# Advancing Factory-Wide Data Quality for APC Applications

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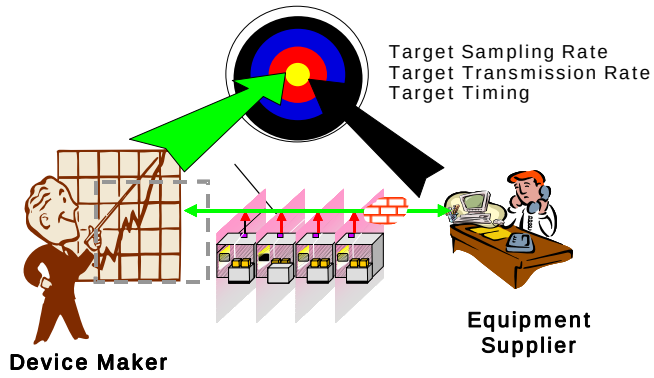
# Outline

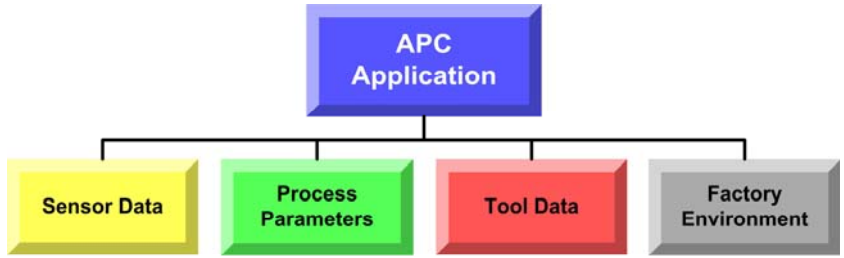
- Data Quality Overview
  - Background
  - Industry Experiences
  - IC Maker Consensus
  - Guiding Principles
- Time Synchronization and time-stamping
  - Guidelines
    - Timing Matrix
  - Standards Ballots
    - Key Features
- Data Quality Key Messages
- References



# Data Quality Background

- As the industry moves toward automated decision-making, the data each tool generates is critical to improving productivity
- Today, the quality of equipment data is poor; it must be dramatically improved if applications are to effectively apply collected data
- APC needs high quality data for accurate decision-making

# Industry Data Quality Needs




Precision Time Stamping to Merge Various Data Streams

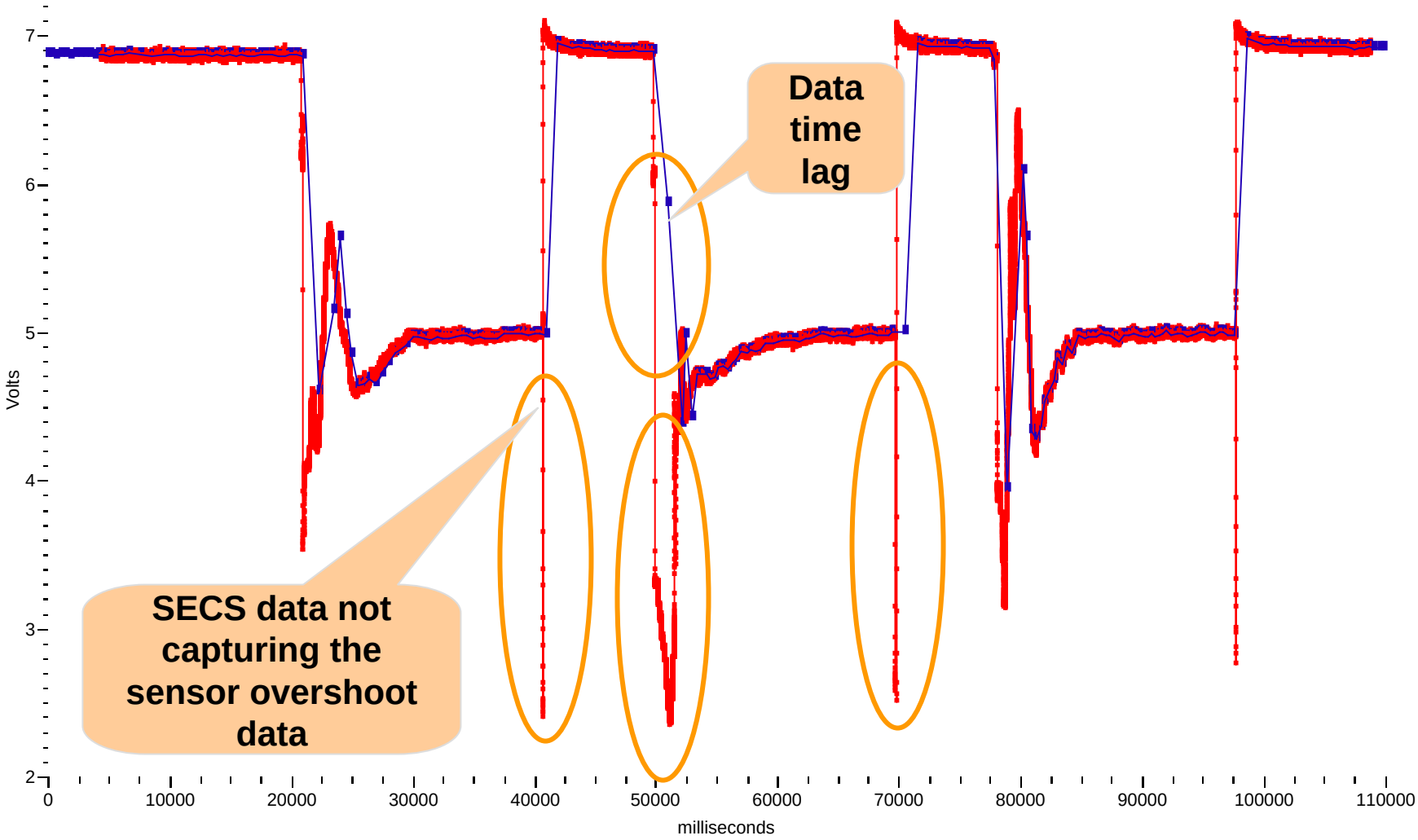
## APC Challenges:

