EDA Factory Applications and Benefits

Smarter Manufacturing Through Better Data:
Applications and Benefits of
SEMI Interface A / EDA Standards Workshop

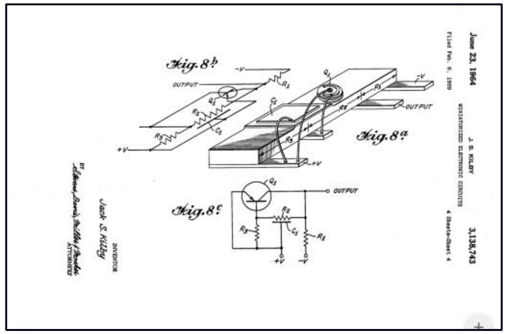
January 10, 2020
Shanghai, China

Outline

- Historical background
- Gigafab context
- Keeping score with ROI
- Data collection alternatives
- EDA factory application examples

60+ years ago…

Jack Kilby and Bob Noyce shared a dream



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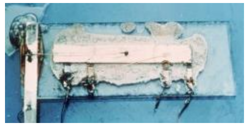

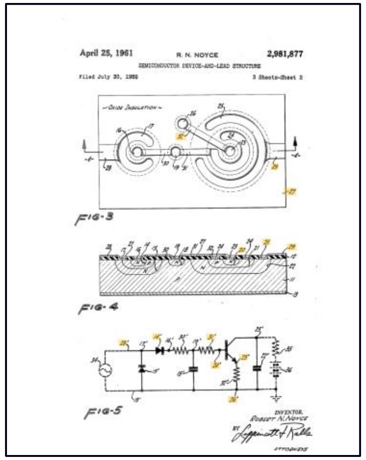

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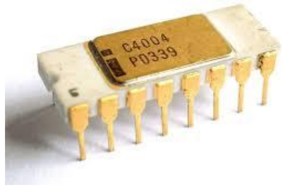
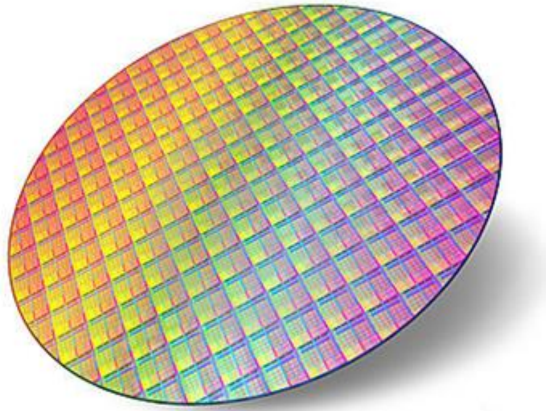


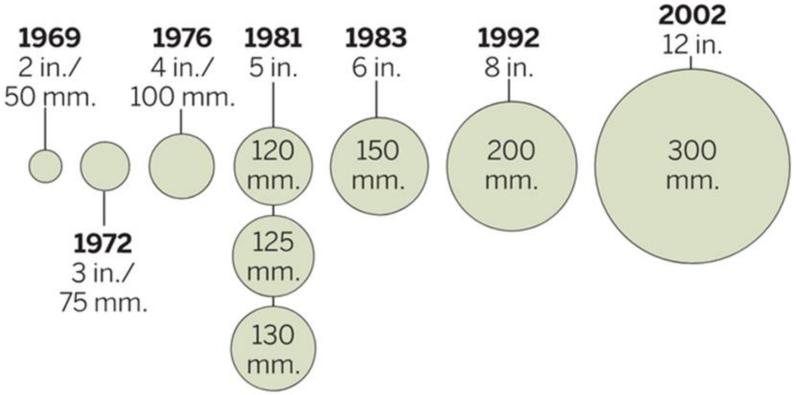


A decade later…

Applied Materials was founded

- And the semiconductor equipment industry was born (1967)
- SEMI was formed with 55 members to support this nascent community (1970) and held its first SEMICON at the San Mateo fairgrounds with 80 exhibitors and 2800 visitors (1971)
- The first SEMI Standard[s] Committee was created to define specifications for production silicon (3"!) wafers (1973)

APPLIED MATERIALS AMS 2600 CVD (1968)



Collaboration culture evolution

Unequalled in other industries

- Drivers have varied from the need for efficiency, the fear of extinction, and the recognition of mutual interdependence…

- Domains of significant collaboration include international trade and technical events, advocacy, standards, research and development

SEMI Standards are the Oxygen for the Industry

Wafers & Substrates

MF SERIES

T SERIES

- Wafer sizes & specifications
- Wafer ID, ID readers/writers
- Wafer edge profiling
- Photomask registration marking
- Defects classification
- Substrate tracking
- Specs for GaAs wafers
- Specs for Indium Phosphide wafers
- Silicon on insulator
- Shipping boxes

Equipment & Communications

E SERIES

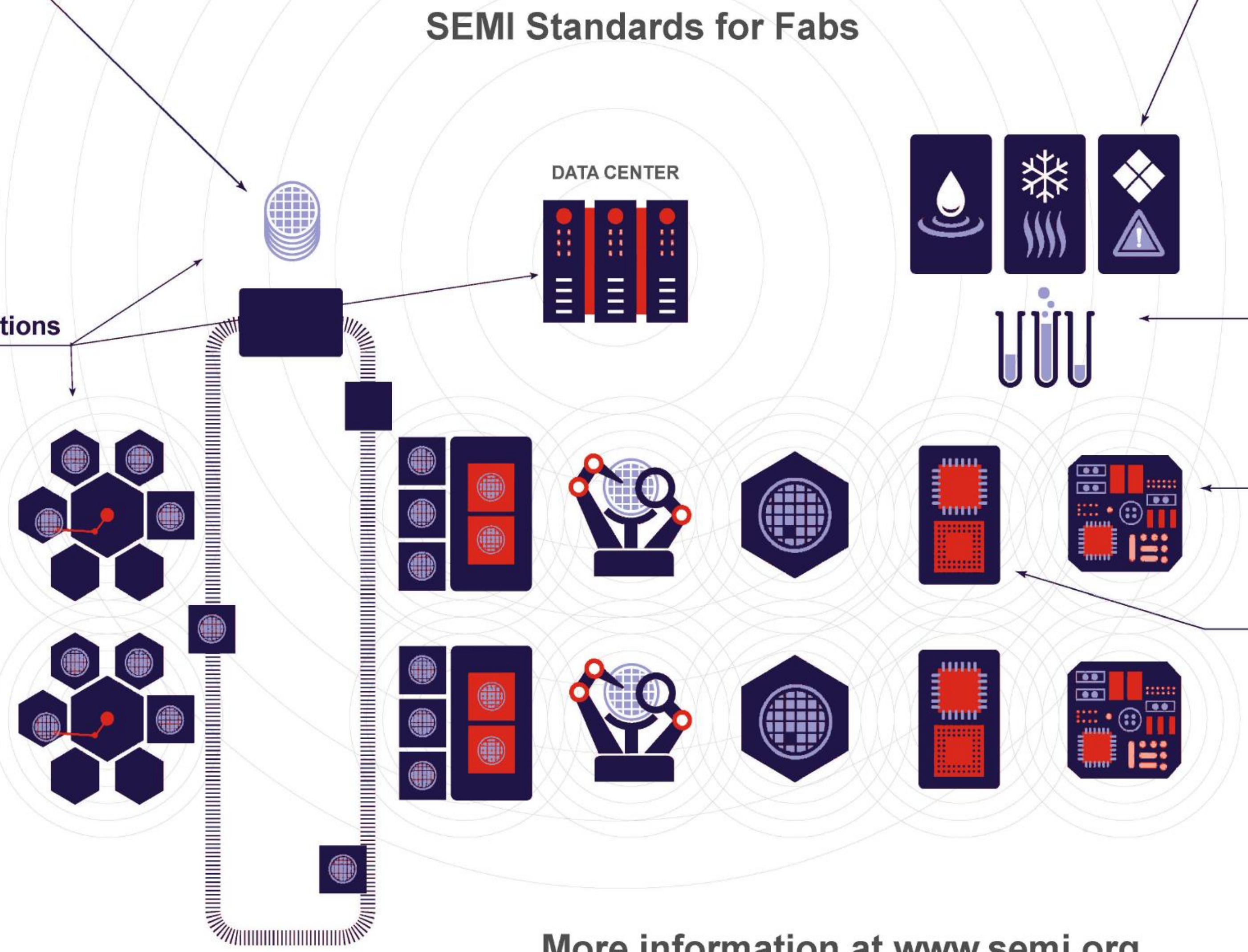
A SERIES

- SECS- II, GEM, GEM300, & EDA
- Carriers & physical interfaces
- CIM Framework
- Cluster tools
- Recipe management
- Sensor/actuator networks
- I/O interfaces
- Equipment process control
- Overall Equipment Effectiveness
- Human-machine interfaces
- Mass flow controllers
- Minienvironments
- Equipment training

Microlithography

P SERIES

- Lithography
- Photomask & Resist
- Defect inspection
- Design data exchange
- Reticle pads



Safety, Ergonomics & Facilities

S SERIES

F SERIES

- S2 Safety guidelines
- Chemical & gas distribution
- Chemical & gas testing
- Facilities – electrical
- Facilities – atmospheric
- Ultra-pure water specs
- Fluorocarbon components
- Stainless steel components
- Chemical hazards
- Fire safety

