ACHIEVING OPTIMAL PROCESS EFFICIENCY: AUTOMATED SOLUTIONS FOR PRODUCT SAMPLING AND TOOL STATE CHANGE

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ABSTRACT

There are multiple factors affecting tool utilization - scheduled and unscheduled downtime. While scheduled downtimes are essential steps in maintaining tool to its tiptop performance, unscheduled downtimes are the unforeseen events that can affect the utilization and entails non-value-added activities to personnel.

The paper will tackle these unscheduled downtimes focused on Sputtering tool. Sputtering is the process of depositing thin layer of metal through Physical Vapor Deposition (PVD) into the substrate. It will be discussed how the utilization trends of these tools where affected by the top two down states which are Qualification Down and Target/Shield Replacement Down which both utilizes the SPC (Statistical Process Control). Most of these downtimes are related to monitoring, verification and tool qualifications. These downtimes are part of the verification and qualification systems of Sputtering tools intended to prevent human-related incidents and out-of-control measurements affecting yield. The downside of having these verification systems are the impact on tool up-time, and the introduction of non-value activities to personnel. To mitigate its negative effect, the paper will discuss on different methods to reduce the occurrence of the problem and how these systems were enhanced by introducing an automatic solution for the top two causes of tool downtime: an automated verification for the TSRC thru the use state logging and real-time material life checking; QLDW solutions for Sputter Automatic optical inspection introduces an algorithmic identification of lots based on historical inspection data to prevent false positive detection. Both of these solutions reduce unnecessary tool downtime and non-value-added activities for engineers, technicians and operators.

1. 0 INTRODUCTION

Sputtering process is among the major bumping processes in Clark. In order to gain more on utilization, a study in its overall productivity focusing on downtime trend was performed. The focus of this paper is to improve the utilization and manpower productivity by reducing the downtime which are non-value adding to the operation. Key subject is to remove non-value-added activities by automating the process using algorithm based on the activities being performed.

Based on the 2nd quarter of 2022 top Sputter downtime data, it shows that the top two reasons of downtimes are Qualification Down (QLDW) with the largest impact of 69% and Target/Shield Replacement Down (TSRD) with 22% as shown on the pareto chart of Figure 1.

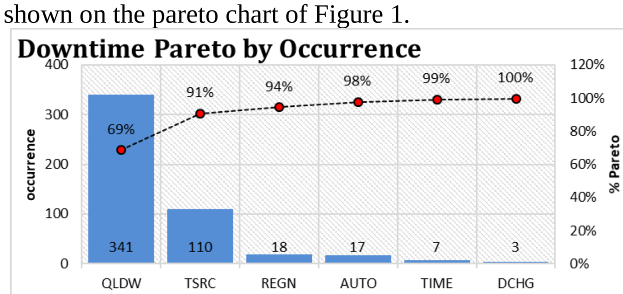

Figure 1. Pareto showing the top contributor of Sputter downtime where QLDW and TSRD top the overall occurrence in 2Q22.

Another view of the effect of down time shows that there is a loss of 13 days for QLDW alone while four days were incurred by TSRC state with a total of 17 days downtime equivalent to 19% of one quarter as shown in Figure 2.

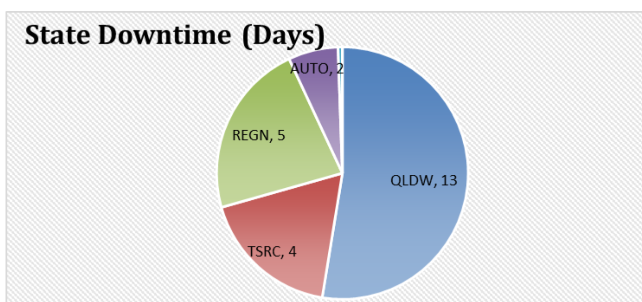

Figure 2. Contribution of downtime (in days) in which QLDW and TSRC still fall in top three of contributors.

The data gathered are coming from performed tool qualification, lot data, tool data and preventive maintenance data that uses the MES (Manufacturing Execution System) that may vary from factory to factory.

1.1 Qualification Down Analysis

Qualification Down or QLDW are tool downtimes coming from tool qualification and inspection which are periodically performed to monitor tool performance. Further analysis of the QLDW shows that the division of downtime are mostly from scheduled film thickness qualifications with an impact of 43%, PM (Preventive Maintenance) contributing to 22%, and AOI (Automatic optical inspection) due to failing particle count covering 32% of the occurrence as shown in Figure 3.

