Moving e-Vehicle Production into the Fast Lane
Todd Bengtsson
Manufacturing in America │ March 20-21, 2019

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Disruptive changes continue to evolve at a rapid pace

Disruptive Innovation
Key to sustained business

Engineering the next product not just the best product for the future
Key Enablers are accelerating EV and Hybrid growth

- **Battery Technology**: Throughput | Costs
- **Government Regulations**: Subsidies | Phase-outs
- **Investments**: Startups | New Models
- **Infrastructure Break-through**: Charging Tech | Infrastructure

Vehicle Electrification
Electrification is here to stay

Global EV sales will grow dramatically through 2030

Source: Boston Consulting Group

[Diagram showing the number of vehicles sold (millions) from 2018 to 2030, with projections for gasoline, diesel, MHEV, HEV, PHEV, and BEV.]

Source: BCG analysis.
Note: EV = electric vehicle, MHEV = mild hybrid electric vehicle, HEV = hybrid electric vehicle, PHEV = plug-in hybrid electric vehicle, BEV = battery electric vehicle. Because of rounding, not all percentages add up to 100.

Source: BCG – The future of Battery Production for Electric Vehicles

Siemens Digital Enterprise and the development of a Digital Twin of Production

Digital Twin Product
- Virtual product
  - Specification
- Validation
  - Verification

Digital Twin Production
- Virtual production
- Continuous improvement
  - Commissioning

Digital Twin Performance
- Real production
  - Automation
- Ideal delivery
  - Real product

Collaboration Platform
- Insights from performance with MindSphere

Virtual product
- Real product

Continuous improvement
- Ideal delivery
- Validation
- Commissioning
Siemens PLM Digital Manufacturing solutions
Catering to a wide range of EV specific manufacturing needs

- **Light Weighting**
  New Materials | Industrialize Additive

- **Battery Production**
  Design for Manufacturing | Production Capacity

- **EV Platforms**
  Assembly Planning | Factory Planning | Logistics

- **Supplier Evolution**
  Quality | Flexible Production | Collaboration

Comprehensive support for Electric Vehicle production
Comprehensive support for Electric Vehicle production
**Challenge:** Increase all-electric range while offsetting the weight increase of batteries and electrified powertrain

- Generational leaps in Powertrain technology have yielded significant weight reductions
- Smarter use of light weighting in structural parts reduce the weight of a vehicle's body and chassis by up to 50 percent
When you set out to transform your business with additive components, what are the possibilities?

**Reimagine products**
- Expand capabilities
- Improve performance
- Reduce material
- Accelerate innovation cycle (Develop tailored, mission-critical components)

**Rethink business**
- Spare parts that are already in "Obsolescence"
- Zero inventory – on demand printing
- Design anywhere. Print anywhere.

**Reinvent manufacturing**
- Eliminate molding/castings/tooling
- Eliminate/simplify assembly process
- Reduce supply chains
- Affordable low volume production

Shift from conventional design to innovative DFAM

STATUS QUO

Manufacturing transformation
Shift from prototyping / experimentation to mainstream industrial production
Our Vision – Integrated End-to-End system from industrializing Additive Manufacturing

Original design

Generative design

Topology optimization

Light weighting

Adapt design (Convergent Modeling™)

Validate

Final part

Post processing and inspection

Slicing, hatching

Prepare for printing
We practice what we preach …

Conventional thinking

Additive Manufacturing thinking

13 → 1 parts
system simplification

26 → 3 weeks
lead time reduction

22% weight reduction

In serial production

Function & performance improvement

Designed in NX

Combustion System
Burner
Swirler/Nozzle/Filter/Mixer

Design & optimization

Evaluate
Consolidate / Optimize
Simulate
Validate
No longer just a vision ... we are expanding usage across our business segments

Siemens businesses use additive for real production

“Functional prototyping”
of gas turbine blades
PG, UK, Lincoln

“Designed-in functionality”
for gas turbine burner tips
PS, Sweden, Finspång

“Spare parts on demand”
for train components
MO Germany, Erlangen

Improved internal cooling for greater overall turbine efficiency
Reduced repair times by 90% (months to weeks)
Reduced supply chain dependency, enabled mass customization
So what are the challenges and implications to manufacturing that can make or break our success?

