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The Challenge and Solution for Implementing Automation and Ai for Electronic Card Assembly

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Abstract

With the increased material and labor cost, and the higher quality expectation from customers, automation has been widely considered for high volume or high mix production in the EMS industry for continuous improvement of the production efficiency, capacity, and quality.

Meanwhile, with the evolution of Smart Manufacturing, AI solutions has been readily available and could be integrated into the overall automation process to further improve the production operation.

This paper discusses the challenges in implementing such automation processes. It introduces an example of the solution for such implementation, including: the strategy of overall tooling and fixture design to support the automation, the process and equipment upgrade to accommodate the automation flow for both front end to back-end processes, and implementation of AI solution to support automatic visual inspection for back end assembly.

Key words: EMS, Automation, Smart Manufacturing, AI

1. Background and Introduction

Electronic Manufacturing Systems (EMS) industry needs to change and adapt according to the customers' demands, requirements, product designs, corporate strategies, government regulation, and etc. Figure 1 depicts the major product drivers[1]. The EMS industry keeps seeking solutions for the challenges such as continuous advancement of component miniaturization and product function complexity, increased material and labor cost, higher customer quality and reliability expectation. In addition, with the expanding social media environment and the drive of a Meta virtual reality, data storage has increased dramatically causing a need for high volume data storage devices including flash. Automation is critical to meet this demand.

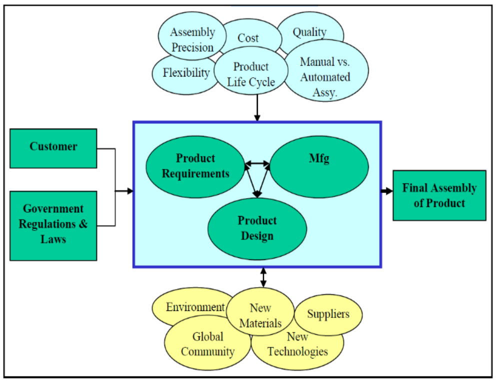


Figure 1. Product Drivers in the EMS Industry

While some price volatility will be short lived, there are general consensus that permanent inflationary pressure will build around commodity and labor costs[1]. According to International Data Corporation（IDC）'s recent survey results, enabling greater automation will be an important criterion for 33% of manufacturing organizations worldwide when making investments related to their digital operations[1]. For example, skill shortages, from truck drivers to machine, operators, continue to drive investment toward higher levels of automation. It is predicted that by the end of 2022, chronic worker shortages will prompt 75% of supply chain organizations to prioritize automation investment resulting in productivity improvements of 10% [2]. With the reduced cycle time and standardized quality in the production line, automation helps reduce the need for specialization in the workforce and economies of scale help bring down prices for goods across the board [3]. The historical practice has proved that automation is more reliable and easily replicated such that accuracy and repeatability is improved, thus driving productivity improvements. In the automation market, the collaborative robotics is a seemingly new and rapidly growing sector of the industrial robotics offering that help bridge the gap between the fully manual assembly process and fully automated production lines. Below figure.2 shows the forecast of collaborative robotics market for the recent years [1].

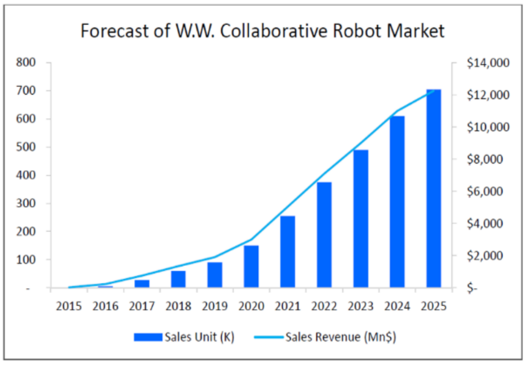


Figure 2. Forecast of Worldwide Collaborative Robot Market (source: Barclays Research, ABB Global 3C Research (2016))

In the context of Industry 4.0 or smart manufacturing, Artificial Intelligence (AI) begins to play a critical role as well. AI's predictive capability supports visualization, automation, robotics, and autonomous operations in which the workforce is used in smarter ways [4]. The use of AI and automation is a powerful pair for EMS industry to drive further improvement of the production efficiency, capacity and quality.

