BEST TOOL MATCHING METHODOLOGY: A HARMONIZED QUALITY TOOL DRIVING OPERATIONAL EXCELLENCE

Marionne Jose F. Javien
Ruel J. Mijares
Benjamin M. Cecilia

Process Development Engineering
Analog Devices Inc., General Trias, Cavite
Marionne.javien@analog.com Ruel.mijares@analog.com Benjamin.cecilia@analog.com

ABSTRACT

Best Tool Matching (BTM) is a Data Mining System used to automatically generate probability plots and identify continuous improvement opportunities derived from comparing the "Best" and "Worst" performing tools on significant signals on the Test Manufacturing floor. The paper discusses the statistical concepts behind the generated 8-Step Methodology using BTM and its sample applications.

Moreover, this study demonstrates the synergy of the developed advanced Data Analytics for Comparative Analysis, Data Mining Systems and Continuous Improvement Models to produce an ideal outcome from the identified BTM matching opportunities such as Operational Equipment Effectiveness (OEE), Electrical Yield and Jam rate. This methodology has been successfully applied in pursuance of Operational Excellence and improved Quality Culture on the Test Manufacturing floor.

1.0 INTRODUCTION

Operational Excellence involves systematically addressing continuous improvements through process and program enhancements for the sake of increasing management effectiveness and efficiency [1]. The company is committed to pursuing Operational Excellence using Advanced Tools and Methodologies. These play a vital role in guiding the project initiators to systematically address issues and effectively implement processes and projects that are aligned with the company's vision.
One of the significant results during the harmonization of processes and tools in ADI is the use of the Data Analytics integrated on the BTM Methodology.

2.0 REVIEW OF RELATED WORK

BTM was introduced on the ADI manufacturing floor to aid engineers in doing quick analysis on heaps of data and be able to yield significant signals or matching opportunities between the "worst" tool and "best" tool [2]. The generated methodology consists of an 8-step process on Figure 1 wherein each step and concepts are discussed thoroughly.

3.0 METHODOLOGY

STEP 1. Identification. The first step consists of Team Composition, Objective/s, Metrics and BMP Alignment. The Objective should be SMART - Specific, Measurable, Attainable, Relevant, and Time Bounded and should also be aligned with the company's BMP on Operational Excellence.
For the metrics, these would include Electrical Test or Post Test Yield, Parts per Jam, Handler Downtime, or Mean Unit Before Jam (MUBJ). Choosing the metrics depends on the project initiator's area of interest and ownership.

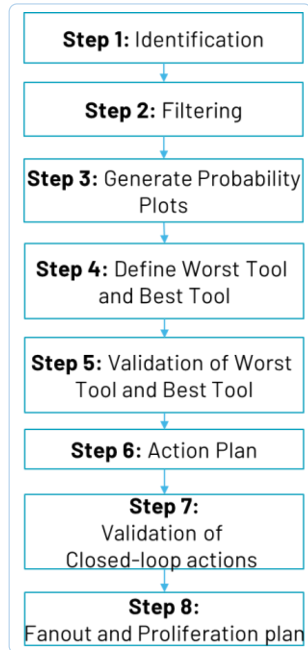


Figure 1. BTM Methodology

STEP 2. Filtering. On the concept of BTM, it is crucial during the comparative analysis stage that the signals identified are filtered and free from confounding variables. Confounding variables or "confounders" are often defined as the variables that correlate (positively or negatively) with both the dependent variable and the independent variable [3]. These variables should be identified to ensure that the signals are valid and can be compared "apple-to-apple".
One of the statistical ways to eliminate confounding effects is through data stratification. This is used to fix the level of the confounders and produce groups within which the confounder does not vary [3].
To cite an example in Figure 2 (next page), the metrics identified for improvement is PPJ on gravity fed Handlers. Comparing the best and worst performing handlers as the tools, data sets should be stratified by having the same set of package types tested, Temperature during the test, and the same handler model.

