Elimination of Wave Soldering Process

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ABSTRACT
Wave soldering of pin through hole devices has been around for a very long time. It is a process that everyone says will go away and each year it is still being used. In the industry, wave solder is to this day considered more art than science, although there is much more effort to characterize the process as much as possible.
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Pin through hole devices tend to be lower cost than surface mount technology components and through hole soldering tend to have robust solder joints that, in most cases, will outlast surface mount components.

The wave solder process has many variables that an engineer need to manage to meet the hole fill requirements on complex board designs: board design, component design, flux types and application methods, pre-heating, solder alloy, dross formation, wave types, etc.

This paper will explore the alternatives to wave solder, such as paste in hole, selective solder, and robotic soldering processes. The advantages and disadvantages will be discussed for each process type, in addition to how each process works. The paper will explore some of the key items in making a decision on which process is most suitable for the application being considered.

Keywords:Wave solder, pin through hole, point soldering, selective soldering, paste in hole, PiH,

INTRODUCTION
Wave soldering, which is running a board over a flowing pot of molten solder, has been around for many years. It was primarily used to connect pin through hole devices onto a circuit board and later used to connect surface mount devices (SMDs) onto the secondary side of a printed circuit board assembly. The components typically are lower cost than SMD components and the process is a high volume gang soldering process as compared to hand soldering.

The wave solder process has been considered more of an art than science as there are many variables that affect the outcome of the process. Many engineers spend many hours trying to perfect the process. Variables such as flux type, amount of flux, type of fluxer, preheat types, how many top/bottom preheat, solder wave types, solder level, height of wave, temperature of the solder pot, speed of pumps for wave, dual wave, chip wave, lamda wave, thermocouple positions, conveyor speed, pallet designs, printed circuit board (PCB) design, amount of copper connected to the through holes, surface finish, solder pot contamination levels and replenishment, and many others make it a challenge to set up and then control the process in order to provide a product that has the appropriate solder hole fill.

Besides all the variables that a process engineer needs to be concerned about, the maintenance of the wave solder system is another area of concern. The removal of dross plays a major role in the cost of operating the equipment. The cleaning of nozzles, heating elements, and spray fluxer systems lead this to be one of the most dirty and hazardous processes on the production floor today. Special personal safety equipment is required to maintain the wave solder systems. Fumes, dross dust, and high temperature molten metals all lead to potential hazards for the personnel maintaining the systems.

On top of all the above concerns, wave solder is also a source for many quality issues. Besides obtaining the desired hole fill, there are many concerns about copper dissolution, potential electro migration issues in the field, flux residues in undesired area, and many more potential quality issues.

Figure1: Typical Wave Solder Equipment

ASSEMBLY PROCESSES

There are many alternative processes available that are suitable for soldering pin through hole (PTH) components.

Selective soldering is very similar to wave soldering. The key difference is that the selective soldering can use a smaller solder pot and a nozzle that moves under the desired soldering areas. Selective soldering is traditionally used when PTH components are in areas that are too close for a wave solder to properly solder, there could be adjacent surface mount technology (SMT) components that cannot be covered by a pallet for wave, or the PTH components are on both sides of the assembly. In the past, one of the key issues was maintaining heat in the board as it was being soldered. Many of the selective soldering machines have solutions to help maintain the heat in the board which allows better solder fill during the process. Selective soldering still has concerns with dross and solder pot maintenance, although there is a lower amount of solder required in most selective solder equipment. These processes are good when a small number of PTH pins are to be soldered.

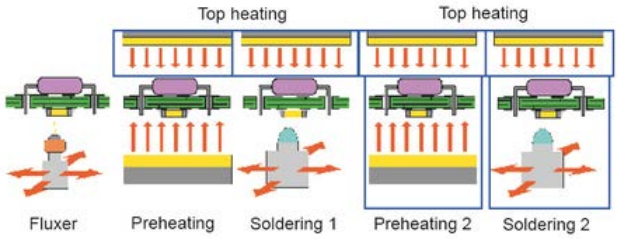

Figure 2: A Selective Solder Schematic

Point soldering or robotic soldering is another methodology that can be used to solder PTH components as well as SMT components. The point soldering system, in simple terms, is a system that typically uses solder wire that is fed through a system to the desired pin and uses either induction, laser, or solder iron to heat the location. The heating happens first and then the wire is fed onto the location with a set amount of solder. One way to think of this is that the manual soldering has been converted into an automated soldering system. These are typically slower than selective or wave solder; in most cases one pin at a time is being soldered. There are also keep out areas in order to allow for access by the wire feed system and the heat source. Less area is needed for laser systems while a solder iron type needs enough clearance to access the target area. Many of the vendors can provide these recommended rules for clearances for their equipment. For larger, thick, high mass boards and components, additional heating may need to be added in order to allow proper soldering.

Figure 3: A Point Soldering System

Paste in hole soldering has been around for many years and is a method where the PTH components are soldered by using the SMT process. The solder paste is deposited into the holes using the screen print process. There are formulas in the industry, most notably the Pappas-Guldin formula, which can estimate the amount of solder required; this estimate is then used to determine the amount of solder paste required.

$V_{(solder\ joint)} = (V_{hole} - V_{pin}) + (2 \times V_{fillet})$

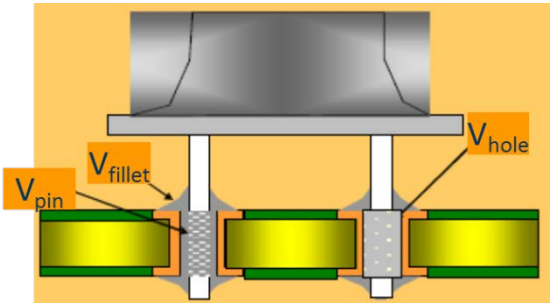

Figure 4: Schematic for Solder in PTH

Once the paste is printed, preforms can also be pick and placed in order to obtain the amount of solder required. The component is then pick and placed onto the board, and the assembly is reflowed as part of the SMT process.

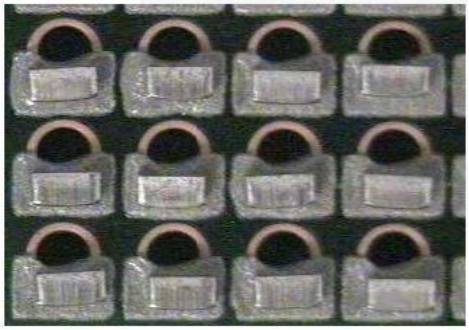

Figure 5: Preforms Placed on Top of the Solder Paste

Some of the key items to allow the use of the paste in hole process, also known as intrusive reflow, are that the components need to be qualified to survive the reflow process and the hole design on the PCB may need to be modified as compared to wave soldering. Also, the components should have a standoff built in so that the component bottom does not touch the solder paste or prevent it from flowing into the hole.

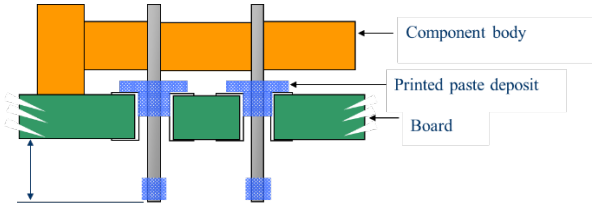

Figure 6: Schematic of Pin Protrusion and Standoff

Some of the disadvantages of paste in hole are that the components will have higher cost, and preforms add cost both in the preform and the need to do these on the pick and place equipment.

The advantages of the paste in hole process are that it is very controllable and allows the hole fill to be very predictable. The board is more uniformly heated by using the reflow ovens and ensures that all holes have very similar amount of hole fill. Since there is a set amount of solder, copper dissolution is not as much of a concern. The solder will be saturated with copper, and there is no fresh solder being continuously replenished as one sees during wave or selective wave soldering.

METHODOLOGY

A team was formed within the company which brainstormed an approach to determine what would be the most appropriate method to eliminate wave soldering.

It was decided that a survey would be conducted internally to collect all the pertinent data from the factories for a wide variety of products that were in production. Data that would be collected would include some of the following:

- PCB descriptions
- number of PTH components and total pins
- volume of pcbs
- current process type: wave, selective, robotic, hand solder, paste in hole
- solder alloy type
- wave/selective solder pot sizes
- amount of dross created
- energy consumption
- N_2 usage
- cycle time

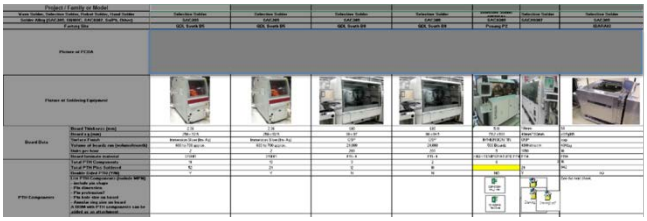
Figure7: Sample of Data Collection

From this data summary, slides were created for each type of process.

Wave Solder System Summary:

Figure 8: Wave Solder Summary

Wave solder is a high volume soldering system and in the data could achieve high number of pins/sec for soldering. The solder pot size was between 350-800kg of solder and dross would be create at an average rate of 3-26kg/24h. The rate would vary as various methods of dross reduction were in practice.

Selective Solder System Summary:

Figure 9: Selective Solder Summary

For selective solder, the number of pins soldered per second was around 8 and the solder pots ranged from 8-550kg, a wide range dependent on the vendor of the equipment. Dross creation was much lower, around 0.2-0.5kg/24h. This is explained by less exposure of solder to the air at one time. A much smaller nozzle is used as compared to the open wave systems.

Robotic Soldering Summary:

Figure 10: Robotic Solder Summary

Robotic soldering had the slowest solder rate at 0.3pins/s. It does not have a pot of solder, but just a spool of solder wire. It does not create dross that needs to be cleaned and recovered. In order to keep up with volumes, multiple stations would be required.

