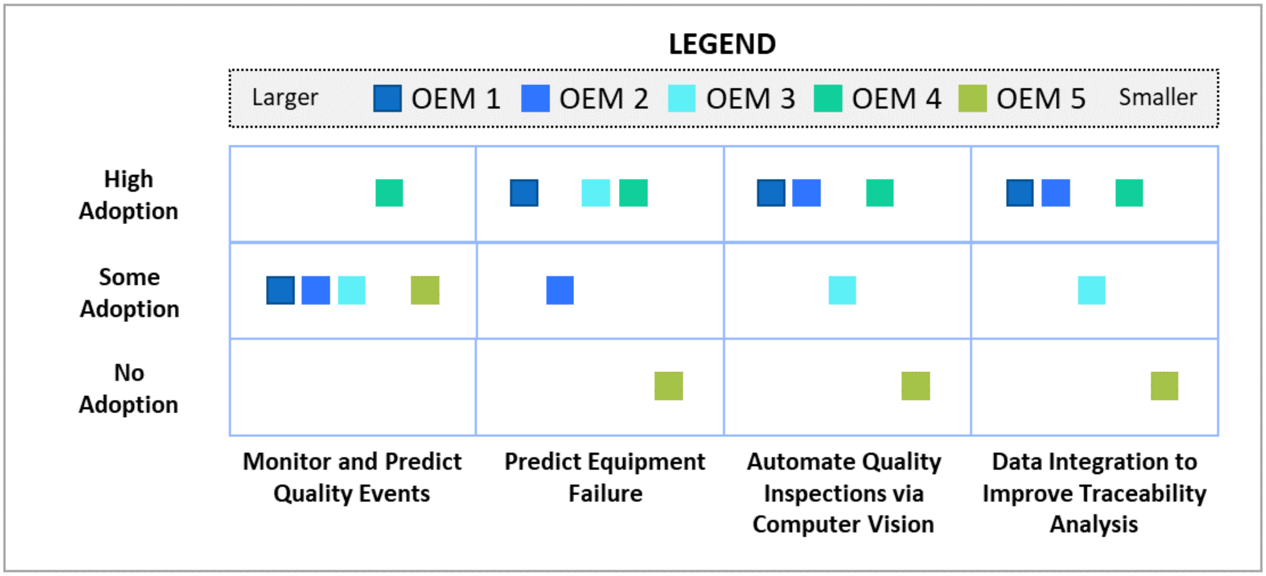

Figure 12: Use of Big Data, Analytics, Artificial Intelligence, and Applications

Figure 12 presents responses to a survey question asking respondents, "in which areas have you adopted Big Data analytics, artificial intelligence (AI), or other applications? Below, we summarize both survey and interview responses.

Key Highlights

- Survey results appear to confirm OEM respondent interest in implementing connected manufacturing and advanced analytics solutions to automate quality inspections via computer vision, with three large traditional OEMs indicating "high adoption" of this technology, one somewhat smaller OEM indicating "some adoption," and on new-entrant OEM indicating "little adoption" of this technology. Asked to explain the limited adoption of computer vision during the interview process, the traditional OEM explained that quality inspections were performed by computer vision AND people. At the same time, the new entrant planned greater levels of computer vision adoption in the future. All respondents indicated that this technology was equally likely to be used in ICE and BEV production.
- Survey respondents also indicated the need to integrate data to improve forensic analysis, with three large traditional OEMs indicating "high adoption" of this technology. This requirement can be explained as the need to capture detailed manufacturing process data, at a vehicle level, from production sensors and transaction systems to provide the ability to "trace" the root cause of vehicle quality problems found later in the field. Interviews revealed the need to capture "end-to-end quality traceability from design and manufacturing perspectives," with another OEM adding, "this is particularly important given the greater level of software being contained within vehicles."
- Likewise, three large traditional OEM respondents indicate "high adoption" of advanced solutions for predicting equipment failures and reducing equipment maintenance costs by

performing maintenance operations.

- In general, the use of advanced solutions for quality assurance was much more likely to be adopted by the larger and traditional OEMs than by the new-entrant OEMs. Asked to explain during the interview, the new entrant OEM explained that “these solutions will come in time, as production ramps up.”

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- Likewise, three large traditional OEM respondents indicate “high adoption” of advanced solutions for predicting equipment failures and reducing equipment maintenance costs by performing maintenance operations.
- In general, the use of advanced solutions for quality assurance was much more likely to be adopted by the larger and traditional OEMs than by the new-entrant OEMs. Asked to explain during the interview, the new entrant OEM explained that “these solutions will come in time, as production ramps up.”

