The Role of Models in Semiconductor Smart Manufacturing

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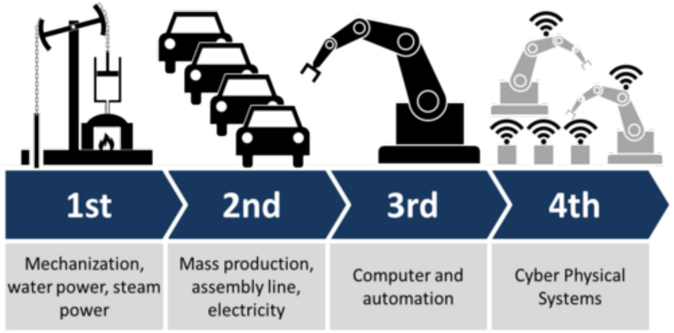
Outline

- What is “Smart Manufacturing?”
- SEMI Standards evolution
- Equipment model examples
- Factory application use cases
- Conclusions

What is “Smart Manufacturing?”

From Industry 4.0 Wikipedia…

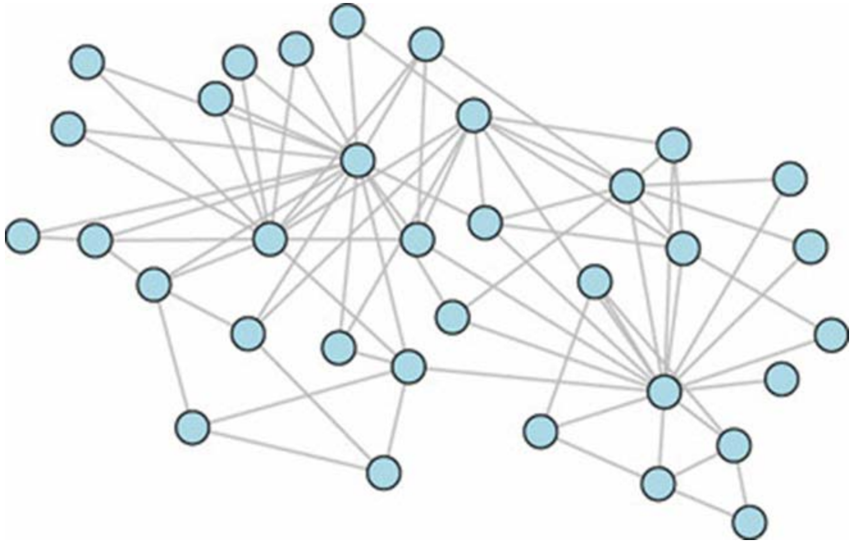
- “… cyber-physical systems monitor physical processes, create a virtual copy of the physical world and make decentralized decisions.
- Over the Internet of Things, cyber-physical systems communicate and cooperate with each other and with humans in real time…”



Components of a Smart Factory

Attributes of all these connected “things”

- Discoverable
- Autonomous
- Model-based
- Secure
- Self-monitoring
- Easy to use
- Compact
- Standards-based



Imagine the collaborative behavior that could emerge !

Key messages

- Equipment models are useful
  - Help understand equipment and process behavior
  - Improve communication with suppliers
- Explicit, standard models are especially useful
  - Support generic applications across equipment types
  - Enable performance benchmarking within/among fabs
- Events and associated data offer untapped benefit
  - Time lost can never be recovered
  - Time is the ultimate unifying concept
- Models are the basis for component interoperability
  - From basic sensors to intelligent subsystems

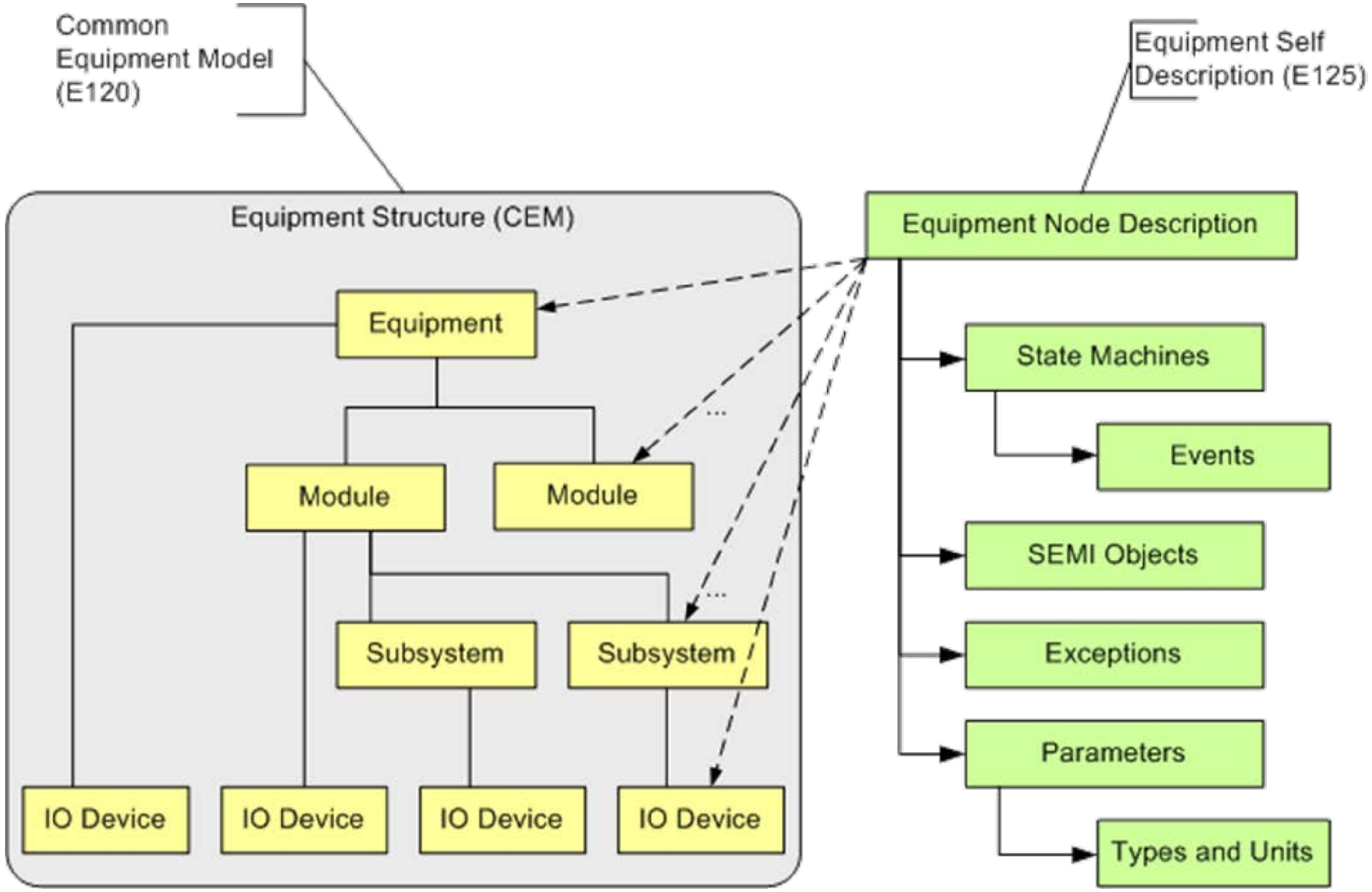
Evolution of equipment models
Referenced in SEMI standards

