Research Needs for Time-Driven Smart Manufacturing

National Workshop on The New Clockwork for Time-Critical Systems

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Outline

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- Time-Driven Smart Manufacturing
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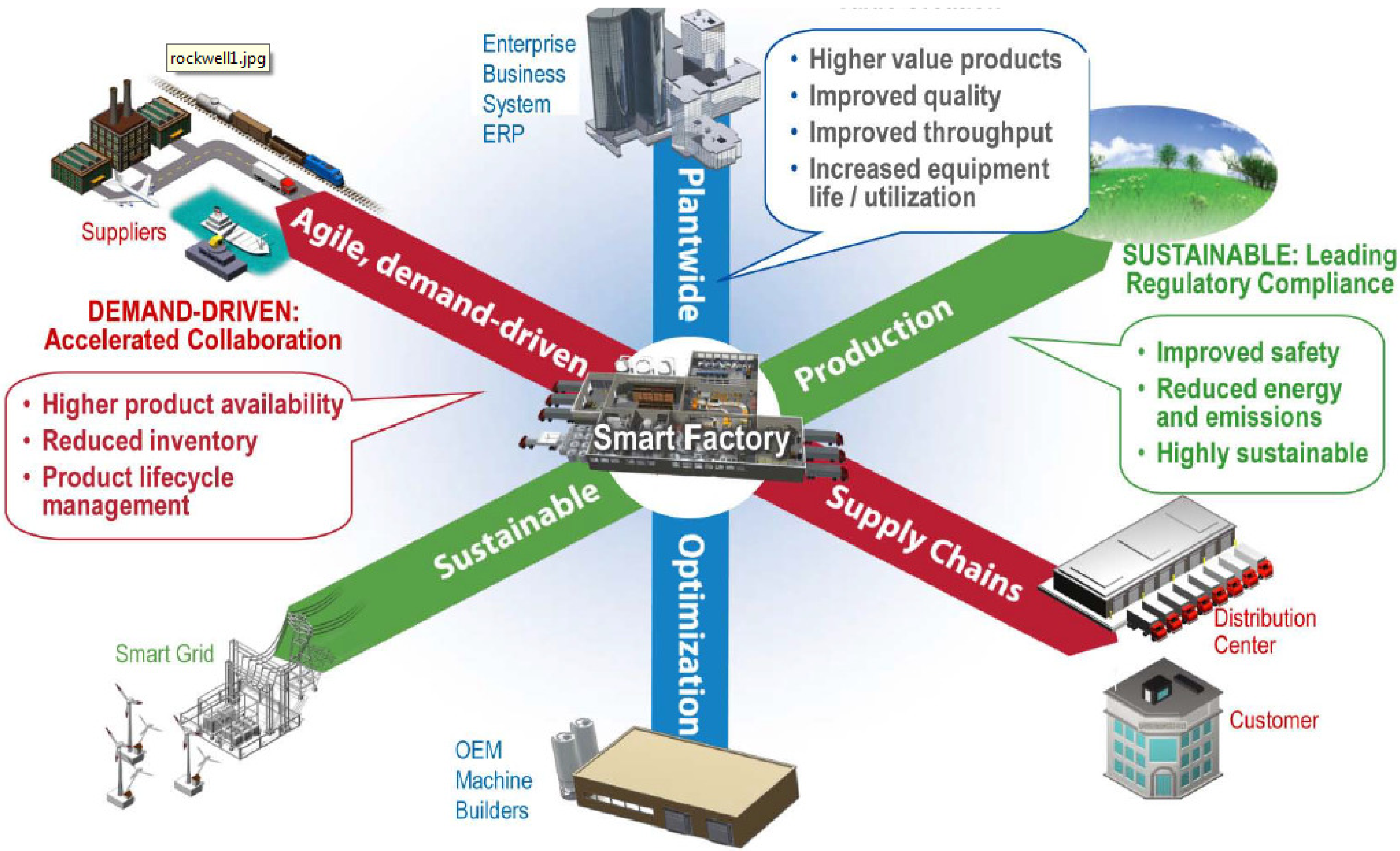
What is Smart Manufacturing ?