- Unsynchronized sensor/tool data available
- Bandwidths/polling rates vary greatly
- Difficult to synchronize data streams

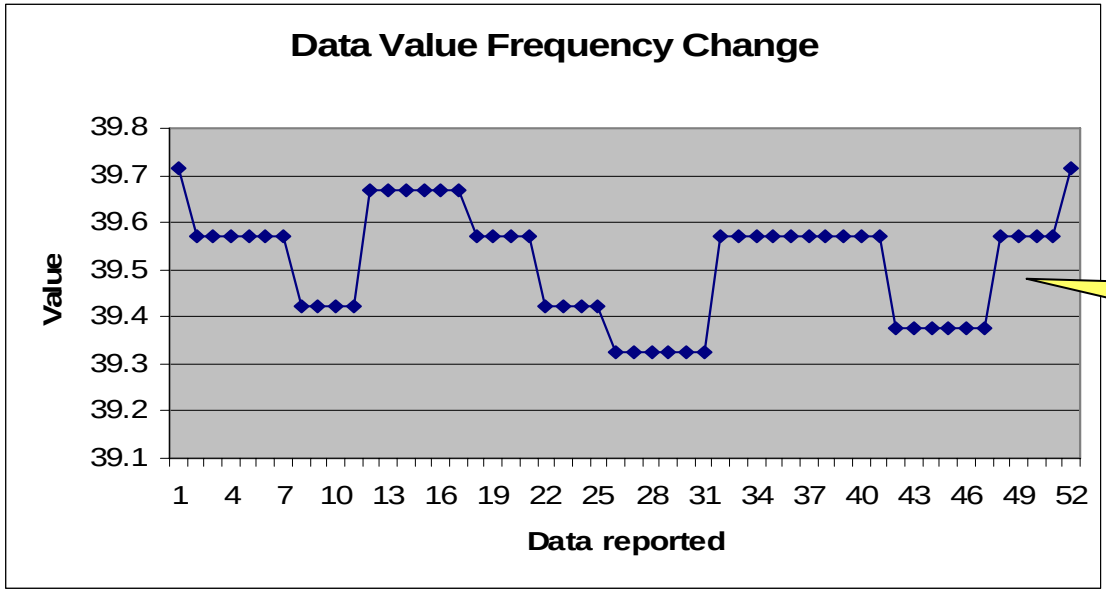
## APC Application Needs:

