e-Manufacturing & Industry 4.0 for the Semiconductor Industry

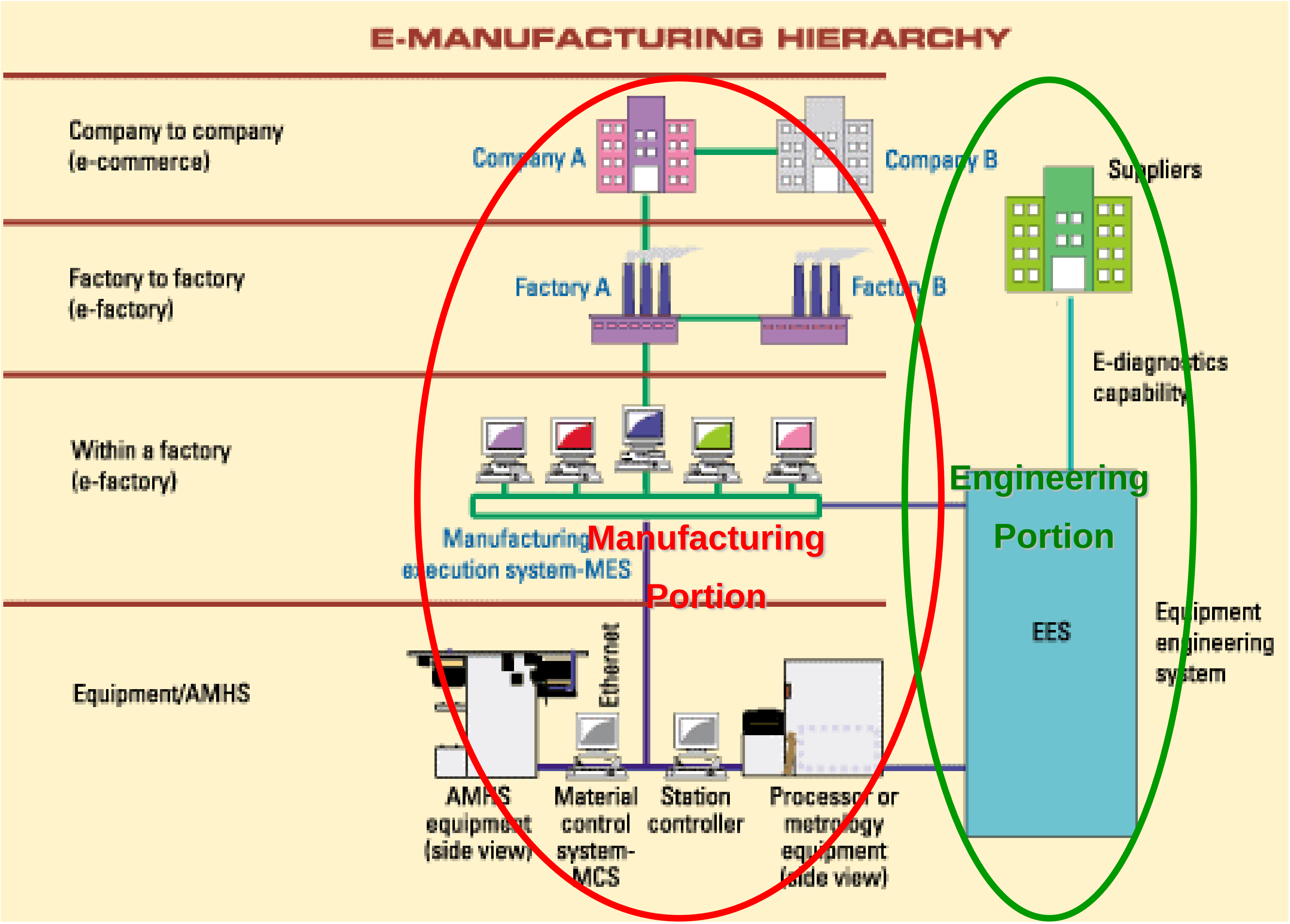
鄭芳田

Fan-Tien Cheng

e-Manufacturing Research Center
National Cheng Kung University
Tainan, Taiwan, R.O.C.

September 18, 2017

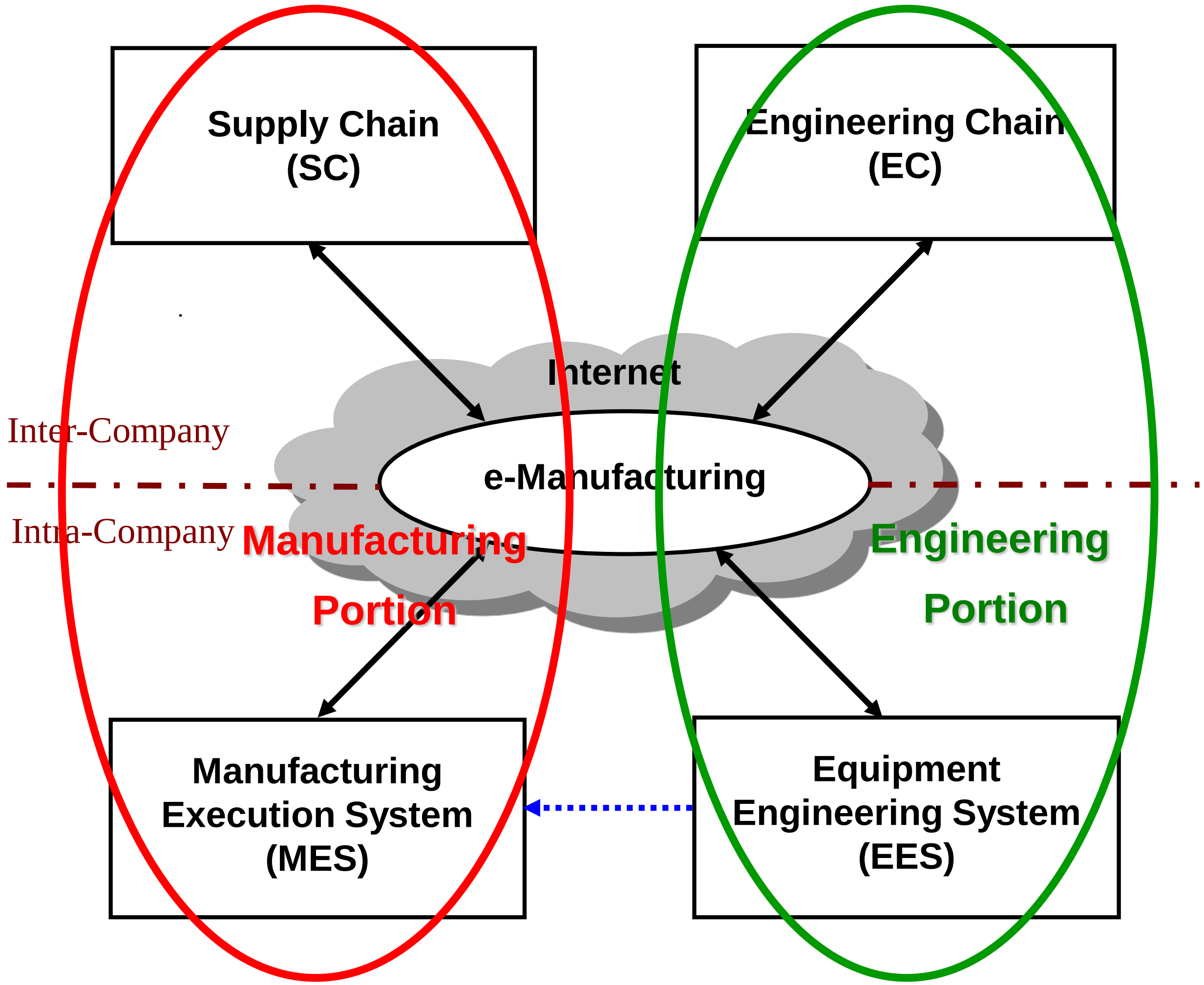
International SEMATECH e-Manufacturing Hierarchy [6]



Introduction (e-Manufacturing Definition)

e-Manufacturing [1][2][3][4] is advanced manufacturing that takes advantage of Internet and information technologies to efficiently integrate the Manufacturing Execution System (MES) [16] and Equipment Engineering System (EES) [6][8][15] within a company (intra-company integration), and the Supply Chain (SC)[30][31][17] and Engineering Chain (EC) [11][12][18][19][20] among member companies (inter-company integration).

e-Manufacturing Components [18][20]



1. Manufacturing Execution System (MES)

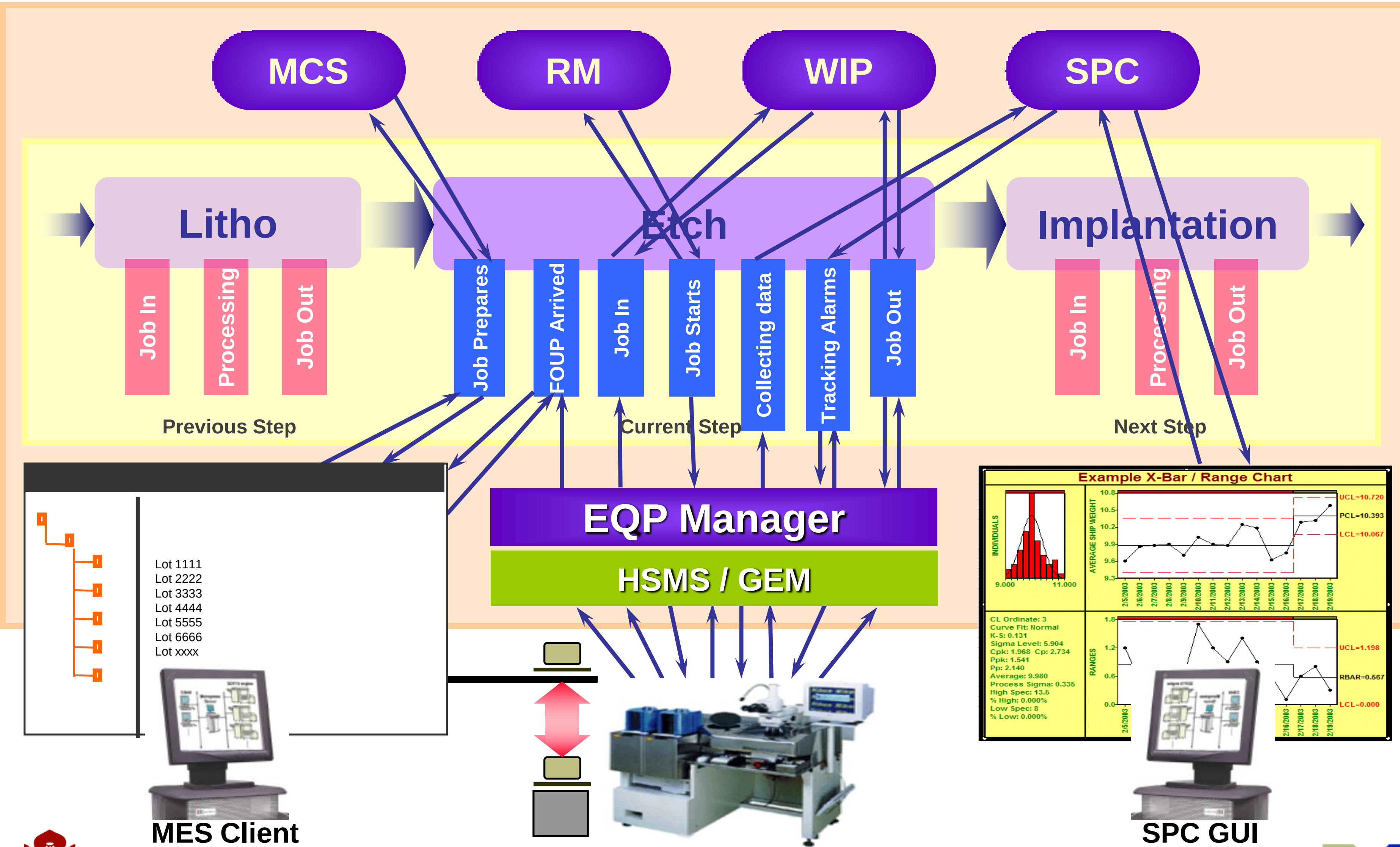
Definition of MES

- **Manufacturing Execution System (MES) is a shop floor control system which includes either manual or automatic labor and production reporting as well as on-line inquiries and links to tasks that take place on the production floor. MES includes links to work orders, receipt of goods, shipping, quality control, maintenance, scheduling, and other related tasks.**