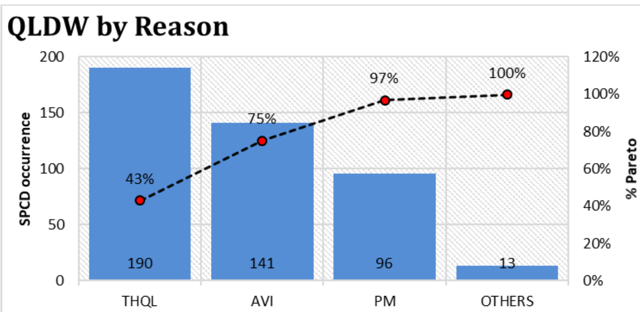

Figure 3. Pareto of QLDW by reason of fails, Top 3: 43% from Thickness Qualification, 32% from AOI and 22% from Scheduled PM.

From the downtime point of view, Figure 4 shows that the highest downtime duration is the AOI, equivalent to 6.8 days followed by the Scheduled Qualification which is only 4.1 days in a quarter.

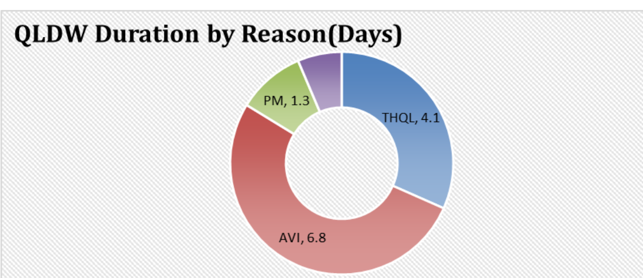

Figure 4. Pie Chart showing the number of days in 2Q22 that the QLDW has consumed. Top 1 AOI, Top 2 Thickness Qualification and Top 3 Preventive Maintenance.

1.2 TSRC Down Analysis

Target and shield are consumables wherein the target is the material being deposited to the substrates, while shield are protective covers preventing the main PVD chamber from accumulating sputtered metal. Target/Shield Replacement Change or TSRC Downtime is part of the verification of sputter equipment every after change of the target/shield material. This verification process was generated to prevent the accidental reset of target/shield life which was caused by human error in the past that cause containment and engineering assessment of the affected materials.

Trigger for TSRC state is every after change of target/shield which is controlled by SPC chart. SPC was setup to detect moving range value based on the difference of life from point to point to check high difference in value from lot to lot. The chart is a lot-based chart and the trigger will reflect after processing 1st lot after the target/shield replacement which entails lot hold and tool down that need verification prior tool release.

2.0 METHODOLOGY

2.1 Materials

- Methodology:
  - Process Elimination based on Pareto and Pie Charts
  - Process Flow
  - Truth Table Logic[2]
- Tools/Systems:
  - MES –Manufacturing Execution System, contains lot information like lot#, technology, quantity.
  - Real-Time Control and Monitoring System Architecture (RTC) – collects data from MES information like lot#, technology and quantity and real time process data. TI Developed software.
- **Type of Control and Monitoring Model**
- **Lot-based models** – start and stop as the lot run on the tool; they are completely reset after processing of lot. Collects process data from start and end of lot processing
- **Persistent models** – start with once the system starts and run indefinitely; they run regardless of whether the tool is processing wafers or not. They are used for continuous monitoring of machine and process signals.

2.2 Procedure

2.2.1 Root Cause Analysis

Sputter Downtime Pareto Trend was used to determine the top root cause to improve Sputter tool utilization based on 2nd quarter of 2022 downtime occurrences. With the top two identified problems which are the QLDW and TSRC, engineering analysis were performed separately to address each cause.

2.2.2.1 QLDW Improvement Identification

A deep dive analysis was performed for QLDW to identify the reasons which are divided into three main reason – Scheduled Thickness Qualification, Sputter AOI particle scan and PM. Two different approach was performed to verify which has the highest impact in tool downtime using the occurrence and duration data.

Table 1 was formulated based in the occurrences and duration of the downtimes, both the Qualification and AOI falls on the top. For occurrence stand point, Qualification shows the highest value, while for the downtime stand point, AOI shows the highest effect with 6.8 days downtime for one quarter.