Impact to Technology

As if the shift from ICE to BEV itself were not consequential enough, this shift occurs against the backdrop of the digital transformation of industry in general. Given this fact, does this provide BEV production opportunities to accelerate the adoption of new digital transformation technologies? The team surveyed respondents on two broad questions, first to assess production challenges encountered and then to assess the technologies pursued to address these challenges.

Production Technology

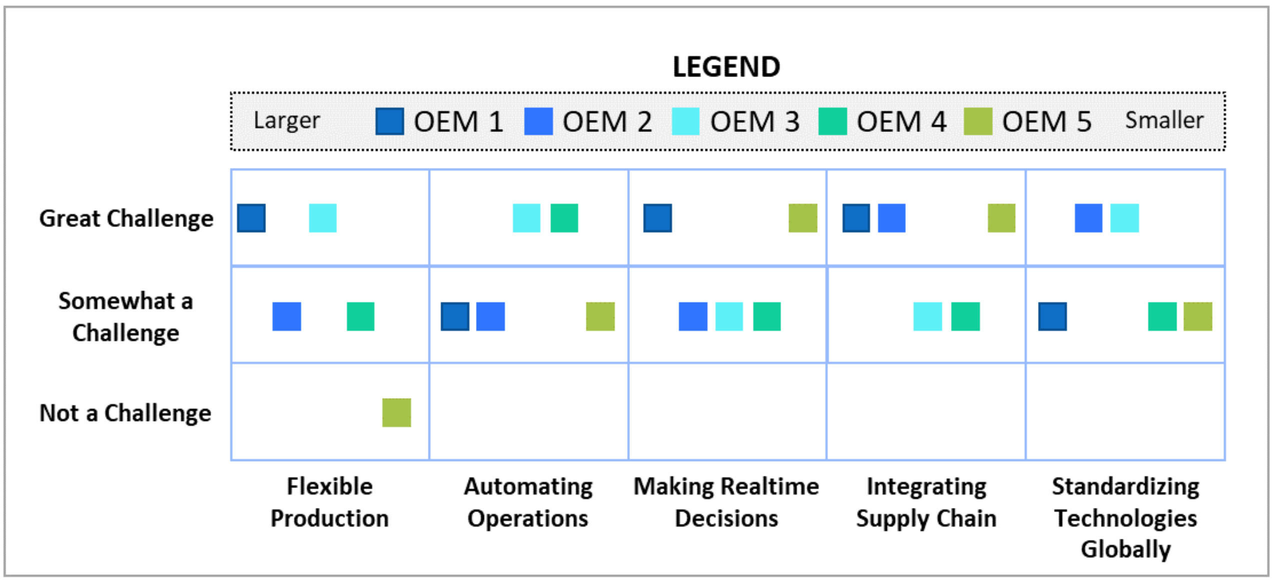

Figure 13: Greatest BEV Production Technology Challenges

Figure 13 presents responses to a survey question asking respondents, "when considering the shift from ICE to BEV manufacturing, what are your greatest production technology challenges?". From this data and subsequent interviews, we draw the following conclusions.

Key Highlights

- While results appear to confirm challenges in all surveyed areas, the extent of these challenges appears somewhat dispersed.
- One surprise in the survey results for this question was the relatively low ranking associated with the challenge of flexible production, given its importance in addressing the BEV demand uncertainty described earlier in this report. Overall, two of the four traditional OEMs addressed this as a "great challenge," while the remaining two traditional OEMs rated this as "somewhat a challenge." During the interview, the two dissenters explained that this was becoming less of a challenge as the company moved from multi-mode (ICE and BEV) production lines to dedicated production lines. Likewise, the new-entrant OEM had less of a need for flexibility given the requirement for BEV-only production.
- Overall, integrating the supply chain was considered to be a "great challenge" by three of five respondents. Interviews revealed that obtaining a sufficient and steady supply of

battery-related materials was of greatest concern, followed by technology solutions to provide greater supply chain visibility.

- Standardizing technologies globally was considered a "great challenge" by two of the five respondents. Interviews revealed that this often results from tensions between centralized technology decisions made at the OEM headquarters and more localized and regional needs. Predictably, this was seen as less of a challenge for the new entrant OEM.
- Automating operations was seen as a "great challenge" for two large traditional OEMs and only "somewhat of a challenge" by the other respondents. Asked to elaborate during interviews, a consensus emerged that while automation was a challenge, it was equally challenging within ICE and BEV production environments.

