先進製造物聯雲

Advanced Manufacturing Cloud of Things (AMCoT)

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Contents

Abstract

Abstract

- Internet of Things (IoT), Cloud Computing (CC), Cyber-Physical System (CPS), and Big Data Analytics (BDA) are key enabling information and communication technologies (ICT) of Industry 4.0 to achieve highly integrated smart manufacturing systems.
- To improve the automation and intellectualization of the manufacturing systems so as to enhance the product yield and reduce production cost, our team utilizes IoT, CC, CPS, BDA, and AVM to develop the Advanced Manufacturing Cloud of Things (AMCoT), and apply it into the high-tech industries like semiconductor, TFT-LCD, and solar-cell industries as well as traditional machine-tool and aerospace industries.
- This study uses the semiconductor bumping and TFT-LCD manufacturing processes as examples to illustrate the functions and operations of AMCoT.
- Applying AMCoT for Smart Machinery is also introduced.
- By applying AMCoT, the goal of nearly Zero Defects of products can be achieved.

Preface

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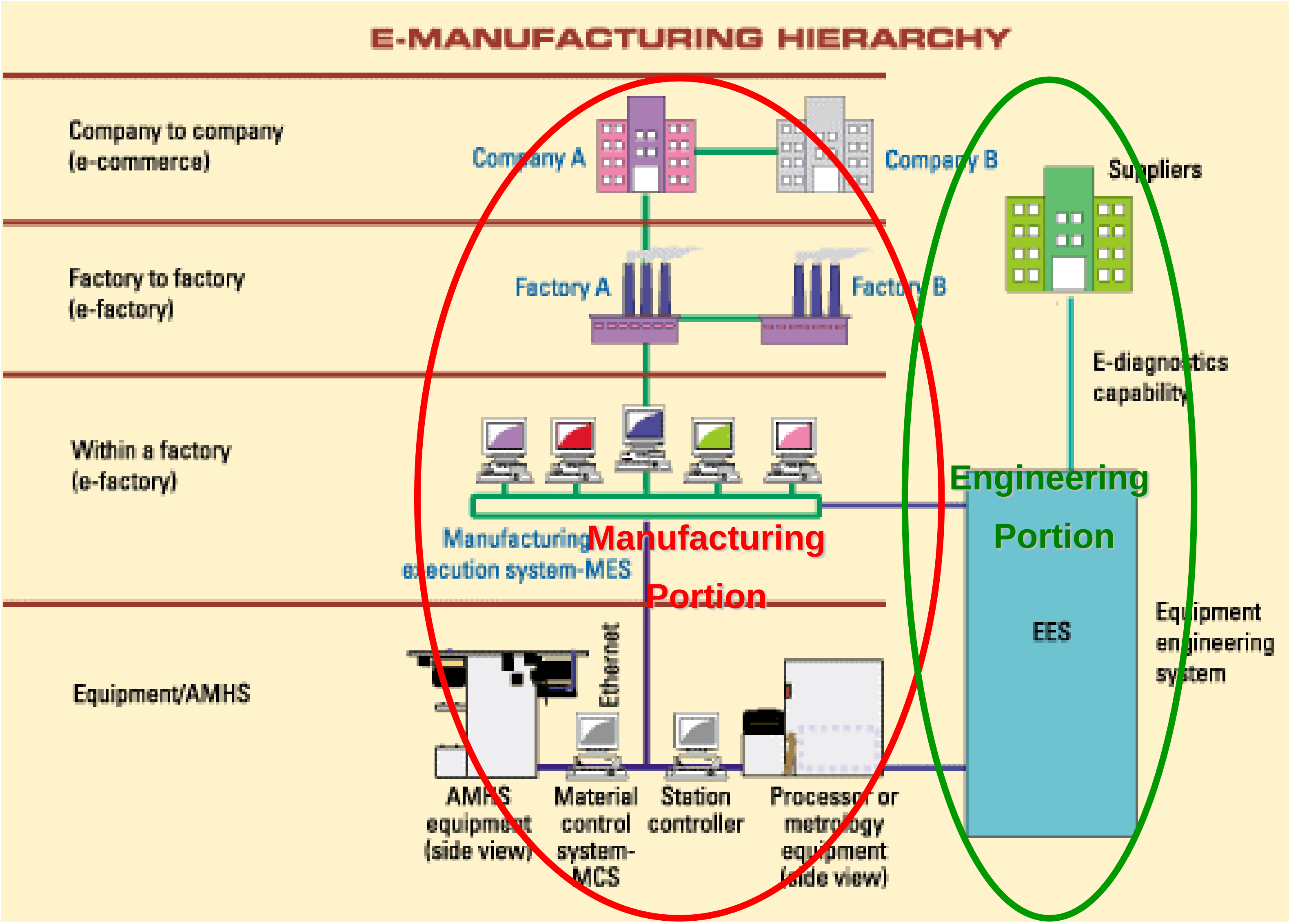
e-Manufacturing & Industry 4.0

for

the Semiconductor / Flat-Panel-Display

Industries

International SEMATECH e-Manufacturing Hierarchy



e-Manufacturing Proposed by ISMI in 2000

What is e-Manufacturing?

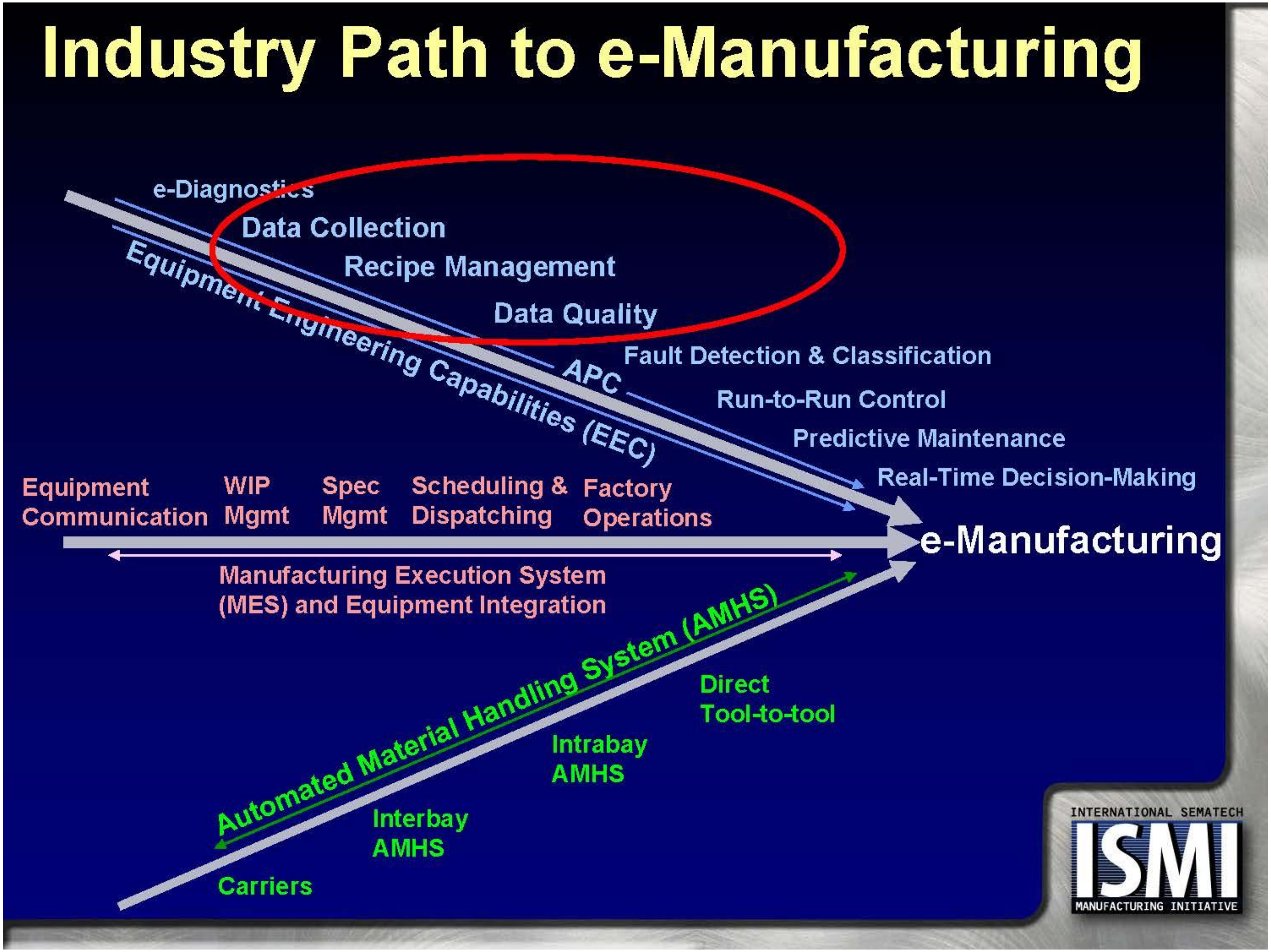
e-Manufacturing is the use of advanced and emerging information technologies to provide automated, data-driven productivity optimization

e-Manufacturing has a wide scope

- –Improved data availability to enable factory decision support (enabled by EDA *Interface A*)
- –Enhanced tools and applications for data utilization in decision making for productivity optimization

INTERNATIONAL SEMATECH
ISMI
MANUFACTURING INITIATIVE

Industry Path to e-Manufacturing

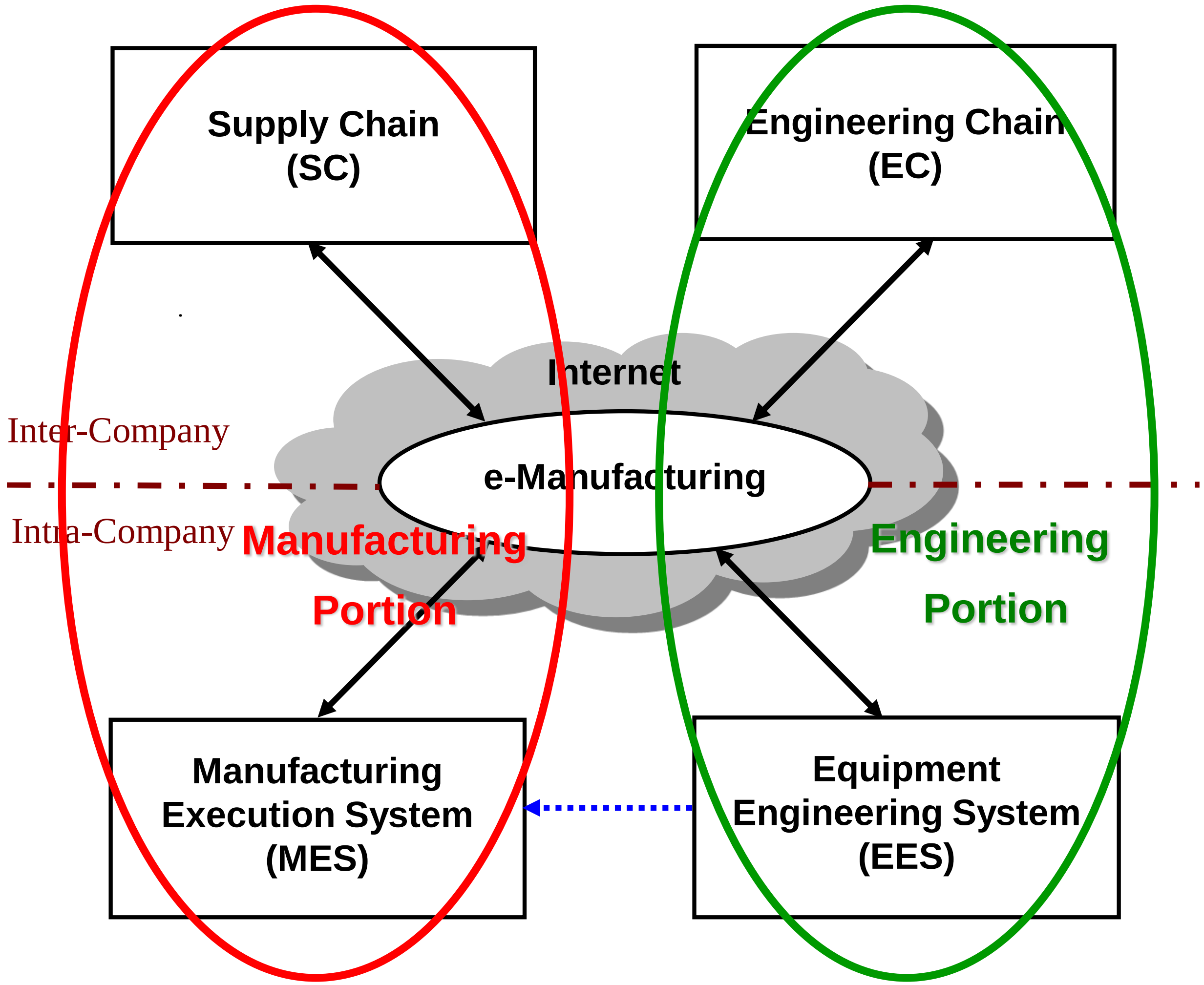


Advanced e-Manufacturing Model* Proposed in 2010

e-Manufacturing is advanced manufacturing that takes advantage of Internet and information technologies to efficiently integrate the Manufacturing Execution System (MES) and Equipment Engineering System (EES) within a company (intra-company integration), and the Supply Chain (SC) and Engineering Chain (EC) among member companies (inter-company integration).

*F.-T. Cheng, W.-H. Tsai, T.-L. Wang, J. Y.-C. Chang, and Y.-C. Su, "Advanced e-Manufacturing Model," *IEEE Robotics and Automation Magazine*, vol. 17, no. 1, pp. 71-84, March 2010.

e-Manufacturing Components



Vision and Conclusions

With e-Manufacturing, the productivity, yield, and overall equipment effectiveness (OEE) of the complete production platform can be improved, the cycles of time-to-market (T2M) and order-to-delivery (O2D) can be shortened; and further the goal of improving agility, efficiency, and decision-making for the entire semiconductor manufacturing processes can be reached.

- **MES improves Productivity and Yield**
- **EES enhances OEE**
- **SC shortens O2D cycle**
- **EC reduces T2M cycle**

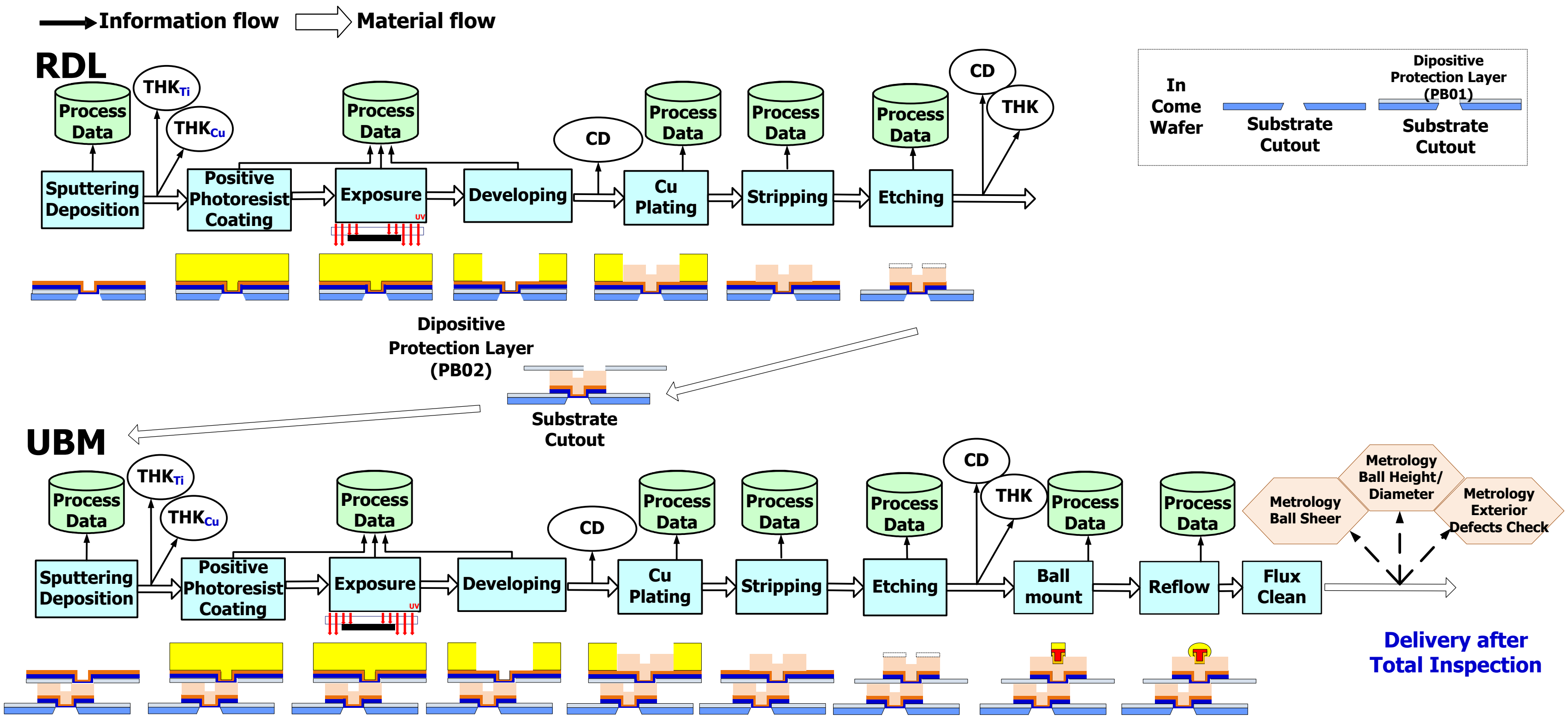
Migration
from e-Manufacturing
to Industry 4.0

Migration from e-Manufacturing to Industry 4.0

- **e-Manufacturing** = MES + SC + EES + EC
- **Industry 4.0** = IoT + CPS + Cloud Manufacturing (CM) + Big Data Analytics
- **e-M** utilizes Equipment Manager to collect all the process and metrology data
- **Industry 4.0** applies IoT technology to collect all the data required
- The functions of EES & SC in **e-M** may be accomplished by the CPS technology of **Industry 4.0**
- The function of EC in **e-M** is not considered in **Industry 4.0**

- The technologies of IoT & CM of **Industry 4.0** may be applied to implement various EES functions (such as AVM, IPM, & R2R) of **e-M** with a more systematic and efficient fashion
- Big Data Analytics of **Industry 4.0** may be applied to find the root causes of a yield loss for yield enhancement and yield management

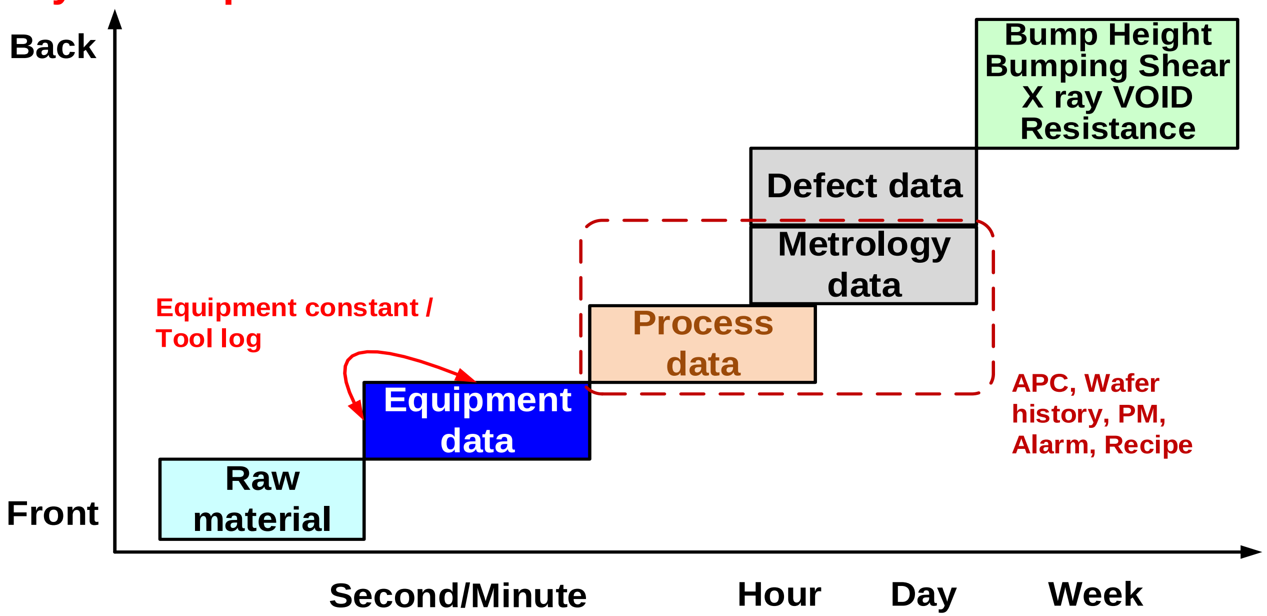
Take Bumping Process for Illustration



RDL: Re-distribution Layer
UBM: Under Bump Metallurgy

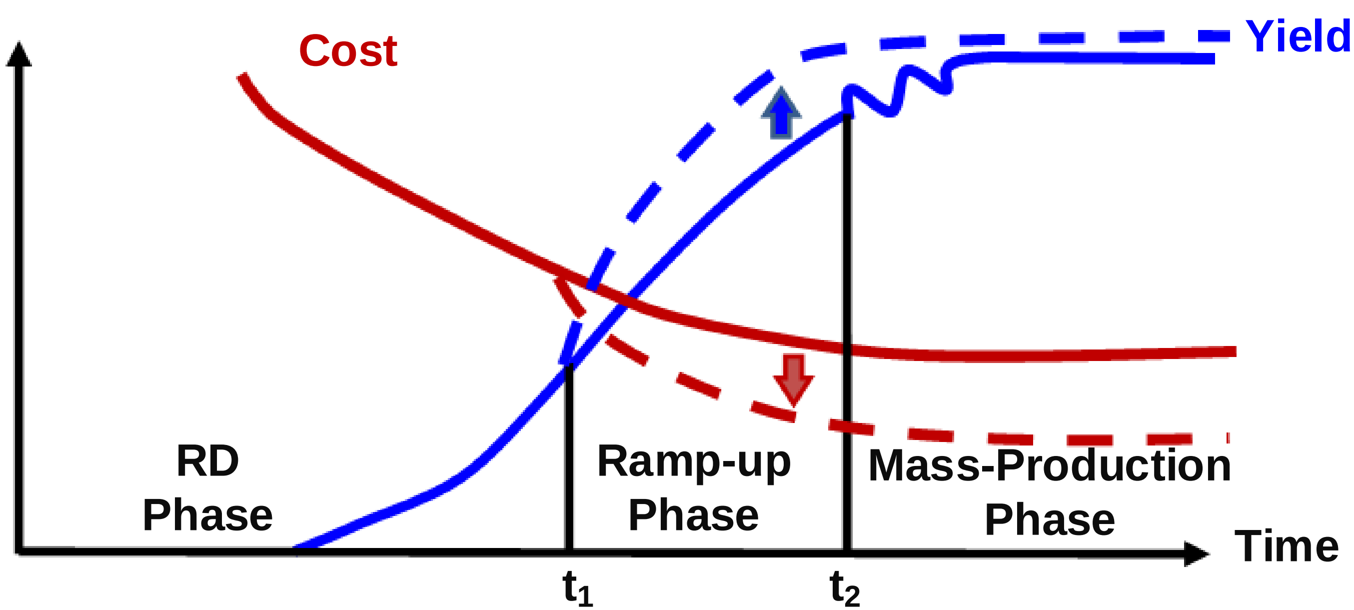
Bumping Process Data Types

- Bumping process goes through the above production steps and will generate various types of data in the final yield rate inspection, and these data range from per second (e.g., tool log) to per week (e.g., yield inspection):
  - Different raw material data
  - Tool data (such as tool log: when to change components, or when to stop the tool, etc.)
  - Production data (such as process, maintenance, alarms, recipe, etc.)
  - **Metrology data** and defect data
  - **Final yield inspection data**



Yield and Cost Changes in Product Development Cycle

- Yields (blue line) will gradually **rise up in the ramp-up phase**, and then keep steady in the mass-production phase. On the contrary, product cost (red line) will decrease as the phases proceed.
- Company's competitiveness would be effectively **enhanced if the blue/red solid lines could be improved into their corresponding segmented lines.**



Strategies for Increasing Yield in Ramp-up and Mass-Production Phases 1/2

- In Ramp-up Phase
  - **Yield Enhancement Service (YES)**
    Find out the root causes among numerous yield-affecting parameters, put them under control and exclude them in a timely manner to increase the yield in ramp-up phase.
  - **Baseline Predictive Maintenance (BPM) & Tool Matching (TM)**
    Establish the tool failure cause relations and create BPM model to infer the timing of the coming tool failure in order to decrease tool abnormality chances and increase yield rate. Tool Matching is also performed in this phase.
- In Mass-Production Phase:
  - **AVM and Intelligent Predictive Maintenance (IPM)**
    Convert the offline sampling inspection with metrology delay into online and real-time total inspection to achieve the goal of defect early warning; and obtain the best tool maintenance timing to reduce maintenance cost.
  - **Run to Run (R2R)**
    Integrate R2R with AVM to enhance the stability of production process (Cpk).
  - **Yield Management System (YMS)**
    Quickly find out the root causes of a yield loss and deal with them.