Table 1. Downtime Duration and Occurrence Table with automated option

Reason	*DT (days)	Occ	Current System	Can apply automated algorithm
QUAL	4.1	190	Daily Monitoring	No
AOI	6.8	141	Shield life-based MES Automation	Yes
PM	1.3	96	Preventive maintenance	No
OTHERS	0.8	14	Other SPC Monitoring Charts	No

**DT – for downtime*

Focusing in automated solutions, a process elimination was also performed if the reason can apply automated algorithm. Qualification and PM SPC are cyclical events that needs to be performed as per tool specification requirements thus automated algorithms cannot be applied. AOI was identified as the only one that can apply automated algorithm due to the process involved in lot selection.

Lots identification for AOI scan based on the current practice involves the shield life of sputter tool which trigger the selection every 15kwhr interval thru MES historical data. The algorithm will then place the lots in the AOI inspection operation if the condition was met.

With the current algorithm of Sputter AOI, current selection of lots are randomized and the possibility of multiple lots going to AOI scan due to the similar chamber process setup. Consumption of shields are also dependent on substrates processed thus high-volume days which may increase the frequency of lot selection. To improve the process of Sputter AOI, lot hold trend analysis was also performed which shows that the top hold contributor for Sputter process is the failing particle count scans due to false rejects as shown in Figure 5.

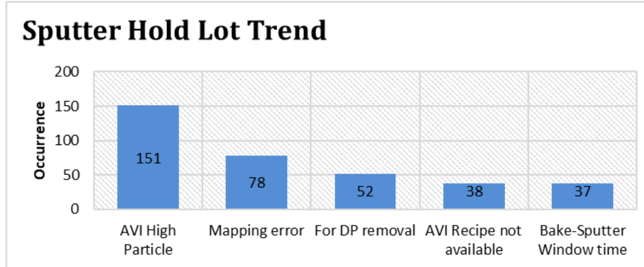

Figure 5. Hold lots trend for Sputter Process shows highest hold is due to Sputter AOI scan.

Verification of these lots with failing particle count shows that 69% of the devices are with layers prior sputter as shown in Table 2. The reason behind the false rejects is due to high GSV variation of the initial layer of the wafer prior sputter process as shown in Figure 6.

Table 2. Number of False Rejects per Technology versus applied layer

Technology	W/o Layer prior Sputter	With Layer prior Sputter
TECH1	2	0
TECH2	5	0
TECH3	2	10
TECH4	0	12
TECH5	0	5

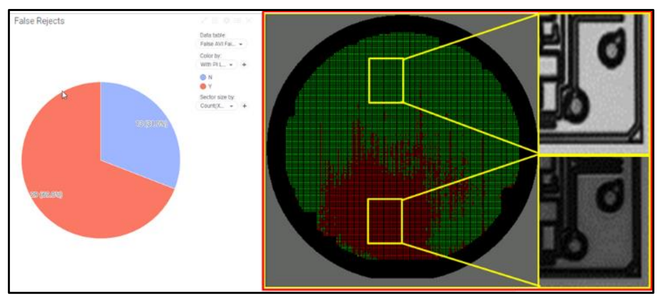

Figure 6. Pie chart showing false rejects with and w/o layer prior sputter thin film. 69% with initial bump layer and 31% w/o initial bump layer.

With all factors identified, Table 3 was formulated which considers bump technology to be sampled at AOI applying the conditions below,

Condition for sampling AOI:

1. Is the Sputter thin film 1st pass process?
2. Is the Device having previous bump layer beneath sputter thin film?
3. Item#1 precedes item#2 condition.
4. Does the last lot identified has elapsed 15 hours?

Table 3. Conditions for Sampling AOI

Technology	Sputter Pass	1st Layer at Sputter Log point	W/ Previous Bump Layer	Identified for AOI
TECH1	1st Pass	TRUE	TRUE	TRUE
	2nd Pass	FALSE	TRUE	FALSE
TECH3	1st Pass	TRUE	FALSE	TRUE
	2nd Pass	FALSE	TRUE	FALSE
TECH4	1st Pass	TRUE	FALSE	TRUE
TECH5	1st Pass	TRUE	FALSE	TRUE
TECH6	1st Pass	TRUE	TRUE	TRUE
	2nd Pass	FALSE	FALSE	FALSE

With this conditions created, a process flow using RTC and MES integration was generated as shown in Figure 7. RTC models consists of three models that serves as lot information checker, timer and MES data uploader.