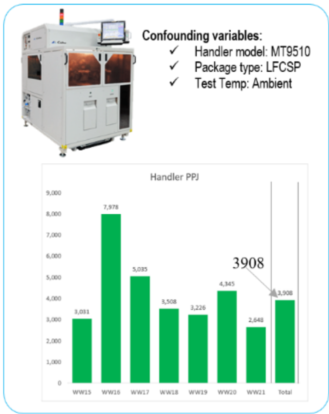


Figure 2. Confounding Variables including handler Model, package type and Test Temp

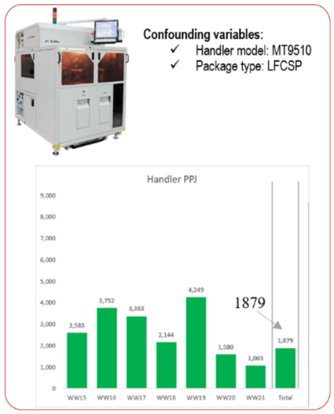


Figure 3. Confounding Variables including handler Model, and package type only

The figures above show how confounding variables affect the analyses of the data sets. Figure 2 shows the PPJ performance of the 2 handlers considering the confounding variables from the previous example while in Figure 3, the Test temperature was not considered. These variables may influence the PPJ performance due to events like additional soaking time or thermal frosting on multi-temp processes. The PPJ performance on the 2 sets of data might seem the same based on the graphs, however, if you look closely at the values, they have ~2000 PPJ delta and that's the effect of a confounding variable (test temp.) that was not considered in Figure 3.

STEP 3. Generate Probability plots. After identifying the confounding variables, probability plots will be used to compare the entire fleet's performance to determine the "Best" and "Worst" performing tools. The probability plots provide a clear visual representation of the performances of the tools without being greatly affected by the outliers.
Probability plots can be generated manually using Excel. Nonetheless, with the advanced technologies on Data Analytics and Software Development that the company have right now, this can already be accessed easily from the different Data Mining Systems developed by ADI. Previously, Tableau was used to compare BTM signals for PPJ. Now, with the harmonization and close collaboration with the Subject Matter Experts, IS Developers and Engineers, the Data Mining Systems for BTM have expanded to greater lengths covering several signals that can be used such as Electrical signals integrated on the Data Analytics software. These can automatically generate probability plots and easily identify the "best" and "worst" and tools as shown on Figure 4.

Web Name	_Link	Signal
PDF Exensio		Electrical Signal - PCI Tool Dashboard
Power BI PPJ		PPPJ
Analy$e		Scrap Cost
Supply Forecast		To validate forecast volume of Tool/setup undergoing BTM
Post Test Yield		Vismech Yield and Defects
TABLEAU		PPJ (AFO- LTC)
Tableau PPJ F1/F2		PPJ F1/F2
TABLEAU		Yield (TR)

Figure 4. BTM Data Mining Systems

These data mining systems were developed using the high-level I/O parameters in Figure 5. IPO explains how these raw Data are transformed into meaningful information that will be used in the succeeding steps. With these systems integrated into BTM, generating probability plots for comparative analysis would just be a few clicks away from the developed platforms.

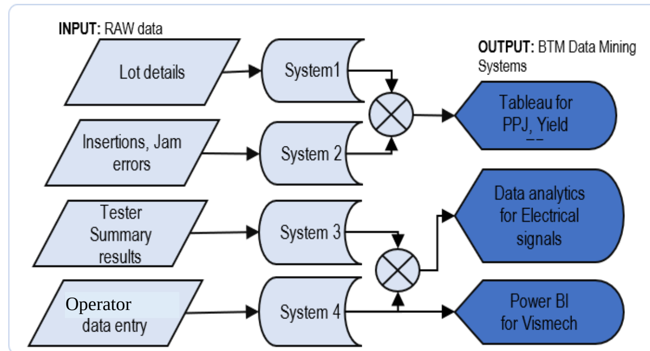


Figure 5. BTM Data Mining Systems I/O parameters

To cite an example of probability plots for comparative analysis, below is an actual generated probability plots from a BTM project using Tableau [4]. Confounding variables are also considered as shown in below figure. After generating the plots, the study can now proceed in identifying the best and worst tools.

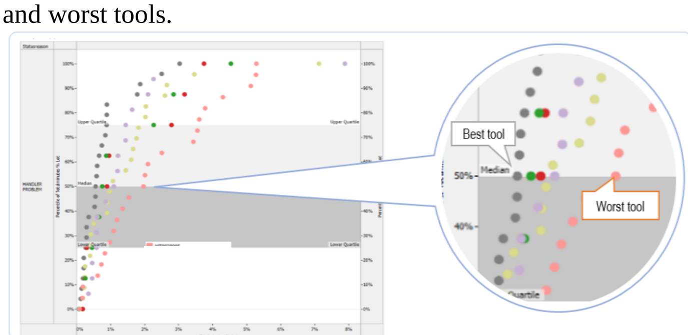


Figure 6. Probability plots using Tableau

STEP 4. Define Worst tool and Best tool. The median from the probability plots is used as the reference in the system for the matching opportunity since the median is less sensitive to outliers and skewed data [5]. Additionally, for statistically sound datasets, the team have programmed the Data Mining systems gathering historical data within the 4-to-6-week timeframe or at least 30 data points whichever would suffice.