Strategies for Increasing Yield in Ramp-up and Mass-Production Phases 2/2

Ramp-up Phase (Rapidly increase yield)

YES

- Key Parameter Analysis (High-Dimensional Linear Model) with p >> n Issue by KSA

BPM / TM

- Failure Prediction
- Signature Matching
- Tool Matching

AVM

- Sampling Rate Reduction
- R2R Integration

IPM

- BPM Integration
- Maintenance Scheduling

R2R Control With AVM

- Select Control Parameter
- Setup Control Strategy

YMS

- The KSA Scheme

Mass-Production Phase (Stabilize production and reduce cost)

Mass-Production Phase (Find out the root causes and solve them)

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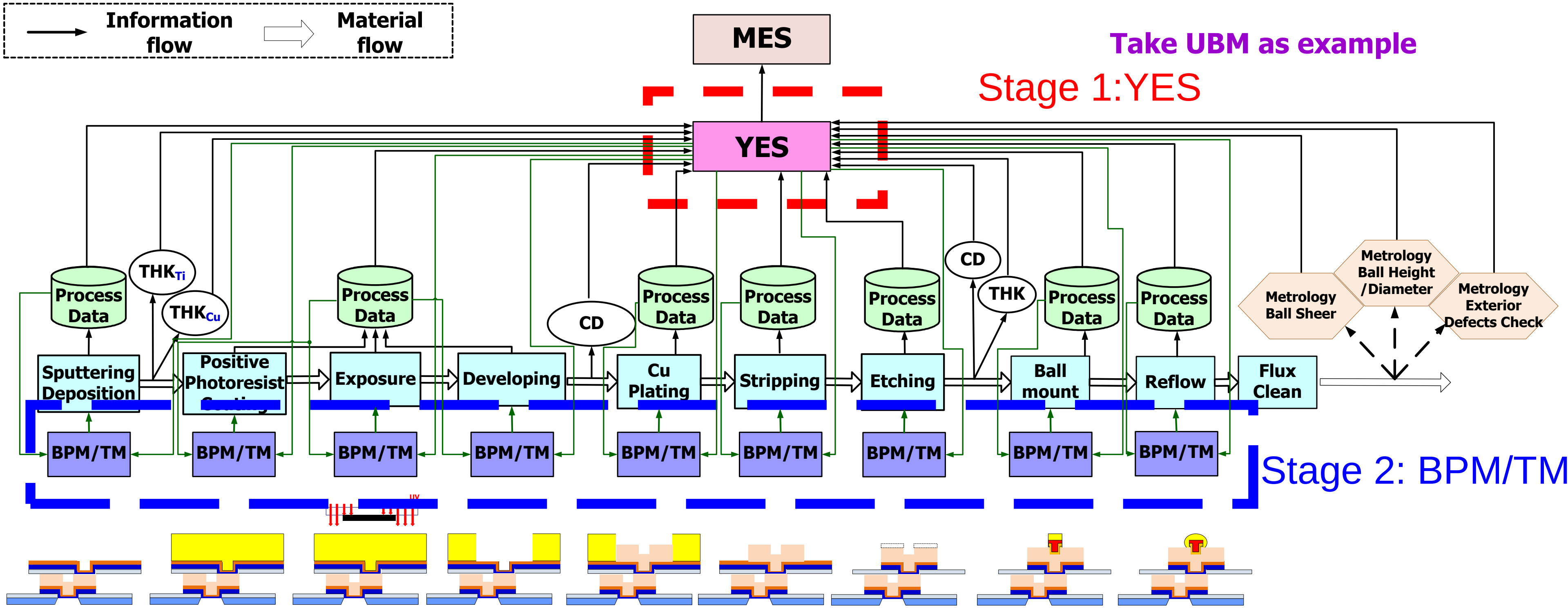
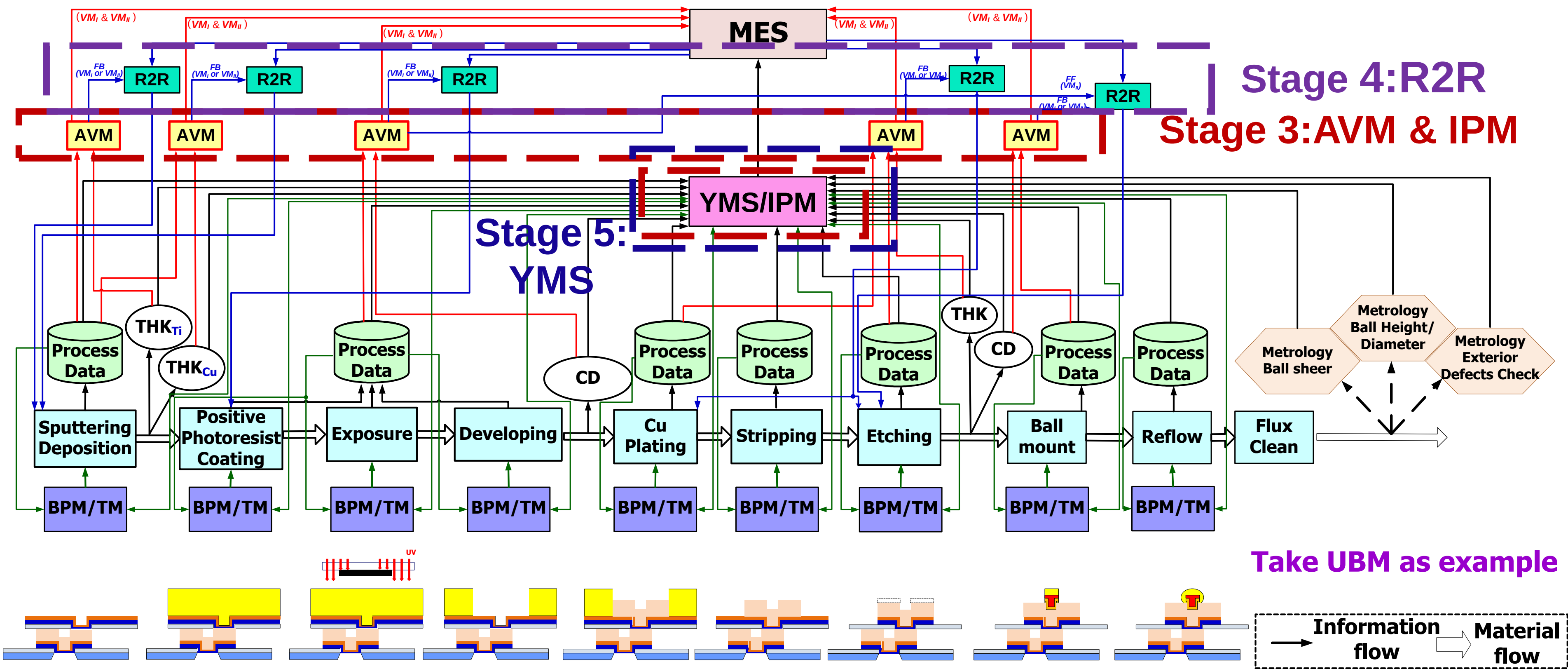
Strategy for Increasing Yield in Ramp-up Phase



Semiconductor Bumping Process

Strategy for Ensuring Yield in Mass-Production Phase



Advanced Manufacturing Cloud of Things (AMCoT)

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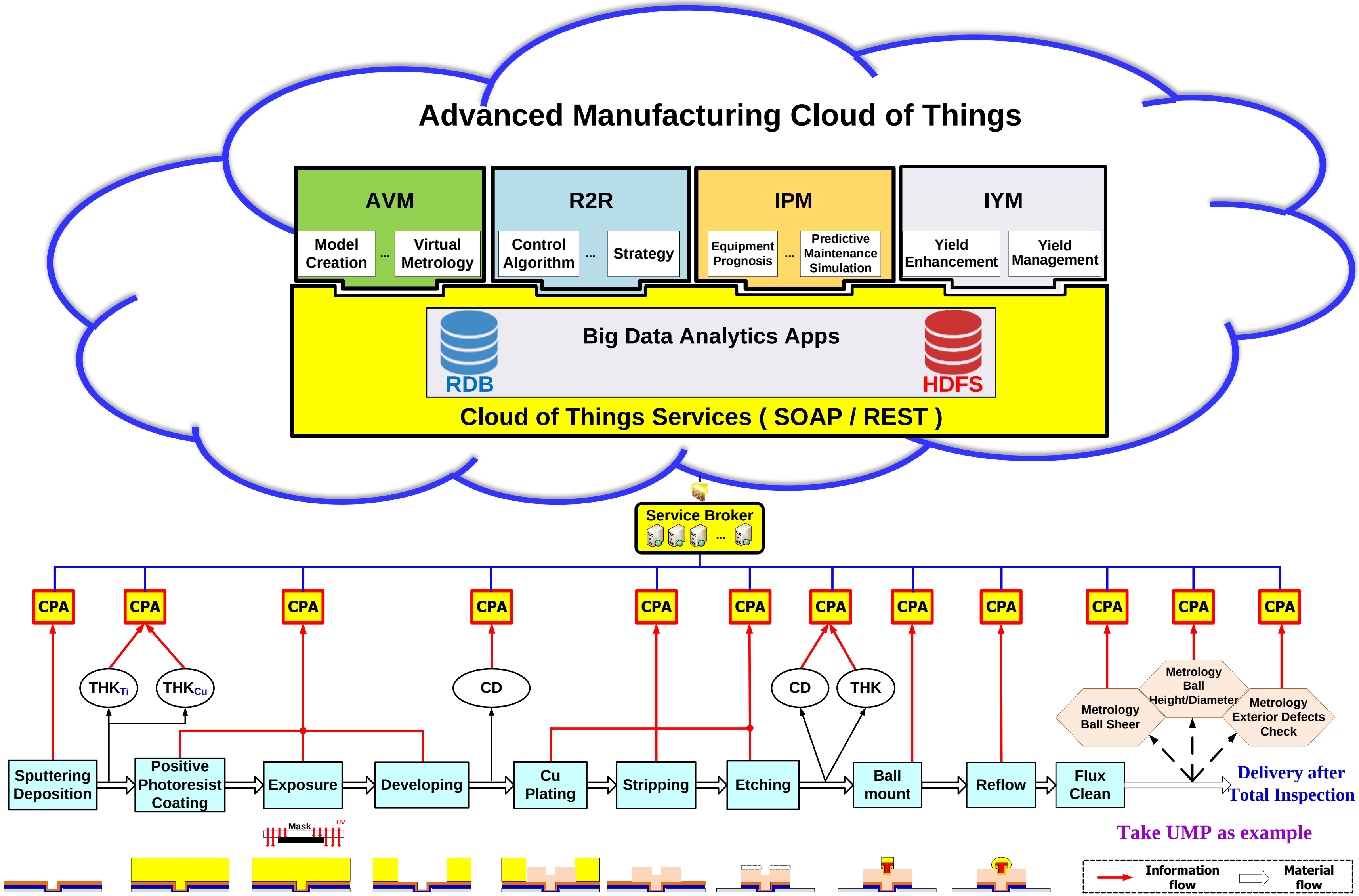
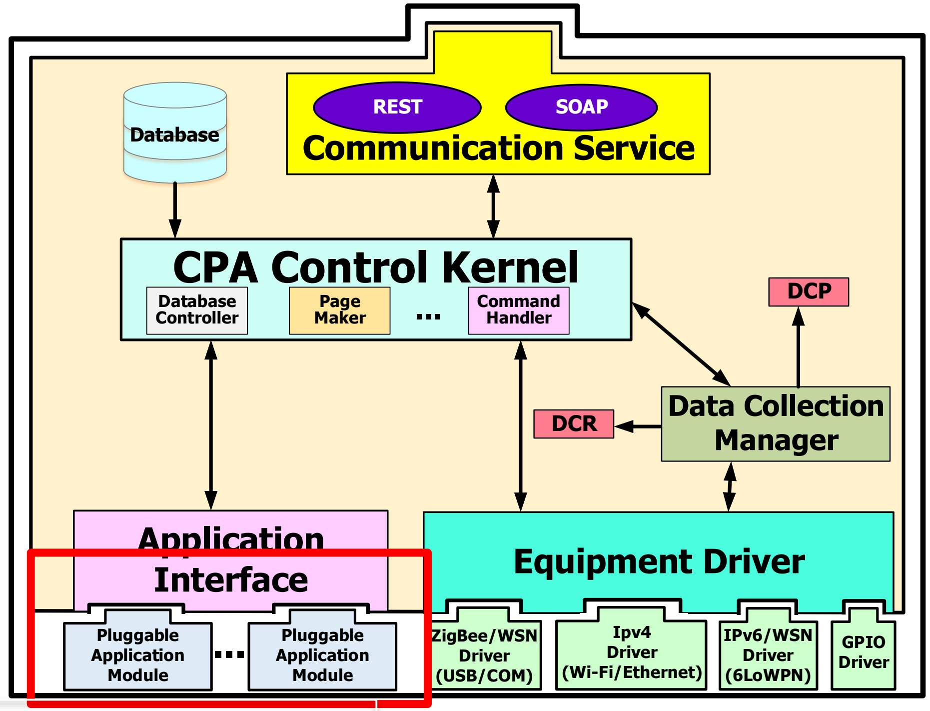


Cyber-Physical Agent (CPA)
An IoT Device

Features of CPA

- **Data Collection and Communication**
  - **Data Collection from all the physical objects is the fundamental feature of CPA.**
  - **Horizontal & Vertical Communications for integrations among physical objects, cyber systems, and human operators can enable reporting and decision making of CPS.**
- **Identification**
  - **All physical objects in WIPs should be uniquely identifiable.**
  - **CPA should know where the object is and what the object does at any time.**
- **Smart Applications**
  - **Various Smart Applications can be implemented as pluggable application modules and plugged into CPA.**



Taiwan Patent : I225606
US Patent：7,162,394
Japan Patent：4303640

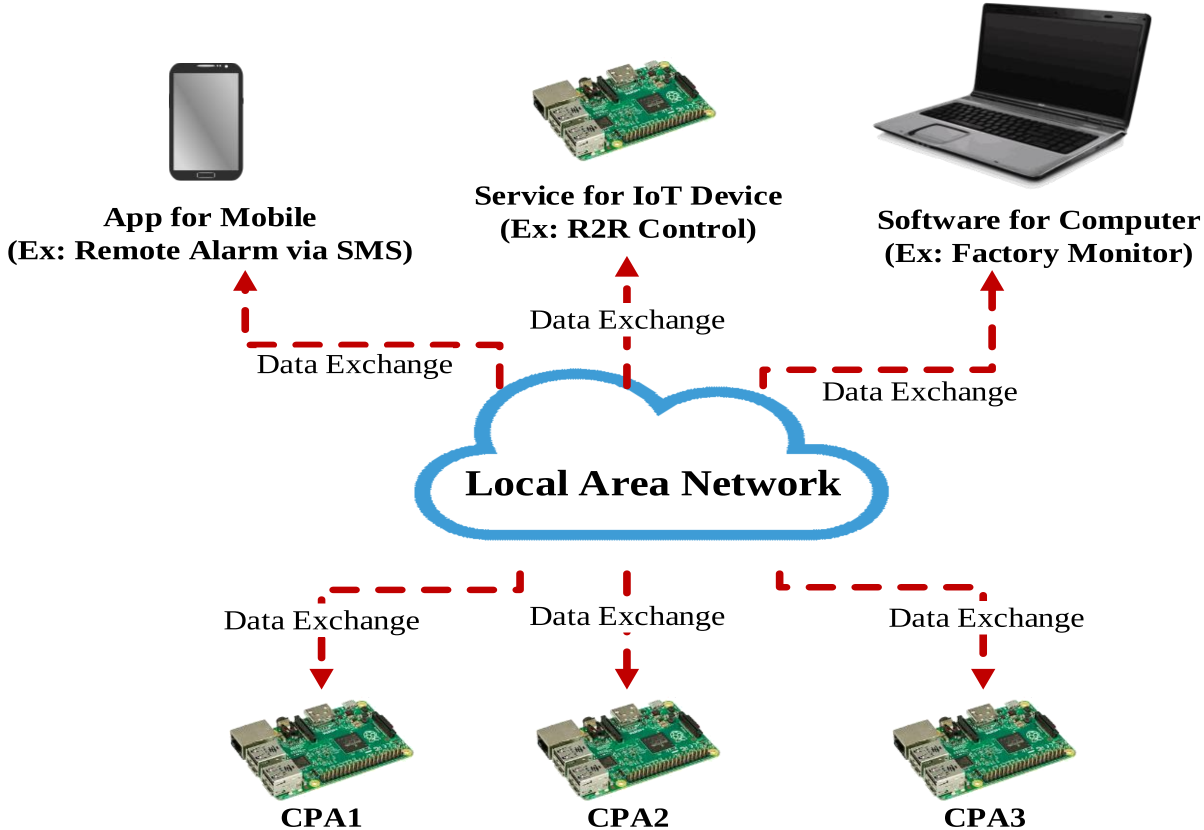
CPA Architecture

Horizontal and Vertical Communications among CPAs

- **Horizontal and vertical integration of communication mechanisms in CPA provide an important foundation for Smart Manufacturing**
  - **Realization of Smart Manufacturing**: all the machines in a Smart Manufacturing factory can communicate and exchange information with one another.
  - **Services Provider:** Service-providing is one of key features in Smart Manufacturing. CPA enables various kinds of terminals (such as PCs, iPADs, smart phones, etc.) or platforms to query information and/or do data exchange. For example, CPA provides a web-services mechanism for querying machine health status.

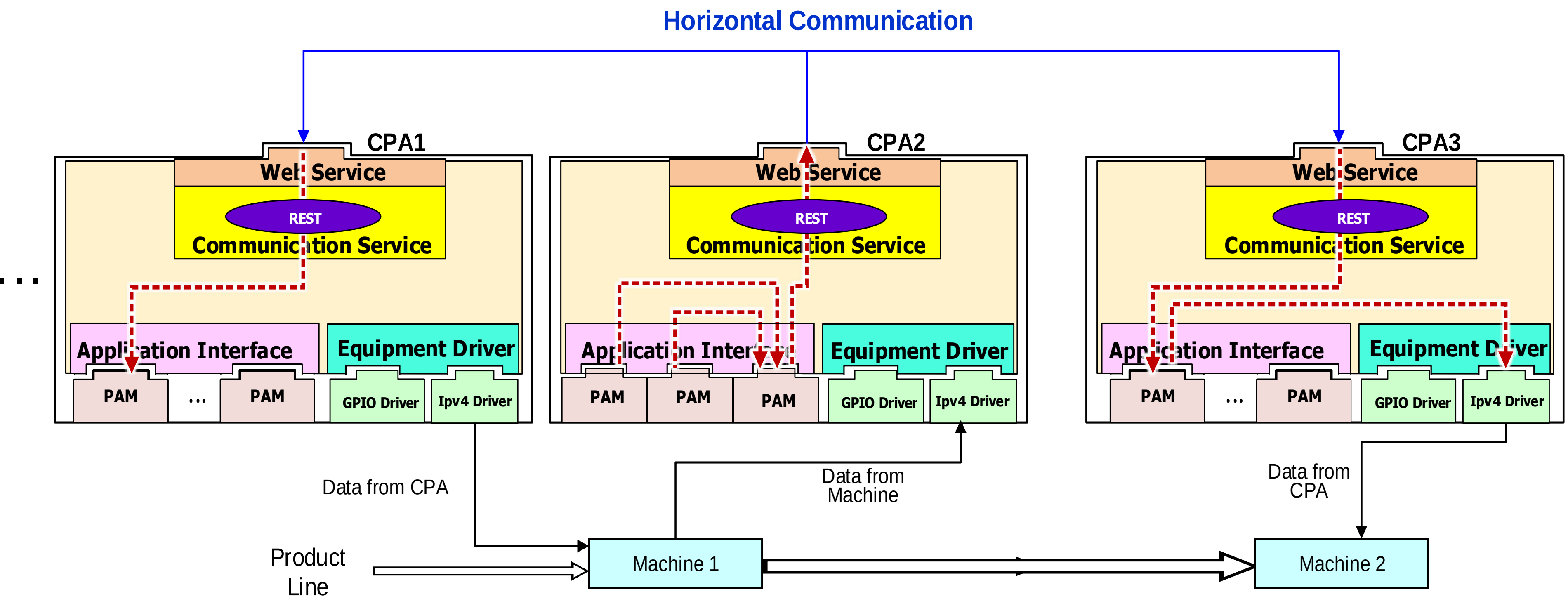
CPA Client GUI Designs

- CPA implements RESTful Service API, and uses JSON as one of the transmission formats. According to the actual needs of the factory and the implementation of the necessary functions, CPA also provide a flexible communication framework.
- Based on the JSON format, various kinds of data-exchange interfaces can be implemented by the necessary application softwares in different types of devices on the client sides.



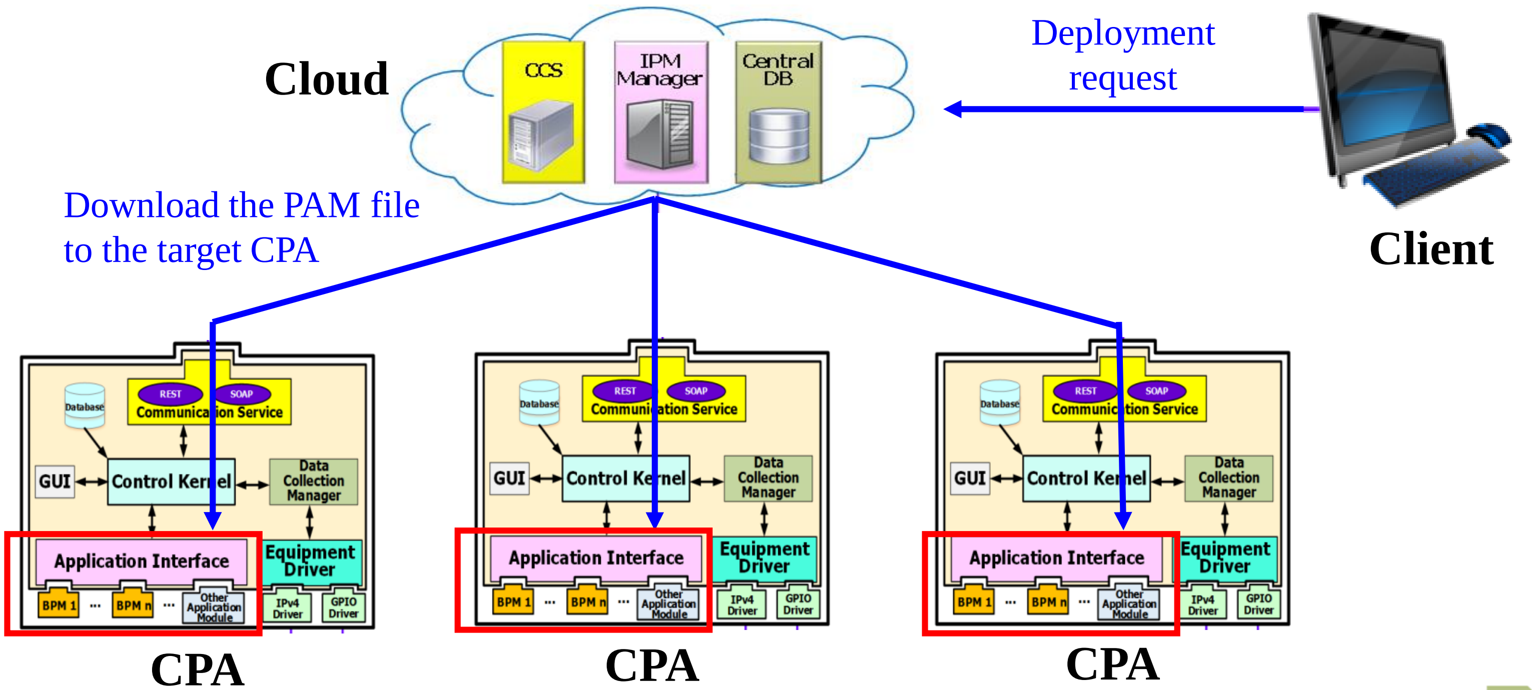
Horizontal-Integration Applications of CPA

- Several CPAs can be aggregated to form Horizontal-Integration Applications.



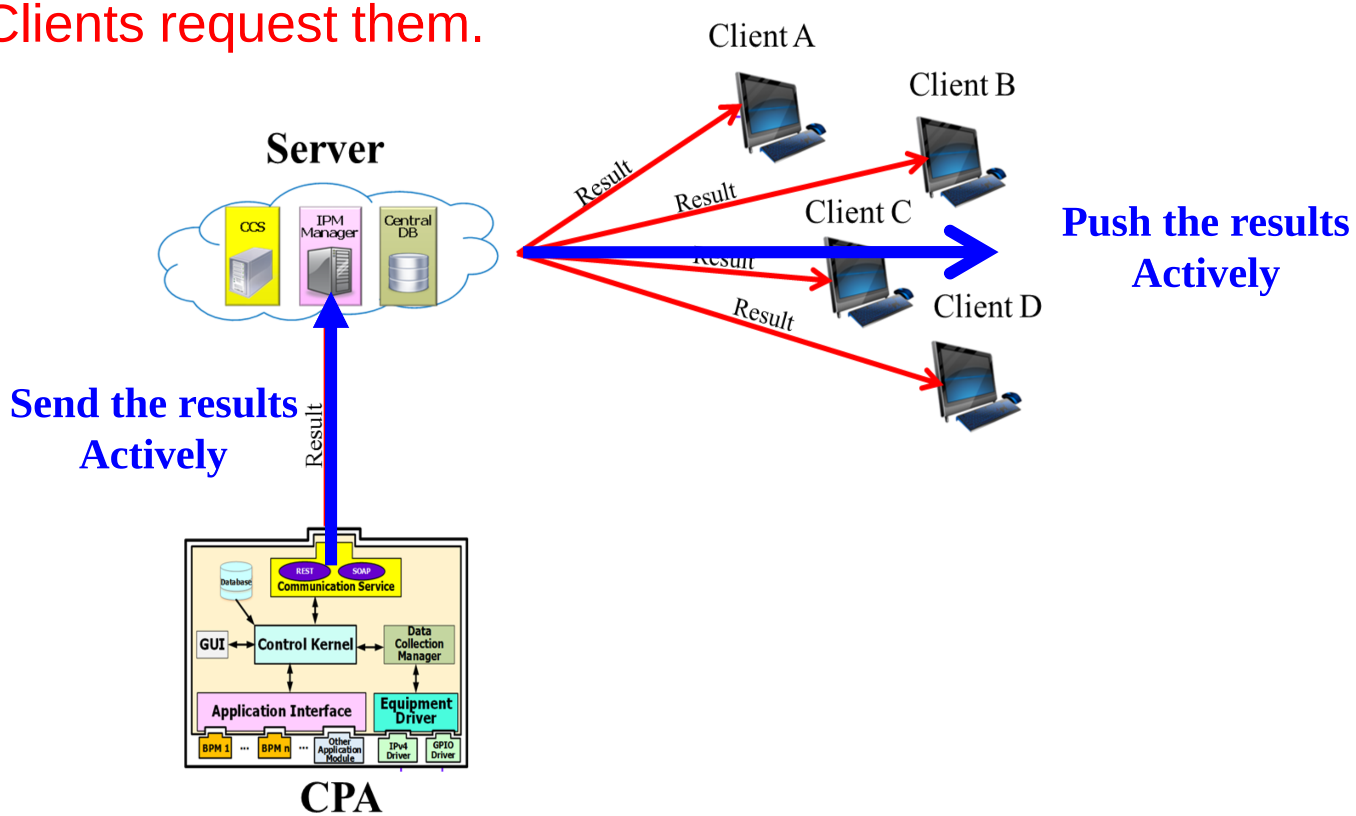
Smart & Pluggable Applications

- Various Smart Applications can be implemented as Pluggable Application Modules and plugged into CPA.
- Typical applications:
  - Data quality evaluations
  - Feature extractions
  - Various predictive maintenance applications, etc.