- Current FDC requirements (10 ms to 1 ms time-stamp precision)
- Support data sampling rates up to 10,000 Hz (< 1 ms precision)
- Equipment/metrology data should synchronize to wafer or lots
- Improve multivariate, advanced correlation and analysis
- Virtual Metrology support
- Expose new cause-effect relationships

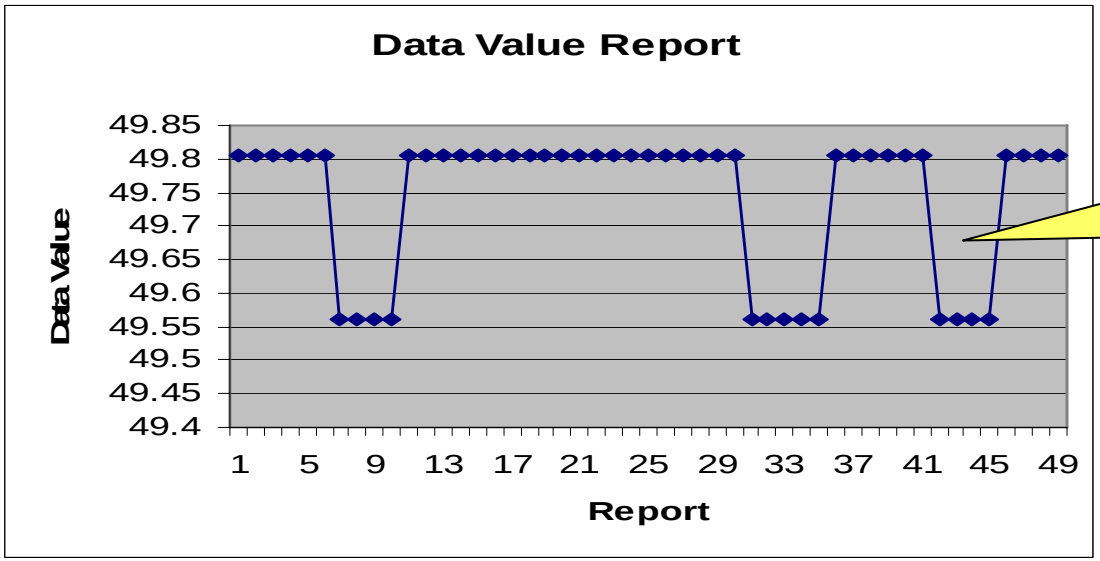
# Sensor vs. SECS Data Comparison



# Interface A Data Freshness




Running DCP at 100ms shows the values change every 400ms to 750ms




Another problem encountered with a parameter is its resolution.
Is a change of 0.2% of full scale acceptable when you may need 0.01% resolution?

# IC Maker Consensus Experiences

- **Issues Experienced**
  - Equipment interface has software defects
  - Documentation does not match software
  - Reports send wrong format of data
  - Equipment performance affected by data collection
    - Resulting in lost data
  - Short data collection period with a high rate can take tool down
    - Resulting in product loss
  - Missing data, including context data
  - Reporting not current data
  - Data report and event latency
  - Inaccurate error reporting
  - Unclear level of data collection limits, without affecting process
    - Not clear what the equipment is capable off
  - Context data missing, e.g., linking data with a wafer
  - Non-existent time synchronization
    - Data reports cannot be used to correlate events, alarms, or process issues
  - Inconsistent point of timestamping and non-existent time synchronization

**Time Synchronization + Time Stamping -> Data Quality**

# Equipment Data Quality Principles

- Data must be provided with sufficient accuracy, resolution, and sampling frequency to allow high fidelity extraction of relevant data features for process/equipment characterization, fault detection, failure diagnosis, and process control

- Event data and context information must be complete, consistent, and correct as well as reflect the actual time and conditions pertaining to the occurrence of the indicated event
- Timely transfer of data is necessary to achieve fault interdiction
- A time synchronization solution is the initial focus

# Time Synchronization Working Group

## Mission

Require accurate equipment and factory clock synchronization for future implementations, while maintaining compatibility with legacy systems

## Goals

- Factory time source
- Factory clock synchronization precision
- Embedded clocks within equipment need to be synchronized with factory clock
- Factory applications timing requirements
- Common time-stamp format/basis
- Consistent point of time-stamping
- Synchronization traceability/quality for verification
- Facilitate data merging and analysis