- **The mission of MES is to increase productivity and yield.**

> **Cited from Bitpipe.com**

MES Operations



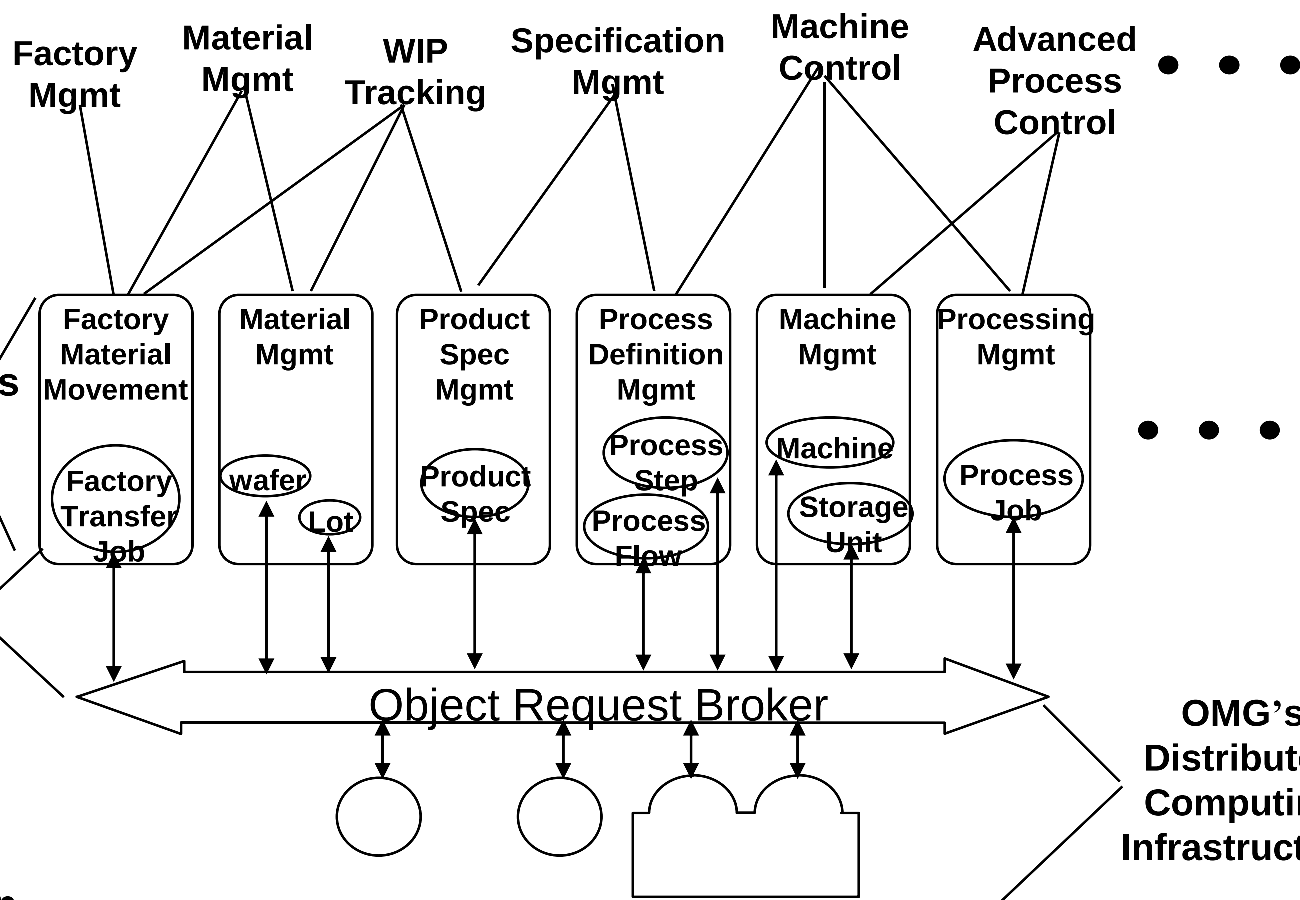
SEMI CIM Framework Functional Architecture

CIM Applications
(example groupings)

CIM Framework

Interoperability **via Common components & component managers**

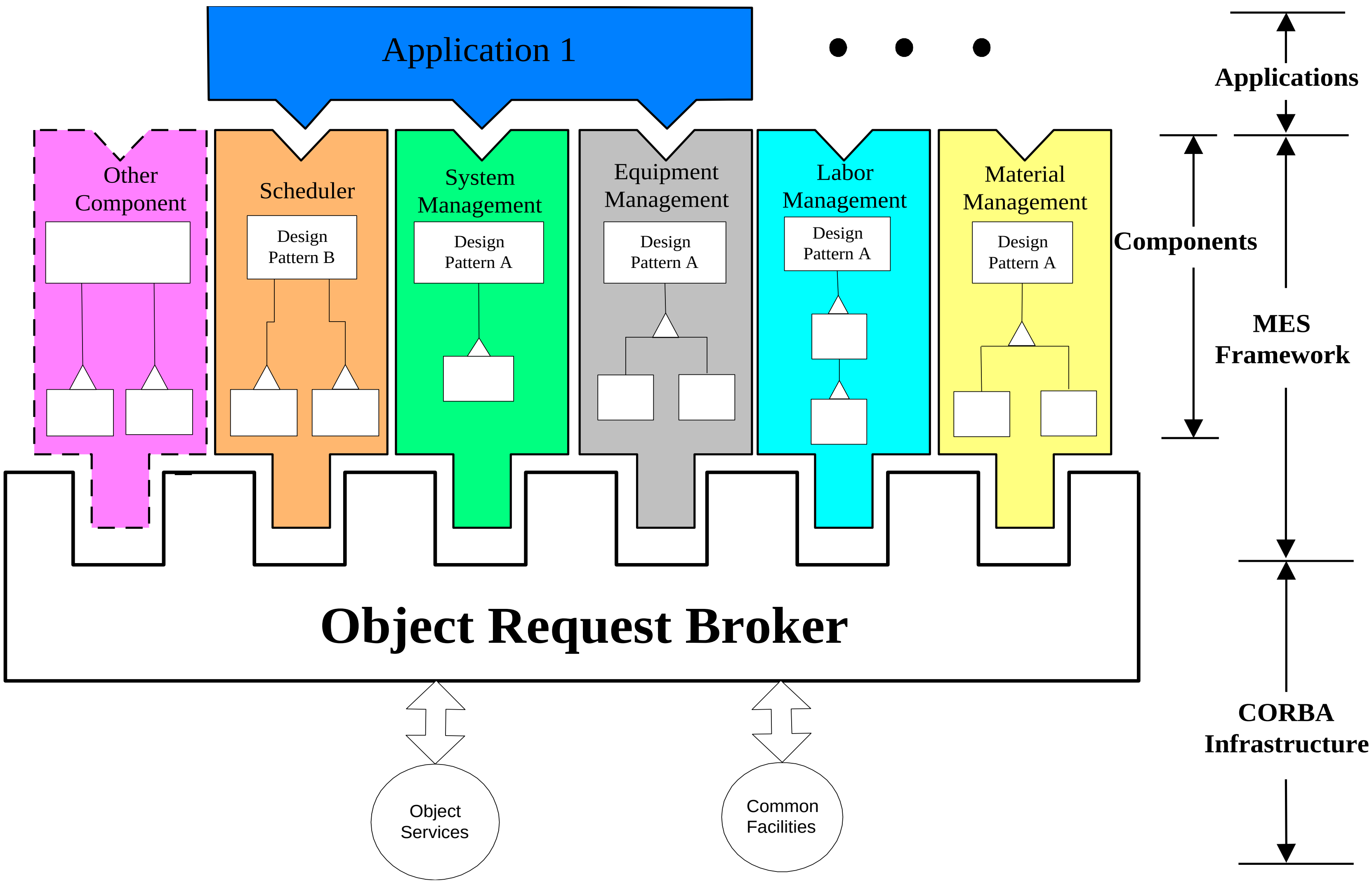
Plug-and-play **via Standard component interfaces**
- **messages, events, exceptions, behaviors**
- **standard application partitioning at component level**



CORBAservices and CORBAfacilities

OMG's Distributed Computing Infrastructure

MES Framework Architecture [29][16]



2. Supply Chain (SC)

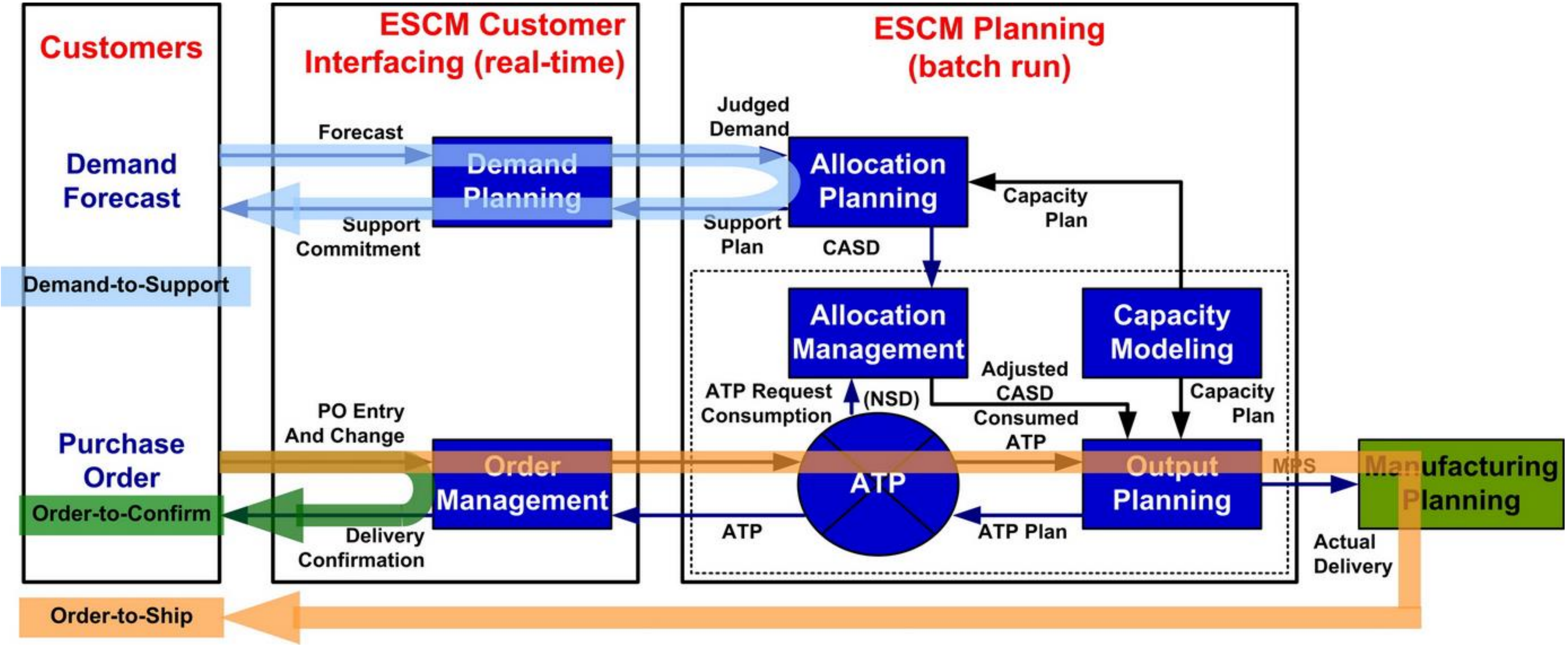
Definition of SC

- Ganeshan and Harrison [30] defined Supply chain (SC) as a network of facilities and distribution options to perform the functions of materials procurement; transformation of materials into intermediate and finished products; and distribution of these finished products to customers.