Figure 13 presents responses to a survey question asking respondents, "when considering the shift from ICE to BEV manufacturing, what are your greatest production technology challenges?". From this data and subsequent interviews, we draw the following conclusions.

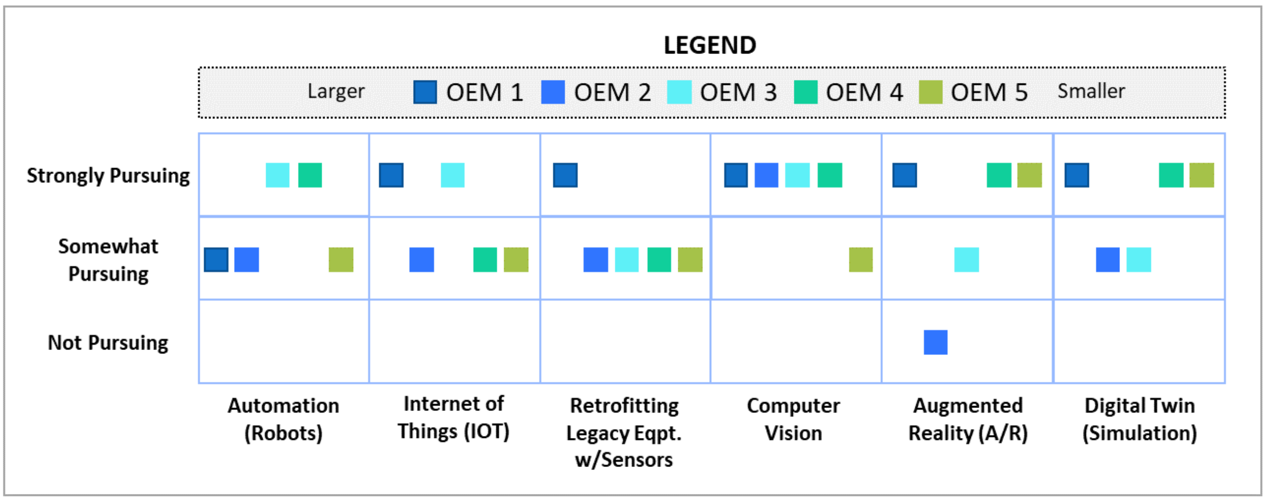

Figure 14: EV Production Technologies Pursuing

Figure 14 presents responses to a survey question asking respondents, "which EV production technologies are you pursuing?". Analysis of the responses follows below.

Key Highlights

- Judging from the survey results, while respondents are pursuing technologies within all surveyed areas, the nature of these pursuits appears somewhat dispersed.
- Computer vision appeared to be the most adopted of these technologies, with four of five claiming that they were "strongly pursuing" this approach. During interviews, participants confirmed that quality inspections represented the greatest use of this technology. Once again, the new-entrant OEM did not discount the value of such solutions but rather pointed out the "early days" of production for the company and an intent to implement more advanced solutions as time progresses.
- OEM respondent organizations reported all other technologies areas as being at least "somewhat pursued." Interviews provided some context to this. While important, these

technologies apply to both ICE and BEV production and have been considered for some time.

Digital Technology (Data, Analytics, Automation, and Machine Learning)

Perhaps one of the more significant manufacturing advances of the last decade involves the advent of connected manufacturing, with entire plant operations being newly equipped with low-cost sensors attached to equipment, easier sensor connectivity via internet-based protocols, and new abilities to leverage this sensor-based data to optimize manufacturing performance via a new generation of analytical and machine learning applications.
However, as is often the case, new technologies are often associated with new challenges. The following question seeks to investigate such issues.