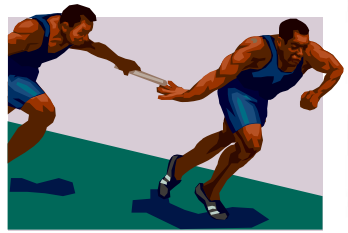
## SEMI Time Synchronization Working Group

- IC makers and equipment/software suppliers
- To participate, contact: Harvey.Wohlwend@ismi.sematech.org

# Time Synchronization Approach

1. **Leverage definitions from standard sources, e.g., NIST, ISO, IEEE**

2. **Publish Time Synchronization Guidelines**
   - **Characterized processes for timing accuracy and precision requirements**
   - **ismi.sematech.org/docubase/abstracts/4781aeng.htm**



3. **Specifications in new standard**
   - **Submitting to SEMI for balloting**

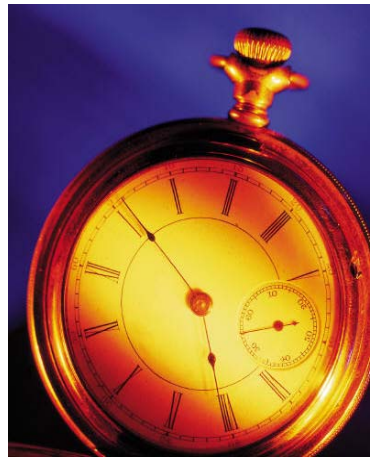
4. **Update existing standards to support time synchronization/time-stamping**
   - **E5, E30, E40, E54, E116, E127, E133, E134**
   - ***Backward compatibility is an absolute requirement***

# Guideline Objective

***To complement the proposed new time synchronization standard and provide guidance in establishing a factory time synchronization architecture for realizing effective data collection and time-stamping***

## Goals:

- **Facilitate the establishment of effective factory time synchronization architecture**
- **Ensure synchronization quality**
- **Provide recommendations and methods for meeting the new SEMI Time Synchronization standard requirements**
- **Guidance on data time-stamping for ensuring data quality**
- **Guidance on current and upcoming time synchronization accuracy requirements**



# Time Synchronization and Time-Stamping Guidelines Overview

## Time Synchronization Architecture

- UTC time scale
- Reference time source and traceability
- NTP strata and modes
- Fault tolerance


## Time Synchronization Quality

- Clock quality
- Synchronization frequency
- Security
- Monitoring

## Accuracy and Precision Requirements

- Current and upcoming requirements based on working group discussions
- General agreement is about 1 ms accuracy for e-Manufacturing applications

## Effective Time-Stamping

- Timestamp format and time base
- Point of time-stamping

# Implementer Roles & Responsibility

| Chapter | Guideline Items | Device Maker | Equipment Supplier | Software Suppliers |
|---|---|---|---|---|
| 6.1 | **Time Synchronization Guidelines** | | | |
| 6.1 | **UTC Time Scale** | | | |
| 6.2 | **Factory Time Servers** | | | |
| 6.3 | **Time Synchronization Traceability** | | | |
| 6.4 | **Fault Tolerance** | | | |
| 6.5 | **Time Source** | | | |
| 6.6 | **Synchronization Protocol** | | | |
| 6.7 | **Client Configuration** | | | |
| 6.8 | **Synchronization Architecture** | | | |
| 6.8.1 | **Stratum Levels** | | | |
| 6.9 | **Clock Quality** | | | |
| 6.10 | **Clock Resolution** | | | |
| 6.11 | **Synchronization Frequency** | | | |
| 6.12 | **Network Jitter** | | | |
| 6.13 | **Synchronization Performance** | | | |
| 6.14 | **Security Practices** | | | |
| 6.15 | **Data Time Stamping Guidelines** | | | |
| 6.15.1 | **Time Base** | | | |
| 6.15.2 | **Time Stamp Format** | | | |
| 6.15.3 | **Time Stamping Data** | | | |
| 6.15.4 | **Time Stamping Resolution** | | | |

# Time Synchronization Requirements

## Equipment clocks must:

- Synchronize to factory time servers via NTP
- Communicate UTC date/time information based on ISO 8601
- Converge to single time base, e.g., NTP
- Provide synchronization quality parameters as defined in SEMI ballot 4291
- Provide synchronization error messages as defined in SEMI ballot 4291
- Provide configurable NTP synchronization parameters

