VERTICAL INTEGRATION STRATEGY STEMS OFFSHORE TIDE FOR AMERICAN MANUFACTURER

James W. Blundon
Whelen Engineering Company, Inc.
Charlestown, New Hampshire, USA
jblundon@whelen.com

ABSTRACT

By controlling the manufacturing process from design through assembly, American companies can use vertical integration to maintain robust product pipelines and avoid many of the issues caused by supply chain shortages and offshoring. One New England-based manufacturer who spent decades refining their vertical integration strategy has seen it payoff in recent years as others in their industry struggle with supply chain shortages related to the pandemic. As a global leader in the emergency warning industry, their American-based facilities have grown to include:

- Automotive Product Assembly – building roof-mounted LED lightbars to customer specifications and hundreds of other products for emergency service and Department of Transportation (DOT) sectors.
- Aviation Product Assembly – complex interior and exterior LED modules for Original Equipment Manufacturers (OEMs) and aftermarket aviation customers.
- Mass Notification Siren Assembly – producing large sirens for alerting, informing, and directing the public during disasters and emergencies.
- "Vendor-Level" Processes:
  - Plastic Injection Molding & Machining – lenses, grommets, gaskets, aluminum-plated plastic reflectors.
  - Magnetic Winding – transformers, chokes, and coils are robotically wound and terminated.
  - Wire, Cable, & Harness Assembly – automated wire and cable processing feeds a diverse variety of harness assemblies.
  - Electronic Production – flexible mix and volume SMT assembly.
  - Sheet Metal Fabrication – brackets, housings, aluminum extrusion finish work, powder coating.
  - Production Machine Shop – precision aircraft lighting components.
  - Printed Circuit Board (PCB) Fabrication – green PCB fabrication facility with industry-leading waste treatment and chemistry reclamation systems producing Very High Density Interconnections (VHDI) and Ultra High Density Interconnections (UHDI) PCBs and Integrated Circuit (IC) substrates. Machinery supporting fabrication processes is also developed internally.
- Engineering – the industry's largest team develops new products and supports the product lifecycle. In-house testing capabilities include anechoic sound and radio frequency (RF) chambers. Automation experts design and implement solutions for manufacturing.

By maintaining a strong vertical integration strategy and focusing on the needs of its customers, this manufacturer has developed a competitive edge that allows end-users a high degree of customization, versus forcing acceptance of a standard model that does not fit their needs, as well as the ability to respond and adapt to changes in the market. The development of a wide array of automation has allowed the business to realize cost savings, avails labor to create products configured to customers' requirements, and has improved efficiencies company-wide.

In addition, their innovative spirit and employee-focus set the pace for the team to take risks and work against the tide of outsourcing to invest in employees and factories in America. They are developing the next generation of leaders, removing the "middlemen" by transforming raw materials into finished products in their own facilities, and harnessing automation to provide the best quality of life for employees while remaining competitive. The totality of their efforts allows them to avoid many of the issues facing manufacturers who rely heavily on outsourcing.

Key words: Onshoring, vertical integration, American manufacturing, assembly

BACKGROUND

Whelen Engineering Company has been an innovator and leader in emergency vehicle warning lighting, white illumination lighting, sirens, and aviation lighting for over seventy years. This case study reviews the history of proven success in its commitment to American manufacturing and in making bold decisions to invest in vertical integration. Unlike many of America's leading companies that have grown beyond the roots of their founding to chase maximum profits at the cost of their communities, the Whelen family remains in full ownership of the company while also investing in the health of the communities which support the organization. The company got its start seventy-one years ago, when George W. Whelen III developed a rotating incandescent beacon to identify his airplane and avoid collisions. Today, Whelen designs and manufactures cloud-connected control suites that integrate with vehicle systems to enhance first responder safety with lighting and audible warning systems on police cars, fire trucks, ambulances, DOT trucks, and tow trucks.

VERTICAL INTEGRATION

A critical facet of the company's long-term success has been vertical integration at its American factories. When the company started, the focus was on assembly and design. As the company expanded beyond the founder's garage in the 1970s, many of the company's original suppliers moved overseas or could not meet the growing demand. Each time that happened, the company viewed it as another opportunity to add capabilities, drive innovation, and better control lead time and quality.