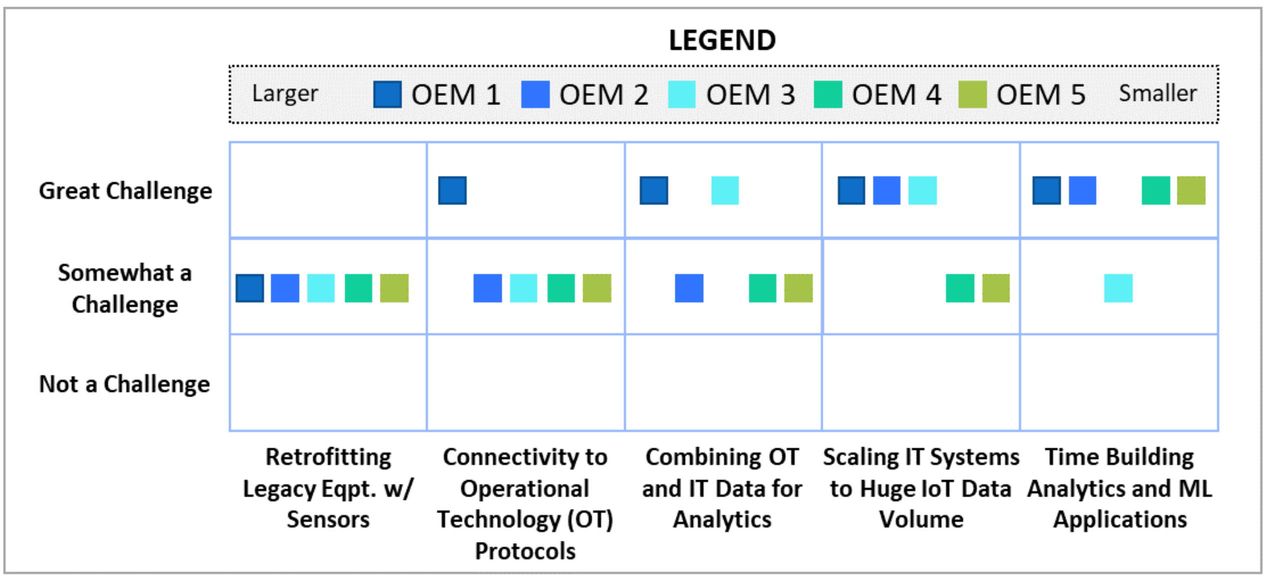

Figure 15: Greatest Digital Technology Challenges

Figure 15 presents responses to a survey question asking respondents, "for BEV production, what are your data management and analytics-related challenges?".

Key Highlights

To begin with, interviews made clear that the data and analytics technology challenges discussed in this question were not unique to BEV production, pertaining equally to ICE production environments. That being said, the following trends become evident.

- Effort building analytics and AI applications was identified as a "great challenge" by four of the five survey respondents and only "somewhat of a challenge" by one traditional OEM, who indicated previous heavy investments in building internal capabilities in this area. In interviews, common themes were the shortage of advanced analytics and machine learning skills available in the marketplace and the need for ecosystem partners to provide "complete end-to-end business solutions and not point solutions."

- Scaling IT systems to huge IoT data volume was identified as a “great challenge” by three of the four traditional OEM survey respondents. Interviews reinforced the large amounts of data being collected and ongoing discussions about where (on-site, edge, or Cloud) this data would be stored and analyzed., Unsurprisingly, this was less of an issue for the new entrant OEM. Still, it was emphasized that this could change as operations reach greater scale.
- Combining OT and IT data for analytics was identified as a “great challenge” to two of the four traditional OEMs and only “somewhat of a challenge” to the remaining OEMs and the new entrant OEM. Interviews surfaced explanations for both “somewhat of a challenge” respondents. One traditional OEM attributed their success in combining OT and IT data for analytics to the fact that they hired OT personnel within the IT organization and then standardized accrued learnings across their global operations. Conversely, the new entrant OEM stated that OT/IT convergence was not yet an issue, given the newness of their operations.

Impact to the Organization

Organization Alignment

It is often said that effectively implementing significant organizational changes “takes a village,” incorporating all levels and domains within the enterprise. Of particular interest when implementing technology-intensive initiatives such as BEV production successes and failures in aligning Management, Labor, and Information Technology (IT) functions to ensure success.

To assess the effectiveness of how automakers have aligned to meet new BEV production and digital transformation-related changes, we interviewed representatives from OEMs and Organized Labor and asked them to comment on “successes and failures experienced in aligning Management, Labor and Information Technology (IT) functions in meeting core strategic BEV production and digital transformation-related initiatives.”

Overall, interview respondents commented that organizational alignment “takes a lot of effort” and that “challenges exist.” From an OEM perspective, challenges in aligning Engineering and Manufacturing functions were highlighted, in addition to difficulty aligning Manufacturing and Information Technology functions. From an Organized Labor perspective, opportunities were seen to enhance Labor involvement and decision-making earlier in the OEM product development process, allowing more strategic input into issues such as labor allocation (specifying the product development and manufacturing tasks performed by labor) and skill development priorities and programs.

Skills

Technology and process transformation are typically accompanied by the need for new and improved organizational skills (management, IT, labor). To assess challenges and opportunities in this area, we asked OEM and organized labor interview participants to describe "in which areas (i.e., Management, Information Technology, Labor) are you seeing skill development opportunities in shifting from ICE to BEV production processes?".