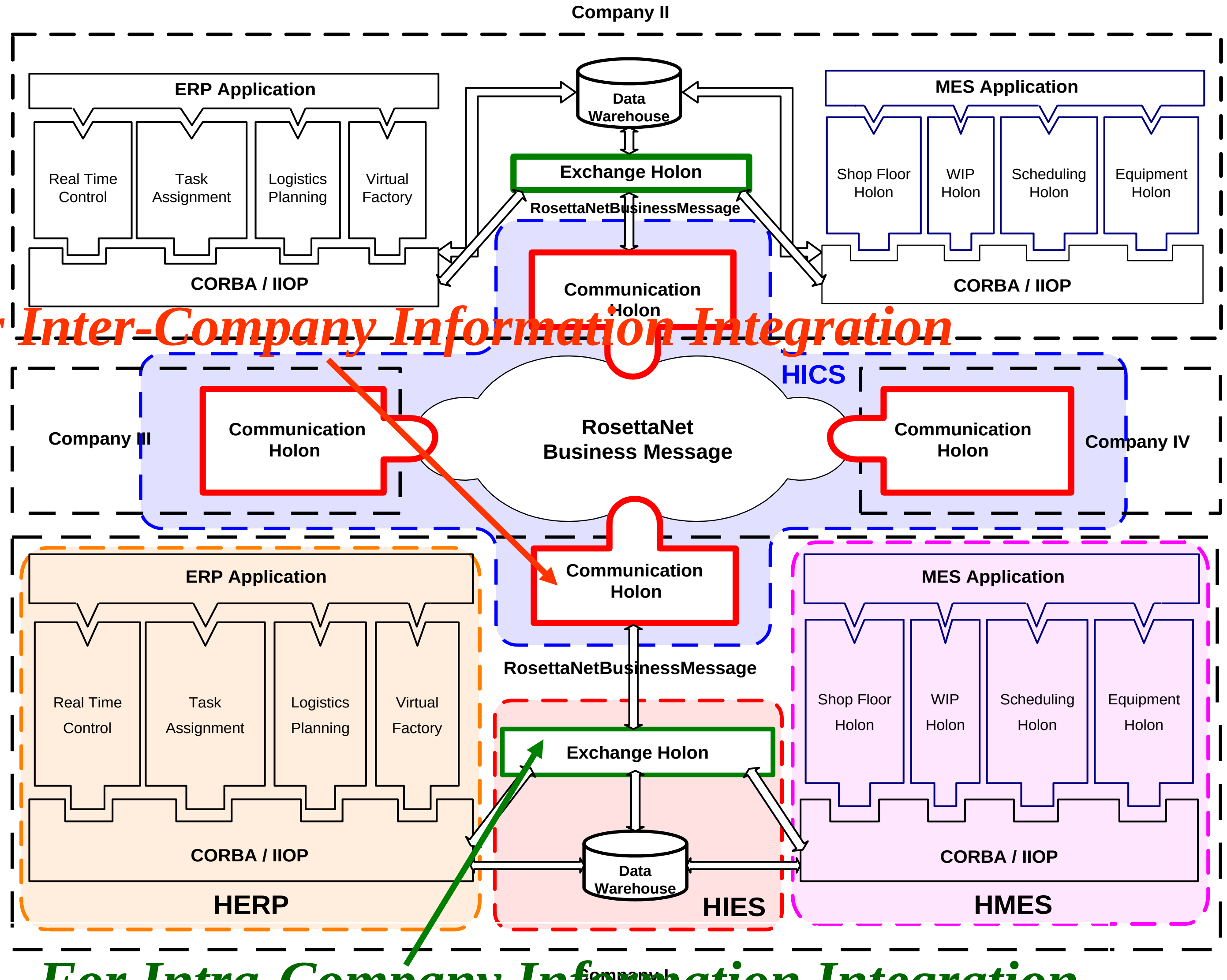
- SC is designed to achieve timely and economical delivery of desired products for accomplishing the cycle of “order-to-delivery (O2D)” [31].

Supply-Chain Architecture and Key Processes

- SC architecture supports the collaborative operations of the semiconductor industry to assure coherent IC manufacturing operations.
- SC consists of a customer interfacing module for accessing demand forecasts and order inputs, and a planning module for allocating capacity to accomplish customer demands and orders to generate work orders for the production floor.



Semiconductor Holonic Supply Chain System [17][24]



For Inter-Company Information Integration

For Intra-Company Information Integration

3. Equipment Engineering System (EES)

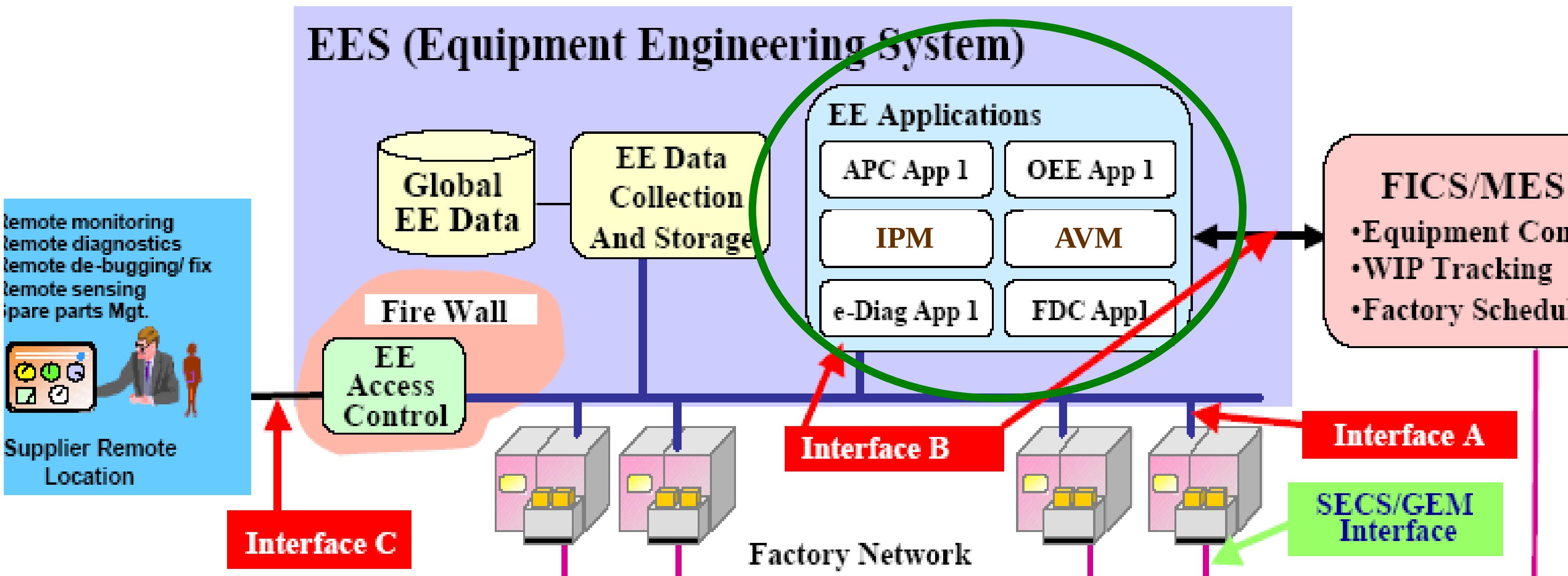
Definition of EES

- **Equipment Engineering System (EES) is defined as the physical implementation of Equipment Engineering Capabilities (EECs), which are applications that address specific areas of Equipment Engineering, such as Fault Detection & Classification, Predictive Maintenance, Virtual Metrology, Run-to-Run Control, etc.**
- **The main purpose of EES is to enhance the overall equipment effectiveness (OEE)**

> **Cited from EEC V2.5**

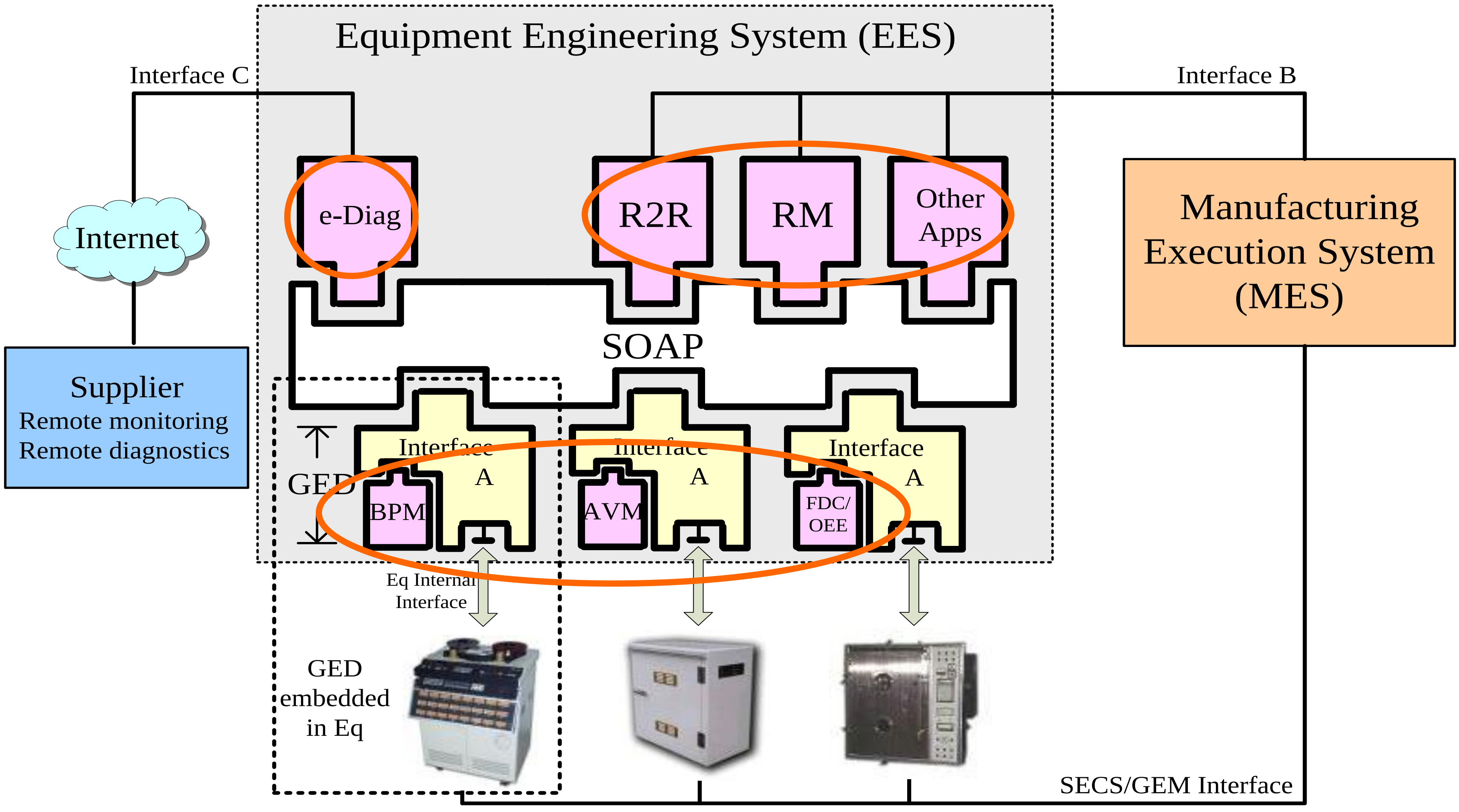
Interfaces for e-Manufacturing

- **SECS/GEM – The Primary Equipment Control I/F**
  - **Interface A – Equipment Data Acquisition [5] Interface (Getting more & better data from the equipment)**
  - **Interface B – Among Applications and to FICS/MES [9]**
  - **Interface C – External Access to e-Diagnostics [7]**



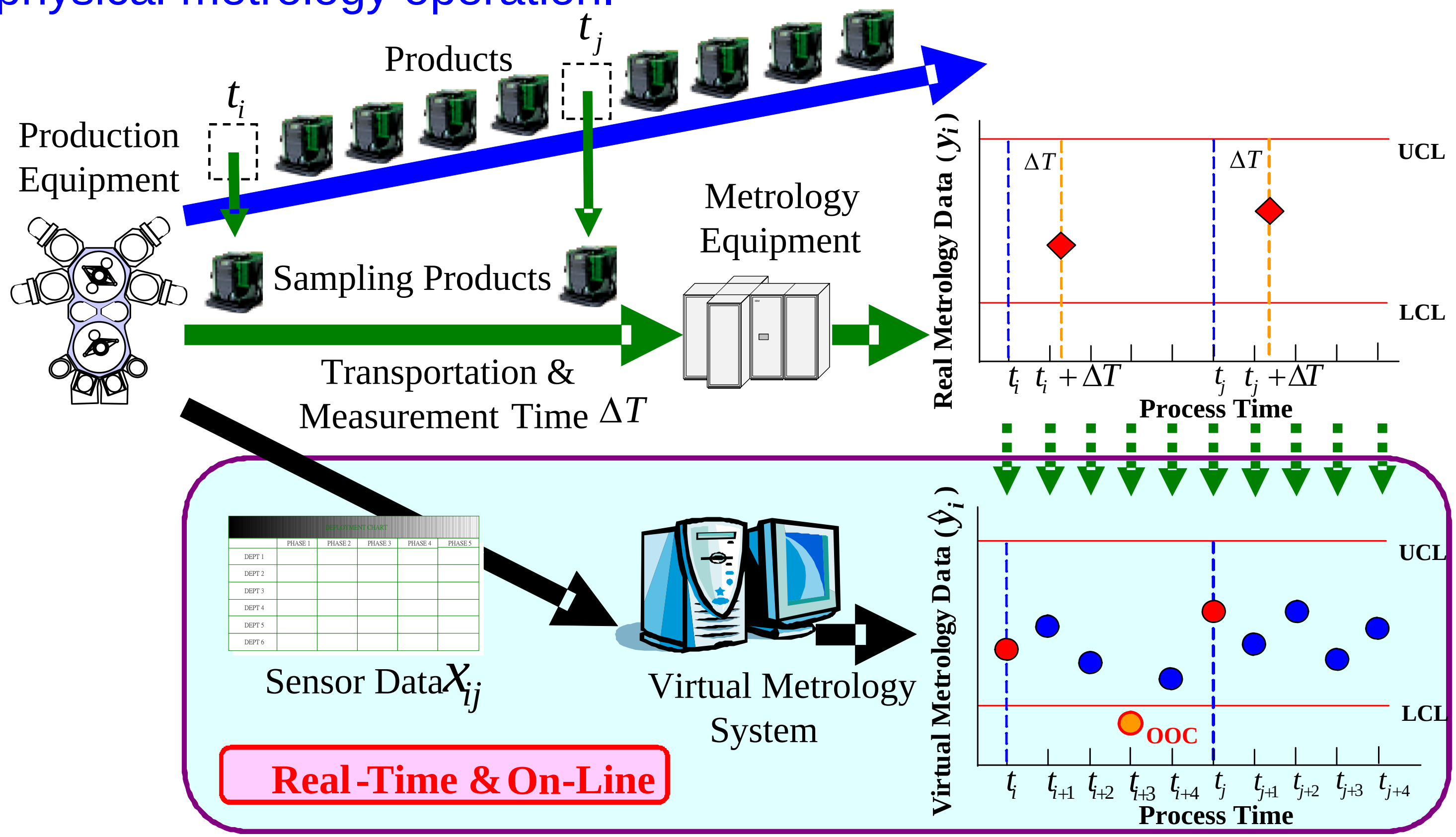
International SEMATECH EES Architecture [6][8]