Chemicals & Gases

M SERIES

C SERIES

- Gas purity & particle specifications
- Chemical & gas testing
- Process gases & specialty gases
- Water systems

Traceability

- Substrate and device tracking
- Device & wafer marking
- Carriers

Packaging

3D SERIES

G SERIES

- Ball grid arrays & lead frames
- Automated test equipment & probers
- Molding compounds
- Package & chip carrier tooling
- Package specifications
- 3DS-IC packaging

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More information at www.semi.org

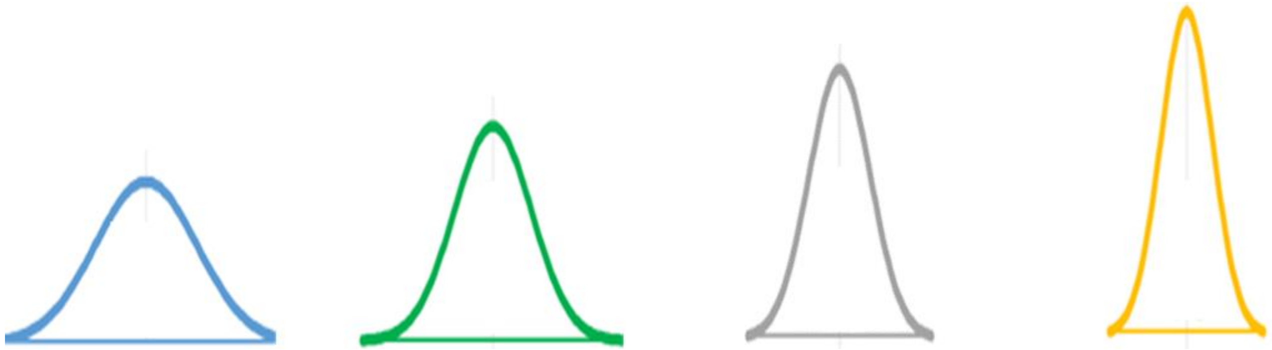
1000 SEMI STANDARDS & COUNTING

Connectivity standards evolution

In response to the insatiable demand for data

Node (nm) 800 600 350 250 180 130 90 45 32 22 14 10 7 3

Process window (C_{pk})



Key applications	SPC	R2R	FDC	VM	PdM	Big Data	AI/ML …
Data generated (MB/sec)	0.016	0.3	2.4	40	240	1000	2500
Supporting SEMI Standards	SECS-II	GEM	GEM300	EDA I	EDA II	E164…	EDA III

Current gigafab context

In every minute of every day…

EDA services collect millions of parameters…

GEM300 events track thousands of activities…

GEM messages coordinate hundreds of transactions…

Keeping score with an ROI model

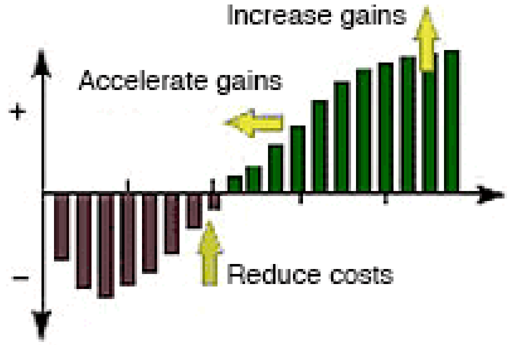
Agree on relative cost and value of key factors

Costs

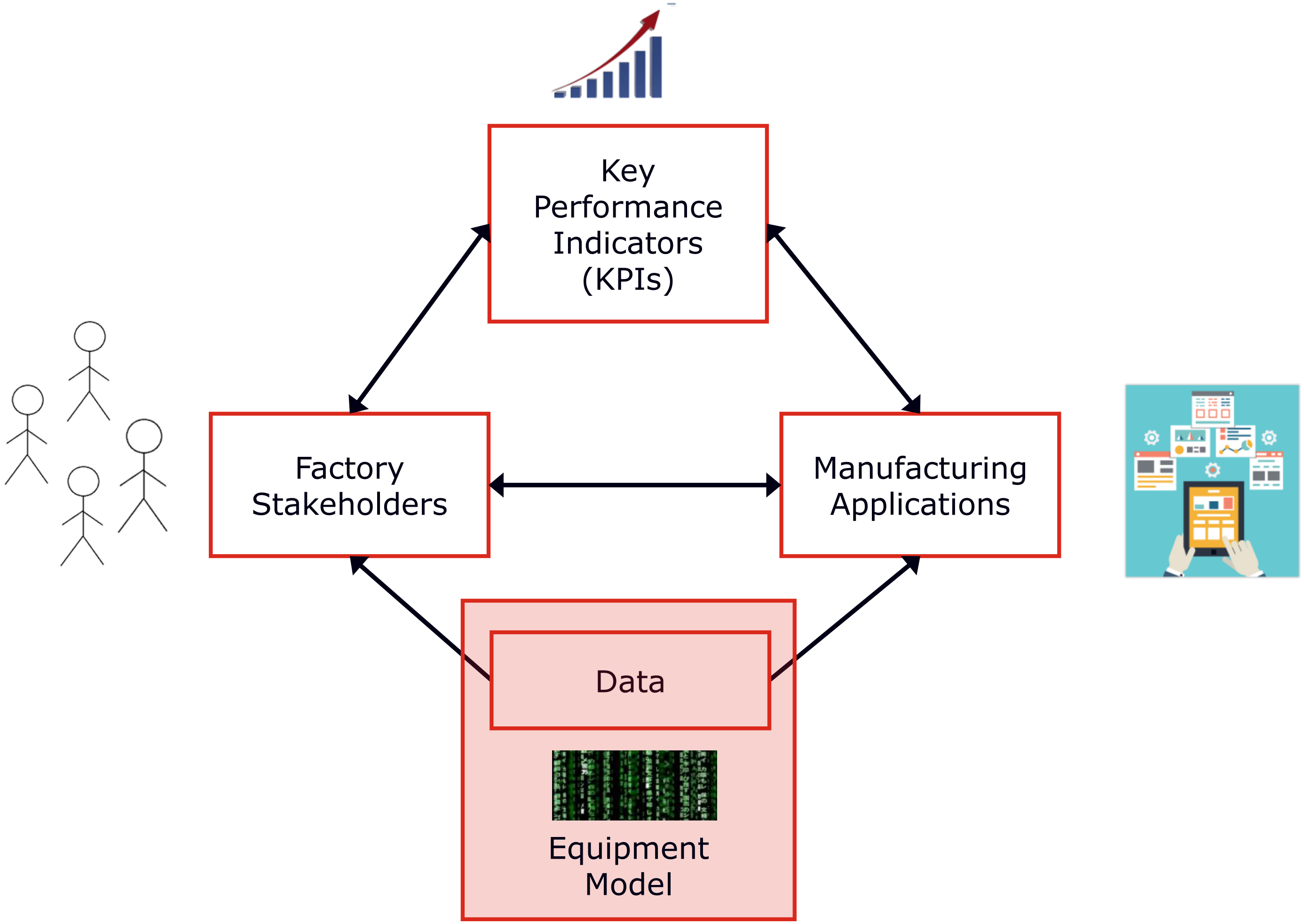
- *Materials/outside services*
  - Software development
  - Technology development
  - Hardware
  - Licenses
- *Internal labor*
  - Operations
  - Engineering
  - Automation
  - Information technology
- *Capital expenses*
  - Equipment
- *Other*

Benefits

- *Product material*
  - Yield
  - Yield ramp
  - Scrap reduction
- *Time*
  - Equipment/fab uptime
  - Factory cycle time
  - New Product Introduction time
- *Cost Reduction*
  - Qual wafers
  - Hardware
  - Licenses
  - Engineering labor
- *Other*



KPIs, stakeholders, applications, …
Importance of the equipment model



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Data collection alternatives
Spec contents, equipment capability

SEMI Standard Level	Functionality	Benefit
GEM/GEM300	Full support for E40, E87, E90, E94, etc.	Baseline: Supplier-specific integration costs; labor-intensive SECS data collection management, tool characterization, software upgrade verification, and fault model development processes
EDA Freeze I (1105)	EDA basics – early metadata models, DCP-based "data on demand", multi-client access	Self-documenting interface capability; quick and easy to change data collection plans as application needs evolve; factory system architecture flexibility
EDA Freeze II (0710)	Conditional triggers in trace requests, simple event support, interface discovery; second-generation metadata models	Precisely "frame" trace data depending on application requirements; one-click connectivity; cleaner model structures with richer event/parameter content; higher performance
EDA Common Metadata (E164)	Complete coverage of GEM300 and E157 objects, state machines, events; standard metadata model structure, content, and names	Programmatically generate DCPs, configure generic tool applications, characterize equipment behavior; simplify mapping to factory data management systems
Factory-Specific EDA Requirements	Process-specific parameters for advanced feature extraction for FDC, PHM, VM; mechanism- and component-level command/response signals for fingerprinting, tool matching; etc.	Dramatically increase visibility into tool and process behavior; enable advanced "smart factory" monitoring and control applications well beyond current capabilities