A common litmus test for developing internal vendor-level processes has been whether the company can get both the quality and quantity of components in the necessary lead time from American suppliers. This mindset has been a mainstay throughout the company's entire history. One of the first employees hired – who later led the company for more than forty years – explained his philosophy, saying "I lived through World War II. Our ability to win the war was (based) on our capacity to manufacture" [1]. Today, the company performs several "vendor-level" processes at their New Hampshire, USA campus. Instead of relying solely on commercial vendors, the vendor-level departments provide circuit board assembly, metal machining, magnetic winding, plastic injection molding and machining; wire, cable, and harness assembly; sheet metal fabrication, and bare PCB fabrication in-house to directly support the final assembly departments.

Assembly & Design

The finished product that the customer receives is the primary driver of any manufacturer. For this company, customization of the finished product is a key differentiator in the market. To support the wide variety of components required to build the catalog of assemblies, several vendor-level processes have been developed internally over the years. They have approximately 10,000 active model numbers available for purchase, and several of them are highly configurable. For example, roof-mounted LED lightbars are available in lengths from 44" (1.11 meter) to 96" (2.44 meter), and the customer can choose to populate the lightbar with a variety of lighthead designs as they configure it for their specific application. Customers also select the color of LED lighthead and lenses to further personalize the finished product. White illumination lighting products are also configurable with options in voltage, light output, lens type, mounting style, and paint color.

As a matter of course, a team of manufacturing engineers works closely with design engineers to develop products which can be assembled with high levels of automation, like their newest generation of vehicle roof-mounted LED lightbars. These include individual lightheads that are assembled, tested, and labeled with laser-etching in multi-station robotic cells. The robotic assembly cells are positioned close to the progressive slide lines where the lightbars are built to customer specifications. By co-locating the robotic cells near final assembly, a Kanban pull system allows for reduced inventory and less movement of parts and people.

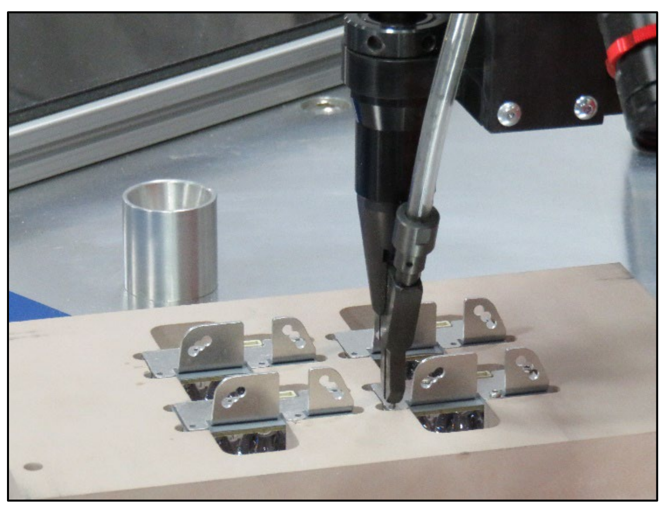

Figure 1. Robotic assembly cell installing screws in an LED lighthead.

The assembly of a small, self-contained lighthead has also been optimized with progressive slide lines and robotic assembly operations. This process originally consisted of several steps including an epoxy fill which had a slow curing cycle. Customer order demand exceeded production capacity quickly, even as offshore competition flooded the market, so the manufacturing-engineering team worked with the assembly team to develop an improved system. Minor changes were implemented by the design-engineering team to make the components compatible with the planned robotic assembly tooling. By working in the company's manufacturing-engineering lab, the three teams worked to prove out the new process without impacting production. As a result, a new heat-curable epoxy sealant was identified, and cure time was reduced to a matter of seconds, before the lighthead receives a plastic lens in a robotic operation. Changes to the design also eliminated screws in favor of thermally-conductive adhesive, which reduced the complexity of the assembly process and simplified the automation process. Once the new process had been proven in the lab, the old production equipment was moved out between shifts and production resumed on the new equipment with minimal delays. The department's capacity also increased by 140%, quickly catching up to the customer demand level with room for continued growth.

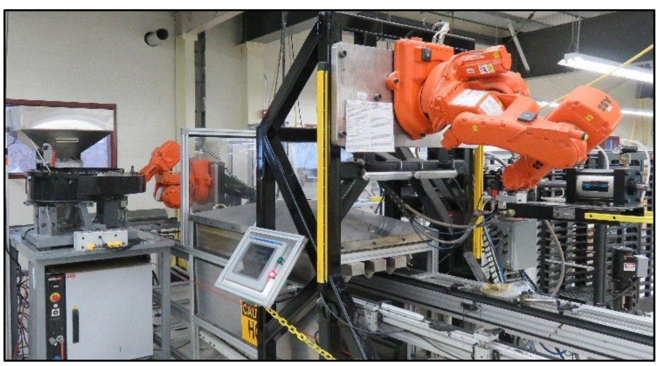

Figure 2. Self-contained lighthead assembly cell. The robot in the upper right dispenses the epoxy. The robot in the background installs the lenses.