## Factory Time Synchronization Recommendations:

- Fault-tolerant synchronization architecture
- Improve clock quality to minimize synchronization resources
- Ensure sufficient synchronization frequency
- Adhere to factory network security measures
- Minimize jitter in network and applications during synchronization
- Ensure sufficient clock resolution for the most stringent requirements
- Monitor synchronization quality

# Time-Stamping Requirements

## Data time-stamping must:

- Adhere to the format defined in the SEMI 4291 ballot
- Reflect only the resolution of the clock

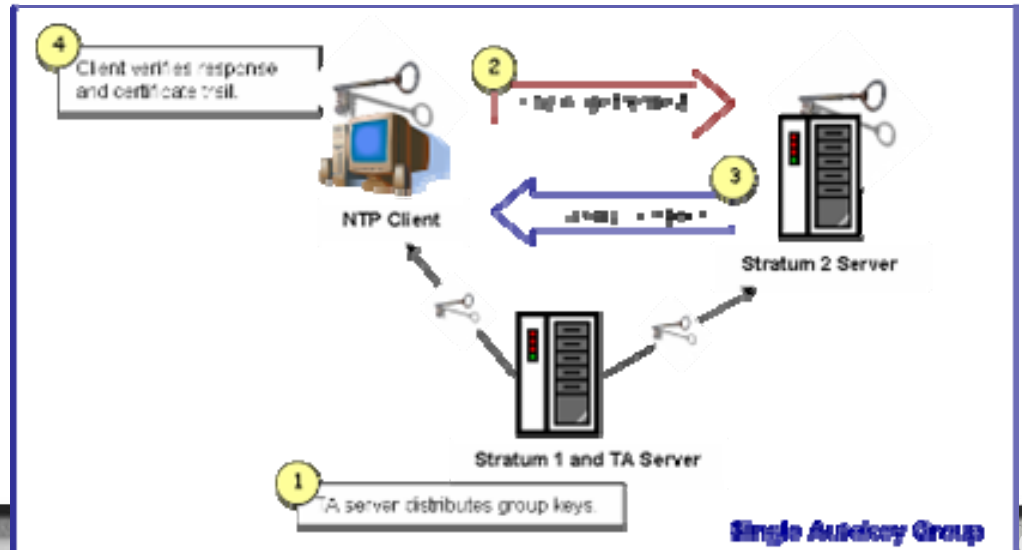
## Data time-stamping recommendations:

- Reflect the time when the data was measured
- Mitigate latencies between data generation and time-stamping
  - Record types of latencies (network, application, etc.)
  - Calculate total latency
  - Provide an estimated timestamp based on calculations

# Time Synchronization Architecture

***Achieving 1 ms time synchronization accuracy requires carefully architected time synchronization system***

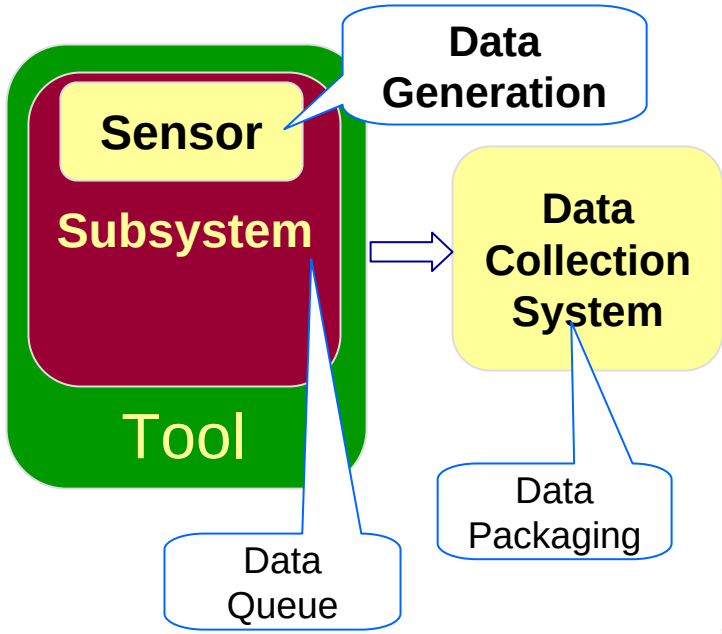
- **Clients should be able to exchange the local time to the server whenever processing and network bandwidth are available**
- **Minimizing network jitter (variability in network delay) improves synchronization quality**
- **A stable, high resolution clock improves time stamping quality while relieving the time synchronization frequency and network bandwidth**
- **Adhere to security precautions to avoid accidental or malicious interference with system clock synchronization**