Push Mechanism of CPA

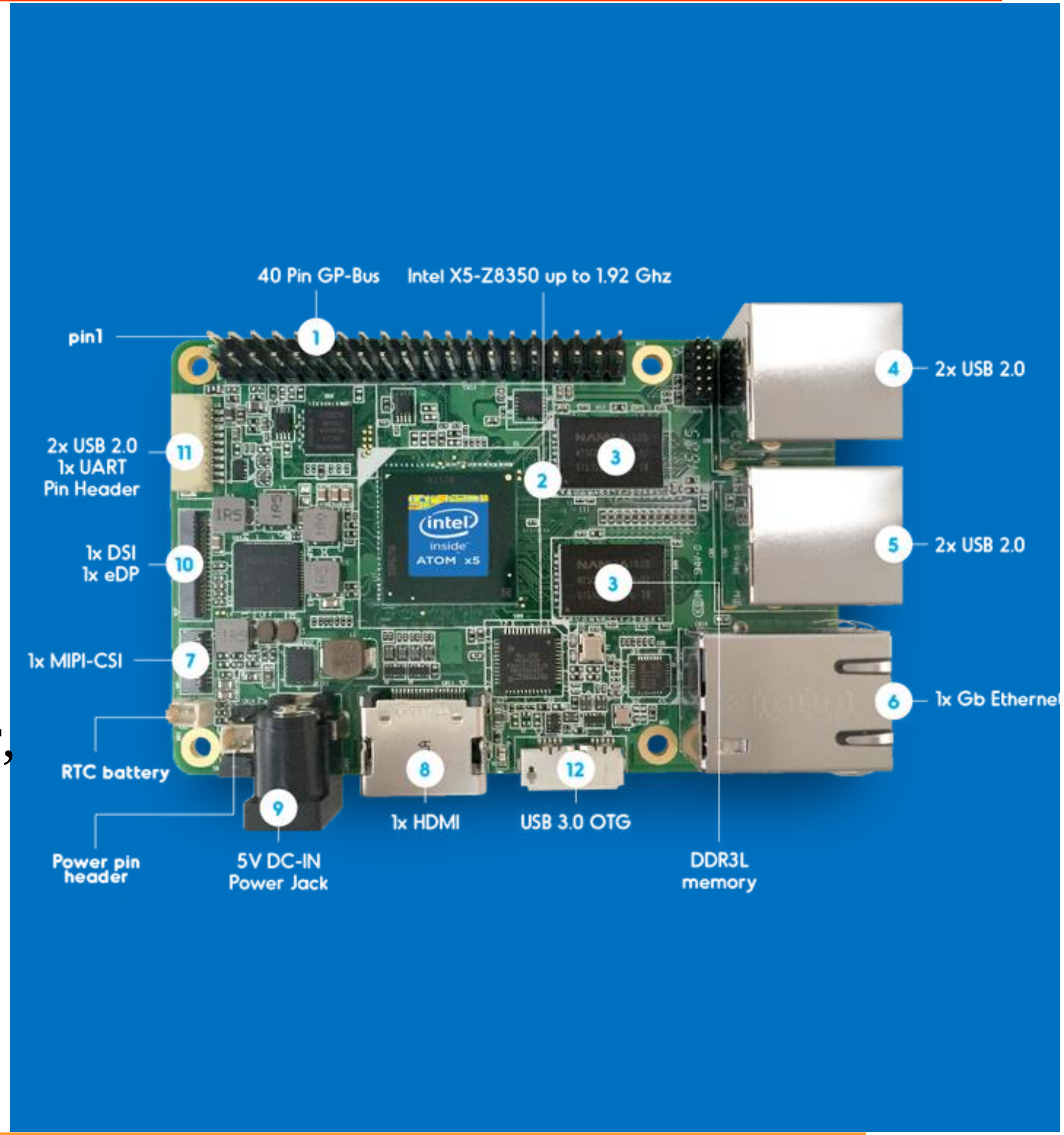
- Non-blocking & asynchronous processing request are adopted in CPA. It can activate a new job without ending the current running job.
- The Push Mechanism is also implemented in CPA. CPA will sent application results to various Clients actively rather than waiting until the Clients request them.



Raspberry Pi 3 Model B for Deploying CPA

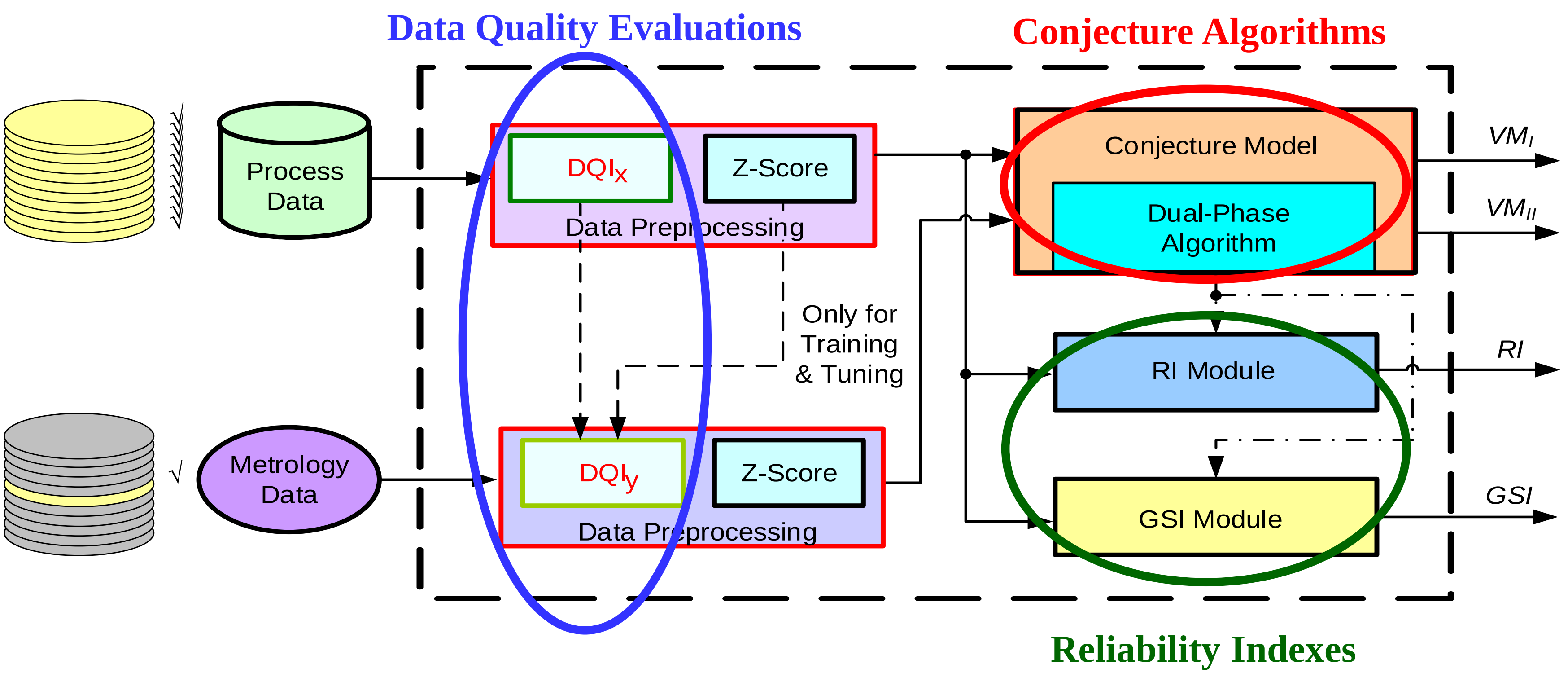
UP Board

- The compatibility with Linux, Android, and all the Windows 10 distributions give you great flexibility, scalability and quick time to market.
- Intel® Atom Processor 64 bit - up to 1.92GHz, The 40 Pin I/O connector, the USB 3.0 OTG, the Gigabit Ethernet, the HDMI and more other features make it a perfect solution for IoT.

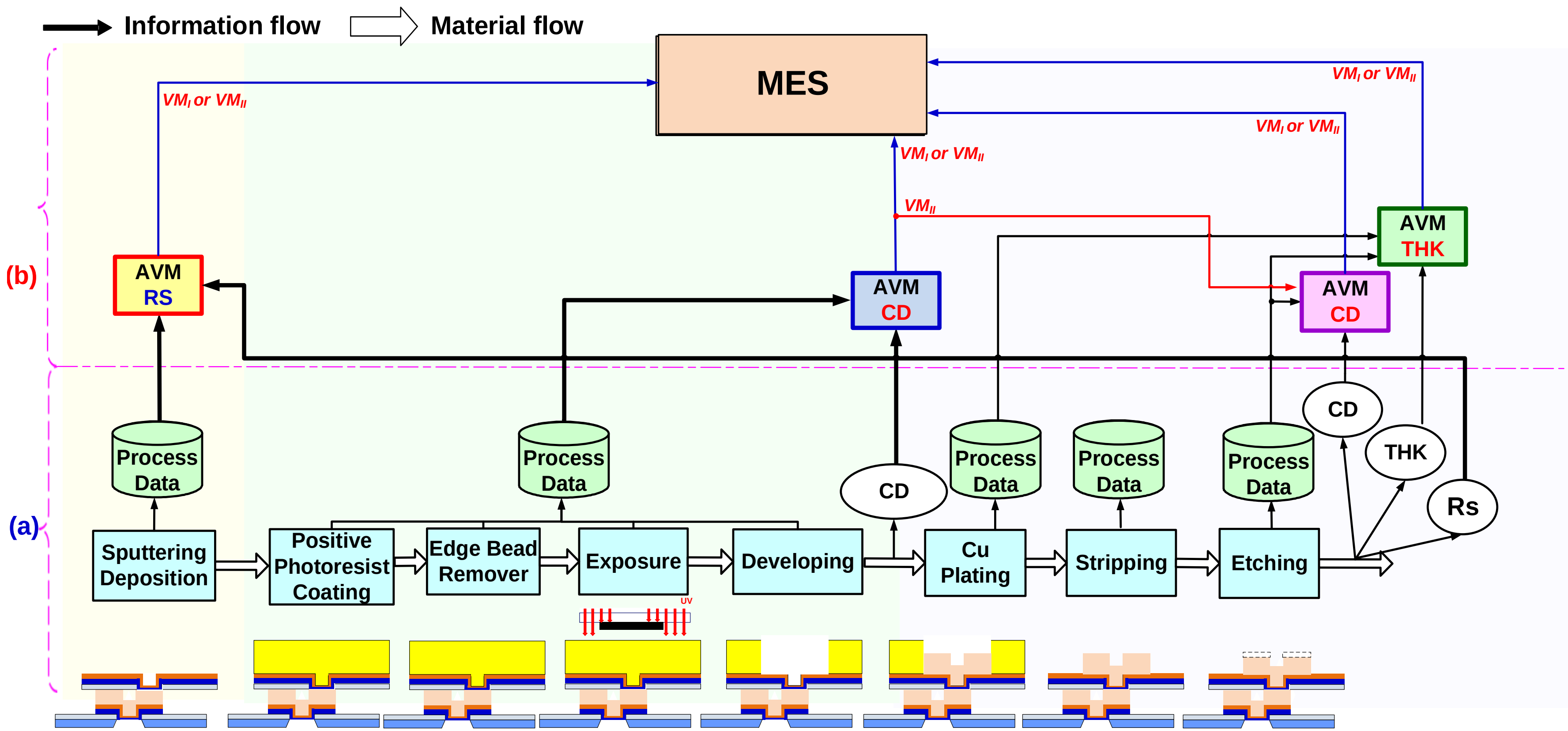


Cloud-based AVM System

AVM Server

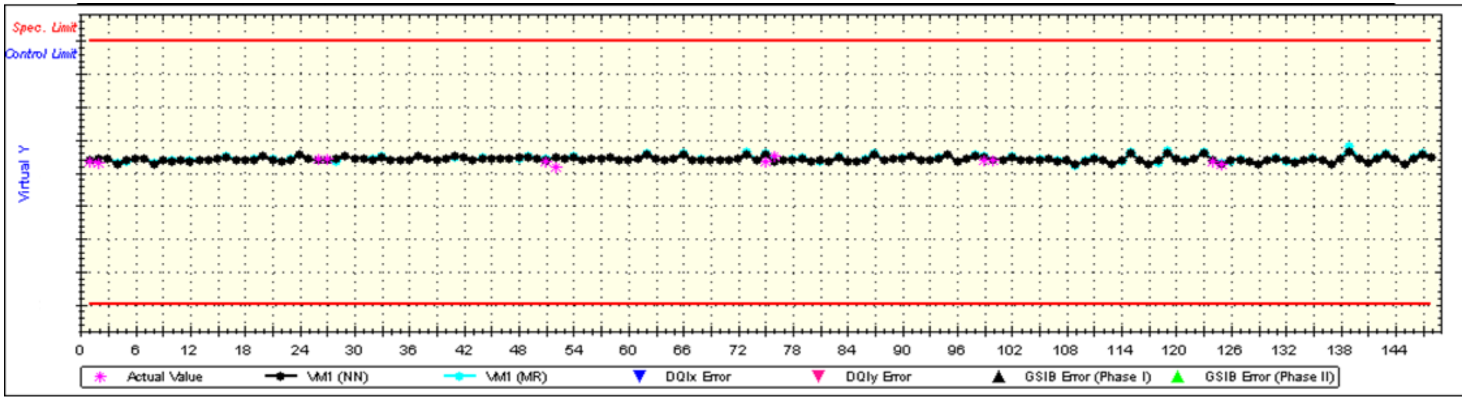

Data Quality Evaluations
Conjecture Algorithms
Process
Data
Metrology
Data
DQIx
Z-Score
Data Preprocessing
DQIy
Z-Score
Data Preprocessing
Only for
Training
& Tuning
Conjecture Model
Dual-Phase
Algorithm
RI Module
GSI Module
VMI
VMII
RI
GSI
Reliability Indexes

AVM Deployment for Bumping Process

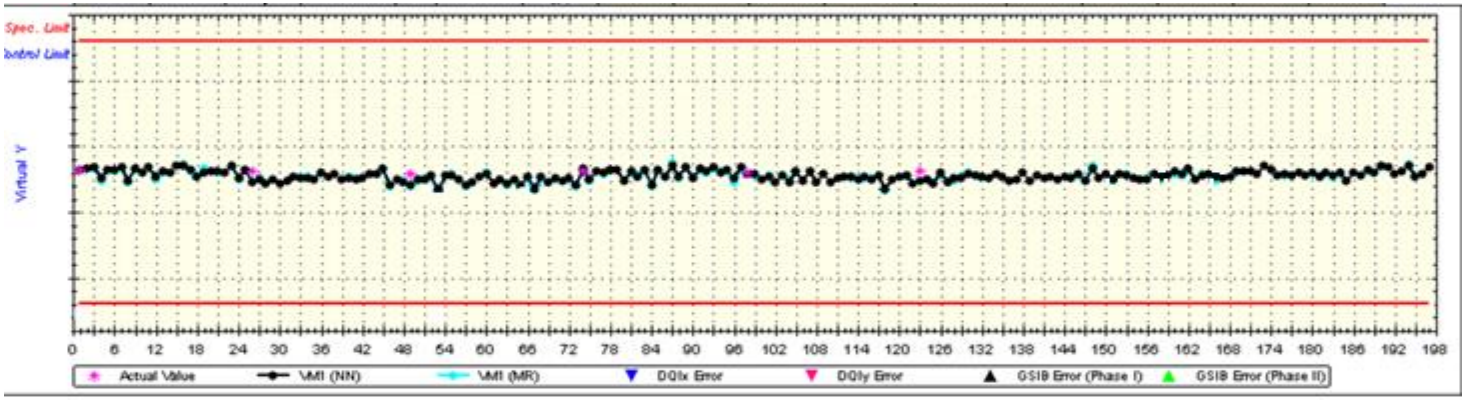


(a) Bumping UBM Process **(b) AVM Deployment**

AVM Results of CD & THK of Etching Process

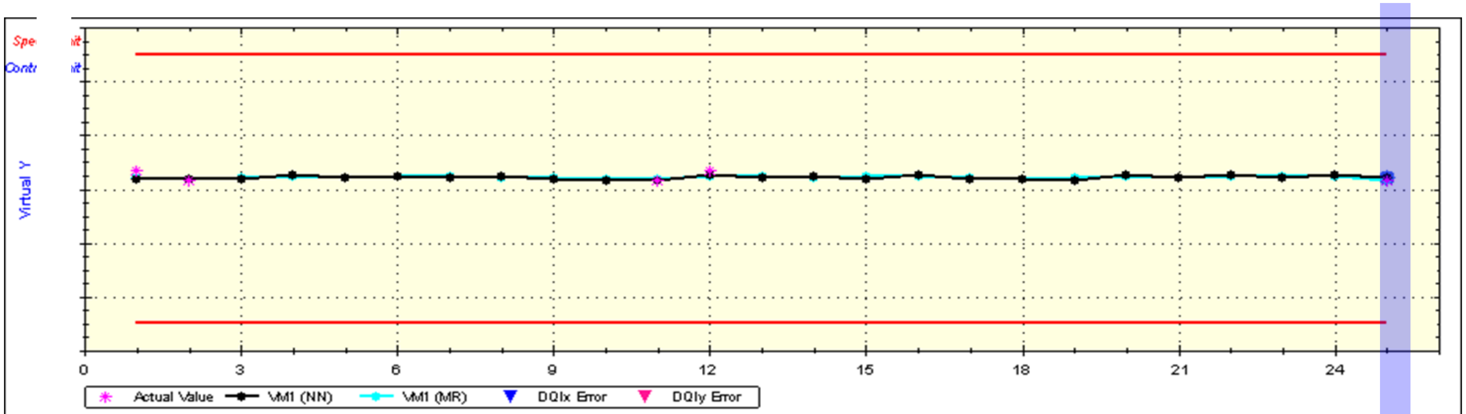


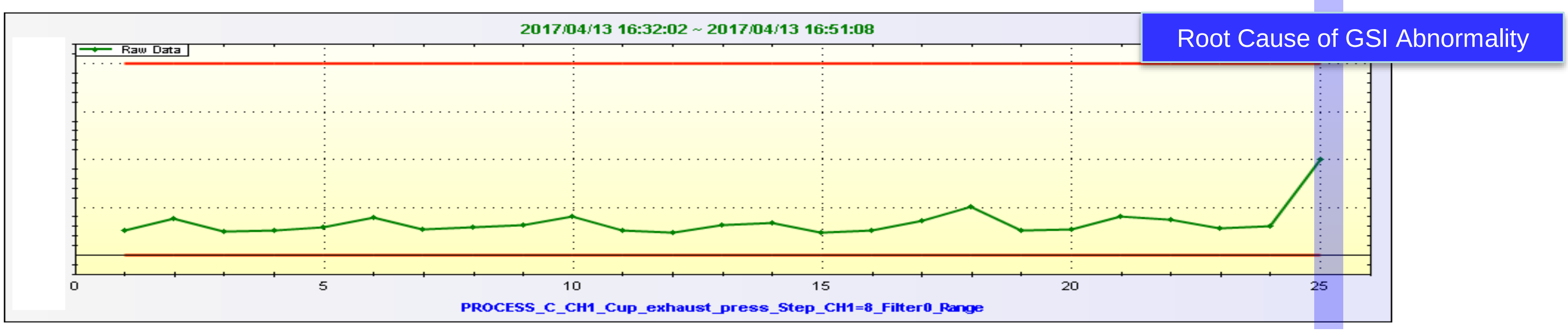
AVM Results of CD



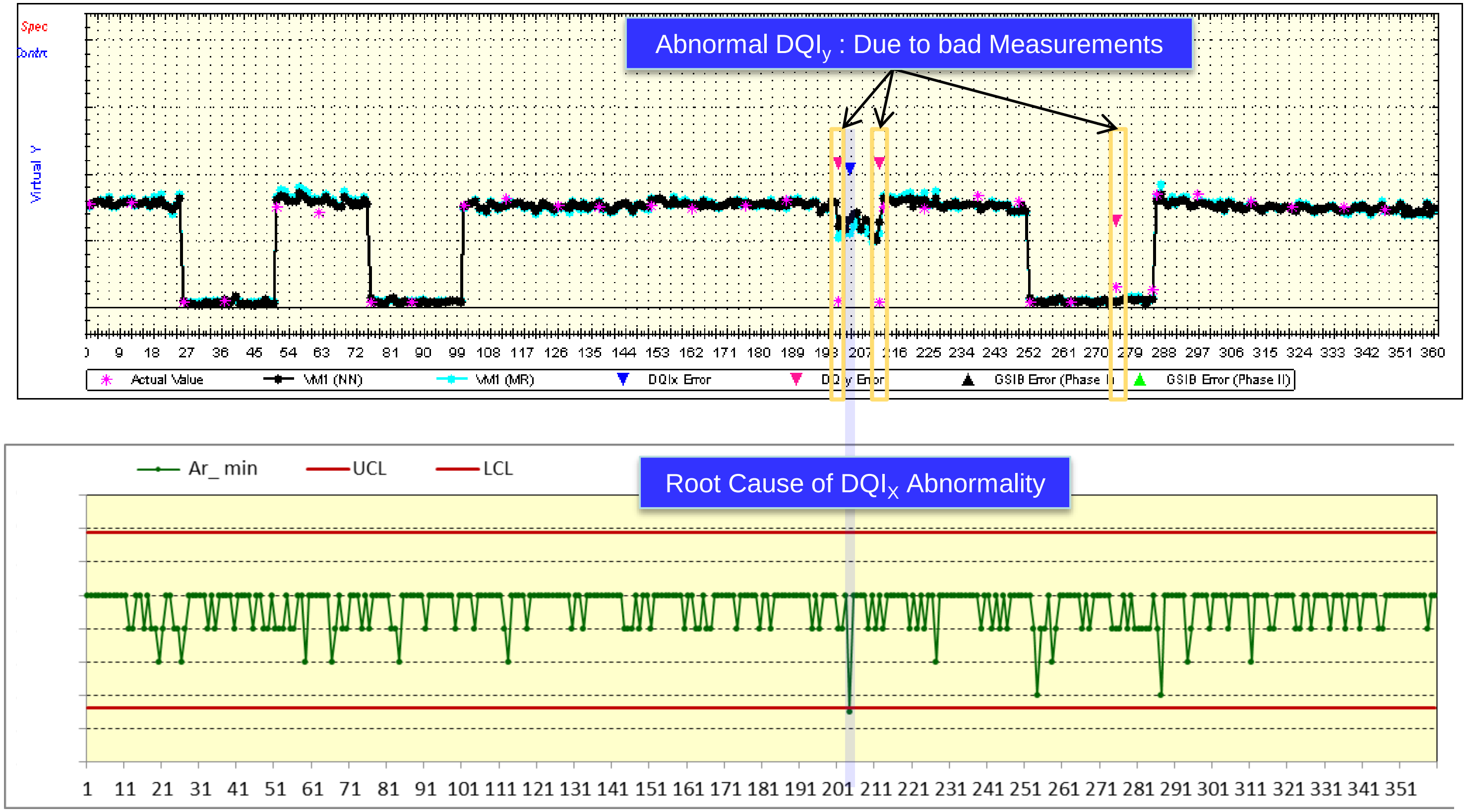
AVM Results of THK

AVM Results of CD of Photo Process

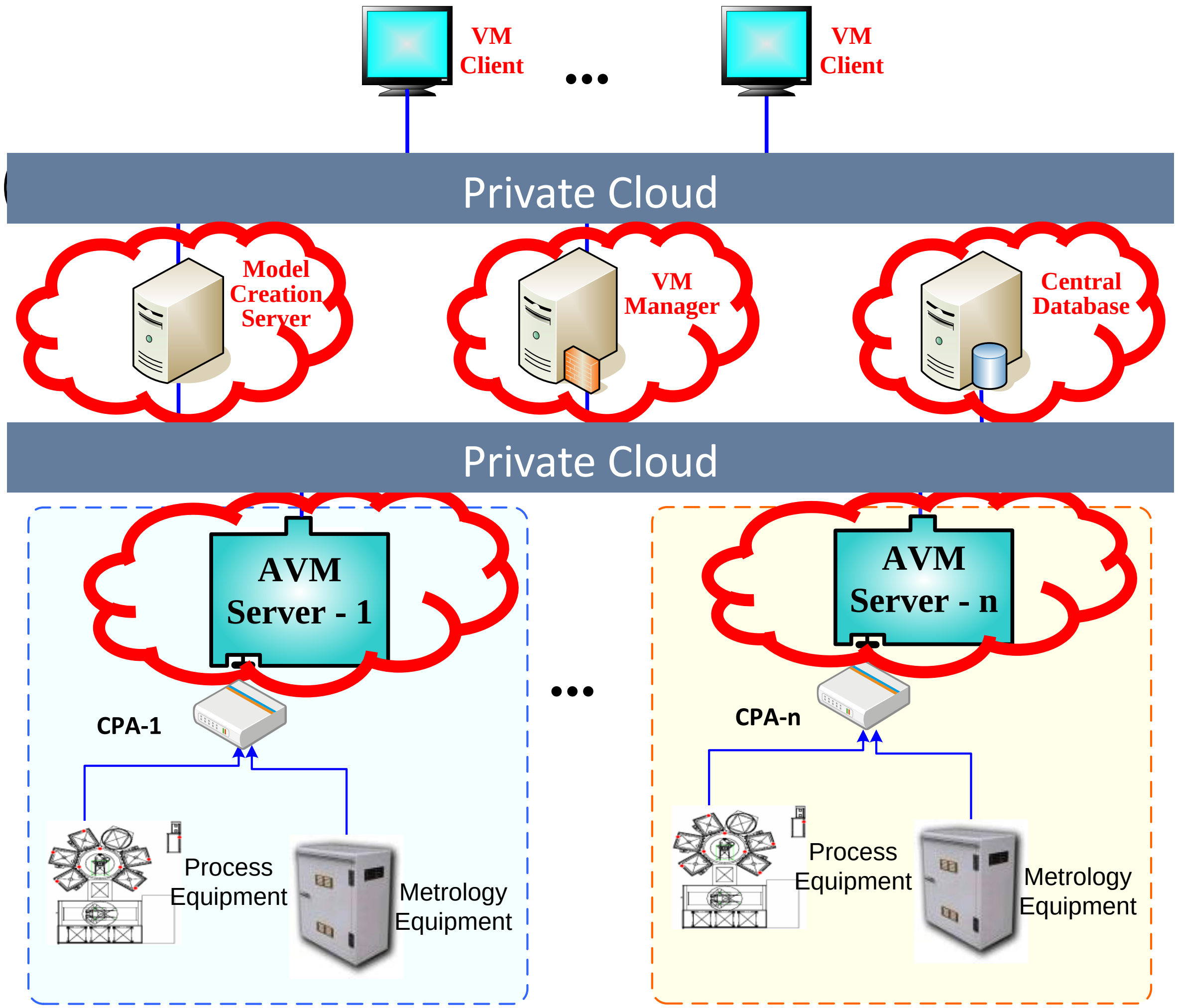




AVM Results of Resistivity



Cloud-based AVM System

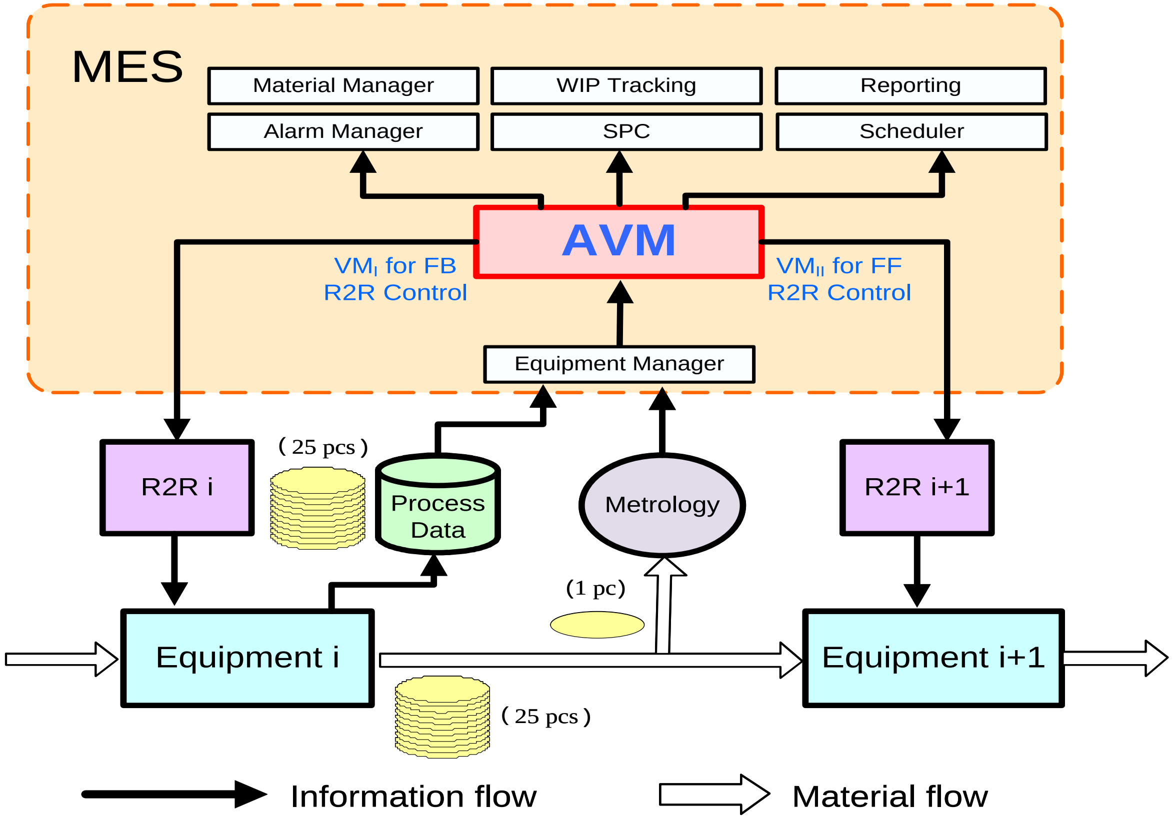


- H.-C. Huang, Y.-C. Lin, M.-H. Hung, C.-C. Tu, and F.-T. Cheng, "Development of Cloud-based Automatic Virtual Metrology System for Semiconductor Industry," *Robotics and Computer-Integrated Manufacturing*, Vol. 34, pp. 30-43, Feb. 2015.

