Perspective Shaped by Experience

• Research and consulting for U S Navy on shipyard planning and scheduling, 1975-82
• Consultant to Clorox for planning and scheduling, 1981-1984
• Consultant to semiconductor industry, 1983 – present
  • Leachman & Associates LLC – software and consulting
• Research on biotech production planning for Bayer Healthcare, 2008-2011
• Consultant and researcher for Asia – USA supply chains, 1983 - present
High-Tech Manufacturing

• Key characteristic: New and challenging manufacturing process, many engineering issues impeding reliability, quality and productivity

• Manufacturing done in parallel with process improvement

• Not one database or system supporting the effort but multiple databases and systems that must be integrated

• Multiple evolving applications supporting different engineers

• Desired applications typically require data from multiple databases and sometimes require collection of new data

• Systems architecture is therefore important
Roles of Manufacturing Systems

- Input *process recipes* to processing machines
- Collect complete “audit-trail” data from process, machines, and product testing
- Advanced process control (SPC, feedback and feedforward, FDC)
- Automated material handling
- Scheduling and automation of manufacturing execution (including both production and nonproduction activity)
- Planning (capacity planning, production planning and delivery quotation)
- Yield and failure analysis, cycle time and efficiency analysis
The Key Databases

• *Recipe Management System (RMS)* – repository of official *process specifications* for products, test units and re-qualification procedures
The Key Databases

• *Recipe Management System* (RMS) – repository of official *process specifications* for products, test units and re-qualification procedures
  • *Process flow* is the sequence of steps to produce a product, perform the re-qualification of a process step or an equipment, or to recycle test units
  • *Recipe* is the set of instructions to the machine for how to perform a process step
  • RMS identifies which machines are currently authorized to perform each step in each flow, and what recipe to use
  • Defines logic determining whether step is to be performed or skipped (e.g., implements sampling rates for in-line inspections and tests)
  • Defines branching logic to *rework process flows*
  • Maintains statistics on what recipe was used at each step and on temporary disqualifications of machines from performing steps
Key Databases (cont.)

- Manufacturing Execution System (MES)
Key Databases (cont.)

• Manufacturing Execution System (MES)
  • Maintains *state vector* for every production lot and every machine resource
    • Lots: What step, current location (specific machine load port or rest location), when step started (if already started), lot status (on hold or can be worked on)
    • Machines: Up/down status, values of counters until maintenance or requalification procedures are due
    • Steps: Values of counters until inspection, test or requalification must be performed
  • Issues command to machine to run lot using particular recipe
  • Retains audit trail for every lot (when each step was performed, by what machine and/or what human)
  • Maintains statistics on cycle times and line yields
Key Databases (cont.)

• Automated Material Handling System (AMHS)
Key Databases (cont.)

- Automated Material Handling System (AMHS)
  - Maintains state vector for all lot moves in progress
    - Origin, destination, when started
  - Maintains statistics on move times between all origin-destination pairs
Key Databases (cont.)

• Equipment Tracking (ET)

Recipe Management (RMS)
Manufacturing Execution (MES)
Automated Material Handling (AMHS)
Key Databases (cont.)

• Equipment Tracking (ET)
  • Maintains current status of all machine resources (available or in various alternative “down” states)
  • Maintains audit trail of all machine-down events and maintenance performed
  • Maintains statistics about availability, about length of non-available periods and statistics about PT and SCT for all recipes on all machines
Key Databases (cont.)

• Engineering Data Collection (EDC)
Key Databases (cont.)

• Engineering Data Collection (EDC)
  • Maintains audit trail of all measurement results at metrology (inspection) steps, and all readings of various physical parameters in the machines during processing (e.g., beam current, lamp intensity, gas flow, pressure, humidity, temperature)
Key Databases (cont.)

- Advanced Process Control (APC)
Key Databases (cont.)

• Advanced Process Control (APC)
  • Includes Statistical process control (SPC), Feedback adjustment of recipes ("run-to-run controllers"), Feedforward adjustment of recipes, Fault detection and classification (FDC), Feedback adjustment of sampling rates
  • Informs MES of lot holds and adjustments to sampling counters, informs RMS of machine disqualifications and recipe adjustments, informs ET of machine non-availability
  • Maintains audit trail of SPC measurements, recipe adjustments, sampling rate adjustments and machine fault detections
  • Maintains statistics on same
Key Databases (cont.)