# Time Stamping Data

***Time stamps coupled with a piece of data shall reflect the time the data was measured, generated as closely as possible to provide a sufficient level of data quality.***

- **Include accuracy information on the time stamp including estimated clock deviation from UTC and estimated time stamping latency from when the event occurred to when it was actually time-stamped**



# Application Timing Requirements
## *On-tool Examples*

| Application | Description/Needs | Absolute Accuracy | Relative Accuracy | Minimum Data Sampling Interval | Precision Required |
|---|---|---|---|---|---|
| **Intra-tool Sensor Integration** | Connect sensors to embedded tool control system for use in real-time control and/or communication to external applications. | 5 sec | 5 ms | 5 ms | 1 ms |
| **End-Point Detection** | Analyze key equipment/process parameters to detect the end of a recipe step. | 5 sec | 10 ms | 10 ms | 1 ms |
| **In-Situ FDC** | Need to correlate sensor data, tool data, and other process data to a specific wafer/lot for multivariate analysis. | 5 sec | 5 ms | 5 ms | 1 ms |
| **Integrated Metrology (IM)** | Standard calls for synchronized clocks to accurately time stamp metrology data. | 5 sec | 100 ms | 100 ms | 1 ms |

# Time Synchronization Ballot (4291)

## Specifications in new standard

- Equipment and factory applications shall support synchronization using NTP
- Time-stamp reporting format (ISO 8601)
  - Format to be used by other standards
- Defines a clock object
  - To readily obtain *time* information from equipment
    - Method to query date/time
    - Accuracy/precision of internal clock
    - Time synchronization status