Natural language analogy...

- SECS-I — vocabulary (data items)
- SECS-II — grammar (streams/functions)
- GEM — sentences (capabilities)
- GEM300 — conversations (scenarios)
- EDA — improv theatre (dynamic DCPs)
- E164 — improv theatre with a point (common model)
- <tbd> — spontaneous flash mob (IIoT, ...)

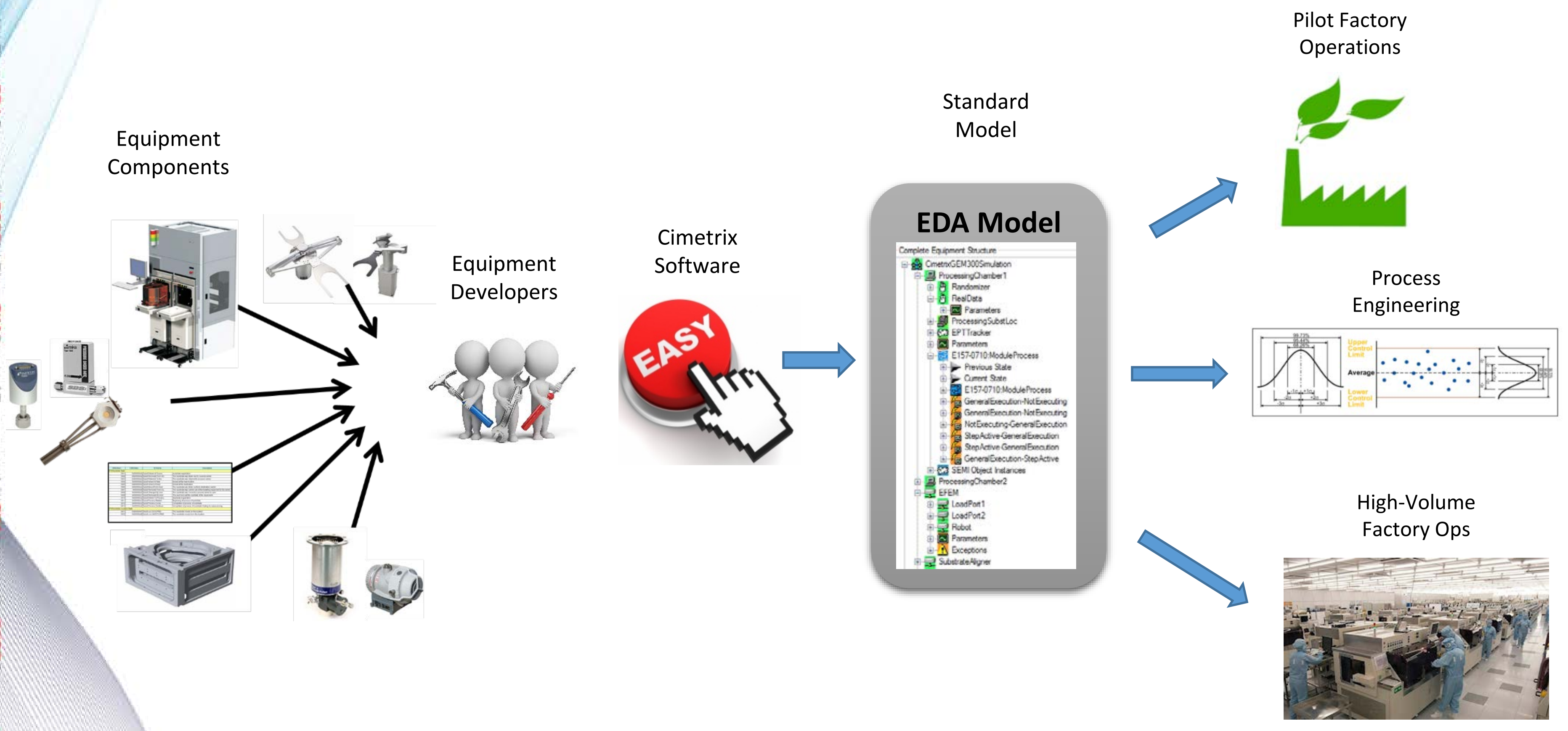
SEMI EDA equipment metadata model

Structure, nodes, self-description services



The equipment model value chain

Control	Connect	Collaborate	Visualize	Analyze	Optimize



<u>KPIs (metrics)</u>

- Time to money
- Yield
- Productivity
- Throughput
- Cycle time
- Capacity
- Scrap rate
- EHS