Paste in Hole Summary:

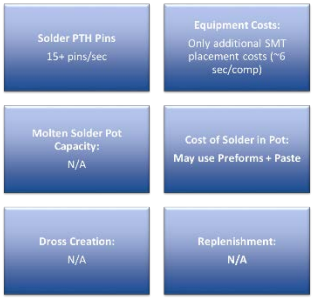

Figure 11: Paste in Hole

Paste in hole was not widely used in this study, and so just a few examples were provided. Paste in hole is also a mass soldering process and can maintain soldering rate similar to wave soldering. The equipment used would be the current SMT process equipment and just needs to account for the additional placement of components and preforms (if used). As mentioned above, there are some key items that need to be addressed up front in the design stage to help enable paste in hole

processing.
From the data collected a what-if calculation was then created to help guide a process engineer in the selection of the most cost effective process. In some cases, wave solder will still be the most cost effective process for the factory, but now an informed decision can be made and the other alternatives can be considered.

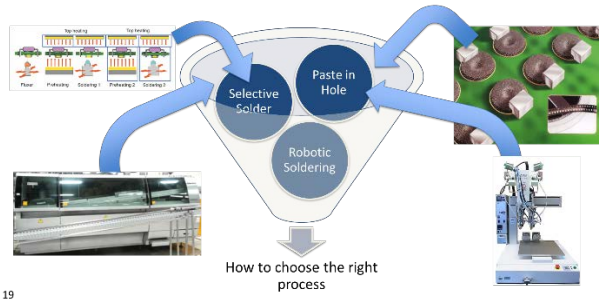

Figure 12: Decision Making Matrix

Inputs to the what-if tool include volume, quantity of PTH components, number of pins per assembly, direct labor rate (varies around the world), days/shifts/hours available, equipment costs, number of fixtures, and cost per fixture. With these items, an estimated process cost can be determined from the tool for each process type. Each process will have different material types and costs associated with them. For example, the alloy cost and dross would be different from the cost of a spool of wire versus. solder paste and preforms. Once these inputs are provided, the engineer can look to see what processes would be the most cost effective.

Category	Assumption	Wave	Selective	Paste in Hole	Robot
General Assumption	#Scenarios Prepared: 4				
	Forecast(Annual Volume)	100,000	100,000	100,000	100,000
	DL Hourly Rate(USD)	3.52 USD/Hour	3.52 USD/Hour	3.52 USD/Hour	3.52 USD/Hour
	Working days per month	23.8 Days	23.8 Days	23.8 Days	23.8 Days
	Shifts per day	3 Shift	3 Shift	3 Shift	3 Shift
	Working hours per shift	8 Hours	8 Hours	8 Hours	8 Hours
	UPH Demand	15	15	15	15
	<Add more assumption here>				
PCBA Assumption	#PCBA Qty: 1				
	PCBA_1	Sample	Sample	Sample	Sample
	PCB Thickness	1.6	1.6	1.6	1.6
	PTH solder pins QTY	1000	1000	1000	1000
	Total # PTH Components	10	10	10	10
	Equipment Cost ($) Overall equipment cost each	$300,000.00	$250,000.00		$60,000.00
	Solder Pot capacity (kg)	800	15		
	Cost of Fixtures for Wave, Selective and Robot	$250.00	$500.00		$150.00
	Number of Fixtures Required (Estimate)	5	1		0
	Cost of nozzles required for Paste in Hole Placement			$100.00	
	Number of new nozzles required for placement			1	
	<Add more assumption here>				

Figure 13: Inputs to What-if Tool

Another set of questions need to be considered to see if that process is suitable for the assembly. A decision flow was also created to help in the asking those questions.

Manufacturing Scenarios	Wave Solder	Selective	Robot	Paste in Hole
Annual Volume	100,000	100,000	100,000	100,000
PCBA UPH_Board1	324	17	15	54
Assy Cycle Time / unit (sec)	10.00	1000.00	3125.00	60.00
#PCBA Lines:	1	5	14	1
$/ Unit	$ 0.70	$ 3.52	$ 1.41	$ 0.70
DL SMT / Shift / Line	1	5	2	1
Total DL (Normal Shift)	3	15	6	3
Total DL (PTH Soldering Process)	3	15	6	3
Total CAPEX Generic Equipment	$ 0.030	$ 2.150	$ 1.634	$ 0.100
Equipment Depreciation Generic Equipment (PTH Soldering)	$ 0.030	$ 2.150	$ 1.634	$ 0.100
Total NRE Unique Fixture	$ 0.013	$ 0.005	$ -	$ 0.001
NRE Unique Fixture (Wave, Selective, Robot)	$ 0.013	$ 0.005	$ -	$ -
NRE Unique Fixture (Nozzles for PiH Placement)	$ -	$ -	$ -	$ 0.001
Total Investment (CAPEX+NRE)	$ 0.042	$ 2.155	$ 1.634	$ 0.101
Total DL$ / unit	$ 0.704	$ 3.520	$ 1.408	$ 0.704
EDM $ / unit	$ 0.577	$ 1.429	$ 0.719	$ 1.697
Other Asset Holding (Soldering Materials in Solder Pot)	$ 31,200.00	$ 585.00	$ -	$ -
Total Cost of Process	$ 1.32	$ 7.10	$ 3.76	$ 2.50

Figure 14: Outputs of What-if Tool

The lowest cost process is highlighted in green on the output page of the what-if tool. In the above example, wave solder is the most cost effective method for this particular board. The tool can also do multiple boards by adding all the PTH components and pins into the tool to help decide which method is the most cost effective.

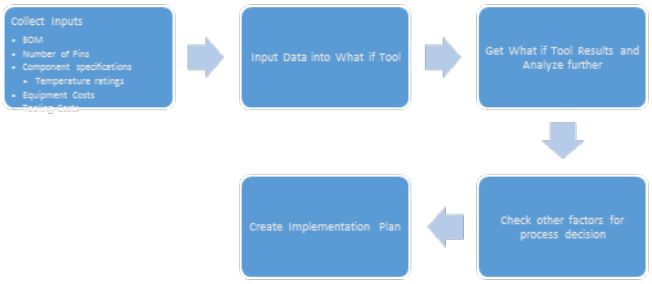

Figure 15: Flow for Decision Making

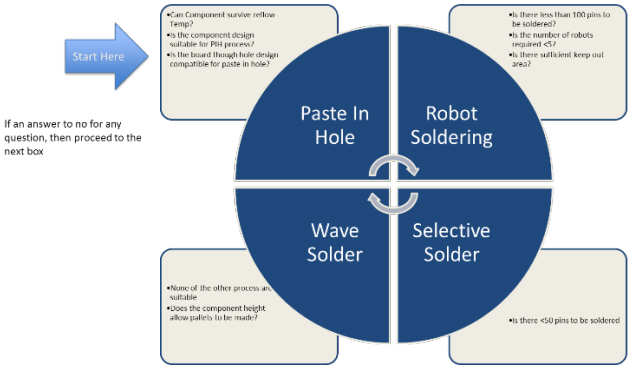

Figure 16: Other Factors for Decisions

By using the chart in Figure 16, some of the other questions that need to be answered can lead the engineer into making the appropriate decision, as all items cannot be answered in the cost analysis. For example, the first area is paste in hole and there are a few items that need to be considered:

1) Can the component survive reflow?
2) Is the component design for paste in hole?
3) Is the board hole size suitable for paste in hole?

If no is answered to any of these question, the next box would be robotic soldering, and then selective, and then wave solder.

Based on these items, the following preference is provided for alternative processes:

1) paste in hole
2) robotic soldering
3) selective soldering
4) wave soldering

Paste in hole soldering tends to give the most repeatable and highest quality results. It is highly recommended to work with design teams to enable higher use of paste in hole processes and help reduce the amount of wave soldering done in the factories.

SUMMARY

Through the work of many engineers around the world, a methodology was developed to help a factory engineer make a decision on which process is the best process for an assembly with a goal of reducing or eliminating the overall use of wave soldering in the PCBA industry.

ACKNOWLEDGEMENTS

The authors would like to thank the worldwide company engineers who participated in this study.

REFERENCES

1) Subbarayan, Guhan, Scott Priore, Paul Keop, Scott Lewin, Rahul Rahut, and Sundar Sethuraman. "Investigation for Use of Pin in Paste Reflow Process with Combination of Solder Preforms to Eliminate Wave Soldering." Proceedings of IPC/APEX (2011).
2) Tim Jensen and Ronald Lasky, “Practical Tips in Implementing the “Pin-in-Paste” Process”, SMTAI conference (2002)

ELIMINATION OF WAVE SOLDERING PROCESS

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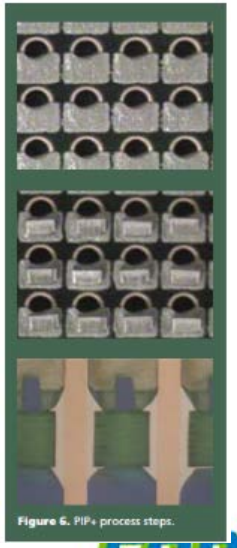


Background

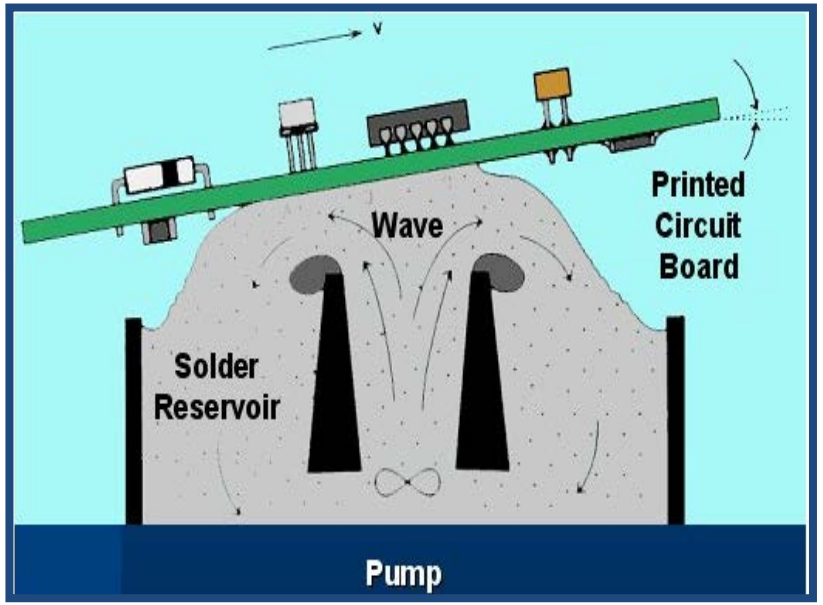
- Many of our factories use wave soldering today, however it is a complicated process to get right and also has many concerns about safety, health and environment. A project was formed to determine how wave solder process can be eliminated

