Product Modeling

• Product models, such as those from computer-aided design (CAD) applications, can be used in many ways to determine how well a product design fulfills its requirements
  – Form, fit, and function analyses, for simple go/no-go answers
  – Finite-element analyses (FEA) for forces, stresses, deformations
  – Multi-physics analyses for fluid flow, heat transfer, and electromagnetic properties

• These analyses can substitute for actual testing, reducing costs and shortening development time
Process Modeling

• Process models can be used in many ways to determine how well a manufacturing process will make the product
  – Unit process selection, operation schedules, tooling and fixturing
  – Equipment programs, process recipes
  – Physics-based simulation at the material level
• Likewise, these analyses can substitute for actual testing and reduce time and cost
  – An issue: processes are often certified, such as production certificates per the FAA requirements to 14 CFR Part 21 (G)
  – *How can modeling effectively substitute for process testing, to achieve the confidence level needed for certification?*
Process Modeling Research Objectives

- Modeling of the system to understand the impact of manufacturing or assembly changes on the final product
- Modeling to predict the impact of such changes on the process, and minimize the need for additional process testing
- Driving these models with real-time information collected automatically and continually
- Three highlights: discrete-event simulation, machining performance, physics modeling
Discrete Event Modeling and Simulation

- DES is used to predict cycle times and throughput, identify bottlenecks, and perform what-if analyses for reconfiguring factories.
- There is a mature software application market.
- The problem is *getting the data*: largely a manual “clipboard army” process.
  - 30% of the cost of DES is associated with data input.
- Open-source standards are helping:
  - The Association for Manufacturing Technology’s MTConnect standard automates data collection.
  - ROS (Robot Operating System) and ROS-Industrial integrate robots and auxiliary equipment.
40-machine cell at Boeing Renton, automatically populating DES applications with real-time data for capacity planning.

Machining Performance Modeling

• At the unit process level, machining performance modeling verifies the correctness of programs for machine tools and helps optimize:
  – Cycle times, tool selection, final part geometry, optimization of machine motion

• There is a mature software application market, but a wide range of proprietary data formats

• Standards are helping:
  – ISO 10303 “STEP” for toleranced geometry, part programs, machine tool performance models
  – ISO 13399 cutting tool information model
Cutting simulation of Airbus test part showing tool paths with instantaneous cross-section area information for speed optimization

Machine tool model with tool changer kinematics

Cutting tool model with semantic tolerances and ISO 13399 parameters
Machine tool performance tests measure many sources of kinematic error, e.g., straightness, angular offsets.

Mathematical models and visualization show simulate how the real machine will respond to particular programs.

Comparisons between measured performance and modeled performance show good agreement.
Physics Modeling

• At the material level, physics modeling computes process value such as force and temperature
  – Can drive other models of deflection, material hardening, vibration, surface finish

• Model development is an active research area

• Opportunities:
  – High-performance computing to model in real time
  – Integrating low-level physics models seamlessly with high-level process models
Analytical “textbook” models drive finite-element analysis and multi-physics analyses.

Models are validated against high-speed data collection, such as this diamond tool cutting experiment.
Summary

• Process modeling supplements product modeling
  – To understand the impact of manufacturing or assembly changes on the final product
  – To predict the impact of such changes on the process
  – To minimize the need for additional process testing
• Process modeling is done at various levels, such as the facility, unit process, and physics levels
• Populating these models is difficult due to the often manual nature of data collection; standards to automate data collection help
• Using modeling and simulation may one day obviate the need for testing, even for high-confidence applications like certification