<table>
<thead>
<tr>
<th>Challenge</th>
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<tbody>
<tr>
<td>❖ New materials are being introduced to reduce overall vehicle weight</td>
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<tr>
<td>❖ New materials are often joined to conventional product components</td>
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<tr>
<td>❖ Structural and vehicle safety requirements cannot be compromised</td>
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<table>
<thead>
<tr>
<th>Manufacturing Implication</th>
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<tr>
<td>❖ Faster transition from prototype to production</td>
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<tr>
<td>❖ Requires advanced manufacturing methods and specialized equipment</td>
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<tr>
<td>❖ Production scale up of new technology and processes</td>
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Courtesy EDAG
Would access to requirements and boundary conditions in a signal environment speed up the process of innovation?

Concept definition and detailed component design
- Capture relevant requirements for subsystem or component design
- Topology optimization
- Adaption and reverse engineering

Increasing Flexibility & Innovation
✓ Fast New Product Introduction
✓ Rapid concept definition
✓ Innovative design creation
✓ Time savings - re-using the facet geometries from topology optimization
Can the need for physical prototypes be minimized?

Validating design solutions in the digital world
- Validation tool for Additive Manufacturing design rules
- Rework and analysis of results within design environment
- Multidisciplinary functional

**Improving Efficiency**
- Virtual tests of load cavities

**Reduce Cost**
- Intensive design check without prototypes
- Fault avoidance - early production validation
Is it possible to predict potential problems before actually 3D printing a part?

Pre-process in the CAx environment to accelerate 3D Printing
- Setup Build Tray
- Support Structures design
- Assign exposure settings
- Generate ‘Build JobFile’ and transfer directly to the printer

Improving Efficiency
- Single data format without conversion
- Support structure library
- Critical area identification
- Rapid, associative changes possible
- Work preparation (pre-process) completely in the CAx environment
Can the same geometry developed for Additive Manufacturing be leveraged in traditional CAM operations?

Performing post-processing operations on parts produced by Additive Manufacturing
- Surface Finishing
- Drilling Holes
- De-Burring

Ensure Quality
✓ Increased flexibility in planning inspection resources
✓ Reduce non-conformances and improve accuracy

Improving Efficiency
✓ Create inspection and NC programs by leveraging PMI directly for design data
✓ Graphically driven programming and simulation
How will assembly processes be effected by the introduction of these new components?

Assembling complex geometries requires precise programming and orchestration
• Welding seam definition based on the product geometry
• Tool orientation with regards to collision constraints and robot configuration
• Robotic Off-line Programming

Increasing Flexibility & Innovation
✓ Faster Ramp-up
✓ Achieve quality requirements

Reduce Cost
✓ Save engineering effort
✓ Shorten commissioning time
Siemens PLM Digital Manufacturing solutions
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Vehicle Electrification

Manufacturing Engineering Planning & Validation Framework

Comprehensive support for Electric Vehicle production
e-Mobility (Electric drive, connectivity, autonomous) are driving new vehicle architectures

- Native EV platforms offer up to 25% larger battery packs
- More range and powertrain options possible

... New platforms, assembly modularity, reuse strategies .. need to be planned and validated
Modular Electrification Toolkit (MEB) is a modular system for manufacturing electric vehicles

- Evolution of the flexible modular system Modular Transverse Matrix (MQB) that superseded platform strategy at VW
- High-volume series production of electric vehicles is only possible leveraging MEB

**“TRANSFORM2025+”**

1M EV’s - 30 different models across Group brands

The Siemens Digital Enterprise is the solutions for the rapid pace of innovation.
Leveraging the connected Digital Twins

