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ENHANCING PROCESS EFFICIENCY AND COST SAVING IN BAG-AND-SEAL PROCESS USING A DMAIC APPROACH: A CASE STUDY IN SEMICONDUCTOR MANUFACTURING FACTORY

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ABSTRACT

The Bag and Seal (BNS) process protects moisture-sensitive substrates before chip attach. In the current method, substrates are moved from liquid crystal polymer (LCP) tray to thermal form tray (TFT) for sealing and then returned to LCP trays, which requires ACL tools and leads to TFT deformation, long cycle time, and scrap cost. This study would examine whether BNS could be done directly on LCP trays to remove these transfer steps. Using a DMAIC approach with design of experiment (DOE) testing, inventory review, quality checks, and routing updates, LCP trays were shown to be stable with no out-of-pocket events. The new process would reduce handling time from 45 minutes to 5 minutes per lot, eliminates USD 42,142 in yearly TFT scrap, and removes ACL tool usage. The updated routes improve responsiveness and lower operational workload while still meeting moisture exposure time (MET0) limits and protecting substrate quality. Overall, LCP tray BNS is a simpler, cost-saving, and scalable method for substrate preparation.

Keywords: DMAIC, LCP tray, Semiconductor manufacturing optimization, Cost saving, Process efficiency

1 INTRODUCTION

Moisture-sensitive substrates must remain within a seven-day MET0 limit once their original moisture barrier bag (MBB) is opened. Substrates act as the package foundation in processor manufacturing, providing mechanical support and housing the electrical routing that connects the die to the board. Because of this role, any moisture absorption can lead to warpage, delamination, or defects during downstream thermal steps such as die attach or reflow. Events such as demand drops, quality holds, or factory cold-downs can extend exposure time and increase the risk of exceeding limit. To control this risk, the factory uses a BNS process where substrates are transferred from LCP trays to TFT, sealed, and later unsealed when production resumes. Although effective at moisture protection, the current BNS flow creates several operational issues. TFT trays deform after sealing and must be scrapped, costing about USD 42,142 per year. The tray-to-tray and cart-to-cart transfers require ACL tools, consuming 0.14 tool capacity. Since ACL is shared across many modules, this added load can slow production especially when BNS demand reaches 421,409 substrates per

quarter (about 2,342 per shift). Each BNS lot also requires roughly 45 minutes of handling, reducing factory responsiveness during low MET0 or resume situations. These challenges highlight the need to simplify the process. A possible solution is performing BNS directly on LCP trays, removing TFT and reducing ACL usage. However, this option has not been formally evaluated for feasibility or operational impact.

This study uses a DMAIC approach to assess whether LCP trays can support BNS without affecting substrate integrity, and to quantify improvements in cycle time, tool loading, and cost.

2 LITERATURE REVIEW

2.1 Define – Measure – Analyze – Improve – Control (DMAIC) methodology

The DMAIC framework is widely recognized as a structured method for improving manufacturing processes by identifying root causes, reducing variation, and eliminating unnecessary steps (Kusumawardani, 2025, George, 2003). Montgomery (2009) emphasizes its suitability for operations in which performance can be quantified through cycle time, defect rate, or equipment utilization metrics that also characterize substrate-handling processes in semiconductor backend factories. Pande and Holpp (2002) further note that DMAIC is effective when both efficiency and quality need to be improved simultaneously. These characteristics align closely with the challenges of the current BNS process, where tray deformation, ACL tool dependency, long handling time, and recurring scrap cost reflect measurable performance gaps. Recent studies show that DMAIC has been successfully applied to bottleneck reduction and tool-capacity optimization in semiconductor operations (Park & Lee, 2019), making it suitable for evaluating whether eliminating TFT and tray transferring steps can improve BNS workflow efficiency. Therefore, DMAIC provides an appropriate analytical structure for assessing the technical feasibility and operational benefits of transitioning to an LCP tray BNS process.

