Open Manufacturing Whitepaper

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Abstract

This guide is designed for beginners who want to turn their ideas into physical products but don't know where to start. Whether you're a hobbyist, a startup founder, or someone exploring manufacturing for the first time, this whitepaper will walk you through the basics of how things get made.

We'll cover the essential steps of the manufacturing process, from designing your product to finding the right partners to produce it. You'll learn about key concepts like prototyping, sourcing materials, working with manufacturers, and ensuring quality. Along the way, we'll share practical tips and real-world examples to help you avoid common pitfalls and make informed decisions.

This guide is not about complex theories or commercial strategies—it's about giving you the tools and knowledge to bring your ideas to life. By the end, you'll have a clearer understanding of how manufacturing works and how you can navigate it to create something amazing.

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GitHub Repository

For the latest updates, issue tracking, and contributions, visit the GitHub repository:
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Issue List

To report issues or suggest improvements, please refer to the issue list on GitHub:
Issue List
WIP:
update realibility tests
update official

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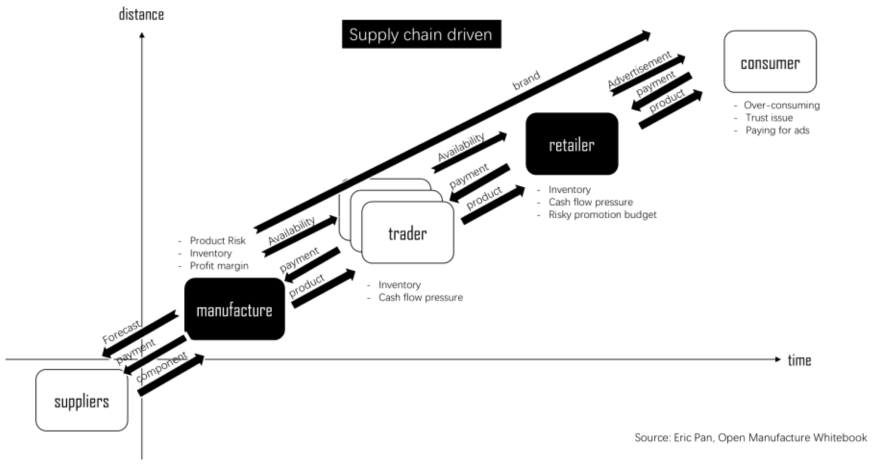
Chapter One: Introduction

Section 1: Evolution of Manufacturing

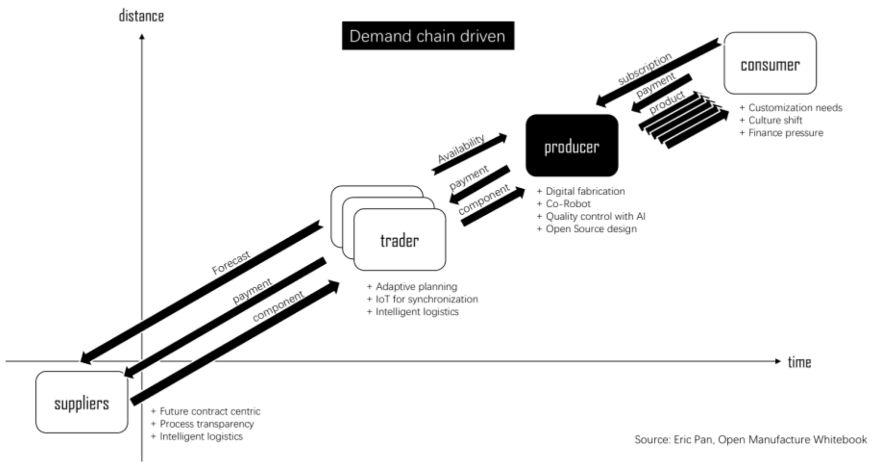
Manufacturing is continuously evolving in terms of its concepts, methods, and tools for producing goods for use or sale. Traditionally, manufacturing is considered an industrial production process where raw materials are transformed into finished products for market sale. Today, manufacturing refers to an integrated concept at all levels, from machines to production systems to entire business-level operations [1].

In its earliest form, manufacturing was typically carried out by skilled and independent craftsmen who produced on a small scale within a specific geographical area. Knowledge was passed down through apprenticeships.

At the beginning of the first industrial revolution in the late 18th century, the factory system was introduced in Britain. Since then, manufacturing companies have driven progress. The main characteristics of this system are large-scale manufacturing, global markets, and continuous accumulation of brand and capital. The centralized manufacturing model has met common consumer demands and led to the widespread distribution of cheap and reliable industrial products globally, significantly improving living standards and work efficiency.



In the post-industrial era, consumer demands can be more efficiently matched through digitalization. Supply chain surpluses also allow special and emerging demands to drive supply chain operations. The iteration of new technologies and the rise of new applications require a more open manufacturing system to efficiently implement and rapidly scale innovative products.



However, more open and decentralized manufacturing is not a utopian concept. It requires the reconstruction of the existing industrial system. Facing the drawbacks of shrinking supply chains and centralized mass production, only by understanding the essence and process of large-scale industrial production and working closely with it can we leverage the advantages of the demand chain in the near future.

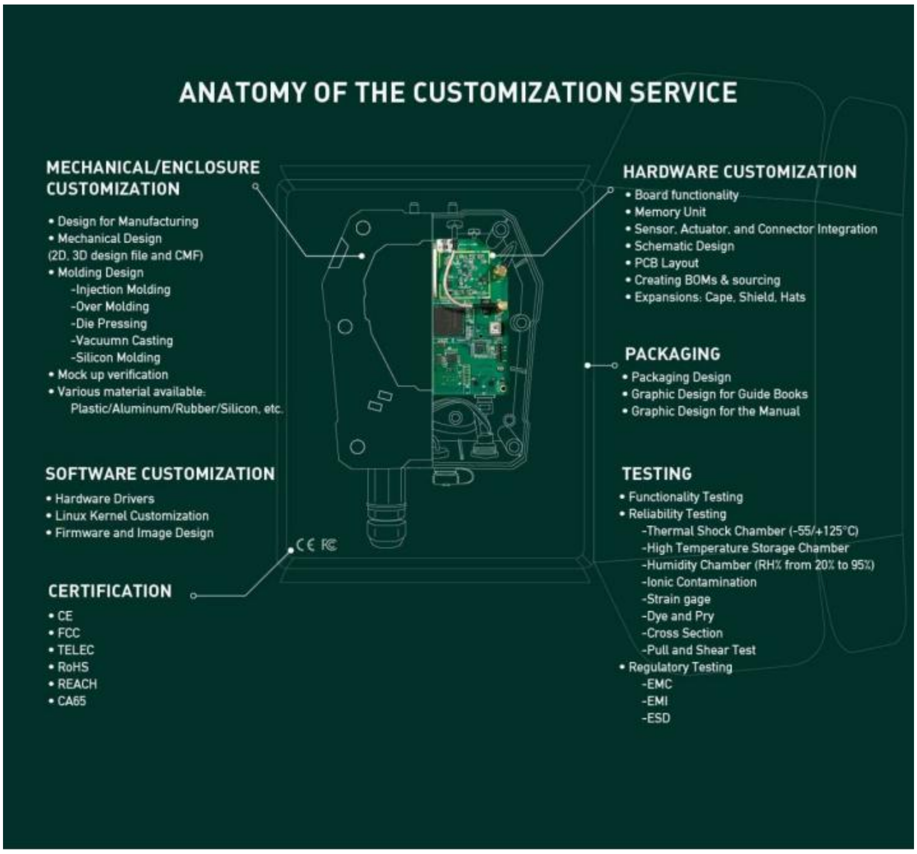
[1] Esmaeilian, B., et al. (2016). "The evolution and future of manufacturing: A review." Journal of

Manufacturing Systems 39: 79-100.

Section 2: Understanding the Manufacturing Process

The process of large-scale industrial production involves many different sections and procedures. The first step to understanding the standardized manufacturing process is to closely examine the components of the product. The common purpose of manufacturing is to assemble different parts of the product into a compatible finished commodity through machine or manual mass assembly. It also includes a broad range of hardware design, software design, mechanical and enclosure design, and packaging design, which generally comes at the end.

The image below is an example of the SenseCAP gateway by Seeed Studio, illustrating the hardware components of the product assembled in an anatomical form. The SenseCAP gateway serves as a typical example demonstrating the different sections of customization services that Seeed Studio provides, which can be implemented in similar industrial-grade products. Manufacturing a customized industrial-grade product involves hardware, software, mechanical, and enclosure customization. The details of the engineering process for each customized component are shown below:



Hardware Customization

In the hardware customization process, it involves the design of board functionality, memory unit, schematic design, and PCB layout design. Besides board design, sensor, actuator, and connector integration can also be customized in this section. Hardware customization commonly includes electronic parts and PCB assembly. In this category, the client needs to provide a Bill of Materials (BOM), component layout drawing, Gerber file, PCB specification, coordinate data file, and other detailed requirements to the manufacturer. The manufacturer receives the files and then provides a Design for Manufacturer Review, production BOM, and alternative parts recommendation. Sourcing, surface mounting, wire bonding, DIP parts manual soldering, auto solder printing, and wave soldering are also part of this section.

Software Customization

Software customization mostly includes program development, hardware driver design, and Linux Kernel customization. The client has to submit their function description and program file, while the supplier (manufacturer) is responsible for the actual software engineering and delivering the program file.

Mechanical and Enclosure Customization

Mechanical and enclosure customization can be quite diverse depending on the application. It involves Design for Manufacturing (DFM), 2D Design, 3D modeling, and molding design. Molding design has a broad range of options, including injection molding, over molding, die pressing, vacuum casting, and silicon molding. Mock-up verification is available in this process, and various materials are provided, such as plastic, aluminum, rubber, and silicon.

Under this customized classification, clients are supposed to submit the BOM and part drawings with application considerations. The manufacturer can generally help with sourcing, CNC, production BOM, laser cutting, 3D printing, die casting, wire-electrode cutting, ultrasonic welding, and aluminum extrusion. In this section, product assembly considerations are required, and the client needs to provide the supplier with the BOM and exploded drawings. On the other hand, the manufacturer is responsible for the DFM Review, cell production, assembly line, and workstation manual assembly.