- The virtual and the real worlds are linked by the Manufacturing Master Data Model and the Common Plant Model created from Automation.
- Decisions can be made based on real-time data from Automation.
- Feeding back all relevant information from production execution creates a nearly real-time image of the digital twin of product, process and resources.
**Proof that it works …**

### Challenges for automotive industry and example Maserati

#### Reducing the time to market
- Shorter innovation cycles
- More complex products
- Larger data volumes

#### Enhancing flexibility
- Individualized mass production
- Volatile markets
- High productivity

#### Increasing efficiency
- Energy and resource efficiency as key competitive factors
- **3 times** more cars produced than before at same very high quality standards
- Integration of two new assembly lines into existing factory

### Example Maserati
- Time-to-market reached in **16** instead of **30** months
- **30%** shorter development time
- Suppliers connected to data stream
- Ghibli available in
  - **27** versions
  - **13** colors
  - **205** configuration options resulting in **70,000** combinations

### Process

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<tbody>
<tr>
<td><strong>Product design</strong></td>
<td><strong>Production planning</strong></td>
<td><strong>Production engineering</strong></td>
<td><strong>Production execution</strong></td>
<td><strong>Services</strong></td>
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<tr>
<td>NX CAD</td>
<td>Process Simulate</td>
<td>SIMATIC</td>
<td>SIMATIC</td>
<td>Traditional Services</td>
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<td>NX CAE</td>
<td>Plant Simulation</td>
<td>SIMATIC IT</td>
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<td>LMS</td>
<td>Teamcenter</td>
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<td>❖ Shift to modular assembly processes with a higher degree of purchased components</td>
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<td>❖ Rapid evolution of assembly methods</td>
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<tr>
<td>❖ Flexible manufacturing processes</td>
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<tr>
<td>❖ Reuse of manufacturing methods across vehicles and assembly facilities</td>
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How do we support component planning scenarios when the same product will be built in multiple locations?

Develop a manufacturing specific views (MBOM) of product
- Re-arrange Product BOM
- Capture manufacturing modules and make/buy items

Production Flexibility
✓ Support different sourcing strategies for multiple production locations
✓ Controlled and/or managed updates between Engineering and Manufacturing
✓ Automation to support speed and standardization where applicable
Can we define and reuse “Best Practices” to reduce the time it takes to plan for new products?

Define the assembly processes for new products
- Review and define assembly content and sequence
- Generate illustrations to communicate to production

Speed and Accuracy
- Intelligent queries to ensure process completeness
- Visual confirmation to aid in decision making
- Reuse “Best Practice” assembly methods
Is it possible to validate planned processes prior to implementation on the production floor?

Evaluate the assembly processes and equipment
- Validate planned assembly sequence
- Comply with manufacturing standards

Improving Efficiency
- Improve manufacturability of parts/assemblies
- Reduce costly late changes to tooling
- Ensure operator health and safety to reduce injury and improve operator productivity
How we better leverage planning and simulation information to reduce production ramp-up?

Distribute work content to support specific production scenarios
- Station specific processes
- Detailed time analysis
- Work load balancing

Capacity Planning and Utilization
✓ Support allocation of work content to achieve a balanced production plan
✓ Adapt quickly to changing market conditions (shift planning, flexible production)
✓ Improve confidence to achieve production targets
✓ Avoid lengthy launch ramp-ups
How can we adapt an existing production facility to support new products?

Plan for assembly logistics to fulfill production requirements
- Material flow
- Space planning
- Validate performance

Capacity Planning and Utilization
- Identify equipment performance requirements
- Evaluate multiple alternatives
- Define system characteristics and space requirements
- Validate system behavior and performance

Adding Charging Extension to Support EV Production
Can we be confident that new production line equipment will not interfere with existing equipment?