2.2 Moisture Sensitivity and MET Compliance

Moisture-sensitive semiconductor substrates must follow JEDEC handling standards. J-STD-033 defines the allowed Moisture Exposure Time (MET) after an MBB is opened and provides guidance on proper handling (JEDEC, 2018). J-STD-020 explains how moisture can lead to failures such as delamination, warpage, and popcorn during thermal processes (JEDEC, 2017). Studies have shown that going beyond MET limits greatly increases the chance of mechanical and reliability issues in advanced substrate packages (Kim et al., 2016). For this reason, factories often use vacuum sealing or dry storage to protect materials.

3 CASE STUDY

This study was conducted in the same semiconductor company, which runs high-volume production for processor and mobile platform products. In this environment, BNS process is used whenever substrates remain on hold for an extended period or when the factory enters cold-down or resume conditions. Factory records show that BNS demand can be high, reaching 421,409 substrates in a quarter. The current BNS flow requires tray and cart transfers using ACL tools. These tools are shared with many other production modules, so using them for BNS can slow down production during busy periods. Engineering reports also show that the TFT used in BNS deforms after sealing and cannot be reused, which creates material waste. Figure 1 shows the current route of BNS process, including the manual bagging step, tray transfer steps, sealing, MET0 pause, and unseal flow. A review of this routing indicates that most of the extra time and tool load comes from the tray-transfer steps, not from the sealing itself.

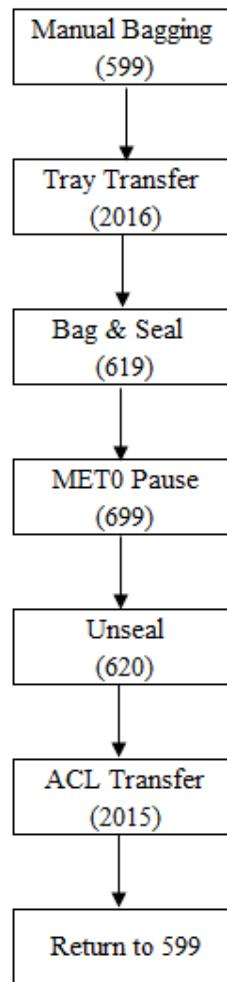


Figure 1: Current Bag-and-Seal routing defined in manufacturing executive system

Based on these observations, this study focuses on evaluating whether BNS can be done directly on LCP trays to remove the transfer steps. The DMAIC approach was chosen to examine the current flow, test feasibility, and measure the impact on cycle time, cost, and tool usage.

3.1 Applied DMAIC

3.1.1 Define Phase

In DMAIC, the Define phase clarifies the problem, scope, goals, and expected benefits so the improvement effort remains focused and aligned with production requirements.

The current BNS process is used to pause moisture exposure for substrates approaching their MET0 limits. Figure 2 shows the existing flow, where substrates must be transferred from LCP trays on JLP carts to TFT trays on Ergo carts at station 2016 before vacuum sealing at station 619. After MET0 pause (699), substrates are unsealed at station 620 and transferred back to LCP trays at station 2015 before returning to normal production. Although this flow prevents moisture over-exposure, it creates several operational issues. TFTs deform during sealing and cannot be reused, resulting in approximately USD 42,142 annual scrap. Mandatory tray-to-tray and cart-to-cart conversions require ACL tool support, consuming about 0.14 tool capacity per working shift and extending handling time up to 45 minutes per lot. Since ACL tools are shared across multiple production modules, this additional load can slow overall factory output, especially when BNS demand reaches 421,409 substrates per quarter (about 2,342 per shift). These constraints reduce responsiveness during low MET0 situations or when the factory resumes after downtime.