Run-to-Run (R2R) Control

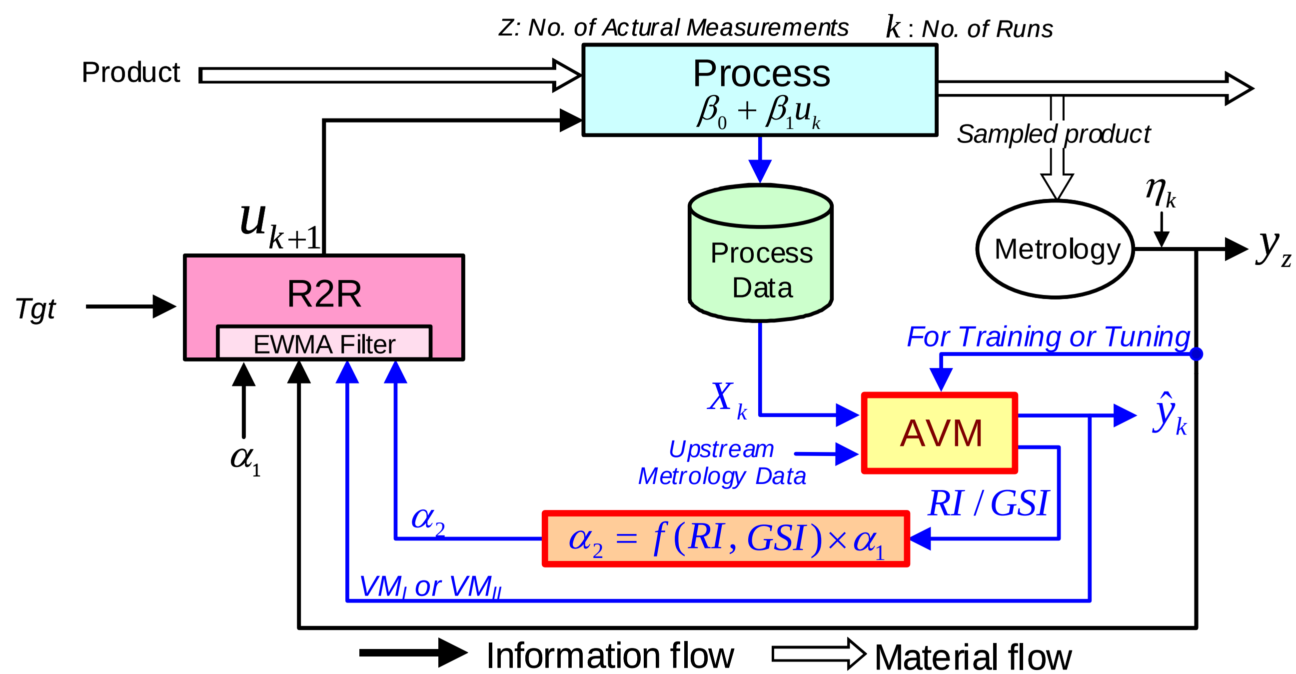
Integrating AVM into MES

- The purpose is to integrate the functions of AVM with those of MES. The interfaces among AVM, other MES components, and R2R (run-to-run) modules in the novel manufacturing system are defined so that the total quality inspection system can be realized and the R2R capability can be migrated from lot-to-lot control to wafer-to-wafer control.



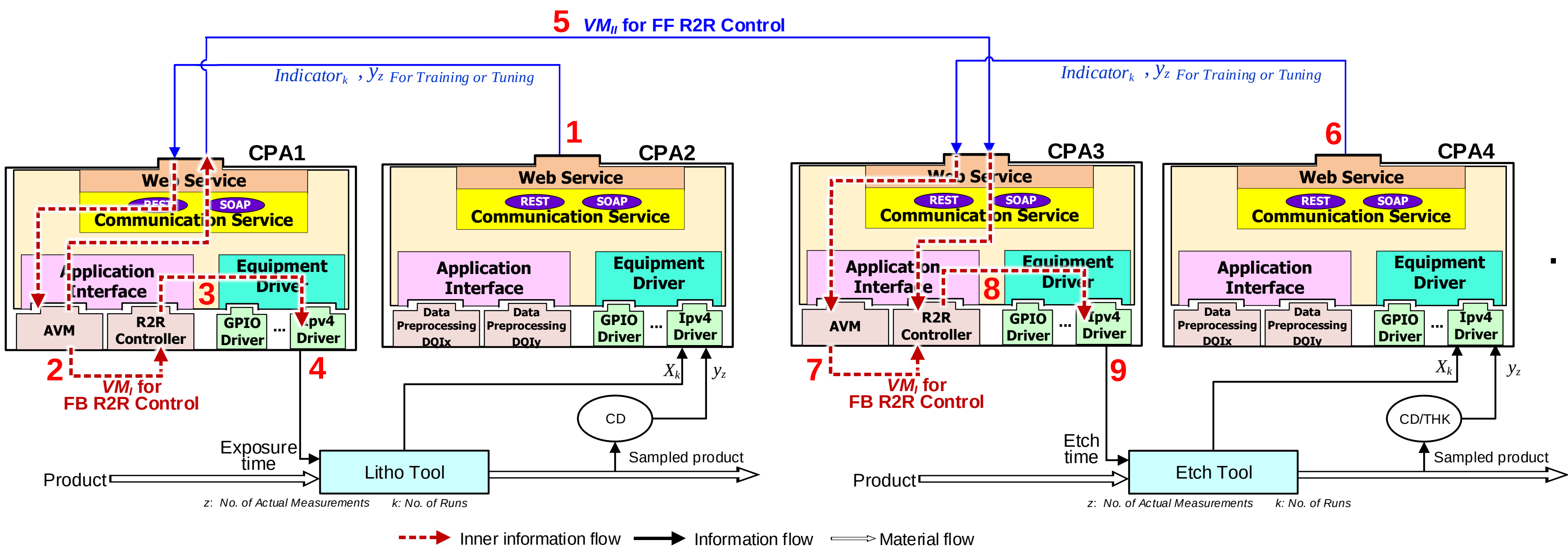
R2R Utilizing AVM with RI/GSI

- A key challenge preventing effective utilization of VM in R2R control is the inability to take the reliance level in the VM feedback loop of R2R control into consideration. The reason is that adopting an unreliable VM value may be worse than if no VM is utilized. The AVM system possesses the RI of VM to gauge the reliability of VM results [2], [A]. Therefore, this novelty is to invent a novel scheme of R2R control that utilizes AVM with RI/GSI in the feedback loop.



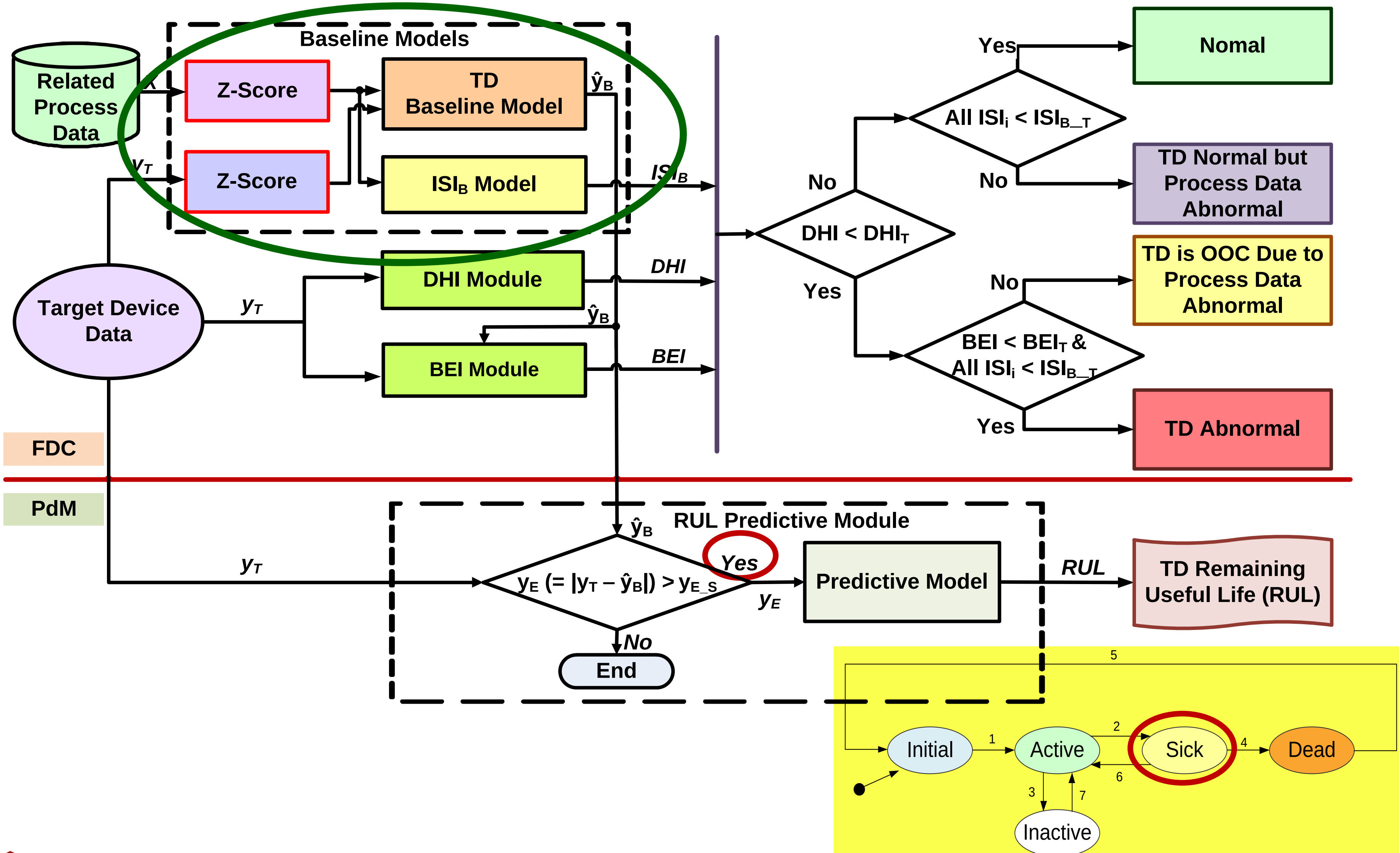
R2R Controls with CPA Horizontal Integration

- Litho and Etch R2R Controls with AVM and CPA Horizontal Integration

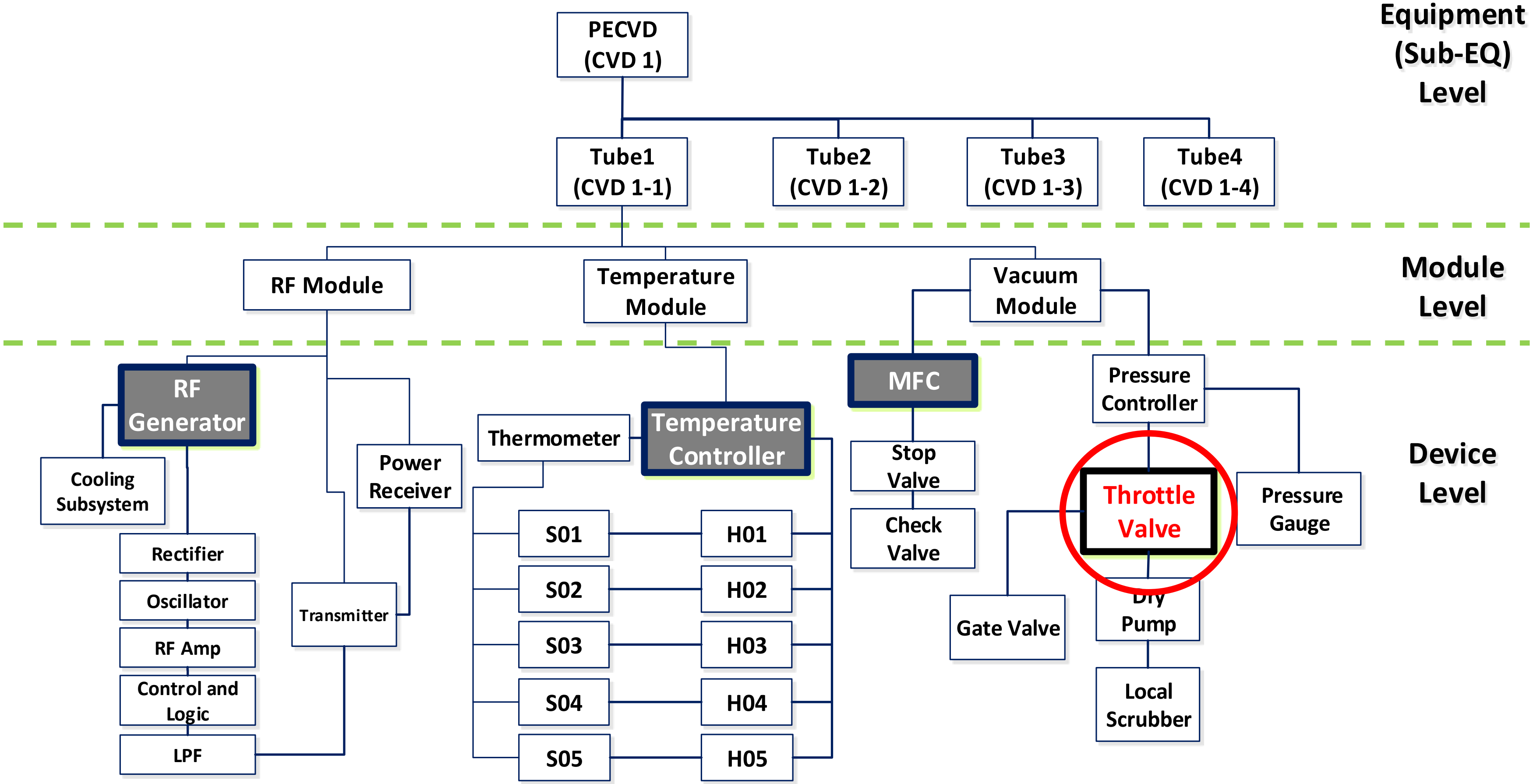


Cloud-based
Intelligent Predictive Maintenance (IPM) System

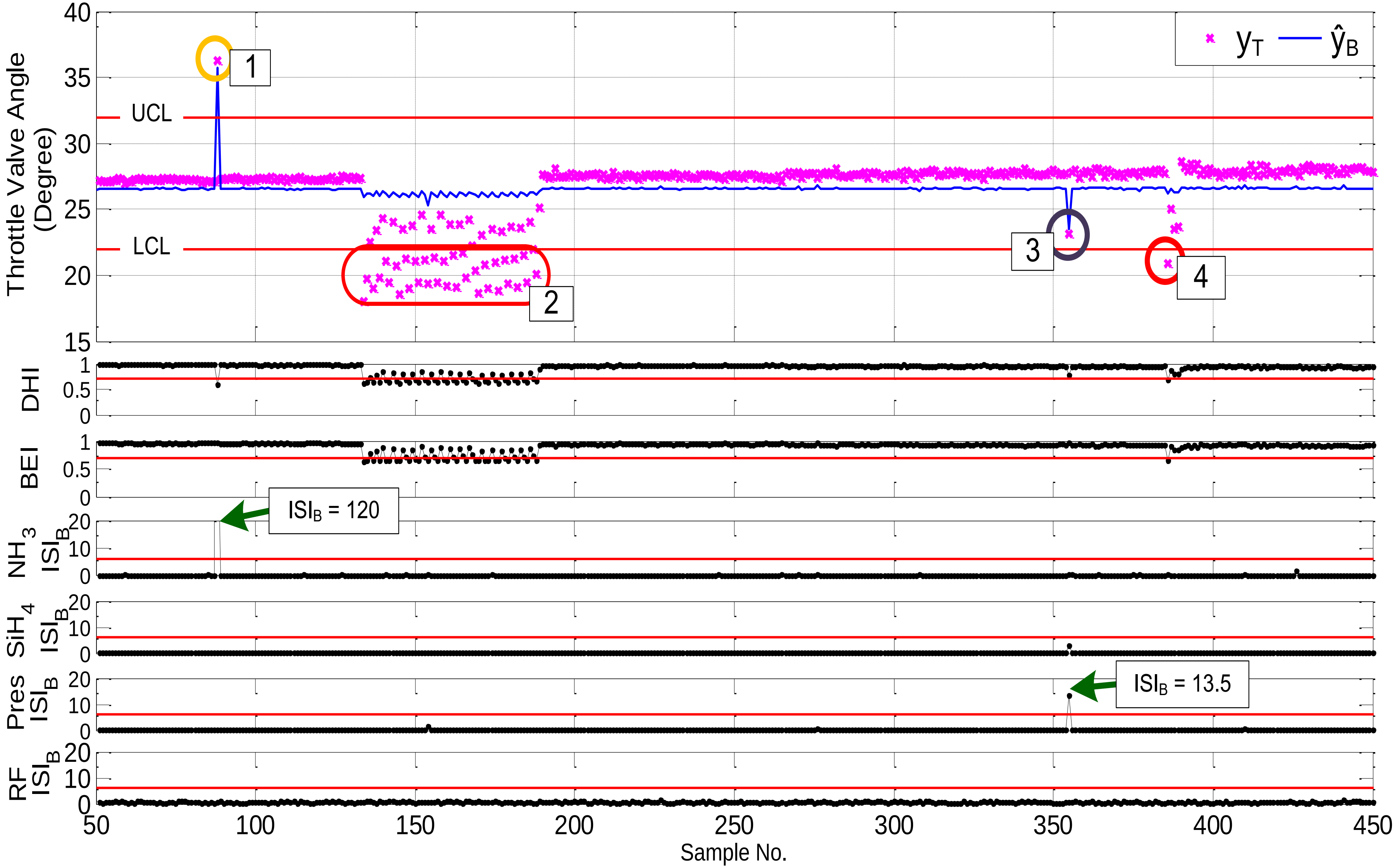
Baseline Predictive Maintenance (BPM) Scheme



Throttle Value of PECVD in Solar-Cell Manufacturing



Illustrative Example of FDC



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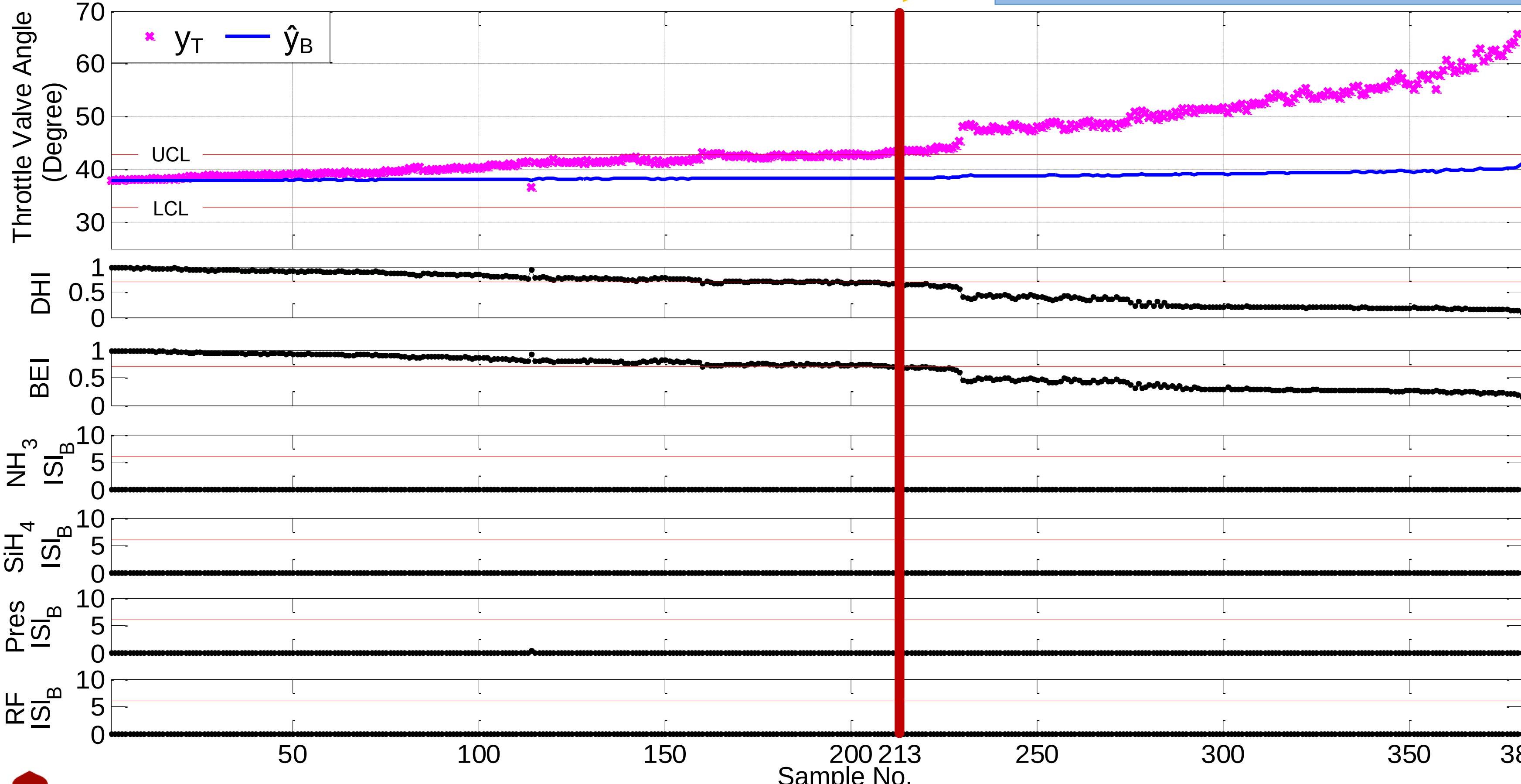
Illustrative Example of RUL Prediction 1/2

Sample 213 is the entry point of the sick state. This event activates the RUL predictive process.