Outline

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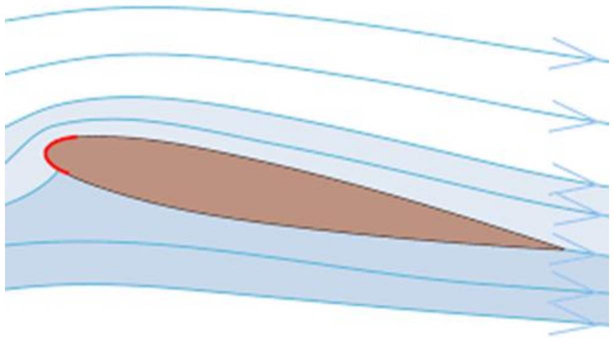
- EDA factory application examples

EDA factory applications
Current leading edge

- Real-time throughput monitoring
- Precision FDC feature extraction
- Product time measurement
- [Lot completion estimation]
- Fleet matching and management
- Specialty sensor access
- Sub-fab data integration/analysis
- Equipment log file processing
- Machine Learning and AI support



Wide range of stakeholder coverage

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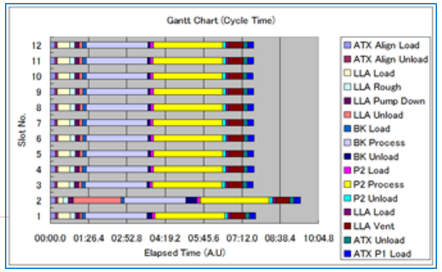
EDA application profile

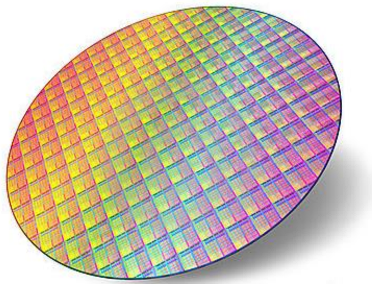
Real-time throughput monitoring

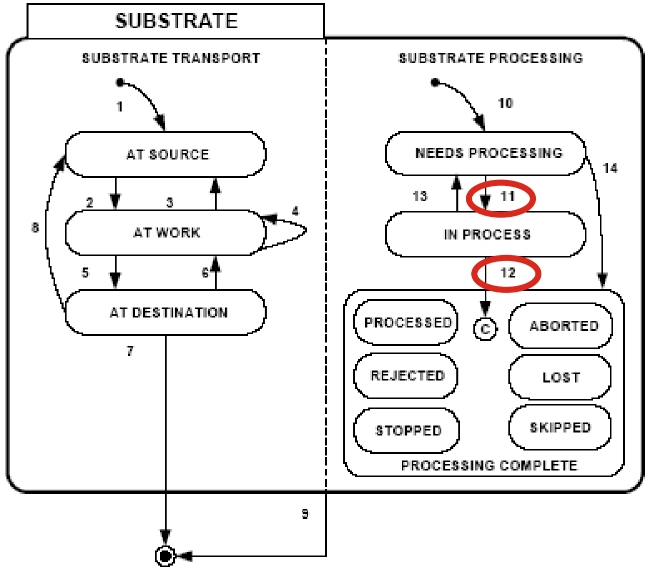


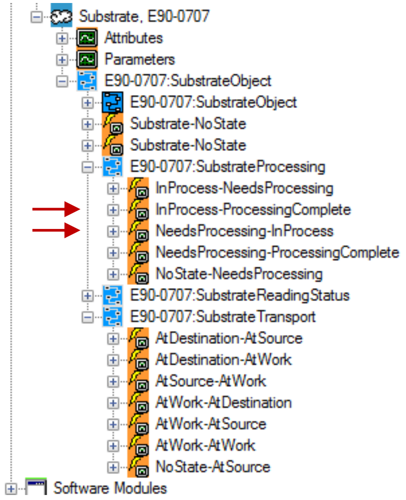
- Problem statement
  - Monitor bottleneck (e.g., litho) tool throughput performance to know when it drifts away from "normal" for whatever reason
  - This is important because any loss of throughput ripples throughout the line
- Solution components
  - Monitor events and calculate process time "on the fly"
  - Evaluate context to compare "equivalent" runs; flag outliers
- EDA leverage
  - Standard material movement and recipe execution events
  - Context available at event occurrence
- Key ROI factors
  - Cycle time, productivity excursion MTTD (50% reduction), equipment throughput improvement (3-5%)

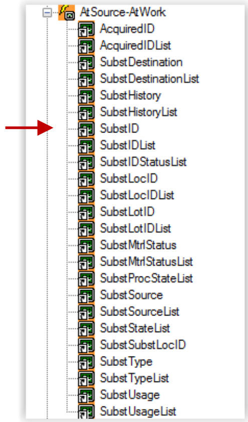
Real-time throughput monitoring

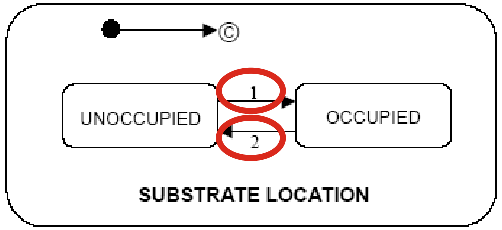
SEMI E90 state machines and model content

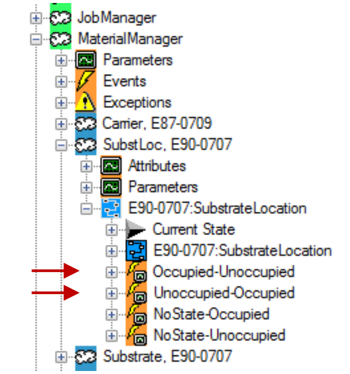


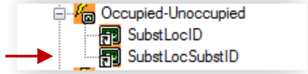












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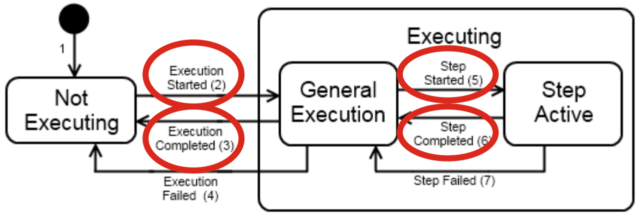
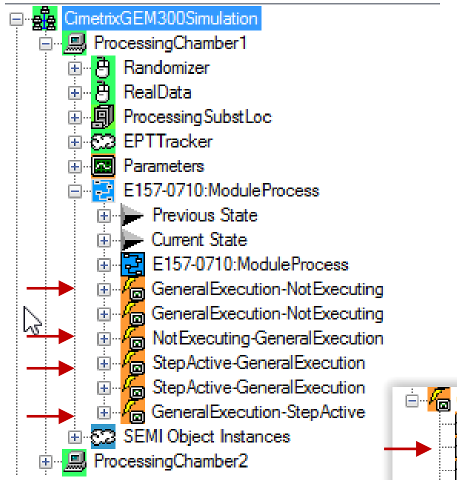
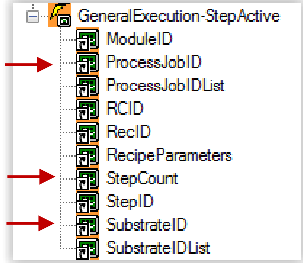
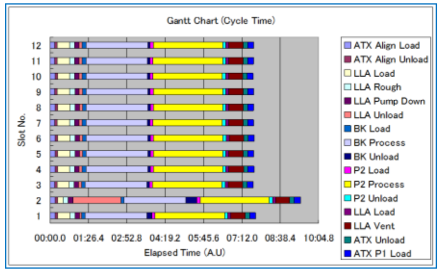
Real-time throughput monitoring

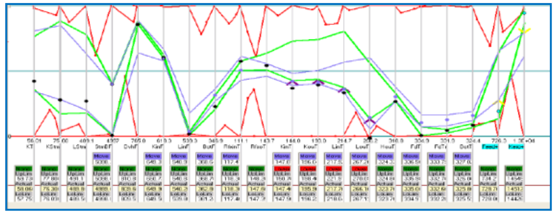
E157 state machine, model content, and results