- Wave Solder Concerns
  - Large pot of molten metal (asset on the floor as part of the equipment)
  - Solder dross and loss of material
  - Fumes
  - Maintenance requires specialized Health and Safety gear to clean the equipment
  - “Dirty” Process
  - Can be source of field related defects due to electromigration issues
  - Hole fill and Copper Dissolution are issues seen with Lead-free solder alloys

Wave Soldering Introduction

What is Wave soldering

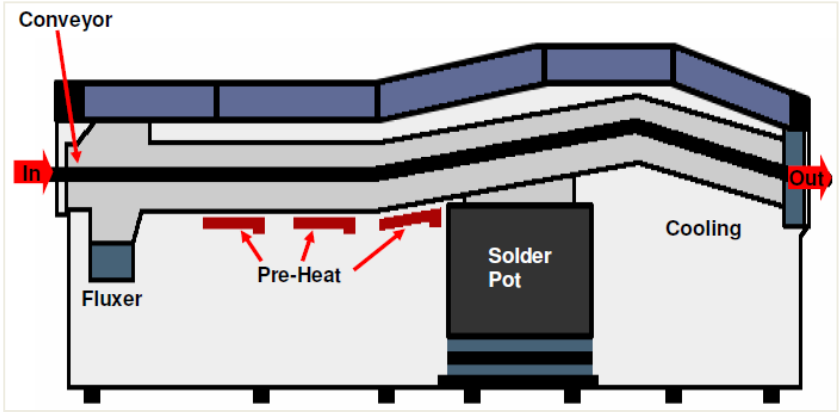
Wave soldering is a bulk soldering process used in the manufacture of printed circuit boards. The circuit board is passed over a pan of molten solder in which a pump produces an upwelling of solder that looks like a standing wave. As the circuit board makes contact with this wave, the components become soldered to the board. Wave soldering is used for both through-hole printed circuit assemblies, and surface mount.

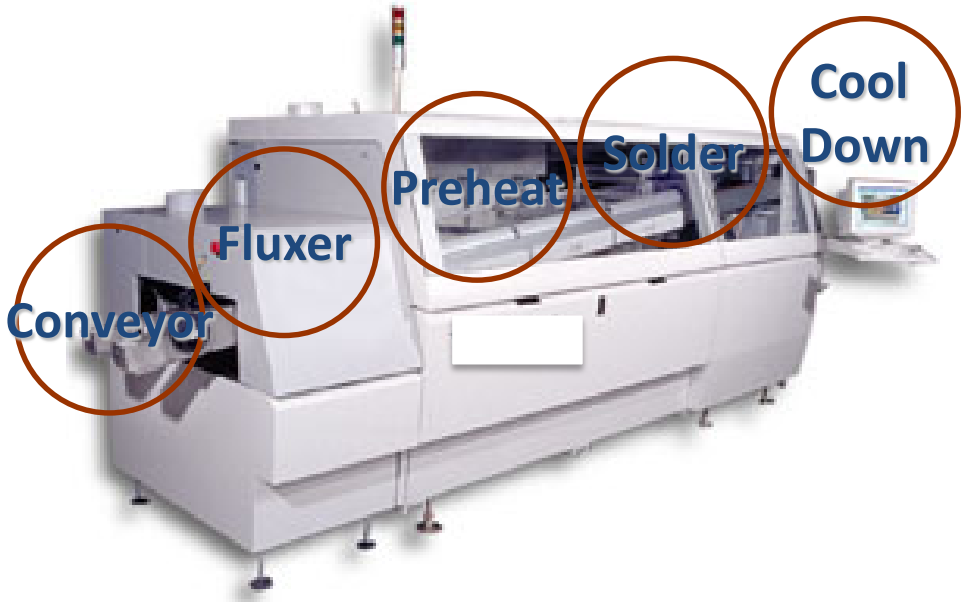


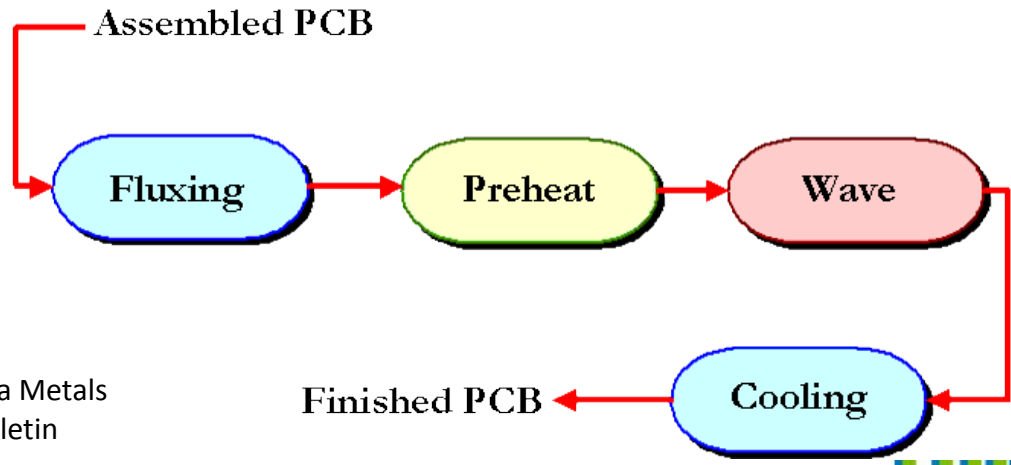
Source: https://en.wikipedia.org/wiki/Wave_soldering

Wave Soldering System Overview

- Conveyor
- Spray Fluxer
- Preheat
- Solder Pot & Nozzles







Wave Soldering Parameter (example)

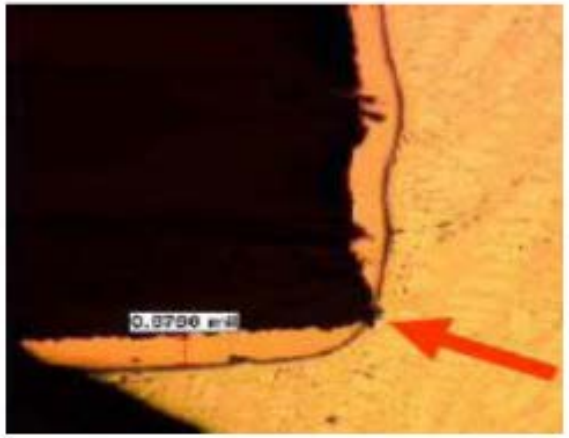
Parameters		Requirements
Solder Pot Temperature		255 - 265℃ (260℃ nominal)
Top Side Preheat Temperature		99 - 113℃
Max Ramp Rate of Topside Temperature		2℃/ second Maximum
Conveyor Angle		6°
Conveyor Speed		0.5 - 0.9 meters/ minute
Contact Time (dwell time)		2 - 4 seconds
Bottom Side PCB Temperature		10℃ Hotter than Top Side

Source: Alpha Metals Technical Bulletin

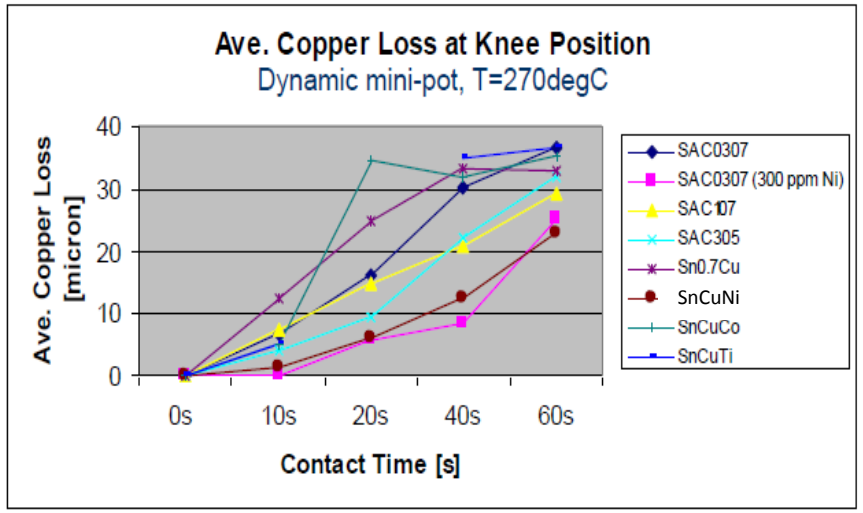
Problems associated with Wave Soldering

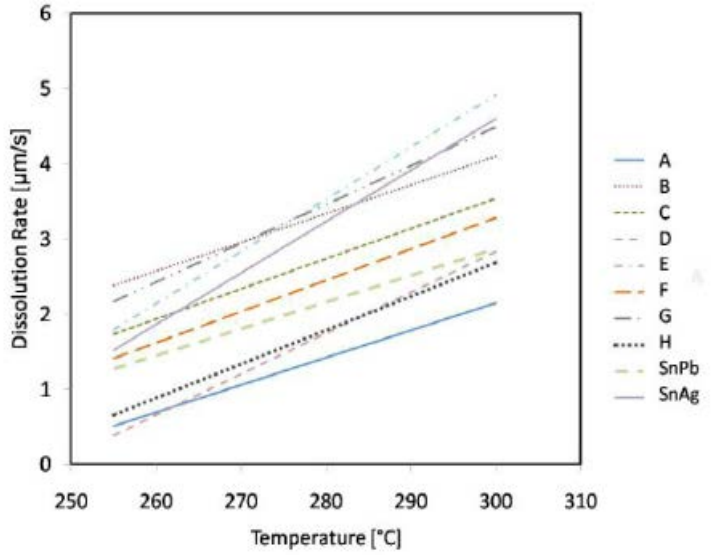
Copper Dissolution

- Copper Dissolution is a metallurgical reaction where the copper (Cu) dissolves into a tin-rich liquid.
- Fast dissolution rate : Sn0.7Cu,SnCuTi,SnCuCo
- Moderate dissolution rate:SAC305,SAC107,SAC0307
- Low dissolution rate: SnCuNi,SAC0307(300 ppm Ni)
- Happens during wave solder and PTH rework