Figure 6 was filtered only leaving the best and worst tools as shown on Figure 7. The worst tool (Handler B) also known as the "Dog Tool" do have a 2.0% downtime based on its median while the best tool is Handler A with a matching opportunity or delta of 1.5%.

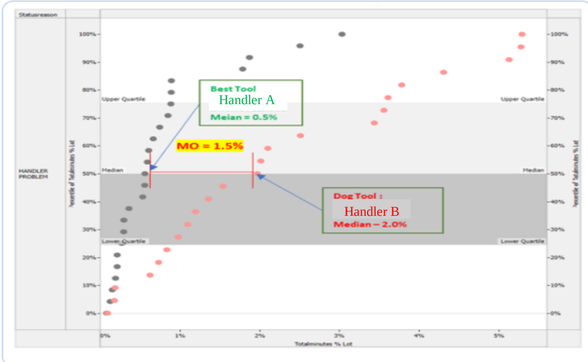


Figure 7. Probability plots with Defined Best tool and Dog tool

With the best and worst tools identified, the next step in comparative analysis is to check the failure parameters on the identified signals considering 80% of the Pareto or at least 3 top failure parameters from the Data Mining Systems. It is recommended to use Parts per Million (PPM) or Percentage instead of count or frequency to avoid misinterpretation when comparing these signals. Figure 8 shows the top parameters having gaps such as the Loader, Test site, and Unloader downtime from the identified Matching opportunity in the above example.

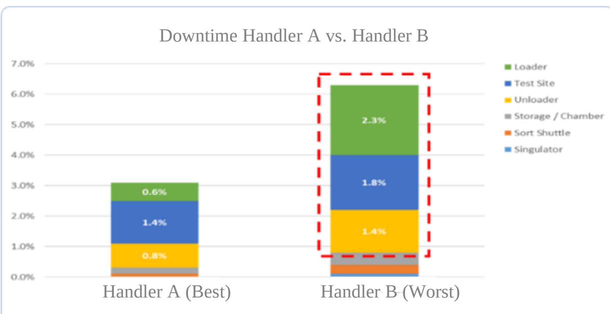


Figure 8. Comparative analysis using Top failure parameters between Best and Dog Tool

STEP 5. Validation Worst tool and Best tool. Validation is where the team identify the major differences between the identified Best and Dog tool. One of the ways of validating these gaps is through GEMBA or actual investigation on the identified tools/areas in the manufacturing line. To cite an example on Table 1, considering the standard requirement was used on identifying the gaps from the previous BTM example on downtime and the identified parameters as mentioned above is where the GEMBA focused on. The analysis of the gaps was made simpler and straight forward as a result of the easy identification of "Best" and "Worst" performing tools.

Items	Description of the Problem	Standard Requirement	Best Tool	Worst Tool	Gaps
Parameter settings (like vacuum setting, speed setting, etc.	Different parameter settings.	MTXXX Handler specs	N/A	N/A	No issue found. Refer to Appendix A on the example detailed review on the parameter settings.
Mechanical issue, (what is the condition is it worn out or end of life, etc.?)	Worn out LGR CNTP guide holes	Hole Diameter = 1.56 +/- 0.03mm	 1.55mm	 1.61mm	0.07 mm difference (1.61-1.51)
	Incorrect LFS top guide orientation	Chamfer should be located on top	 chamfer ARROW CORRECT	 WRONG chamfer	Incorrect guide orientation
	Incorrect sensor part number	PN: XXXA	PN: XXXA 	PN: XXXE 	Incorrect sensor part number used

Table 1. Line Investigation Results template with example

STEP 6. Action Plan. With the identified gaps from best and worst tools, continuous improvement models such as PDCA or 4W1H are used to document the actions on closing these gaps. Table 2 shows an example action plan using 4W1H

What (Identified Gaps)	**How** (Identified actions to address the Gaps)	**When** (Target/ Due date)	**Where** (Handler for implementation – worst Tool)	**Who** (Action owner)	**Status/** Remarks
1. Worn Out LGR w/ 0.7mm difference	Replace LGR CNTP	WW341	MT9928095 handler	Equipment engineer – (specify name)	Done
2. Incorrect LFS top guide orientation	Corrected top guide orientation of worst tool	WW341	MT9928095 handler	Equipment engineer – (specify name)	Done
3. Incorrect sensor part number	Replaced sensor w/ correct PN	WW338	MT9928095 handler	Equipment engineer – (specify name)	Done

Table 2. Sample Action Plan – 4W1H

STEP 7. Validation of Closed-loop actions. After the implementation of these actions, the project initiator will gather additional data sets for probability plots to check the effectiveness of the solutions. The team also recommends extracting more or with equivalent time frame or number of data points from the previously generated probability plots to compare and validate the performance of the Dog tool before and after the corrective actions (CA).