Design assembly lines to accommodate new products
- Select and position equipment
- Define equipment installation plan

Production Flexibility
- Identify and select equipment based on process requirements
- Encourages reuse of standards through managed libraries
- Confirm and plan equipment installation in the context of the existing plant
Is it possible to avoid delays at start of production?

Commission automation control logic
- De-bug controls logic
- Test safety interlocks
- Validate HMI and diagnostics messaging

Speed and Accuracy
✓ Utilize standards and libraries to reduce programing time
✓ Validate system performance and function prior to physical ramp-up
✓ Train production personnel to avoid length downtimes during production

Virtually Commission AGVs Controlled by Siemens SIMOVE
The Digitalization of manufacturing production can help our customers meet their targets related to ...

- **Early Planning (sourcing)**
- **Accurate Manufacturing BOM**
- **Change management**
- **Line design**

- **Process for every part**
- **Assembly Planning**
- **Process Documentation**
- **Virtual Commissioning**

- **Rapid evolution of assembly sequence**
- **Validated sequence**
- **Validated tooling**
- **Manufacturing standards**

- **Effective use of resources**
- **Develop time estimates**
- **Balance work content**
- **Validate system behavior**

**Production Flexibility**

**Speed and Accuracy**

**Improving Efficiency**

**Capacity Planning and Utilization**
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Catering to a wide range of EV specific manufacturing needs

Battery Production
Design for Manufacturing | Production Capacity

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Supplier Evolution
Quality | Flexible Production | Collaboration

Comprehensive support for Electric Vehicle production
Planned Production Increases will Create Price Pressures

Challenge: Balancing economies of scale with evolving battery technologies

- Focused efforts on cell production costs by higher energy density (accuracy & chemistry) and manufacturing cost reduction
- Module and Pack assembly costs reduction can be gained by applying factory of future concepts

Digitalization will play a key role in the Battery Factory evolution
Massive Production capacities are/being brought online

... Factory Evolution

Battery Pack Cost is a key factor for EV adoption -- 70% reduction over 7 years in Battery Pack

- Estimated at $1,000 per (kWh) in 2010
- Tesla's Model 3 battery pack estimated $190/kWh
- 2017 Chevy Bolt estimated at $205/kWh

- 20+ “Gigafactories” in construction globally since Tesla’s 2014 Gigafactory (35GWh).

- China has doubled to 125 GWh since 2014. Projection is 250GWh by 2020.

- 60 new “Gigafactories” by 2037

$125–$150 ($/kWh) target that makes EVs competitive with conventional gasoline vehicles
Reducing the cost of battery costs by increasing production capacity

How do we keep up with the rapid pace of new product advancements for battery production without disrupting current production or experiencing lengthy ramp-up cycles?
Comprehensive Digital Enterprise solution for battery manufacturing

Digital World

1. Product design
2. Production planning
3. Production engineering
4. Production execution
5. Services

Digitalization
- Battery Process Know-how

Planning
- Battery plant simulation

Digital Equipment
- Automation concepts based on battery libraries

Integrated Plant
- Battery Production Control Center

Service
- Predictive Maintenance
- Condition monitoring

Real World

This integration provides essential a contraction of time-to-production and risk reduction.
Northvolt – Siemens Partner

Construction: 2018 – 2023
Square meters: 400 000
Capacity: 32 GWh/year

The next generation lithium-ion battery manufacturing

In order to deliver affordable and high quality batteries we need economies of scale. We also need deep vertical integration, a high level of automation and plenty of green and attractively priced energy.
So what are the challenges and implications to manufacturing that can make or break our success?

**Challenge**
- Rapid introduction of new products and/or manufacturing methods
- Maintaining flexibility to be able to adapt to changing market conditions
- Avoiding lengthy launch periods

**Manufacturing Implications**
- Select the correct level of automation to support production goals
- Digital validation in order to identify problem areas and mitigate risks
- Capture and leverage “lessons-learned”
Can changing the design of a product improve production?