Proposed EES Framework [21]



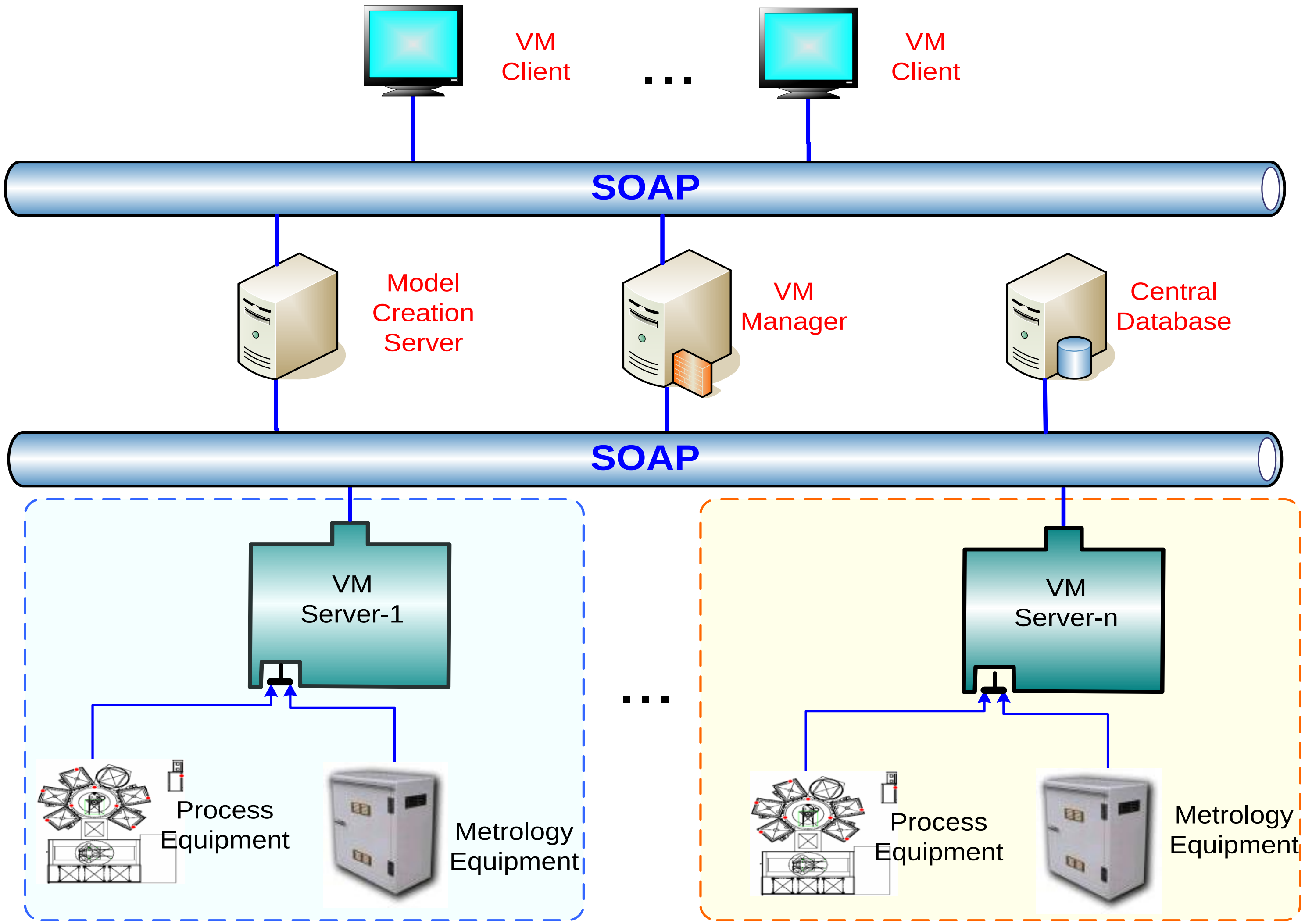
EEC Example 1-1: Virtual Metrology

- Virtual Metrology (VM) is a method to conjecture manufacturing quality of a process tool based on data sensed from the process tool and without physical metrology operation.



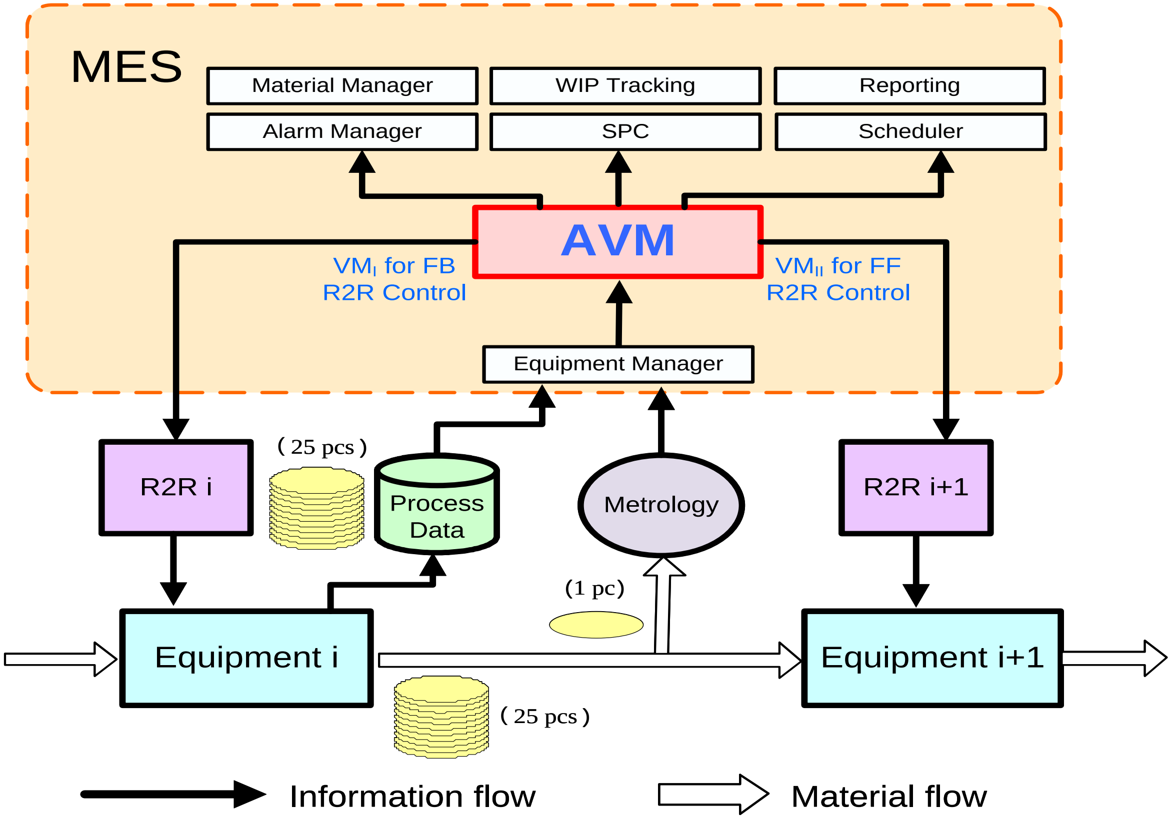
- VM can convert sampling inspections with metrology delay into real-time and on-line total inspection.

EEC Example 1-2: The AVM System [26]

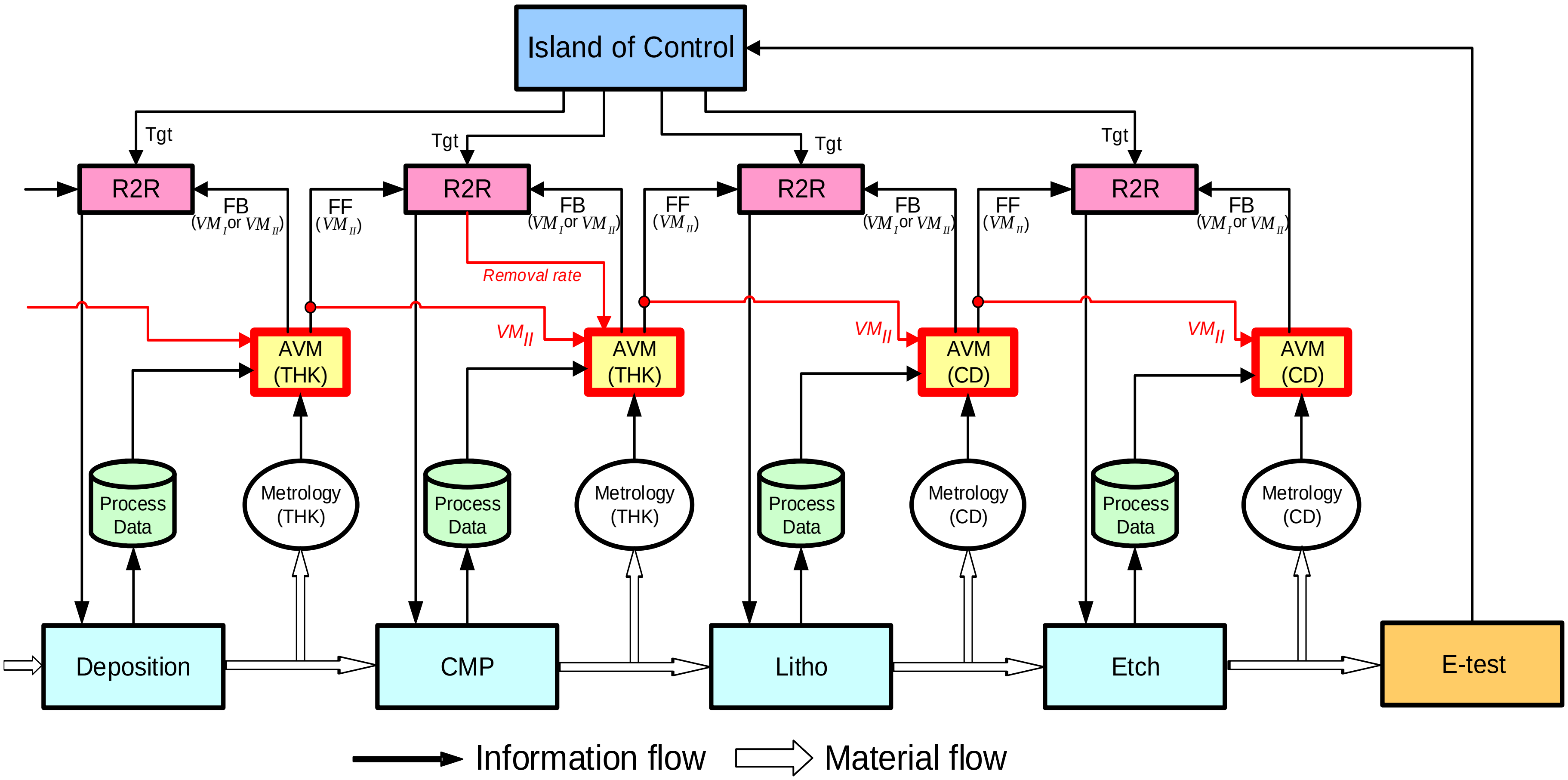


Example 2: Integrating AVM into MES [20]

- 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.



