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3. Product design trends
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Final Assembly

iNEMI Roadmap definition:

*Final Assembly encompasses operations that integrate or assemble electronic subassemblies with other electronic, mechanical and optical content.*

- Typical final assembly processes:
  - sticklead / thru-hole assembly, board depanelization, pick and place, screw driving, a variety of bonding and joining technologies, dispensing, labeling, testing, and packaging.

- Final Assembly is a key part of manufacturing process.

- Final Assembly strategy and implementation plans are directly impacted by key factors such as customer demands, corporate issues, and government regulations.
Key drivers for Final Assembly (1/2)

- **Customer Requirements**
  - Smaller size
  - Higher performance
  - Increased product functionality and integration
  - Lower cost
  - Product personalization
  - Increased product quality and reliability

- **Government Regulations**
  - Dynamic Tax Laws, Content Regulations, and Import / Export Policies
  - Product traceability
  - Lead free
  - End of Life / Recycling
Key drivers for Final Assembly (2/2)

• Corporate Strategies
  – Customer and Market Diversity and Requirements:
    • Different product sectors have different customer and market locations and requirements that can impact manufacturing strategies.
      – E.g. Defense industry secrecy requirements result in almost exclusive domestic fabrication with a very local and focused manufacturing enterprise.
      – Consumer Portable product group’s customer and market base are truly global → the capability to produce and distribute product in all regions of the globe is needed.
  – Manufacturing Location:
    • Typically, financial factors and corporate logistics drive the decision to produce products locally, regionally or globally.
    • Other infrastructure issues impacting decisions:
      – Employee skill level and availability
      – Equipment, process, and material availability and support
      – Supply and distribution chain
Product Design Trends impacting Final Assembly (1/2)

- **Increased product density and miniaturization**
  → increased assembly precision and accuracy requirements

- **More complicated product to component connectorization**
  → new connector products and assembly processes have been developed which, in turn, drive new assembly processes and equipment

- **Increased integration of product functions**
  - Wide variety of components to assemble and wide variety of assembly processes
  - The continued demand for increased performance and up-integration will drive the need for innovative assembly technologies and materials in areas such as:
    - Thermal management
    - EMI shielding
    - New assembly and joining technologies
Product Design Trends impacting Final Assembly (2/2)

- Product differentiation at Final Assembly
  → Flexibility requirements
- Quality and Reliability
- Cost Reduction
  → Search for less expensive components and methods for assembly
    - The difficult challenge still remains in developing cost models that accurately reflect the true overall cost of a product design and its impact on manufacturing, quality, and reliability.
Portable and Consumer Products:

- **Portables:** Mobile phones, digital cameras and camcorders, PDAs, compressed audio players (e.g. MP3 players)
- **Non-portables:** Televisions, DVD players, digital video recorders, stereos

- The phenomenal growth rate is expected to cool to 2.1% through 2010.
- This sector is under the most pressures
  - very high volume
  - very short product life cycle
  - relatively high product mix
  - continual pressure to reduce cost
  - has customers in all global markets
  - must remain flexible and agile to adjust to its dynamic landscape

- The typical strategy is to establish manufacturing in the low cost areas within each geographic region.
### Product Sector Analysis (2/5)

**Automotive Electronics Products:**

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Powertrain Electronics</strong></td>
<td>Engine controllers, transmission controllers, and any other items that controls the drive train.</td>
</tr>
<tr>
<td><strong>Entertainment Electronics</strong></td>
<td>All on board entertainment, including video and satellite radios.</td>
</tr>
<tr>
<td><strong>Safety and Convenience</strong></td>
<td>Air bag systems, climate controls, collision avoidance systems, and security.</td>
</tr>
<tr>
<td><strong>Vehicle and Body Control</strong></td>
<td>Suspension, traction and steering systems.</td>
</tr>
<tr>
<td><strong>In-Cabin Information</strong></td>
<td>Instrument displays and telematic navigation systems.</td>
</tr>
<tr>
<td><strong>Non-Embedded Sensors</strong></td>
<td>Speed, temperature, fluid level, and others.</td>
</tr>
</tbody>
</table>