Overall, both OEM and Organized Labor agreed that the rate of change in the automotive industry is driving the need for enhanced skills. However, a recurring theme from interviewees punctuated this point by pointing out that these skills were digital transformation-related, much more than being only BEV-related. In other words, skills associated with new digital technologies (i.e., data management requirements, advanced analytics, machine learning, and automation) remain a development priority. Still, they pertain equally to both BEV and ICE vehicles. In the words of one Organized Labor interviewee, "skills are shifting from more manual labor to digital, with skilled trades taking on more digital tasks including troubleshooting, fixing and reprogramming."

Interestingly, while a consensus exists regarding the need for more advanced skills, perspectives seemed to diverge somewhat when discussing where these skills should reside organizationally. OEM interviewees unanimously described efforts to build digital and new BEV-related technical skills within their organizations. Likewise, although Organized Labor described a similar desire, interviewees described OEMs as potentially reluctant to allocate more advanced and higher value activities outside their organizations.

Where Can Partners Help?

While automakers have indicated the need to develop new digital transformation and production skills internally within their organizations, they also acknowledge that there are focused capabilities in which partners can most definitely augment these efforts. This section investigates areas of potential need.

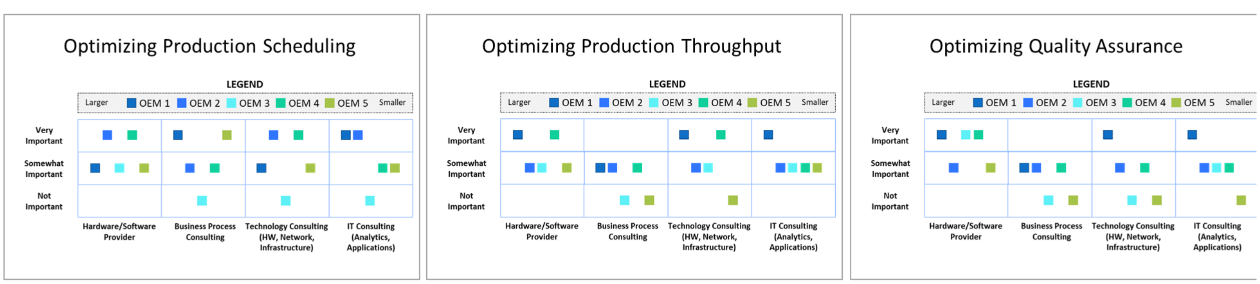

Figure 16: Areas Where Partners Can Help, Quality Assurance

Figure 16 presents responses to a survey question asking respondents "where partners can help" in select business process areas (production scheduling, optimizing production throughput, and optimizing quality assurance). Simultaneously, we asked which type of partner products and services (hardware/software supply, business process consulting, technology consulting, and IT consulting) are most required for each business process area. In general, survey responses were somewhat dispersed across the board. However, “very important” (the highest importance level) ratings did appear at least somewhat in all three business process areas surveyed and across the different partner products and services. This is not entirely surprising, given the current marketplace’s high demand for digital transformation skills.

The interview process provided additional insight when discussing areas where partners can assist OEMs. Three of the five OEM participants pointed to the need for more complete and automotive industry-focused solutions. Interviewees quickly pointed out the value of “turn-key” application solutions that would minimize OEM resource requirements for implementation.

Conclusion

Overall, this study confirmed the epic changes in today’s automotive industry. While the shift from internal combustion vehicles to battery electric vehicle production is hugely challenging individually, the ongoing digital transformation of the automotive industry presents challenges that are at least equally paradigm-shifting.

It is crucial to identify and analyze the drivers that stimulate the digital conversion in manufacturing processes, specifically in automotive industries. Based on the interviews conducted throughout the research, digital transformation involves profound changes in the business model of the organizations, which foster modifications in processes, resources, operational methodologies, and quality assurance standards.

So, what are our key takeaways? First, from a production perspective, though many ICE and BEV assembly processes will remain similar, automakers are being challenged to scale-up new BEV production processes, particularly in the area of battery cell production. Second, the industry appears to be in the midst of a fundamental restructuring of the automotive supply chain, with new BEV technologies driving the need for new supply chain partners able to meet growing market demand. Further, in the face of uncertain BEV demand, established OEMs are pursuing greater levels of production flexibility to accommodate changing ICE/BEV production mixes over time. Finally, the shift to BEV production coincides with the digital transformation of the automotive industry. Automakers are developing new skills within their extended enterprises (consisting of internal, organized labor, and partner resources), paving the way for a rapidly evolving automotive manufacturing future.