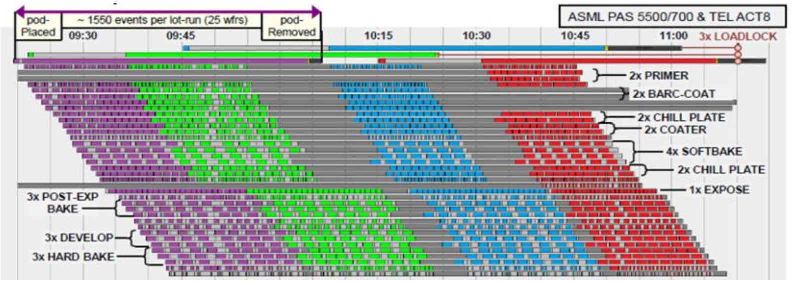






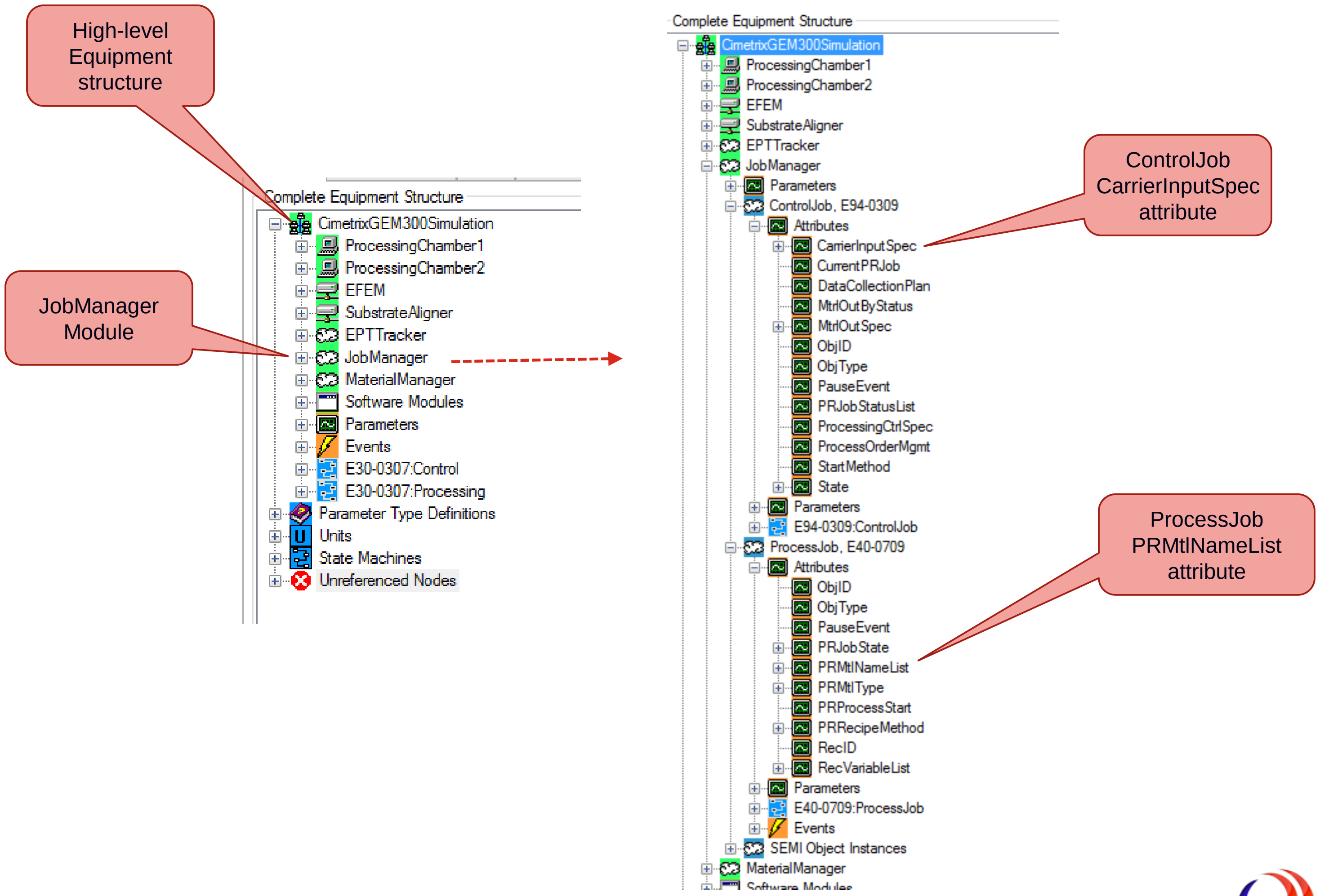






Real-time throughput monitoring

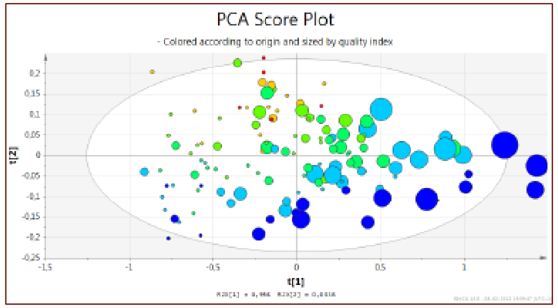
E40 and E94 required context information

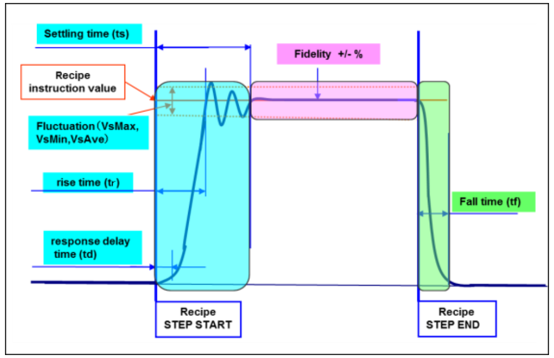


EDA application profile

Precision FDC feature extraction

- Problem statement
  - Multivariate statistics used to develop reduced-dimension equipment fault models for equipment operating points
  - Fault model accuracy depends on calculating “features” using trace data collected during key recipe steps
- Solution components
  - Multivariate analysis tools
  - Context evaluation for grouping fault models into equivalence classes (“threads”)
- EDA leverage
  - Conditional triggers, context data in metadata model, multi-client access for effective model development
- Key ROI factors
  - Delta yield (25% fewer excursions), lower false alarm rate (50%), rapid excursion detection (50% MTTD, severity reduction), scrap, equipment uptime, engineering efficiency





Data collection alternatives
Fault Detection and Classification (FDC)

SEMI Standard Level	Functionality	Benefit
GEM/GEM300	Fault models difficult to change after initial development if data collection requirements change	Baseline
EDA Freeze I (1105)	Easy to change equipment data collection plans as fault models evolve and require new data; Model development environment can be separate from production system	Engineering labor reduction; improved fault models and lower false alarm rate
EDA Freeze II (0710)	Use conditional triggers to precisely “frame” trace data while reducing overall data collection needs; Incorporate sub-fab component/subsystem data into fault models	Even better fault models; reduced MTTD (mean time to detect) of fault or process excursion; little or no data post-processing required
EDA Common Metadata (E164)	Include standard recipe step-level transition events for highly targeted trace data collection; Automate initial equipment characterization process by using metadata model to generate required data collection plans	Faster tool characterization and fault model development time
Factory-Specific EDA Requirements	Incorporate previously unavailable equipment signals in fault models; Update data collection plans and fault models automatically after process and recipe changes; Include recipe setpoints in the equipment metadata models	TBD (Not yet applicable)

ROI factors and FDC false alarm costs

Hypothetical megafab

- Factor values
  - Number of tools - 2000
  - Hour of tool time - $2200 (average raw and finished wafer value)
  - Qual wafer cost - $250
  - Hour of engineering/tech time - $150
- Cost of false alarms
  - Tool time to resolve (incl. 0.5 hour metrology) – 5 hours
  - Qual wafers required – 6
  - Engineering/tech time required – 2 hours
  - Cost per false alarm = 4.5*2200 + 6*250 + 2*150 = $11,700
  - False alarm rate – 2 per tool per year
  - Total false alarm cost = $11,700*2000*2 = $46.80M
- Benefit of advanced data collection
  - Reduction in false alarm rate – 50%
  - Annual savings = $23.4M

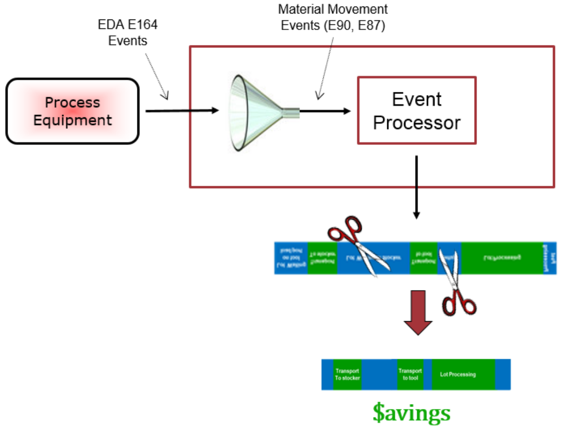
ROI factors and process excursion costs
Hypothetical megafab

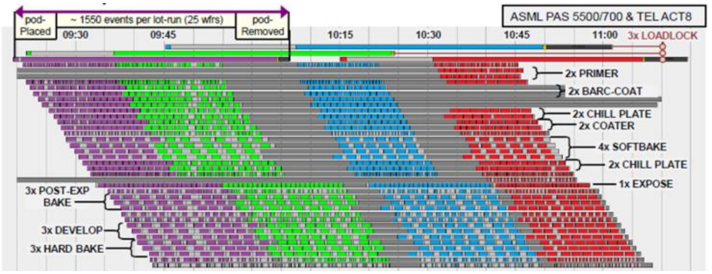
- Factor values
  - Wafer value - $10,000 (average cost of WIP)
  - Hour of engineering/tech time - $150
- Cost of process excursions
  - Wafers per excursion – 500
  - Delta yield per excursion – 3%
  - Engineering time required to resolve – 160 hours
  - Cost per excursion = 500*10,000*.03 + 160*150 = $174,000
  - Excursion rate – 24 per year
  - Total excursion cost = $174,000*24 = $4.12M
- Benefit of advanced data collection
  - Reduction in # and severity (yield loss) of process excursions – 25%
  - Annual savings = $1.72M