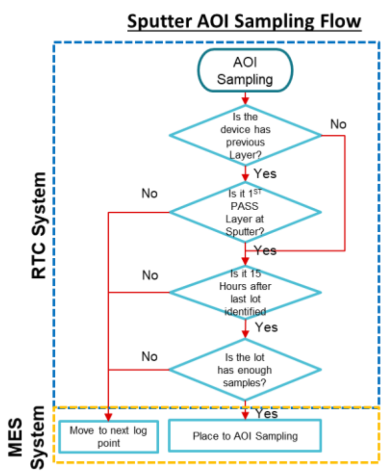

Figure 7. Process flow used for the algorithm used by RTC and MES.

The first model is the lot information checker, set-up as a lot-based model, this model will function as the factor identifier. It will recognize the device technology and layer based on its current log point if lot is for AOI scan. It will forward lot information like lot number and the result of selection algorithm based on current layer and technology. This information will be sent to the timer model.

The second model is the timer model, set-up as a persistent model, that uses lot information sent by the first model. This model resides on the tool RTC and act as timer for the daily qualification frequency for particle count. If the timer reached its limit which is set to 15 hours, it will then set the lot for sampling AOI scan and pass the information to the third RTC model.

The last and third RTC model, MES data uploader, a lot-based model which upload data feeding it to MES which reflect to the lot MES historical data. The uploaded data from lot history will then be used by the MES auto-logout algorithm.

The Auto-logout function of MES allows the lot to move out of the Sputter AOI log point if the condition is met and stays on the AOI operation if the condition is not met. MES sampling data parameter was used and will be populated from the lot data. The algorithm of auto-logout if the value is "Y" will remain to Sputter AOI process for scanning while if the value is either blank or "N" it will auto-logout from the Sputter AOI process to the next process. The process of auto-logout was made thru MES automation script.

2.2.1.2 TSRC Improvement Identification

TSRC down is cyclical activity every after target/shield change in which the 1st lot will be held and verified by process engineer if the lot was processed with target/shield life was correctly reset after material change, this scenario happens every after target/shield change. The sputter equipment is also placed to down state by SPC Chart setup on MES that prompts the equipment technicians/engineers to verify the actual value of target/shield life and the historical event of the tool if there has been a true change of material.

With these conditions, an algorithm can be formed by using MES and RTC systems integration. A process flow was generated to meet the condition of TSRC activities as shown in Figure 8.

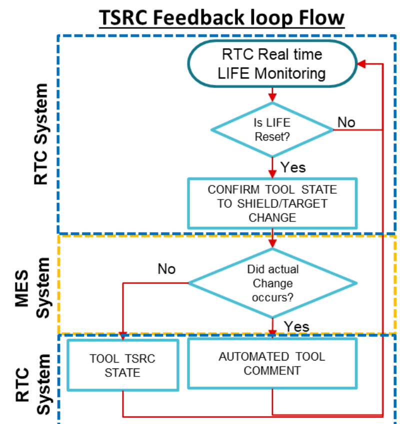

Figure 8. Feedback loop using RTC and MES systems integration for automated Target/shield Change verification.

RTC setup for Sputter is by Mainframe and by chambers as shown in Figure 9, for this process flow the communication with the mainframe and process chambers is needed as part of the feedback loop.

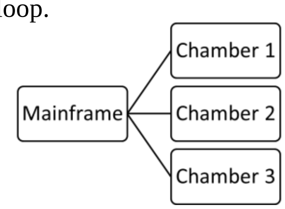

Figure 9. Shows a sample of Sputter hierarchy of Mainframe and Chambers.

There are conditions that are to be fulfilled in the auto-verification of TSRC state to trigger. Table 4 Logic Truth[2] table shows how RTC will function based on Inputs of Mainframe State, Chamber state and the change in Life value of the target/shield.

Table 4. Logic Truth Table representing Input-Output Relationship of Mainframe and Chamber States and Life Reset.