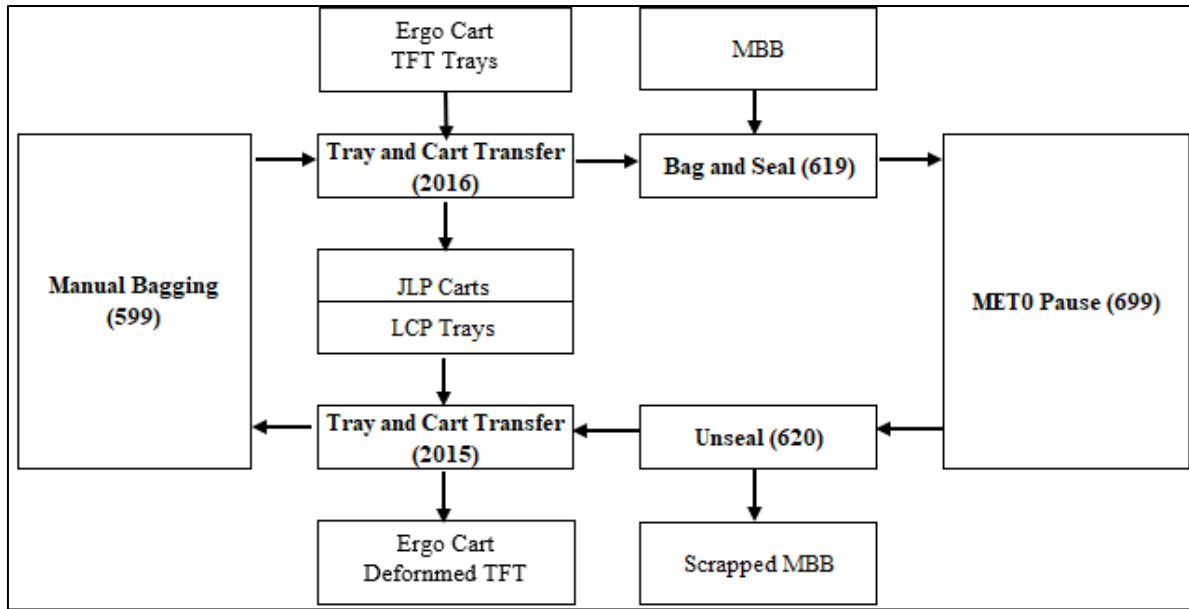


Figure 2: Current Bag-and-Seal (BNS) Process Flow

Table 1 summarizes the main issues and their impact.

Table 1: Summary of Issues and Operational Impact

Issue	Impact
TFT tray deformation	USD 42,142 annual scrap
ACL tool load	0.14 tool capacity consumed
Handling cycle time	~45 min/lot
Low responsiveness	Delay when MET0 remaining is low

To evaluate whether the BNS flow can be simplified, this study investigates performing BNS directly on LCP trays to eliminate TFT and reduce ACL tool dependency. The critical to quality (CTQ) requirements guiding this assessment are listed in Table 2.

Table 2: Critical-to-Quality (CTQ) Requirements

CTQ Item	Requirement
MET0 compliance	No over-exposure
Substrate integrity	No warpage, crack, contamination
Cycle time	Reduce handling time
Cost	Reduce tray scrap cost
Tool dependency	Reduce ACL usage

3.2 Measure Phase

The Measure phase establishes the baseline performance of the current Bag-and-Seal (BNS) process so that later improvements can be evaluated objectively. Data were collected from factory cost reports, ACL utilization logs, time studies at stations 2016 and 2015, and historical BNS volume records.

First, TFT deformation was verified through visual checks and post BNS flatness inspection. All TFTs used in BNS lose rigidity after vacuum sealing and cannot be reused. Figure 3 shows the TFT deformation post BNS.



Figure 3: TFT deformation after BNS sealing, resulting in non-reusable trays

This results in 100% scrap and an annual cost of approximately USD 42,142. Second, measurement of tool usage showed that the tray-to-tray and cart-to-cart transfers at stations 2016 and 2015 require ACL tool support. With a quarterly BNS volume of about 421,409 substrates, these transfers consume roughly 0.14 of ACL tool. Because ACL tools are shared across multiple modules, this load reduces tool availability for normal production operations. Third, a time study of the handling steps confirmed that each BNS cycle—including tray transfer, cart exchange, and alignment—takes about 45 minutes per lot. This long handling time contributes to slow response when MET0 is low or when the factory needs to restart quickly after downtime. Table 3 summarizes the baseline measurements used for comparison against the proposed LCP Tray BNS process.