- Lower volumes and longer lifecycles compared to other sectors.
- Suppliers vertically integrated
- Manufacture typically in the region of final use.
  - Automobiles are typically assembled in-market.
- Major drivers in automotive industry: Increasing cost, quality, and reliability pressures.
### Office / Large Business / Communication:

<table>
<thead>
<tr>
<th>Computers and Office Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Computers</strong>: PCs, workstations, and servers.</td>
</tr>
<tr>
<td><strong>Computer Peripherals</strong>: Printers, scanners, keyboards, monitors, PC cameras.</td>
</tr>
<tr>
<td><strong>Storage Systems</strong>: Hard disk drives, SAN / NAS (Storage Area Networks / Network Attached Storage)</td>
</tr>
<tr>
<td><strong>Office Equipment</strong>: Copiers, fax machines, digital projectors</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Communications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Small Office / Home Equipment</strong>: Routers, wireless LANs</td>
</tr>
<tr>
<td><strong>Enterprise Equipment</strong>: Mid-range switches and routers, PBXs, VoIP phones.</td>
</tr>
<tr>
<td><strong>Service Provider Equipment</strong>: Wireless base stations, central office switches, cable modem termination systems, core routers.</td>
</tr>
</tbody>
</table>

- Largest segment within Electronics industry
- Office Equipment account for 37% and Communications for 15% of the whole $1.2 trillion industry.
- Asia is the leading manufacturing region.
Defense and Aerospace Electronics Products:

**Weapon Systems:** Missiles and smart bombs that have internal guidance systems.

**Sensors and Acquisition Systems:** Laser range finders, radar, sonar, GPS, thermal/night vision goggles, ground imagery systems, and other surveillance equipment, all of which are used to acquire, identify, and track targets.

**Survivability Systems:** Electronic jamming equipment and false target generators.

**Networking Communications:** Radios, satellite systems, fiber optic networks, and other networks used to share information in real time.

- U.S. is the biggest investor in this sector
  - Expected 73% of overall production in 2006

- High reliability, low volume, liability, and security restrictions on many defense systems have severely limited contract manufacturer penetration to about 1%.
Medical Electronics Products:

- Growth is primarily driven by the worldwide demographical shift to an older population.
- Most products are produced in the region where they are consumed.
  - North America is the largest market for these products, and largest producer accounting for 58% of total production.
  - China and India are the fastest growing markets.
- The contract manufacturer penetration has been limited due to the reliability and liability requirements, government regulations and the proprietary nature of designs.

Large Infrastructure Medical Equipment: Medical imaging systems (e.g., x-ray and MRI), IT equipment (e.g. picture archival communication systems PACs), and biochemical analysis equipment (e.g. lab instruments and DNA analyzers).

Small Stationary and Portable Medical Equipment: Patient monitoring systems and home diagnostics (blood pressure and blood glucose meters).

Implantable Medical Equipment: Pacemakers, implantable cardioverter defibrillators (ICDs), neurostimulators (e.g. for Parkinson’s disease) and drug pumps (e.g. for insulin release).
The key factors impacting the product sectors

<table>
<thead>
<tr>
<th></th>
<th>Automotive</th>
<th>Aerospace / Defense</th>
<th>Medical</th>
<th>Consumer / Portable</th>
<th>Office / Large Business / Comm</th>
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<tbody>
<tr>
<td>Cost Pressures</td>
<td>↑</td>
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<tr>
<td>Quality &amp; Reliability</td>
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<tr>
<td>Expectations</td>
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<tr>
<td>Flexibility Requirements</td>
<td>↑</td>
<td>→</td>
<td>→</td>
<td>↑</td>
<td>↑</td>
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<tr>
<td>Product Life Cycles</td>
<td>↓</td>
<td>→</td>
<td>→</td>
<td>↓</td>
<td>↓</td>
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<tr>
<td>Assembly Precision</td>
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Figure 3: Trends by Product Sector
Figure 4: Projected Regional Electronics Production by Product Sector for 2006

Source: Prizmark Report to iNEMI. Report No. 3217 (June 2006)

Advancing manufacturing technology
Product sectors’ actual production revenue by region

Figure 5: Projected Regional Electronics Production by Product Sector for 2006 ($ Billion)

Source: Prismark Report to iNEMI, Report No. 3217 (June 2006)
Percentage of outsourcing by product sector