Packaging

Packaging design comes at the last step of the customization process. Manufacturers can help with the design of the box, guidebooks, and the product manual. Clients need to provide part drawings, exploded assembly drawings, and be clear with shipment requirements. The suppliers provide services including sourcing, production BOM, package parts design, package reliability tests, and shipping.

Testing

After the engineering and design process, testing follows to determine whether the product is appropriately designed and manufactured to perform as intended. There are three major testing techniques: functionality testing, reliability testing, and regulatory testing. Reliability testing involves Thermal Shock Chamber (-55/+125°C), High-Temperature Storage Chamber, Humidity Chamber (RH% from 20% to 95%), ionic contamination, strain gauge, dye and pry, cross-section, pull and shear test. Regulatory testing includes EMC (Electro Magnetic Compatibility), EMI (Electro-Magnetic Interference), and ESD (Electro Spark Detector).

Certification

At the end of a customized manufacturing process, certification is issued by the manufacturer upon request. The major certifications generally provided by big manufacturers are CE, FCC, TELEC, RoHS, REACH, and CA65.

Chapter Two: Preparation before Manufacturing

Section 1: Requirements and Description of Production Documents

1. BOM (Bill of Materials)

The BOM(Bill of Materials) is one of the most important documents in the manufacturing process, used by almost all departments. The BOM records all lower-level materials used in the product, including material specifications, descriptions, quantities, packaging, and other relevant information. It also captures the hierarchical relationship between the finished product and its subcomponents and other attributes. In the ERP system, an accurate, complete, and precise BOM is crucial for accurately calculating material requirements, material demand times, and detailed material information.

In all production-related data, the BOM has the most significant impact, and the accuracy of the BOM is highly required. The BOM is one of the original data provided by the client and is essential for various processes, including accepting customer orders, material procurement, production process formulation, production lead time calculation, product cost calculation and quotation, DFC, DFP, material procurement planning, warehouse preparation, production material collection, production warehousing, logistics tracking, and other indispensable documents. These tasks involve the company's sales, engineering, planning, procurement, production, finance, and other departments. From this perspective, the BOM is not just a technical production document but also a management document, serving as an important link and communication channel between various departments. Almost all departments in the company need to use the BOM.

Based on the different business uses of the BOM in production and the varying levels of detail required for each use, the BOM can be divided into DBOM (Design BOM), EBOM (Engineering BOM), CBOM (Customer BOM), PBOM (Planning BOM), MBOM (Manufacturing BOM), etc.

Manufacturers provide production services for various clients and require clients to provide a CBOM. To reduce later issues due to unclear or inconsistent material information and to lower production risks, clients need to provide an accurate BOM the first time. For an accurate BOM, the following requirements must be met:

1. The BOM must include product hierarchy information to help Seeed engineers accurately understand the BOM.
2. The BOM must include detailed MPN (Manufacturer Part Number) information.
3. It must include material manufacturer information.
4. SMT and DIP materials must include detailed location and quantity information, and the quantity and location information must be consistent.
5. If there are client-supplied materials, it must be clearly noted in the BOM.
6. If the client has designated procurement channels or suppliers, the supplier contact information must be detailed in the BOM.
7. The BOM must include detailed material descriptions, packaging, and values.
8. Material information must be clear and accurate, and the same material information must be consistent.

Accurate material information helps improve quotation accuracy, avoid material shortages, shorten the quotation cycle and material procurement time, enhance overall product quality, and reduce production risks.

In past project DFMs, Seeed has found common BOM errors from clients, such as inconsistent MPN and material packaging, inconsistent actual location quantities and material quantities, and discrepancies between assembly drawings and the BOM.

2. Gerber File

Gerber is a 2D vector image file format used in the printed circuit board (PCB) industry. It is the standard format for describing PCB images, primarily used to transfer PCB design data from design to production. The Gerber format was initially developed by Gerber Systems Corporation and is now owned by Ucamco, which acquired Gerber Systems Corporation. Ucamco continuously updates the Gerber specification. The current Gerber specification is version 11, released in December 2012, and can be downloaded for free from Ucamco's website.

PCBs are typically designed by PCB designers using professional electronic design automation (EDA) or computer-aided design (CAD) software (commonly used design software includes Protel, Allegro, Mentor Pads, Cadence, etc. Seeed's R&D team uses Cadence and Eagle). The design is then output in Gerber format. PCB factories input Gerber files into computer-aided manufacturing (CAM) systems to convert design information into original design data for each PCB production process. There are two Gerber formats, with the extended Gerber format, also known as RS-274X, being widely used. Gerber files also transmit drilling information, typically using the Excellon format.

A complete Gerber file must include the following information:

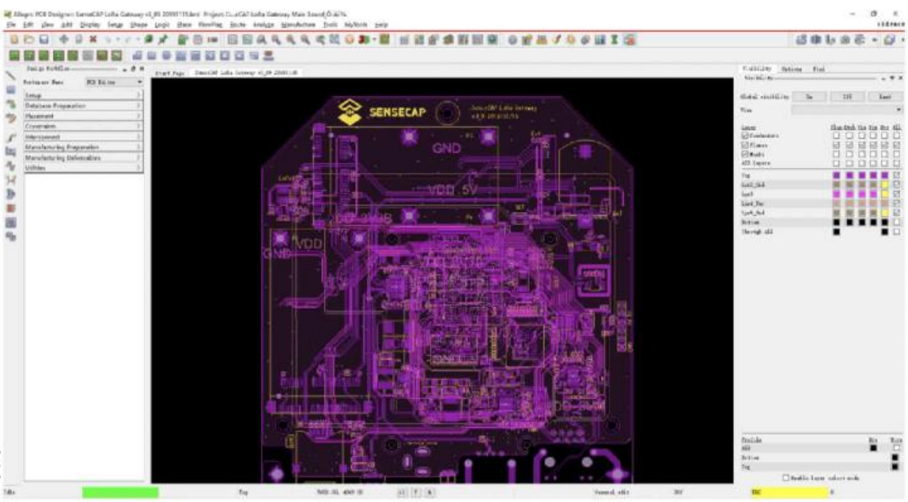
- It must include information for all PCB layers.
- It must include all component coordinate files.
- It must include all drilling files.
- PCB silkscreen or Gerber files should preferably include version and date information.
- Clients should provide detailed board size information.
- If clients have other special requirements or tolerance requirements, they should be provided together.

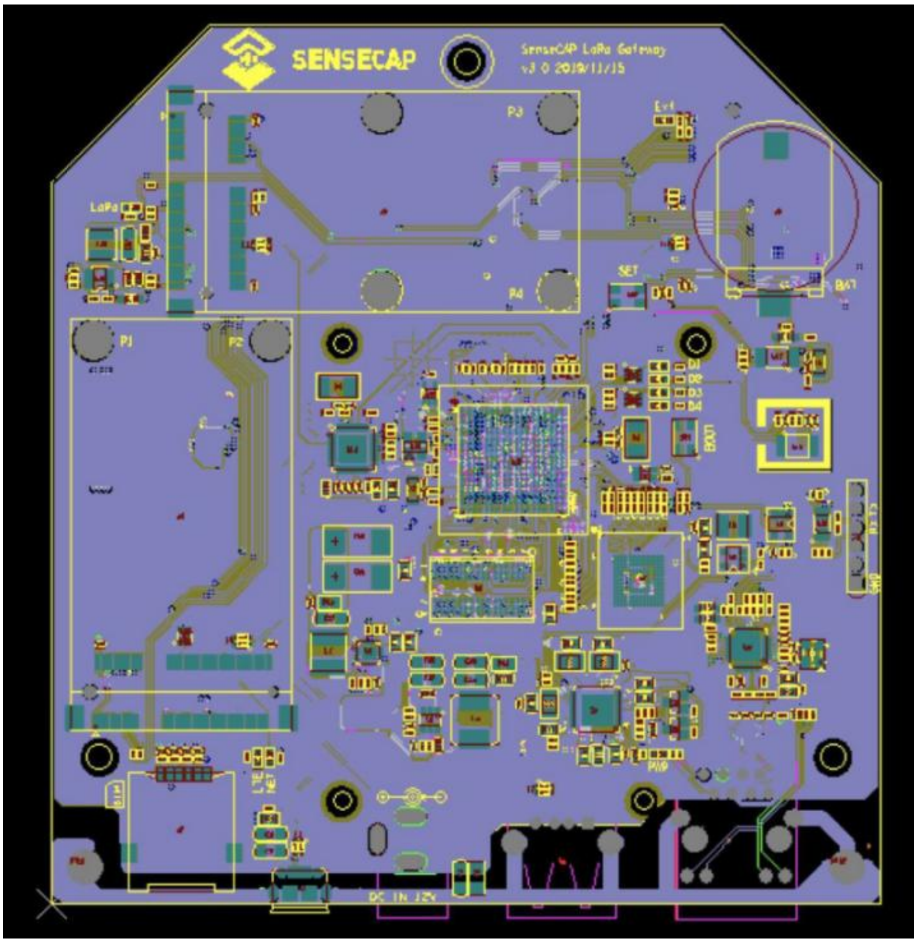
The standard file extension for Gerber files is .GBR. Taking Protel as an example, the Gerber output layer suffixes are as follows:

- GTL: Top Copper Layer
- GBL: Bottom Copper Layer
- GTO: Top Silkscreen Layer
- GBO: Bottom Silkscreen Layer
- GPT: Top Paste Layer
- GPB: Bottom Paste Layer
- GTS: Top Solder Mask Layer
- GBS: Bottom Solder Mask Layer
- GD1: Drill Drawing Layer

Based on past project experience, clients often encounter issues when providing Gerber files, such as incomplete Gerber files (missing drilling or outline layers), missing coordinate files (used for programming pick-and-place machines), Gerber files not in RS-274X format, and missing PCB tolerance information.

Providing correct and accurate Gerber files is crucial to avoid repeated confirmations, shorten project lead times, and ensure the produced PCB fully meets the client's design requirements.