Cu dissolution after PTH rework (SAC305)



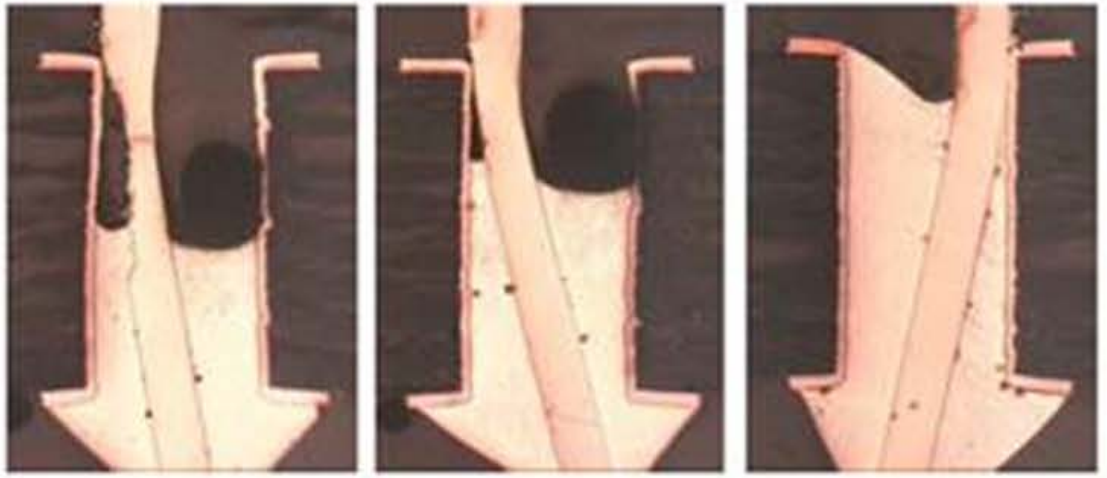


Reference : [1]

Problems associated with Wave Soldering

Hole fill is a common issue on wave soldering process, and it is big challenge on the thick PCB , PCB with DFM design, and incorrect process setting also impact the hole fill, sample as below:

Solder pot temperature will play a role in hole-fill as temperature is increased. The photos to the right, indicate the degree of hole-fill as solder temperature increases from 240, 250 to 260°C using SAC solder.



Reference: [2]

Goals & Objectives

- Define Methodology How to Eliminate Wave Solder Process

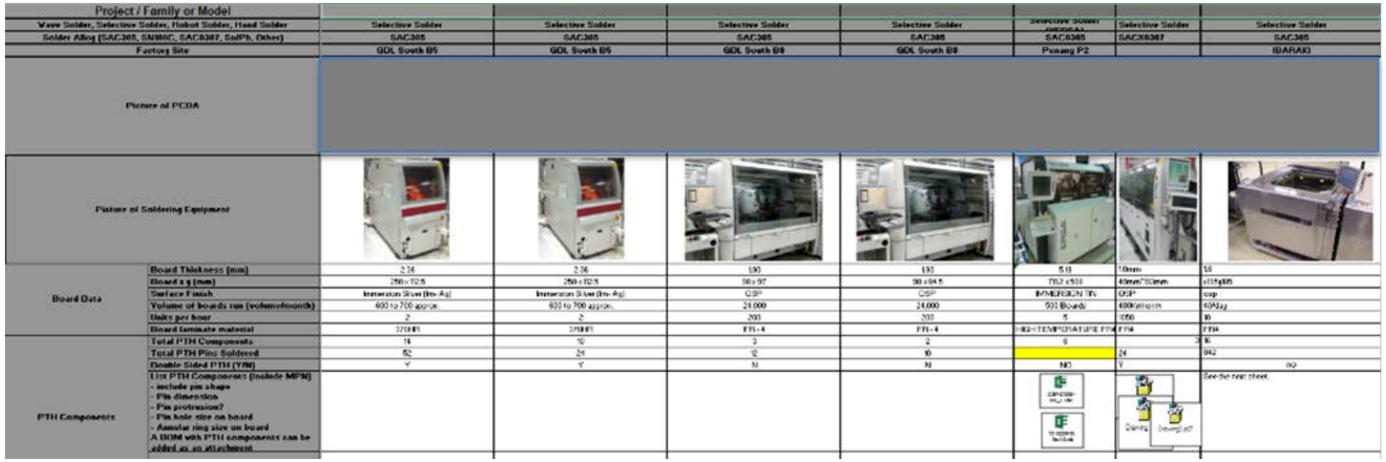
- Define criteria and methodology
- Automation vs Paste in Hole vs Low Temperature Paste in Hole vs Selective

Items to be Considered

- Point Soldering Process
  - Design Rules (board thickness, pitch, component type, etc)
  - Cost per pin (cycle time, defects, amount of solder)
  - Laser vs Solder Iron
  - Wear Out of tips
- Paste in Hole Process
  - Component capability to survive SAC305 reflow
  - Design rules (stencil, preform, component)
- Low Temperature Paste in Hole
  - Use Sn/Bi/Ag for lower temperature reflow
  - 3rd SMT type process
  - Dispensing solder paste + Preform
  - Component types
  - Costs

Data Collection

- Survey was formed
- Data from each region was collected into a master survey form. Attempted to get a good cross section of board types, volumes and process types already being used in the company



Project / Family or Model								
Wave Solder, Selective Solder, Robot Solder, Hand Solder		Selective Solder	Selective Solder	Selective Solder	Selective Solder	Selective Solder [illegible]	Selective Solder	Selective Solder
Solder Alloy (SAC305, SN100C, SAC0307, SnPb, Other)		SAC305	SAC305	SAC305	SAC305	SAC0305	SACX0307	SAC305
Factory Site		GDL South B5	GDL South B5	GDL South B8	GDL South B8	Penang P2		IBARAKI
Picture of PCBA								
Picture of Soldering Equipment								
Board Data	Board Thickness (mm)	2.36	2.36	1.90	1.90	[illegible]	1.0mm	[illegible]
	Board x y (mm)	250 x 172.5	250 x 172.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Surface Finish	Immersion Silver (Im-Ag)	Immersion Silver (Im-Ag)	OSP	OSP	IMMERSION TIN	OSP	osp
	Volume of boards run (volume/month)	600 to 700 approx.	600 to 700 approx.	24,000	24,000	500 Boards	[illegible]	40/day
	Units per hour	2	2	200	200	5	1050	10
	Board laminate material	370HR	370HR	FR-4	FR-4	HIGH TEMPERATURE FR4	FR4	FR4
PTH Components	Total PTH Components	14	10	3	2	6	3	16
	Total PTH Pins Soldered	52	24	12	10		24	[illegible]
	Double Sided PTH (Y/N)	Y	Y	N	N	NO	Y	NO
	List PTH Components (include MPN) - include pin shape - Pin dimension - Pin protrusion? - Pin hole size on board - Annular ring size on board A BOM with PTH components can be added as an attachment							See the next sheet.

- Board Data
- Component Information
- Volume
- Units per Hour (UPH)
- Yield
- Soldering process and equipment
- Solder pot size

Summary Wave Solder

Solder PTH Pins
15+pins/sec

Equipment Costs:
$200-300k

Molten Solder Pot Capacity:
350-800kg

Cost of Solder in Pot:
SAC305: $13,650-$31,200
SAC0307: $10,902-$25,920

Dross Creation:
3-26kg/24hr

Replenishment:
8-50kg per day

Summary of Selective Solder

Solder PTH Pins
~8 pins/sec

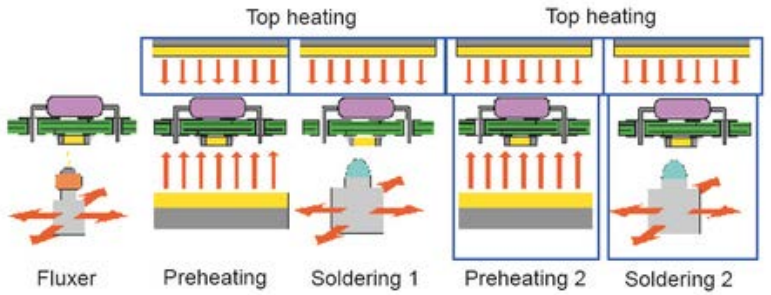
Equipment Costs:
$100,00 – 300,000

Molten Solder Pot Capacity:
8-550kg

Cost of Solder in Pot:
SAC305: $585-$15,600
SAC0307: $500-$12,500

Dross Creation:
0.2-0.5kg/24hr

Replenishment:
3-10 kg per day



Summary of Robotic Soldering

Solder PTH Pins
0.3 pins/sec

Equipment Costs:
$25,000-70,000

Molten Solder Pot Capacity:
N/A

Cost of Solder in Pot:
Cost of solder paste to fill hole

Dross Creation:
N/A

Replenishment:
N/A

Summary of Paste in Hole

Solder PTH Pins

15+ pins/sec

Equipment Costs:

Only additional SMT placement costs (~6 sec/comp)

Molten Solder Pot Capacity:

N/A

Cost of Solder in Pot:

May use Preforms + Paste

Dross Creation:

N/A

Replenishment:

N/A

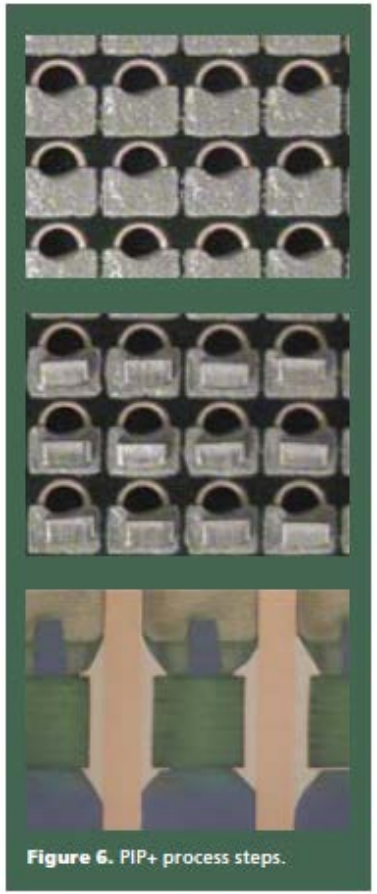
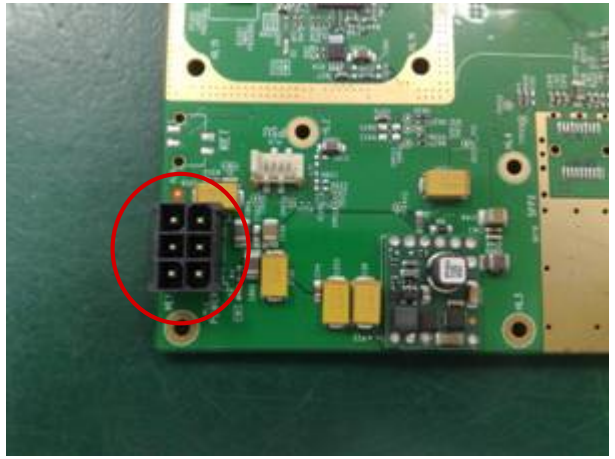


Figure 6. PIP+ process steps.