Figure 7: % Outsourced Final Assembly Production Value by Product Sector

Source: PrizmArk Report to iNEMI. Report No. 3217 (June 2006)
Total production by region

Projected Production by Region for 2006
($ Billion)

Figure 6: Projected Production by Region for 2006

Source: Prizmark Report to iNEMI. Report No. 3217 (June 2006)
### Quantified Key Attribute Needs for Final Assembly (1/3)

#### Table of Quantified Key Attribute Needs for Final Assembly

<table>
<thead>
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</thead>
<tbody>
<tr>
<td>Automated Assembly Cells</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$ / Cell (Untooled)</td>
<td>$55 K</td>
<td>$51 K</td>
<td>$47 K</td>
<td>$44 K</td>
<td>$40 K</td>
<td>$37 K</td>
<td>Base cells need to reach commodity level pricing.</td>
</tr>
<tr>
<td>$ / Cell (Tooled &amp; Functional)</td>
<td>$150 K</td>
<td>$139 K</td>
<td>$128 K</td>
<td>$119 K</td>
<td>$110 K</td>
<td>$102 K</td>
<td>Equipment suppliers will differentiate by adding value to base cell.</td>
</tr>
<tr>
<td>Cell Footprint</td>
<td>1.5 m²</td>
<td>1.5 m²</td>
<td>1.25 m²</td>
<td>1.25 m²</td>
<td>1.0 m²</td>
<td>1.0 m²</td>
<td>Reduction in assembly line lengths and floor space constraints will continue to drive smaller footprints.</td>
</tr>
<tr>
<td>% Reusable Content</td>
<td>80%</td>
<td>80%</td>
<td>85%</td>
<td>85%</td>
<td>90%</td>
<td>95%</td>
<td>Process module standardization is a key driver to improving this metric.</td>
</tr>
<tr>
<td>Rebuild Cost: Base Cell %</td>
<td>10%</td>
<td>8%</td>
<td>6%</td>
<td>4%</td>
<td>4%</td>
<td>4%</td>
<td>Base cell and process module standardization should make this expense negligible.</td>
</tr>
<tr>
<td>Rebuild Cost: Process Module %</td>
<td>40%</td>
<td>35%</td>
<td>30%</td>
<td>25%</td>
<td>25%</td>
<td>20%</td>
<td>Process module standardization is a key driver to improving this metric.</td>
</tr>
</tbody>
</table>
Miniaturization of floor space

Year

2002

Cell Footprint: 1.5 m²

Cell Footprint: 0.7 m²

Assembly line based on HiSAC 1000 Cells

Assembly line based on HiSAC 500 Cells

Source: PMJ automec Oyj
Desktop Factory by Bosch Rexroth

- Standard module width 220 mm
- Different widths possible
- Plug-in modules allow any combination
- Module change over time ≤ 2 min

Basic Cell with safety enclosure

- Plug-in modules may be used on the feeding side
  - Feeding Module
- Feed units, e.g.:
  - Axes + Grippers
  - Palletizers ... can be integrated

Plug & Play system
- One transfer unit per Plug-in module
- Overtake of parallel station

INEMI
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TUT-Microfactory
## Quantified Key Attribute Needs for Final Assembly (2/3)

### Table of Quantified Key Attribute Needs for Final Assembly

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<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Time to Procure Equipment (weeks)</td>
<td>14</td>
<td>13</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>9</td>
<td>This time is based on time a Purchase Order is released to the time the equipment is delivered to the manufacturing site. Development of standardized assembly cells and process modules are key factors to facilitating dramatic improvement.</td>
</tr>
<tr>
<td>Average Time to Install Equipment and Approve for Production Use (days)</td>
<td>10</td>
<td>9</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>7</td>
<td>This will be a particularly challenging metric to meet as companies reduce engineering and technical support in Final Assembly. Equipment suppliers will differentiate by providing equipment and process turn-key solutions.</td>
</tr>
</tbody>
</table>
### Table of Quantified Key Attribute Needs for Final Assembly