Fugure 1&2: Gerber File of SenseCAP

Board Thickness (T) Tolerance	T ≤ 1.0	±0.10		Smaller than this tolerance requires special processing		If the tolerance is taken as a unilateral tolerance, it should be a multiple of the tolerance value, for example: if 1.8mm requires a positive tolerance, the tolerance should be 0-0.36mm
	1.0 ≤ T ≤ 1.6	±0.13				
	1.6 ≤ T ≤ 2.5	±0.18				
	2.5 ≤ T ≤ 3.2	±0.23				
	T ≥ 3.2	±8%				

Maximum Finished Board Size	Single, Double-sided Boards	580x580mm	580x680mm	580x1380mm (CS)	If the finished size of both length and width is greater than 580mm or the single side size is greater than 1380mm	When the customer's part size is greater than 630mm on one side or both sides are greater than 478mm, it requires outsourcing for lamination
	Multi-layer Boards	550x550mm	550x650mm	550x1350mm (CS)		
Minimum Finished Board Size		≥20mm	10mm ≤ Size < 20mm	<10mm		
Gold Finger Bevel	Bevel Angle	20° 30° 45° 60°		<20° or >60°		
	Bevel Angle Tolerance	>±5°	±5°	<±5°		
	Bevel Depth Tolerance	Tolerance > 0.15mm	0.15mm < Tolerance ≤ 0.1mm	Tolerance < 0.10mm		
Outward Dimension Tolerance		Tolerance ≥ 0.15mm	±0.10mm ≤ Tolerance < ±0.15mm		Tolerance < ±0.10mm or more than two types of outward dimension tolerance control	
V-CUT	Angle	30, 45, 60	\	Outside this range requires special processing		
	Maximum V-CUT Blades	Within 20 blades	Within 30 blades	Within 40 blades		More than 20 blades require outsourcing
	Compensating Width	80mm < Width < 610mm	60mm (Width)	Width (50mm)		Middle section bottom can consider CNC V-CUT, first V then outline.
	Board Thickness	1.6MM Thickness ≤	3.5mm ≤ Thickness < 0.6mm	Thickness 0.5mm or Thickness >		

		2.4mm		2.4mm		
	Gold Thickness	>0.4mm	0.25mm < Gold Thickness ≤ 0.40mm	<0.25mm		
	V-CUT Method	Regular V-CUT	Skip-cut V-CUT	Outside this range requires special processing		Skip-cutting also requires outsourcing

Table 1: Process Capability Parameter

3. PCB Fabrication File

The PCB fabrication file defines key PCB process information in detail. With this information, PCB engineering can fully formulate the PCB production process to ensure the produced PCB meets the designer's requirements.

The main PCB process information includes:

- PCB finished board thickness and tolerance requirements.
- Detailed PCB stack-up information.
- Copper thickness requirements for each layer.
- PCB impedance information.
- PCB material requirements and material TG value requirements; whether performance-similar alternative materials are acceptable.
- Solder mask color requirements, matte or glossy board surface requirements.
- Silkscreen color.
- PCB surface treatment methods.

To help clients clearly define and communicate PCB process information, Seeed provides a standard template for clients to select the corresponding information.

Clearly and reasonably defining PCB process information is essential to meet client requirements for product functionality and appearance, enhance overall product competitiveness, ensure that PCB factory production meets quality and lead time requirements, and promote PCB cost reduction. Overly high requirements can extend PCB lead times, increase scrap rates, and significantly raise PCB costs.

Taking PCB surface treatment methods as an example, PCB, as the support body for electronic components and the carrier for electrical connections, has surface treatment methods that are a crucial aspect of PCB performance. Common PCB surface treatment methods include Hot Air Solder Leveling (HASL), Electroless Nickel Immersion Gold (ENIG), Immersion Silver (ImAg), and Organic Solderability Preservatives (OSP). The characteristics and manufacturing costs of different surface treatment methods are compared in the table below:

Surface Treatment	Coating Characteristics	Manufacturing Cost
HASL	Lead-free, uneven coating surface, mainly suitable for boards with large pads and wide line spacing, not suitable for HDI boards. The process is dirty and smelly, with high temperatures.	Medium-High
OSP	Uniform coating, flat surface. Difficult to inspect visually, not suitable for multiple reflow soldering, packaging needs to prevent pad scratches. Simple PCB process, inexpensive. Good soldering reliability.	Lowest
ENIG	Uniform coating, flat surface. Good solderability, good contact, good corrosion resistance, can assist heat dissipation. Poor process control can lead to gold embrittlement, black pad, and poor component soldering.	High
ImAg	Uniform coating, flat surface. Good solderability, can withstand multiple assembly operations. High environmental storage requirements, prone to yellowing and discoloration.	Medium

According to market statistics from 2003 and 2007, the market share of HASL surface treatment PCBs has sharply declined. With the rapid development of small-sized and fine-pitch BGA/IC components and their increasing market share, the uneven coating surface of HASL has been magnified. Meanwhile, OSP and ImAg surface treatment PCBs have steadily increased their market share, becoming the top two choices in the lead-free electronics industry.

Seeed has a professional engineering team that, at the project's initial stage, analyzes and evaluates whether the selected PCB support parameters are reasonable based on product functionality, appearance, quality, cost, and delivery requirements, aiming to achieve the best balance among these factors.

4. Assembly Drawing and Schematic File

The Assembly Drawing mentioned here refers to the component placement diagram for PCBA. For new projects, in addition to providing key documents such as BOM and Gerber files, clients also need to provide a PDF format assembly drawing. Note that this assembly drawing specifically refers to the component placement and polarity direction indication for the top and bottom sides of the PCBA.

In production, the component placement diagram is mainly used by quality inspection stations to verify component soldering positions, soldering quality, and soldering direction, especially at the SMT first-article inspection station. Some clients also label all component reference designators and component directions in the Gerber files. However, using Gerber files for quality inspection on the production line is inconvenient, and some boards cannot label all component reference designators and polarity directions due to component density and board size limitations. Therefore, the component placement diagram is an indispensable document.

The component placement diagram must meet the following requirements:

- It must accurately indicate component positions and corresponding reference designators. The corresponding components should preferably be labeled with their outlines for accurate positioning, especially for densely populated PCBAs.
- It must label the soldering direction and polarity points for all polarized components.
- The silkscreen for through-hole components must be labeled on the component insertion side.
- The component positions in the placement diagram must be consistent with the component coordinate file.

Common issues with client-provided component placement diagrams include missing polarity points for polarized components, silkscreen and reference designators for through-hole components marked on both the top and bottom sides of the PCB, and discrepancies between the assembly drawing and the component coordinate file.

The schematic diagram is one of the original design documents of the product. In production, the schematic diagram is also an important auxiliary document. The schematic diagram can be used for:

- Abnormal test analysis.
- Product functional anomaly analysis.

When providing production documents, clients are encouraged to provide the schematic diagram, which will greatly assist engineers in handling production anomalies. The provided schematic diagram should preferably include version and date information for document traceability.

5. Production Testing

Production testing is an essential process in product manufacturing. Through production testing, process defects in the manufacturing process can be discovered, production risks can be warned, and process optimization can be promoted. Functional performance testing of single boards ensures that shipped products have all functional modules working correctly, thereby enhancing customer satisfaction and brand influence.

Detailed production testing processes and methods include AOI, X-Ray, ICT, FVT, etc.

- **AOI (Automated Optical Inspection):** Refers to using automated optical equipment to compare the produced product with a golden sample to actively discover process defects such as wrong parts, missing parts, reversed parts, and outsourcing defects. Seeed requires 100% AOI testing to ensure product quality.

- **X-Ray Inspection:** Refers to using X-Ray to conduct penetrating tests and inspections on the product and compare it with a golden sample to actively discover and warn of defects such as insufficient solder, solder bridges, and missing parts, especially for BGA, QFN, and module components. Seeed requires X-Ray testing for the first article and periodically during production.
- **ICT (In-Circuit Test):** A testing method to check and confirm manufacturing defects and component failures by testing the electrical performance and connections of components on the PCBA. ICT testing can discover defects such as soldering shorts, cold solder joints, and reversed parts.
- **FVT (Functional Verification Test):** A testing method based on client testing requirements and guidelines to test product functionality, mainly focusing on whether the product can achieve the designed functions. FVT testing may include firmware burning. In actual production, Seeed requires 100% functional testing.

In product production testing, there is a 10x theory in the industry: for each defect detected in a process, if the defective product flows to the next process before being discovered, it will cost 10 times more to test. In other words, the earlier a process defect is discovered, the smaller the loss. Therefore, accurate and efficient production testing is crucial in the production process.

The requirements for test firmware and test guidelines in production testing are as follows:

- **Test Firmware:** For tests requiring test firmware or shipping firmware, clients need to provide the firmware file, including firmware version and development time information. This information is mainly used for traceability and distinguishing different firmware versions to prevent using the wrong firmware in production.
- **Test Guideline Requirements:**
  - Define the hardware requirements for product testing.
  - Define the software requirements for product testing, including the operating system and test software, which should be provided together.
  - Define the firmware programmer model and programming method.
  - Provide detailed test operation guidelines.
  - Provide detailed test result phenomena and confirmation methods.

Seeed's R&D department can provide firmware development and product testing solutions for a fee. Development requires clients to provide basic testing requirements (demonstrating this capability is sufficient; however, actual firmware development and testing require a long time cycle and significant NRE investment. Priority is given to clients who provide firmware and test guidelines, with Seeed performing test verification).

6. PCB Panel Design

PCB dimensions vary, and we need to redesign a PCB panel for production because:

- Ensure production possibility (to prevent components close to the PCB edge from interfering with the machine conveyor track).
- Improve production efficiency (improve OEE and make the best use of production machines).
- Ensure panel strength (if the panel is not strong enough, it may cause soldering issues during the SMT process).

- Lower PCB costs as much as possible.

7. Assembly Drawing for PCBA

The following information must be included:

- Designator mark for all components in the right location.
- Orientation mark for all polarity components (recommended and used for FAI).
- Silkscreen for wave soldering components must be designed on the component insertion side (it is forbidden to design the silkscreen on both sides or on the opposite side).
- Assembly drawing must be consistent with the X&Y file.