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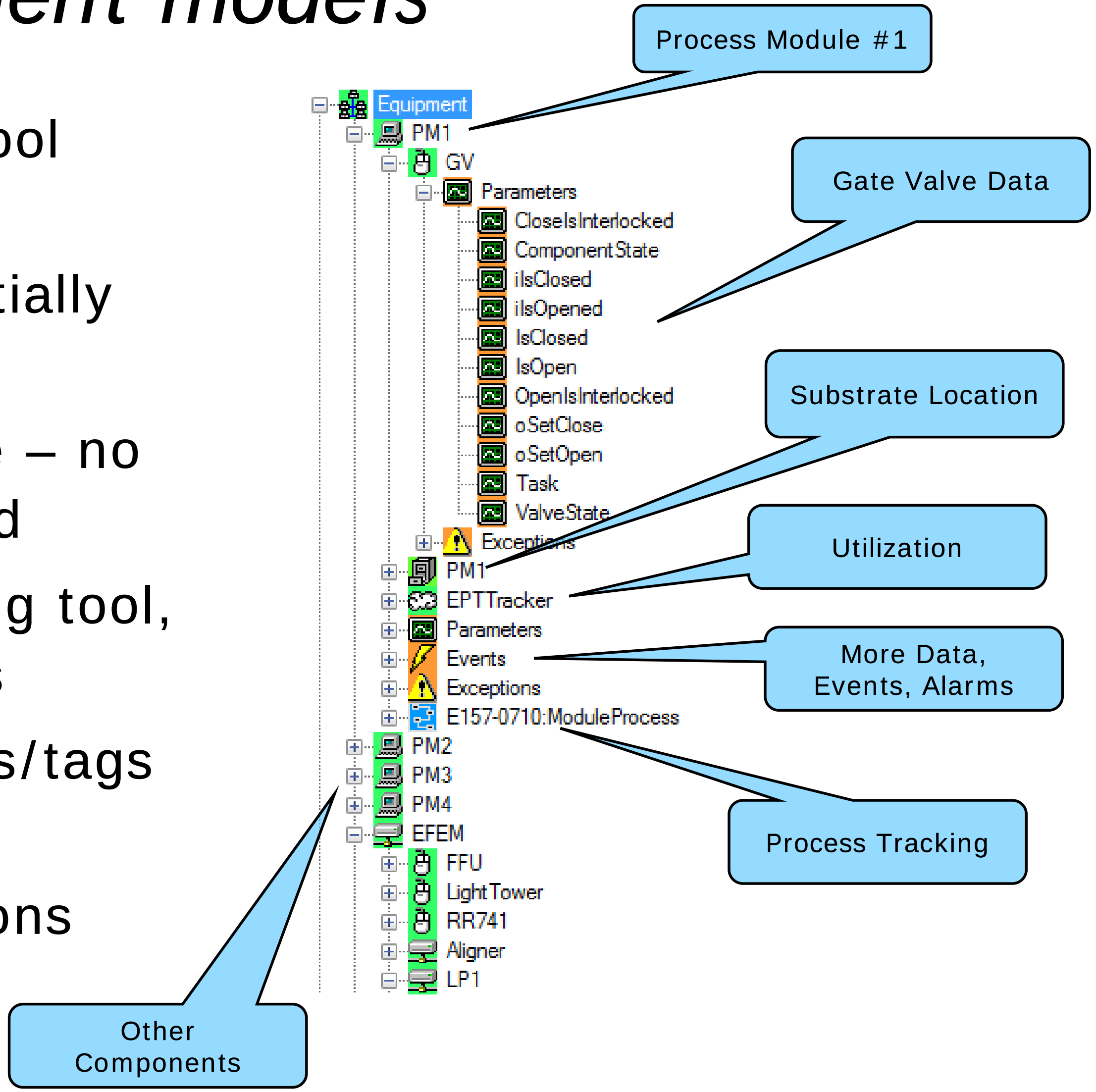
Equipment metadata model benefits

Standards for all equipment models

- Model structure exactly reflects tool hardware organization
- Complete description of all potentially useful information in the tool
- Always accurate, always available – no additional documentation required
- Common point of reference among tool, process, and factory stakeholders
- Source of unambiguous identifiers/tags for database [auto] configuration
- Enables “plug and play” applications



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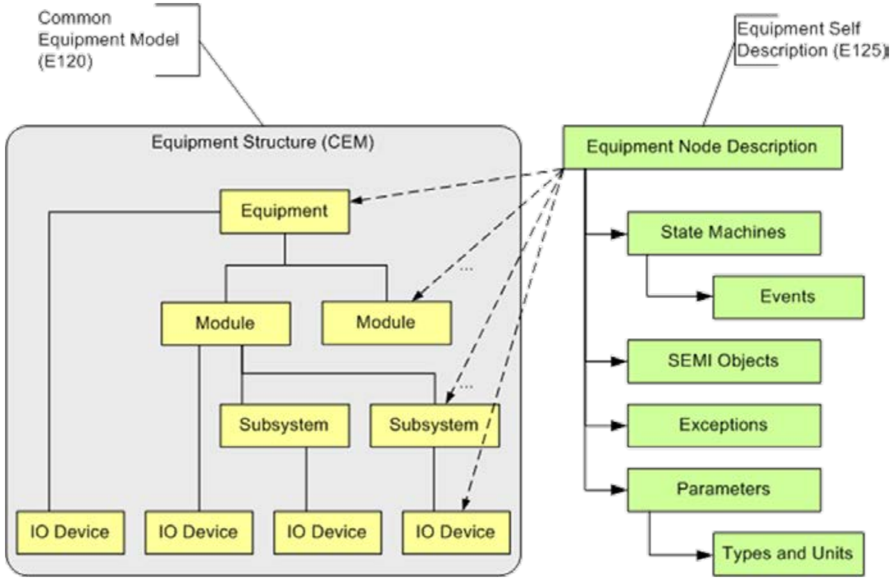
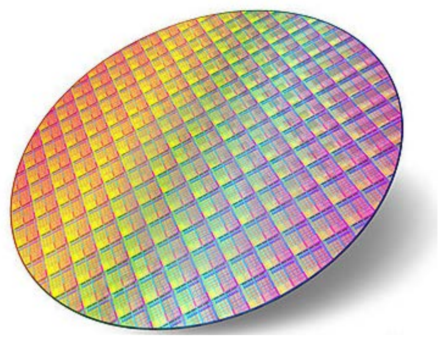
Example model-based applications