- Manufacturing systems are composed of cyber-physical components that require measurement and control of their activities to ensure the efficient production of quality products
- Smart manufacturing leverages large volume of real-time and historical data and predictive models for the complete optimization of a manufacturing plant
- Smart manufacturing interconnects and better harmonizes individual stages of manufacturing production to advance plant-wide efficiency
- Smart manufacturing systems enables a flexible enterprise responsive to consumers and the supply chain
- Smart manufacturing systems consist of the integration of many continuous and discrete systems to form heterogeneous distributed systems
- Networks play key roles in smart manufacturing systems, e.g., sensor networks, factory equipment networks, enterprise communication networks

Smart Manufacturing - Framework



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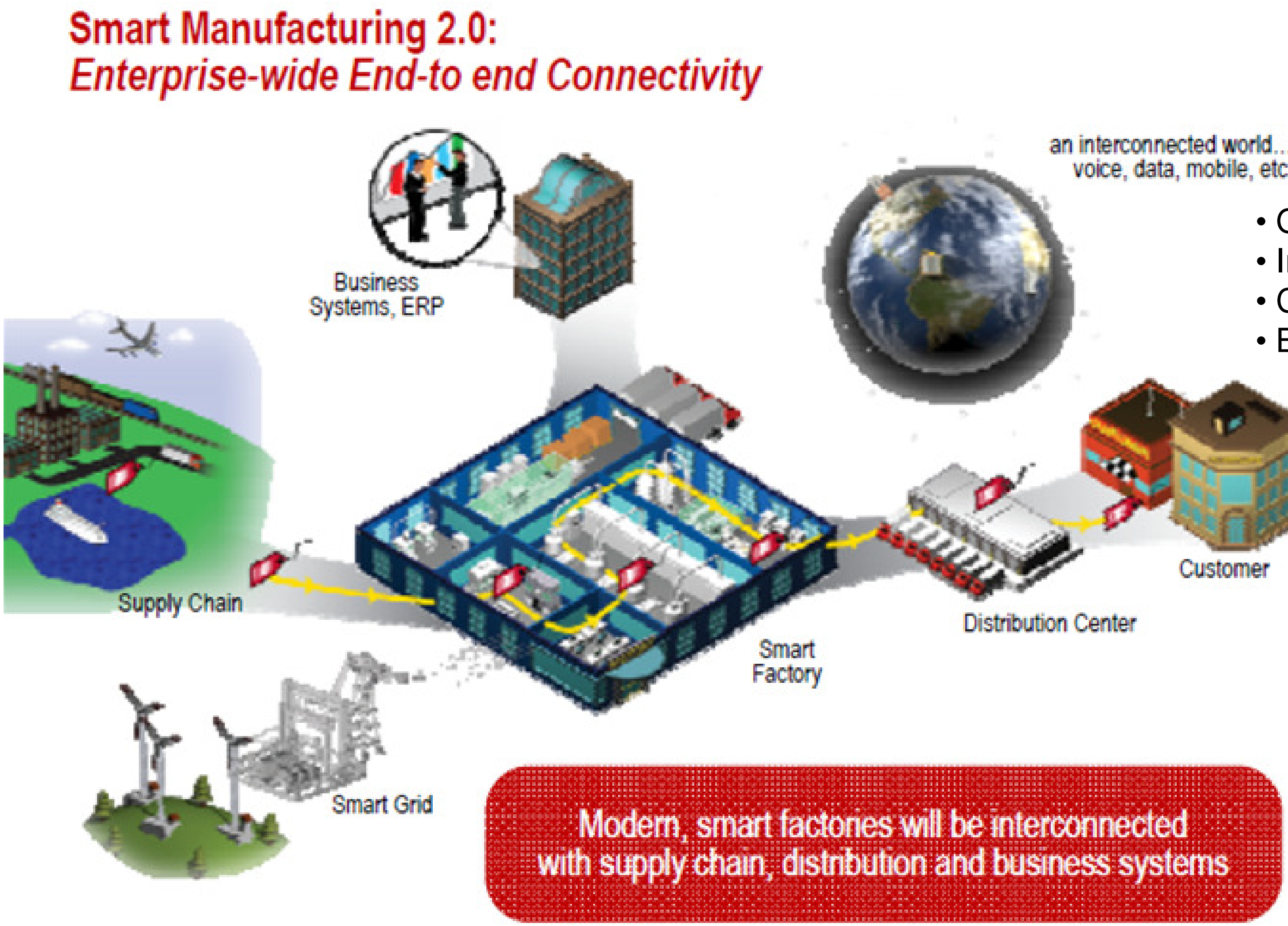
Smart Manufacturing - Connectivity