Vertical integration efforts are also evident in their latest generation of automotive warning and white illumination lighting, which is built using hot-melt silicone technology. Plastic lenses and aluminum baseplates are plasma-etched before the silicone adhesive is applied. This process removes labor by eliminating the need for screws to secure the baseplate to the lens, while increasing product performance by reducing the potential points of moisture intrusion. This automated work cell was designed with flexibility and future growth in mind. Single-minute changeovers and lot sizes of one have become achievable with their redesigned process.

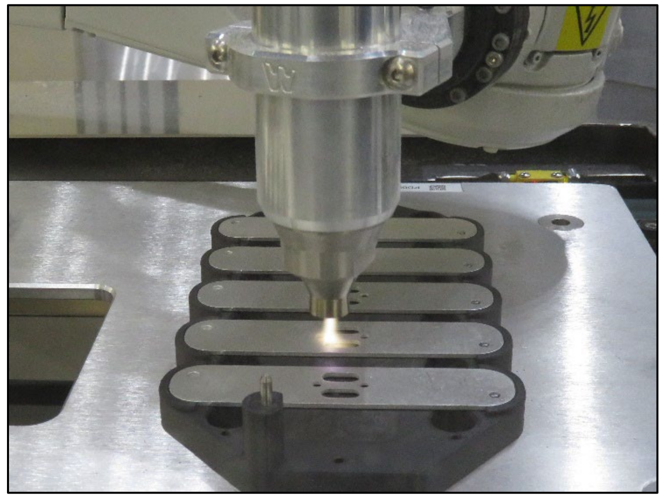

Figure 3. A robotic arm plasma-etches aluminum base plates before hot-melt silicone adhesive is applied.

At the start of the process, design engineering and product testing are performed in-house. This allows for close control of new product introduction and allows for efficient product development. Instead of working with a manufacturing team on a different schedule on a different continent, design engineers can walk across the company's campus to visit the assembly floor in person. As soon as products are built, they can be tested to a range of industry standards in captive engineering laboratories. Anechoic sound and radio frequency chambers and photometric testing equipment are equipped to certify products to specifications published by governing bodies including SAE International, Automotive Manufacturers Equipment Compliance Agency, Inc. (AMECA), Economic Commission for Europe (ECE), Federal Motor Vehicle Safety Standards (FMVSS), and the Federal Communications Commission (FCC). Additionally, the laboratories are equipped to carry out vibration, galvanic and chemical corrosion, ultraviolet (UV) exposure, and thermal cycling. Testing can also be completed internally for water, moisture, and dust intrusion to Ingress Protection (IP) rating standards.

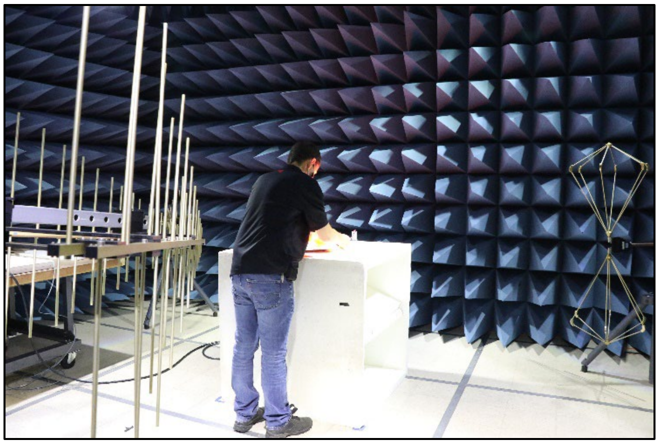

Figure 4. An engineer prepares a unit for test in an anechoic radio frequency chamber.

At the end of the process, finished products are warehoused in a network of twelve, 42’ (12.8 meter) tall storage towers and a series of conveyors. Software links the towers, conveyors, and the company’s enterprise resource planning (ERP) system. Every fifteen minutes, the software processes a series of transactions to efficiently present shelves of finished products to operators who sort them into totes on the conveyors. As the totes move to each picking station, more parts are added until the order is complete. The automated equipment uses less floor space and fewer material-handling employees while simultaneously doubling output. Conveyors deliver the tote to a packaging station, then to a shipping terminal. With a single barcode, software is used to automate the generation of a packing list and creation of a shipping label, as well as the marking of an order as “shipped” in the ERP system and sending an advanced shipping notification to the customer.