8. Schematic File

Clients shall provide the schematic file as it is important for production:

- It will be used for debugging.
- It will be used for troubleshooting.
- It is better to include schematic file version and date information (used for file tracking).

9. Testing Specification

Clients shall provide firmware if it is mandatory:

- Hardware requirement.
- Software requirement.
- Programmer.
- Programming method.
- Testing instruction.

Manufacturers can also help to develop the testing specification. Clients only need to clarify what detailed functions should be tested (We have the capability to do this, but we do not recommend it, as developing and verifying a testing specification is a substantial task).

In this step, a sample of PCBAs will be tested to ensure quality. Common mistakes include components that are not connected, misaligned components, and shorts that connect portions of the circuit that should not be connected. The most common tests are:

- **ICT (In-Circuit Test):** When you design the PCB, you often will reserve some test points for debugging, programming, and other purposes. The ICT machine will use these test points to do the open/short test and will check if the values of the passive components (resistor, inductors, capacitors) are within specifications.
- **AOI (Automatic Optical Inspection):** The manufacturers use a "golden sample" — a reference PCBA to compare with others. For this test, the hardware creators will need to provide the specifications and tolerance to the manufacturer to set the parameters.

- **X-ray:** The PCBA manufacturers will use X-ray to check the internal structure of the PCBA, especially for BGA and QFN components.

9. Quality Requirement

Usually, we will follow IPC 610 quality level 2:

- Special product requirement.
- CTQ requirement.
- PV requirement (Process validation).
- Client product inspection standards (e.g., Code Jumper) (*Client special requirement).
- Client AQL requirement (e.g., Code Jumper) (generally GB/T2828 AQL) (*Client special requirement).
- Client quality standards (e.g., Audi/Testo) (*Client special requirement).
- Client DFX guideline (e.g., Schneider DFM/DFT guideline) (*Client special requirement).

Section 2: Notes of Caution Regarding Electronic Manufacturing

We need to pay attention to several factors related to electronic manufacturing:

- Component MPN.
- Component detail designator.
- Component manufacturer.
- FOC part list (Components which will be provided by the client for free of charge).
- DNP part list (Components which will not be populated onto the board).
- It is better to provide component quantity / component description / component value / component package, etc.
- Component information must be clear and correct.
- For each component, all information like MPN & description package, etc., must be consistent.

Section 3: Notes of Caution Regarding Mechanical Parts and Packaging

1. Mechanical Parts

Client must provide the following engineering documents if the product includes mechanical parts:

- Application instruction.
- BOM.
- 3D drawing (for parts matching checking).
- 2D drawing (better with tolerance mark).

- CMF document (color & material & finishing).
- Quality requirement.

2. Package Requirement and Document

The client must provide the following engineering documents if customized package material is needed:

- Packing instruction.
- Packing BOX design file and material.
- QSG design file and material.
- Design file for other customized packing material.
- Carton design file and requirement.
- Carton Label requirement.
- Pallet requirement.
- Other requirement (desiccant, etc.).

Section 4: Notes of Caution Regarding Software (Firmware)

Customized firmware requirements:

- Must include file version and date information.
- Version and date information is very important for firmware tracking.

Section 5: Other Information and Notes of Caution Regarding Manufacturing and Delivery

DFx

DFx is to apply manufacturing influence to the product development stage, but the focus of DFx is differentiated in different product stages. In EVT and DVT stages, difficult manufacturing is acceptable on deviation:

- **From 0 to (EVT & DVT):** DFx focuses on functional OK / Better have a backup plan.
- **From 1 to 100 (Pilot-Run):** Certification / DFx focuses on manufacturing possibility, e.g., hand soldering is acceptable for a volume of 1~100 but not for MP.
- **From 100 to ∞ (Mass production):** DFx focuses on manufacturing efficiency / manufacturing cost / Good product quality / Good product reliability, e.g., automatic machines are recommended for high-volume production.

Section 6: Standard Operating Procedure (SOP)

Manufacturers analyze each product and develop a dedicated SOP to ensure correct product production and optimal product quality. SOP is crucial for production, and the following information will be included in the SOP:

- Manufacturing tooling needs key parameter definition.
- Manufacturing material part number and quantity.
- Detailed operation process for line operators.
- Good sample pictures and operation guide pictures.
- CTQ and quality inspection requirements for each station.

The only key to a "good quality" product is the operator on the production line. The SOP will tell the operator how to produce a good part and how to prevent a bad part; it will write what the operator should do and require the operator to do what the SOP writes.

Section 7: Test Plan

Reliability testing helps process professional reliability testing and output testing reports to validate product reliability. Detailed testing items are as follows:

- High-temperature working.
- High temperature and high humidity.
- Cold and hot shock experiment.
- Low-temperature working.
- Cold and hot cycle.
- Normal temperature aging test.
- High-temperature storage.
- Humidity and hot cycle.
- Low-temperature storage.
- High-temperature aging experiment.
- Steady damp-heat.
- Salt spray test.
- Packaging drop test.
- Button Life Test.
- Push-pull test.
- Earphone hole insertion.
- Vibration test.
- Soft pressure test.
- DC block insertion.
- DC header insertion.
- Battery plug and pull.
- USB hole insertion.

- Bending and swing test.
- Drop test.
- TF/SD card plug and pull.
- Bending test.

Section 8: Certification

- CE (Council of Europe).
- FCC (Federal Communication Commission).
- MIC (Ministry of Internal Affairs and Communications).
- IC (Industry Canada).
- CCC (China Compulsory Certificate).
- RCM (The Regulatory Compliance Mark).
- CPSIA (The Consumer Product Safety Improvement Act).
- RoHS (Restriction of Hazardous Substances).
- REACH (Registration, Evaluation, Authorization and Restriction of Chemicals).

Chapter Three: Different Stages of Manufacturing

Section 1: Quality, Cost, and Delivery Time

In the phase of mass production, three core dimensions are quality, cost, and delivery time. They are like the three legs of a stool on which the customer would sit (see figure below)[1]. Manufacturers need to make choices based on the planned objectives and actual conditions to form an optimal model. I will elaborate on these three indicators below:

Quality: Whether the products meet the expectations of target customers. Questions that one should consider in terms of quality include: How to standardize the quantization expected by customers? How to ensure that all the manufactured products meet this standard during delivery and service life?

Cost: Necessary to consider the marginal cost that is equally amortized to each product. Besides the direct material cost and manufacturing expenses, manufacturers also need to regard the indirect cost such as engineering cost of production, adjustment cost, jig and mold cost, training cost, the cost of inactive products and inventories, the cost of waste and spare parts, and emergency expenses, etc.

Delivery Time: How long the products can be delivered. The delivery time depends on the longest critical path, especially the procurement time of key materials and the impact of abnormal production processes, such as abnormal quality, insufficient jigs, engineering changes, etc. After successful trial production, it is essential to further improve production efficiency, manage the capacity of suppliers, and continue to optimize the balance of supply and demand.

[1] Domingo, Rene T. "THE QCD APPROACH TO OPERATIONS MANAGEMENT". Retrieved 21 July 2020.

Section 2: Total Quality Management and Quality Management System:

How can your products consistently meet user expectations

throughout their lifecycle?

- Each business product line has its own development process and project management process (project kick-off, DFX review, process definition, BOM creation and order release, prototype establishment, NPI trial production, trial production report review, issue closure, transfer to mass production).
- Product lifecycle quality planning (APQP) and reliability testing plan.
- TR technical review increases external consultant resources to assist in the review (resource pool establishment).
- Technical review node review checklist (mold & layout & structure & electronics & packaging) and dynamic updates.
- Document and record management: Output reports after review and testing.
- Product design specification establishment (PCB layout / mold / structure / packaging & accessories).
- Identify key materials and custom parts list from BOM, material testing and approval import (key parameter material specification and establishment), special material list, special equipment list, DFMEA, hand sample and sample review, DFM design review, FAI first article inspection report, small batch trial production report.
- Project summary report output.

- R&D quality NPI monthly report output.

Section 3: Quality Management of Suppliers

- Supplier import review mechanism and AVL list level management.
- Sign procurement and quality agreements with suppliers, as well as quality targets.
- Supplier KPI performance (QCDS) monitoring & continuous improvement and coaching.
- Early-stage mold opening and trial production stage ME and DOE factory coaching and monitoring.
- Supplier provides weekly and monthly quality data, dynamic monitoring, and management.
- Annual audit plan and regular inspections and PDCA closed-loop.

Section 4: Quality Control of Production Process

Production process quality control monitors the product production process: IQC, SMT, DIP, FCT, PCBA, Visual Inspection, Assembly, Finish, and Visual Packaging, FQC.

- **Incoming Quality Control (IQC)**:
  - Sampling level: IQC incoming inspection follows AQL (Acceptance Quality Limit) sampling level for sampling or full inspection.
  - Inspection standard: IQC follows the material inspection SIP inspection specification for inspection.
  - Outsourcing line follow-up: The first mass production engineering and quality go to the outsourcing factory for line follow-up and process audit and inspection.

- **Process Quality Control (PQC)**:
  - Identify production process risks before mass production, formulate PFMEA and QCP, and formulate preventive measures for potential risks.
  - Manage 4M1E (Man, Machine, Material, Method, Environment) and ECN change management at each process on the production site.\
  - Self-inspection and mutual inspection at each process in the production process, strictly adhere to the "three no principles": "Do not accept defective products, do not manufacture defective products, do not pass on defective products."
  - IPQC FAI inspection and routing inspection.

- **Outgoing Quality Control (OQC)**:
  - Sampling level: OQC follows AQL (Acceptance Quality Limit) sampling level for sampling or full inspection before shipment.
  - Inspection standard: Follow IPC-A-610G electronic component acceptability standard and product inspection specification SIP for PCBA or complete machine sampling or full inspection before shipment.
  - QC inspection checklist dynamic updates and QC personnel training.
  - Mass production product reliability testing plan implementation to ensure product quality continuously meets product design requirements.

- **Information System Monitoring and Traceability:**
  - Use MES and ERP for monitoring and traceability, which can trace the production time of each PCBA, the testing time of each process, and the online time and material maintenance time of each material.