This paper introduces the launch of an automation program for a high density, standard 2.5 form factor Non-Volatile Memory Express （NVME） storage electronic card product under a HVLM (High Volume Low Mix) production mode. The card consists of a hybrid flex/printed circuit board (PCB) laminate area that can fold to allow higher flash memory density storage application. This application allows storage device to be as small as drive within a laptop. The reflow soldering typically induces the card warpage due to the configuration of the hybrid flex/PCB construction. A support fixture was designed to hold and fix the card in place during the whole surface mount technology (SMT) process including: solder printing, solder paste inspection (SPI), component pick & place, reflow, automatic optical inspection (AOI), and etc. In the past, additional operators were assigned to complete the card fix and handling operation. Due to the component configuration and high-quality requirements of the product, the solder printing process was a bottle neck for the front-end process, before automation. For the backend assembly before automation, most of the operation was completed by manual labor. This manual labor required highly trained operators with skills/experience, which applied pressure on operation headcounts for labor. The legacy manual processes often did not meet demands, particularly during the order volume ramp up phase of end of quarter cycles. The overall performance of the production line needed improvement of further optimization to meet the capacity and quality requirements.

As a result, automation and AI technology was applied to upgrade the production line for operation performance improvement, which included the uses of collaborative robot, Automated Guided Vehicle (AGV) , and the Smart Visual Inspection using AI classification services. The details are described in next sections.

2. Automation and AI Strategy

Automation in manufacturing is the process of using production management software and/or robotic tools to operate a factory that make physical products. These tools are built to perform operations to help businesses with tasks such as processing, assembly, inspection, inventory management, and production planning. Automation is a term for technology applications where human intervention is minimized and replaced with autonomous machines. A good strategy to implement automation and AI together starts from understanding the current production situation and the overall future expectation for the operation from a cost, efficiency, and quality perspective.

The legacy assembly process flow and control plan was thoroughly reviewed to determine suitable solutions for different processes, such as:
process combination and optimization, 3 or 4 axis robot introduction, data collection for AI solutions, and AGV vehicle for transportation. Meanwhile, the Return on Investment (ROI) for all the solutions was also carefully evaluated to finalize the project funding.

3. Automation and AI solution proposal and plan

3.1 Frontend SMT process

The legacy production process and layout was reviewed. The SMT line was configured as a single side mode to populate least component population side (bottom side) first, following a changeover of about 40minutes before populating the greater component population side (top side). This process required 3 operators for card handling, which includes:

- Manually placed PCB to the support pallet and placed Kapton tape to fix the PCB on support pallet before solder printing.
- After AOI, the operator needed to remove the Kapton tape with tweezer and took out the PCB from support pallet for next process.
- The empty support pallet was manually transferred to the printing station by trolley.

Due to the changeover step, the overall output from the legacy SMT process was an average of 27 units per hour (UPH). Thus, plenty of opportunities for further improvement of the legacy SMT process flow, quality and overall throughput. In response of the assessment of the legacy SMT process, a new process with automation was assessed. This new process optimizes the production line efficiency, throughput, and quality by minimize human manual labor.

In the new automation SMT process, the factors below were considered:

- New support pallet was designed to offer mirror card (Top + Bottom side) support simultaneously. The new support pallet would fix the card across the whole SMT process till the end of post-reflow at AOI inspection.
- Dedicated pick & place machine program to automatically recognize different card configuration on support pallet.
- Dedicated reflow profile recipe to process different

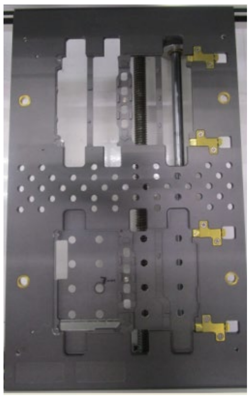
card configuration on support pallet.
- Automation robot was set up for card handling and card fixing on support pallet.
- AGV was used for card and support pallet transfer.