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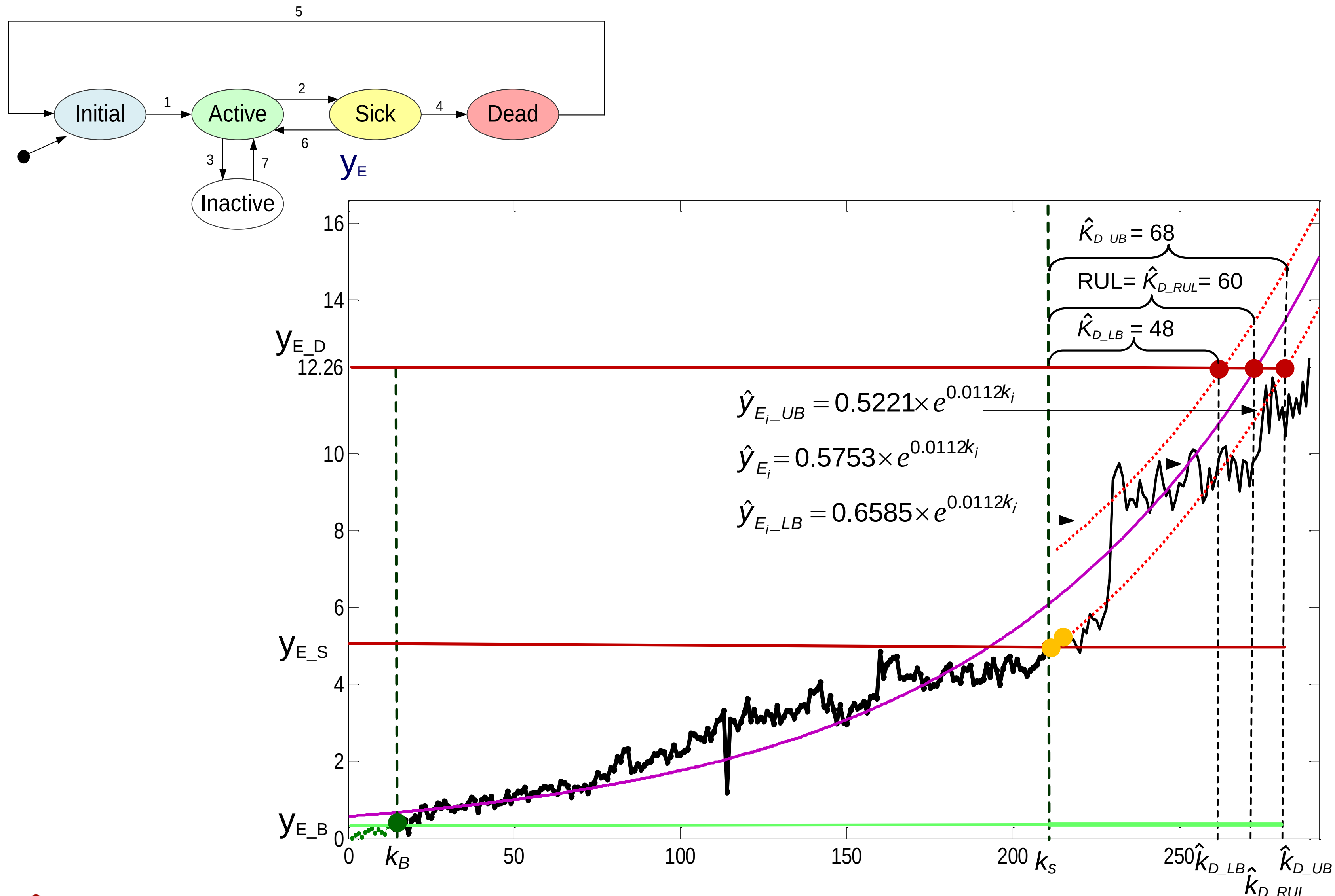
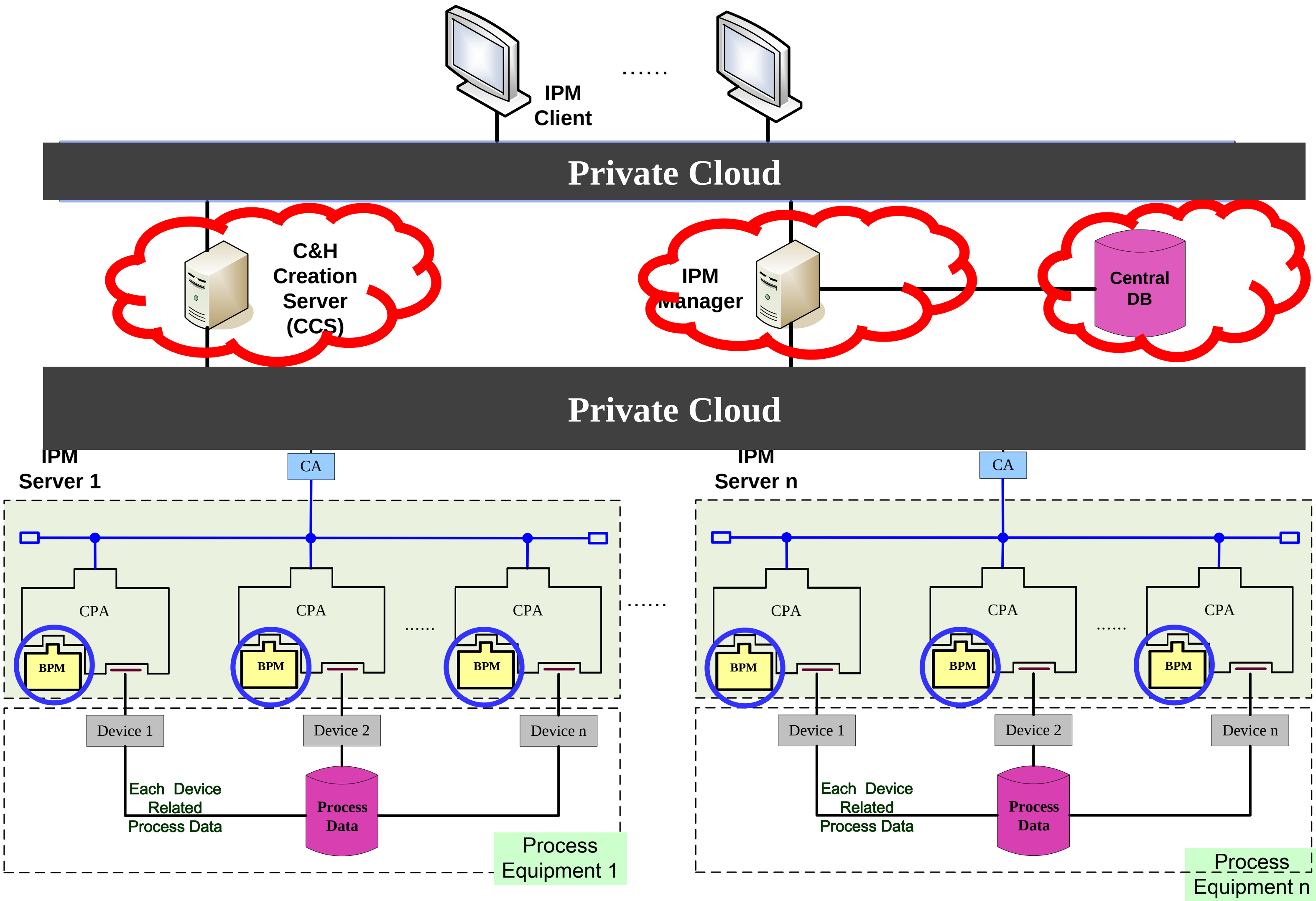
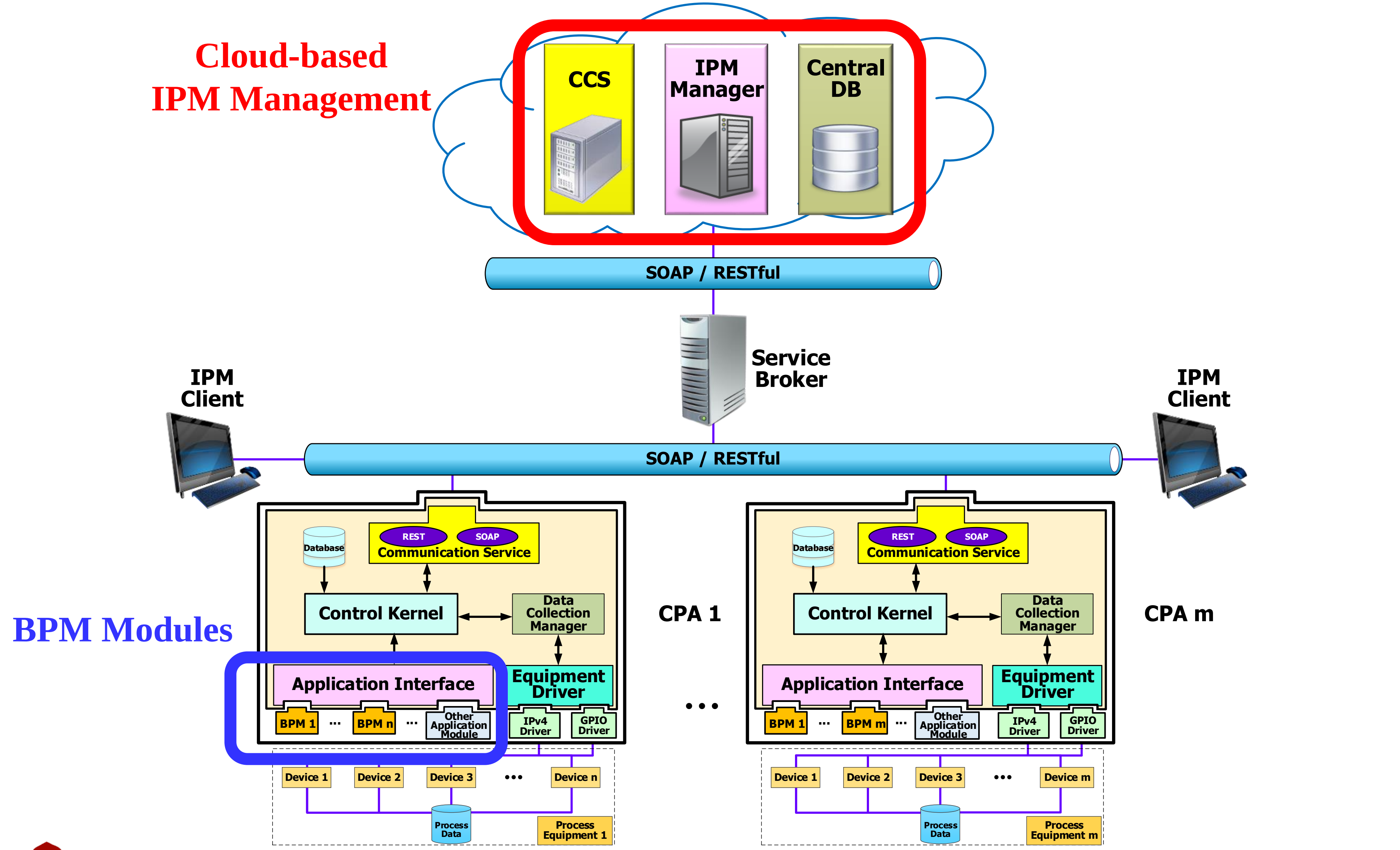
Illustrative Example of RUL Prediction 2/2



Cloud-based IPM System 1/2

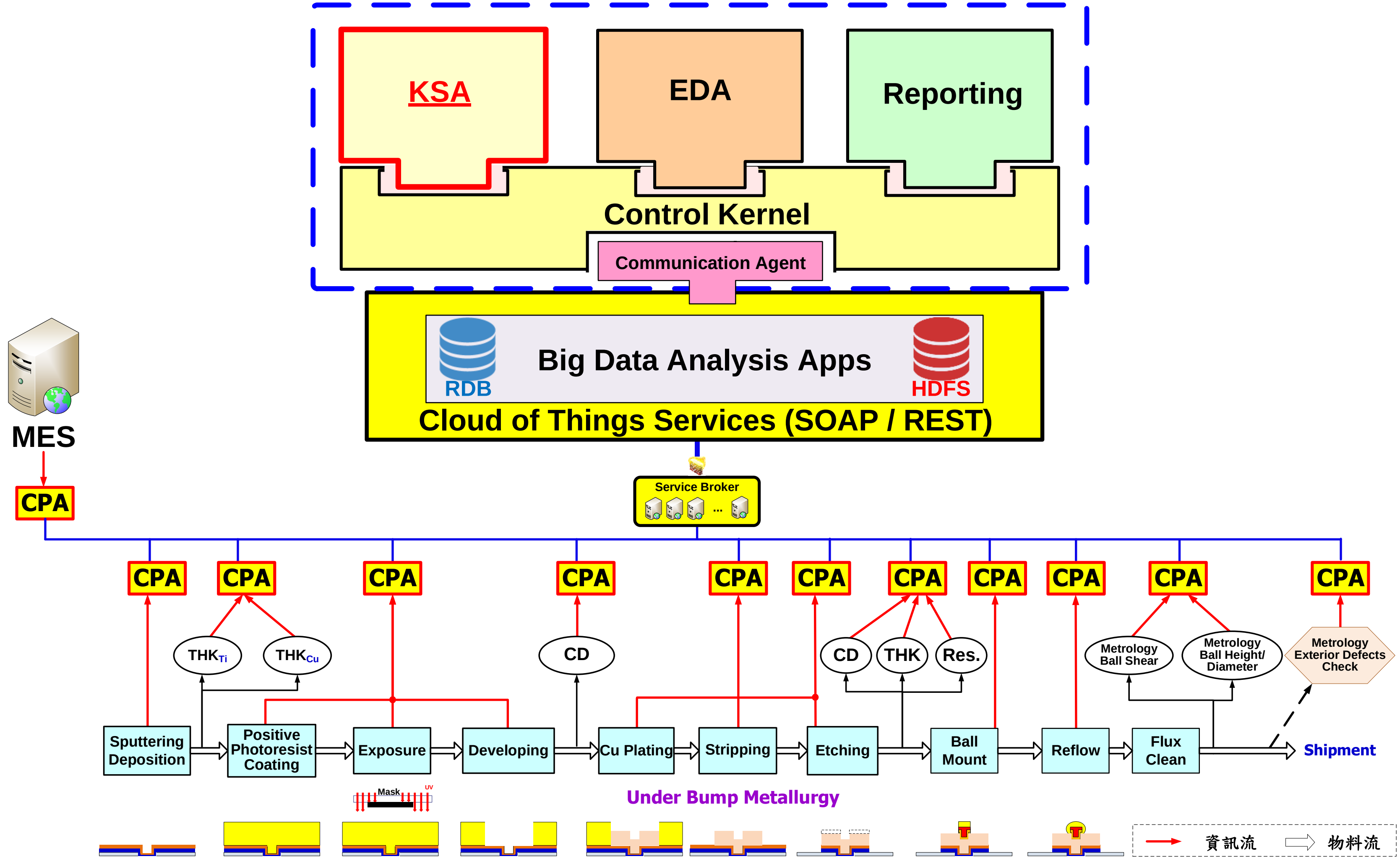


Cloud-based IPM System 2/2



Cloud-based
Intelligent Yield Management (IYM) System

Intelligent Yield Management (IYM) System Framework



Yield and Cost Changes in Product Development Cycle

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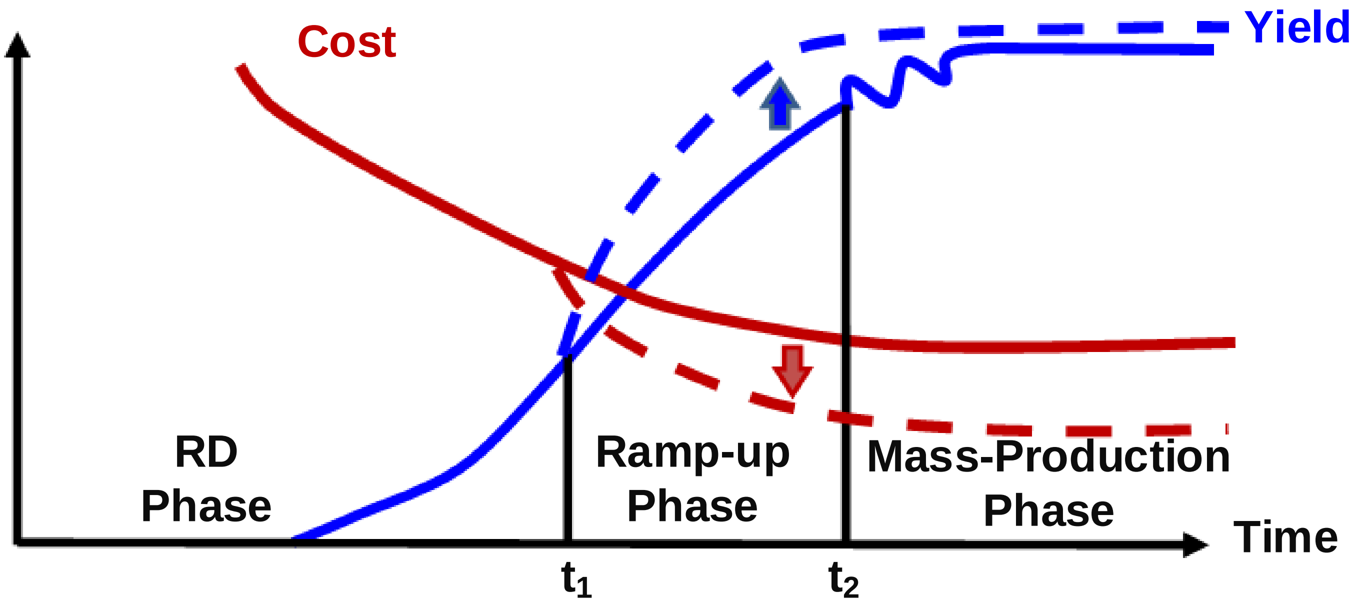


Fig. 1. Yield and cost changes in product development cycle.

Yield-Management Requirement Analysis

Yield-Management Requirement Analysis

- Product yield directly affect production cost, **manufacturers hope to effectively enhance product quality and yield in the R&D and manufacturing phases, or to quickly figure out the root cause when yield abnormality occurs in order to stabilize the ramp-up phase for cost reduction.**
- The current yield management systems analyze collected process data to find out the key information, and stabilize process by adjusting tool parameters; these are the ways that they try to enhance the yield. **However, data collection, analysis, and continuous cost waste of targeting the abnormalities could all lead to higher production cost.**
- In addition, the semiconductor manufacturing comprises more than dozens or hundreds of processes, with the parameters of each process and metrology results included, there could be thousands of possible causes of affecting the yield. **Engineers cannot effectively analyze and figure out the root cause among so many potential factors.**
- **To tackle these problems, a comprehensive yield enhancement and management system should be able to:**
  1. **Integrate in-fab data bases to effectively grab all possible data of poor yield for root cause analysis.**
  2. **The core algorithms could execute the calculation when "p >> n", and provide accurate results.**

Yield-Management Systems Comparison

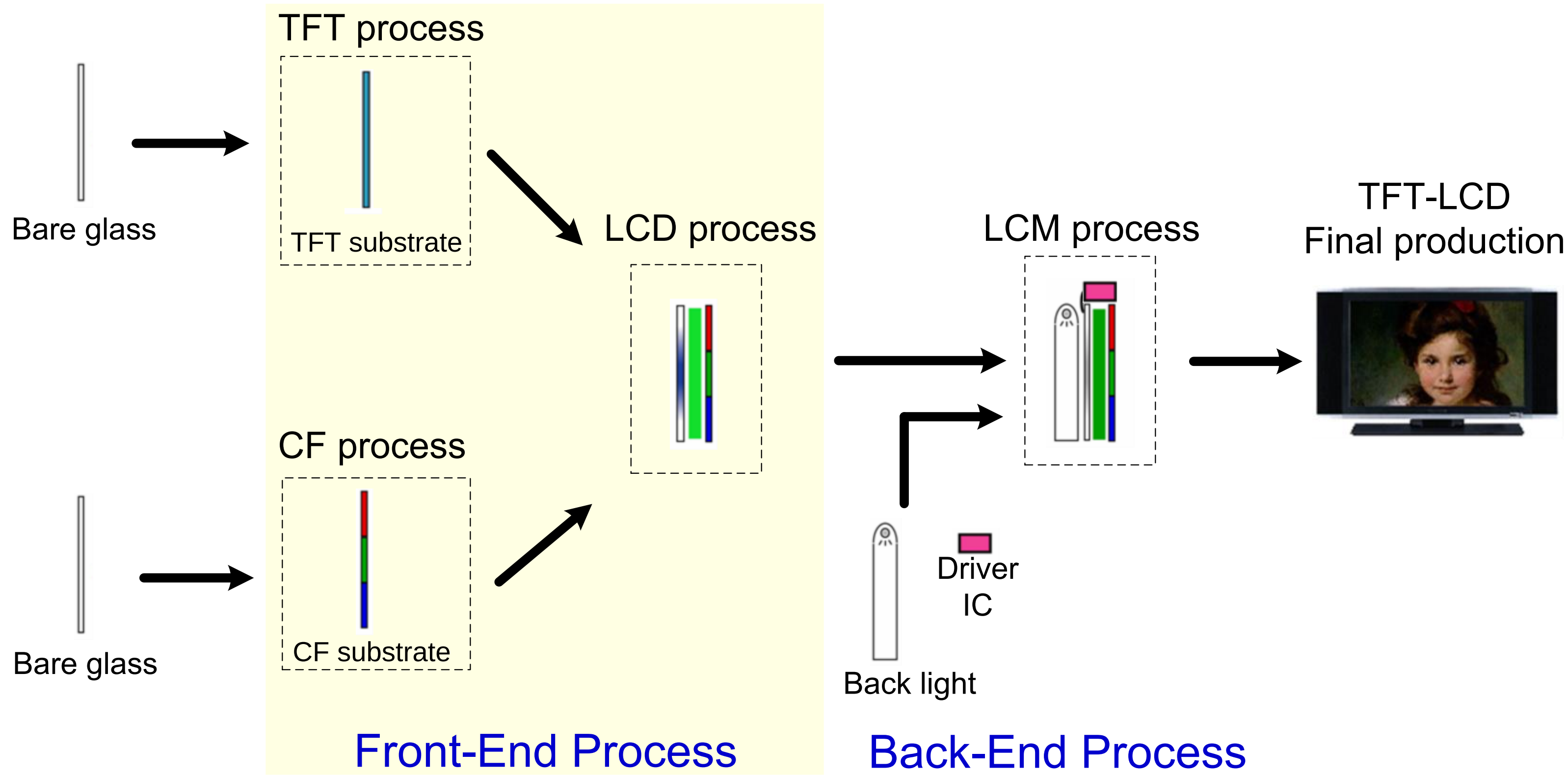
Yield-Management Systems Comparison among IYM System and Other Products

Item	IYM (KSA included)	Product of Company A	Product of Company B
Core algorithms can solve the problem of “p >> n”	Yes	No	Partially
Shorten T2M	Yes	No	No
Interface for in-fab database integration	Yes	Partially	No
RI_k and BSA	Yes	No	No
Interaction analysis among devices	Yes	No	Partially (Two-two comparison)
AVM integration	Yes Able to integrate the AVM results such as metrology value, RI, GSI, DQI_X, and DQI_y. Can figure out the problematic stages of certain devices after KSA analysis.	No	No
Basic statistical methods / Analysis charts	Yes	Yes	Yes

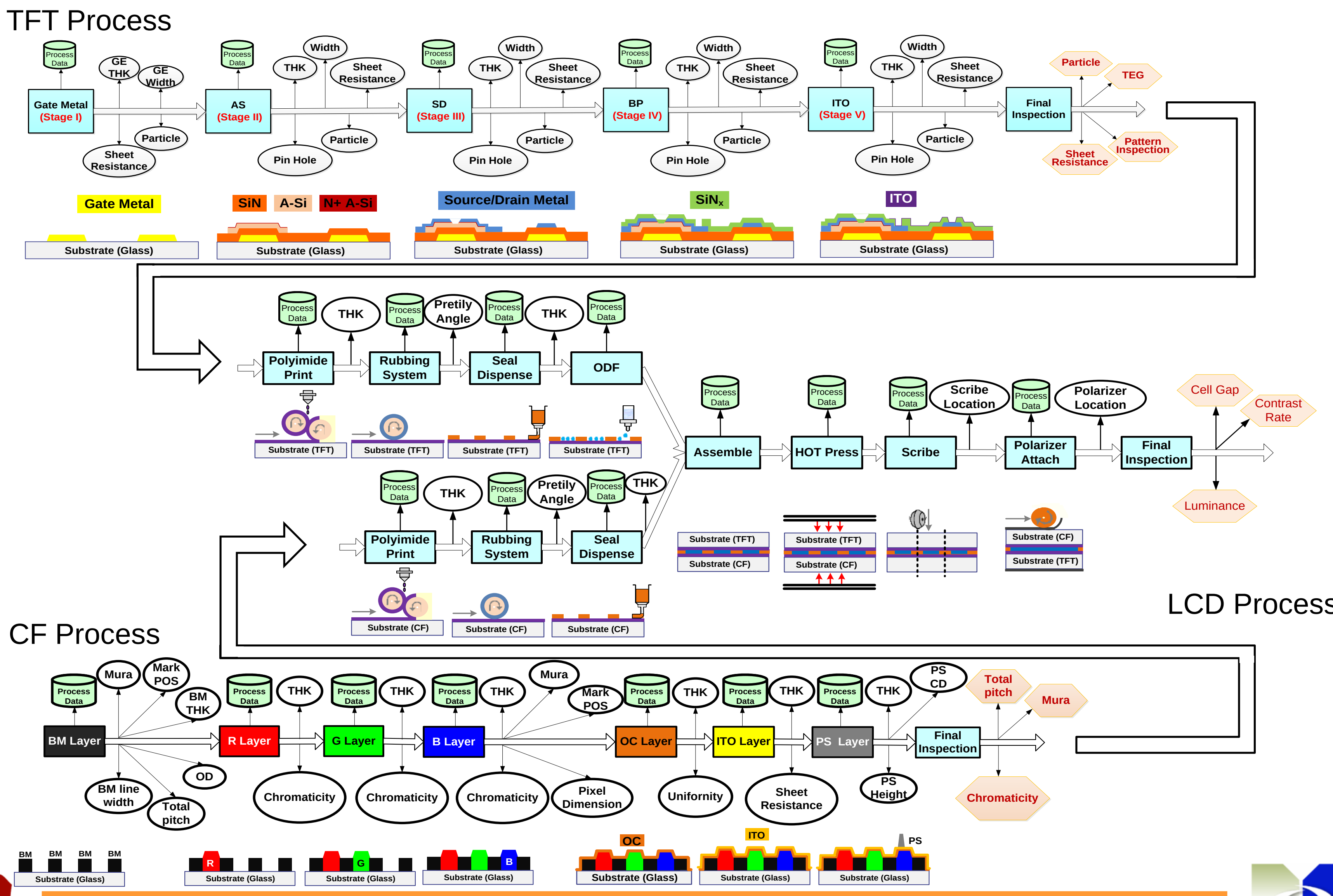
Key-variable Search Algorithms (KSA)
of IYM for Finding the Root Causes of Yield Losses

Process Flow of TFT-LCD Manufacturing

- The TFT-LCD manufacturing flow consists of four processes: TFT, CF (color filter), LCD, and LCM (liquid crystal module).