Section 5: After-Sales Quality

- **Offline**:
  - Customer complaint problem timely update to CHECKLIST and inspection specification.
- **Online**:
  - Online negative review collection and analysis improvement.
  - Weekly report feedback online negative reviews and customer complaint problems and analysis improvement.

Section 6: IT-lized Quality Management

- Process MES system monitoring and error-proofing.
- Quality data real-time collection and real-time monitoring.
- Quality complaint CAPA report online feedback and tracking closed-loop.
- Customer satisfaction survey online feedback.

Section 7: System and Product Certification

- The company has passed ISO9001:2015 quality system certification.
- The company has passed ISO14001 environmental management system certification.
- The company's products have passed CE, FCC, and other product certifications.

Section 8: Project Management: What Determines Project Duration?

Let's take a look at what factors determine the project duration and how these factors affect the project duration and status.

Based on our experience, these factors mainly include the following:

1. Detailed Project Plan

From the perspective of project management, the control of project time first requires a detailed and executable project plan. When formulating the project work plan, based on our experience, we need to plan and schedule the product demand time and the key steps involved in the entire process in advance. Here are a few production milestones that determine your schedule: (Project Overall Schedule-before manufacturing)

- Production Preparation Phase (Gantt Chart): Design For Manufacturing/Assembly/Testing

DFM.
- Production Tooling Release: Stencil, Test jig, etc.
- Small Batch Trial Production: First article verification.
- Mass Production.
- First Batch Shipment.

After the project work plan is formulated, it is necessary to strictly and closely track the execution plan. If changes occur, take corrective measures as early as possible. Do not expect to make up for the time at the end.

2. Material Lead Time Instability:

In the manufacturing process of a product, the lead time of materials is absolutely a decisive factor for the manufacturing lead time of each product. Therefore, after initiating production, if the manufacturing lead time of the project needs to be updated, more than 80% of the cases will be due to the lead time of one or some materials changing.

The reasons can be various, summarized as follows:
- Instability of market inventory supply of the material.
- Supplier's initial lead time reply error (the supplier's reply lead time is inaccurate and cannot be delivered on time).
- Material quality and quality issues after delivery. Even if only one material in the product is delayed, it will affect the lead time of the entire product. (Purchasing material)

Solution:
- Risk assessment
- Sample confirmation of structural materials.

Based on the above problems, we recommend doing some risk assessments and measures in the early product design stage. We recommend the following points:
- Do a good job of DFM for BOM materials in product design, try to use conventional materials that are common in the market. For ICs and other materials that are expensive and have long lead times, you can arrange risk materials in advance to shorten the risk of long lead times or lead time delays.
- For some structural materials, samples need to be confirmed in the early stage, and engineering samples are sealed and provided to suppliers for self-inspection reference.

3. Functional Testing (During the Manufacturing):

The lead time of materials is a very important factor affecting time in the production preparation process. Similarly, based on our experience, the most likely factor affecting time in the manufacturing process is functional testing. At Seeed, mass-produced products will undergo 100% functional testing. Customers or Seeed's R&D personnel will provide the product's test plan. Seeed's R&D department can provide simple test fixtures and test processes. In this process:
- The stability of the test fixture.
- The number of test fixtures.
- The convenience and operability of the test process determine the efficiency of the entire test process.

Section 9: Cost Control

1. Manufacturing Cost Control

The manufacturing cost of a product, also known as the production cost, is the cost incurred to produce the product. It is the utilization of various resources such as raw materials, auxiliary materials, spare parts, employee wages, machine depreciation, etc., in the production process. Under the premise of ensuring that the produced products meet customer quality and delivery requirements, reducing manufacturing costs as much as possible can help customers reduce the overall product cost and simultaneously help enterprises improve profit margins. Effective control of manufacturing costs is an important indicator to measure the comprehensive technology and management level of an enterprise.

The manufacturing cost of a product is mainly composed of direct material cost, direct labor cost, and manufacturing overhead. Direct material cost refers to the processed objects in production. Through effective processing actions, these raw materials become semi-finished or finished products that meet the requirements and can be delivered. This process transforms the value of the processed objects from a relatively single and low value to a comprehensive and higher use value. Direct labor cost refers to the cost of human resources consumed in the product manufacturing process, including production line employees, quality inspection, warehousing, logistics, and other departments. Direct labor cost is usually calculated using wages and welfare expenses. Manufacturing overhead refers to the cost of machines, factories, other equipment, and auxiliary materials used in the product production process. The composition of manufacturing overhead is mainly included in the manufacturing cost through depreciation, maintenance, and auxiliary material usage.

Effective control of product manufacturing costs involves all aspects of the product's entire lifecycle. Seeed mainly achieves effective control and reduction of manufacturing costs through the following methods and approaches:

- Product design determines more than 70% of the product's manufacturing cost. For controlling manufacturing costs, Seeed's main strategy is to move control forward to the design stage, allowing the product to meet the most economical solution at the design stage, meeting customer requirements and expectations, and helping end customers obtain higher cost-effective products.

  The main way to achieve manufacturing cost control forward is to establish a project team to conduct a comprehensive DFX evaluation of the product, including Design for cost, Design for manufacturing, Design for purchasing, Design for testing, etc. Seeed has direct cooperative relationships with more than 3000 suppliers, and behind Seeed, there are the Pearl River Delta and even the entire China's supplier and distributor resources, with complete material and solution resources. Upon receiving customer information, Seeed's professional engineering, R&D, procurement, and other teams will conduct a detailed analysis of customer information and provide and recommend high-cost-effective solutions based on detailed customer, product, and application requirements. Seeed's professional team will help customers make the most reasonable choice in the early stage, and customers can enjoy convenient and comprehensive resource dividends in the entire product lifecycle.
- Seeed has a comprehensive manufacturing cost management system and a very professional manufacturing cost management team.

  The comprehensive manufacturing cost management system and professional team help

Seeed achieve a PDCA cycle in manufacturing cost management, achieve comprehensive and mature manufacturing cost management, avoid and eliminate various forms of waste, reduce manufacturing costs, and increase profit income, and establish a comprehensive and global manufacturing cost management strategic concept.

- Correctly interpret the relationship between quality and manufacturing cost based on product and customer requirements. The quality and manufacturing cost of a product are a dialectical relationship. High-quality requirements will lead to high costs to a certain extent, and low-quality products will inevitably affect and restrict the long-term sales of the product. Both will affect the company's profits. If the relationship between product quality and cost is not correctly understood, it will inevitably bring adverse effects to the company's human, financial, and brand in the long run. Strengthening accurate and comprehensive quality management, avoiding over-quality, comprehensively promoting lean production, reducing the scrap rate, improving the quality awareness of all employees, and adhering to the principle of "doing it right the first time" are the best ways to eliminate waste and reduce manufacturing costs.
- Comprehensively promote product standardization and part standardization.
- Promote the introduction of Industry 4.0 production technology, scale production, and fully automated production.
- Fully automated incoming material production inspection, verification, and warehousing.

Section 10: Manufacturing Stages

1. EVT (Engineering Verification Test)

As mentioned earlier, the EVT stage mainly completes the product design and review from scratch, the production of engineering prototypes, testing, review, and rectification.

This stage involves the production of R&D prototypes, which will not be too many in number but may involve multiple prototype productions. This is mainly because hardware design iterations are very slow, unlike software, which can be recompiled and built once. Hardware iterations from drawings to prototypes take at least several weeks. Is there a better way to save time in the EVT stage and avoid repeated pitfalls? In fact, using open-source hardware modules can greatly improve the success rate of the first-time design of the product. The main reason is that open-source hardware has been verified by the market and users for a long time, and the technical defects of the modules have been optimized and improved by many people. Moreover, using open-source hardware for early functional prototype verification in the EVT stage of the product can save 5 times or even 10 times the time.

This process is long and requires a lot of engineer resources. This stage mainly includes ID design, MD design, PCBA hardware design, software design, and DOE quality design. These five design points are carried out in parallel, and each engineer needs to fully consider the constraints from other aspects of the product while completing their own design work. Engineers work closely with each other and communicate frequently. Product managers and project managers coordinate and control the balance points in each part of the design process. Finally, deliver a product design that satisfies customers.

In ID design, MD design, PCBA hardware design, and software design, we have set up review points. We have a dedicated review committee responsible for the review of each design. Each review point has standardized input, input data requirements, and standardized review plans. The review committee will continuously track the effectiveness of our reviews, summarize which issues have been missed by the review interception, and then update the review plan to cover the previously missed issues. In this way, the entire design review forms a closed loop.

While designing, our procurement and quality personnel have already participated. Quality personnel will output a detailed quality management plan based on our product design requirements. This plan will explain the key points that need to be controlled, the inspection plan for each part of the design, and the complete machine test plan. Procurement personnel will help R&D source new materials and new suppliers that meet the requirements. Before the actual material sampling and production, the cooperation with suppliers and the standards for material delivery have been confirmed.

As for our sample production method, we will complete sample production through structural hand samples, ID hand samples, CNC, 3D printing, and fast board production in a fast and low-cost manner to verify our design.

After completing the sample production, we will debug and test the prototype. The debugging at this stage includes hardware function software, software driver debugging, and the joint debugging of hardware and software that need to cooperate with each other. After the function is running, test engineers and quality engineers will intervene to conduct functional testing and performance testing of the prototype to verify whether our design meets the requirements.

The project manager will summarize all the issues found in our testing, organize everyone to participate in the issue review, and discuss rectification measures. The EVT stage can be divided into multiple sub-stages, EVT1, EVT2, until the requirements are met.

Throughout the EVT stage, we have implemented the golden triangle of project management: quality, cost, and delivery time.

- **Quality**: Quality control is mainly reflected in four aspects: design review, quality inspection requirements for new material imports, quality requirements for new supplier imports, and engineering prototype testing plans.
- **Cost**: Choosing a design solution that meets the requirements, matches the performance level, and has a low cost can maximize the control of the product's BOM cost. At this time, you can choose low-cost methods such as soft molds and simple sampling to verify the feasibility of the design, assess risk points, and improvement measures.
- **Duration**: In the design stage, ID, structure, and hardware are split out and carried out in parallel, with high collaboration and interaction to shorten the development cycle.