<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Process Modules</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pick &amp; Place - General</td>
<td>$5 K</td>
<td>$5 K</td>
<td>$5 K</td>
<td>$4 K</td>
<td>$4 K</td>
<td>$4 K</td>
<td>Too broad and application specific to realize significant cost reductions.</td>
</tr>
<tr>
<td>Adhesive Dispense (1-part)</td>
<td>$15 K</td>
<td>$14 K</td>
<td>$13 K</td>
<td>$12 K</td>
<td>$11 K</td>
<td>$10 K</td>
<td>A relatively stable process technology. Only modest cost reductions will be realized. Advancements in process monitoring may offset any cost reductions.</td>
</tr>
<tr>
<td>Screw Driving</td>
<td>$10 K - $20K</td>
<td>$9 K - $19K</td>
<td>$8 K - $18K</td>
<td>$7 K - $17K</td>
<td>$6 K - $16K</td>
<td>$5 K - $15K</td>
<td>Cost reductions in electronics and controls will allow for lower cost drivers with greater process control and monitoring capability</td>
</tr>
<tr>
<td>Vision Inspection</td>
<td>$7 - $20K</td>
<td>$7 - $20K</td>
<td>$6 - $18K</td>
<td>$6 - $18K</td>
<td>$5 - $15K</td>
<td>$5 - $15K</td>
<td>Advances in computing capability and decreasing cost will drive lower cost and higher performance vision systems.</td>
</tr>
</tbody>
</table>

Table 1: Table of Quantified Key Attribute Needs
Two clear trends impacting Final Assembly:

- Continued reduction in Final Assembly Costs
  - 15.4% average yearly cost reduction

- Continued reduction in Final Assembly procurement Cycle Time
  - 15% yearly reduction in NPI Cycle Time
Lack of Common Industry Strategies and Solutions for Final Assembly

- The Surface Mount (SMT) industry has basic industry standards and solutions for key items such as:
  - Product design standards.
  - Component sizes, shapes, and configurations standards.
  - Component packaging and delivery standards and solutions (tape and reel etc.).
  - Product programming standards.
  - Industry standard process specifications.
  - Off-the-shelf equipment and process solutions.
  - Equipment integration and communication standards.

- The SMT industry provides a model and template that should be emulated by Final Assembly.
- Implementing those standards will enable more rapid deployment of Final Assembly applications, enable reuse of standard process modules and equipment, and provide more cost effective solutions.
Use of Design for Assembly / Manufacturability Tools

- Design for Assembly and Design for Manufacturability are key enablers to developing effective Final Assembly solutions.
- The implementation of DFA / DFM tools is often unsuccessful due to several factors.
  - Lack of commitment or time to use the tools.
  - Lack of defined or existing standards
    - Product design building blocks
    - Manufacturing building blocks
    - Industry standard final assembly process and equipment solutions.
  - Poor communication or interaction between the product design and manufacturing organizations.
Advancements in Human Centered Automation

• There is a need for better integration of automation and human skills.
• A typical approach is Human Centered Automation.
  – The focus is on the role of the operator and the way automation can assist him (or her) in accomplishing the assigned task.
  – The strategy is to automate labor consuming, or, quality critical work phases (screw driving, labeling, test handling, ultrasonic welding, dispensing...) and leave the other tasks, such as loading, unloading, part transport, and simple assembly tasks to the human.
  – Provides an optimum balance of efficiency, flexibility, and cost.
Increasing Product Traceability Requirements

• Key drivers for increasing traceability requirements:
  – Quality, reliability, environmental regulations, and liability concerns
• Product traceability includes both the assembly process metrics and a hierarchy record of subcomponent assembly.
• Effective execution can be difficult
  – Lack of industry standard electrical communication and software interface between Final Assembly equipment and Factory Information Systems often leads to extensive software customization and debug costs.
  – The Integration of product traceability into manual / semi-automated assembly stations can be cost prohibitive - and does not always ensure true traceability.
Development of Product Design Standards

- The lack of product design standards inhibits the development and use of standard processes and equipment building blocks and ultimately impacts the Final Assembly cost and reuse metrics.

Quality Improvement - Test and Performance Metrics

- The ability to test and measure the success of the assembly operation is a common problem within several assembly processes in Final Assembly.
  - E.g. bonding and joining processes (ultrasonic welding, heat staking, etc), adhesive component assembly, fastener assembly, cable and connector assembly, and others.
- The absence of test and performance metrics makes process and quality improvement an impossible task.
Product Customization and Design Postponement

• Configure to Order (CTO), Build to Order (BTO), and Mass Customization (MC) are common terms and techniques used to drive product differentiation and customer satisfaction within Electronic industry.