Paste in Hole Example



Paste in hole example 2 :

Solder paste used : lead-free (type 3)

Board thickness : 93 mils

Pin dimension : 45 mils x 45 mils

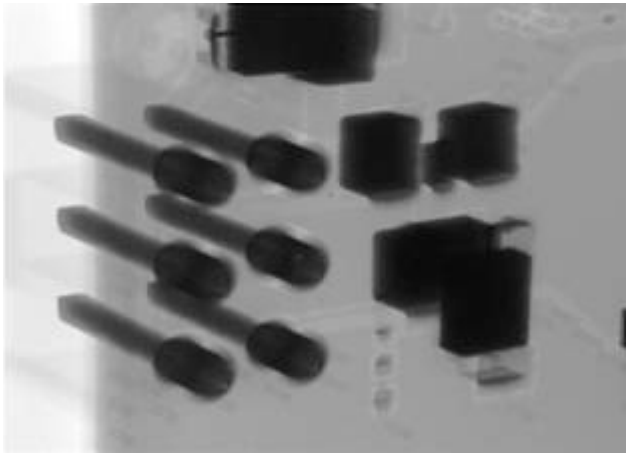
Hole diameter : 71 mils

Annular ring OD : 100 mils

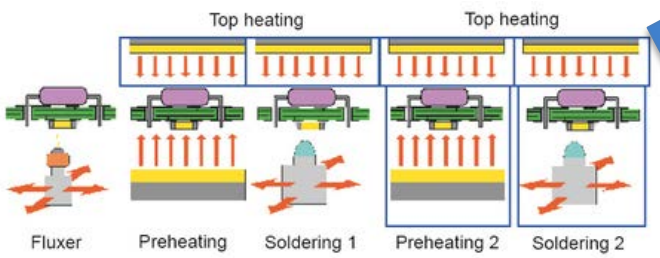
Stencil aperture : 150 mils x 230 mils

Stencil foil step thickness : 8 mils

3-D X-Ray image showing 100% barrel fill



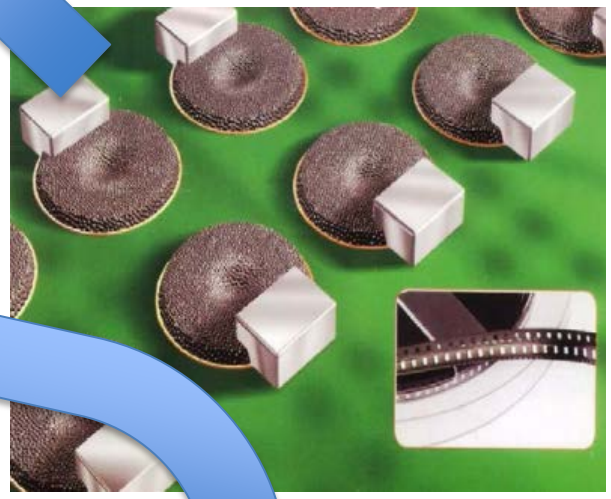
Decision Making Process



Selective Solder

Paste in Hole

Robotic Soldering



How to choose the right process

What If Tool

- Tool developed to help in decision process
- Inputs include
  - Volume per year (PCBA)
  - Number of PTH Pins to be soldered per PCBA
  - Number of PTH Components per PCBA
  - Direct Labor rate
  - Days/shifts/hours available
  - Equipment Costs
  - Number of fixtures & cost per fixture
- Calculations do not include component loading as this is considered the same for each product

Volume/year	#pins	# comp	thickness	Wave Solder	Selective	Robot	Paste in Hole
10000	3	1	1.6	$5.54	$5.35	$5.29	$5.31
10000	10	1	1.6	$5.54	$5.41	$5.30	$5.32
10000	50	2	1.6	$5.56	$5.72	$5.40	$5.39
10000	100	3	1.6	$5.59	$6.09	$5.51	$5.49
10000	500	5	1.6	$5.78	$8.93	$6.22	$6.19
10000	1000	10	1.6	$6.01	$11.69	$7.17	$7.09
25000	3	1	1.6	$2.83	$2.68	$2.65	$2.66
25000	10	1	1.6	$2.83	$2.74	$2.66	$2.67
25000	50	2	1.6	$2.85	$3.05	$2.76	$2.75
25000	100	3	1.6	$2.87	$3.42	$2.87	$2.84
25000	500	5	1.6	$3.06	$6.26	$3.70	$3.54
25000	1000	10	1.6	$3.30	$10.18	$4.76	$4.44

What if Tool: Assumption Screen Inputs

Category	Assumption	Wave	Selective	Paste in Hole	Robot
General Assumption	#Scenarios Prepared: 4				
	Forecast(Annual Volume)	100,000	100,000	100,000	100,000
	DL Hourly Rate(USD)	3.52 USD/Hour	3.52 USD/Hour	3.52 USD/Hour	3.52 USD/Hour
	Working days per month	23.8 Days	23.8 Days	23.8 Days	23.8 Days
	Shifts per day	3 Shift	3 Shift	3 Shift	3 Shift
	Working hours per shift	8 Hours	8 Hours	8 Hours	8 Hours
	UPH Demand	15	15	15	15
	<Add more assumption here>				
PCBA Assumption	#PCBA Qty: 1				
	PCBA_1	Sample	Sample	Sample	Sample
	PCB Thickness	1.6	1.6	1.6	1.6
	PTH solder pins QTY	1000	1000	1000	1000
	Total # PTH Components	10	10	10	10
	Equipment Cost ($) Overall equipment cost each	$300,000.00	$250,000.00		$60,000.00
	Solder Pot capacity (kg)	800	15		
	Cost of Fixtures for Wave, Selective and Robot	$250.00	$500.00		$150.00
	Number of Fixtures Required (Estimate)	5	1		0
	Cost of nozzles required for Paste in Hole Placement			$100.00	
	Number of new nozzles required for placement			1	
	<Add more assumption here>				

What if Tool: Output

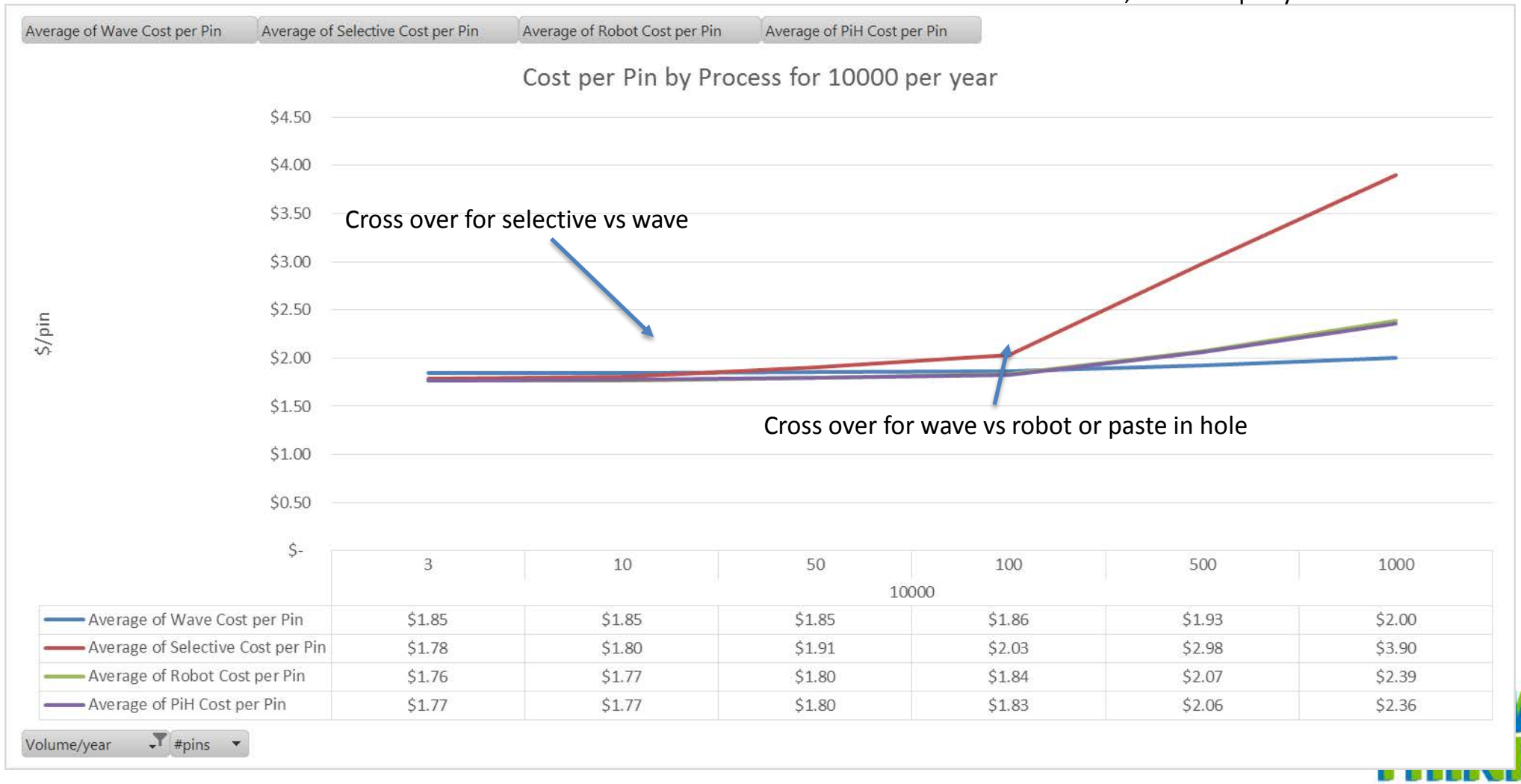
- Manufacturing Scenarios Sheet

- This worksheet is showing the comparative cost for each of the processes based on the inputs provided
- The total process costs will highlight the lower costs process that can be taken into the next decision making process
- The total costs includes breakdown of (A)
  - EDM Costs (B)
  - NRE Costs (amortized over the yearly volume) (C)
  - Capex cost per boards (5 year depreciation) (D)
  - DL costs based on the labor rate entered (E)