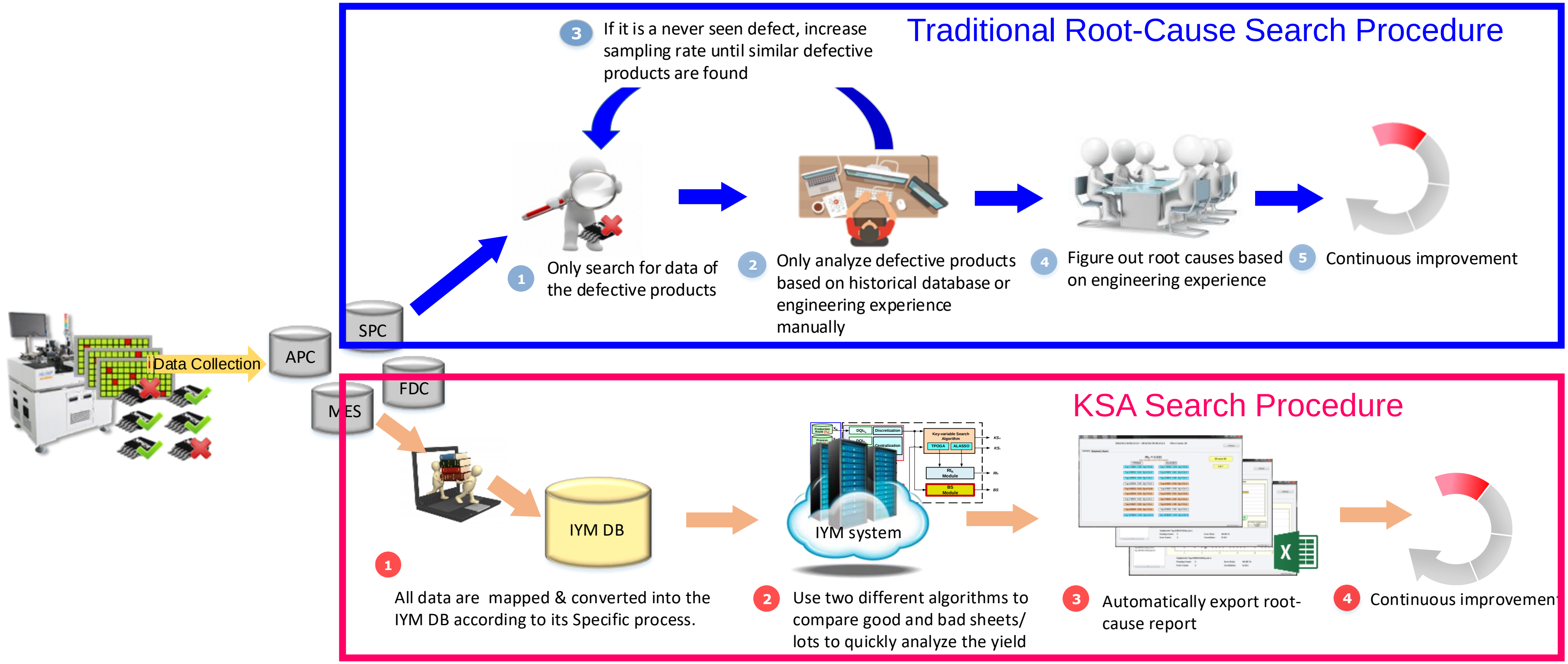


TFT-LCD Front-End Process



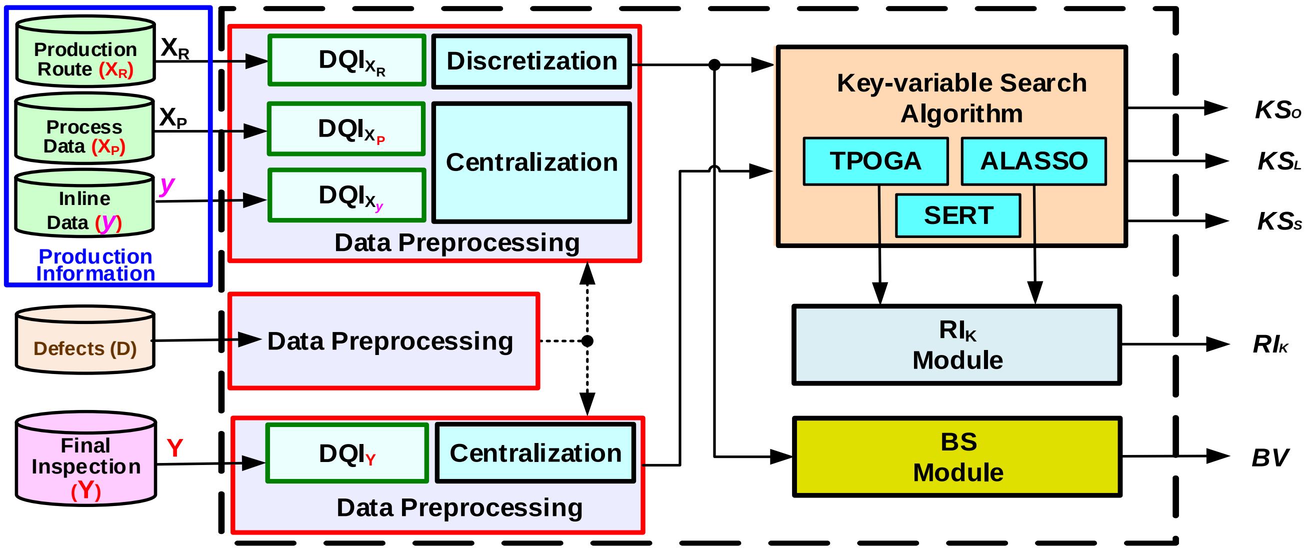
KSA Functions of the IYM System

- **By collecting routing data from MES, tool FDC data, SPC data, and final yield data, KSA can quickly find out the device that causes the yield loss and the root cause of the yield loss when the yield is poor.**
- **The KSA algorithms can be executed under the situation of "p >> n". It can figure out the target device that cause yield loss even during the R&D and ramp-up phases so as to shorten the time to market.**



KSA Scheme 1/2

- KSA Scheme includes:



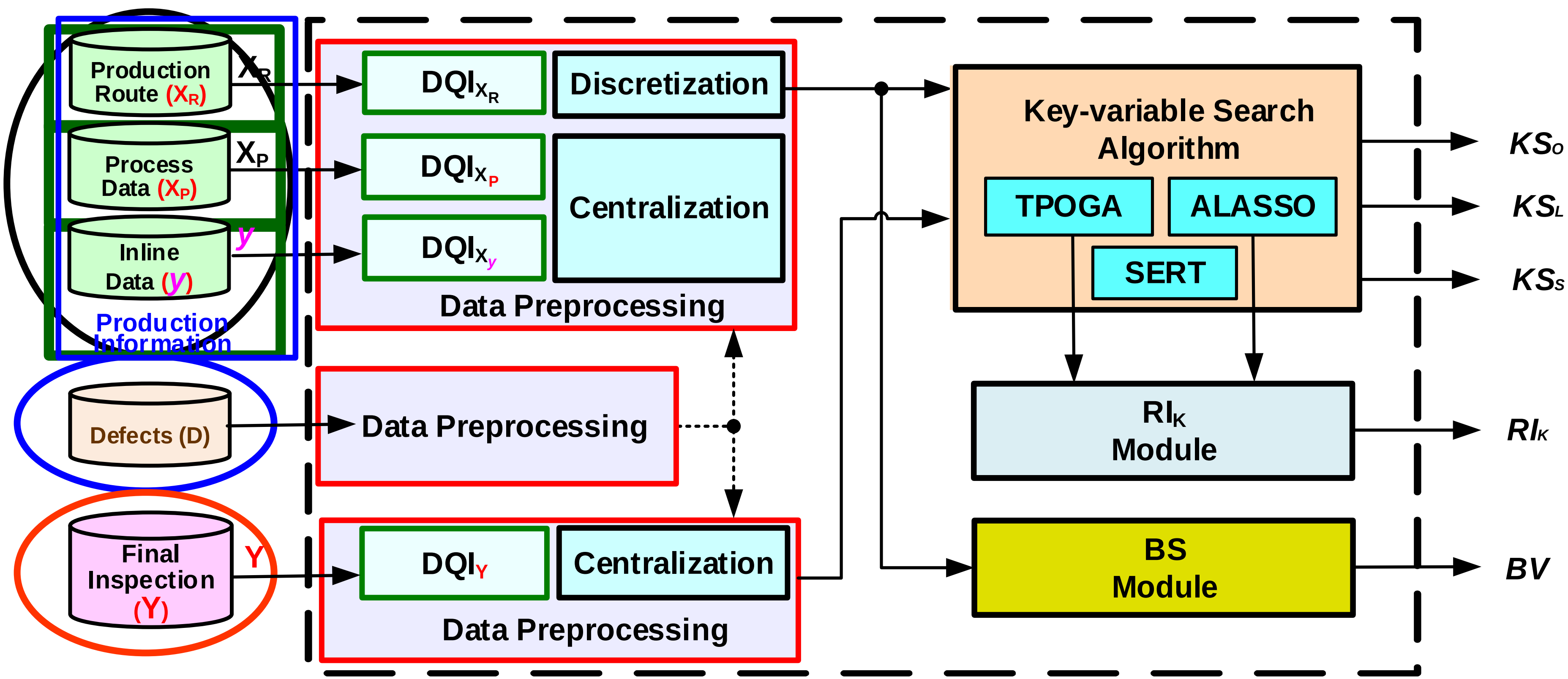
- **Data-Preprocessing Module:** includes data centralization, data discretization, and data quality checks.
- **KSA Analysis Module:** utilizes algorithms such as TPOGA (Triple Phase Orthogonal Greedy Algorithm), ALASSO (Automated Least Absolute Shrinkage and Selection Operator), and SERT (Sample-Efficient Regression Trees) to find out key stages for user reference.
- **RI_K Module:** generates a Reliance Index (RI) through comparing TPOGA and ALASSO results to show users the reliance level of the key-variable search results.
- **BSA Module:** assists the three KSA algorithms to find out the possible key-stage devices affecting the final yield that might be missed out due to certain production limits.

F.-T. Cheng, Y.-S. Hsieh, J.-W. Zheng, S.-M. Chen, R.-X. Xiao and C.-Y. Lin, "A Scheme of High-Dimensional Key-Variable Search Algorithms for Yield Improvement," *IEEE Robotics and Automation Letters*, vol. 2, pp.179-186, no. 1, January 2017.

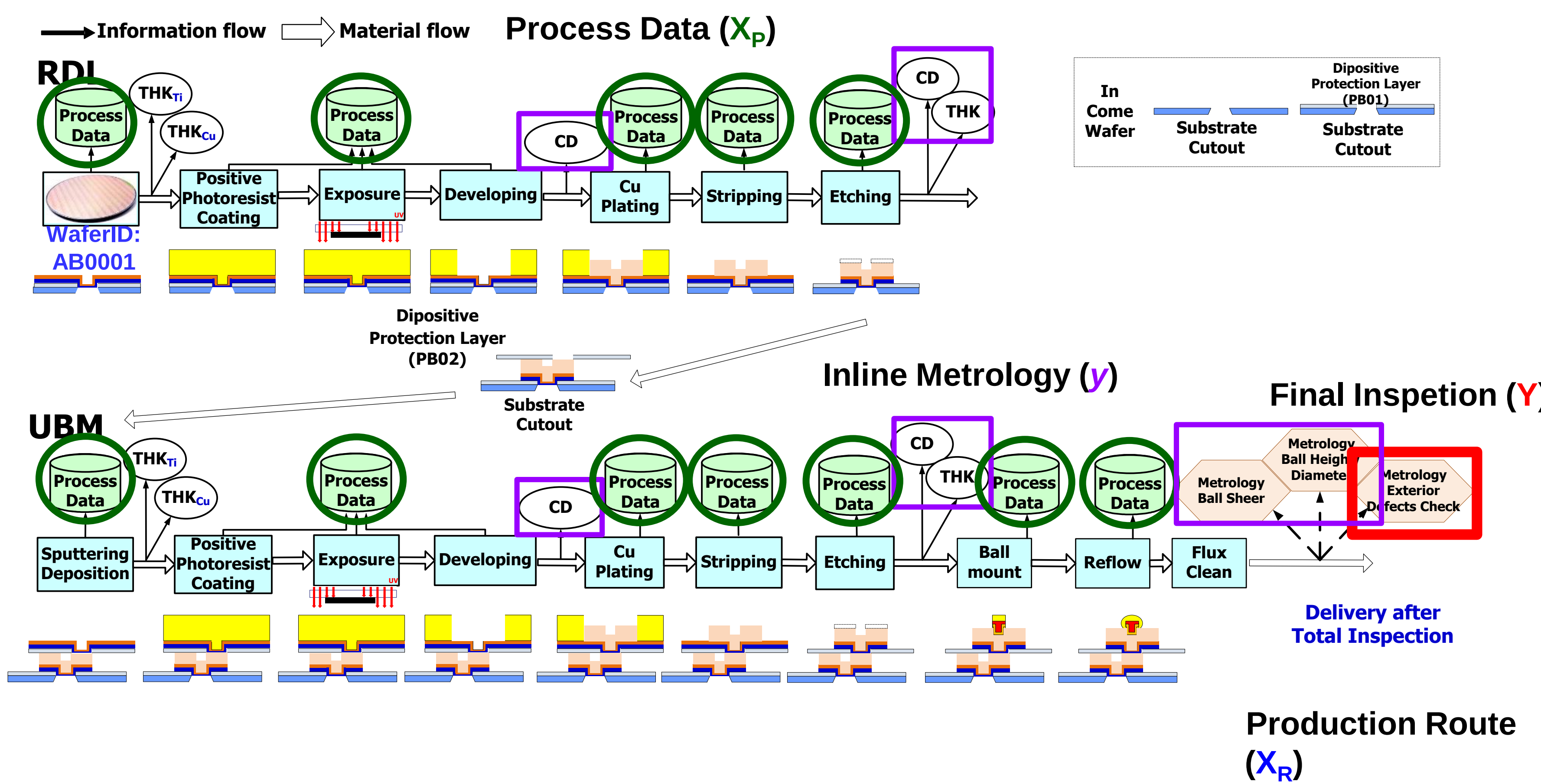
KSA Scheme 2/2

- Input data of the KSA scheme can be sorted into three types:
  - **Production Information**
  - **Defects**
  - **Final Inspection**

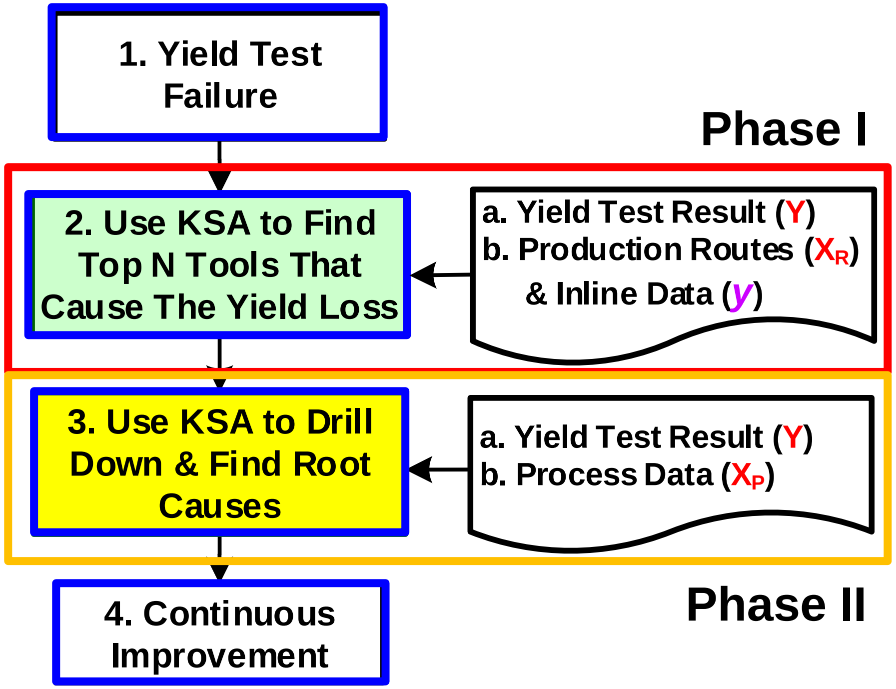
- Production information includes: **1. Production route (X_R), 2. Process data (X_P), and 3. In-line metrology values which may contain real metrology (y) or Virtual Metrology ($\hat{y}$) values.**



Input Data of KSA
Take Bumping Process for Illustration



Procedure for Finding the Root Causes of Yield Losses by Applying the KSA Scheme



Procedure for finding the root causes of a yield loss by applying the KSA scheme.

- Step 1: When a yield test failure is encountered, the root-cause search procedure is launched.
- Step 2: The data of yield test result (Y) as well as inline data (y) and production routes (X_R) are fed into the KSA scheme to search for the Top N (=3 for example) devices that cause the yield loss.
- Step 3: The same data of yield test result (Y) and the process data (X_P) of all the devices of the stage to which the most suspicious device belongs are fed into the KSA scheme to search for the key variables that cause the yield loss.
- Step 4: Issue a notice to the relevant departments for fixing the problem and for continuous improvement.

KSA Experimental Results

KSA Experiment – Bumping Process (Y = Final Defect)

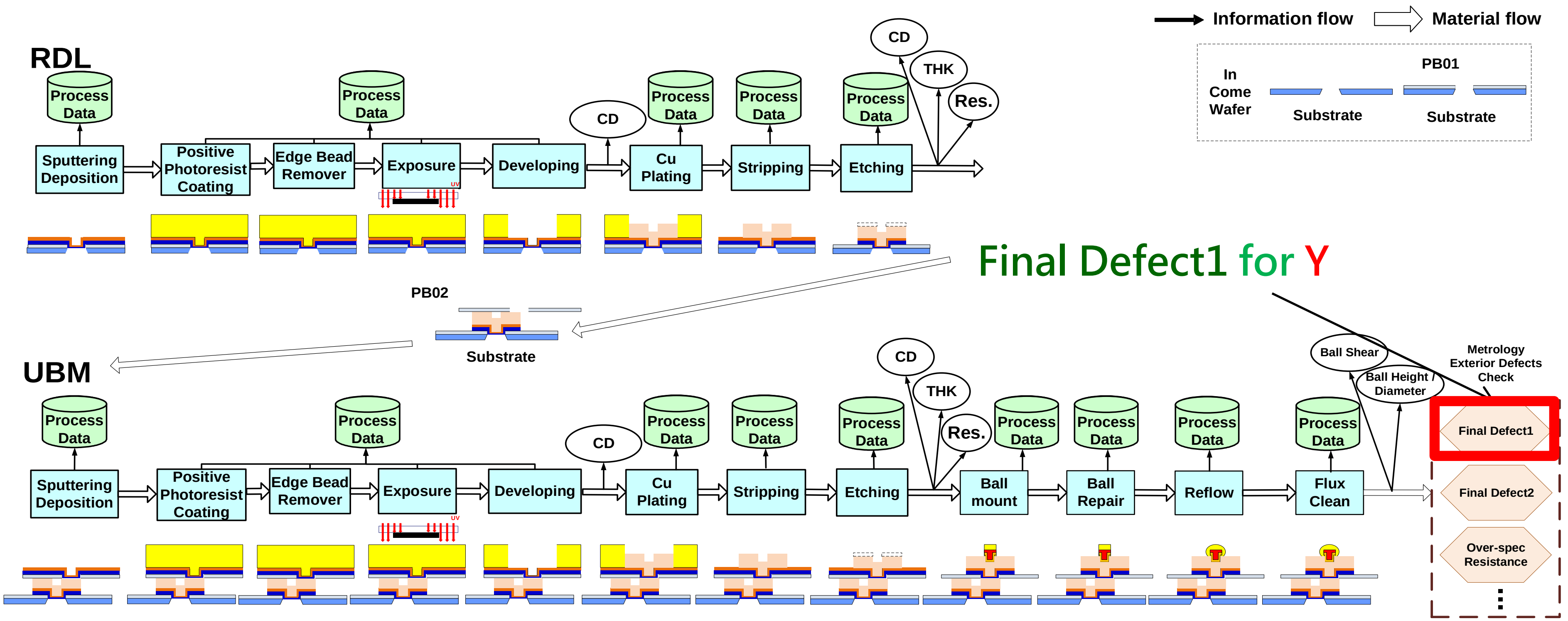
KSA Experiment Illustration and Summary

- **KSA can analyze the key parameters that increase (positive correlation) or decrease (negative correlation) Defects so as to quickly find out the target (worse or better yield) devices for engineers reference.**
- KSA is used to conduct Defect Analysis.
  - **Execute Expert Search by gathering expert experience.**
  - **Carry out Blind Search if no expert experience is available.**
- Analysis is focused on two frequently-occurred Defects: **Final Defect1** and **Final Defect2**:

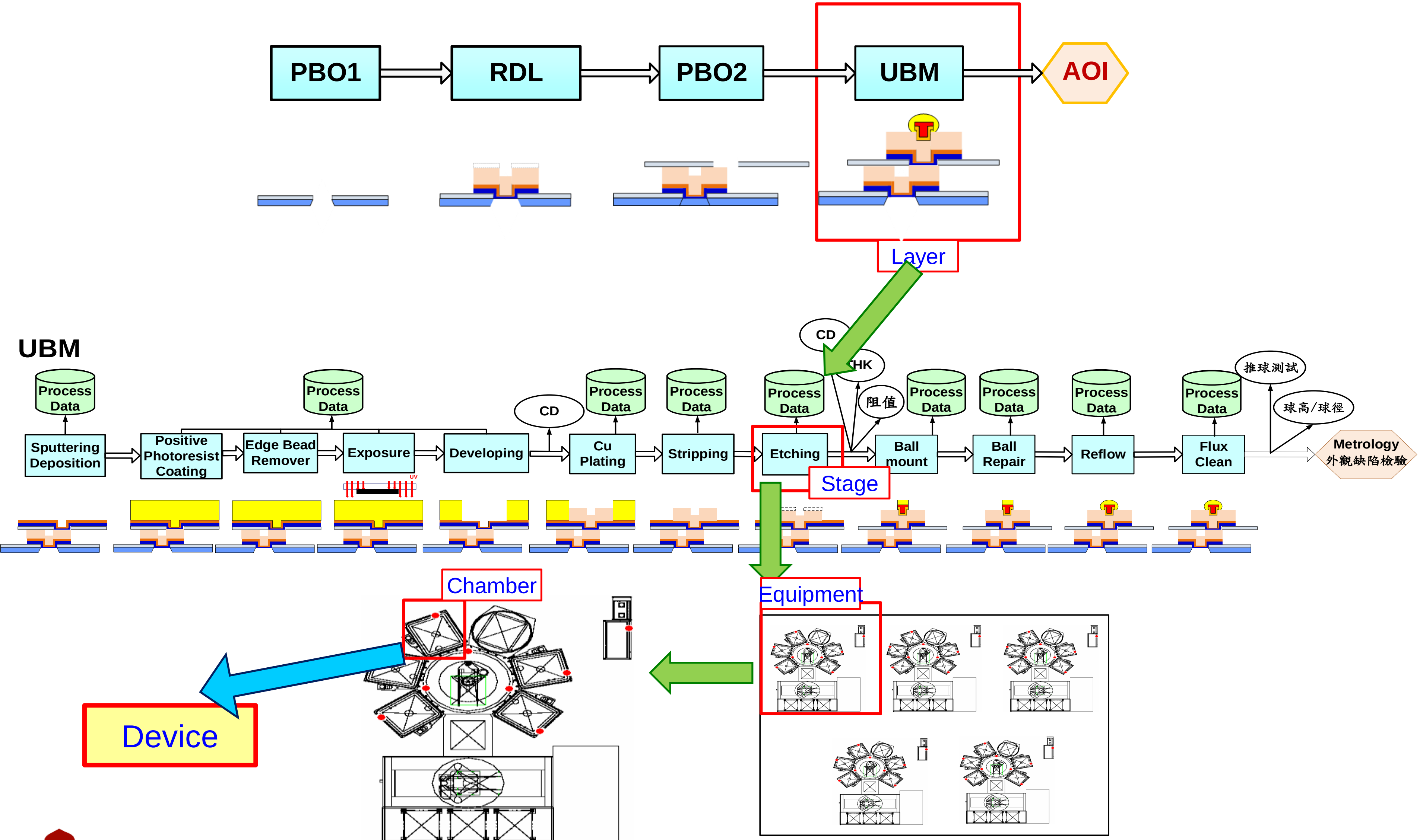
Defect	Month	DEFECT DIE_QTY
(Final Defect1)	2016/12	4753
	2017/01	6896
	2017/02	2761
(Final Defect2)	2016/12	2369
	2017/01	4713
	2017/02	1786

- After discussing about physical meanings with the engineers, it is found that both **Final Defect1** and **Final Defect2** occur more often in the RDL layer. **The comparison is done between the result analyses with (only RDL stages are analyzed for Expert Search) and without (all data are included for Blind Search) expert experience.**
- **The results indicate that the analysis done of Blind Search are quite similar to that with Expert Search; and the accuracy is confirmed well by users.**
- **It is proved that even dealing with Defect items without expert experience (Blind Search), the KSA system can generate a key parameter affecting the yield with high reliance index for the engineers to achieve the goals of quickly handling the abnormal devices and enhancing product yield.**

KSA Data Analysis

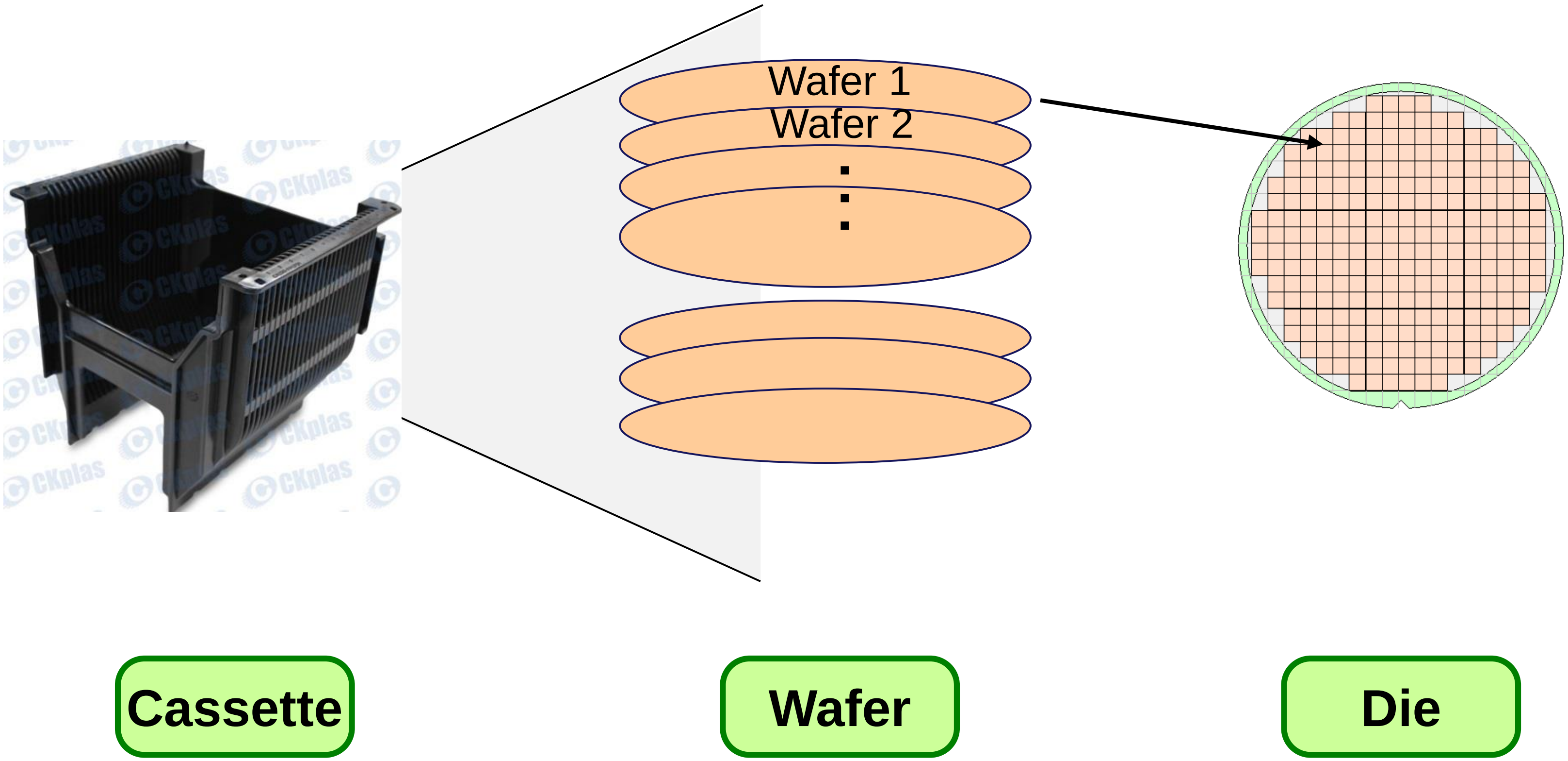


Hierarchy of Bumping Process 1/2



Hierarchy of Bumping Process 2/2

- **Production unit**



Experiment Conditions
-By Lot-

	Content			
Source	Bumping Process			
Data Info.	Metrology Item	Filtering Condition	Analysis Period	Tools for Analysis
	Final Defect1	All Lots	2016/12/16~12/31	Bumping Process (Metrology tools excluded)
Test Info.	No.	Final Defect1		
	Count	267 Lots		