Example 3: Applying AVM for W2W Control [34]



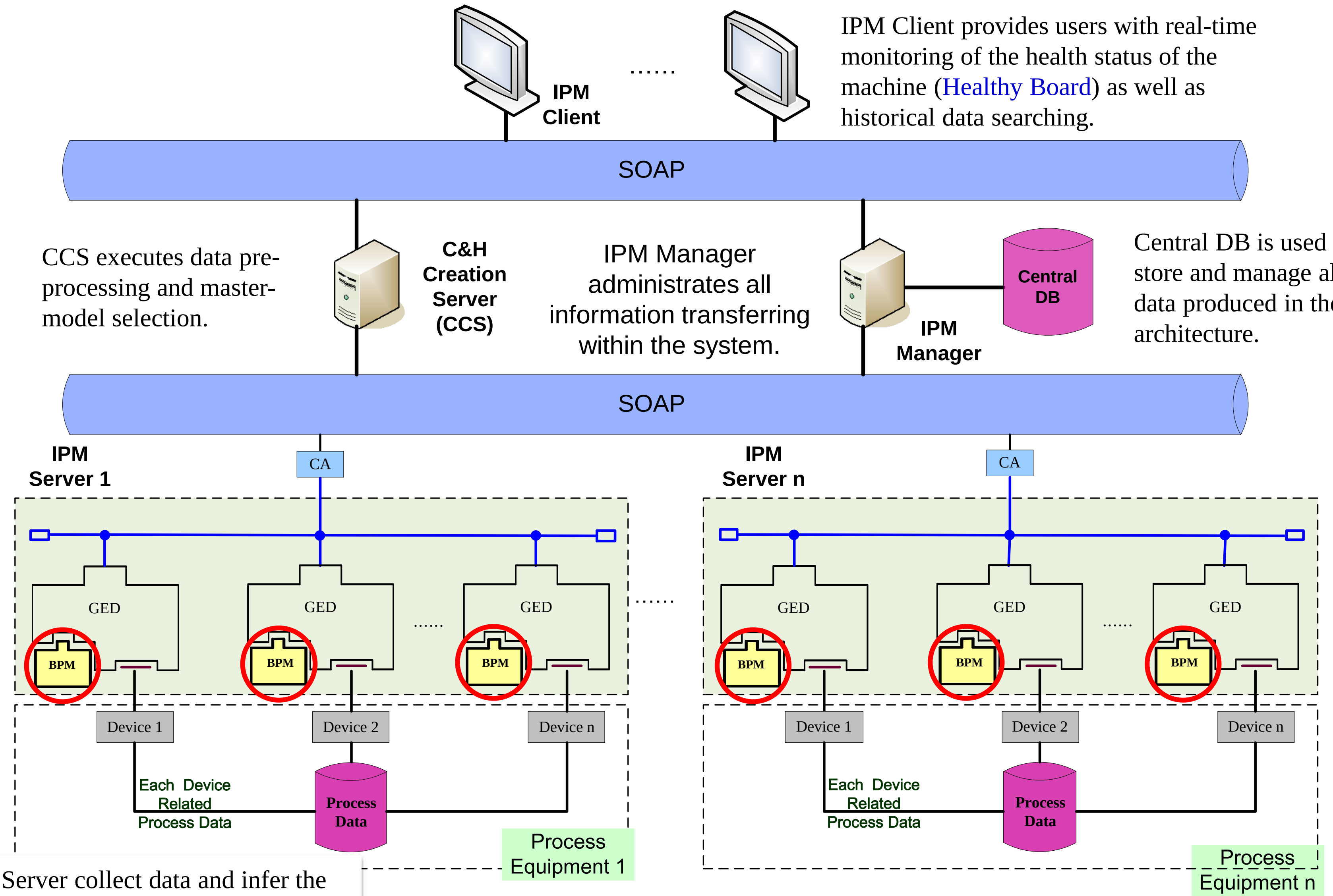
EEC Example 4:
IPM System Architecture for Predictive Maintenance [33]

IPM Client provides users with real-time monitoring of the health status of the machine (Healthy Board) as well as historical data searching.

CCS executes data pre-processing and master-model selection.

IPM Manager administrates all information transferring within the system.

Central DB is used to store and manage all data produced in the architecture.



IPM Server collect data and infer the healthy status and deliver related information to IPM Manager for data management.

4. Engineering Chain (EC)

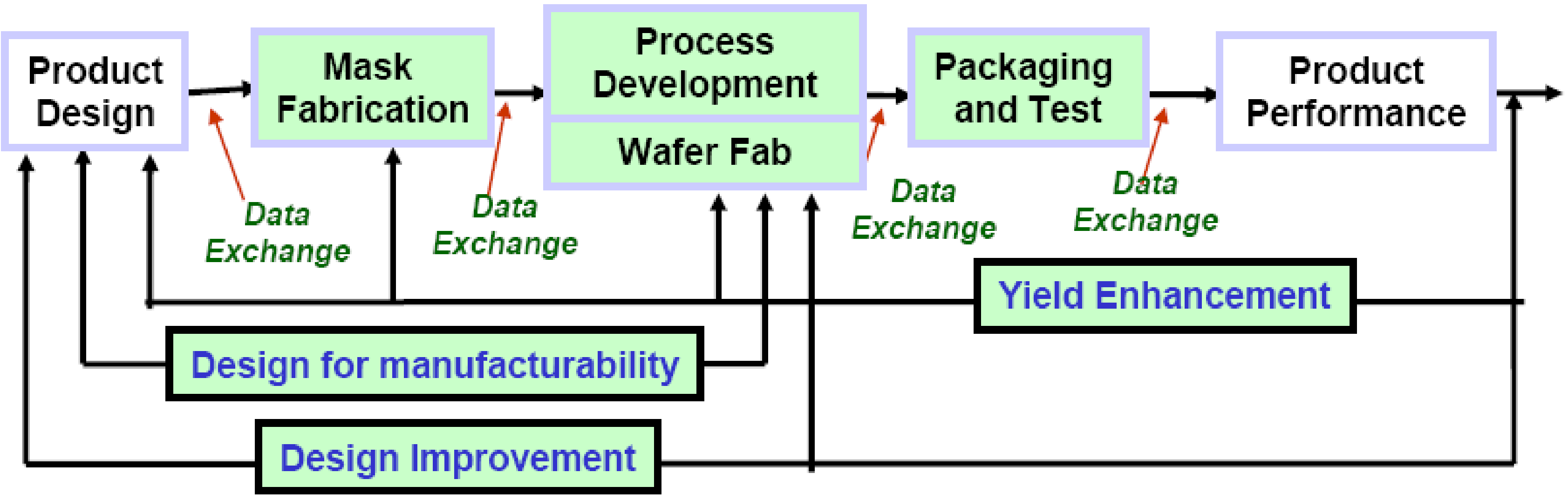
Definition of EC

- **ITRS proposed the concept of Engineering Chain (EC) to cope with design collaboration in the semiconductor industry [32].**
- **EC in the semiconductor industry was defined as a network of facilities and distributed services that performs device design; verification of design; manufacturing pilot run; assembly and test operations; yield improvement; and final release for mass-production [20].**
- **The goal of EC is to shorten the time-to-market (T2M).**

Concept of Engineering Chain

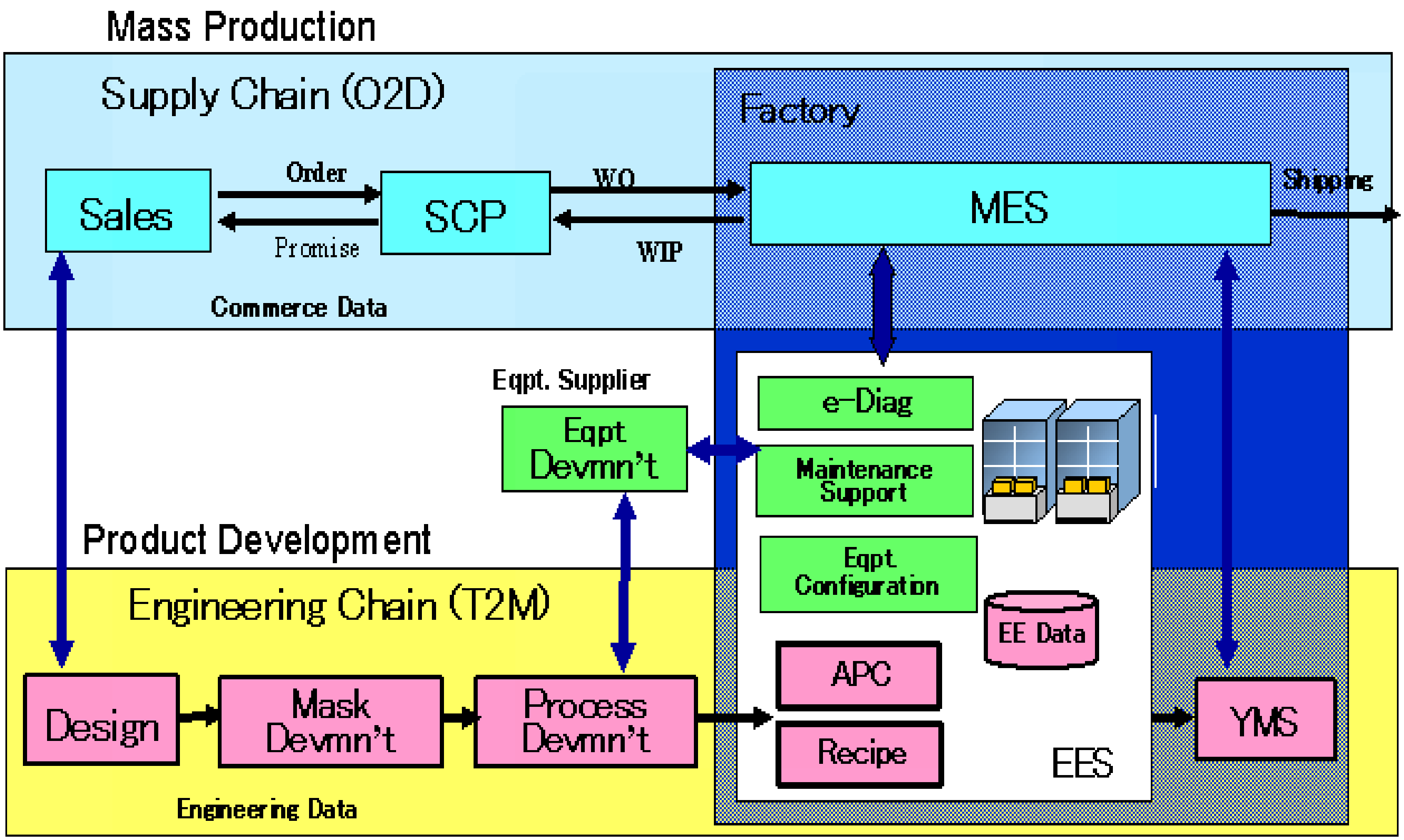
- **Challenge** – **Customers want new products delivered much faster.**
- **Key Concept** – **The Engineering Chain integrates rapid, accurate, flexible data exchange from design to new chip delivery to the customer to ensure customer cycle times are met.**

Interface protocols standardization and flexible system framework are essential to realize Engineering Chain Management

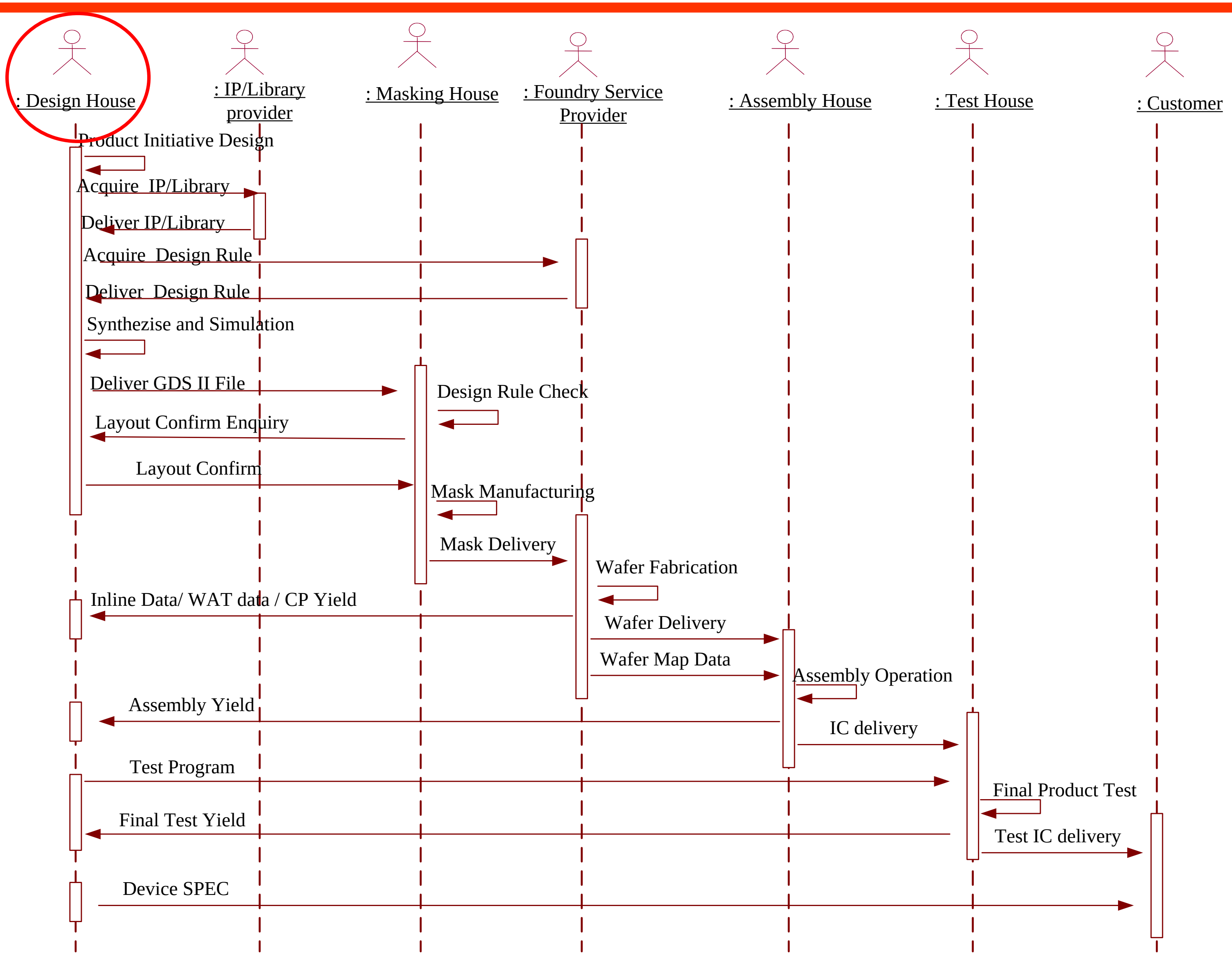


➢ **Modified from 2003 ITRS Factory Integration Factory Information & Control Systems**