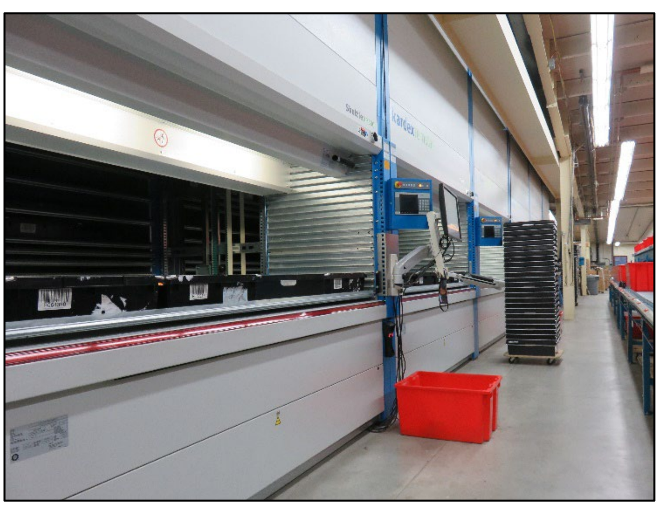

Figure 5. Finished goods automated warehouse.

Circuit Board Assembly

As product lines evolved from mechanical rotating beacons into electronic flashers and then strobe lighting, printed circuit boards became critical to the company’s success and growth. Over time, this vendor-level process has grown from manually placed and soldered through-hole components, to using the latest generation of surface-mount technology (SMT) assembly equipment to populate fine-pitch micro components with full automation.

Through the evolutions of products, the circuit board assembly departments have also evolved. Single-layer through-hole PCBs with hand-inserted resistors and capacitors were replaced with two-layer through-hole and then hybrid SMT designs. Now, four-layer PCBs are common. Production is balanced between two facilities and eight SMT production lines which produce more than six million PCB assemblies each year. This high volume of work led to the creation of an automated depaneling cell (which utilizes linear and tab-route depaneling methods), which in turn led to the design of the next evolution of circuit board assembly: a production line able to process PCBs from start to finish. This includes all the elements required to perform circuit board assembly: bringing a bare panel through solder paste printing and solder paste inspection, pick-and-place, reflow, inline test and programming, conformal coating, depaneling, and packing. The non-value-added time reduction for this process compared to the previous batch-and-queue process is calculated to be greater than 70%.

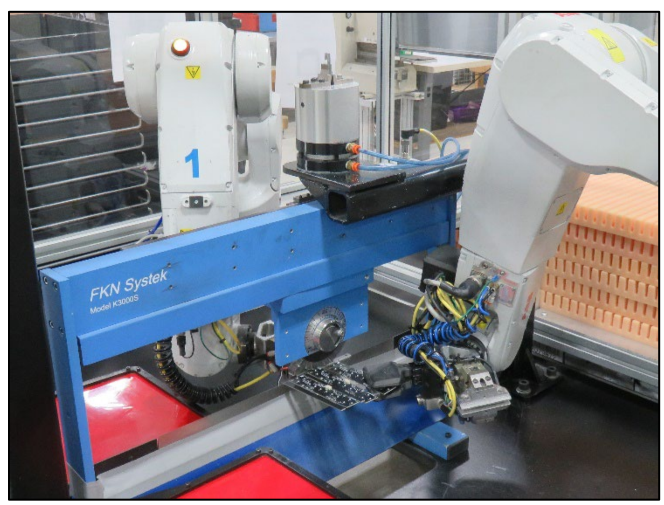

Figure 6. Two robotic arms position a circuit board panel for processing in a depaneling cell.

Metal Machining

Metal machining was the next vendor-level process brought in-house. Detailed heatsinks, chassis, and assemblies using aluminum extrusions were needed for products like roof-mounted lightbars and strobe power supplies. The company's facilities now include 3-axis, 5-axis, and horizontal Computer Numerical Control (CNC) machining centers, plus sophisticated lathes and Swiss turning centers to perform more complex operations like creating precision aircraft lighting components and surface-finish machining of cast-metal parts. The company partnered with a German machining automation supplier to install three robotic pallet loaders to tend to CNC milling machines. These automated pallet loaders allow machinists to dedicate time to value-added activities, and they also allow for lights-out machine operation. A single skilled machinist can set up as many as twenty workpieces in one automated pallet loader before moving on to work with the next cell. The CNC milling machines are equipped with tool detection probes used at each tool change so if a tool breaks, the probes will recognize the issue and stop the machine [2].