Table 3: Baseline Measurements of the Current BNS Process

Metric	Baseline Value	Source
TFT Tray reuse rate	0% (100% scrapped)	Post-BNS inspection
Annual TFT Tray scrap cost	USD 42,142	Factory cost report
ACL tool load	0.14 tool capacity	ACL utilization log
Handling cycle time	~45 minutes/lot	Time study
BNS volume	421,409 units/quarter	Production record

3.3 Analysis Phase

The Analyze phase identifies the main factors causing inefficiencies in the current Bag-and-Seal (BNS) process. Baseline data and observations show that most issues originate from the use of TFT trays and the extra handling steps required to support them.

3.3.1 TFT tray deformation

TFT trays lose flatness after vacuum sealing as shown in Figure 4 and cannot be reused. This leads to a 0% reuse rate and an annual scrap cost of USD 42,142. Tray warpage also creates handling instability after unsealing,



Figure 4: TFT tray stack prepared and tightened before vacuum sealing

Extra handling steps from legacy process design

TFT were originally selected for BNS because they were already used for sealing and shipping finished goods. No evaluation was performed at that time to determine whether LCP trays could also support vacuum sealing. As a result, each BNS lot requires two additional transfers:

LCP → TFT before sealing,

TFT → LCP after unsealing.

These steps extend handling time to approximately 45 minutes per lot.

3.3.2 ACL tool dependency

Both transfer steps require ACL tool support. Using the actual BNS volume of 421,409 substrates per quarter, these transfer activities consume about 0.14 of ACL tools. Because ACL tools are shared across many modules, this added load reduces tool availability and slows substrate preparation when METO is low or when the factory restarts after downtime.

These findings indicate that the main inefficiencies in the current BNS workflow come from the legacy decision to use TFT, which leads to single-use material waste, additional handling, and reliance on a shared ACL tool.

4 WHY ROOT CAUSE ANALYSIS

To further validate the main source of inefficiency, a 5 Why analysis was performed in the Table 4.

Table 4: Five Why Analysis of BNS Process Inefficiency

Why Level	Question	Answer
Why 1	Why is the BNS process slow and costly?	Because substrates must be transferred twice and TFT trays are scrapped after sealing.
Why 2	Why do substrates need to be transferred twice?	Because BNS uses TFT instead of LCP trays.
Why 3	Why is BNS performed on TFT?	Because TFT were historically used for sealing finished goods, so the same approach was applied to substrates.
Why 4	Why was LCP tray capability not considered?	Because no initial evaluation or study was performed to test LCP trays under vacuum sealing.

Why 5	Why was no evaluation performed?	The process was designed based on existing practice rather than capability assessment or DOE.
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4.1 Improve Phase

The Improve phase focuses on evaluating whether the BNS process can be performed directly on LCP trays to eliminate TFT usage, reduce handling steps, and remove ACL tool dependency. A cross-functional team was formed to validate feasibility and operational impact. The team included Media (Tray) Engineering, Tray Inventory Management Team, Quality Engineering, and Manufacturing Systems Engineering (MSE).

4.1.1 Media Engineering DOE (Tray Stability Test)

Media Engineering conducted DOEs to verify substrate stability during typical operator handling on LCP trays when BNS. Four scenarios were tested, covering tilt-and-shake, flip, and Z-axis vibration. These tests simulate manual handling and sudden movement during WIP flow.

Table 5: Summary of LCP Tray Stability DOE

Scenario	SOOP (Out-of-pocket)	Risk Level	Result
Tilt tray 45° to short edge and shake (simulate manual handling or WIP movement and stop suddenly - Hammer DOE)	No	Low	Pass
Tilt tray 45° to long edge and shake (simulate manual handling or WIP movement and stop suddenly - Hammer DOE)	No	Low	Pass
Flip tray and shake (simulate manual handling or WIP movement and stop suddenly - Hammer DOE)	No	Low	Pass
Shake tray on Z-axis (simulate manual handling or WIP movement and stop suddenly - Hammer DOE)	No	Low	Pass

No substrate out-of-pocket (SOOP) events were observed. This confirms that LCP trays maintain substrate retention under handling conditions required for BNS. Figure 5 shows LCP tray stability during tilt-and-shake to long edge DOE.