EC Integrating with EES, MES, & SC [11]

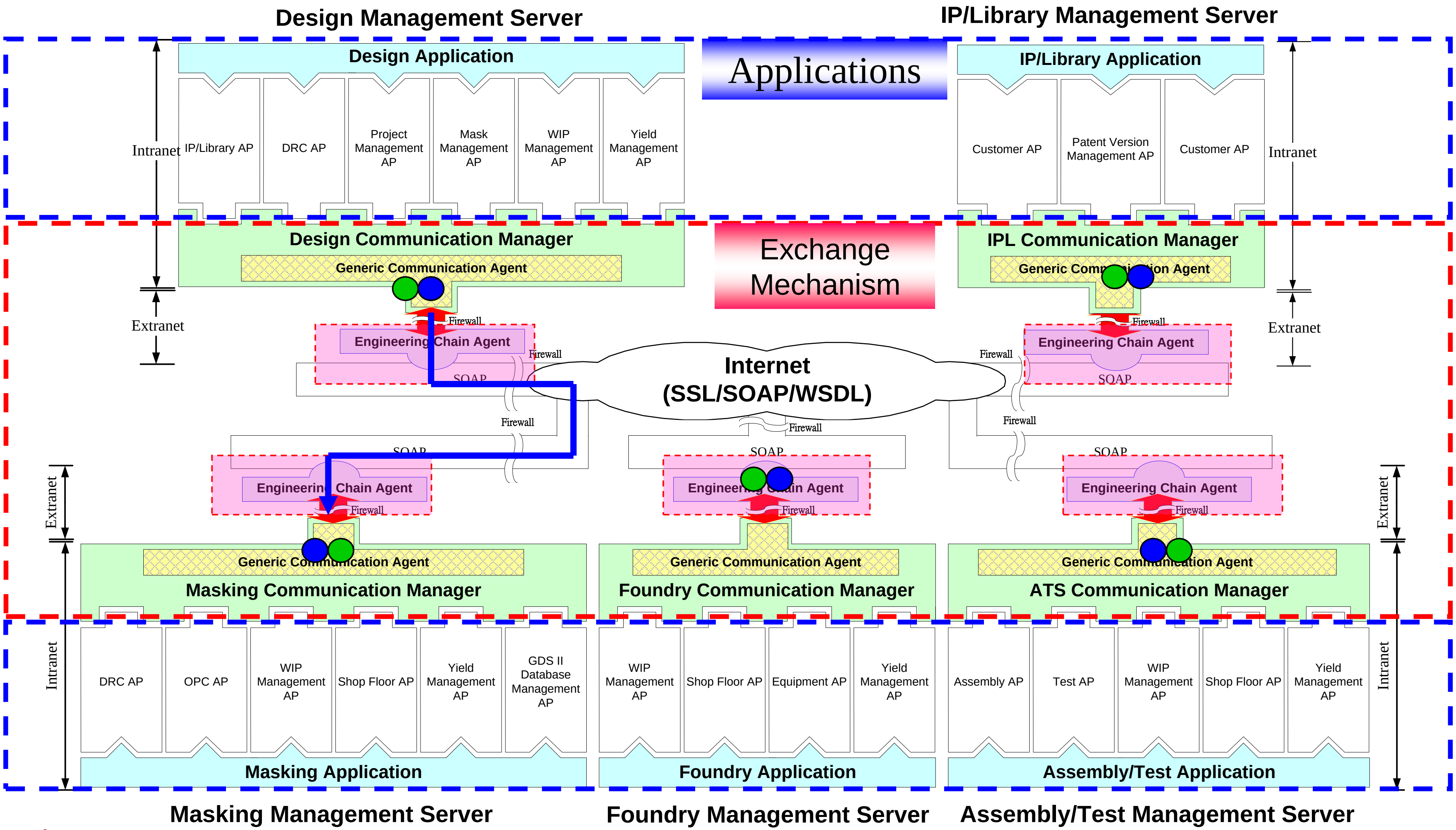


Workflow of Engineering Chain



Engineering Chain Management System [20]

3. Complicated Business Flow)S II File)



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**

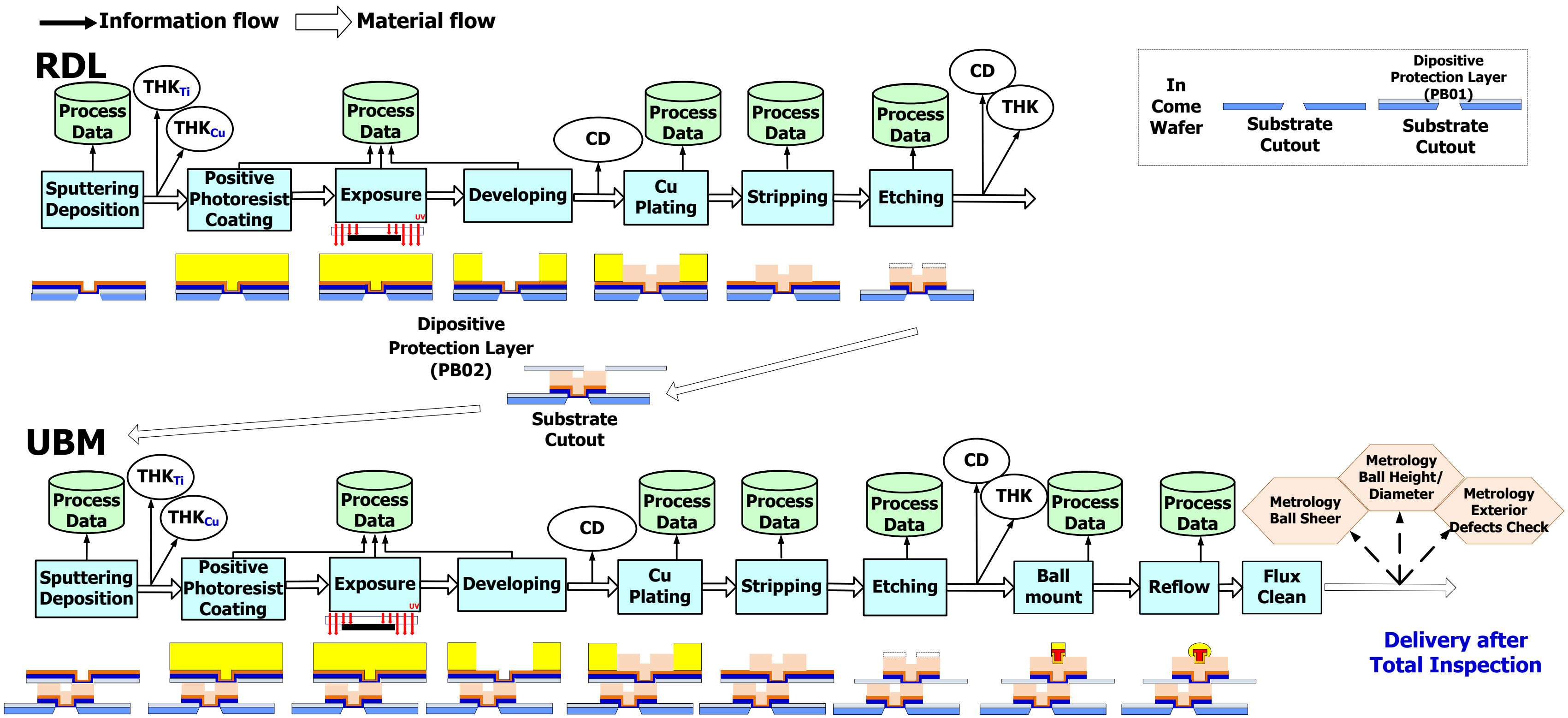
Migration
from e-Manufacturing
to Industry 4.0