On the probability plot on Figure 9, a wider time frame including pre-CA probability plots were considered to check the effectiveness of CA from the previous example. Result shows a significant decrease of downtime on Handler B (worst tool) before and after CA from 4.3% to 0.9%.

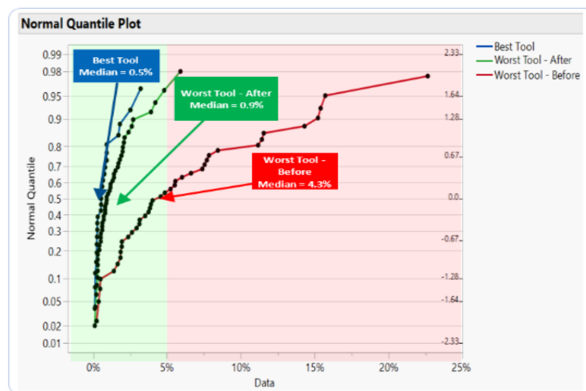


Figure 9. Probability plots on Dog Tool Performance before vs. after CA vs. Best Tool

However, there is still 0.4% matching opportunity in reference to the best tool. To close this gap, preventive and fanout actions were also considered as these are vital actions to sustain the observed improvement from the closed signals. The preventive actions and key learnings from the previous case led to innovative solutions such as (1) go or no go jig that will easily detect worn-out guide pins/holes and misalignment and (2) an integrated PM checklist on the identified gaps.

STEP 8. Fanout and Proliferation plan. The fanout plan using a Gantt chart is expected to be generated on this step considering the long-term preventive actions to be implemented across the entire fleet (not just the worst tool). This will produce a greater impact in pursuance of Operational Excellence and will serve as a preventive approach to eliminate process variations and avoid decreasing yield performance on the other setup as observed from the Dog tool. The applicability of these learnings will now then be shared, assessed, and reviewed by the whole team across all sites.

4.0 RESULTS AND DISCUSSION

Challenge: During the early implementation of BTM, one of the challenges encountered was the long duration of post corrective action (CA) spent to be able to generate valid probability plots for comparison. Consequently, the Volume Forecast was integrated on the BTM systems so that the post CA validation will just be within the expected timeframe.

Results: The creation of BTM Methodology integrated on the developed Data mining systems made it easier for the engineers to identify matching opportunities. This implementation has resulted to several closed BTM projects having a significant improvement on PPJ, OEE and Yield. Below table shows some of the closed BTM signals including the sample BTM project used in the 8-Step Discussion. Apart from the actual improvements, several Key Learnings were generated and fanned across the site as part of the 8 step BTM methodology (see Table 3).

Essentially, the implemented improvements across the site have resulted to several $$ Cost Savings and expected to produce continuous Revenue Growth with the relentless pursuit of the company to be the Best in Class.

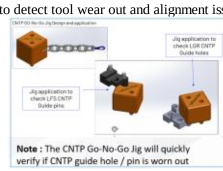
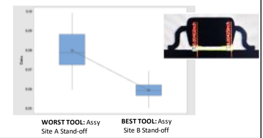
BTM Projects	Signal	Actual Improvement	Key Learnings
1. MTxx Gravity Fed Handler DT Improvement	Handler Downtime	4.3% to 0.9% Handler Downtime on MTxx Gravity Fed Handlers	-Use of a go-no-go jig to check guide pins and holes to detect tool wear out and alignment issues.  -iPM checklist needs updating to include issue found on this project.
2. Temp Stabilization problem reduction for PNP Handler	Handler Downtime	2.48%to 0% Temperature Stabilization problem downtime on PNP Handler	-Reworked the plunger tee's sharp edges to chamfered, reducing the incidence of early worn-out plunger tee. 
3. MTxx Gravity fed Equipment MUBJ (Mean Units Before Jam) Improvement	Mean Unit Before Jam (MUBJ)	149 to 1163 MUBJ Improvement on MTxx Gravity fed MUBJ	-All transition sensors must be fully assembled to avoid unstable locking and intermittent false detection.  -Linear bearing must be replaced after 2.5M -PM checklist needs to be updated to include check of linear slide on PM kits and magazine unloader sensor mounting.
4. Improvement of PPJ in PNP dual temp setup by reduction of index jam	Handler Parts per Jam	12K to 23K PPJ Improvement on PNPxx Dual Temp	-Worn-out Diaphragm causes inconsistency in vacuum. iPM checklist needs updating to include this part. 
5. Visual Mechanical Yield Improvement on TSOT parts addressing Max Stand-off Failure	Visual-Mechanical Yield	1.5% Vismech Yield Improvement on TSOT parts	-Marginally High stand-off from the identified upstream processes (Assembly) have a higher risks of rejection as observed during the comparison of different Assembly sites. 