Mainframe State	Chamber State	Life Reset	Output
A	B	C	!(A‖B)&&C
T	T	T	$^{T}F^{T}\,\mathbf{F}\;T$
T	T	F	$^{T}F^{T}\,\mathbf{F}\;F$
T	F	T	$^{T}F^{F}\,\mathbf{F}\;T$
T	F	F	$^{T}F^{F}\,\mathbf{F}\;F$
F	T	T	$^{F}F^{T}\,\mathbf{F}\;T$
F	T	F	$^{F}F^{T}\,\mathbf{F}\;F$
F	F	T	$^{F}T^{F}\,\mathbf{T}\;T$
F	F	F	$^{F}T^{F}\,\mathbf{F}\;F$

Boolean Logic Term:

- ‖ - Boolean OR logic
- && - Boolean AND logic
- ! – Boolean NOT logic

Two persistent RTC models were created based on the process flow, the first model is the Mainframe model which exist in the tool Mainframe while the second model or the Chamber model/s resides in the chambers RTC servers. Both models monitor the tool/chambers MES state activities, they monitor the occurrence of shield change and target change state as it can be change on either mainframe or chambers. The information from the Mainframe model were sent to the Chamber model, which checks the overall tool state change across the mainframe and chamber. The Chamber model is where the real-time monitoring of target and shield life happens thru RTC, if the change in target/shield life is abrupt the model will then tag it as a reset. All this information will then be processed and must follow the Truth Table 4 input relationships.

In summary, the output of models if the conditions are TRUE will put the tool on TSRC state and needs to verify the activities on the tool. While if the output is FALSE the model will only place MES comment that the verification of Life reset is true and that the SHLD/TCHG was successful. Figure 10 shows example of the output action to tool MES.

Figure 10. Sample output from RTC model with TRUE and FALSE output.

3.0 RESULTS AND DISCUSSION

3.1 QLDW Results

After the Sputter AOI sampling algorithm implemented in the 4th Quarter of 2022, 3% decrease only was realized, prompting for further optimization of the algorithm. In mid of 1st quarter of 2023 the window time of automated selection was increased from 10 hours to 15 hours. By the end of 2nd quarter of the rejection rate decreased up to 17% rejection rate, reducing the occurrence from 131 to 59 resulting to 55% reduction of QLDW due to AOI failure, as shown in Figure 11.

Figure 11. QLDW Rejection rate data quarter on quarter where 4Q22 is the start of implementation of the Sputter AOI Algorithm.

Productivity was realized by reducing the manning of sputter AOI, a 2.7% reduction of lots going to sputter was gained as shown in Figure 12. With 16 min/lot average loading of lot a total of 470 lots per quarter was reduced, equivalent to 5.2 days per quarter non-value-added activity was reduced for the operators. NVA reduction on equipment and process side removing 12 hours/quarter of verification each based on average 10min/occurrence verification.

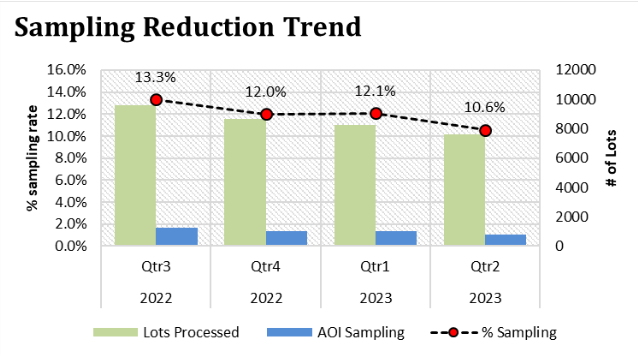

Figure 12. Trend showing percentage of lots going to sputter from 3Q22 up to 2Q23. Reduction of lot sampling from 13.3% to 10.6%.

Downtime was also reduced from 6.8 days to 3.9 days, giving additional 2.9 days production time as shown Figure 19.

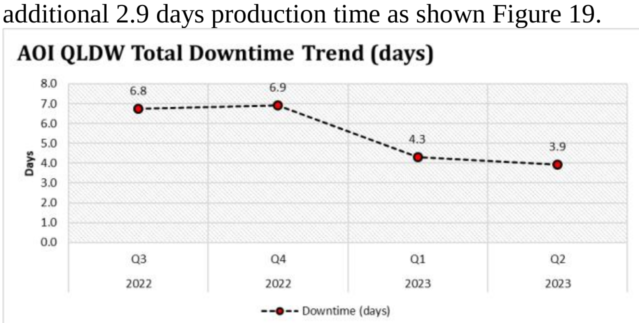

Figure 19. Trend showing downtime due to QLDW from AOI sampling going down from 6.8 to 3.9 days.

3.2 TSRC Results

With TSRC Algorithm implemented mid of 3rd quarter of 2022, only 12% improvement was realized after the 4th quarter of 2022. Additional improvement on the model was made by reducing false interdiction mid of 4th quarter of 2022, where downtime occurrence was reduced from 80 to 23 which is equivalent to 75% reduction at the end of 2nd quarter of 2023 as shown in Figure 19.