- Global Manufacturing
- Internet Connectivity
- Cloud Computing
- Big Data

Courtesy of Smart Manufacturing Leadership Coalition

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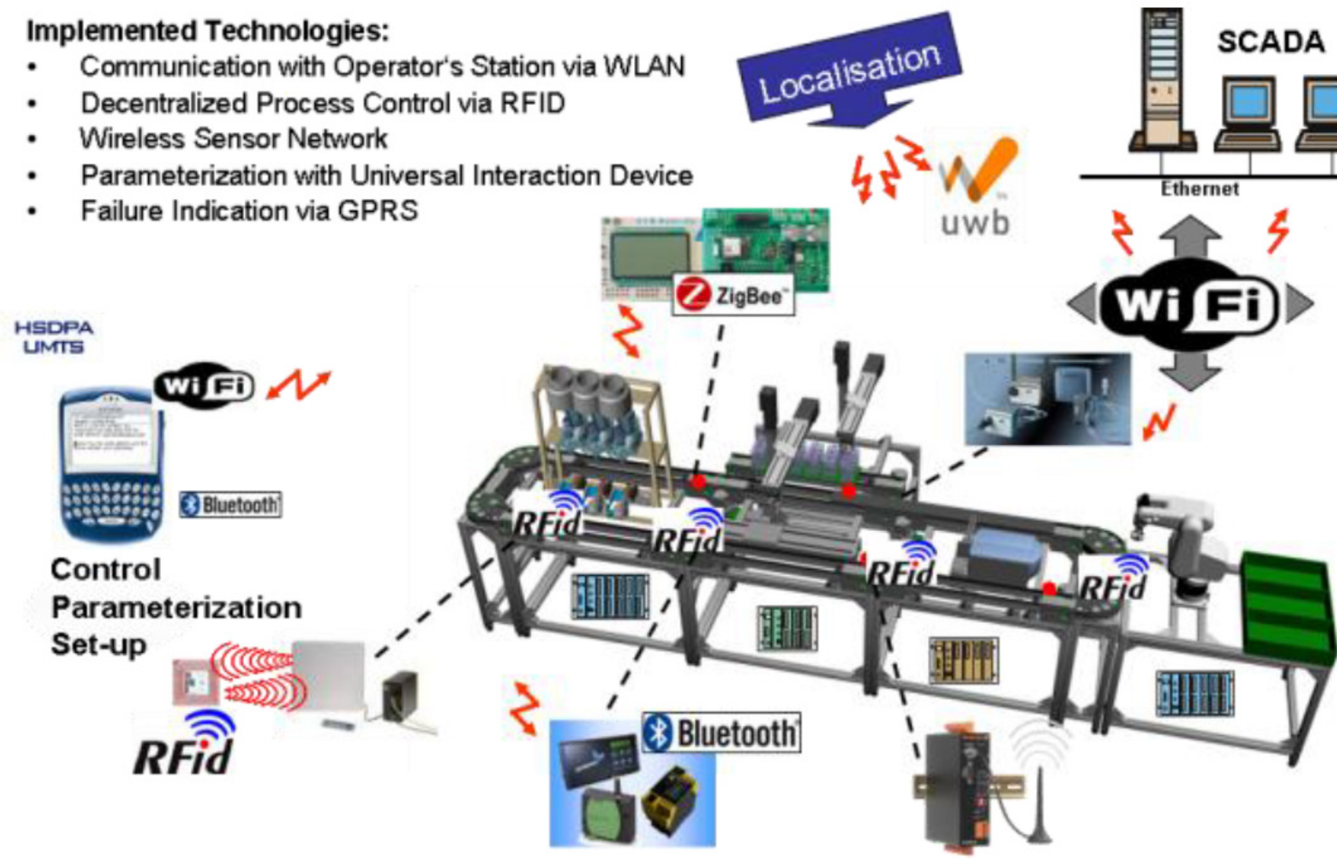
Information and Communication Technology Structure in the *SmartFactory*