EDA application profile

Product Time Measurement (E168)

- Problem statement
  - Find systemic problems in equipment and factory throughput and identify root causes
- Solution components
  - Event processor that analyzes material movement events at all substrate during lot processing, with absolute and relative timestamps and durations for each
  - Standard "time element" definitions (using SEMI E168) allow calculation of detailed "active" and "wait" time elements
- EDA Leverage
  - Substrate tracking events directly support this function but are not usually collected sufficiently using GEM to support this need
  - All other events required to classify all time segments in a substrate's life cycle are mandated by metadata model standards
- Key Performance Indicators (KPI) Affected
  - Increased equipment productivity and reduced process variability





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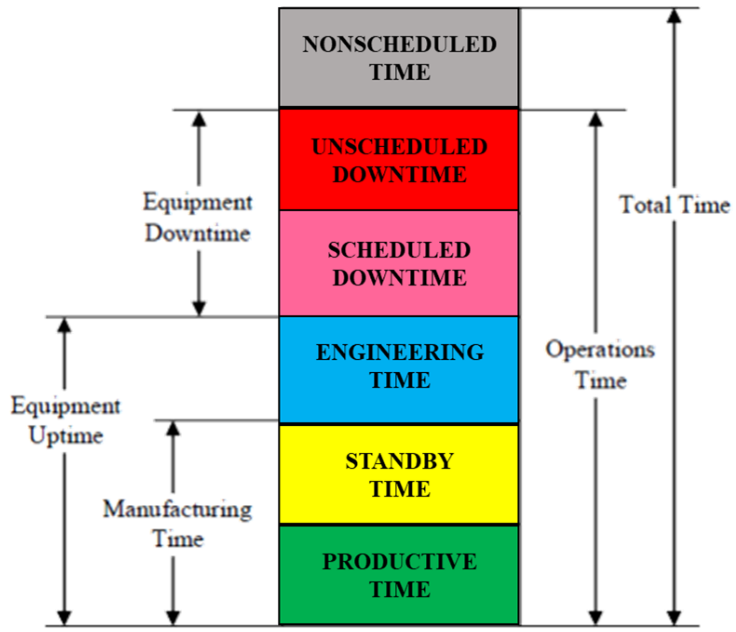
Where does the time go?

Equipment perspective… (OEE metrics)

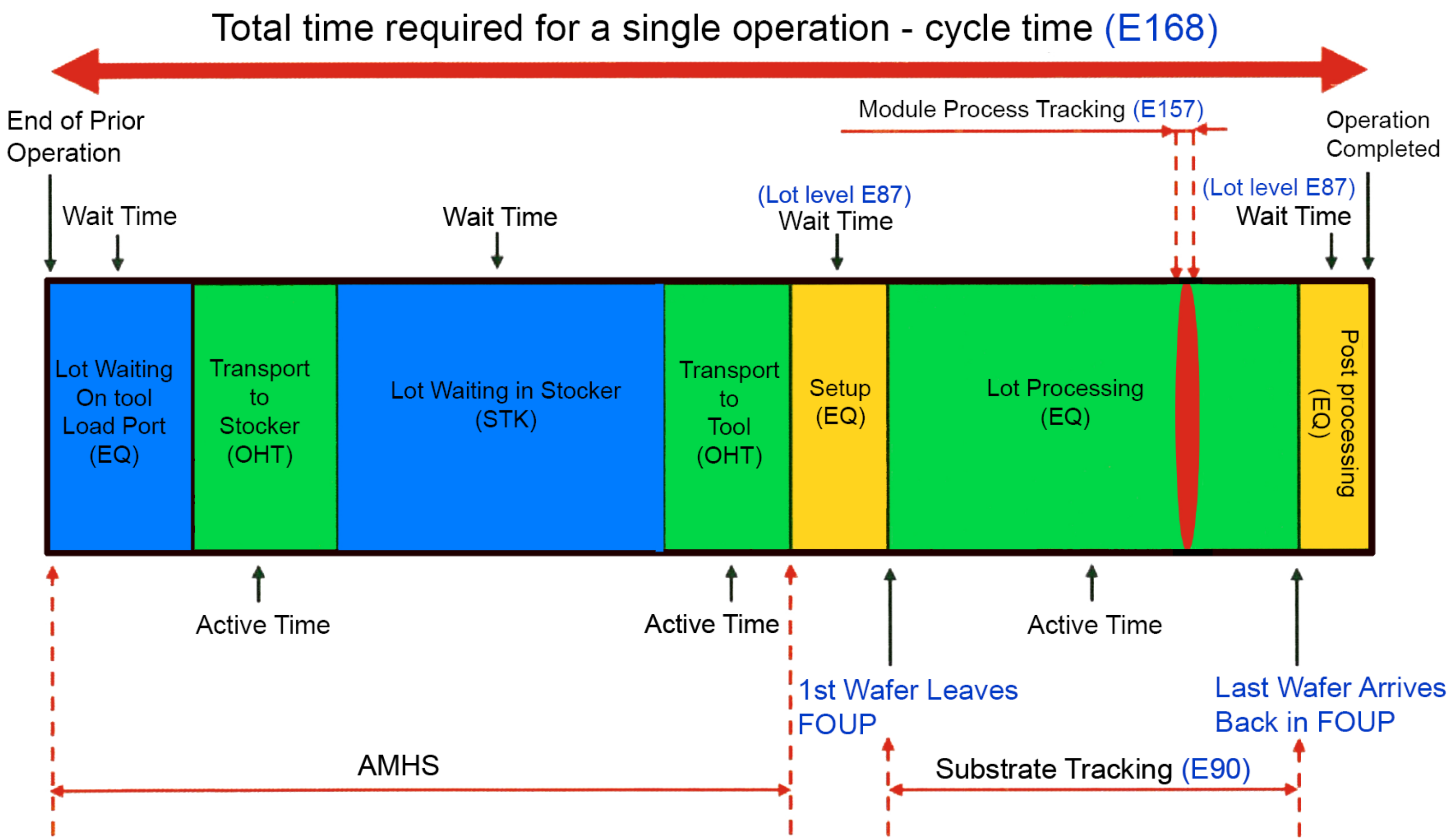


Legend
Undefined
Wait
Exception
Machine Failure
Maintenance
Engineering Time
Waiting for Setup
Change Lot / Setup
Standby for Operator
Standby for Material
Engineering for Sale
Productive Time

SEMI E10, E58, and E79 (and supporting GEM300 standards)

Where does the time go?

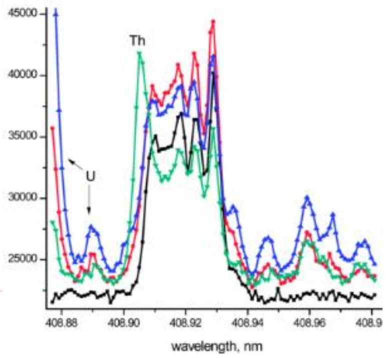
Product perspective… (WTW/PTM metrics)



SEMI E168 (and supporting GEM300 standards)