The detail of the new automation SMT process is described as 3 different card configurations during the automation SMT build process:
1. Single SMT Bottom side
2. SMT Bottom + Top side (mirror mode)
3. Single SMT Top side

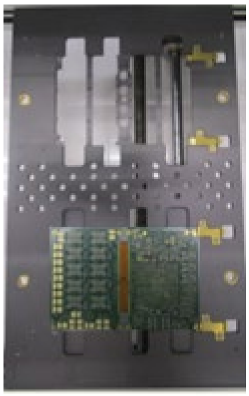
Take the mirror mode production (SMT Bottom + Top) as the example of the automation flow of SMT solution as below:
1) After the production of the board with bottom side, the robot turns the board Top side up and places it on the cavity for Top side position of the support pallet.
2) The robot then takes a new raw PCB with Bottom side upward and loads it on the cavity for Bottom side position of the support pallet. With that loading completed, the support pallet contains both cards with Bottom side upward and Top side upward in a mirror mode.
3) The robot then flows the support pallet with mirror mode cards into the storage magazine.
4) The AGV transports the support pallet with mirror mode to the SMT loading station.
5) The solder printing machine groups, firstly print the solder on the Bottom side card by the 1st printing machine, then print the solder on the Top side card by the 2nd printing machine. The stencil for the Top side printing is cut out at the Bottom side card area to avoid solder disturbance for the Bottom side card.
6) The SPI machine inspects both mirror cards based on their marking and positions on the support pallet.
7) The Pick & Place machines process both mirror cards based on their marking and positions on the support pallet, the Pick & Place machines are capable of automatically detecting the cards' locations and populate the components accordingly. No changeover is needed as materials is pre-loaded.
8) During reflow soldering process, the recipe of reflow oven is capable to process this mirror card configuration on the support pallet.
9) The AOI machine inspects both mirror cards based on their marking and positions on the support pallet
10) When the assembled mirror cards on the support pallet reach the robot position, the robot will remove the assembled mirror cards and place them on the finished tray, and flip the assembled bottom side card to Top side upward, and load a raw PCB with Bottom side upward into the support pallet.
11) The cycle of work is repeated until all the cards with Bottom side assembled are consumed.

At the last phase of production, when all the boards are finished with the Bottom side, there'll be about 50 pcs of the remaining cards with Top side upward that need to be produced specifically.
Specific to the card inspection via AOI, the support pallets have 4 different loading card configurations as shown in Figure.3

The SMT machines and robot automatically recognizes the configuration based on a marking (shown in Figure 4) on the fixture corresponding to the PCB Bottom and Top side respectively. When the PCB is loaded, the corresponding marking is covered, thus the machine determines whether there is a PCB loaded by reading this marking status.



Empty



Bottom only

Mirror (Top+Bottom)   Top only

Figure 3. Support pallet loading card configurations

Figure 4. Recognition marking on support pallet

Comparing to the existing SMT process, the new automation SMT process has minimize the manual operations as below, with comparison shown in Figure. 5:

- The card is auto loaded into the support pallet by robot vs manual loading.
- The card got fix by robot and a rotating feature on the support pallet vs manual fix by Kapton tape.
- The card is auto loaded into boxes by robot vs manual loading.
- The card and fixture were auto transferred by AGV vs manual transfer in a trolley.

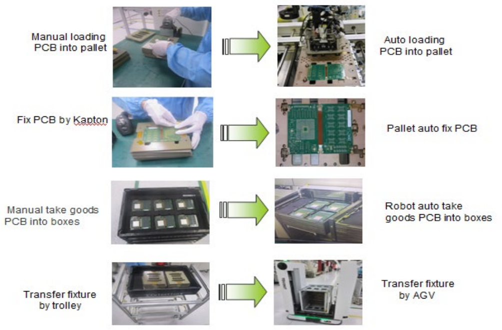


Figure 5. Comparisons between automation SMT process and current manual operation.