2. DVT (Design Verification Test)

When the engineering prototype of the product completes the expected functional verification, the project can enter the DVT stage. This stage mainly verifies the product design indicators, so for the complete machine equipment, all components need to be finalized, such as the shell needing to be assembled with plastic parts formed by molds. The internal circuit boards, connecting wires, hardware accessories, packaging design, nameplate stickers, etc., of the product also need to be the final size. At this time, suppliers also need to provide parts and sample specifications that are consistent with the R&D design for sample confirmation.

The main key activities in the DVT stage include:

- Complete machine assembly testing to verify whether each circuit board matches the shell structural parts and whether the key design indicators are met.
- Mold opening and structural parts finalization. This is a very important link and a key link that affects the quality of subsequent mass production. The quality of a mold greatly affects the speed of capacity ramp-up.
- Reliability and stability testing to verify whether the equipment meets the environmental requirements of the use scenario and whether it works stably and normally. It can be verified through some EST use cases or HALT test cases.
- Regulatory certification. At this stage, regulatory certification must be completed, such as FCC in the United States, CE in the European Union, and CCC in China. Many projects are delayed in listing because they cannot pass the regulatory certification of the country, resulting in repeated design modifications and ultimately delayed listing.
- Manufacturability DFM. At this time, DFM becomes more important and is even one of the key steps. The production process of the product also needs to be designed, and DFM is to find out those processes that are not easy to achieve on the production line.
- Key material sample confirmation. If the quality of the supplier's incoming materials is not good, the goods are not as per the sample, and the consistency is poor, it will greatly delay the production process and even lead to repeated rework, increasing manufacturing costs.
- Quality standard definition. DQE needs to define the acceptance standards related to product parts at this stage, confirm that all drawings of R&D are correct, and then specify the functional test acceptance standards of the product.

The completion of the DVT stage is marked by the preparation of all materials for the product to transfer to PVT, the closure of important issues in the R&D stage, and the confirmation that all designs of R&D meet the requirements and can be manufactured.

- **Quality**: In the DVT stage, analyze and rectify the issues exposed in EVT, conduct pre-mold opening reviews, and add DFT/DFM improvements. Reliability testing and safety testing are fully carried out at this stage.
- **Cost**: In the DVT stage, the product has been finalized, and the cost is relatively stable. The main cost control measures are to optimize the design and reduce the BOM cost.
- **Duration**: In the DVT sample production, long-cycle materials, especially standard parts, are prepared in advance to shorten the sample production cycle. In the later testing stage, various tests are carried out in parallel while ensuring the function of the prototype.

3. PVT (Pilot Verification Test)

The PVT stage is the trial production stage, mainly to test the entire production process before mass production. The trial production must ensure the number of production samples, such as 100pcs or 200pcs. Too few samples can easily miss some hidden low-probability problems, but these problems will lead to a large number of defective products in mass production, increasing rework, repair, and scrap rates.

The main key activities in the PVT stage include:

- Production process design, formulate Flow Chart, clearly design each intermediate link from the start of production to warehousing.

- SOP/fixtures, process engineers formulate product production SOP, SOP will contain standard operation guidelines for each process stage.
- Quality standard execution, strictly run the formulated quality standards, and uniformly review the reasons for incoming material defects, process defects, and test function defects in the trial production process, requiring each part to solve the problem or modify some overly strict quality standards.
- Supplier small batch verification. The quality of the supplier's incoming materials is likely to have problems because for them, the first small batch delivery is also their internal PVT process. The products provided may have discrepancies with our quality requirements, or the consistency is not high, the stability is poor, etc. Therefore, the trial production process also hopes to find such problems in advance so that suppliers can also improve the process synchronously and finally meet the quality stability requirements during mass production supply.
- Trial production process and improvement. Generally, there will be no problem in the trial production process, but the problems that appear also need to be managed by grade. Fatal and serious problems must be closed before entering mass production, so to close these problems, multiple PVT trial productions may be required.
- Random reliability check. A lot of reliability verification has been done in the product R&D design process, but the number of samples is generally not large, so it is necessary to randomly check the reliability of the products from the trial production process, such as high and low temperature tolerance, vibration test, drop test.

- **Quality**: In the PVT stage, analyze and rectify the issues exposed in DVT. Key materials should be temporarily sampled as the basis for supplier PVT sample production. Quality inspection standards are formed and communicated with suppliers and processing plants at this stage. Production SOP is formed. Fixtures are delivered before PVT production.
- **Cost**: In the PVT stage, the product has been finalized, and the cost is relatively stable. The main cost control measures are to optimize the design and reduce the BOM cost.
- **Duration**: In the PVT sample production, long-cycle materials, especially standard parts, are prepared in advance to shorten the sample production cycle. Product certification, demo, and application development are carried out in parallel with material preparation and production to shorten the product launch time.

4. MP (Mass Production)

Whether it can enter the mass production stage needs to be reviewed. The main review contents include:

- Mass production SOP finalization.
- Quality inspection specifications have covered all materials, finished product processing, and testing links.
- Confirm the completion of all key material samples.
- The issues in the trial production report have been improved and closed.

After entering mass production, it is necessary to continuously pay attention to the product production process and the efficiency of product ramp-up, whether to increase fixture tooling equipment, optimize factory site layout, and expect to reach the maximum capacity state of the factory in the shortest time. However, blindly expanding production capacity is not rational. It is also necessary to carry out capacity ramp-up in an orderly manner according to the production and inventory forecast plan, to complete the product manufacturing and delivery on time and in quantity with the smallest manufacturing resource cost, such as rolling inventory, long-cycle material planning in advance, and capacity locking in advance.

- **Quality**: Through the transfer MP review, check the preparation of MP, control the quality of MP. Production process quality control plan is implemented. Production yield ramp-up.
- **Cost**: According to the capacity plan, improve the efficiency of suppliers and production line production, and continuously reduce costs.
- **Duration**: Long-cycle materials are pulled out for key control, balance production and sales, and prepare safety stock. Normal lead-time materials other than long-cycle materials have a preparation time of 4 weeks and production time of 2 weeks. Achieve a standard delivery time of 6 weeks.

Chapter Four: Case Studies

Section 1: XIAO

1. What is XIAO?

A single embedded functional module made of PCBA.

2. Preparation of Manufacturing

- Hardware
  - PCB Design Files
  - Seeeduino XIAO Schematic.
  - Seeeduino XIAO Gerber Files.
  - Bill of Material (BOM).
- Software
  - Test firmware.
  - Factory firmware.
- Test Plan
- SOP (Standard Operating Procedure)
- NPI (New Product Introduction) Report

3. Manufacturing

- The Operational Procedure
  - PCB (DFM).
  - PCBA (DFM).
  - Test.

    - Quality Inspection.
    - Packaging.
    - Warehousing.

Section 2: Wio Terminal

1. What is Wio Terminal?

Instead of being a single embedded functional module such as Seeeduino Xiao, Wio Terminal is a simple and tiny device to build I/O with the physical world, equipped with a 2.4-inch LCD and a compact enclosure.

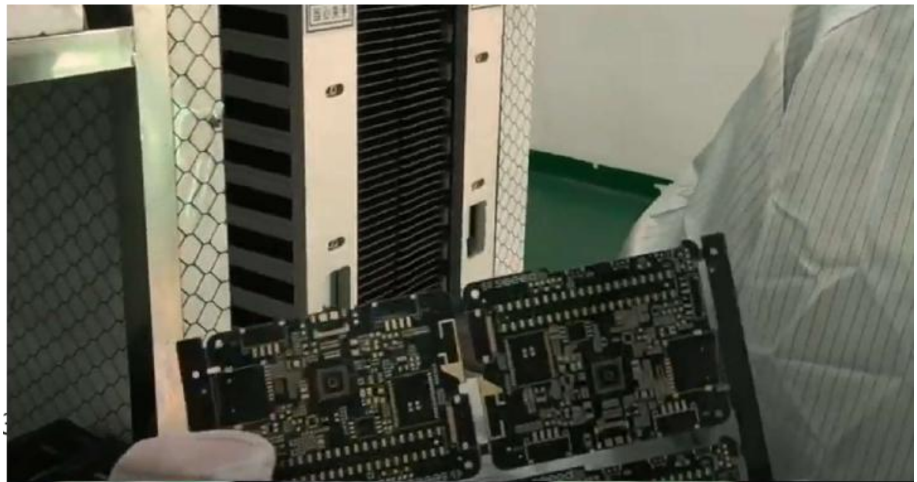
2. Preparation of Manufacturing

- Hardware
    - PCB Design Files.
    - Bill of Material (BOM).
- Software
    - Test firmware.
    - Factory firmware.
- Enclosure
    - Molding Files.
    - Color Scheme.
    - Inspection and Testing Plan.

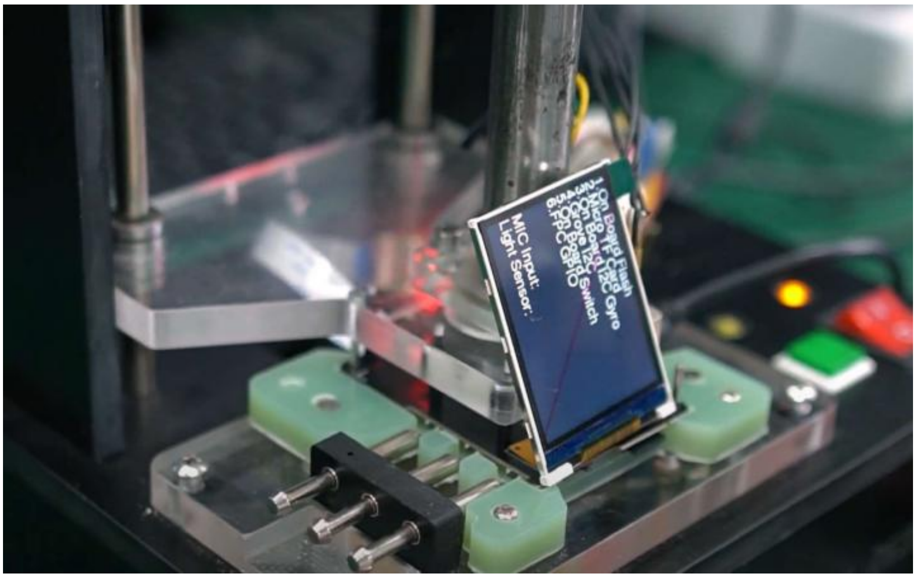
- Test Plan
- SOP (Standard Operating Procedure)
- NPI (New Product Introduction) Report

3. Manufacturing

- The Operational Procedure
- PCB.