- **Time synchronization of networks**
- **Common interface for data sharing**

SmartFactory – A Vision becomes Reality **Prof. Dr. Detlef Zuehlke**

Time-Driven Smart Manufacturing

- A **paradigm shift** in the approach to manufacturing characterized by:
  - **Time synchronized** approach to high speed operations
  - **Real-time simulation** integrated with physical processes
  - **End-to-end connectivity** including to supply chain and resource providers
  - Agile, **demand-driven production**, quick response manufacturing (QRM)
  - **Time-driven** operations

- Providing benefits of:
  - **Higher productivity** through more effective use of resources.
  - **Reduced costs and increased output** through short and long-term prediction/forecasting of all aspects of production
  - **Higher quality output** through higher precision, higher-speed, time-coordinated production.
  - **Predictive agility and reduced time to market** through prediction of needs for re-configuration and better connectivity to consumer space.

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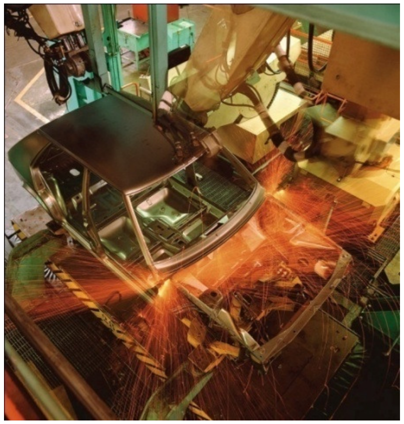
Opportunities of Time Synchronization in Smart Manufacturing

- **Automation**
  - Equipment scheduling
  - Equipment coordination
  - Time interval to completion
- **Process Control**
  - Cause-effect correlation analysis

The main idea is Time Synchronization distributed across the factory (devices to enterprise) to the microsecond level or better.



- **Monitoring**
  - Know exact time of occurrence (e.g. virus attack SCADA system)
- **Fault Diagnostics**
  - Forensic analysis: establish sequence of events
- **Network Operations**
  - Security
  - Quality of service
  - Auditing (e.g. Pharmaceutical Industry)

Time-based Control

- **Today ➔ Problem statement**

  Traditional control is either event or sampling/polling based

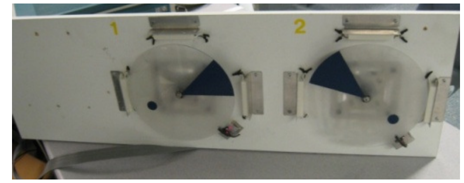
  Imprecise time results in:

  – Out of order reporting of events (loss of robustness)

  – Non-deterministic sampling rates (loss of precision)

  – Inefficient, lower throughput operations (lack of synchronization)

  ➢ Overuse of network bandwidth for interlock communication, handshaking, and conservative over-sampling can increase overall delays and degrade performance