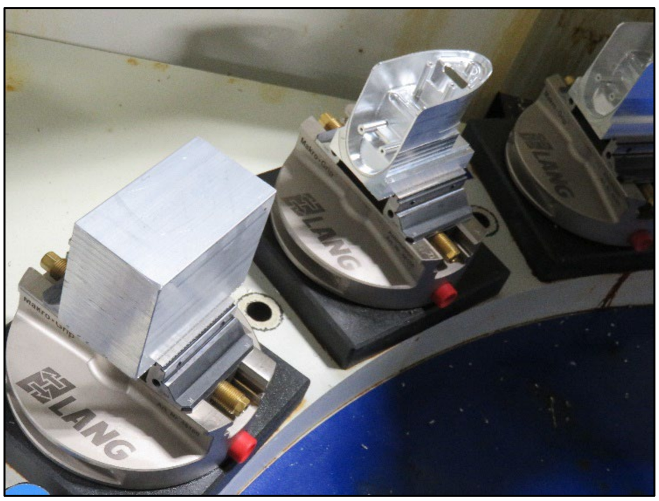

Figure 7. (Left) Aluminum stock and (Right) machined part in an automated pallet loader.

The Swiss turning centers produce custom fasteners and support production fixtures in other vendor-level departments as well. One complex metal reflector used in an OEM automotive cornering light had previously been manufactured using a series of lathes, mills, and polishing stations. The polishing alone required six minutes of labor per piece. Once the reflector was programmed to run in a screw machine, raw aluminum was transformed into a finished, machine-polished part from start-to-finish in less than two minutes. The screw machines can also run lights-out, further reducing labor costs and lead times.

Figure 8. Machined aluminum parts including the reflector (Bottom) for use in an automotive cornering lamp assembly.

Magnetic Winding

In the 1980s, the company's primary markets were strobe lighting systems and emergency sirens, both of which were dependent on transformers and magnetic coils – electrical components made of tightly wound copper wire that supplied the high voltage needed for the bright flash of a strobe light or that amplified the warning tone of a siren. Meanwhile, large-scale transformer suppliers had been moving operations to Asia. Recognizing the risk of delays and being concerned with quality, the company began to invest in equipment and build relationships with suppliers of magnetic wire, coil bobbins, and cores.

Today the magnetic winding process is done on automated machinery which feeds the termination work cell. This cell includes three robotic workstations which are programmed to complete the mechanical connection of magnetic wire to the bobbin pins. This process has reduced cycle time and decreased worker fatigue and injuries by eliminating a repetitive activity.

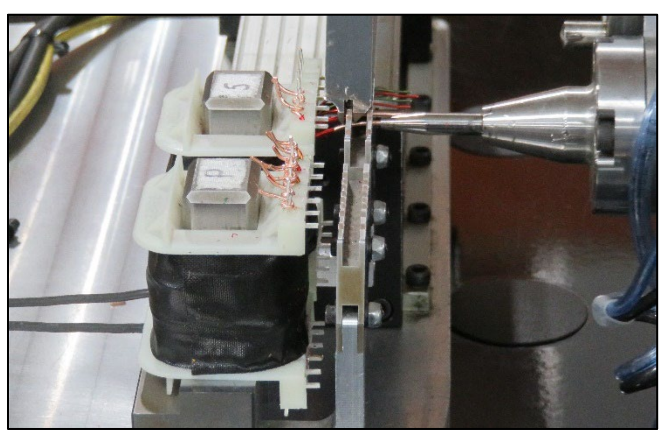

Figure 9. A wire gripper prepares to twist a wire onto a pin in an automated transformer termination cell.

Plastic Injection Molding & Machining

Warning lights rely on reflectors to focus light, and on lenses to direct light and enclose assemblies. As part of their vertical integration efforts, the company began insourcing plastic injection molding to ensure control of this aspect of their operation as well. Today, the plastics division has grown to support every facet of the injection molding process. Their precision tool fabrication facility uses sinker- and wire-electrical discharge machining (EDM) to hold very tight tolerances in the creation of molding tools that are used in the injection molding machines (IMMs). Depending on the size of the plastic component being manufactured, the molding tool is mounted into a compatible IMM. The capacity of IMMs at this facility ranges from 55 to 1,500 tons force US (490 to 13,790 kilonewtons). The addition of silicone molding has allowed them to innovate new designs that incorporate gaskets molded into the polycarbonate lenses of the lightbars, creating a better product by reducing the occurrence of moisture intrusion into finished LED warning lights. To further protect the integrity of the polycarbonate lenses, silicone hard coating is also applied in-house, in an enclosed conveyor process that includes robotic spray application and UV curing.