EDA application profile

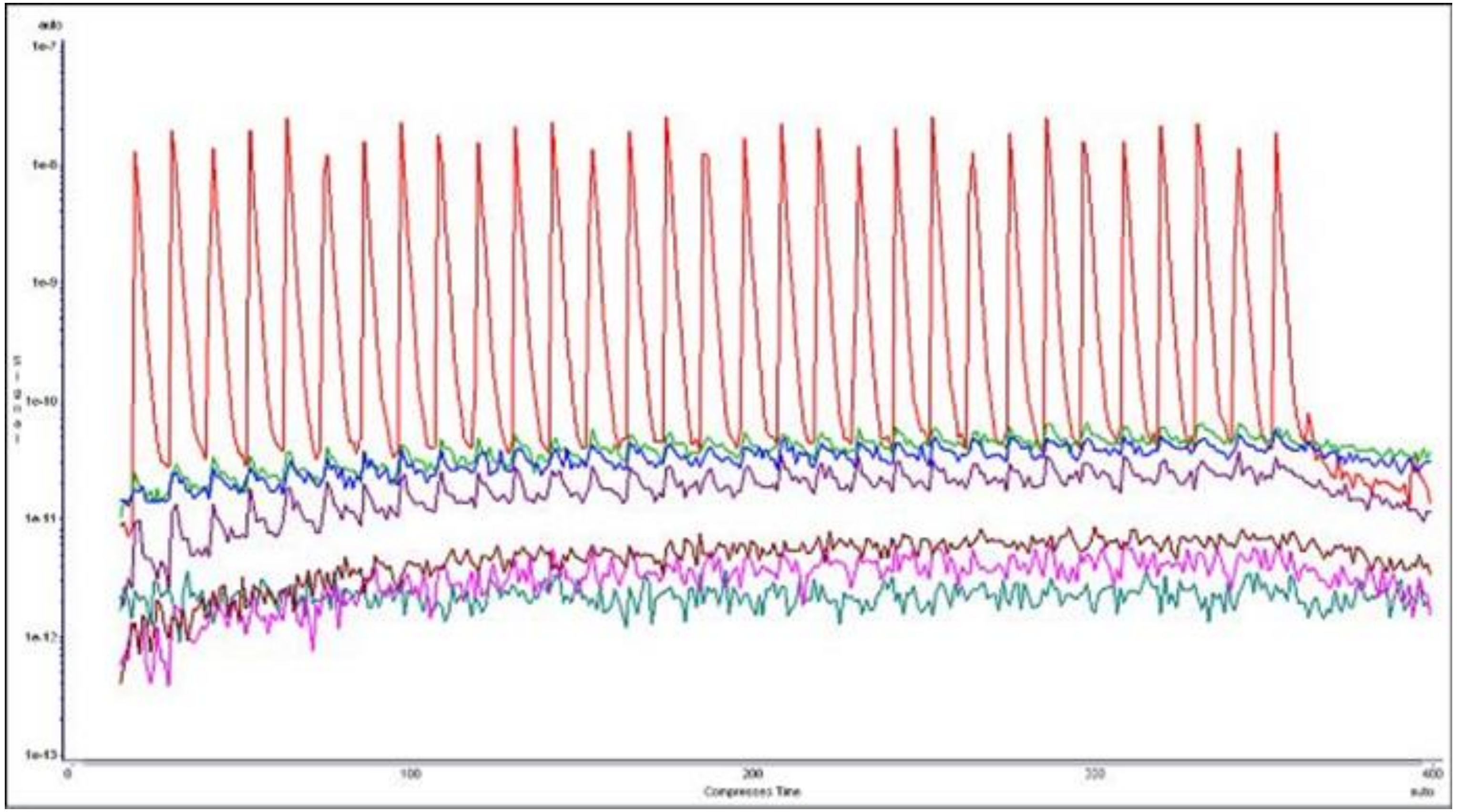
Specialty sensor data access



- Problem statement
  - Reduce effort required to parse complex sensor data on equipment local file systems and merge it with the EDA-collected FDC data
  - Sensors include OES, RGA, pyrometers, NDIR, Mass spec, high-frequency RF, QCM, …
- Solution components
  - Format conversion, data compression, new EDA metadata types and interface modules
- EDA leverage
  - Multi-client capability, powerful DCP structure, model-based interfaces
- Key ROI factors
  - Tool availability, test wafer usage, engineering effort
  - Presented at eMDC Conference (Taiwan)

Specialty sensor data access

RGA Samples during ALD Process (for one wafer)



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EDA application profile

Fleet matching and management

- Problem statement
  - Maintain large sets of similar equipment at same operating point to maximize lot scheduling flexibility (i.e., no "dedicated" tools)
  - Tools drift apart over time, especially when manual adjustments are made
- Solution components
  - Capture equipment configuration and status information
  - Track behavior of key equipment mechanisms, independent of process recipe
- EDA leverage
  - Metadata model content at sensor/actuator command level
  - Access vector of important equipment constants
- Key ROI factors
  - Cycle time (dispatching flexibility), equipment uptime, yield ramp

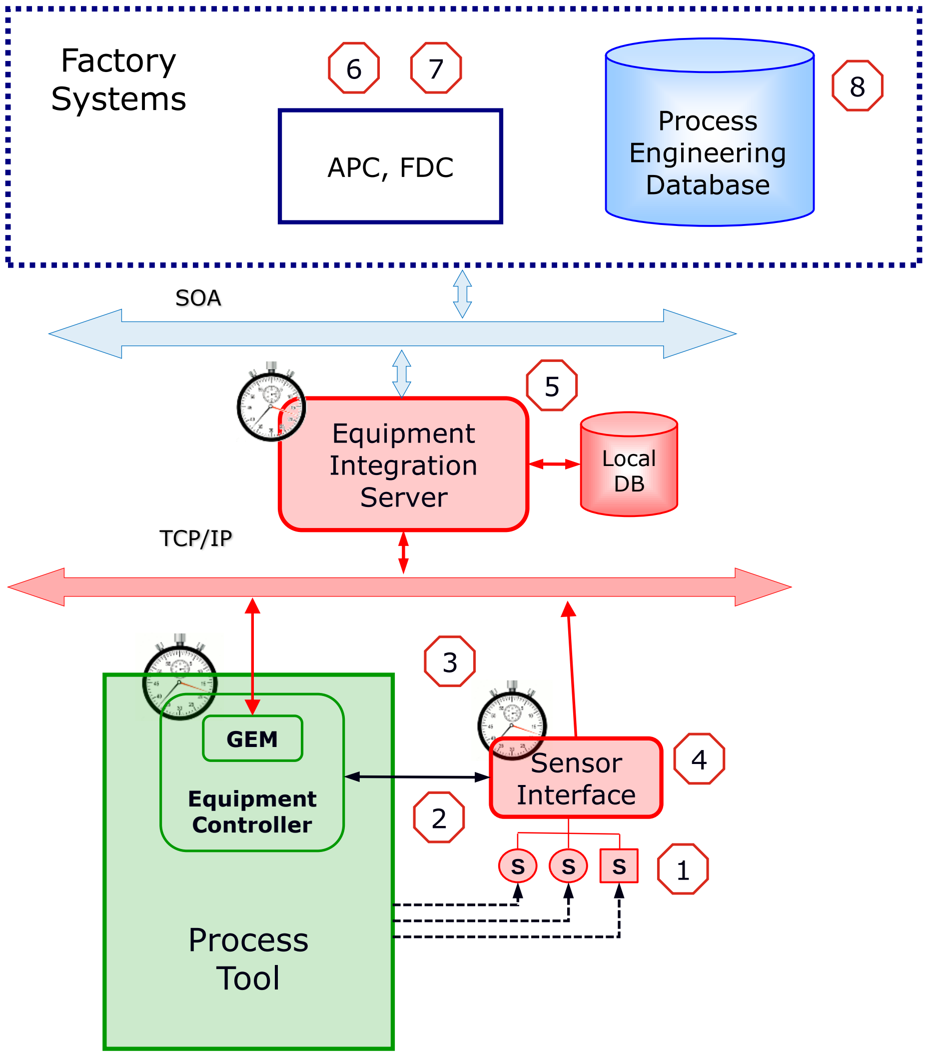
EDA application profile

Sub-fab data integration/analysis

- Problem statement
  - Reduce effort required to extract, transform, and use detailed data from important sub-fab systems (e.g., dry pumps)
- Solution components
  - Sub-fab data gateway
  - Process equipment context data collection
  - Algorithms for failure prediction and yield correlation analysis
- EDA leverage
  - Multi-client capability, shared metadata models
- Key ROI factors
  - Delta yield (failure prevention), equipment uptime (pump PDM improvement), scrap rate, engineering efficiency

External sensor integration example

Typical approach (and challenges)

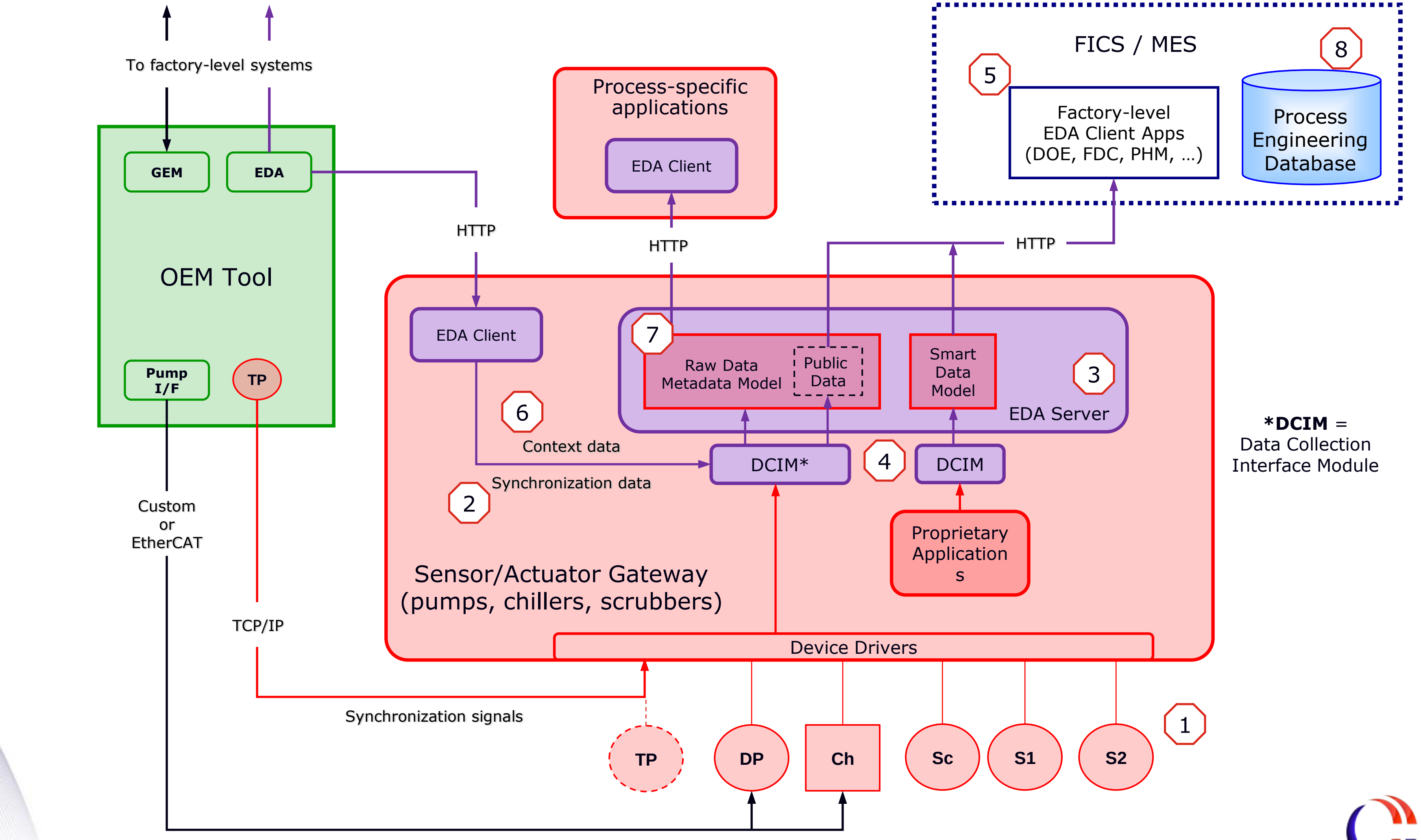


Sensor Integration Challenges

1. Finding a sensor that works
2. Sampling/process synchronization
3. Dealing with multiple timestamps
4. Scaling and units conversion
5. Applying factory naming convention
6. Associating context and sensor data
7. Ensuring statistical validity
8. Aligning results in process database