Input

MES (X_R)

1. Expert Search (E): Only devices in the RDL layer.
2. Blind Search (B): All data.

EDA Defect Data (Y)

Final Defect1

Output

Suspicious Defect Killer

Final Defect1
2016/12/16~12/31

Experiment Results
RI_K & BS

Top 2 key devices are the same

Expert Search (E): $RI_K = 0.821$ — The Key-Stage from KSA Search		Blind Search (B): $RI_K = 0.786$ — The Key-Stage from KSA Search	
RDL Exposure Process: Tool A	RDL Exposure Process: Tool A	RDL Exposure Process: Tool A	RDL Exposure Process: Tool A
RDL Plating Process: Tool B	RDL Plating Process: Tool B	RDL Plating Process: Tool B	RDL Plating Process: Tool B
Dry Process After RDL Photo: Tool A	RDL Remove Process: Tool B	Dry Process After RDL Photo: Tool A	RDL Remove Process: Tool B
RDL Sputter Process: Tool A	RDL Remove Process: Tool A	UBM Clean Process: Tool A	RDL Remove Process: Tool A
RDL Exposure Process: Tool B	Dry Process After RDL Photo: Tool A	Reflow Process: Tool B	Dry Process After RDL Photo: Tool A
RDL Coating Process: Tool A	RDL Sputter Process: Tool A	RDL Coating Process: Tool B	RDL Sputter Process: Tool A
RDL Descum Process: Tool A	RDL Sputter Process: Tool C	RDL Exposure Process: Tool B	RDL Sputter Process: Tool C
RDL Remove Process: Tool A	RDL Exposure Process: Tool B	RDL Sputter Process: Tool A	RDL Exposure Process: Tool C
RDL Etch Process: Tool A	RDL Exposure Process: Tool B	RDL Descum Process: Tool A	PBO1 Exposure Process: Tool A
RDL Sputter Process: Tool B	RDL Coating Process: Tool A	PBO1 Exposure Process: Tool A	RDL Exposure Process: Tool B

Expert Search (E)

Blind Search (B)

Blind Stage (BS)

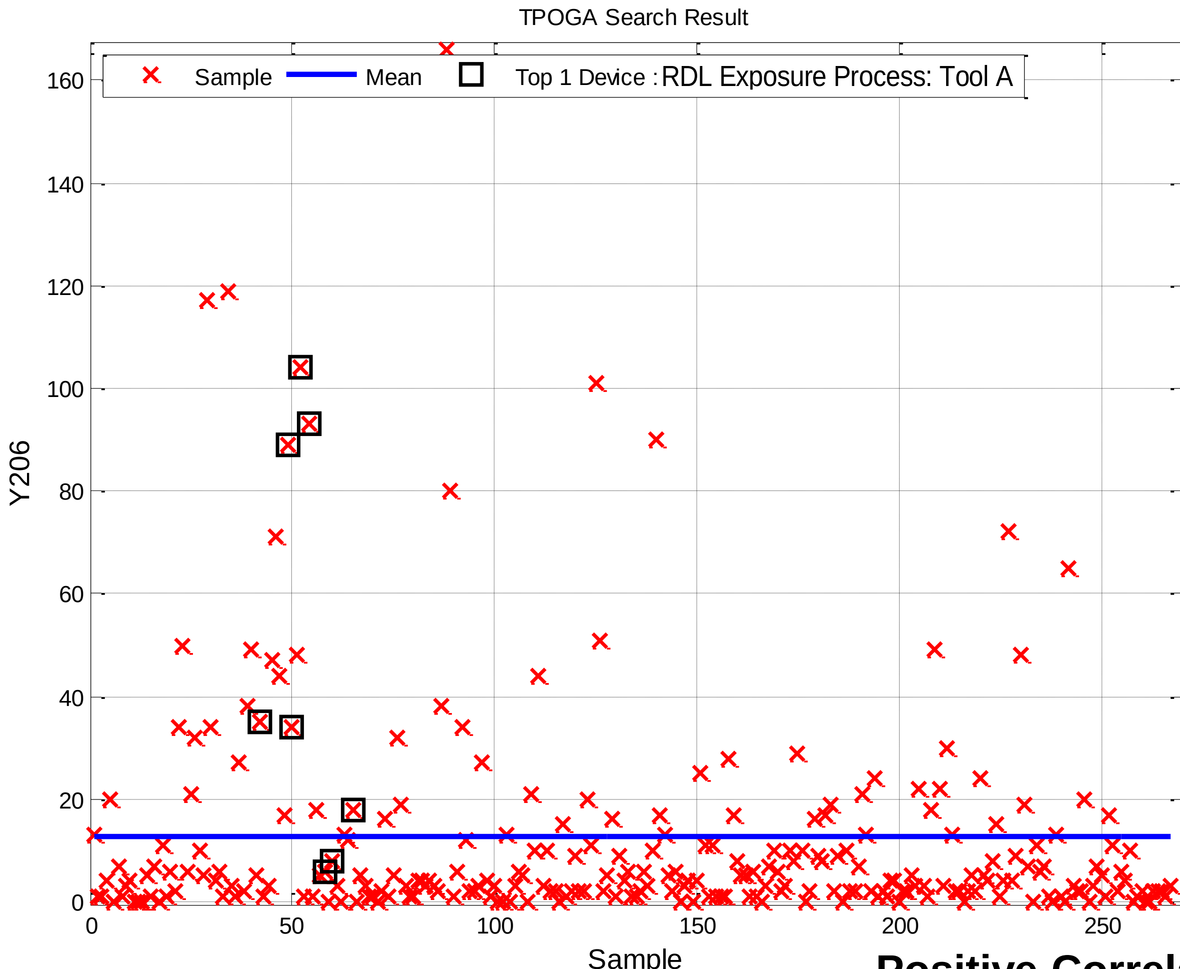
Debox Process:ToolA

It's confirmed that passing through this device won't cause defects.

Final Defect1
2016/12/16~12/31

Final Defect1

TPOGA Selection 1 (E) / TPOGA Selection 1 (B)



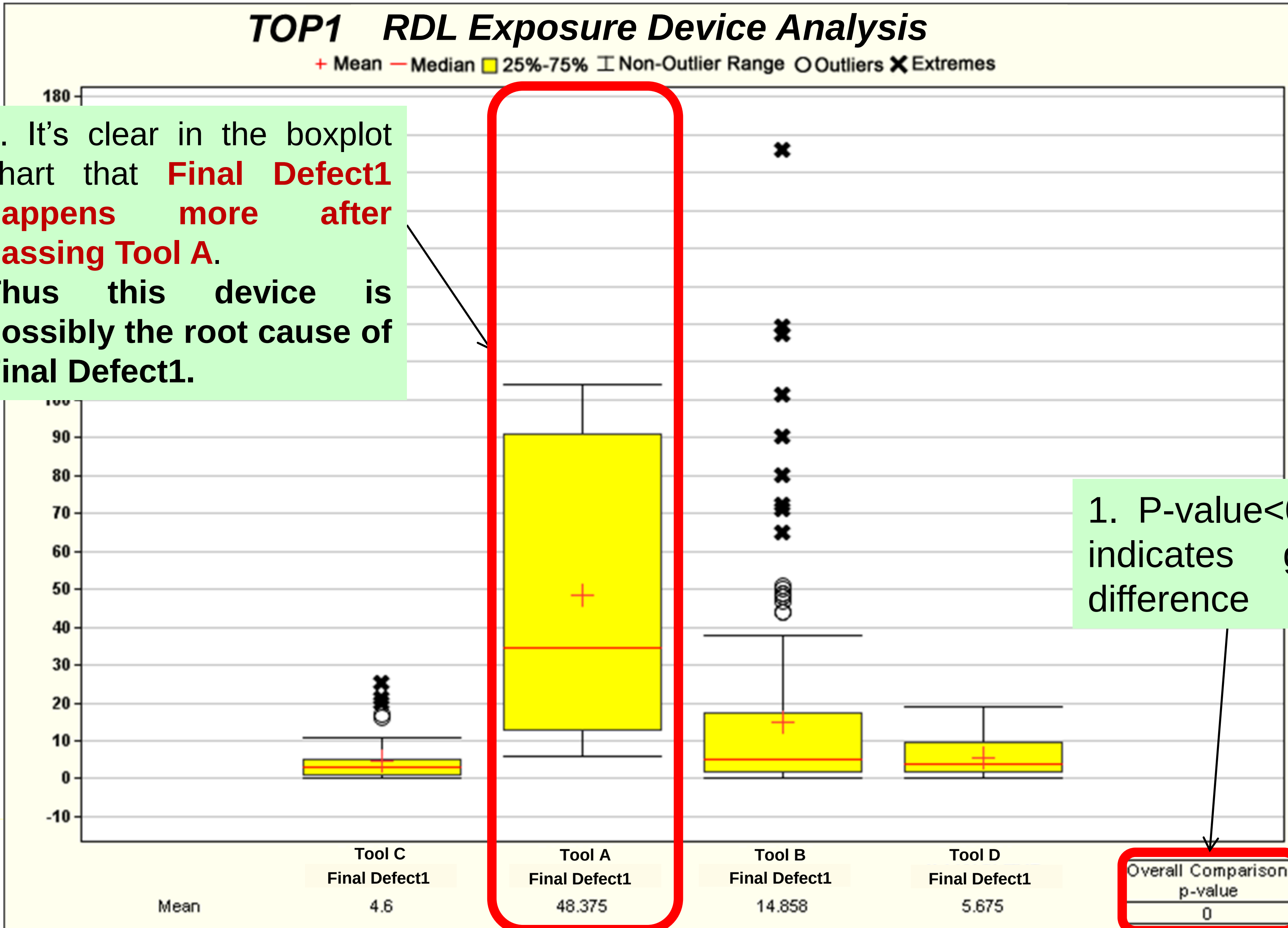
Lot no. of passing through	Correlation
8	0.2844

Positive Correlation: Defects would be increased after passing through this device.

TOP1 RDL Exposure Process Device Analysis

Confidential

Boxplot

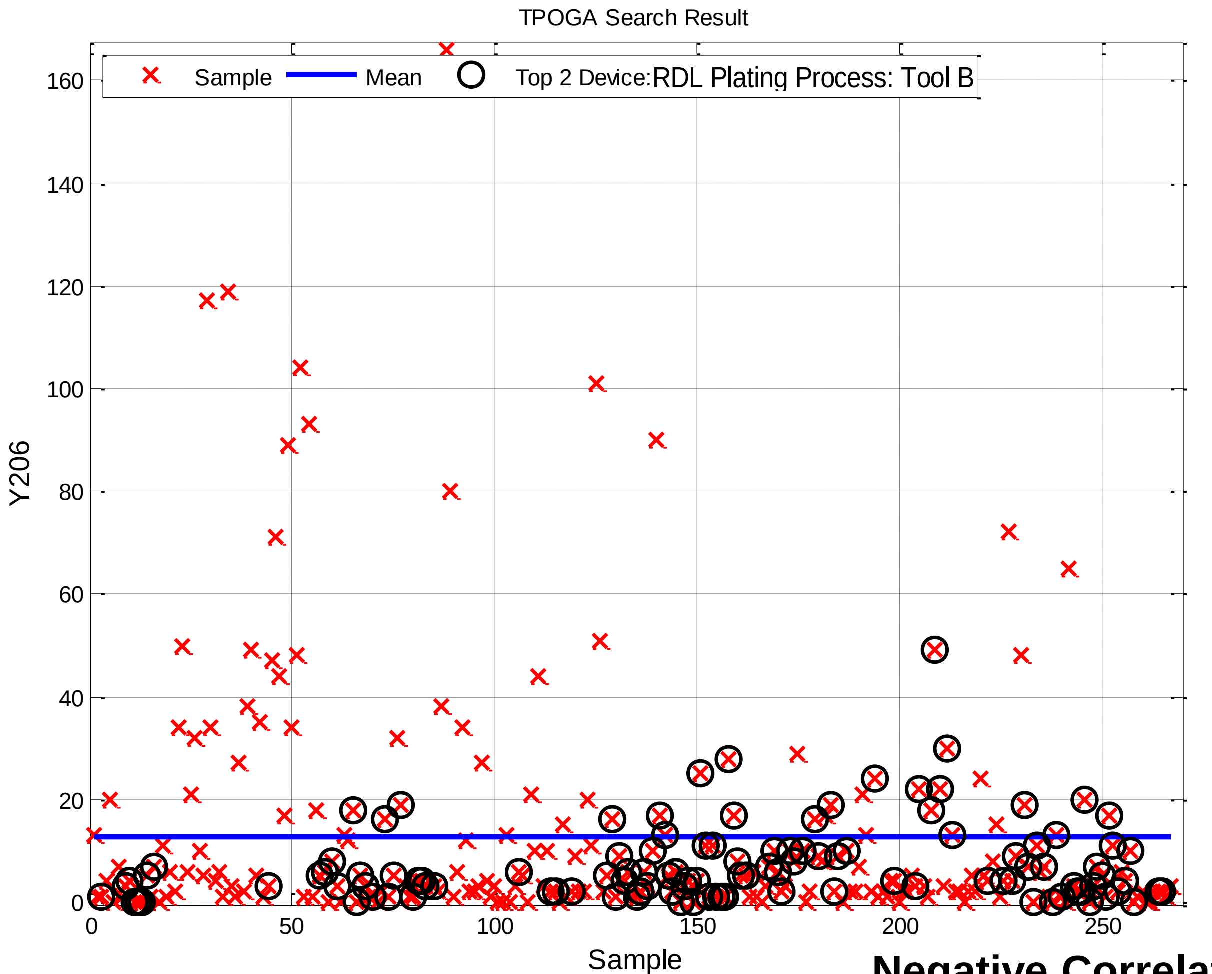


2. It's clear in the boxplot chart that **Final Defect1 happens more after passing Tool A.**
Thus this device is possibly the root cause of Final Defect1.

1. P-value<0.05: indicates great difference

Final Defect1

TPOGA Selection 2(E) / TPOGA Selection 2(B)

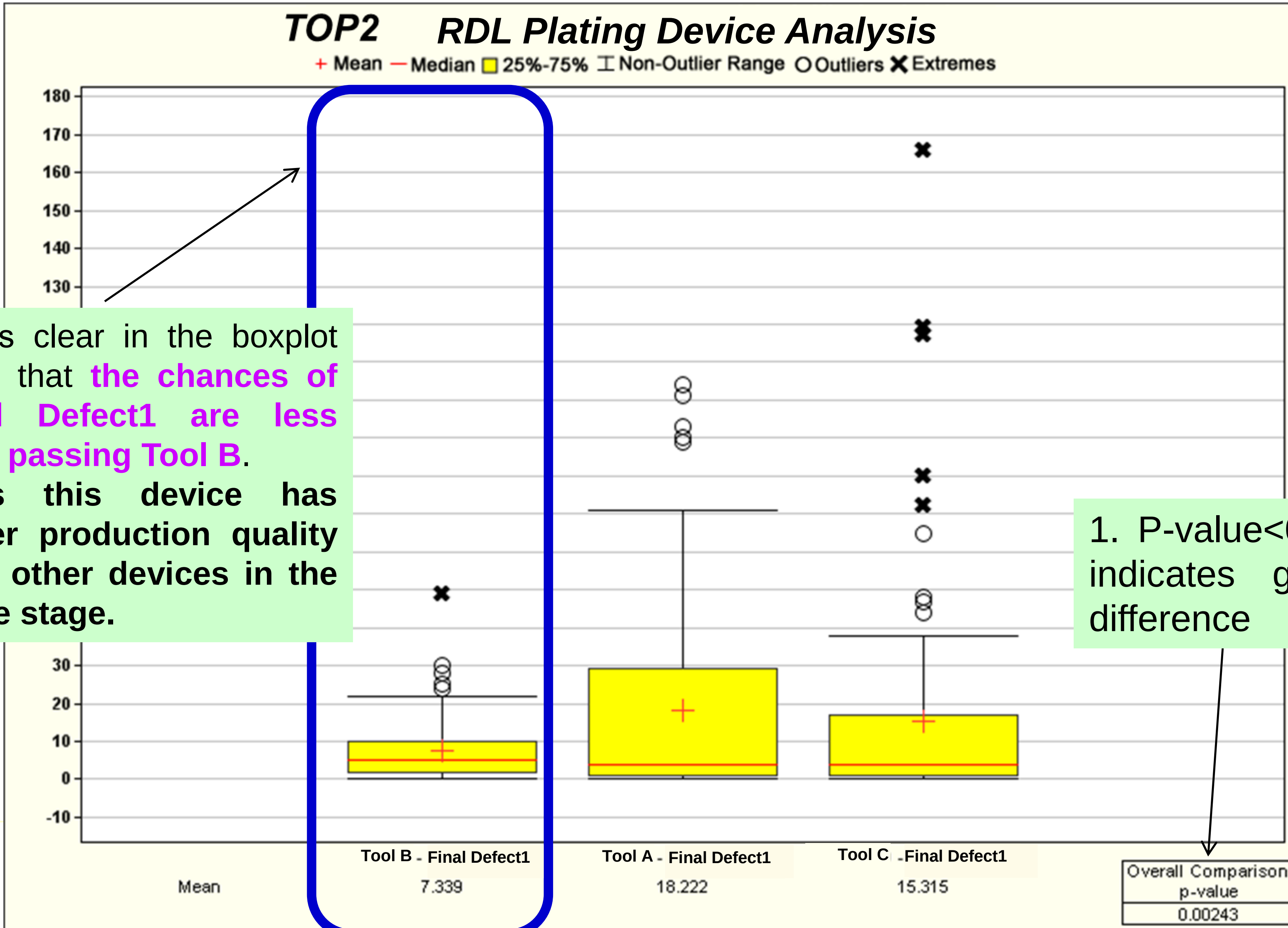


Lot no. of passing through	Correlation
115	-0.2054

Negative Correlation: Less chances of defects after passing through this device.

TOP2 RDL Plating Device Analysis

Boxplot



2. It's clear in the boxplot chart that **the chances of Final Defect1 are less after passing Tool B**. **Thus this device has better production quality than other devices in the same stage.**

1. P-value<0.05: indicates great difference

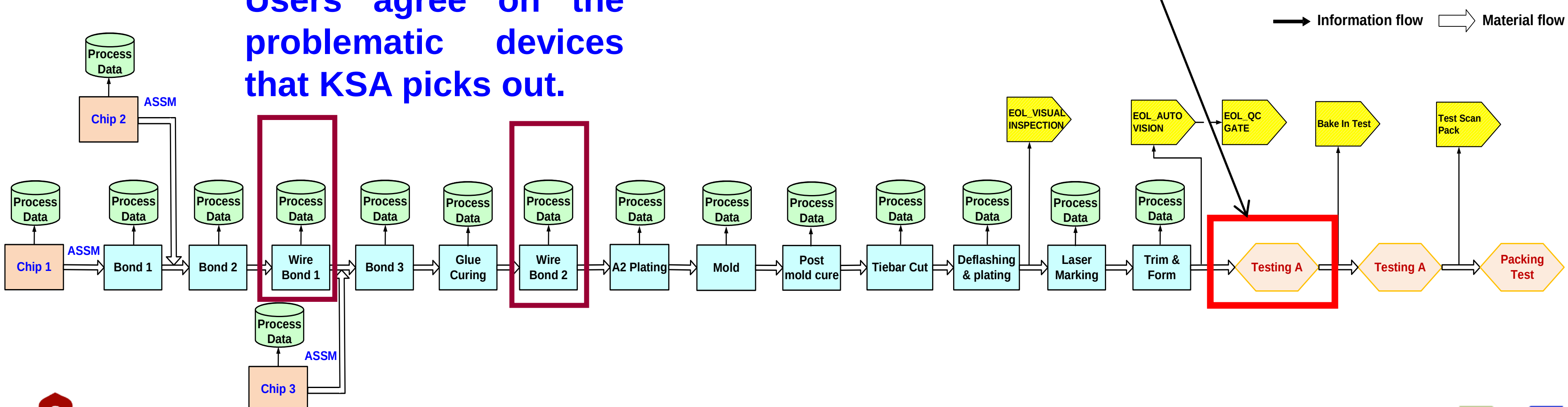
KSA Experiment – Fan-Out Package Process (Y = Final Defect)

Fan-Out Packaging Process of Cooperative Company

- Test A (in-circuit-test / electrical test) is the analysis target.
- There are 161 devices used for manufacturing in this packaging process, with Lot as the unit of analysis.
- Analysis period: Jan.-Feb., 2017.
  - Both long-term (113 Lots in 2 months) and short-term analysis (21 Lots in 1 week) are analyzed.
- The results of both long-term and short-term KSA analysis indicate that Wire Bond 1 and Wire Bond 2 process devices are the problematic devices. This conclusion has been confirmed to be highly accurate by the users.

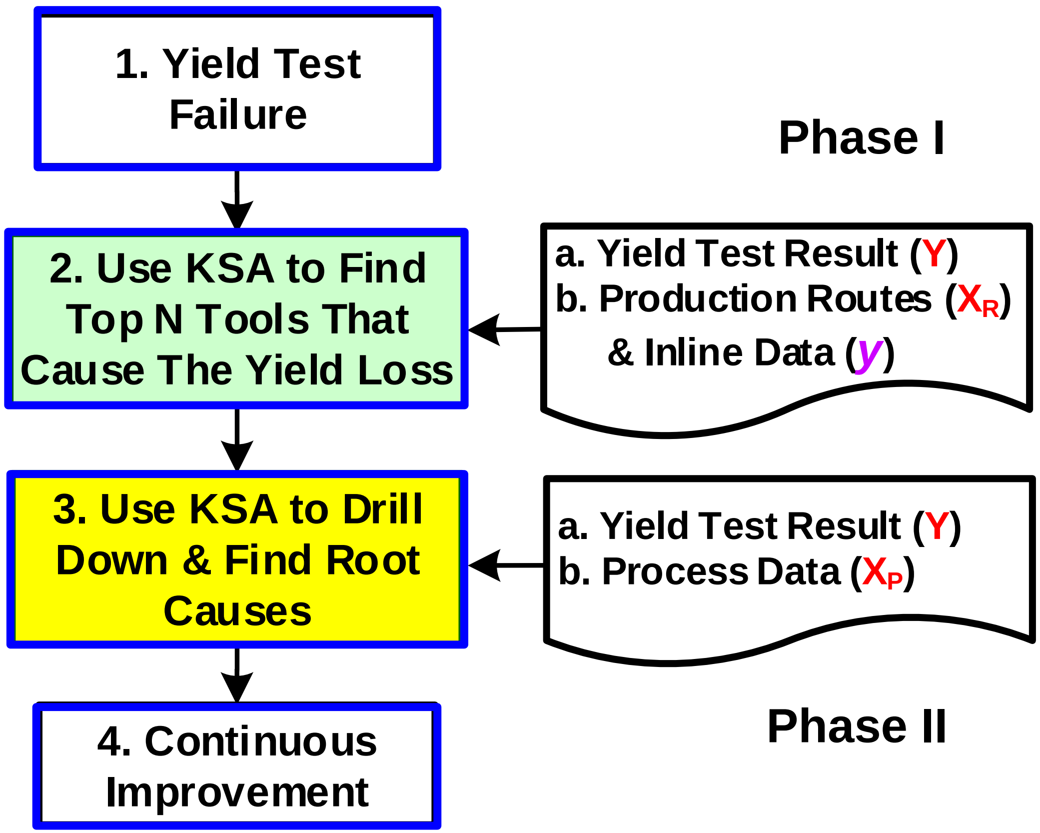
TEST A for Y_{TA}

Users agree on the problematic devices that KSA picks out.



KSA Operation Demo

Procedure for finding the root causes of yield losses by applying the KSA scheme.