While chrome plating is still in use for decorative finishes, the coating on all plastic reflectors has been applied in-house in an environmentally friendly vacuum metalizing cell for more than a decade. The work area was developed with a focus on increasing capacity without additional labor. The result is a combination of five IMMs, robotic IMM tenders, conveyors, and four physical vapor deposition (PVD) machines. Uncoated reflectors are identified using a machine vision system which instructs robotic arms to transfer the raw parts from conveyors to the associated PVD machine fixtures. The same robotic arms load and unload the fixtures from the metalizing machines where the finished aluminum-coated parts are inspected and packaged.

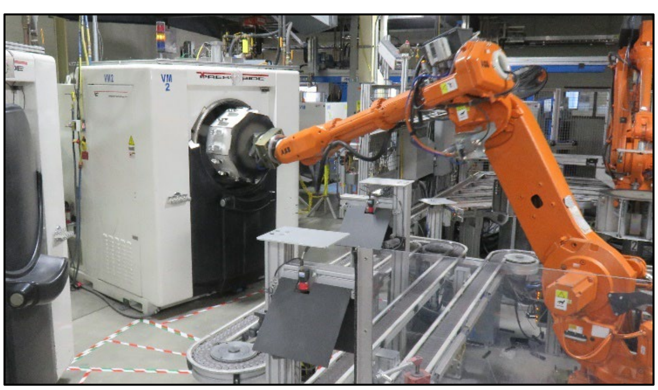

Figure 10. A robotic arm unloads a fixture loaded with plated plastic parts from a PVD machine.

Even the largest IMMs are equipped with robotic tenders which allow production workers to utilize their time efficiently as they collect finished parts off conveyors from multiple machines. Two work cells are each comprised of seven IMMs with tenders and dual-level conveyors. This automation allows a single worker to simultaneously process the work from all seven IMMs in the cell.

Figure 11. Conveyors deliver molded plastic parts from a series of IMMs.

Plastic vacuum forming capability was added approximately fifteen years ago, allowing for the introduction of low-cost manufacturing to support products with frequently changing designs. One example is the housing designed for mirror-mounted lights. In the United States, police departments commonly use standard vehicle models for their fleets that have been customized for the police market, with vehicle designs updated every few years. With frequent design updates required, the cost to fabricate plastic injection molding tools previously made mirror-mounted warning lighting cost prohibitive. Instead, with plastic vacuum forming capabilities, sheets of ABS plastic can be heated and formed over a low-cost tool using a vacuum. These tools can be milled from aluminum or steel and can be finished using fiberglass autobody filler. Once the sheet is formed, a worker loads it into one of three robotic CNC milling machines where the finished edge is trimmed, and features are added to enable the mounting of a warning light.

Figure 12. (Top left) A tool for vacuum forming plastic. (Top right) A formed plastic piece which will be cut into shape before being mounted on a customer's vehicle (Bottom).

Wire, Cable, & Harness Assembly

This process has evolved from a simple operation producing a small assortment of cut wires to a robust set of wire and cable termination operations. Utilizing automation, more than 250,000 cut wires can be processed in a single day. Meanwhile, more than two million feet of multi-conductor cable is transformed each month into power and communication harnesses. Individual wire assemblies are built into circuit board assemblies or harnesses. The multi-conductor cables are built into finished products, mated with wire assemblies into harnesses, or shipped to customers in kits to make connections between vehicles and components of the lighting, siren, and control systems.

Sheet Metal Fabrication

Manual movement of large sheets of steel and aluminum can require large amounts of open space and is potentially hazardous to the people involved. To avoid this issue, sheets are delivered from suppliers' trucks to an enclosed, purpose-built dock. Sheets are then transferred into one of two automated vertical storage towers that feed three laser/punch combination machines and two flat-sheet lasers. Thousands of different brackets and housings are fabricated using automated brake presses, hardware insertion machines, and finishing equipment. Most parts run through an automated powder coating line.

The automated brake presses are equipped with robotic arms capable of changing tooling, selecting from multiple product inputs, and delivering to multiple outputs (conveyors, stacks, or trays) even during lights-out runs, which allows for smaller batch sizes and maximizes the investment in new equipment. These hybrid brakes combine the speed of electronic brakes with the force and accuracy of hydraulic brakes to produce repeatable, fast, accurate bends in a machine footprint that is smaller than traditional equipment.