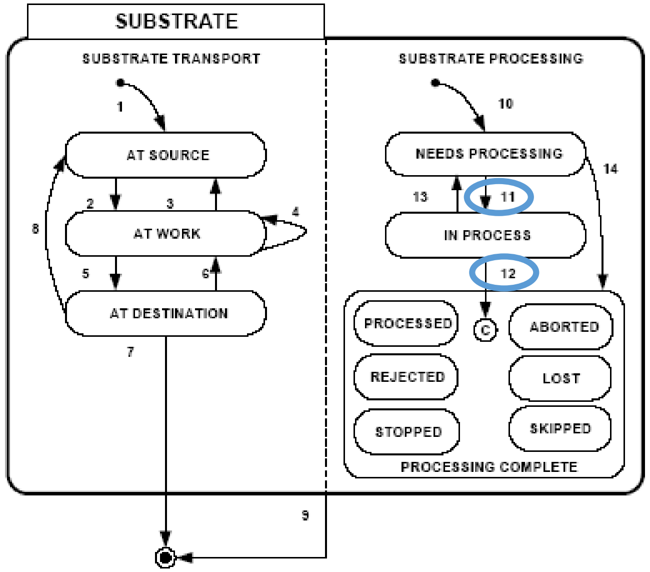
In general order of increasing complexity…

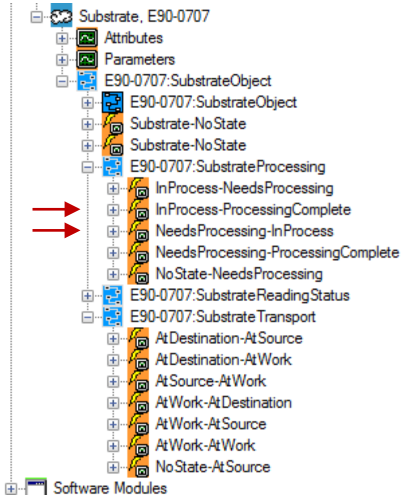
- OEE calculation
- Substrate tracking
- Process execution tracking
- Lot completion estimation
- Product time measurement
- Fault detection/classification
- External sensor integration
- Component fingerprinting
- Others…

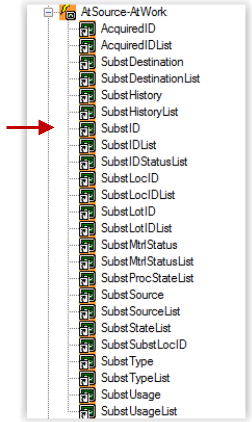


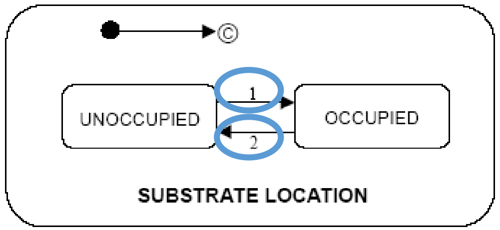
Substrate tracking
E90 state machines and model content

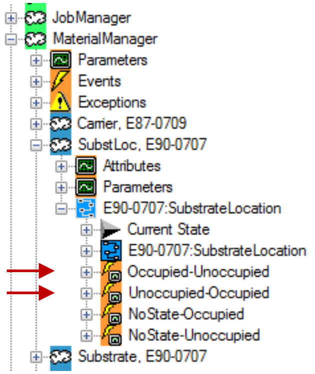


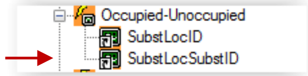






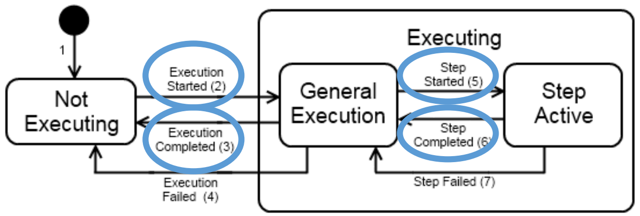


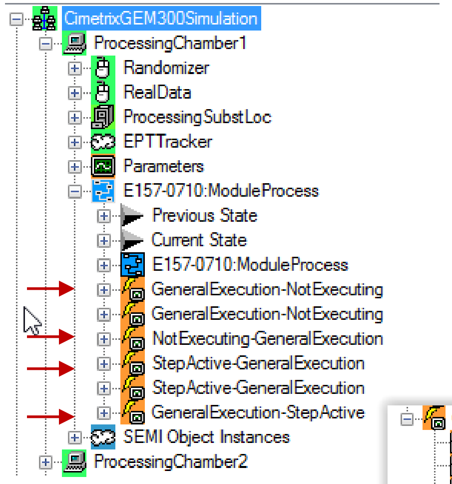


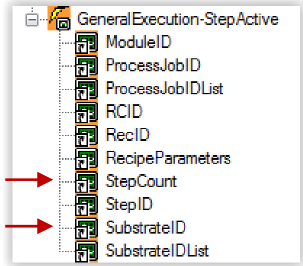


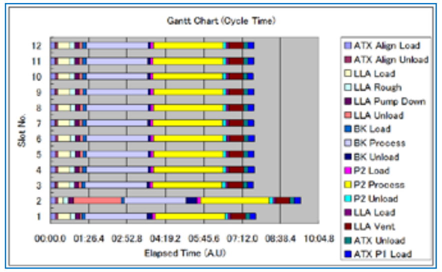
Process execution tracking

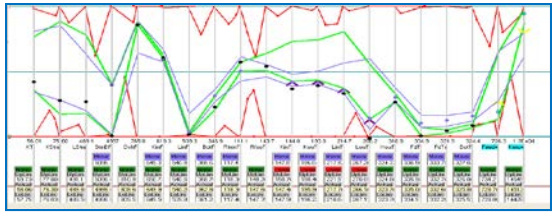
E157 state machine, model content, and results