External sensor integration example

Sub-fab data integration/analysis



***DCIM** =
Data Collection Interface Module

<u>Sensor Integration Challenges</u>

1. Finding a sensor that works
2. Sampling/process synchronization
3. Dealing with multiple timestamps
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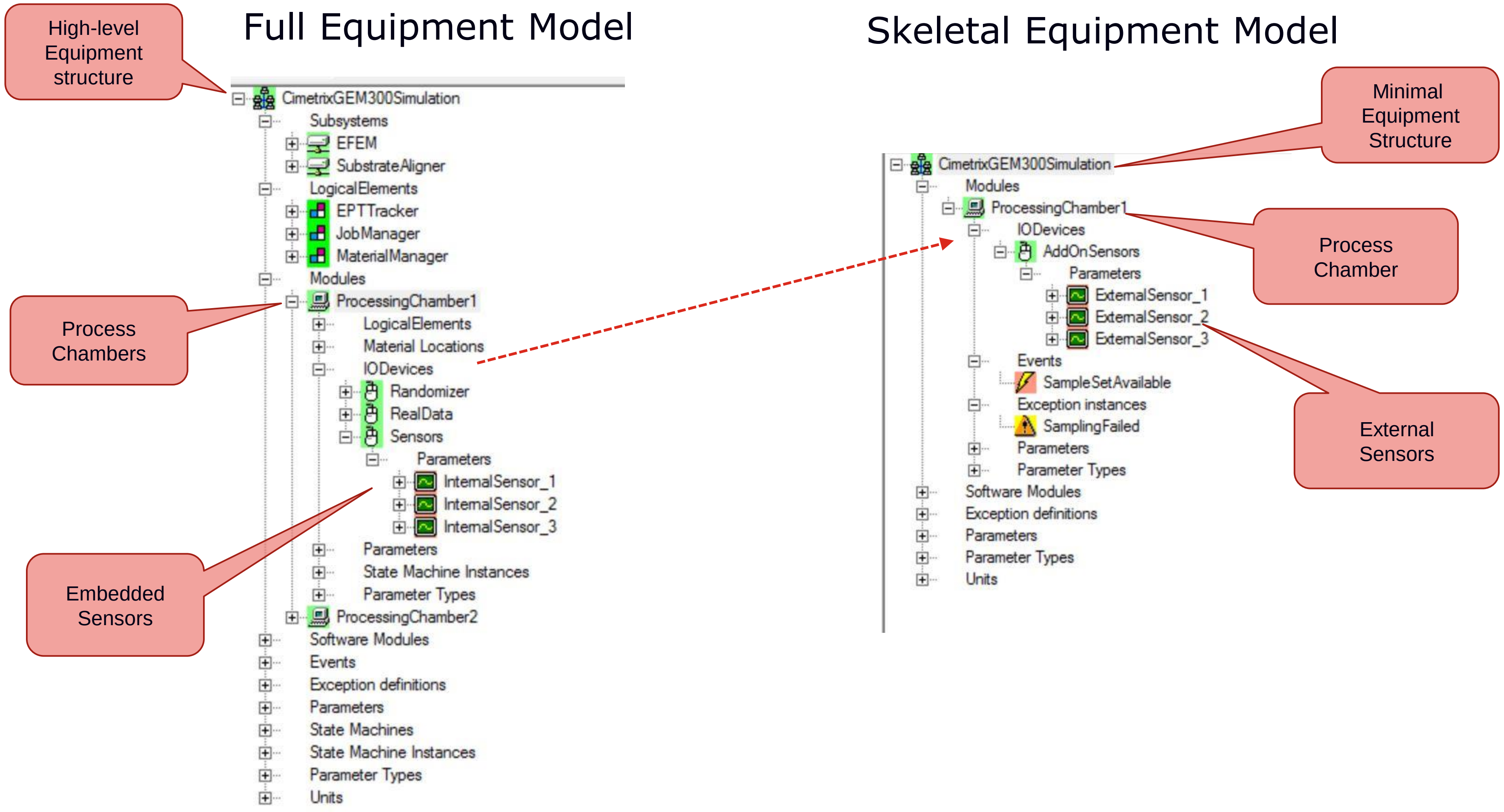
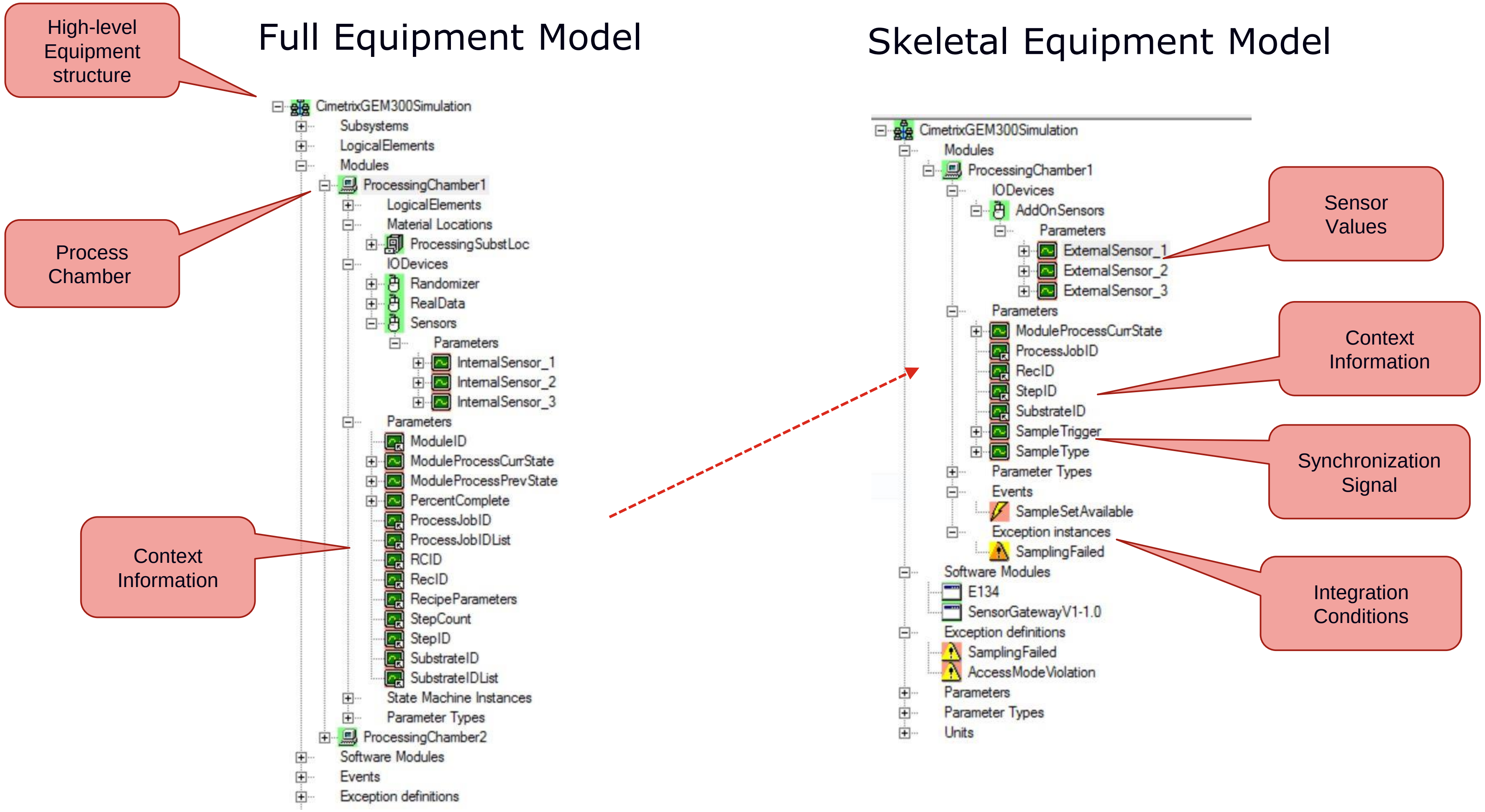
Shared equipment model