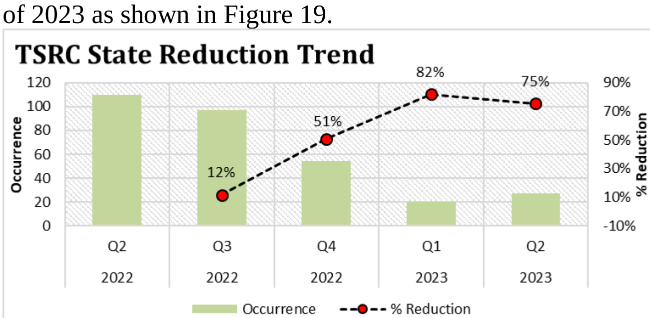

Figure 19. TSRC occurrence trend quarter on quarter occurrences and % reduction.

With decreased in occurrences, the equivalent decrease in downtime from 4.43 days to 1 day, a 3.43 days per quarter reduction of downtime as shown in Figure 20. Also, NVA on the equipment technicians and engineers thru verification was by reduced by 13 hours per quarter on average of 10min/occurrence.

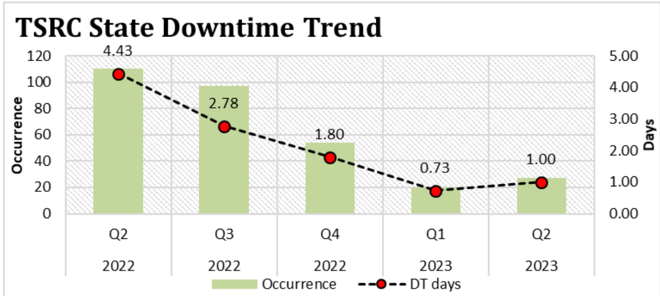

Figure 20. Downtime trend quarter on quarter after implementation of TSRC algorithm showing decreasing downtime.

3.3 Overall Results

Overall QLDW and TSRC downtime were reduced thru the use of MES and RTC integration which reflects 62% improvement on occurrences of non-value downtime which can be done thru automated algorithms.

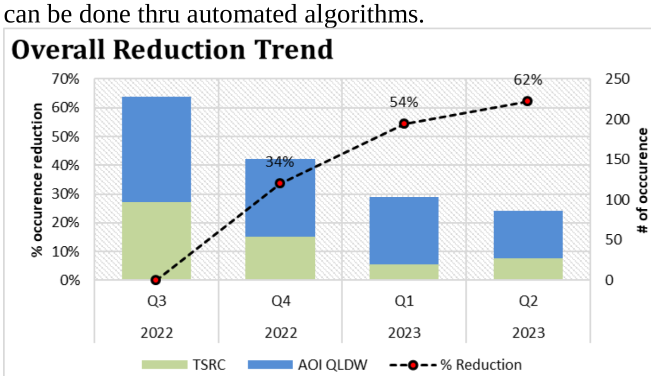

Figure 20. Occurrence reduction trend of TSRC and AOI QLDW downtime from 3Q22 to 2Q23.

4.0 CONCLUSION

Overall impact of the automated solutions on SPC downtime was improved by 17% AOI QLDW rejection rate at the end of 2Q23. It also reduces lots sampling to 2.7% with smart sampling, 5.2 days non-value-added activity reduction and additional 2.9 days production time. TSRC downtime was improved after the implementation of automated verification which reduces the occurrence to 75% which is equivalent to 3.43 days additional tool up time.

In summary, RTC and MES systems integration can be used as an automated tool material change verification and sampling inspection algorithm, which can be customized per process needs. With the proper systems integration and deep dive process analysis, the project can impact reduction of downtime and non-value-added activities.

5.0 RECOMMENDATIONS

With the integration and inclusion of algorithms of RTC and MES systems in the tool activity verification and sampling scheme, it can be used to reduce tool downtime and non-value-added activities. With the proper assessment and use of logic diagrams such as flow chart and truth table, automating process verification can be performed with the existing systems.

With the implemented algorithms on Sputter tools, it is recommended to explore other process log points that have the same scenario or post material change and sampling inspection. It is also not limited to bumping process but also to other sites with similar activities.

6.0 ACKNOWLEDGMENT

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7.0 REFERENCES

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