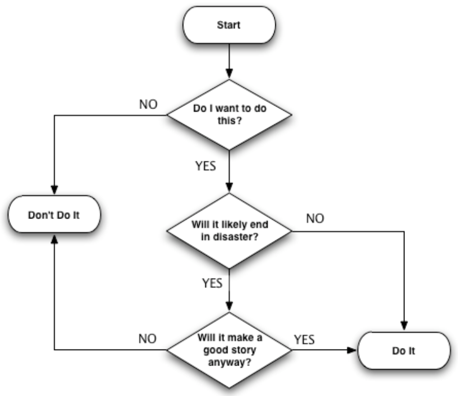


Lot completion estimation
Motivation and requirements

- Motivation
  - Inter-process wait times have direct negative impact on yield for critical process steps
  - Many advanced processes include a number of direct tool-to-tool material delivery steps
  - Productivity KPIs are also affected by inaccurate carrier completion estimates
- Requirements
  - Provide continuously updated estimates for current lot completion and equipment idle time for MCS/AMHS dispatching decision support
  - Provide notification events at configurable thresholds
  - Maintain substrate process times per recipe

Lot completion estimation

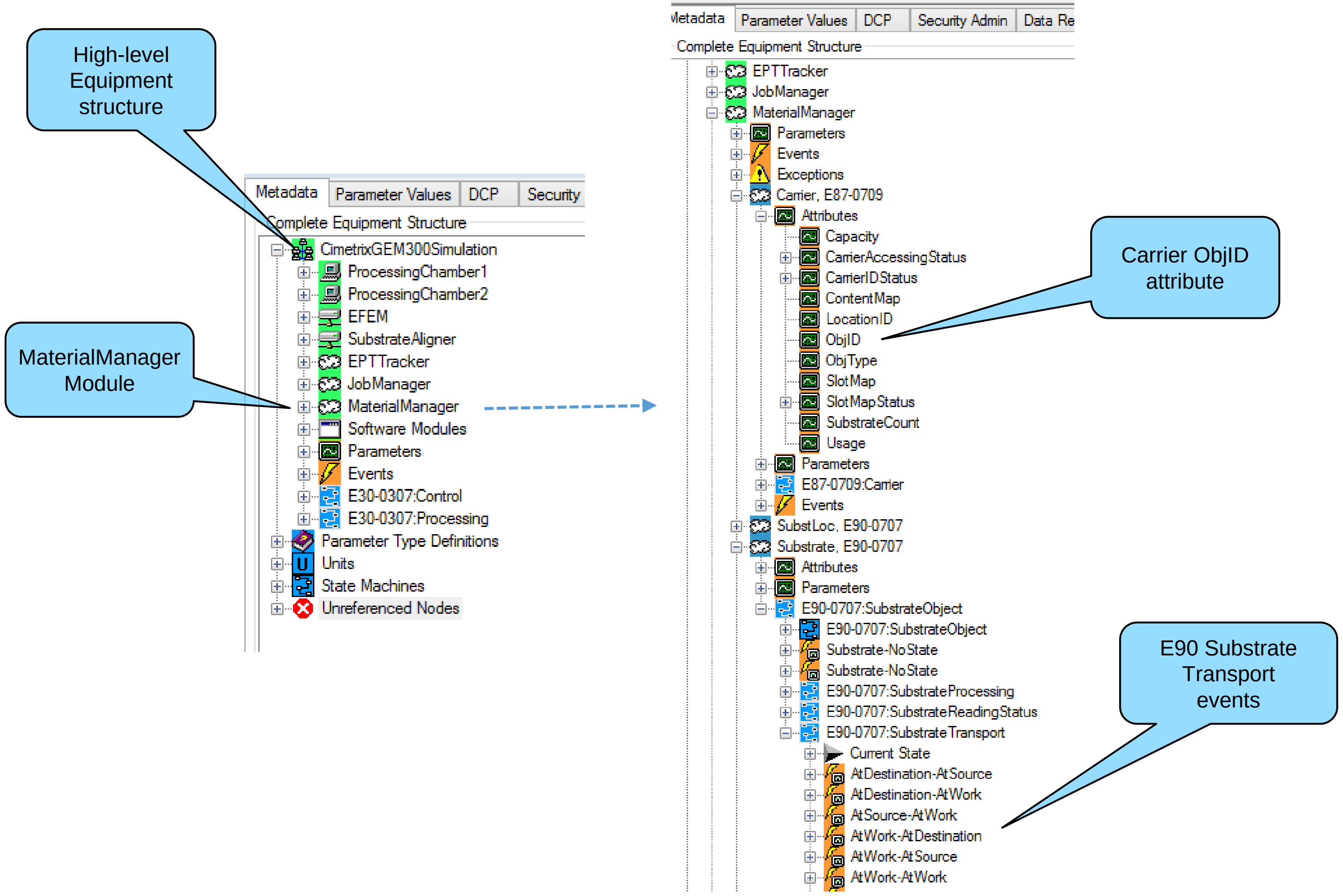
Algorithm summary



- Sum # of wafers to be processed
  - For each Carrier SEMI Object instance select ControlJobs with CarrierInputSpec that contains Carrier's ObjID
  - For each ControlJob, count the # of substrates listed in each ProcessJob's PRMtlNameList attribute
- Calculate average time to return substrate to destination carrier
  - Record time when first AtWork-AtDestination event is reached
  - When next AtWork-AtDestination event is reached, record difference as current average time to return substrate to carrier
- Calculate initial carrier completion estimation
  - = # remaining substrates * current average substrate return time
- Update carrier completion estimation
  - When each AtWork-AtDestination event is reached, subtract timestamp of first event from latest event, and divide by # of substrates
  - Use this value as new average substrate return time in calculating new carrier completion estimation