4.1.2 Tray Inventory Management Team check

Tray Management reviewed BNS demand and validated that LCP tray inventory was sufficient for quarterly BNS volume, removing the need for TFT. No inventory shortage risks were identified.

4.1.3 Quality Engineering Assessment

Quality reviewed upstream and downstream processes to ensure that using LCP trays in BNS does not create contamination or water retention risk. Only flow configurations containing de-flux processes require TFT, since water droplets may collect in LCP tray slots. For normal flows, LCP trays were approved.



Figure 5: LCP Tray stability during tilt-and-shake DOE.

4.1.4 Routing redesign using CTT tools

Since LCP trays no longer require tray transfer, the ACL steps at stations 2016 and 2015 can be removed. MSE created a simplified future-state routing using CTT tools at station 2160 and 2161 for cart transfer as shown on Figure 6.

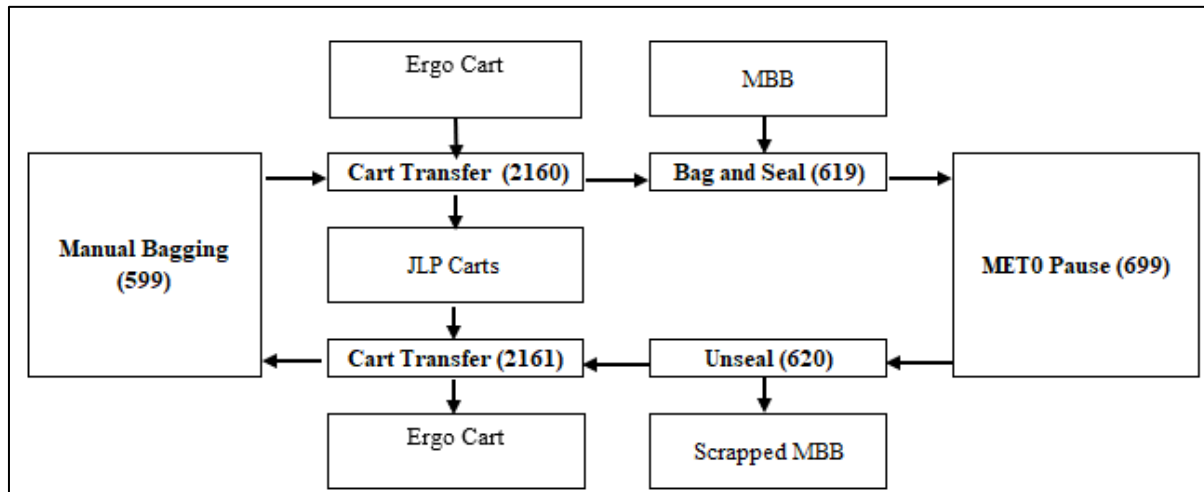


Figure 6: Future State LCP Tray BNS process

4.1.5 Process Flow Comparison as in Table 6

Table 6: Comparison of the current-state TFT Tray BNS process and the future-state LCP Tray BNS process.

Category	Current-State (TFT Tray BNS)	Future-State (LCP Tray BNS)
Tray type	TFT Trays	LCP Trays (reusable)
Tray condition after BNS	Deformed	No deformation observed
Tray scrap cost	USD 42,142 / year	0 USD (no scrap)
Handling steps	Tray transfer + cart transfer	Cart transfer only
Tray transfer tool	ACL tool	Eliminated
Cart transfer tool	ACL tool	CTT tool
Tool capacity usage	0.14 ACL tool consumed	0.02 CTT tool consumed
Cycle time per lot	~45 mins	~5 mins (cart-only movement)
Process routing	599 → 2016 → 619 → 699 → 620 → 2015 → 599	599 → 2160 → 619 → 699 → 620 → 2161 → 599
Compatibility	All substrates	All except de-flux families
Responsiveness (resume / low MET0)	Slow due to 45 mins cycle time	Fast due to 5 mins cycle time
Overall performance	High cost, high cycle time, tool load	Low cost, fast cycle time, no ACL load

These results confirm that performing BNS on LCP trays provides a simpler, faster, and more cost-effective workflow.