While the laser/punch combination machines and the automated brake presses had streamlined the sheet metal fabrication process, there was still room for improvement. A progressive die punch press was added which eliminated the movement of in-process brackets from the combination machines to the brake presses. Now, a roll of sheet metal is fed into the punch press. At each cycle of the machine (approximately one second) the material indexes forward and the part is formed by another stage of the die. Finished brackets leave the machine at the end of each cycle. This reduction in process time – paired with the ability to run smaller batches – has resulted in further cost savings.

Simple saws and scratch-built drill machines have been replaced with a precision, five-axis, laser-cutting machine. Aluminum extrusions in a variety of profiles (flat, curved, and "I" beam) can be loaded into multi-position fixtures for fast, repeatable, clean cutting from the top, sides, and underneath.

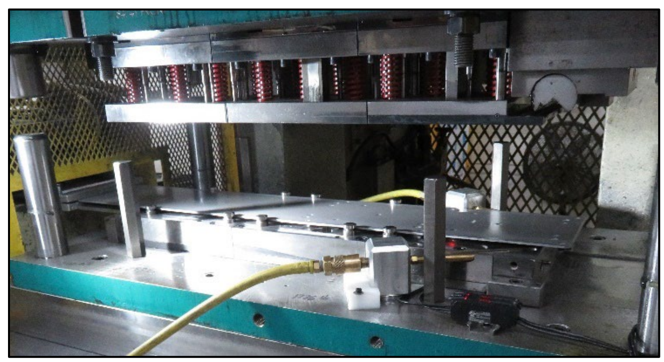

Figure 13. A 0.13 in (3.3 mm) thick coil of hot-rolled steel moves through a progressive die punch press. Holes are punched and text is stamped before the part is bent 90° and cut.

In 2022, the company added an automated welding cell to the production floor. This has replaced a manual process previously performed by an outside vendor which required substantial quantities of semi-finished components and resulted in process delays. Now, in the same building where aluminum and steel components are cut and bent, they are loaded into fixtures to support them while a robot completes the welding operation. The manufacturing engineers were brought in to work alongside the production welders to develop the machine and fixturing, and in many cases, the production machine operator was even able to manufacture the fixtures on nearby CNC milling machines.

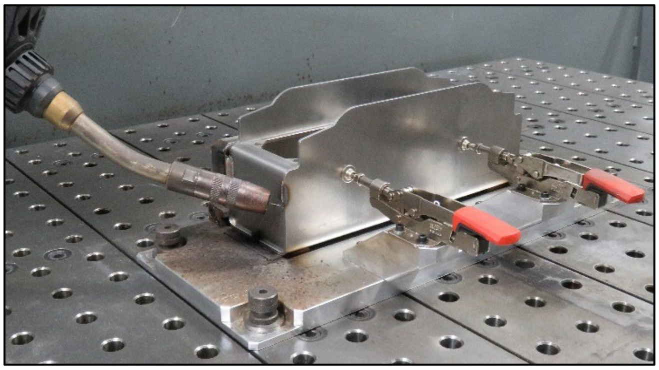

Figure 14. A robotic welding system welds aluminum into a housing for vehicular warning lights.

Bare Board Fabrication

The company's largest single investment into vertical integration has been in bare PCB fabrication. Originally envisioned as a captive fabrication supplier for the estimated six million PCBs per year required for the company's circuit board assembly lines, it has grown into a separate business unit that is leading the global fabrication industry. It is now partnering with other companies looking to produce their own bare PCBs and IC substrates in North America with cutting-edge detail, in a green, zero-liquid-discharge facility. Laser drills can create accurate holes below 50 microns, and the imaging line can hold tolerances with measurements as small as 30 microns. When the facility came on-line, the news was historic enough that it was the subject of the entire October 2018 issue of *PCB007* Magazine. In one example, the lean, just-in-time flow process includes only 38 steps, as compared to the 112 steps in a standard multilayer fabrication process [3]. Once the fabrication process is complete, panels move across the campus to the circuit board assembly department.