As a summary, the new automated SMT process performs corresponding work according to the status and position of the board. The solder printing machine, SPI, pick & place machine, AOI machine and robot automatically switches between different modes, which solves the bottleneck challenge caused by solder paste printing from high quality requirements. Sensors have been integrated into the automation SMT process, which can effectively ensure the quality and reliability of the finished product.

As a result, the UPH of the new automation SMT process has been improved from 27 to 48.

3.2 Backend assembly process

The legacy backend assembly process and layout was reviewed where 6 operators were required to complete the manual operations:

- Lubricant dispensing
- TLA (Top Level Assembly) assembly including flex card bending, mechanical parts screwing, TIM (Thermal Interface Material) dispensing, insulator attachment etc.
- Agency label printing
- Quality inspection
- Build traceability information upload to shop floor system

The layout and flow for the backend manual operation are shown in Figure.6 respectively.

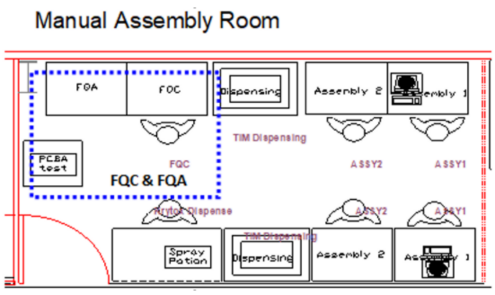


Figure 6. Process flow for backend assembly

Implementation of automation for backend assembly used 4 sets of robots to replace most of the manual labor, except for the step-in folding/bending the card due to strain sensitivity. Meanwhile, automation assembly involves fool-proofing and cross check design which makes sure the process is stable and the quality is improved. As a result, only 1 operator is needed to handle the overall automation backend process.

The process layout of automation backend assembly is shown in Figure. 7.

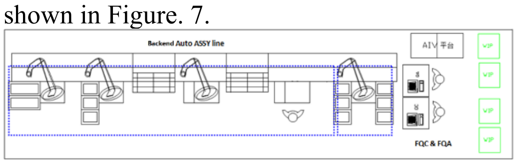


Figure 7. Automation backend layout

The flow and operations for the 7achines, robots and operator for automation backend assembly is described as below:

1. Robot loads the PCBA into the BSCAN fixture and testing, coats the lube to Base inner surface, loads the Base into tray.
2. Operator loads the PCBA into the folding fixture, the strain is sensitive and requires experienced and skillful operator, assembles the bracket and insulator A then folding, unloads and load the PCBA from/into the tray.
3. XY axis machine dispenses TIM on FPGA component.
4. Robot overturns the PCBA, loads PCBA into Base, screws and sticks the insulator B.
5. XY axis machine dispenses TIM on NAND component.
6. Robot coats the lube to Cover inner surface and loads the Cover.
7. Finally uploads the finished cards.

3.3 Design for Automation

During the development of the automation process, some design aspects were identified as incompatible with the automation process, which was feedback through the Design for Automation process as listed below:

Through the design for Automation analysis, some existing material incoming packages can’t support the automation assembly process, the project team has worked with the supply chain suppliers to change the material package and layout to support the automation assembly process, for example:

1) For the insulator package, the current package is in bulk pack. To support the automation process, the package has changed to Roll package
2) For the brand label on its roll package, the direction of

the label doesn't matter for manual operation, however it does not compatible for the automation process, so the feeding direction of the brand label has rotated by 180^0

3.4 Smart Visual Inspection with AI

After the TIM dispensing on 36 component locations for both sides of the card, quality inspection is required to assure the expected quality level. Dispensing defects such as excessive adhesive, insufficient adhesive, misaligned adhesive, and provide dispensing traceability must be screened out. It was very challenging for manual inspection to achieve desired accuracy and efficiency for such TIM defects on many component locations. Therefore, Smart Visual Inspection with AI technology is applied to improve the inspection capability for both inspection efficiency and inspection accuracy.

The overall architecture of the Smart Visual Inspection solution is illustrated in Figure 8.