• In order to use automation in a practical, cost-effective manner, a partial standardization of design is required.

• A similar challenge regarding the standardization of design is posed by Design for Postponement (DP), in which critical aspects of a product's design are fixed at the last possible moment.

• In order to compete with the manual and fixture-assisted manual final assembly environments in which DP has been realized, the use and reuse of well-defined process modules with plug-and-play compatibility is critical.
Design for Postponement – Late Personalization

Final assembly (personalization) moves closer to the customer (Variants/ Personalization)

Parts mgf → Sub-assemblies → Engine assembly (Product platform) → Final assembly

Raw Mat. → Machining/Fab → Sub-assembly → Final Assembly

Distribution Centers → Point of Sale

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Assembly Process and Technology Divergence
• The combination of product miniaturization, and integration of an ever widening variety of component types, drives an equally increasing diversity in assembly processes and technologies.

Pressure to Reduce Final Assembly Costs
• The key factors enabling cost reduction are:
  – Standardization
    • Product design and process building blocks
  – Cell Flexibility
    • Ability to meet low volume / high mix product demands.
    • Reconfigurable to meet shorter product life cycle demands
    • Time to market
Technology Needs

• Technology needs and gaps exist within the various Final Assembly processes.
• These can be divided into a couple of categories:
  – Lack of adequate assembly process control, monitoring, and verification.
  – Lack of adequate and economical assembly solutions.
Gaps and Showstoppers

Lack of Definitions / Standards

– Standards for base cells, process modules, and development tools.

– Without these standards, it will be impossible to achieve the roadmap’s projected cost reductions for a “tooled and functional” cell.

Lack of Standard Process Metrics

– Causes problems in measuring and comparing “conversion costs” for final assembly processes.

Extended Deployment Time

– Shortened time to market and supply chain cycle times put pressures on manufacturing system deployment times.

– While a deployment time of two to four months is achievable for an individual cell, large lines and systems can often take longer to deploy and reconfigure.

Process Monitoring and Verification Gaps

– Requirements for process monitoring and verification within Final Assembly increases, because of the increase in quality, reliability, and product traceability requirements.
### Electronic Interconnection Standards for e-Commerce (IPC-2500 series)

**CAMX**

<table>
<thead>
<tr>
<th>IPC Number/Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPC-2500 CAMX Framework</td>
<td></td>
</tr>
<tr>
<td>IPC-2510 GenCAM Product Data</td>
<td></td>
</tr>
<tr>
<td>IPC-2520 Quality Product Data</td>
<td></td>
</tr>
<tr>
<td>IPC-2530 SRFF Process Data</td>
<td></td>
</tr>
<tr>
<td>IPC-2540 Shop Floor Communicate</td>
<td></td>
</tr>
<tr>
<td>IPC-2550 Execution Communicate</td>
<td></td>
</tr>
<tr>
<td>IPC-2560 Enterprise Communicate</td>
<td></td>
</tr>
<tr>
<td>IPC-2570 Supply Chain Communicate</td>
<td></td>
</tr>
</tbody>
</table>

- **IPC-2501** – Message Framework
- **IPC-2541** – Generic SMT Processes
- **IPC-2546** – Assembly Processes
  - Screen Printing
  - Adhesive Dispensing
  - Pick and Place
  - Reflow
  - Automated Final Assembly
- **IPC-2547** – Test and Inspection Processes
  - AOI and AXI Inspection
  - In-Circuit and Functional Test

*Published 10.2.2005*
Recommendations

• Form a working group to develop standards for the various Final Assembly technologies. The group would generate the following list of key deliverables:
  • Identify and define key assembly processes and technologies.
  • Establish respective assembly process definitions, standards, requirements, and metrics.
  • Establish key product design standards that enable this process.
  • Define critical equipment integration and communication standards.
    • Mechanical
    • Utilities
    • Electrical interface and communication
    • Software and programming
  • Identify approved off-the-shelf equipment and process solutions.
  • Publish as industry standards.
www.inemi.org

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