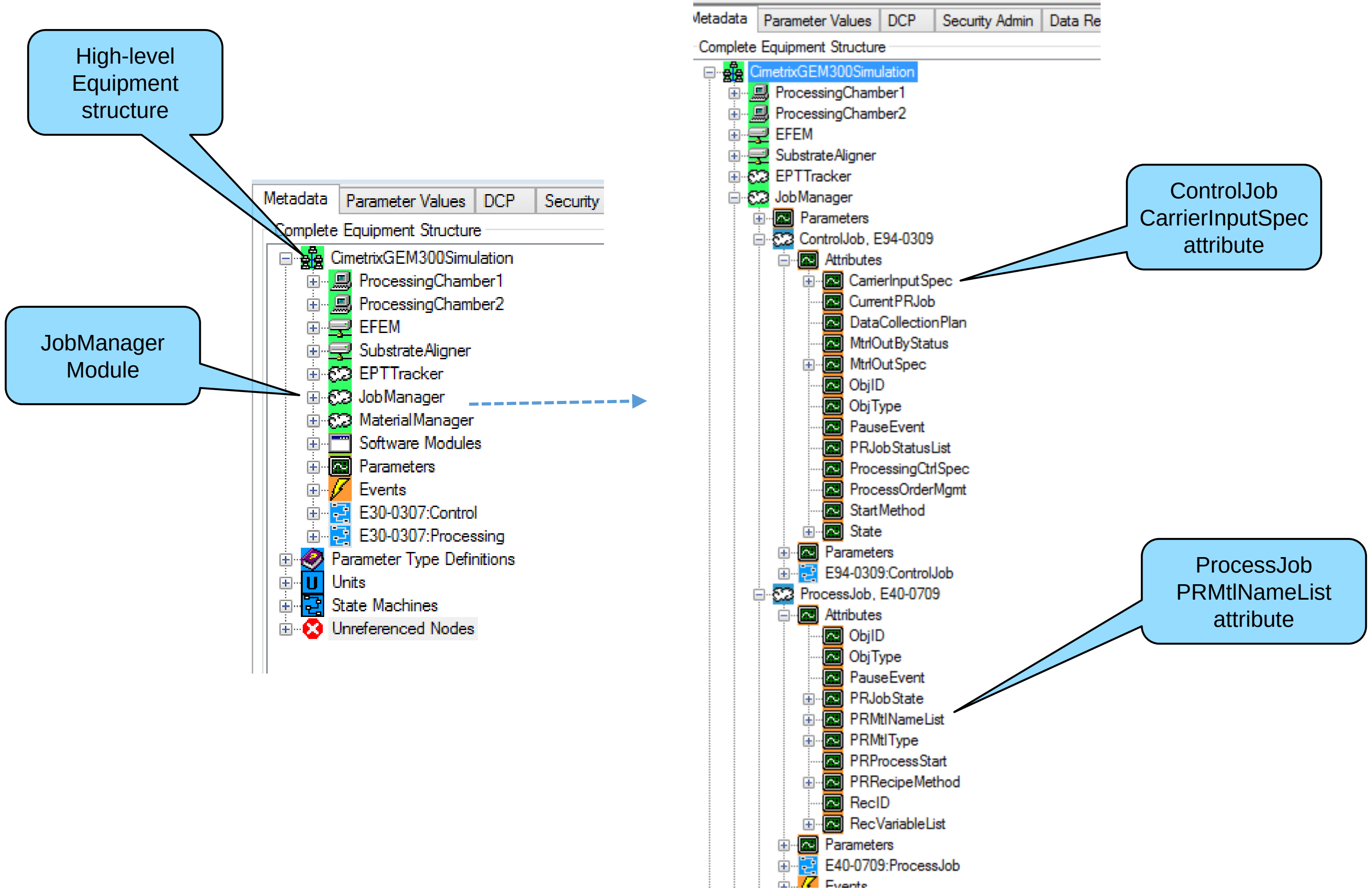
Equipment model content

Used in lot completion estimation algorithm (1)



Equipment model content

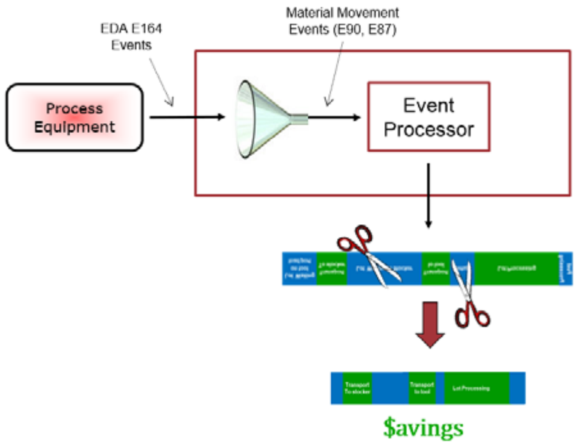
Used in lot completion estimation algorithm (2)

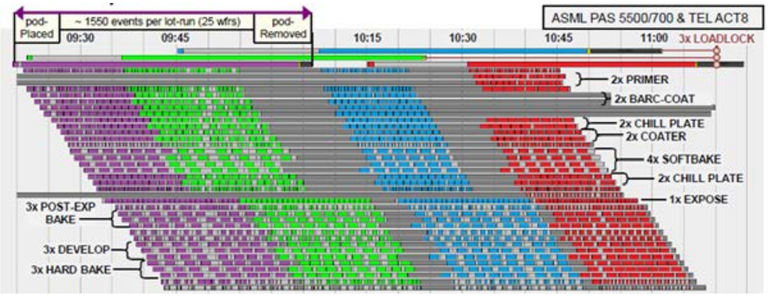


Model-based application examples

Product Time Measurement (Wait time waste analysis)

- Description
  - Capture locations visited by each substrate during lot processing, with absolute and relative timestamps and durations for each
  - Use knowledge of process module execution status to calculate “active” and “wait” time elements for each substrate (now standardized in SEMI E168)
- KPIs affected
  - Equipment productivity by identifying unnecessary wait times and understanding/addressing the associated root causes
  - Process variability through increased tool behavior visibility
- EDA model 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