Product / component design for manufacturing & service
- Assembly Feasibility
- Grip and Clearance
- Visibility

Design for Manufacturing
✓ Improve designs to facilitate assembly and disassembly operations

Efficient Production
✓ Avoid tedious or time consuming assembly tasks
Should everything in the plant be fully automated in order to increase volume?

Workplace design and simulation
- Process Validation
- Layout Refinement
- Ergonomics

Improve efficiency
- Validate processes and cycle time
- Balance the level of automation and manual processes

Ensuring Operator Health & Safety
- Minimize lost worker days due to poorly designed processes
How can robotics be utilized to support flexible processes?

Designing flexible manufacturing workcells
- Validate capabilities
- Develop robot programs
- Verify robotic interlocks with automation control

Increase Flexibility & Innovation
- Ensure equipment function and placement
- Reduce programming time

Minimize Ramp-up Time
- Commission workcell prior to physical launch
Can we avoid dedicated product lines with hard tooling and conveyance?

Plan and design logistics and material delivery systems
- Consider production rate
- Identify delivery locations
- Review aisles and routes for delivery

Increase Flexibility & Innovation
- Evaluate alternatives for material delivery
- Select appropriate equipment to support process requirements
- Validate interlocks between material handling, robotics and tooling
Does the material flow in production effect the bottom line?

Evaluate and optimize overall system performance
- Material flow and logistics
- Product mix
- Energy Consumption

Improving Efficiency
✓ Verify Throughput
✓ Evaluate Capacity and Equipment Utilization
✓ Optimize Energy Consumption

Reducing Inventory
✓ WIP Inventory / Turns
The Digitalization of manufacturing production can help our customers ...

- Improve production efficiency
  - Identify issues in advance
  - Validate capabilities
  - Optimize equipment utilization

- Speed up new product introduction
  - Confirm workplace safety
  - Leverage Best Practices
  - Evaluate system performance

- Reduce Ramp-up to Volume
  - Improve productivity
  - Validate functionally
  - Verify system throughput

Power Consumption
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Comprehensive support for Electric Vehicle production
Trend: OEM’s are on the move to increased outsourcing of a proportion of their value add business to suppliers

- Tier1 suppliers will play a critical role at both existing OEMs and new EV OEM entrants
- Traditional powertrain suppliers must evolve their portfolios to remain competitive
- Emergence of new disruptive suppliers with expertise in battery technology, electronics ..
With a larger role for supplier comes greater risks ....

OEMs with a focus on design, innovation and marketing that are outsourcing to Tier1’s, continue to ask for shorter time to market while complexity drastically increases

Impact on Processes

New complex collaboration dependencies with OEM & Tier 1, 2 suppliers

IMPLICATION

Suppliers are paying higher percent of the cost of quality
Suppliers are making key decisions on core competency and investment as EV production ramps up.

The eAxle
New impulse for electro-mobility
Less weight, greater range, and more efficiency

THE FUTURE OF CARMAKING MAY LIE IN MODULES LIKE THIS
Supplier ZF's electric-car-in-a-box module hints at core car-making elements.
JUNE 30, 2017

Why BorgWarner CEO says propulsion specialist 'can't lose'

Continental AG added 48-volt systems to its portfolio by spending $1.2 billion to develop technologies for EV

... rapid NPI's, global manufacturing footprint and IP management are imperative
The Siemens Digital Enterprise is the solutions for the rapid pace of innovation.

Teamcenter and the Digital Twin
Use simulation to achieve foresight in the virtual World

MindSphere
Use Big Data Analytics to gain insight and drive continuous improvement

MOM
Seamlessly coordinate and control resources in the real world
Leveraging the connected Digital Twins

- The virtual and the real worlds are linked by the **Manufacturing Master Data Model** and the **Common Plant Model** created from Automation.

- Decisions can be made based on **real-time** data from Automation.

- Feeding back all relevant information from production execution creates a nearly real-time image of the **digital twin of product, process and resources**.
Not just a vision ...