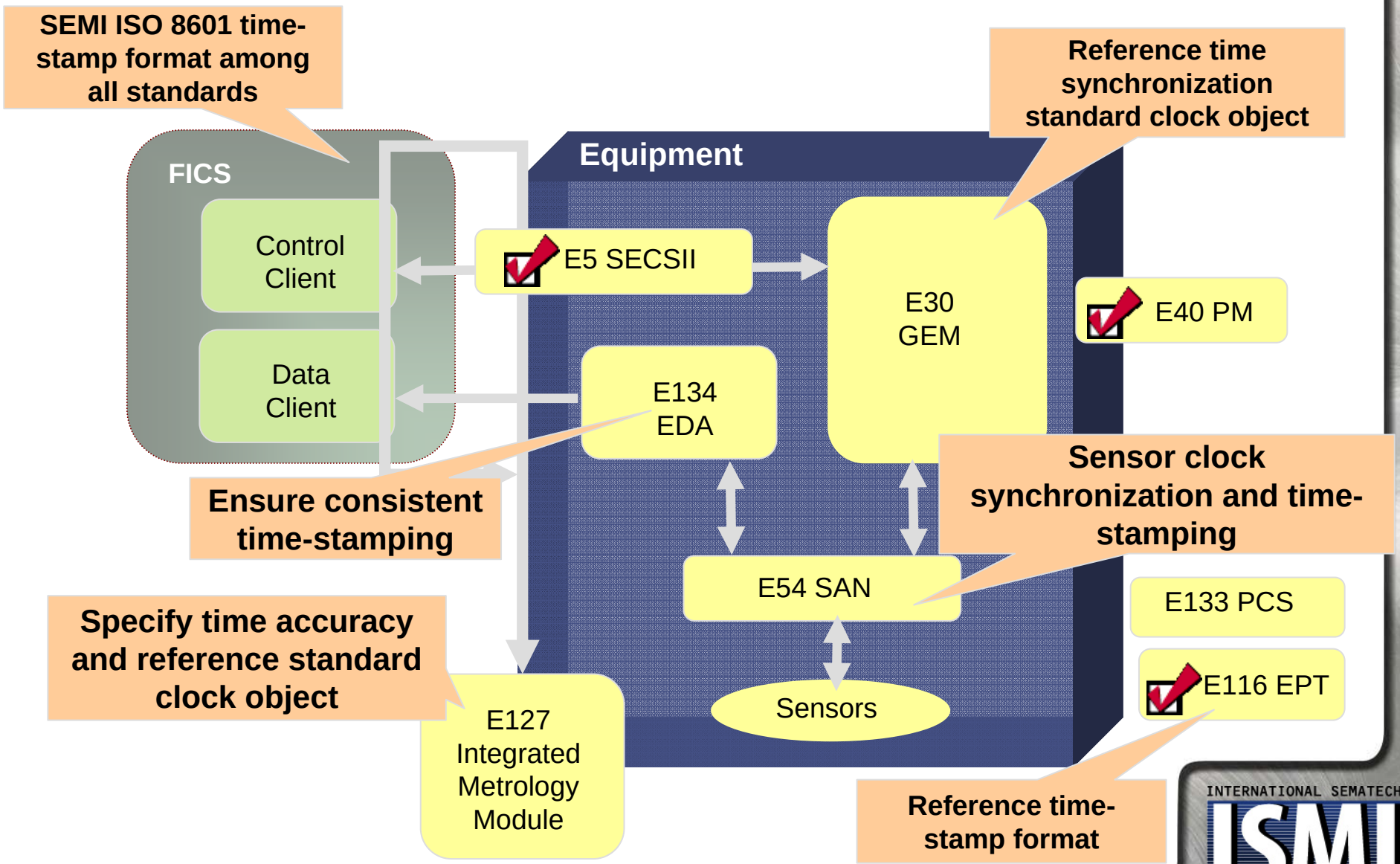
# Existing Standards Update

***Define immediate needs and specific tasks for updating and developing SEMI standards to facilitate rapid deployment of factory and equipment clock synchronization.***

## Goals

- Establish factory clock synchronization
- Facilitate data merging
  - Common time-stamp format
  - Consistent point of time-stamping
  - Time-stamp traceability/quality
- Leverage new SEMI Time Synchronization ballot
- Maintain compatibility with legacy systems

# SEMI Standards: Planned Updates



# Time Synchronization Summary

- **Data from sensors and tools cannot be readily merged today to meet factory application needs**
  - **Unreliable time-stamps prevent advanced analysis capabilities**
  - **Clocks within the tools should readily synchronize**
    - **All tool and tool components' clocks should support synchronization**
- **Synchronization solutions exist**
  - **The factory provides accurate timing**
    - **Time servers and time sources inside the factory should propagate timing information to all equipment and equipment modules using mainstream synchronization protocols**
- **Standards/guidelines being developed to**
  - **Improve synchronization communication of equipment clocks**
    - **Provide consistent time-stamping**
  - **Verify clock synchronization/time-stamping quality**
- **Time synchronization is an initial step to addressing the overall data quality issue**

# Data Quality Key Messages

- Data producers are the equipment suppliers; they are the only ones that can improve data quality.
- Data consumers are IC makers, who are at the mercy of the producers; the quality of the decisions made is wholly dependent on the quality of the data.

**Garbage in, garbage out**

- Semiconductor equipment generates data critical to improving equipment and factory productivity.
- Data must be provided with sufficient accuracy, resolution, and sampling frequency for process/ equipment characterization, fault detection, failure diagnosis, and process development/control.

How does your organization measure data quality?

What are the costs associated with the lack of data quality?

# Time Synchronization References

## ISMI Reports

- ***Factory and Equipment Clock Synchronization and Time Stamping Guidelines***
  **ismi.sematech.org/docubase/abstracts/4781aeng.htm**
- ***Using Network Time Protocol (NTP): Introduction and Recommended Practices***
  **ismi.sematech.org/docubase/abstracts/4736aeng.htm**
- ***Semiconductor Factory and Equipment Clock Synchronization for e-Manufacturing***
  **ismi.sematech.org/docubase/abstracts/4557aeng.htm**

## ISO 8601:2004

- Internet standard for date/time format: **www.w3.org/TR/NOTE-datetime.html**

## NTP

- **www.ntp.org**
- **Latest official NTP RFC 1305: www.ietf.org/rfc/rfc1305.txt**
- **NTP version 4 Working Draft: www.ietf.org/internet-drafts/draft-ietf-ntp-ntpv4-proto-02.txt**

## IEEE 1588

- **ieee1588.nist.gov**