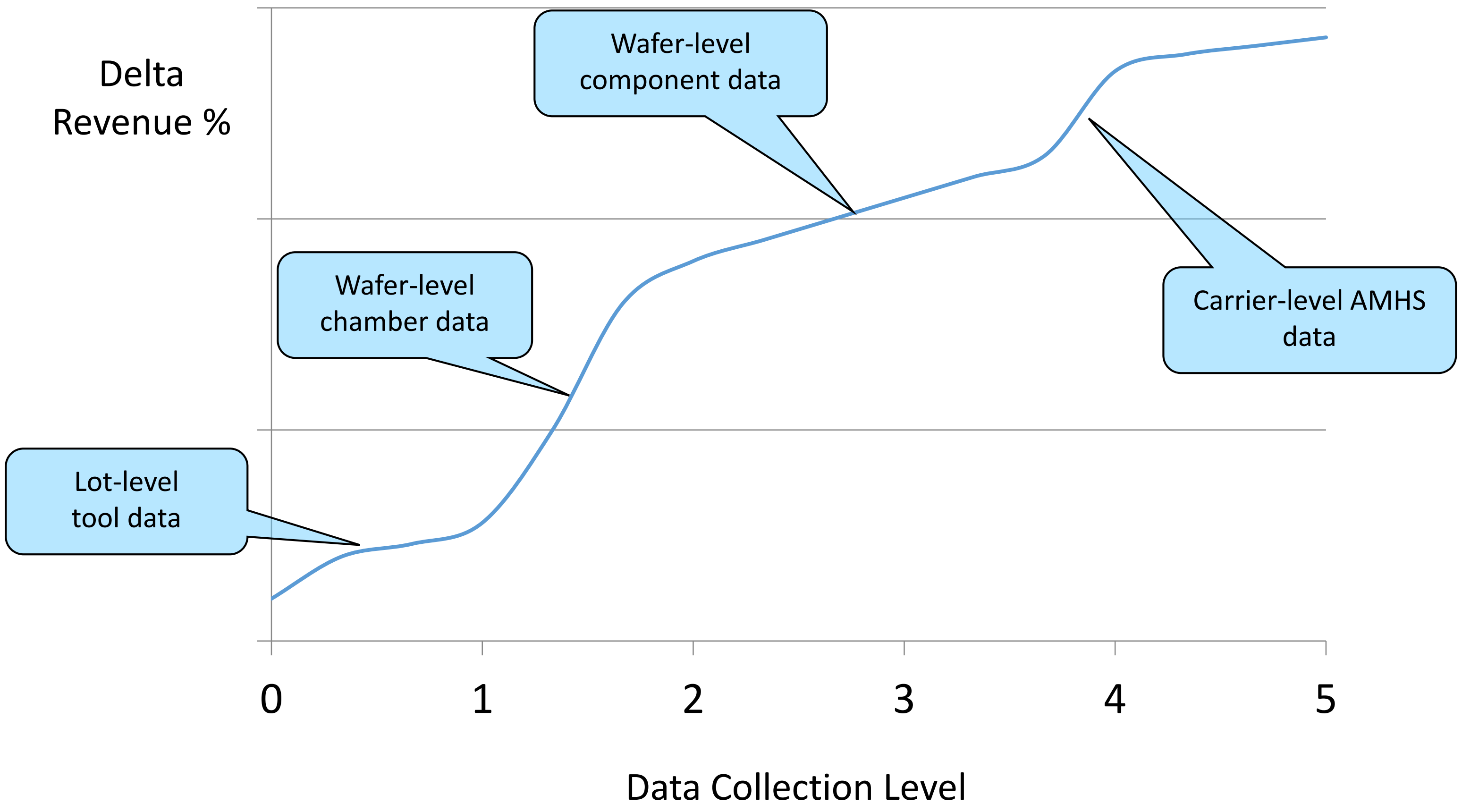
How much data is required?

The more data, the greater the benefit

Data Used	Analysis Enabled	Benefit / ROI
Lot start/stop events (from MES)	Average throughput calculations by product and process	Establish performance baseline
Lot start/stop events (from equipment)	Actual throughput rates by product, recipe, and tool	Identify bottlenecks and laggards among toolset
Chamber-level wafer process start/stop events	Actual throughput rates by product, recipe, and chamber; tool-level wait time per wafer	Identify areas for improvement in equipment and process engineering
Wafer transport and location status events within equipment	Details of wait and active time per wafer	Identify recipe and equipment design issues
Other component-level signals related to wafer movement	Fine-grained analysis of wafer movement behavior	Identify even more recipe and equipment design/calibration issues
AMHS carrier movement and storage events	Wait and active (transport) time between tools; door-to-door value chain analysis	Identify areas for improvements needed in production scheduling, dispatching, and operations

Data Collection Level vs. Benefit

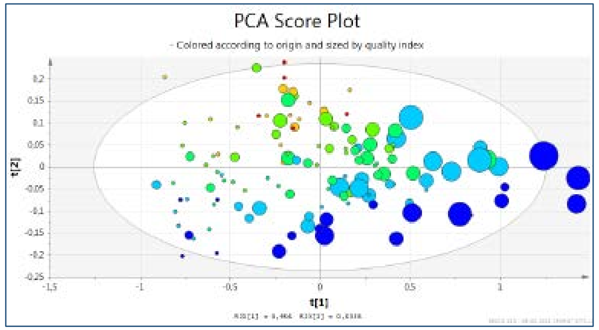
Revenue improvement potential

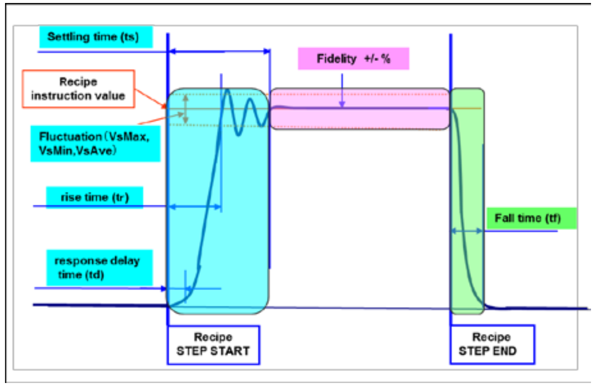


Model-based application examples

Multivariate Fault Detection and Classification (FDC)

- Description
  - Multivariate statistics used to develop reduced-dimension equipment fault models for various operating points
  - Fault models evaluated in real-time to detect process drift and/or impending tool failure
  - May interdict tool operation in mid-run to prevent/reduce scrap
- KPIs affected
  - Process yield and scrap rate through higher detection sensitivity
  - Equipment availability resulting from fewer false positives
- EDA model leverage
  - Conditional triggers in trace request frame data collection
  - Metadata model contains context to select proper fault detection algorithms
  - Multi-client access to develop, evaluate, and update fault models