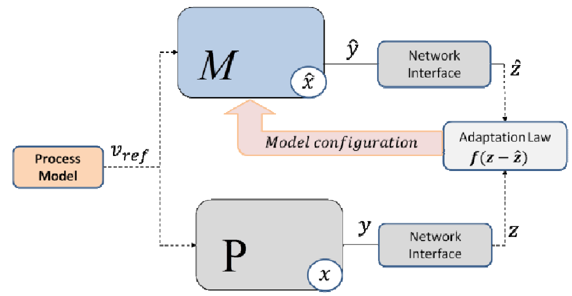
- **Future**

  Enforcing a universally coordinated time base and precise event time-stamping:

  – Improves the efficiency, modularity and scalability of a networked control system

  – Optimizes use of event triggers and sampling rates

  Promotes the use of model-based methods for control and estimation by improving the quality of trace data and the liveness of integrated cyber-physical systems



- **Research challenges**

  – New control design principles that leverage precise timing and synchronization

  – Analysis and design tools for the potentially unprecedented scale in coordination

  – Software design and model integration methods for tightly coupled 'cyber' & 'physical' components

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Robot Coordination and Collaboration

- **Today → Problem Statement**
  - Agile and high-speed manufacturing will require more coordination and collaboration of robotic operations
  - Today, coordination/collaboration is usually done through handshaking
- **Future**
  - High-speed time-synchronized coordination will eliminate the need for handshaking
  - Physically separated (autonomous) coordination
  - Robotic programming/control would be optimized to support time-synchronized coordination
  - New paradigm for production would allow flexible robots to act as configurable resources negotiating to collectively achieve agile production goals
    - Agile from perspectives of design and adaptive real-time control
- **Research challenges**
  - Time-synchronized, resource based robotic programming and control
  - Factory operations (e.g., MES) control rules structured for collaborative robotics
  - Next generation agile manufacturing exploiting collaborative robotics resources

Smart Assembly

- **Today → Problem Statement**
  - Precise time and activity coordination and collaboration of people, tools, and equipment
  - Real world and simulation are not synchronized
- **Future**
  - Time synchronized high-speed assembly
  - Real-time monitoring, analyzing, and responding to assembly environment
  - Flexible and reconfigurable (tool and equipment Plug & Play)
  - Model-based simulation and validation using virtual reality

- **Research challenges**
  - Precise time synchronization of "real world" and "virtual reality"
  - High precision synchronization of wireless networks/systems
  - Real-time wireless monitoring and control of high-speed assembly
  - High-precision time synchronization and coordination of tools and equipment

High-Speed Data Synchronization

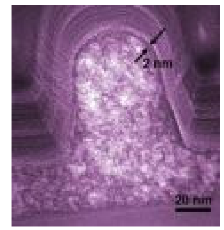
- **Today → Problem Statement**
  - Coordination of some manufacturing diagnostics and control operations requires synchronization to better than 1 microsecond

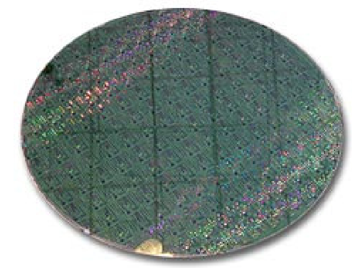
    Ex: semiconductor arc detection, telecom switching, and smart grid signal coordination

- **Future**
  - High-speed manufacturing control and diagnostics systems will leverage high-speed, time-synchronized data collection
- **Research challenges**
  - Reusable mechanisms and standards for high-speed data merging and data mining of high-speed, time-synchronized systems
  - Incorporation of high-speed prediction into these systems

Use Case: Semiconductor Manufacturing

- **Today ➔ Problem Statement**
  - Difficult to merge data - sensors do not have clocks for time-stamping
  - Sampling frequency on order of seconds
  - Event-based scheduling / dispatching





- **Future**
  - High sampling frequency for rare, transient events:
    - ❖ Arc detection requiring 1 to 250 kHz signal bandwidth to capture detection and precise duration
  - High speed merging of other sensor parameters to pinpoint cause
  - High speed dynamic coordination of factory tools with automated material handling systems and manufacturing execution systems
- **Research challenges**
  - Cost-benefits and feasibility of high-speed sampling and analytics
  - Uncertainty bounds, leveraging real-time simulation/prediction
  - Reliability over time of the time-synchronized fab