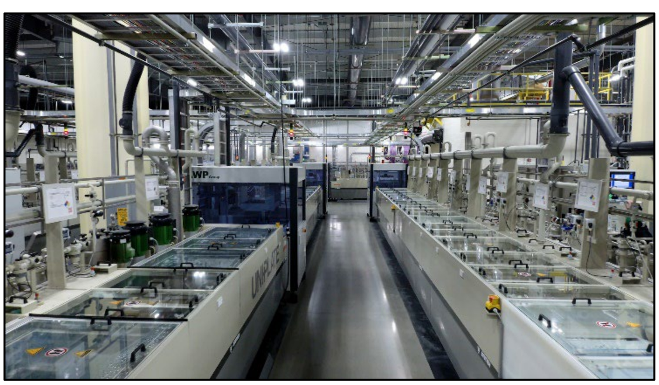

Figure 15. Electroless plating equipment in a PCB fabrication line.

THE PEOPLE OF MANUFACTURING

In a facility where so many different processes are carried out, there is a need for employees of all skill levels. The engineering team has some members who hold multiple Ph.Ds, while some areas of manufacturing employ teams of people with intellectual and other disabilities (through local organizations) [4]. The skills gap in the American labor market has also been a driver of the company's dedication to innovation and efficiency. In 2011, the company partnered with secondary schools in a program designed to introduce the next generation to the careers available in manufacturing. Students visit the campus daily over a fifteen-week semester where they learn about industrial safety and electronic theory before working alongside production team members throughout assembly and the vendor-level departments. The goal of this program is to bridge the skills gap by introducing young people to a variety of available career opportunities while they are developing their plans for entering the workforce or pursuing postsecondary education.

The students who complete this program earn credit just like they would in a traditional class. Additionally, they have the opportunity to learn directly from production workers about the importance of working for a company with competitive benefits, and they get a chance to hear about opportunities for tuition reimbursement as an alternative to expensive student loans. Thought leader Ryan Craig, the Co-Founder and Managing Director of Achieve Partners, an organization devoted to improving job market outcomes for American workers through innovations in skill development, said, "Academic programs at accredited postsecondary institutions are controlled by faculty members who typically aren't incentivized to align curricula to employer needs. Few are interested in what employers are seeking, particularly for entry-level positions. Many have never worked in the private sector or have only outdated or tenuous connections to non-academic employers" [5]. The company recognizes this fact and has taken the initiative to partner with postsecondary institutions at the community, state, and public levels in their efforts to enact change from the current educational trends.

Beyond the school program, students are encouraged to work in a seasonal capacity during summer breaks, or as part-time year-round employees after school. Throughout the company, there are many success stories of people who joined the company as teenagers who have been able to learn and find their fit – whether it is as a machinist, material handler, housekeeper, electrician, quality assurance specialist, engineer, groundskeeper, sales representative, manager, or any one of dozens of other career tracks.

The operation of an organization that consists of so many levels of manufacturing and assembly must have meaningful connections at every step from raw goods suppliers all the way through customers and after-sales service and support to be successful. The procurement team is responsible for securing the supply chain of an estimated 18,000 unique stock-keeping units (SKUs) while they work with a task force that includes engineers, operations management, and sales, to forge new links in the supply chain when electronic components are no longer available, or when suppliers enact force majeure clauses due to the coronavirus pandemic, geopolitical conflicts, or natural disasters. When these disruptions occur, the task force is prepared to leverage the capabilities and capacity of every part of the company. Procurement sources alternate or new components, engineering alters designs, and the manufacturing and assembly departments build prototypes which are delivered quickly to engineering for testing and certification.

CONCLUSION

Throughout the history of the company in this case study, the owners and management have resisted the tide of large-scale offshoring. As seen by the investments made into the number of vendor-level processes integrated into their New England facilities, there were plenty of opportunities to seek fast, higher profit margins. Instead of looking overseas, the company continues to invest in new technology, automation, and training and development of their employees in America. With the continued focus on innovation, education, vertical integration, and customer relationships, the company is well-positioned to continue to be a lighthouse – reliable, dependable, and built on a strong foundation – for generations to come.

REFERENCES

[1] Jeff Woodburn, "Making it in America: Whelen Engineering's John Olson shows how U.S. manufacturing can thrive," *New Hampshire Business Review*, September 23, 2011.

[2] Russ Willcutt, "Optimal Machine Cell Automation," *Modern Machine Shop* Magazine, November 2015

[3] Happy Holden, "Innovative PCB Processes are Lean and Green," *PCB007* Magazine, October 2018.

[4] Meghan Pierce, "Whelen Engineering Joins School Sowing Seeds for Manufacturing," *New Hampshire Union Leader*, March 17, 2012.

[5] Ryan Craig, "America's Skills Gap: Why It's Real, And Why It Matters," Progressive Policy Institute, March 2019.