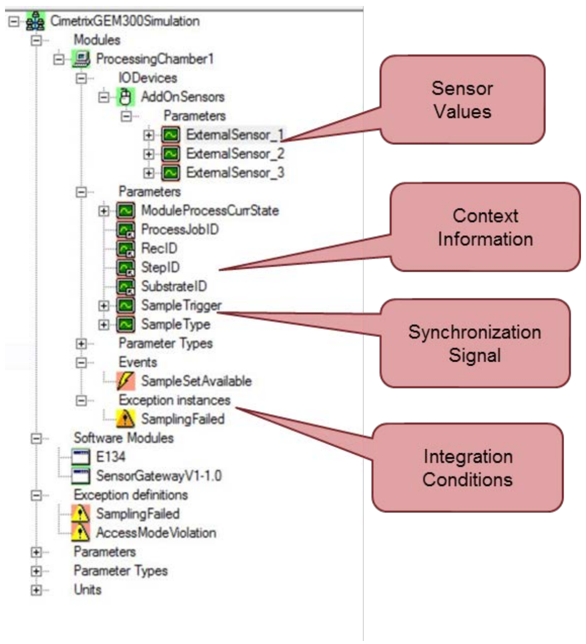
Model-based application examples

External sensor/subsystem integration

- Description
  - Create “sockets” in equipment model for common external sensors, key subsystems, and associated context information
  - Address most of the key challenges in external sensor integration using shared metadata model and EDA services to associate context and timing information close to the data source
  - Directly applicable to integration of sub-fab components (pumps, chillers, scrubbers, abatement systems)
- KPIs affected
  - Process capability and yield through improved control capability
  - Engineering efficiency through reduced custom integration effort
- EDA model leverage
  - Shared metadata model aggregates data from multiple, diverse data sources, presenting unified perspective to client applications
  - Multi-client capability enables experimentation with additional sensors and control techniques without disrupting production

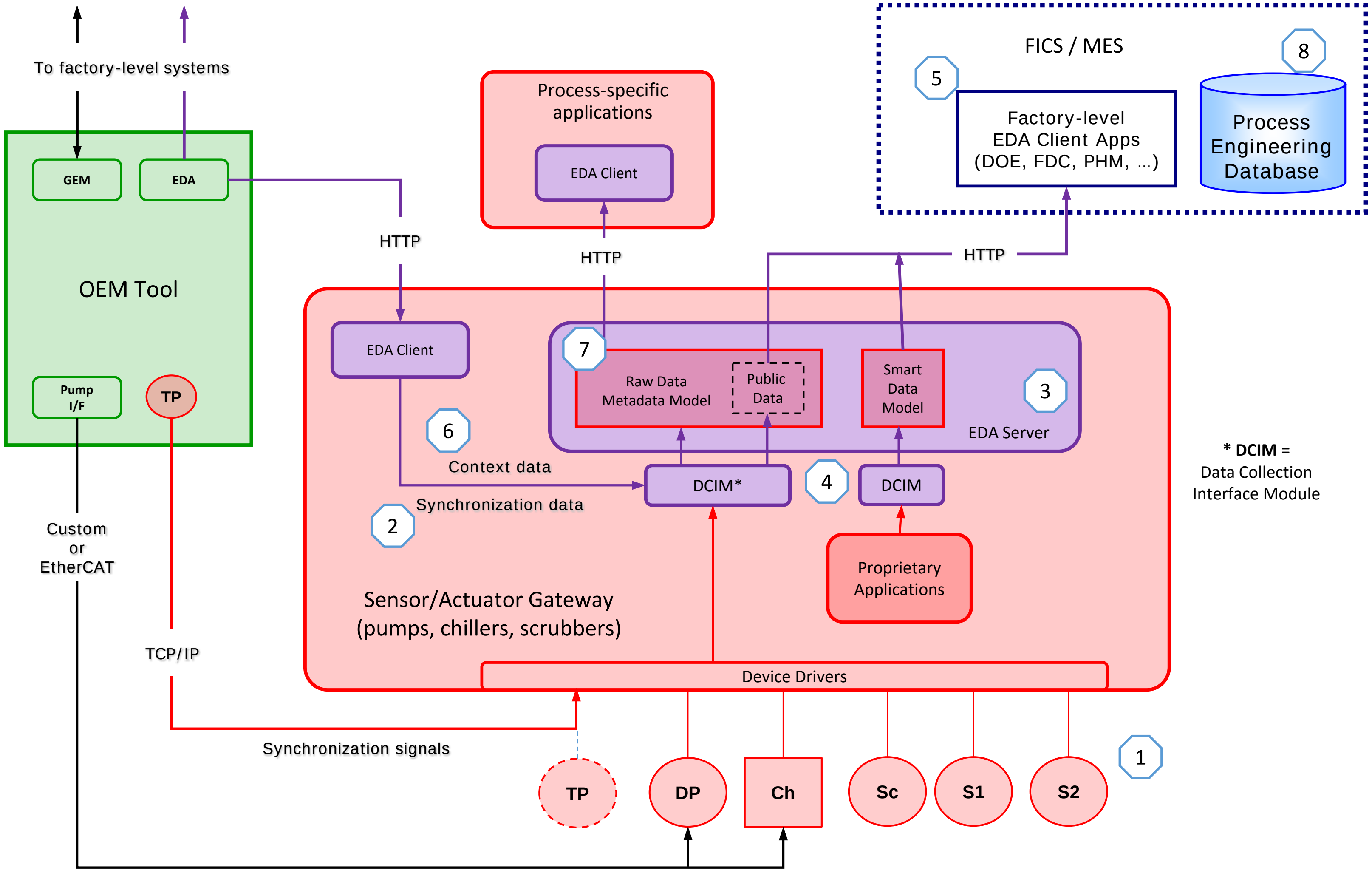
Sensor Integration Challenges

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

With challenge areas addressed



Conclusions

- Models have been at the core of SEMI's Information and Control standards for decades
- Models help components of a smart manufacturing system understand one another
- The sophistication of these models is now sufficient to support true application interoperability
- Industry standard models can greatly reduce factory application development cost
- Models will play an increasingly important role as the number and variety of components multiply