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Additive Manufacturing (3D Printing)

- **Today → Problem Statement**
  - Problem in precisely controlling various additive manufacturing processes, e.g., selective laser sintering, direct laser metal sintering, fused deposition modeling, electron beam melting, to produce parts of high surface finish with low part variation in high speed and low cost
- **Future**
  - Combined cyber physical systems technology and physical models with characterized uncertainty for small-volume manufacturing
- **Research challenges**
  - Development of accurate physics-based dynamics models for control and defect prediction
  - Precise synchronization of multiple measurements and sensor data for precise in-process control
  - Precise coordinated timing of multiple mechanisms or builds to increase production speed and improve surface finish of parts or devices being produced simultaneously

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Future of Manufacturing

Rapid production of technically complex products, highly customized, and anticipatory of customer requirements.

Factory as a cyber-physical system:

Monitor, control, and optimize systems in the manufacturing life-cycle performance with interacting networked (cyber) and engineered (physical) components continuously and automatically—by learning from and adapting to past events, changing current events, and possible/desired future states

Benefits:

- Dramatic increase in manufacturing performance while reducing unit costs through improved communication, awareness and intelligence
- Precision control of manufacturing processes through real-time flexible, physically separate coordination using robotics, automation, and in-situ sensing and controls
- Precision control to enable highly complex and technologically advanced products
- Adapt knowledge from all domains into product design through modeling and simulation and information processes to achieve rapidly customizable products

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Time-Driven Smart Manufacturing Barriers & Opportunities

On factory floors, it is difficult to achieve:

- Integration of real-time data and models
- Factory-level situational awareness
- Timely predictive and precise control
- Freedom from physical connectivity

Precision Synchronization → Communication → Awareness → Intelligence → Coordination

Technology Opportunities:

- **Precision Time Synchronization:** Feasibility, reliability, robustness.
- **Communication:** Standards to enable integration and interoperability of timing
- **Awareness:** High-speed synchronization of real-time sensor, measurement, and control data to gain sufficient awareness of the manufacturing situation
- **Intelligence/Coordination:**
  - Understand the situation through dynamic, validated models
  - Respond to the situation through dynamic predictive models and simulations
  - Coordinate tasks based on the understanding of how timing precision affects uncertainty models, simulations, and coordination

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Timing Research Needs for Smart Manufacturing

Precision Time Synchronization: Enabling Timing Capabilities On the Factory Floor and Beyond

- Timing reliability and robustness to support manufacturing
- Characterization of sources of timing uncertainty
- High-precision synchronization of wireless networks/systems

Communication: Enabling Interconnectivity and Integration

- Time-based software design and model integration methods for tightly coupled ‘cyber’ & ‘physical’ components
- Precise time synchronization of real world and virtual reality
- Reusable mechanisms and standards for high-speed data merging and data mining of time synchronized systems

Awareness: Enabling Monitoring of All Levels from Tool Sensors to Cross-Enterprise

- Real-time wireless monitoring
- Precise synchronization of multiple measurements and sensor data for precise in-process control
- Cost-benefits and feasibility of high-speed sampling and analytics

Intelligence: Enabling High-Fidelity Modeling and Simulation for Optimized Control and Prediction

- Uncertainty bounds, leveraging real-time simulation/prediction
- Development of accurate physics-based dynamics models for control
- Incorporation of high-speed prediction into these systems

Coordination: Enabling Efficient, Precision Coordination

- New control design principles that leverage precise timing and synchronization.
- Real-time control of high-speed assembly
- Precise coordinated timing of multiple mechanisms or builds to increase production speed and improve surface finish of parts or devices being produced simultaneously
- Time-synchronized, resource based robotic programming and control
- Analysis and design tools for the potentially unprecedented scale in coordination using high-precision time synchronization.
- Next generation agile manufacturing exploiting collaborative robotics resources


Questions