**Siemens Amberg plant**

- **Fast!** ~1 Million monthly production of SIMATIC products
- **Flexible!** 1200+ Teamcenter managed products shipped to 60,000+ customers worldwide each year 24 hour lead time for new orders
- **Efficient** 75% OEE plus 20% buffer for overcapacity
- **Quality!** ~11 dpm means near perfect quality – every time
So what are the challenges and implications to manufacturing that can make or break our success?

- Shorter lead times for OEM response
- Optimizing production footprint and locations
- Sharing of manufacturing information, traceability to OEM

**Manufacturing Implication**
- Smart use of automation, flexible manufacturing processes
- Rapid evolution of assembly methods
- Knowledge sharing across sites, continuous improvement

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**Challenge**

**Market Uncertainties**
- Flexibility to quickly shift production

**Global Operations**
- Build anywhere with consistent Quality

**Portfolio Evolution**
- Reduce time to market

**Productivity Initiatives**
- Deliver on expected efficiencies
Can we ensure the we have achieved quality KPIs before a product leaves are factory?

Leverage model based definition to improve designs for manufacturing
- Performa Variation Analysis
- Develop CAM programs
- Inspection planning

First time quality
- Assembly stack-up variation optimized early using embedded PMI
- Automation of CAM programming based on product features
- Inspection program tied to change process
- Faster quality ramp-up with analytical production root cause
How do we validate production lines with high degree of automation before building?

Plan and design machine lines to accommodate new products
- Select and equipment to meet process requirements
- Validate equipment performance

Optimize Capital Spend
- Identify and source equipment early
- Analyze and optimize system performance to achieve flexibility requirements
- Define system footprint and floor space reservation
- Reduce debug during ramp-up
Can I analyze the impact to upgrading existing Production facilities and lines?

Incorporate new line designs into existing facilities
- Review current as-is plant
- Verify floor space and fit
- Define installation plan

Faster Production Ramp-up
✓ Design in plant context to avoid late changes do to existing plant monuments
✓ Facilitate plant involve during engineering phases
✓ Speed-up launch activities by eliminating late changes
Is it possible to get process consistency and quality, yet build anywhere at different line rates?

Plan for global or multi-plant production scenarios
- Share lessons learned or best practices
- Utilize standards
- Provide for local variations

Process Consistency
- Drive standardization of process based on a Product BOP
- Time Analysis based on standards
- Factor in plant specific line rates, product mixes and equipment
- Production attainment with balanced lines
Wouldn't it be nice if we share information in a plant context to others that are in different manufacturing facilities?

Share and collaboration relevant information
- Work instructions
- Process Documentation
- Dashboards
- ...

Faster Production Ramp-Up
✓ Line up, Process comprehension - connection to backbone
✓ Current status visibility - dashboards
✓ Contextual information, reduce time spent in information search
✓ View lead or other plant processes

Process Consistency
✓ Access to Set-Up documents, Work Instructions, Equipment information

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Supplier Evolution – Support for Electric Vehicles

**Product Manufacturing Information (PMI) leverage**
- Variation Analysis
- Automated CAM
- Root Cause

**First Time Quality**

**Greenfield Planning**
- 3D Layout Design
- Off Line Programming
- Cycle Time Validation

**Optimize Capital spend**

**Production Footprint**
- As-Operated
- Impact Analysis
- Buy off

**Faster Production Ramp-Up**

**Production Footprint**
- Standard Process
- Line Balancing
- Collaboration

**Process Consistency**
Siemens Digital Enterprise ... Moving e-Vehicle Production into the Fast Lane

Digital Twin of the product

Digital Twin of the production

Digital Twin of the performance
Contact Information

Todd Bengtsson
Director Automotive Industry Solutions
DF / PL / MFE / PRM
38695 West Seven Mile Road
Suite 300
Livonia Michigan, 48154

Mobile: +1 248-982-2714
E-mail: todd.bengtsson@siemens.com