Manufacturing Scenarios	Wave Solder	Selective	Robot	Paste in Hole
Annual Volume	100,000	100,000	100,000	100,000
PCBA UPH_Board1	324	17	15	54
Assy Cycle Time / unit (sec)	10.00	1000.00	3125.00	60.00
#PCBA Lines:	1	5	14	1
$/ Unit	$ 0.70	$ 3.52	$ 1.41	$ 0.70
DL SMT / Shift / Line	1	5	2	1
Total DL (Normal Shift)	3	15	6	3
Total DL (PTH Soldering Process)	3	15	6	3
Total CAPEX Generic Equipment	$ 0.030	$ 2.150	$ 1.634	$ 0.100
Equipment Depreciation Generic Equipment (PTH Soldering)	$ 0.030	$ 2.150	$ 1.634	$ 0.100
Total NRE Unique Fixture	$ 0.013	$ 0.005	$ -	$ 0.001
NRE Unique Fixture (Wave, Selective, Robot)	$ 0.013	$ 0.005	$ -	$ -
NRE Unique Fixture (Nozzles for PiH Placement)	$ -	$ -	$ -	$ 0.001
Total Investment (CAPEX+NRE)	$ 0.042	$ 2.155	$ 1.634	$ 0.101
Total DL$ / unit	$ 0.704	$ 3.520	$ 1.408	$ 0.704
EDM $ / unit	$ 0.577	$ 1.429	$ 0.719	$ 1.697
Other Asset Holding (Soldering Materials in Solder Pot)	$ 31,200.00	$ 585.00	$ -	$ -
Total Cost of Process	$ 1.32	$ 7.10	$ 3.76	$ 2.50

Cost Curves for Various Volumes and Pins to be Soldered

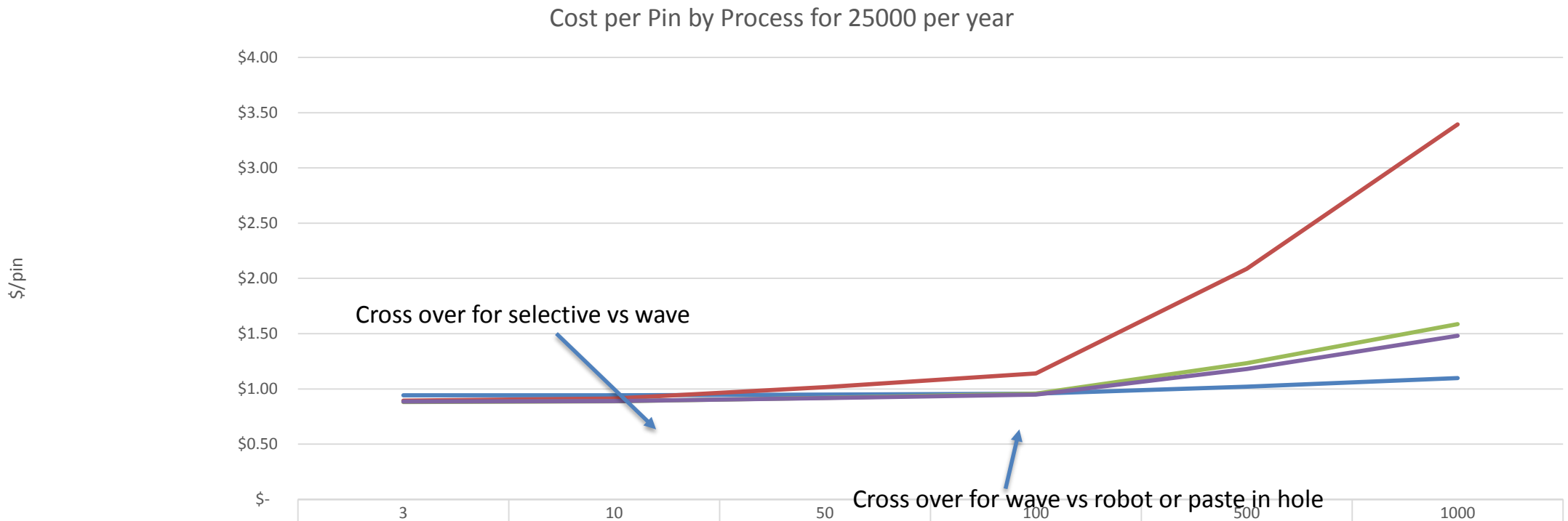
10,000 units per year



	3	10	50	100	500	1000
Average of Wave Cost per Pin	$1.85	$1.85	$1.85	$1.86	$1.93	$2.00
Average of Selective Cost per Pin	$1.78	$1.80	$1.91	$2.03	$2.98	$3.90
Average of Robot Cost per Pin	$1.76	$1.77	$1.80	$1.84	$2.07	$2.39
Average of PiH Cost per Pin	$1.77	$1.77	$1.80	$1.83	$2.06	$2.36

Cost Curves for Various Volumes and Pins to be Soldered

25,000 units per year



25000	3	10	50	100	500	1000
Average of Wave Cost per Pin	$0.94	$0.94	$0.95	$0.96	$1.02	$1.10
Average of Selective Cost per Pin	$0.89	$0.91	$1.02	$1.14	$2.09	$3.39
Average of Robot Cost per Pin	$0.88	$0.89	$0.92	$0.96	$1.23	$1.59
Average of PiH Cost per Pin	$0.89	$0.89	$0.92	$0.95	$1.18	$1.48

Cost Curves for Various Volumes and Pins to be Soldered

100,000 units per year

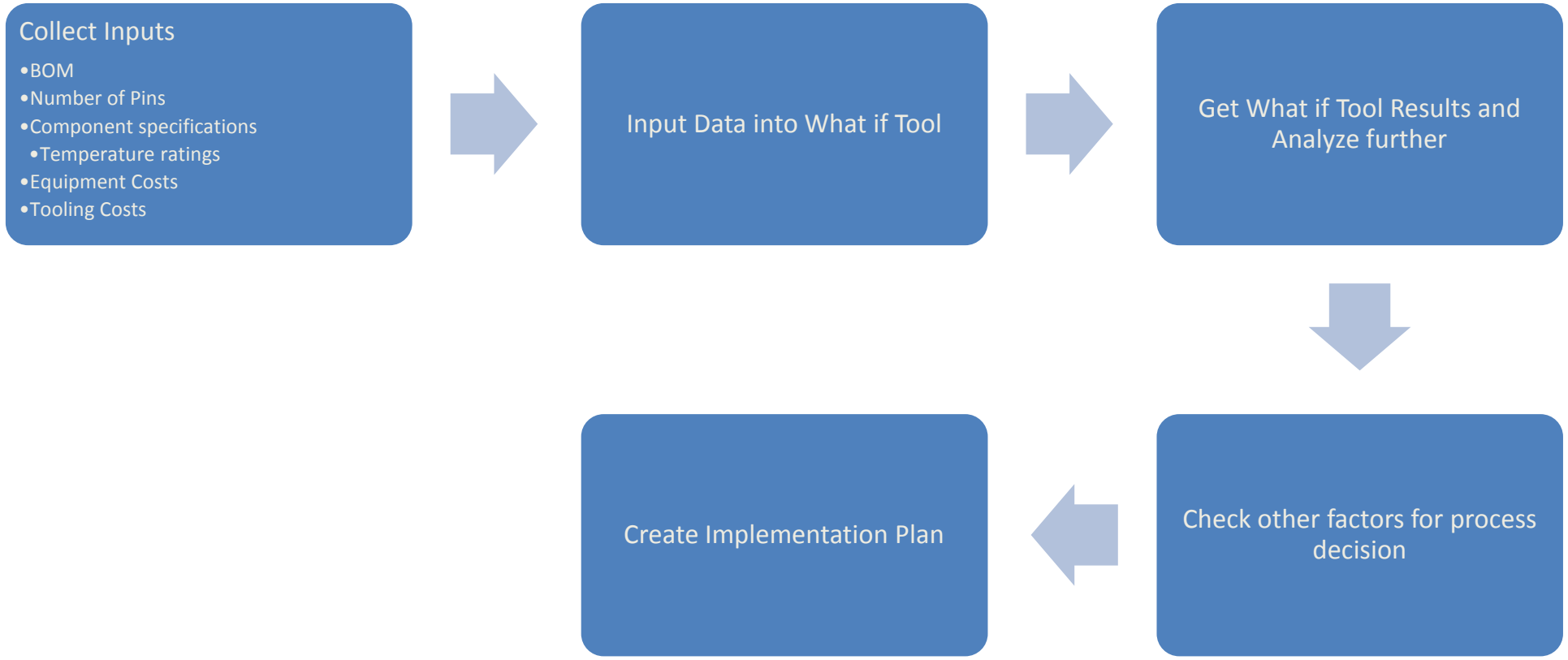
	3	10	50	100	500	1000
Average of Wave Cost per Pin	$0.28	$0.29	$0.29	$0.30	$0.36	$0.44
Average of Selective Cost per Pin	$0.24	$0.26	$0.37	$0.49	$1.42	$2.37
Average of Robot Cost per Pin	$0.24	$0.24	$0.27	$0.31	$0.63	$1.25
Average of PiH Cost per Pin	$0.24	$0.24	$0.27	$0.30	$0.53	$0.83