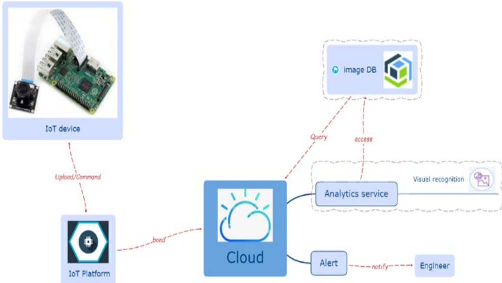


Figure 8. Smart Visual Inspection architecture

The flow of the Smart Visual Inspection solution is as below:

- Firstly, an IoT device integrated with a camera is installed at the TIM dispensing machine to capture the image of the dispensing result
- The image data was uploaded to the IoT platform for data consolidation and transfer purpose
- The IoT platform receive and process the image data and send it to the Cloud platform
- The Cloud platform is the central environment to offer all the related service like cloud DB storage, Analytics service, and alert notification etc.
- access for further services
- The Analytics service includes a pre-trained Visual Recognition AI module, This Visual Recognition AI model was trained separately with 2 types of image data which are "good" and "abnormal" as shown in Figure.9, the AI module performance like accuracy was adequately evaluated to be over 92% before deployed to the Analytics service. The Analytics service will access the Cloud DB and obtain the image data based on the user request, then the Visual Recognition AI module will classify these new image data into either a "good" or "abnormal" with a given confidence level.
- If abnormal image was detected from the Visual recognition, an alert message will be sent to notify the related engineering team for disposition. Also, the abnormal image result will trigger a signal to send back to the IoT device via the IOT platform, in order to command and highlight a alerting LED for operator awareness and reaction. This will form a quality close loop for the TIM dispensing operation.

An inspection result with the classification and confidence level from the Visual Recognition AI module is shown in Figure 10.

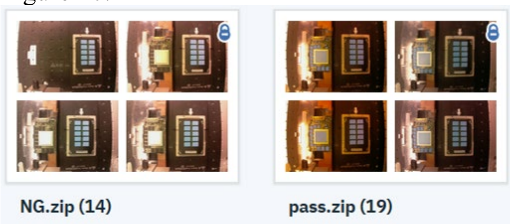


Figure 9. Data sets for AI model training

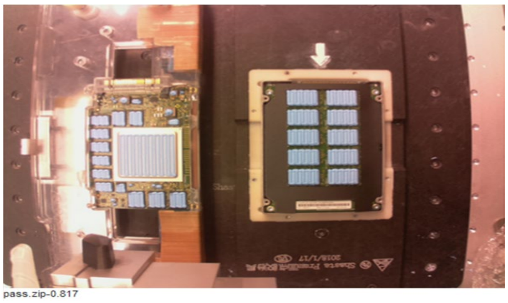


Figure 10. Classification result with confidence level from Visual Recognition AI module

3.5 Overall project schedule

Thorough preparation, communication and engineering evaluation has been conducted in order to implement the automation and AI solution in the production successfully. It took total 10 months for this automation and AI solution to be implemented into production, from the early planning to final approval and execution.

The overall schedule of the automation and AI solution is shown in Figure.11

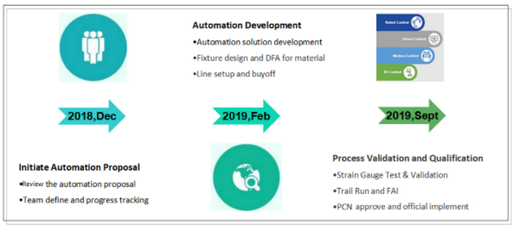


Figure 11. Overall schedule for the automation and AI solution

3.5.1 Initial automation and AI proposal

The initial automation and AI proposal was communicated mutually for awareness, including the overall automation strategy, and the expected ROI (return of investment) on cost, efficiency and quality, and the necessary supporting resources.

3.5.2 Automation and AI development

During the automation and AI development, end to end process review was conducted to identify the opportunities of the automation and AI upgrade on the machines, custom designed fixtures, robots and codes.

3.5.3 New Process Validation & Qualification

After development of the automation and AI solution, the buyoff process was conducted on the automation equipment and AI related solution to make sure the expected functionality is achieved. The buyoff also involves the strain gage evaluation across the process and reliability test on the card assembly.