Illustrative Examples

- The TFT process data are adopted as the illustrative example.
- DQI_{XR} check: 113 Lots => 104 Lots.
- Lot 49 contains 28 sheets, 789 devices in this TFT process.
- High dimensional variable selection problem
  - (P=) 789, (n=) 28

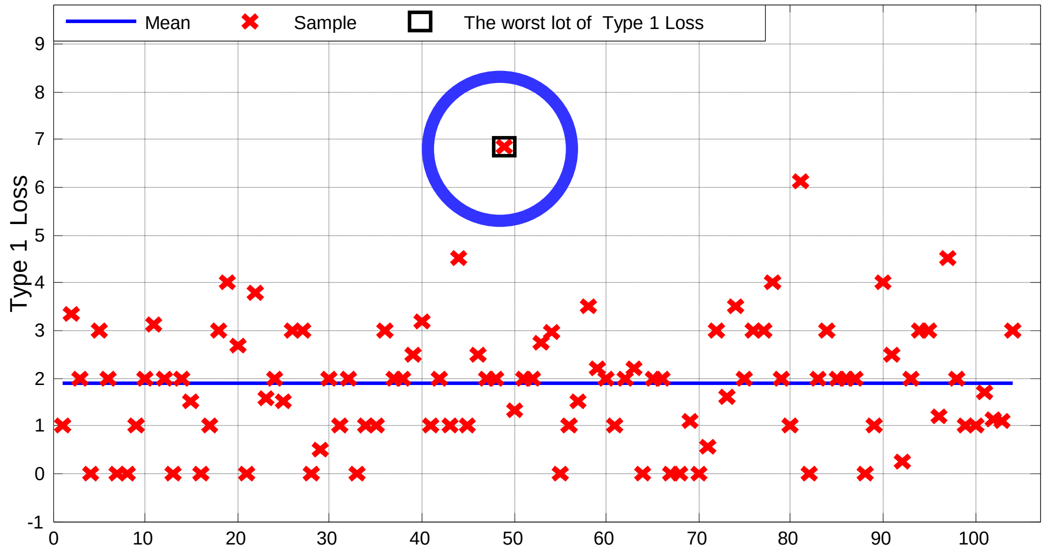
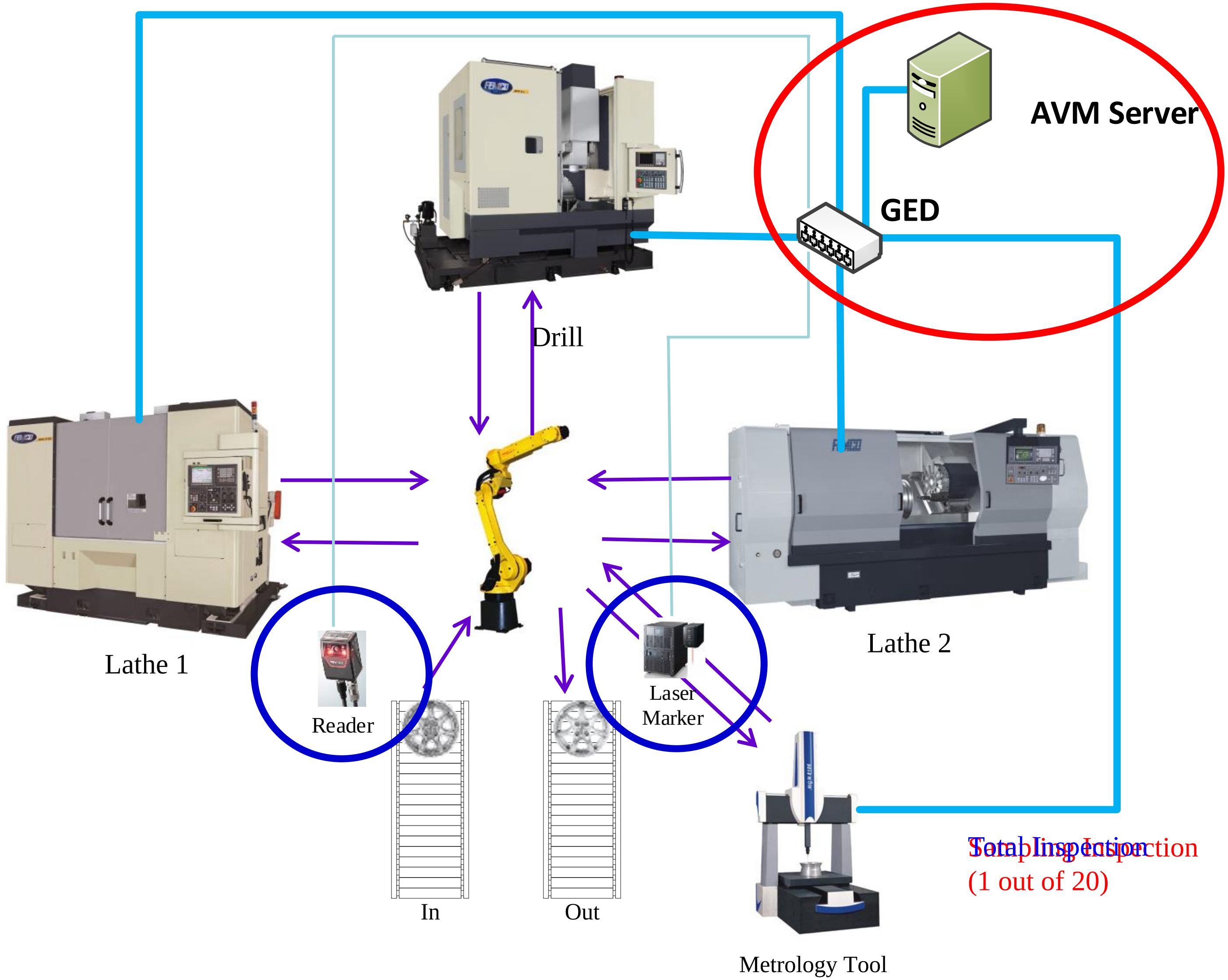


Fig. Accumulated Type 1 Loss results

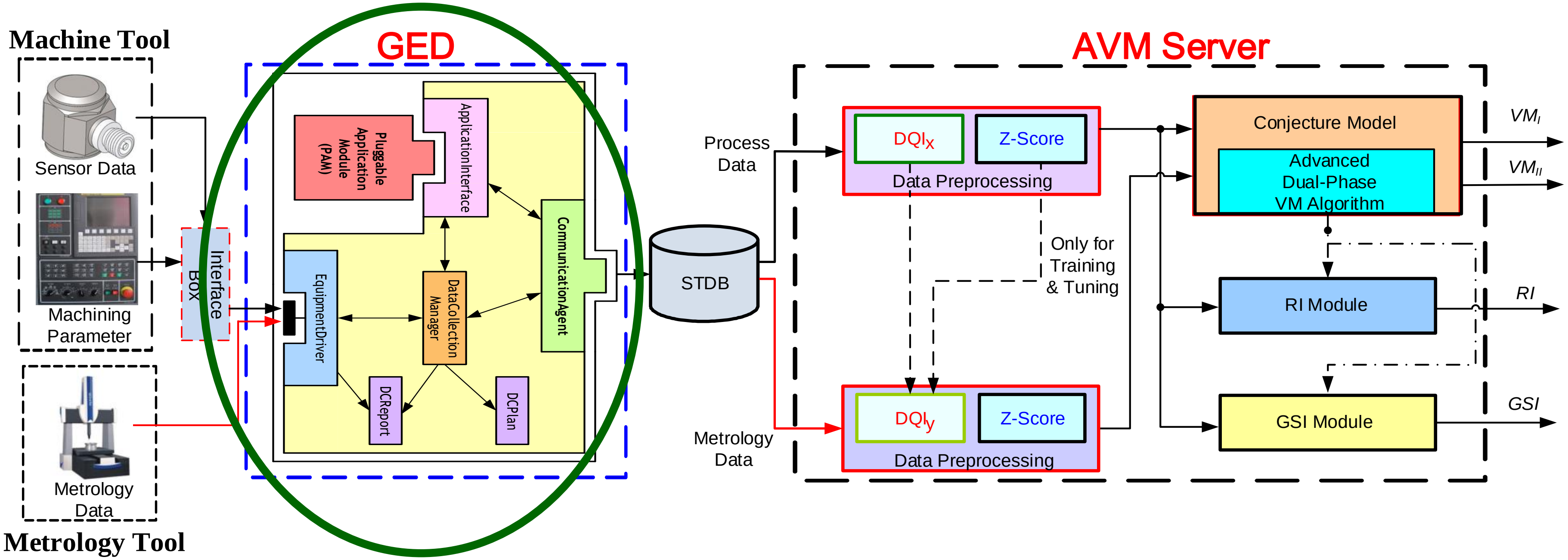
Procedure for finding the root causes of yield losses by applying the KSA scheme.

AMCoT for Smart Machinery

Applying AVM to the Total Inspection of Wheel Machining Automation (WMA)

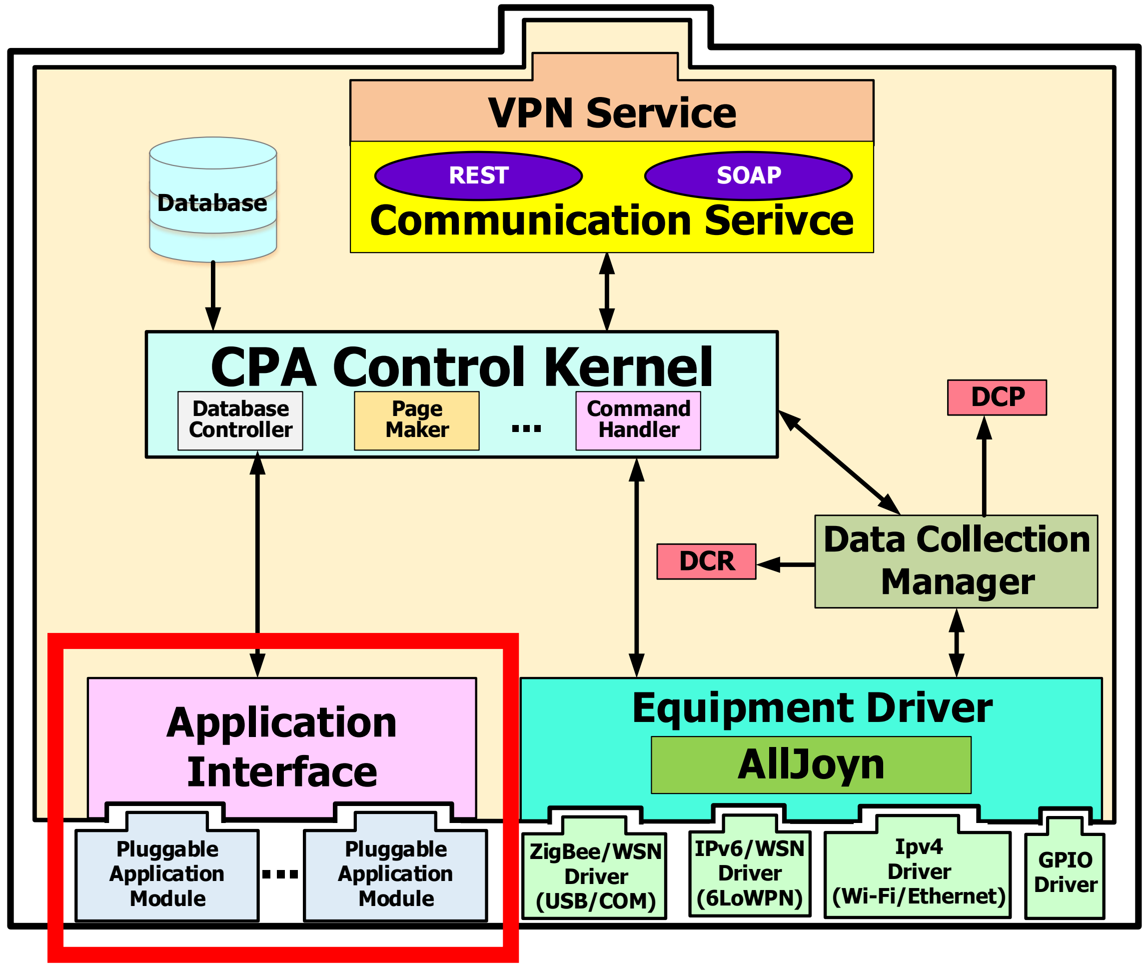


GED + AVM for Machine Tools



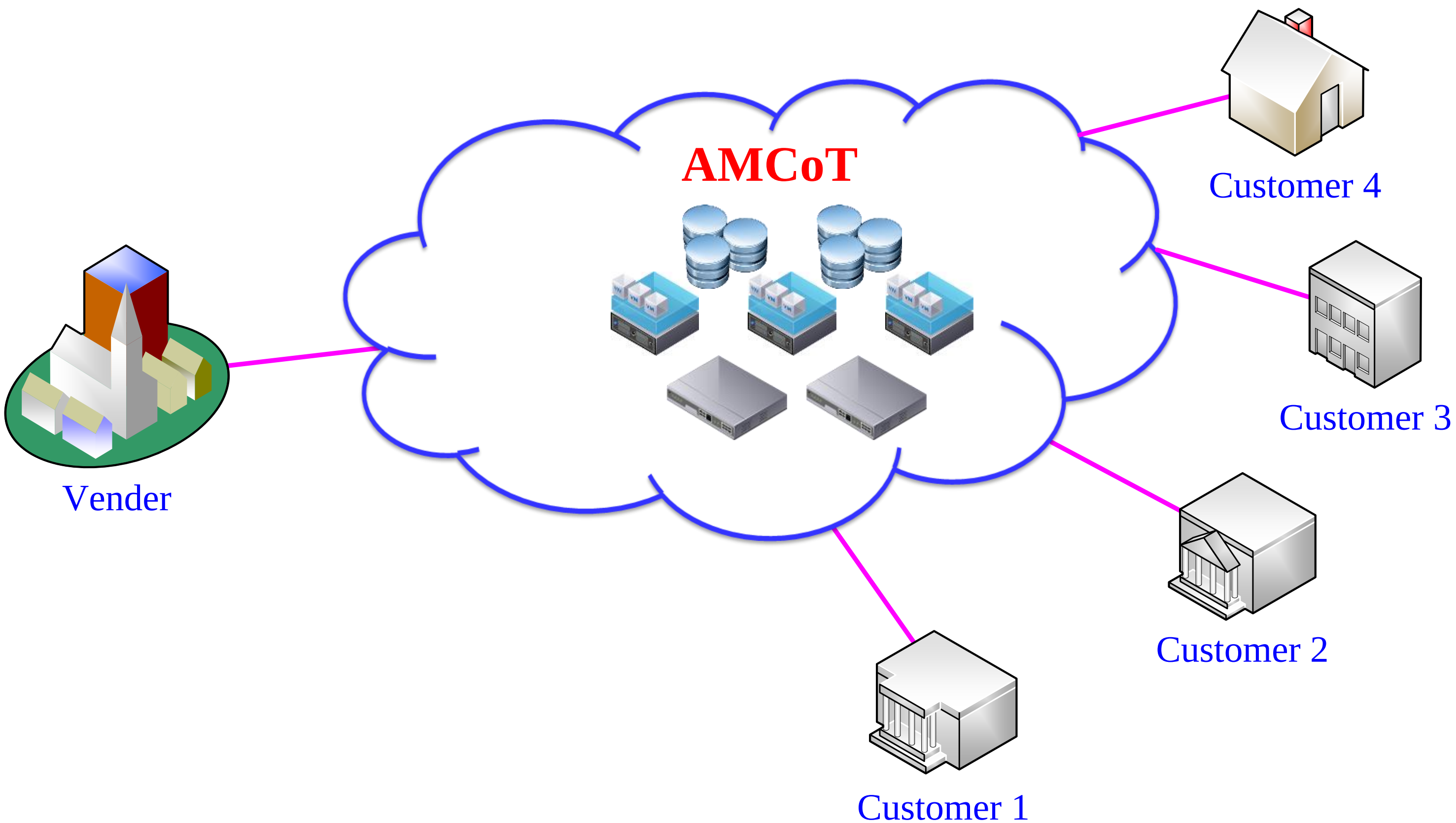
Internet of Things (IoT) Component: Cyber-Physical Agent (CPA)

Enhance GED functions to make it as an IoT Component: Cyber-Physical Agent (CPA)

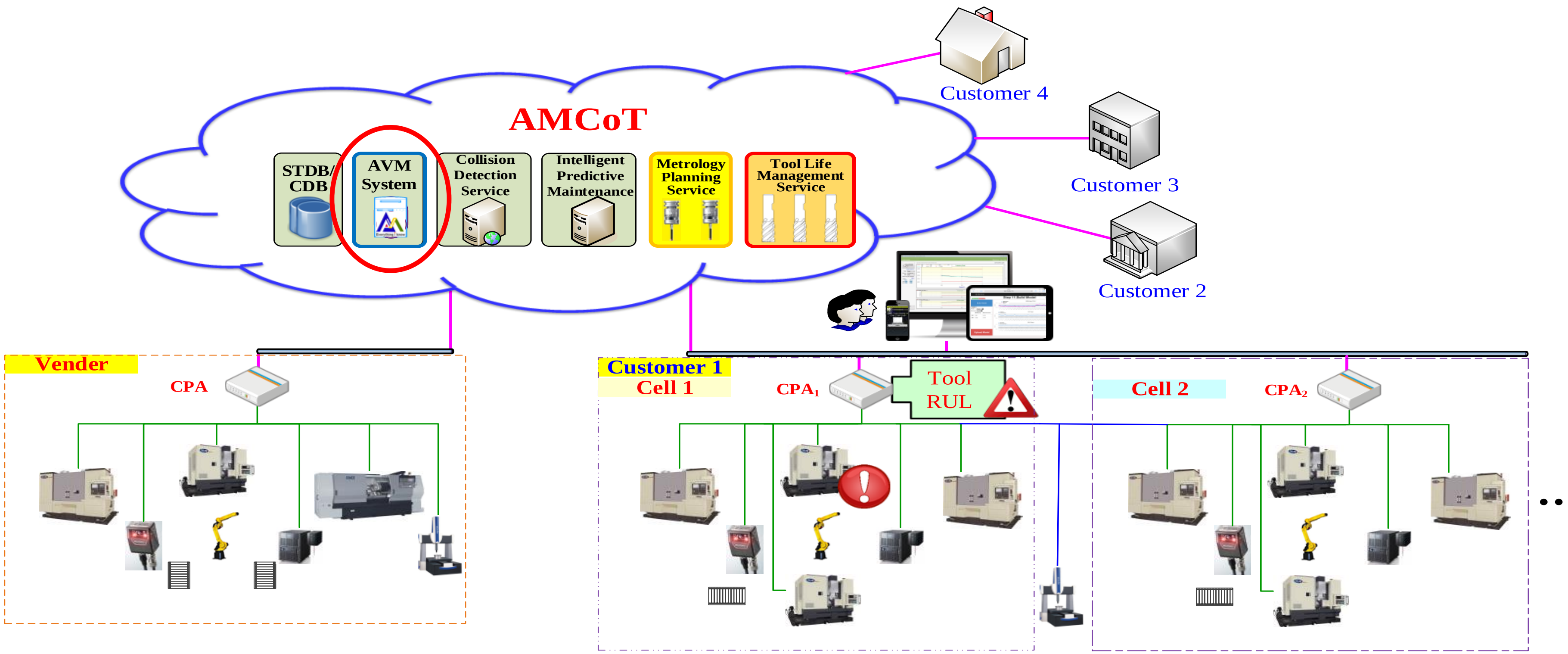


Taiwan, R.O.C. Patent no.: I225606
U.S.A. Patent no.: 7,162,394
Japan Patent no.: 4303640

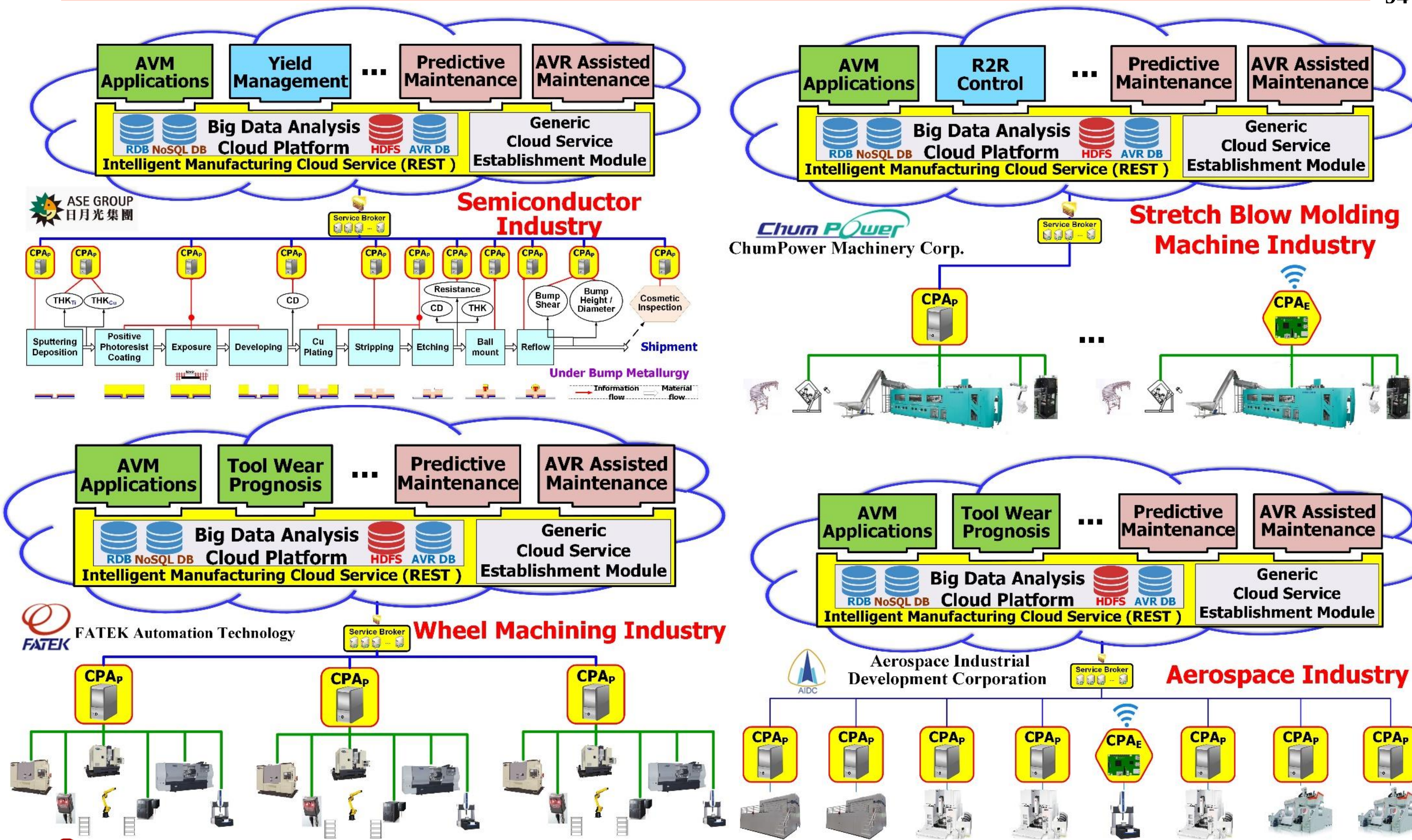
Application Diagram of AMCoT



Integrating WMA's Vender and Customers into AMCoT



AMCoT Application Scenarios



Industry 4.0 & Industry 4.1

Industry 4.0

- Industry 4.0 = IoT + CPS + Cloud Manufacturing (CM) + Big Data Analytics.

- Industry 4.0 only emphasizes "Enhancing Productivity" but not "Improving Quality".

- Industry 4.0 does not address about how to achieve the goal of Zero Defects.

- Zero Defects (ZD)
  - ZD has been one of the quality-improvement objectives for accomplishing manufacturing quality [1].
  - Through prevention methods, ZD aims to boost production and minimize waste.
  - ZD is based on the concept that the amount of mistakes a worker makes doesn't matter since inspectors will catch them before they reach the customer [1].

[1] Halpin, James F. *Zero Defects: A New Dimension in Quality Assurance*, New York: McGraw-Hill, 1966.

Industry 4.1

Industry 4.0 + AVM = Industry 4.1

→ **To achieve the goal of Zero Defects (ZD)**

- **Stage 1: Accomplishing the goal of zero defects of all the deliverables**
- **Stage 2: Accomplishing the goal of zero defects of all the products**
  (Big Data Analytics & Continuous Improvement)

Industry 4.0 + AVM = Industry 4.1

332 IEEE ROBOTICS AND AUTOMATION LETTERS, VOL. 1, NO. 1, JANUARY 2016

Industry 4.1 for Wheel Machining Automation

Fan-Tien Cheng, *Fellow, IEEE*, Hao Tieng, *Student Member, IEEE*, Haw-Ching Yang, *Member, IEEE*, Min-Hsiung Hung, *Senior Member, IEEE*, Yu-Chuan Lin, *Student Member, IEEE*, Chun-Fan Wei, and Zih-Yan Shieh

***Abstract*—Industry 4.0 is set to be one of the new manufacturing objectives. The technologies involved to achieve Industry 4.0 are Internet of Things (IoT), cyber physical systems (CPS), and cloud manufacturing (CM). However, the current objectives defined by Industry 4.0 do not include zero defects; it only keeps the faith of achieving nearly zero-defects state. The purpose of this paper is to propose a platform denoted advanced manufacturing cloud of things (AMCoT) to not only achieve the objectives of Industry 4.0 but also accomplish the goal of zero defects by applying the technology of automatic virtual metrology (AVM). As such, by applying Industry 4.0 together with AVM to achieve the goal of zero defects, the era of Industry 4.1 is taking place. The application of wheel machining automation is adopted in this letter to illustrate how AMCoT and Industry 4.1 work.**

***Index Terms*—Intelligent and flexible manufacturing, factory automation, industry 4.1, zero defects, automatic virtual metrology (AVM).**

GED	Generic embedded device.
GPIO	General purpose input/output.
GSI	Global similarity index.
IB	Interface box.
ILM	In-line metrology.
IoT	Internet of things.
IP	Internet protocol.
IPv4	The fourth edition of IP.
IPv6	The sixth edition of IP.
IT	Information technology.
NC	Numerical control.
OMM	Off-machine measuring.
PAMs	Pluggable application modules.
RMS	Root mean square.
SC	Status change.

AMCoT / Industry 4.1
Related Papers & Patents

AMCoT / Industry 4.1 Related Papers

[1] F.-T. Cheng, H. Tieng, H.-C. Yang, M.-H. Hung, Y.-C. Lin, C.-F. Wei, and Z.-Y. Shieh, "Industry 4.1 for Wheel Machining Automation," *IEEE Robotics and Automation Letters*, vol. 1, no.1, pp. 332-339, January 2016.

[2] F.-T. Cheng, Y.-S. Hsieh, J.-W. Zheng, S.-M. Chen, R.-X. Xiao, and C.-Y. Lin, "A Scheme of High-dimensional Key-variable Search Algorithms for Yield Improvement," *IEEE Robotics and Automation Letters*, vol. 2, pp.179-186, no. 1, January 2017.

[3] H. Tieng, C.-F. Chen, F.-T. Cheng, and H.-C. Yang, "Automatic Virtual Metrology and Target Value Adjustment for Mass Customization" *IEEE Robotics and Automation Letters*, vol. 2, issue 2, pp. 546–553, April 2017.

[4] Y.-C. Lin, M.-H. Hung, H.-C. Huang, C.-C. Chen, H.-C. Yang, Y.-S. Hsieh, and F.-T. Cheng, "Development of Advanced Manufacturing Cloud of Things (AMCoT) -- A Smart Manufacturing Platform," *IEEE Robotics and Automation Letters*, vol. 2, no. 3, pp. 1809-1816, July 2017.

[5] F.-T. Cheng, C.-Y. Lin, C.-F. Chen, R.-X. Xiao, J.-W. Zheng, and Y.-S. Hsieh, "Blind-stage Search Algorithm for the Key-variable Search Scheme," *IEEE Robotics and Automation Letters*, vol. 2, no. 4, pp. 1840-1847, October 2017.

[6] Y.-C. Chiu, F.-T. Cheng, H.-C. Huang, "Developing a Factory-wide Intelligent Predictive Maintenance System based on Industry 4.0," to appear in *Journal of the Chinese Institute of Engineers*, accepted in December 2016.

AMCoT / Industry 4.1 Related Patents

[A] Fan-Tien Cheng, Guo-Wei Huang, Chun-Hung Chen, and Min-Hsiung Hung, "Generic Embedded Device and Mechanism Thereof for Various Intelligent-Maintenance Applications," Taiwan R.O.C. Patent no.: I225606, U.S. Patent no.: 7,162,394 B2, Japan Patent no.: 4303640.

[B] Fan-Tien Cheng, Yao-Sheng Hsieh, Jing-Wen Zheng, "System and Method for Identifying Root Causes of Yield," Taiwan R.O.C., U.S., and China Patent Pending under nos. 105135570, 15/260,343, and 201610984212.7, respectively.

Thank you for your listening !

Q & A