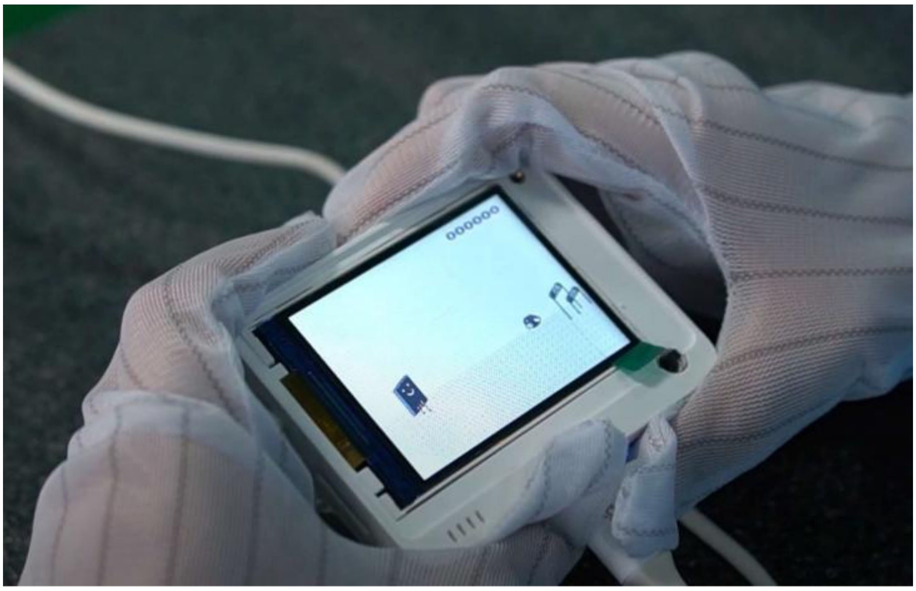


- PCBA.
- PCBA Test.



- Incoming Inspection of Other Materials (e.g., Screen/Enclosure/etc.).

- Assembly.
- Complete Machine Testing.



- Quality Inspection.
- Packaging.

- Warehousing.

Section 3: SenseCAP

1. What is SenseCAP Gateway?

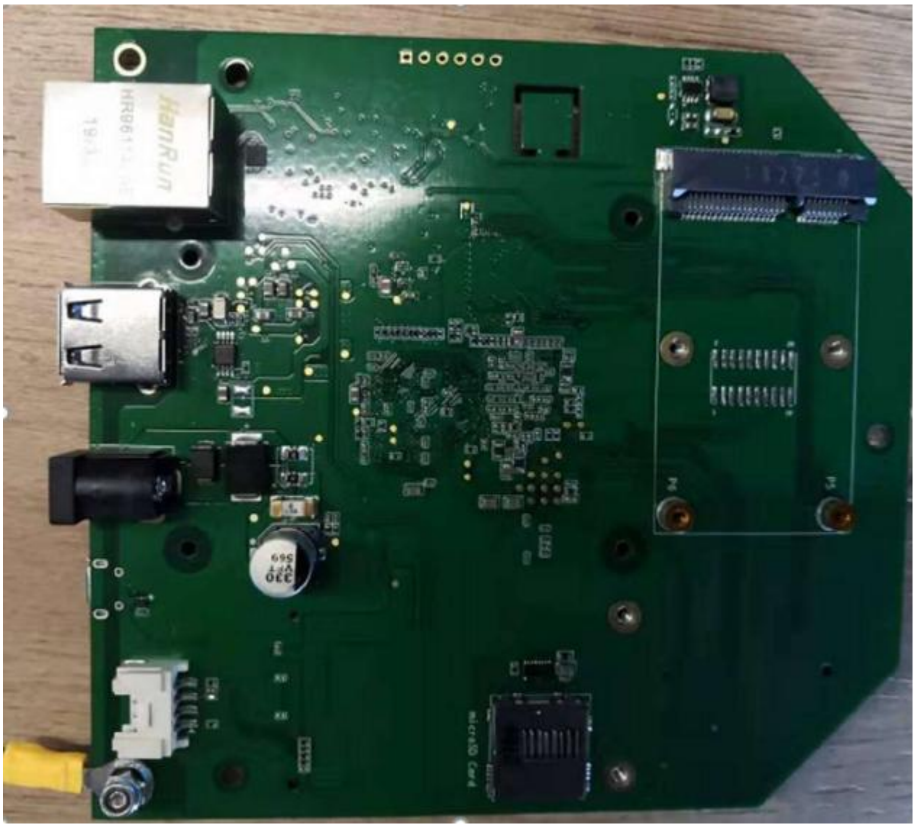
SenseCAP LoRa Gateway is based on the LoRaWAN™ protocol, applicable for low-power, long-distance environmental data collection and monitoring in scenarios such as smart agriculture and smart city, etc. As the central device of the LoRa network, the gateway is used for collecting data from different Sensor Probes and transmitting the data to the cloud platform via 4G or Ethernet cable. Equipped with a high-performance processor and telecom-operator-level LoRa chip, this gateway ensures stable and high performance in a large-scale network. The gateway is designed with an IP66-protection-level enclosure, making it suitable for industrial applications in outdoor severe environments.

2. Preparation of Manufacturing

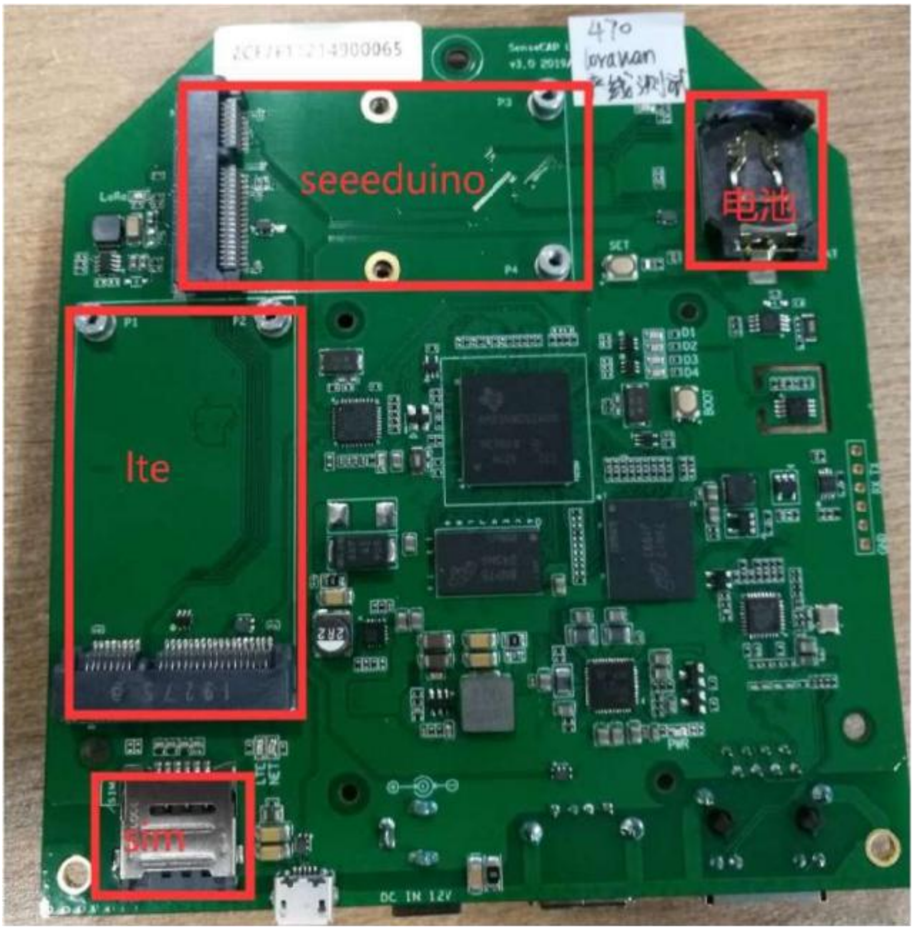
- Hardware
  - PCB Design Files.
  - Bill of Material (BOM)
- Software
  - Test firmware
  - Factory firmware
- Enclosure
  - 2D and 3D Mechanical Files.
- Test Plan
- SOP (Standard Operating Procedure)
- NPI (New Product Introduction) Report

3. Manufacturing

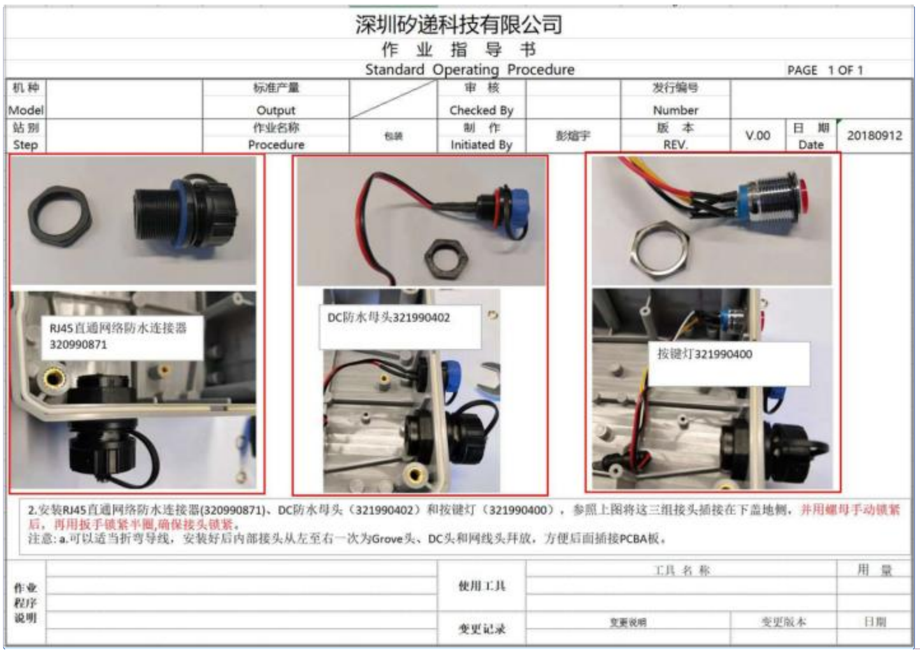
- The Operational Procedure
    - Incoming Inspection of Materials.
- PCBA



- PCBA Testing.