Table 3. BTM Closed Projects and Key learnings.

5.0 CONCLUSION

Key item #1. The team has established a systematic approach on improving low-performing platforms/tools in reference to the best-performing tools. Also, this innovation has helped the engineers to easily analyze problems, generate and validate solutions with a higher level of sophistication due to the readily available and expanded Data Mining Systems developed for BTM.

Key item #2. The BTM capabilities were transformed from a Data Mining system to a Continuous improvement model. The BTM methodology was utilized to close several projects that addresses various issues and even open Revenue Growth opportunities across the company.

Key item #3. BTM has enriched the Company's continuous improvement programs by providing an additional tool in Problem-solving methodology and encouraging users to be creative on addressing issues and bridging boundaries in the Intelligent Edge.

This strategic program significantly helps in achieving the "Best-in-Class" performance. Thus, the use of BTM methodology is considered as one of the solutions where "Creativity and Technology unite for Tomorrow's Innovation".

6.0 RECOMMENDATIONS

This tool has been effectively and successfully utilized to several signals on the Test manufacturing floor (OEE, Jam rates, Electrical yield and Tape and reel yield) and its application could still expand to greater lengths driving continuous improvement across any Manufacturing Environment (Fab, Assembly, Test, etc.).

7.0 ACKNOWLEDGMENT

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- OR partner and Technical Writing mentor Rex Robielos
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8.0 REFERENCES

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9.0 ABOUT THE AUTHORS

Marionne Jose F. Javien obtained his bachelor's degree in Electronics Engineering from Saint Louis University, Baguio City in 2017, Cum Laude and an ADI scholar. He earned his professional license in 2017 and joined Analog Devices Inc. in the same year. Now, he is currently working as Test Process Development Engineer and an ASQ Certified Six Sigma Green Belt.

Ruel J. Mijares, BS ME, 6σ BB, Patentee. Worked 12 years in the Semiconductor Industry and 3 years in Solar Cell Manufacturing prior to joining Analog Devices in 2017 under the Process Engineering Department at Final Test and Tape and Reel processes. Currently handling Package/Die Crack Advocacy, SME for Best Tool Matching Methodology, TQM Facilitator (DMAIC), and developing inline monitors and detection tools with Machine Learning (ML) techniques.

Benjamin Cecilia, BS ECE, has joined ADI in October 2018 as Process Engineering Manager. With over 20 years of work experience in the Electronics and Semiconductor industry in different roles and capacities.

10.0 APPENDIX

APPENDIX A. Parameter Setting review on Best Tool vs. Worst tool from Step 5.

Module	Parameter Setting	Best Tool (MT120)	Dog Tool (MT095)	Comparison Result
Tube to LGR	LGR Right Input Sensor supported	-	-	Same
	LGR Left Input Sensor supported	-	-	Same
	Tapping while filling LGR-Track	enabled	enabled	Same
	Air-Acceleration while filling LGR-Track	enabled	enabled	Same
	Jam-Clearing at Tube-to-Track-Transition is	none	none	Same
	Jam-Clearing -Count [0 .. 10]	1	1	Same
	Check for Empty-Tube [s] [0.5 .. 2.0 ...]	10.0	10.0	Same
	Wait after Jam-Clearing [s] [0.5 .. 2.0 ...]	2.50	2.50	Same
	Check for Tube has been emptied [s] [0.5 .. 2.0 ...]	2.50	2.50	Same
	generate error after ? Empty tubes	disabled	disabled	Same
LGR to LFS	Tapping while filling LFS-Track	enabled	enabled	Same
	Air-Acceleration while filling LFS-Track	disabled	disabled	Same
	LFS-Track-Filling Timeout for first Device [s] [0.5 .. 1.0 ...]	2.0	2.0	Same
	LFS-Debouncing-Time for last Device [s] [0.3 .. 5.0]	2.0	2.0	Same
LRG Jam-Clearer	LGR-JAM-Clearer	not installed	not installed	Same
	Polarity of activation-signal	standard	standard	Same
	Jam-Clearer is activ [s] [0.05.. 1.0]	0.20	0.20	Same