External sensors appear in same structure



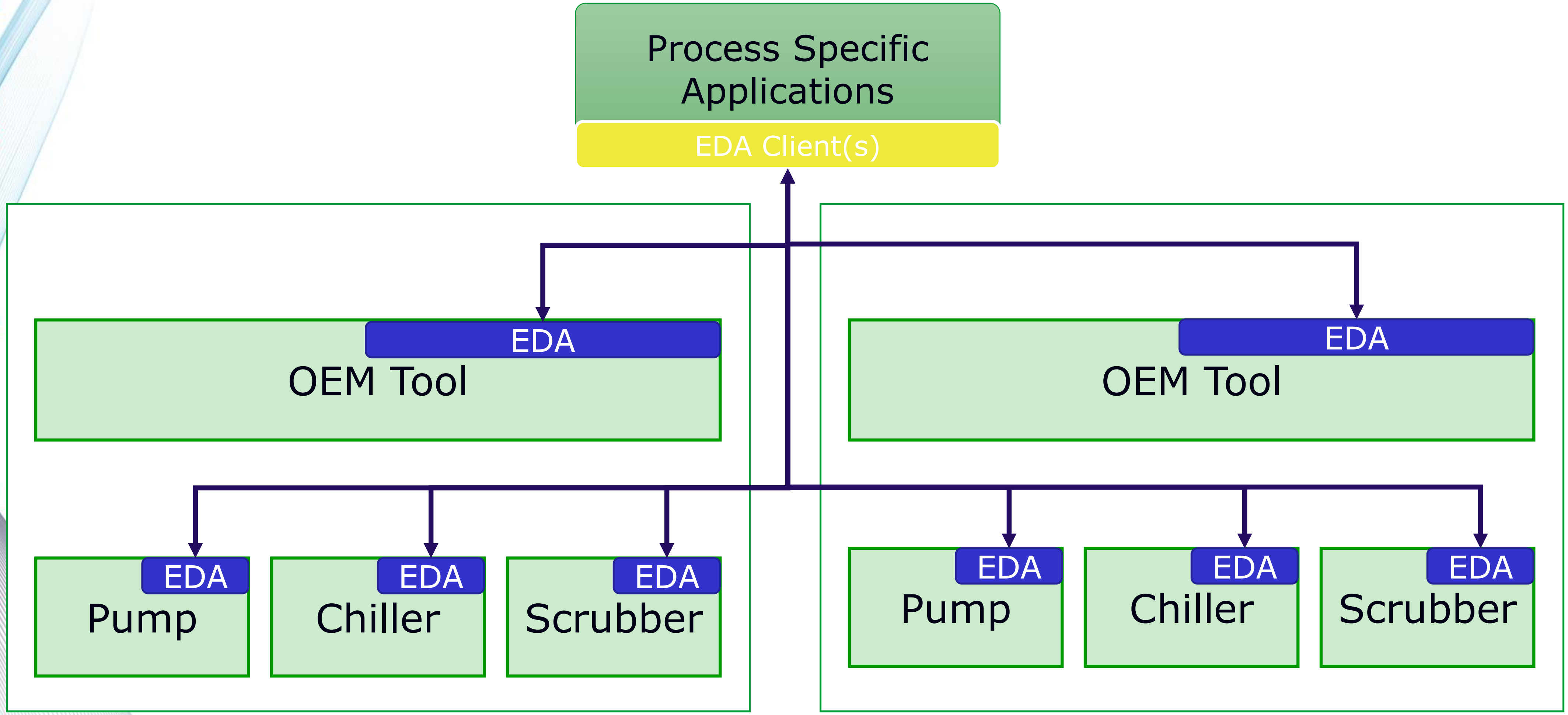
Shared equipment model

Context information (required subset)



Equipment and sub-fab integration

For subsystems with native EDA interfaces



EDA application profile

Equipment log file processing

- Problem statement
  - Access important information in equipment log files with minimal investment in custom software
  - Leverage existing data collection management infrastructure components to seamlessly integrate log file data
- Solution components
  - Data source model that maps log file tags to EDA metadata
  - Log file processor (push or pull file from equipment)
  - EDA server that processes DCPs for "recent history"
- EDA leverage
  - Metadata model and DCP architecture concepts
- Key ROI factors
  - Software engineering efficiency (minimal custom code), equipment uptime (rapid failure recovery), equipment engineering efficiency

Issues with equipment log files

Their formats are custom designs

- Optimized for ease of creation
  - NOT consumption
- Type of information included varies
  - Mixture of events, parameters, alarms
  - Mixture of critical data and “just in case” stuff
  - Parameter values often stored in native, binary form
- Format may change throughout the log
  - Not just a simple set of identical records
  - Multiple sections, headers, record layouts, even files

Issues with equipment log files

They disappear over time

- Usually circular file system
  - Fixed limits for file sizes and number
  - When limits are reached, oldest files are overwritten
- Retention period may vary with activity
  - And available storage space

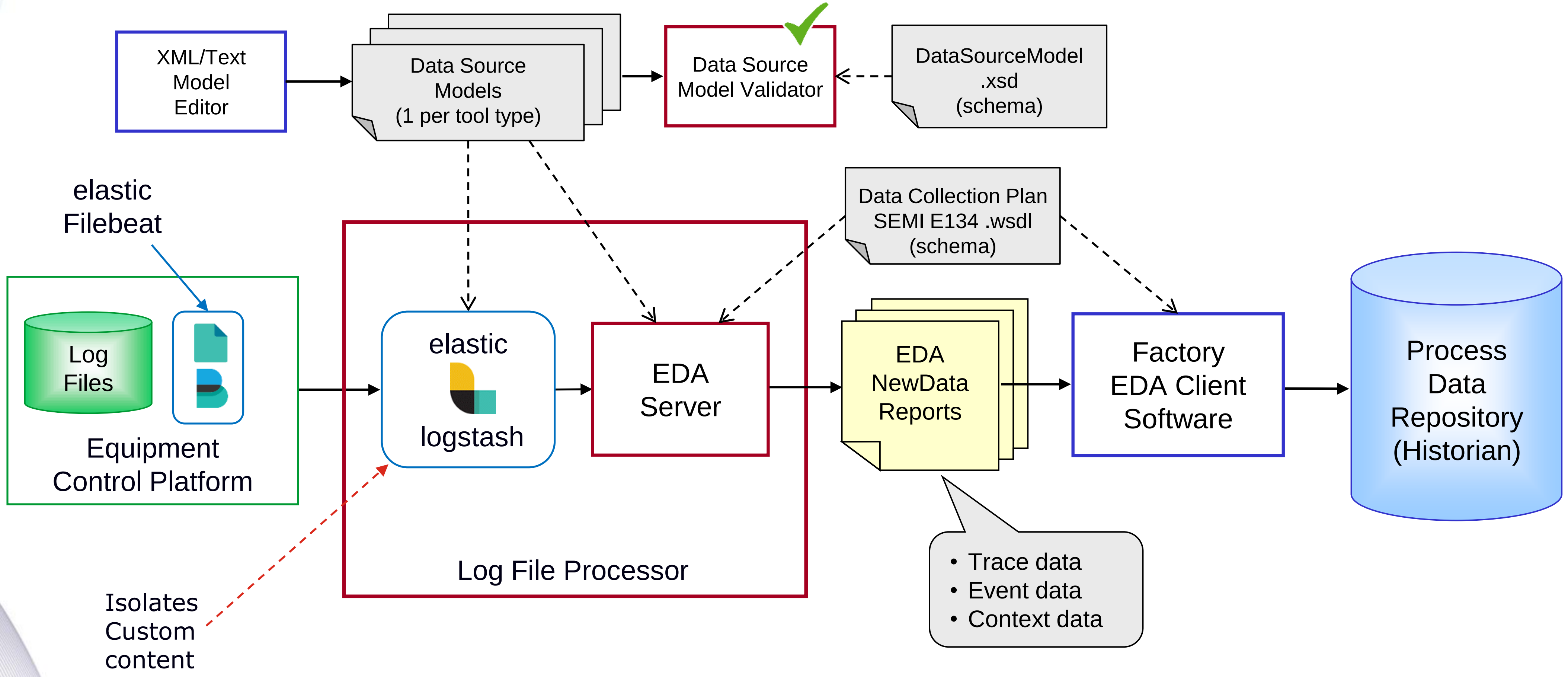
Issues with equipment log files

They reside on the tool

- Part of the local file/directory system
  - Access methods dictated by platform technology
  - Special permissions may be required to keep from invalidating tool warranty
- They depend on the tool's clock
  - So the timestamps are almost always wrong…
  - May be able to correct reports if offset from factory reference clock is tracked continuously

Example solution architecture

Equipment Log File Processing



EDA factory applications

Future possibilities

- Recipe-driven DCP generation
- Automated tool characterization
- Specialty sensor data repository [re-]sampling
- Equipment mechanism fingerprinting
- Post-PM tool auto-requalification
- Wafer-less process requalification
- Process-specific control strategies
- Disparate data source aggregation

Thank you

- 谢谢
- Danke
- 감사합니다
- 謝謝
- Merci
- ありがとうございます
- Gracias