- Assembly.



- Complete Machine Testing.

- Reliability Testing.
  - High and Low Temperature.

批注 [1]: 这个图和下面的可靠性测试都感觉比较原始且还有中文字，是否需要替换

批注 [2]: 这个文档可以持续修订升级，每次有新的内容可以重新传播一遍

<table>
<tr><td rowspan="4">2、高温高湿试验（网关）</td><td rowspan="4">将成品放入70℃、90% RH湿度恒温恒湿箱，实验时间24H，运行工作。</td><td>1、试验前：样机无外观不良、测试功能正常。</td></tr>
<tr><td>试验前图片

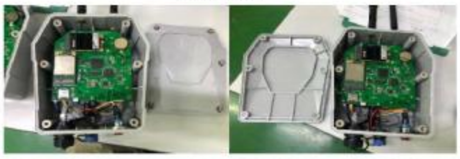
</td></tr>
<tr><td>2. 试验过程：
A、将 LpRaWAN 网关通电联网，再将传感器开机联网，然后登陆 senseeCAP 云平台确认联网状态已经数据上传状态；
B、把连接网络后的网关放进恒温恒湿箱中；
C、根据实验条件设置好恒温恒湿箱的试验温度、湿度后，开始进行试验；</td></tr>
<tr><td>试验中图片
</td></tr>
</table>

- High Temperature and High Humidity.
- Waterproof and Dustproof.

试验中图片

3. 试验后： 样机外观无异常、未出现松动、异响等现象，试验后样机功能测试无异常。

实验后图片



- Quality Inspection.

- Packaging.

- Warehousing.

Chapter Five: Open-Source Hardware and Manufacturing

Section 1: Open-Source Hardware

Open-source hardware not only makes design easier but also allows different projects to share supply chain and DFM experience. Mature open-source hardware projects have been verified by actual production, and based on their design, most DFM-related problems can be avoided.

When materials are adopted by popular open-source designs, there is an opportunity to derive a large number of projects for reuse, thereby increasing the total demand to help suppliers maintain supply and reduce costs.

Section 2: Cell Manufacture

Open-source hardware not only makes design easier but also allows different projects to share supply chain and DFM experience. Mature open-source hardware projects have been verified by actual production, and based on their design, most DFM-related problems can be avoided.

When materials are adopted by popular open-source designs, there is an opportunity to derive a large number of projects for reuse, thereby increasing the total demand to help suppliers maintain supply and reduce costs.

Section 3: Shenzhen Tech Ecosystem

In the past thirty years, Shenzhen has transformed from a small village in the hinterland of China to the world's hub of electronics manufacturing. Shenzhen, located in the Pearl River Delta region, has gathered talents in the global electronics manufacturing industry.

A large number of small and medium-sized enterprises (SMEs) can serve various fragmented needs of customers flexibly and quickly. These SMEs can also help them grow into companies with large-scale global supply of new products. The assembly process of large-scale mature products is moving to inner China, Southeast Asia, and Eastern Europe. However, Shenzhen maintains its absolute advantage in the development and rapid iteration of new products, and this advantage will be further consolidated with the diversification of technological applications.

表 3　2018 年粤港澳大湾区分地区工业经济创新主要指标

地区	R&D 经费投入（亿元）	R&D 人员数（万人）	有 R&D 活动的企业数（个）	有研发机构的企业数（个）	发明专利申请量（个）	发明专利授权量（个）
合计	1982. 18	75. 05	14807	17710	207282	51658
广州	267. 27	9. 56	1865	2132	50169	10797
深圳	966. 75	28. 94	3488	4347	69969	21309
珠海	82. 77	3. 08	527	485	13139	3452
佛山	235. 17	9. 33	2881	3406	29709	5058
惠州	221. 24	11. 20	2822	3943	24674	6716
东莞	59. 28	3. 66	966	992	8165	1875
中山	38. 35	3. 01	1041	1249	4089	712
江门	89. 32	5. 02	786	712	5222	1445
肇庆	22. 03	1. 25	431	444	2146	294

注：本表数据为规模以上工业企业数据，来源为《广东统计年鉴》和历年各市统计公报。

批注 [3]: 原文本中是 2018 年的数据，感觉有点老了，我找了下图 2022-2023 的数据，2024 年的暂时还未找到合适数据，是否需要替换

批注 [4]: 要修改

Figure 1: Vigor and Resilience of High-Quality Development: The Innovation Dynamics Index Report of the Manufacturing Industry in the Greater Bay Area (Observation of 9 Mainland Cities)

Section 4: Try Not to Manufacture

If a product can be customized, there is no need to redesign and manufacture from the beginning. It is very easy to manufacture a well-equipped mobile phone by ODM, the same for tablets, robots, drones, etc. ODM will have a relatively high Non-recurring Engineering Expense (NRE), but its efficiency and high probability of success are worth choosing this way.

A brand-new product involves a lot of structural design and engineering innovation. Even if one has an enough budget, one might face difficulties in finding an experienced partner to complete the product. In this case, it is worth setting up a core team to do it. Nevertheless, it is necessary to have a deep understanding of the existing technology platform, process and materials, and design based on the mature supply chain.

Avoid competition on the hardware itself. Instead, try to use software, business relationships, brand design, and other aspects as differentiators.

Section 5: OEM and ODM Project Service Breakdown and Standard Fee Reference

Since 2009, Seeed Technology has provided customized manufacturing services to global customers, with 11 years of manufacturing service experience. Seeed Technology provides customers with a full set of one-stop OEM production services: from PCB manufacturing, parts procurement, PCBA, and mechanical parts production and processing, testing, packaging, quality inspection to global logistics delivery. The company has one processing factory and a global warehousing center for rapid prototyping and small batch verification orders; there are also three strategic cooperative outsourcing factories to assist in undertaking large-scale production needs. The company's customized manufacturing service has successfully cooperated with 7,200 cases, including Microsoft, Schneider, ADI (Analog Devices Inc), Walmart, Arduino, American Printing House for the Blind, and the world's leading steam education brand Piper; manufacturing products involve industry, chip original development boards, IoT overall solution kits, education, and other categories.

Seeed Technology's customized manufacturing service features include:

- Experienced customer manager team, providing customers with efficient, flexible, and professional butler-style service.
- Professional manufacturing engineering team, from the perspective of manufacturing, providing design, testing, supply chain, and other optimization suggestions, such as professional DFM (Designing For Manufacturing) suggestions, leading professional and complete new product introductions.
- From supplier quality control, incoming inspection, process inspection to final inspection, to achieve a complete system quality control process.
- Professional supply chain management team covering procurement, material control, production management, and global logistics, helping customers complete order material sourcing and professional production control.

Seeed's OEM service fee structure is as follows:

Item	Fee Category	Fee Description
1	BOM Cost	This BOM Cost is the total unit price of each material in the product material list.
2	Material Loss	0.05%
3	Processing Fee	Processing fees include: SMT fee, DIP fee, testing fee, assembly fee, packaging fee.
4	Overheads	Including project management fees, engineering fees, etc.
5	Margin	Production profit margin.
6	NRE	NRE fees include: Engineering DFM fee, stencil fee, test fixture, production carrier. NRE fees are one-time fees, generated during the first production of the product. If replenishment is made later, and the production design remains unchanged, it does not need to be charged again.

Appendix

Common Processes and Materials

Common Special Terms

Agile Manufacturing Glossary

A

AQL (Acceptable Quality Level)

B

BOM (Bill of Materials)

C

CNC (Computer Numerical Control)

D

DFT (Design for Testing)

DFM (Design for Manufacturing)

DVT (Design Verification Testing)

DFMEA (Design Failure Mode and Effects Analysis)

E

ECN (Engineering Change Notice)

EMC (Electro Magnetic Compatibility)

EMI (Electro-Magnetic Interference)

EOL (End of Life)

EVT (Engineering Verification Test)

ERP (Enterprise Resource Planning)

ESD (Electro Spark Detector)

F

FQC (Final Quality Control)

G

H

I

IPQC (InPut Process Quality Control)

IPD (Integrated Product Development)

IQC (Incoming Quality Control)

J

K

L

M

MES (Manufacturing Execution System)

MOQ (Minimum Order Quantity)

MP (Mass Production)

MRP (Material Requirements Planning)

N

NPI (New Product Introduction)

NRE (Non-Recurring Engineering Cost)

O

OEM (Original Equipment Manufacture)

OQC (Outgoing Quality Control)

P

PCB (Printed Circuit Board)

PCBA (Printed Circuit Board Assembly)

PMP (Project Management Professional)

PVT (Pilot Verification Test)

PRD (Product Requirement Document)

Q

QMS (Quality Management System)

R

RoHS (Restriction of the use of certain Hazardous Substances)

S

SBC (Single Board Computer)

SMT (Surface Mounting Technology)

SOP (Standard Operating Procedure)

SoW (Statement of Work)

T

TOM (Total Quality Management)

U

V

W

Manufacturing Services

批注 [5]: marketing 入口集中放在了最后，主要放了 Fusion、ODM 和 Co-create 的链接

Seeed Fusion: Seeed Fusion One-Stop PCB Assembly & Custom Hardware Manufacturing

Custom Hardware Manufacturing Services: Seeed Fusion One-Stop PCB Assembly & Custom Hardware Manufacturing

Co-create with Seeed Fusion: Co-create and launch your ideas with Seeed Studio

This concludes the optimized and reorganized English version of the Agile Manufacturing Whitepaper.