Cost Curves

- Summary of Cost Curves
- In the cost curves presented the following can be inferred from the charts
- For Selective vs Wave soldering the curves tend to cross at the 10 pin or greater line.
  - If <10 pins then the decision is Selective, Robot or Paste in Hole
  - If >10 pins then the decision is Wave, Robot or Paste in Hole
- Wave soldering is most effective when number of pins to be soldered >100 pins
  - <100 pins the decision is usually between robotic soldering and paste in hole

DECISION MATRIX

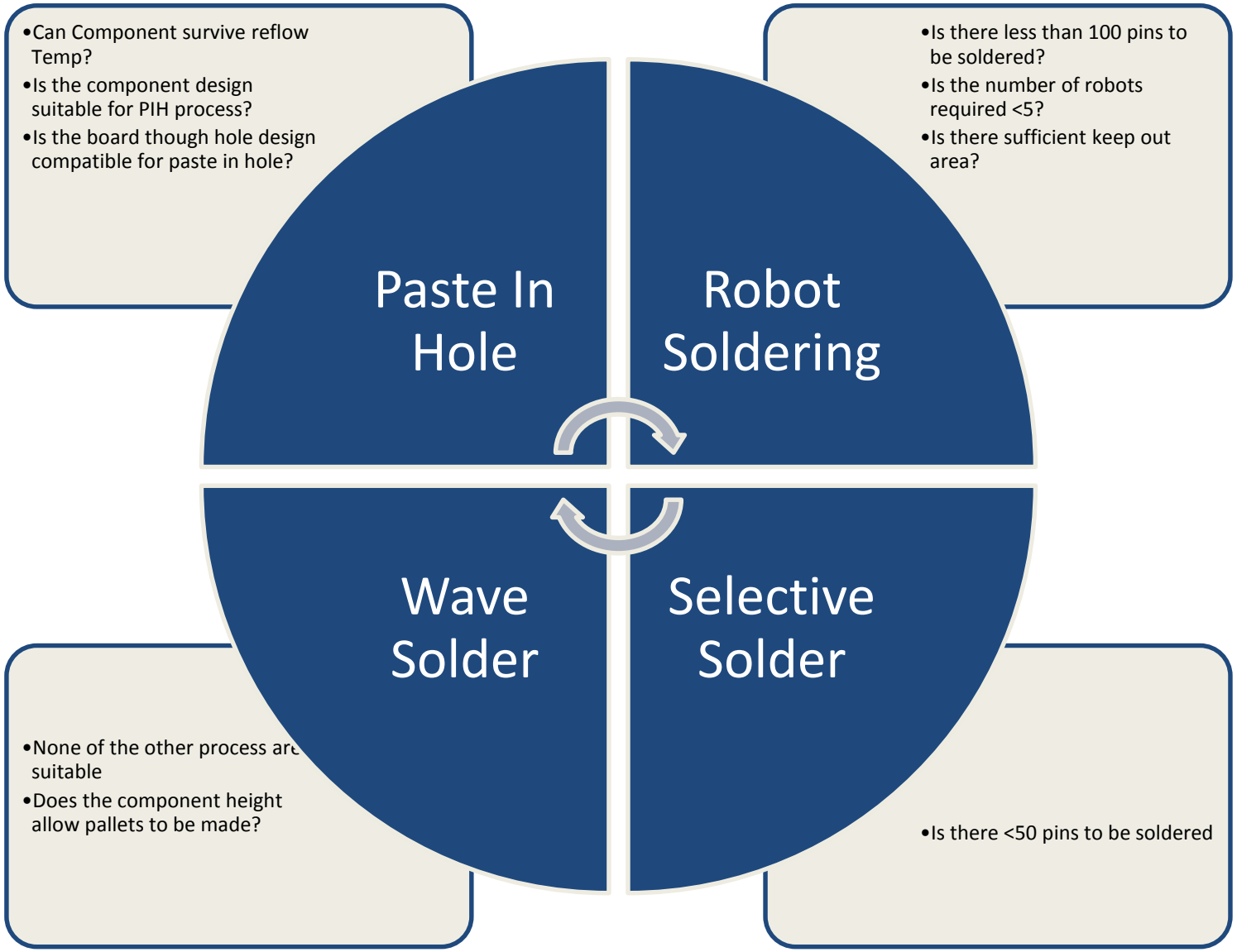
Decision Matrix



Process Specific Questions

Start Here

If an answer is no for any question, then proceed to the next box



Alternative solutions to Wave Soldering

Item	Factors	Method			
		Paste In hole	Robot Soldering	Selective solder	Wave Solder
1	Component can survive reflow Temperature	√	√	√	√
2	Component can't survive reflow temperature	x	√	√	√
3	The component design suitable for PIH process	√	√	√	√
4	The component design isn't suitable for PIH process	x	√	√	√
5	The board though hole design is compatible for paste in hole	√	√	√	√
6	The board though hole design isn't compatible for paste in hole	x	√	√	√
7	The pins of component need to be soldered <50	√	√	√	√
8	The pins of component need to be soldered <100	√	√	√	√
9	The pins of component need to be soldered ≥100, PTH comp can be P&P	√	x	x	√
10	The pins of component need to be soldered ≥100,but PTH comp can't be P&P,need manual insertion	x	x	x	√
11	The robot quantity require more than 5 set	N/A	X	√	√
12	there is sufficient keep out area	N/A	√	√	√
13	there isn't sufficient keep out area	N/A	x	x	√
14	The bottom side SMD component's height < 8mm	√	√	√	√
15	The bottom side SMD component's height ≥ 8mm	√	√	√	x
16	Double side with PTH component (For Bot side PTH component)	x	√	√	x
17	PCB thickness ≥3mm	x	x	√	√

Note: Highlight with green is the priority

CASE STUDIES ON DECISION MATRIX

Case Study 1

- Name: LED Board
- # PTH Pins: 32
- # of PTH Components: 2
- Board x/y: 225 x 83 mm
- Thickness: 1.57 mm
- Annual Volume: 24000

Category	Assumption	Wave	Selective	Paste in Hole	Robot
General Assumption	#Scenarios Prepared: 4				
	Forecast(Annual Volume)	24,000	24,000	24,000	24,000
	DL Hourly Rate(USD)	3.52 USD/Hour	3.52 USD/Hour	3.52 USD/Hour	3.52 USD/Hour
	Working days per month	23.8 Days	23.8 Days	23.8 Days	23.8 Days
	Shifts per day	3 Shift	3 Shift	3 Shift	3 Shift
	Working hours per shift	8 Hours	8 Hours	8 Hours	8 Hours
	UPH Demand	4	4	4	4
	PCBA Space Required (sqm)/Line				
	<Add more assumption here>				
PCBA Assumption	#PCBA Qty: 1				
	PCBA_1	Sample	Sample	Sample	Sample
	PCB Thickness	1.6	1.6	1.6	1.6
	PTH solder pins QTY	32	32	32	32
	Total # PTH Components	2	2	2	2
	Equipment Cost ($) Overall equipment cost each	$300,000.00	$250,000.00		$60,000.00
	Solder Pot capacity (kg)	800	15		
	Cost of Fixtures for Wave, Selective and Robot	$250.00	$500.00		$150.00
	Number of Fixtures Required (Estimate)	5	1		5
	Cost of nozzles required for Paste in Hole Placement			$100.00	
	Number of new nozzles required for placement			1	
	<Add more assumption here>				

Case Study 1

- According to what if analysis either Robot Soldering or Paste in Hole would be lowest cost options
- Component is not able to survive reflow temperature so robot soldering is the preferred solution
- Would need 1 robot station to do the quantity required

Manufacturing Scenarios	Wave Solder	Selective	Robot	Paste in Hole
Annual Volume	24,000	24,000	24,000	24,000
PCBA UPH_Board1	324	102	33	270
Assy Cycle Time / unit (sec)	10.00	32.00	100.00	12.00
#PCBA Lines:	1	1	1	1
$/ Unit	$ 2.64	$ 2.64	$ 2.64	$ 2.64
DL SMT / Shift / Line	1	1	1	1
Total DL (Normal Shift)	3	3	3	3
Total DL (PCBA + FATP)	3	3	3	3
Total CAPEX Generic Equipment	$ 0.030	$ 0.072	$ 0.053	$ 0.020
Equipment Depreciation Generic Equipment (PTH Soldering)	$ 0.030	$ 0.072	$ 0.053	$ 0.020
Total NRE Unique Fixture	$ 0.052	$ 0.021	$ -	$ 0.004
NRE Unique Fixture (Wave, Selective, Robot)	$ 0.052	$ 0.021	$ -	$ -
NRE Unique Fixture (Nozzles for PiH Placement)	$ -	$ -	$ -	$ 0.004
Total Investment (CAPEX+NRE)	$ 0.082	$ 0.093	$ 0.053	$ 0.024
Total DL$ / unit	$ 2.640	$ 2.640	$ 2.640	$ 2.640
EDM $ / unit	$ 0.120	$ 0.174	$ 0.023	$ 0.054
Other Asset Holding (Soldering Materials in Solder Pot)	$ 31,200.00	$ 585.00	$ -	$ -
Total Cost of Process	$ 2.84	$ 2.91	$ 2.72	$ 2.72

Case Study 2

- Name: GDL Board
- # PTH Pins: 42
- # PTH Components: 6
- Board x/y: 127 x 127 mm
- Thickness: 1.50 mm
- Annual Volume: 204,000