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

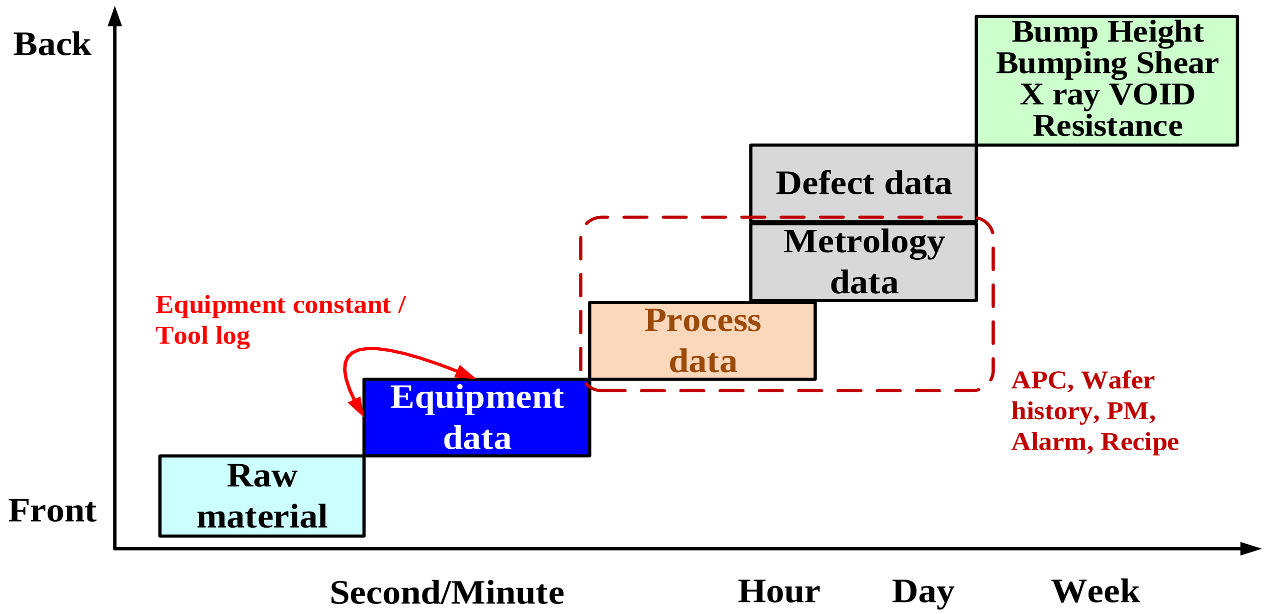


RDL: Re-distribution Layer

UBM: Under Bump Metallurgy

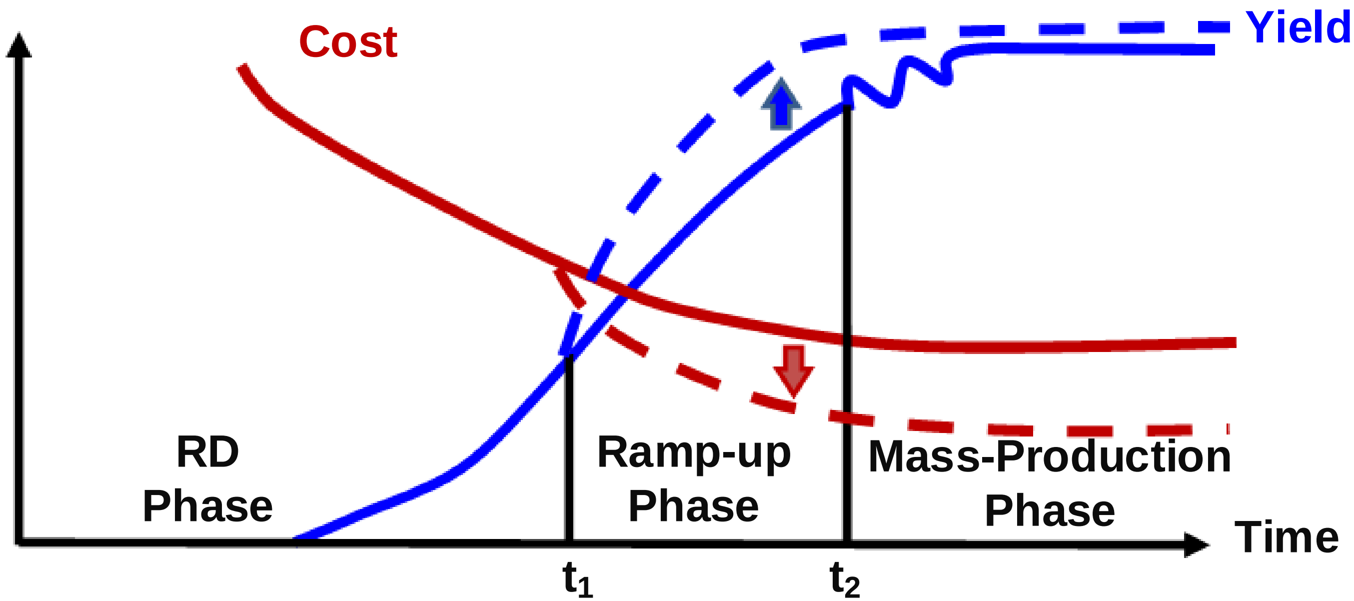
Bumping Process Data Types

- 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

- 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

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

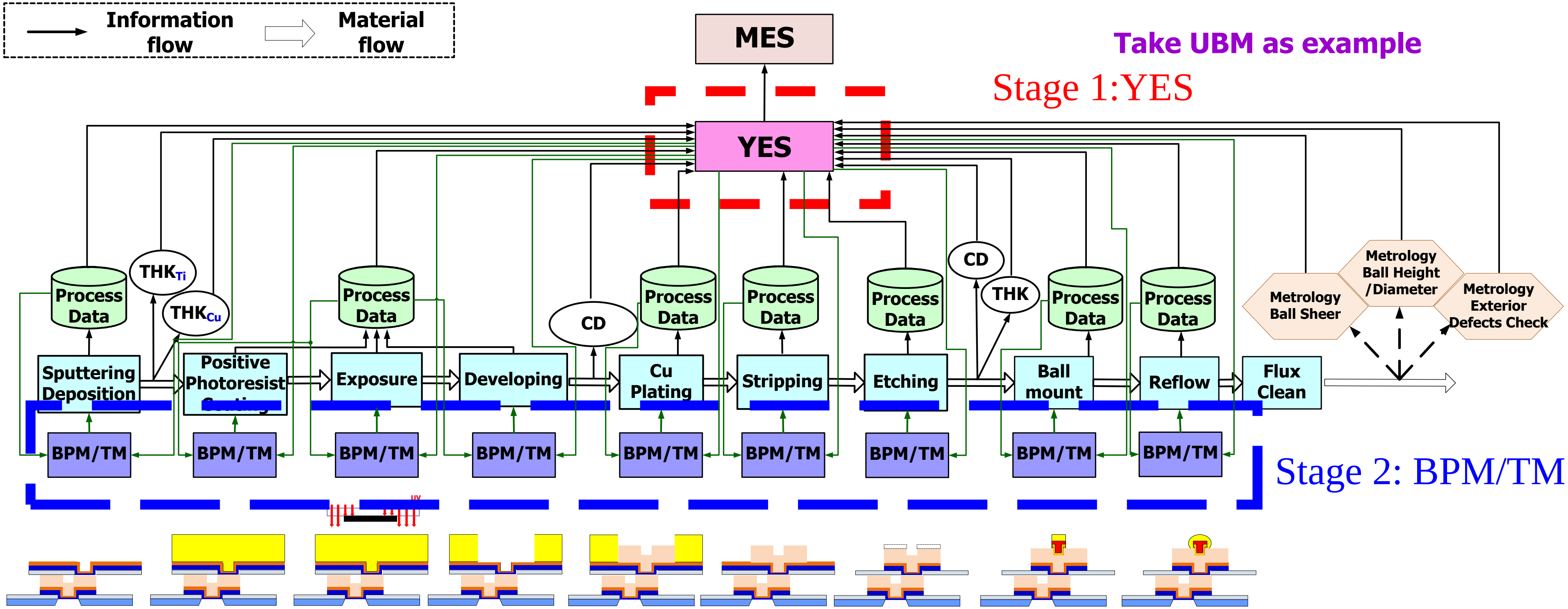
YMS
- The KSA Scheme

Mass-Production Phase (Stabilize production and reduce cost)

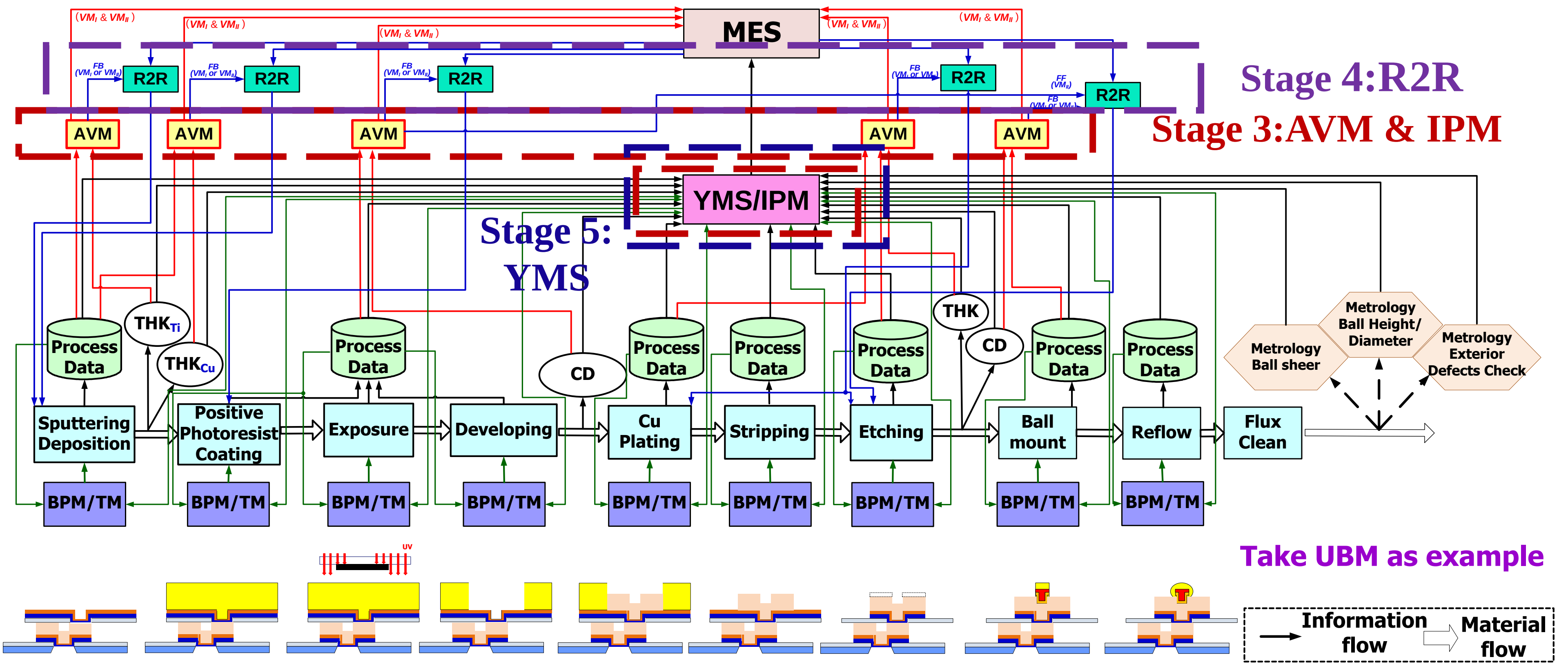
Mass-Production Phase (Find out the root causes and solve them)

Semiconductor Bumping Process

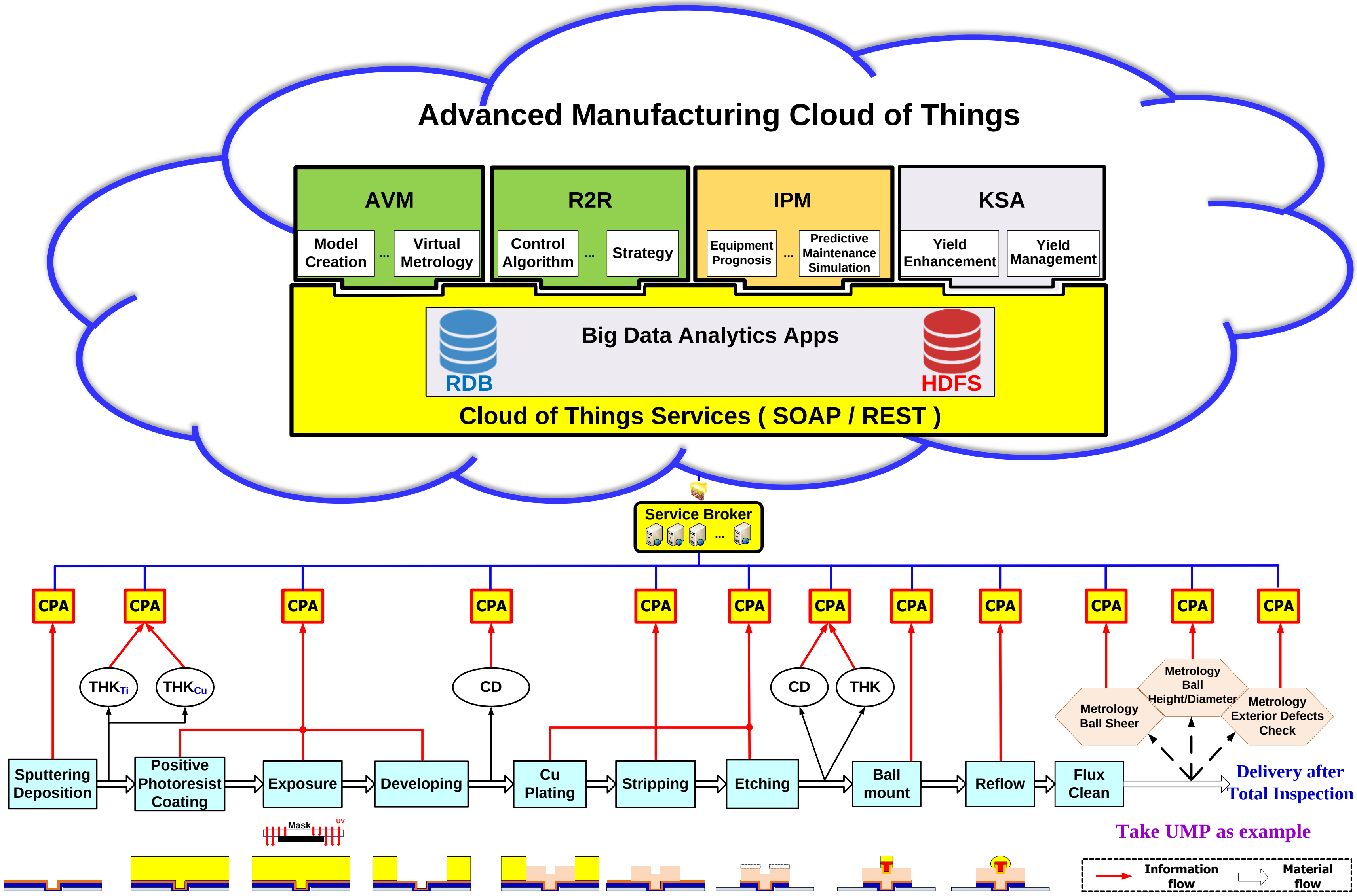
Strategy for Increasing Yield in Ramp-up Phase



Strategy for Ensuring Yield in Mass-Production Phase



Advanced Manufacturing Cloud of Things (AMCoT)