4.2 Control Phase

To ensure long-term stability of the new LCP Tray BNS process, several control mechanisms were implemented across engineering, operations, and manufacturing systems.

4.2.1 Standard Work and Routing Control

The updated routing (599 → 2160 → 619 → 699 → 620 → 2161 → 599) was locked in the Assembly and Test Manufacturing System where control all the routes, product attributes and allow production lot only move as the set up

hear, to prevent accident use of legacy ACL stations 2016 and 2015. New standard for Seal and Unseal operations were revised to reflect cart-only handling in the SPEC of factory to ensure to have same practice.

4.2.2 Operator Training and Certification

Operators at stations 599, 619, 620, 2160, and 2161 were trained on the new process sequence and CTT cart-transfer requirements. Certification logs were updated to ensure only trained operators run the revised flow.

4.2.3 Quality Safeguards for Deflux Flows

A control flag was added in MES to identify substrate families containing deflux processes. These families are automatically routed to the legacy TFT tray BNS flow to avoid water accumulation risks.

4.2.4 MET0 Remaining and Cycle-Time Tracking

MET0 exposure time continues to be monitored automatically. Cycle-time tracking at stations 2160 and 2161 is used to confirm that handling time remains within the expected 5-minute target. Deviations trigger corrective action.

4.2.5 Periodic Performance Review

A quarterly review with Manufacturing, Quality, and Tray Management teams is conducted to evaluate:

- tray usage and condition
- tool load trends
- utility consumption
- any abnormal BNS events or SOOP incidents
- No SOOP events have been observed after implementation.

5 CONCLUSION AND FUTURE WORK

This study showed that performing Bag and Seal directly on LCP trays is a practical and more efficient alternative to the traditional TFT Tray BNS process. DOE testing, routing updates, and cross-functional reviews confirmed that LCP trays maintain substrate integrity while removing the need for ACL tray-transfer steps. The new process eliminates USD 42,142 in annual tray scrap cost, reduces handling time from 45 minutes to about 5 minutes per lot, and removes 0.14 ACL tool capacity usage. It also lowers utility consumption and operational dependency. These results demonstrate that the LCP Tray BNS method is technically reliable, operationally scalable, and improves responsiveness during low-MET0 situations or factory resume events. Overall, the future-state process provides a more stable, lower-cost, and higher-throughput solution for substrate preservation.

Although the LCP Tray BNS method brings clear improvements, additional work can further strengthen the process. A long-term tray life study should be performed to understand LCP tray durability over extended cycling and to develop a replacement guideline. Automation of the CTT cart transfer may also help reduce operator variation and improve repeatability. Adding inline monitoring such as tray cleanliness checks or simple sensor detection could reduce contamination risks for high-density substrates. Finally, future evaluation may determine whether some deflux substrate families can also use LCP Tray BNS if design or cleaning steps are adjusted. These follow-up studies will support wider adoption and continued improvement of the process.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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APPENDIX

No.	Acronym	Meaning
1	BNS	Bag-and-Seal process
2	MET0	Moisture Exposure Time counter (reset when MBB is opened)
3	MBB	Moisture Barrier Bag
4	LCP Tray	Liquid Crystal Polymer tray (rigid, reusable)
5	TFT Tray	Thermoformed tray (soft, single-use)
6	ACL Tool	Automated Cart & Tray Lift tool
7	CTT Tool	Cart Transfer Tool used in new routing
8	DOE	Design of Experiments
9	CTQ	Critical-to-Quality requirement
10	OOP	Out-of-Pocket (substrate leaves pocket)
11	SOP	Standard Operating Procedure
12	SPEC	Internal documentation system for operation procedures
13	MES	Manufacturing Execution System
14	PA	Preventive Action
15	CA	Corrective Action
16	COOLDOWN	Planned factory shutdown period
17	RESUME	Factory restart after cooldown