Category	Assumption	Wave	Selective	Paste in Hole	Robot
General Assumption	#Scenarios Prepared: 4				
	Forecast(Annual Volume)	204,000	204,000	204,000	204,000
	DL Hourly Rate(USD)	3.52 USD/Hour	3.52 USD/Hour	3.52 USD/Hour	3.52 USD/Hour
	Working days per month	23.8 Days	23.8 Days	23.8 Days	23.8 Days
	Shifts per day	3 Shift	3 Shift	3 Shift	3 Shift
	Working hours per shift	8 Hours	8 Hours	8 Hours	8 Hours
	UPH Demand	30	30	30	30
	PCBA Space Required (sqm)/Line				
	<Add more assumption here>				
PCBA Assumption	#PCBA Qty: 1				
	PCBA_1	Sample	Sample	Sample	Sample
	PCB Thickness	1.5	1.5	1.5	1.5
	PTH solder pins QTY	42	42	42	42
	Total # PTH Components	6	6	6	6
	Equipment Cost ($) Overall equipment cost each	$300,000.00	$250,000.00		$60,000.00
	Solder Pot capacity (kg)	800	15		
	Cost of Fixtures for Wave, Selective and Robot	$250.00	$500.00		$150.00
	Number of Fixtures Required (Estimate)	5	1		0
	Cost of nozzles required for Paste in Hole Placement			$100.00	
	Number of new nozzles required for placement			1	
	<Add more assumption here>				

Case Study 2

- According to what if analysis either Robot Soldering or Paste in Hole would be lowest cost options
- Component is not able to survive reflow temperature so robot soldering is the preferred solution
- Would need 2 robot stations to do the quantity required
- Assumes auto loading for robot station to minimize direct labor cost

Manufacturing Scenarios	Wave Solder	Selective	Robot	Paste in Hole
Annual Volume	204,000	204,000	204,000	204,000
PCBA UPH_Board1	324	78	50	90
Assy Cycle Time / unit (sec)	10.00	42.00	131.25	36.00
#PCBA Lines:	1	1	2	1
$/ Unit	$ 0.35	$ 0.35	$ 0.35	$ 0.35
DL SMT / Shift / Line	1	1	1	1
Total DL (Normal Shift)	3	3	3	3
Total DL (PCBA + FATP)	3	3	3	3
Total CAPEX Generic Equipment	$ 0.030	$ 0.094	$ 0.070	$ 0.060
Equipment Depreciation Generic Equipment (PTH Soldering)	$ 0.030	$ 0.094	$ 0.070	$ 0.060
Total NRE Unique Fixture	$ 0.006	$ 0.002	$ -	$ 0.000
NRE Unique Fixture (Wave, Selective, Robot)	$ 0.006	$ 0.002	$ -	$ -
NRE Unique Fixture (Nozzles for PiH Placement)	$ -	$ -	$ -	$ 0.000
Total Investment (CAPEX+NRE)	$ 0.036	$ 0.096	$ 0.070	$ 0.060
Total DL$ / unit	$ 0.352	$ 0.352	$ 0.352	$ 0.352
EDM $ / unit	$ 0.123	$ 0.227	$ 0.028	$ 0.067
Other_Asset Holding (Soldering Materials in Solder Pot)	$ 31,200.00	$ 585.00	$ -	$ -
Total Cost of Process	$ 0.51	$ 0.68	$ 0.45	$ 0.48

Case Study 3

- Name: Penang Board
- # PTH Pins: 228
- # PTH Components: 20
- Board x/y: 265x175mm
- Thickness: 1.545mm
- Annual Volume: 42792

Category	Assumption	Wave	Selective	Paste in Hole	Robot
General Assumption	#Scenarios Prepared: 4				
	Forecast(Annual Volume)	42,972	42,972	42,972	42,972
	DL Hourly Rate(USD)	3.52 USD/Hour	3.52 USD/Hour	3.52 USD/Hour	3.52 USD/Hour
	Working days per month	23.8 Days	23.8 Days	23.8 Days	23.8 Days
	Shifts per day	3 Shift	3 Shift	3 Shift	3 Shift
	Working hours per shift	8 Hours	8 Hours	8 Hours	8 Hours
	UPH Demand	7	7	7	7
	PCBA Space Required (sqm)/Line				
	<Add more assumption here>				
PCBA Assumption	#PCBA Qty: 1				
	PCBA_1	Sample	Sample	Sample	Sample
	PCB Thickness	1.545	1.545	1.545	1.545
	PTH solder pins QTY	228	228	228	228
	Total # PTH Components	20	20	20	20
	Equipment Cost ($) Overall equipment cost each	$300,000.00	$250,000.00		$60,000.00
	Solder Pot capacity (kg)	800	15		
	Cost of Fixtures for Wave, Selective and Robot	$250.00	$500.00		$150.00
	Number of Fixtures Required (Estimate)	5	1		0
	Cost of nozzles required for Paste in Hole Placement			$100.00	
	Number of new nozzles required for placement			1	
	<Add more assumption here>				

Case Study 3

- According to what if analysis either Wave soldering is the low cost solution

Manufacturing Scenarios	Wave Solder	Selective	Robot	Paste in Hole
Annual Volume	42,972	42,972	42,972	42,972
PCBA UPH_Board1	324	15	10	27
Assy Cycle Time / unit (sec)	10.00	228.00	712.50	120.00
#PCBA Lines:	1	1	2	1
$/ Unit	$ 1.51	$ 1.51	$ 1.51	$ 1.51
DL SMT / Shift / Line	1	1	1	1
Total DL (Normal Shift)	3	3	3	3
Total DL (PCBA + FATP)	3	3	3	3
Total CAPEX Generic Equipment	$ 0.030	$ 0.487	$ 0.350	$ 0.200
Equipment Depreciation Generic Equipment (PTH Soldering)	$ 0.030	$ 0.487	$ 0.350	$ 0.200
Total NRE Unique Fixture	$ 0.029	$ 0.012	$ -	$ 0.002
NRE Unique Fixture (Wave, Selective, Robot)	$ 0.029	$ 0.012	$ -	$ -
NRE Unique Fixture (Nozzles for PiH Placement)	$ -	$ -	$ -	$ 0.002
Total Investment (CAPEX+NRE)	$ 0.059	$ 0.499	$ 0.350	$ 0.202
Total DL$ / unit	$ 1.509	$ 1.509	$ 1.509	$ 1.509
EDM $ / unit	$ 0.209	$ 1.187	$ 0.158	$ 0.374
Other Asset Holding (Soldering Materials in Solder Pot)	$ 31,200.00	$ 585.00	$ -	$ -
Total Cost of Process	$ 1.78	$ 3.20	$ 2.02	$ 2.08

Case Study 4

- Name: Penang Board
- # PTH Pins: 24
- # PTH Components: 3
- Board x/y: 265x175mm
- Thickness: 1.0mm
- Annual Volume: 481,536

Category	Assumption	Wave	Selective	Paste in Hole	Robot
General Assumption	#Scenarios Prepared: 4				
	Forecast(Annual Volume)	481,536	481,536	481,536	481,536
	DL Hourly Rate(USD)	3.52 USD/Hour	3.52 USD/Hour	3.52 USD/Hour	3.52 USD/Hour
	Working days per month	23.8 Days	23.8 Days	23.8 Days	23.8 Days
	Shifts per day	3 Shift	3 Shift	3 Shift	3 Shift
	Working hours per shift	8 Hours	8 Hours	8 Hours	8 Hours
	UPH Demand	71	71	71	71
	PCBA Space Required (sqm)/Line				
	<Add more assumption here>				
PCBA Assumption	#PCBA Qty: 1				
	PCBA_1	Sample	Sample	Sample	Sample
	PCB Thickness	1	1	1	1
	PTH solder pins QTY	24	24	24	24
	Total # PTH Components	3	3	3	3
	Equipment Cost ($) Overall equipment cost each	$300,000.00	$250,000.00		$60,000.00
	Solder Pot capacity (kg)	800	15		
	Cost of Fixtures for Wave, Selective and Robot	$250.00	$500.00		$150.00
	Number of Fixtures Required (Estimate)	5	1		0
	Cost of nozzles required for Paste in Hole Placement			$100.00	
	Number of new nozzles required for placement			1	
	<Add more assumption here>				

Case #4

- According to what if analysis either Robot Soldering or Paste in Hole would be lowest cost options
- Component is not able to survive reflow temperature so robot soldering is the preferred solution
- Would need 2 robot stations to do the quantity required
- Assumes auto loading for robot station to minimize direct labor cost

Manufacturing Scenarios	Wave Solder	Selective	Robot	Paste in Hole
Annual Volume	481,536	481,536	481,536	481,536
PCBA UPH_Board1	324	135	87	180
Assy Cycle Time / unit (sec)	10.00	24.00	75.00	18.00
#PCBA Lines:	1	1	2	1
$/ Unit	$ 0.15	$ 0.15	$ 0.15	$ 0.15
DL SMT / Shift / Line	1	1	1	1
Total DL (Normal Shift)	3	3	3	3
Total DL (PCBA + FATP)	3	3	3	3
Total CAPEX Generic Equipment	$ 0.030	$ 0.054	$ 0.040	$ 0.030
Equipment Depreciation Generic Equipment (PTH Soldering)	$ 0.030	$ 0.054	$ 0.040	$ 0.030
Total NRE Unique Fixture	$ 0.003	$ 0.001	$ -	$ 0.000
NRE Unique Fixture (Wave, Selective, Robot)	$ 0.003	$ 0.001	$ -	$ -
NRE Unique Fixture (Nozzles for PiH Placement)	$ -	$ -	$ -	$ 0.000
Total Investment (CAPEX+NRE)	$ 0.032	$ 0.055	$ 0.040	$ 0.030
Total DL$ / unit	$ 0.149	$ 0.149	$ 0.149	$ 0.149
EDM $ / unit	$ 0.112	$ 0.127	$ 0.011	$ 0.025
Other Asset Holding (Soldering Materials in Solder Pot)	$ 31,200.00	$ 585.00	$ -	$ -
Total Cost of Process	$ 0.29	$ 0.33	$ 0.20	$ 0.20

References

- 1. C. Hunt and D. De Maio, A Test Methodology for Copper Dissolution, IPC APEX conf. , 2009.
- 2. P. Biocca, Lead-free Wave Soldering – Some insight on how to develop a process that works, Kester, 2005.