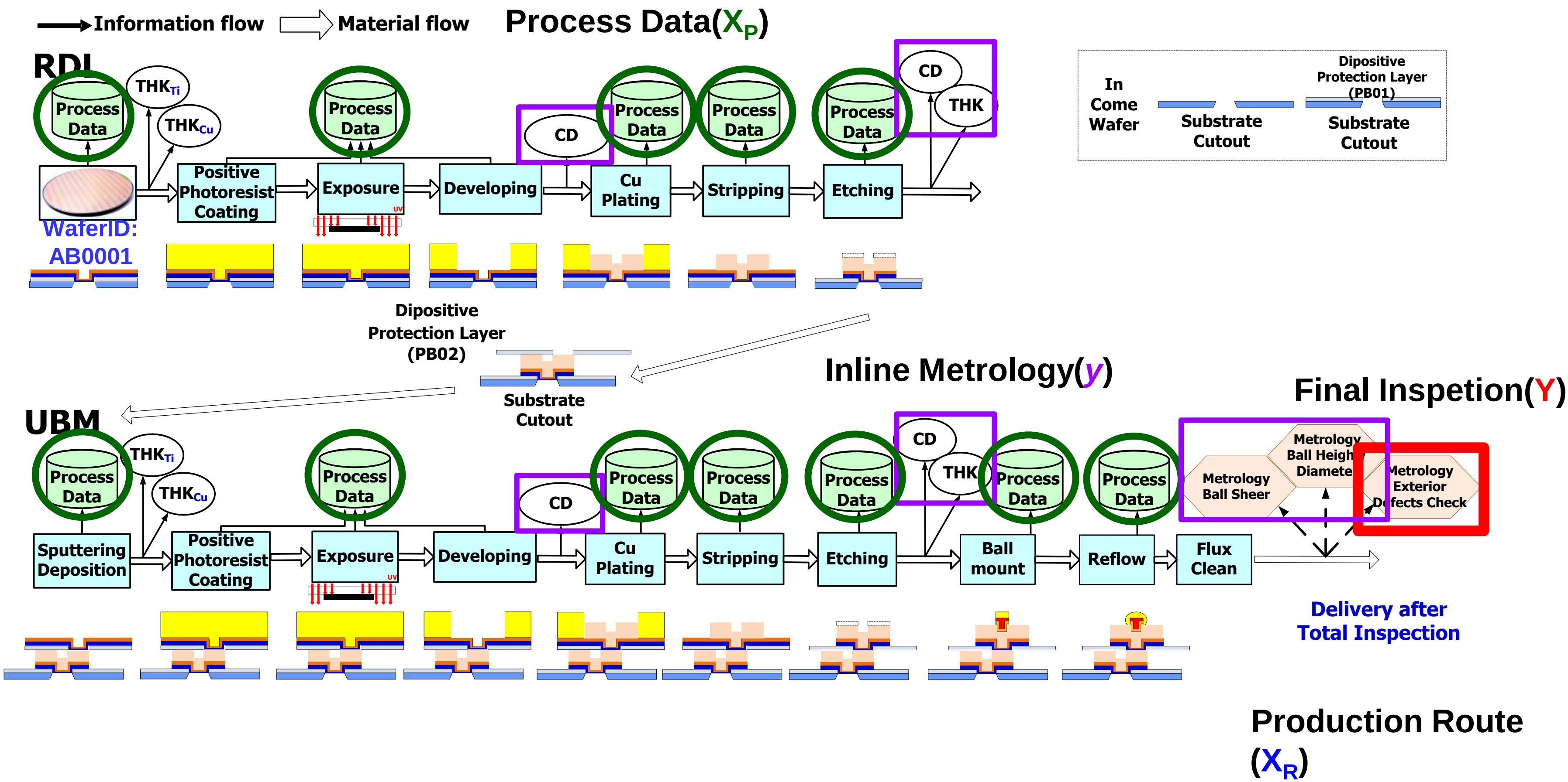
Requirements of Key-variable Search
Deficiencies of Traditional Yield Management

- The major drawbacks of the traditional root-cause search process are:
  - The information contained in the defect mode database may not be complete such that associated sampling rates need to be raised, which will increase the production cost;
  - Even the current defect mode is in the database, the search tool (such as EDA) may not find out the root cause easily.

- To solve the problems mentioned above, **Key-variable Search Algorithm (KSA) scheme is proposed and will be presented next.**

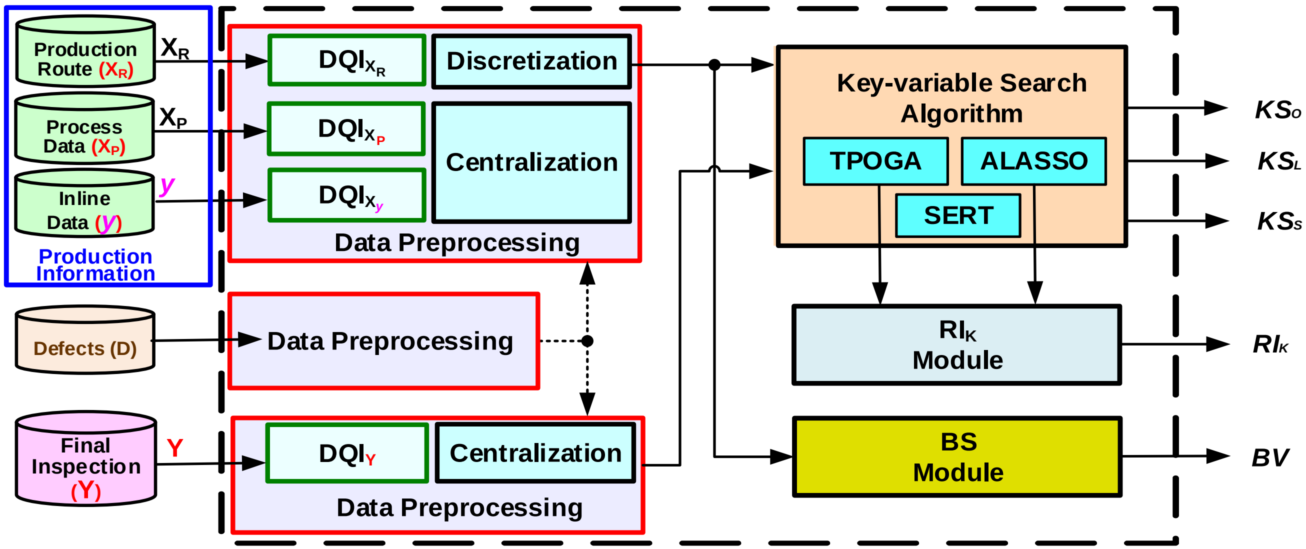
Input Data of KSA

Take Bumping Process for Illustration



KSA Scheme [36]

- 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.

References (1/4)

[1] *An e-Manufacturing Strategy Need Developed from the Manufacturing Strategy*, AMR Research, Inc, August, 2000.

[2] M. Koc, J. Ni, and J. Lee, "Introduction of e-Manufacturing", NAMRC 2003, e-Manufacturing Panel, McMaster University, May, 2003.

[3] *Exploiting e-Manufacturing: Interoperability of Software Systems Used by U.S. Manufacturers*, National Coalition for Advanced Manufacturing (NACFAM), Washington, D.C., 2001.

[4] A. Yurko, Beyond Six Sigma - e-Manufacturing in the Dot.com Era, in *GEO European Conference*, May 2001.

[5] SEMI EDA Standards: E120, E125, E132, E134, Web Site of Semiconductor Equipment and Material International (SEMI). [Online]. Available: http://www.semi.org

[6] Equipment Engineering Capabilities (EEC) guidelines, v2.5, International SEMATECH, July, 2002. [Online]. Available: http://ismi.sematech.org/emanufacturing/docs/eecguidebook.pdf

[7] *e-Diagnostics Guidebook*, version 1.7, International SEMATECH, October 2004. [Online]. Available: http://ismi.sematech.org/emanufacturing/docs/guidebook.pdf

[8] L. Rist, "e-Manufacturing/EEC Standards – from e-Mfg Workshop at SEMICON West," in *1st Symposium on Current SEMI Standards Information & Control Activities*, 2002.

[9] SEMI Interface B Standard: E133, Web Site of Semiconductor Equipment and Material International (SEMI). [Online]. Available: http://www.semi.org

[10] Web site of the Center for Intelligent Maintenance Systems (IMS). [Online]. Available: http://www.uwm.edu/CEAS/ims/

[11] ITRS Factory Integration: Factory Information & Control Systems, International Technology Roadmap of Semiconductor (ITRS), 2003. [Online]. Available: http://public.itrs.net/Files/2003ITRS/LinkedFiles/Factory/2003%20FICS%20Backup.ppt

References (2/4)

[12] Definition of Engineering Chain, INITIA Business Terms Dictionary, 2004. [Online]. Available: http://www.initiaconsulting.co.jp/archives/dictionary/a_e.html

[13] EEC High-level Requirements for APC, June 15, 2004, [Online] Available: http://ismi.sematech.org/emanufacturing/docs/EECReqs.pdf

[14] F.-T. Cheng, H.-C. Huang, and C.-A. Kao, "Dual-Phase Virtual Metrology Scheme," *IEEE Transactions on Semiconductor Manufacturing*, vol. 20, no. 4, pp. 566-571, November 2007.

[15] F.-T. Cheng, Y.-T. Chen, Y.-C. Su, and D.-L. Zeng, "Evaluating Reliance Level of a Virtual Metrology System," *IEEE Transactions on Semiconductor Manufacturing*, vol. 21, no. 1, pp. 92-103, February 2008.

[16] F.-T. Cheng, C.-F. Chang, and S.-L. Wu, "Development of Holonic Manufacturing Execution Systems," *Journal of Intelligent Manufacturing*, vol. 15, no. 2, pp. 253-267, April 2004.

[17] F.-T. Cheng, H.-C. Yang, and J.-Y. Lin, "Development of Holonic Information Coordination Systems with Failure-Recovery Considerations," *IEEE Transactions on Automation Science and Engineering*, vol. 1, no. 1, pp. 58-72, July 2004.

[18] J. Chang and F.-T. Cheng, "Engineering-Chain Requirements for Semiconductor Industry," in *Proc. 2005 IEEE International Conference on Automation Science and Engineering,* Edmonton, Canada, pp. 381-386, August 2005.

[19] F.-T. Cheng, Y.-L. Chen, and J. Y.-C. Chang, "Engineering Chain: A Novel Semiconductor Engineering Collaboration Model," *IEEE Transactions on Semiconductor Manufacturing*, vol. 25, no. 3, pp.394-407, August 2012.

[20] F.-T. Cheng, J. Y.-C. Chang, H.-C. Huang, C.-A. Kao, Y.-L. Chen, and J.-L. Peng," Benefit Model of Virtual Metrology and Integrating AVM into MES," *IEEE Transactions on Semiconductor Manufacturing*, vol. 24, no. 2, pp. 261-272, May 2011.

References (3/4)

[21] Y.-C. Su, F.-T. Cheng, M.-H. Hung, and H.-C. Huang, “Intelligent Prognostics System Design and Implementation,” *IEEE Transactions on Semiconductor Manufacturing*, vol. 19, no. 2, pp. 195-207, May 2006.

[22] M.-H. Hung, F.-T. Cheng, and S.-C. Yeh, "Development of a Web-Services-based e-Diagnostics Framework for the Semiconductor Manufacturing Industry," *IEEE Transactions on Semiconductor Manufacturing*, vol. 18, no. 1, pp. 122-135, February 2005.

[23] M.-H. Hung, T.-L. Wang, F.-Y. Hsu, and F.-T. Cheng, “Development of an Interface C Framework for Semiconductor e-Diagnostics Systems,” *Robotics and Computer-Integration Manufacturing*, vol. 24, no. 3, pp. 370-383, June 2008.

[24] F.-T. Cheng and C.-T. Lin, "A Holonic Information Exchange System for e-Manufacturing," in *Proc. of The 30th Annual Conference of the IEEE Industrial Electronics Society (IECON 2004)*, Busan, Korea, November 2004.

[25] F.-T. Cheng, J. Y.-C. Chang, H.-C. Huang, C.-A. Kao, Y.-L. Chen, and J.-L. Peng," Benefit Model of Virtual Metrology and Integrating AVM into MES,“ *IEEE Transactions on Semiconductor Manufacturing*, vol. 24, no. 2, pp. 261-272, May 2011.

[26] F.-T. Cheng, C.-A. Kao, C.-F. Chen, and W.-H. Tsai, “Tutorial on Applying the VM Technology for TFT-LCD Manufacturing,” *IEEE Transactions on Semiconductor Manufacturing*, vol. 28, no. 1, pp. 55-69, February 2015.

[27] J. Chang and F.-T. Cheng, "Manufacturability of Multivariate Applications in the Semiconductor Industry," in *Proc. 2006 IEEE International Conference on Automation Science and Engineering*, Shanghai, China, October 2006.

References (4/4)

[28] Y.-T. Huang and F.-T. Cheng, "Automatic Data Quality Evaluation for the AVM System," *IEEE Transactions on Semiconductor Manufacturing*, vol. 24, no. 3, pp. 445-454, August 2011.

[29] F.-T. Cheng, E. Shen, J.-Y. Deng, and K. Nguyen, "Development of a System Framework for the Computer-Integrated Manufacturing Execution System：a Distributed Object-Oriented Approach," *International Journal of Computer Integrated Manufacturing*, vol. 12, no. 5, pp.384-402, September/October, 1999.

[30] R. Ganeshan and T. P. Harrison, “An Introduction to Supply Chain Management”, Penn State University, [Online]. Available: http://silmaril.smeal.psu.edu/misc/supply_chain_intro.html

[31] *Performance Indicators in Logistics*, IFS Publications / Springer-Verlag, NEVEM-workgroup, 1989.

[32] *International Technology Roadmap for Semiconductor* 2005 Edition, ITRS, Dec. 2005. [Online]. Available: http://public.itrs.net/

[33] Y.-S. Hsieh, F.-T. Cheng, H.-C. Huang, C.-R. Wang, S.-C.Wang, and H.-C. Yang, “VM-based Baseline Predictive Maintenance Scheme,” *IEEE Transactions on Semiconductor Manufacturing*, vol. 26, no. 1, pp. 132-144, February 2013.

[34] C.-A. Kao, F.-T. Cheng, W.-M. Wu, F.-W. Kong, and H.-H. Huang, "Run-to-Run Control Utilizing Virtual Metrology with Reliance Index,“ *IEEE Transactions on Semiconductor Manufacturing*, vol. 26, no. 1, pp. 69-81, February 2013.

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

[36] 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. DOI: 10.1109/LRA.2016.2584143.