A small batch trial build is conducted to collect the actual production yield performance feedback to the tooling and program of the automation and AI solution for further optimization.

Finally, the PCN is submitted and obtain mutual approval before final implementation into production

There are e various sections for the validation and qualification task, as described below:

i. Buyoff and validation

The project team has checked and buyoff the below area for the automation and AI solution:

1) Safety: including the review of protection to human, any interference of robot motion etc.
2) ESD: including ESD measurement based on ESD S20.20 standard
3) Functional test on the finished card assembly
4) Calibration on the measurement and inspection machines and tools
5) Preventive Maintenance definition and execution review.
6) Strain gage measurement on the critical assembly processes
7) All the above buyoff items have been checked and passed

ii. Qualification

An FAI build was conducted to collect the production yield performance, the result shows no defect found for all the automation and AI process. The detailed FAI result is shown in Figure.12.

PCBA Station	Station Name	Total	Pass	Fail	Yield
1200	SMT bottom AOI	25	25	0	100.00%
1400	SMT TOP AOI	25	25	0	100.00%
1800	5DX	25	25	0	100.00%
3100	FQC	25	25	0	100.00%
3200	FQA	25	25	0	100.00%
TLA Station	**Station Name**	**Total**	**Pass**	**Fail**	**Yield**
1990	Bring up	25	25	0	100.00%
2681	Soak1	25	25	0	100.00%
2682	Soak2	25	25	0	100.00%
2683	Soak3	25	25	0	100.00%
2018	Data thrash	25	25	0	100.00%
3100	FQC	25	25	0	100.00%
3200	FQA	25	25	0	100.00%
3700	Packing	25	25	0	100.00%

Figure 12. Qualification FAI build result

iii. Reliability and Destructive test

To evaluate the long-term reliability of the card assembly from the automation and AI solution, reliability test was conducted. A sampling of cards was selected to conduct the ORT soak test, following with a Dye & Pry (D&P) destructive analysis. The D&P test is passed, and no dye penetration/pad cratering at the critical BGA locations. The solder joint on the cards had good integrity and robustness. An example of D&P test result is shown in Figure. 13.

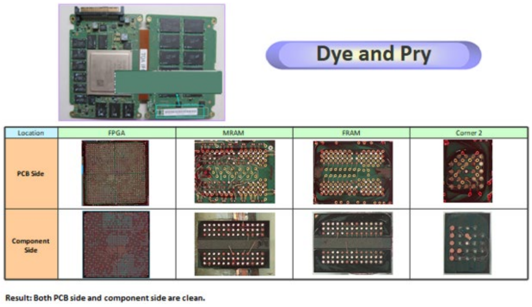


Figure 13. Dye & Pry test result

The overall validation and qualification result is shown in Figure.14

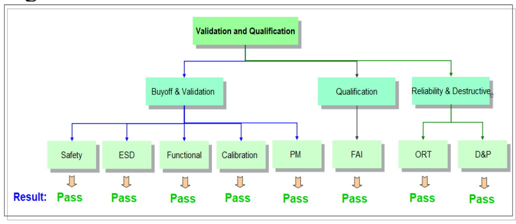


Figure 14. overall validation and qualification result

4. Conclusion

This paper introduced the end-to-end development and deployment example of an automation and AI solution for a HVLM electronic card assembly, as well as the evaluation plan and qualification to support the mass production. The example in this paper demonstrated, automation and AI could be successfully applied to electronic card assembly for operation efficiency, capacity, and quality improvement, with proper strategic planning, process flow and tooling design, machine upgrade, digitalization with data collection and AI model deployment, and thorough evaluation and qualification.

5. Future work

Some future work tasks are being considered as listed below:

- Duplication the automation and AI solution to other production lines.
- Further development and coverage of the AI solution to frontend and backend inspection, and close-loop quality control.

6. Acknowledgement

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IBM Rochester MN Supply Chain Engineering team
IBM Shenzhen IIC Supply Chain Engineering team

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