- Test/QA Data Collection

- Test and QA Data Collection
- Engineering Data Collection (EDC)
- Advanced Process Control (APC)
- Equipment Tracking (ET)
- Manufacturing Execution (MES)
- Recipe Management (RMS)
- Automated Material Handling (AMHS)

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Key Databases (cont.)

• Test/QA Data Collection
  • Audit trail of detailed results of end-of-line tests and quality assurance inspections
Key Applications

• Yield Analysis
Key Applications

• Yield Analysis
  • Integrates audit trail data from MES, ET, EDC, APC and Test/QA
  • Provides capability to perform correlation analysis across low- or high-yielding wafers or lots
Key Applications (cont.)

- Scheduler
Key Applications (cont.)

• Scheduler (Short-term production targets by product-step guiding asynchronous area schedulers that strive to meet those targets)
  • Maintains “living” Gantt Chart for all machine resources (both production and non-production activity)
  • Receives input from MES (current factory state vector and CT statistics), AMHS (moves in progress, statistics on move times), RMS (what is next step, recipe for next step, what machines are qualified), ET (machine status, statistics on process time and standard cycle time)
  • Schedules next step for all running lots
  • Tells MES what to do, tells AMHS what to do
Key Applications (cont.)

- Cycle Time Analysis (Entitlement Cycle Time Analyzers)
Key Applications (cont.)

• Cycle Time Analysis (Entitlement Cycle Time Analyzers)
  • Provides capability for “what-if” estimations of cycle time by process step
  • Estimates *entitlement cycle time*: For a given mix of products at given volumes, the average cycle times for each step on each product we should expect if manufacturing execution were perfect, but reflecting the statistics about process trouble, equipment trouble and rework
  • Considers the actual process flows and qualified machines for each recipe, actual process times, standard cycle times, AMHS move times and sampling rates
  • Receives data from RMS, MES, AMHS, ET
  • Separate ECT analyzer for each process area
Key Applications (cont.)

- Capacity Planner

- Test and QA Data Collection
- Engineering Data Collection (EDC)
- Manufacturing Execution (MES)
- Automated Material Handling (AMHS)
- Scheduler
- Yield Analysis
- Advanced Process Control (APC)
- Recipe Management (RMS)
- Equipment Tracking (ET)
- Cycle Time Analysis (ECT Analyzers)
- Capacity Planner

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Key Applications (cont.)

• Capacity Planner
  • Determines least-cost resource equipment acquisition plan to achieve given volume and mix for given target cycle times for the products
  • Links the ECT Analyzers for all manufacturing areas to do this
Key Applications (cont.)

• Production Planner

- Test and QA Data Collection
- Engineering Data Collection (EDC)
- Manufacturing Execution (MES)
- Automated Material Handling (AMHS)
- Scheduler
- Recipe Management (RMS)
- Production Planner
- Advanced Process Control (APC)
- Equipment Tracking (ET)
- Cycle Time Analysis (ECT Analyzers)
- Capacity Planner
- Yield Analysis
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Key Applications (cont.)

• Production Planner
  • Receives input from Capacity Planner (process flows, sampling rates, machine qualifications, cycle times and process times, machine counts, U/A limits for all machines)
  • Receives input from company business systems (customer commitments, forecasts, ASPs, build rules, material availability, etc.)
  • Establishes target start and out schedules for all factories, makes source-product allocation and inter-plant shipping plans, makes delivery quotations
Key Applications (cont.)

- Compliance Analyzer

- Test and QA Data Collection
- Engineering Data Collection (EDC)
- Manufacturing Execution (MES)
- Automated Material Handling (AMHS)
- Scheduler
- Compliance Analyzer
- Manufacturing Systems Architecture

- Advanced Process Control (APC)
- Recipe Management (RMS)
- Cycle Time Analysis (ECT Analyzers)
- Capacity Planner
- Production Planner

- Equipment Tracking (ET)
- Yield Analysis

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Key Applications (cont.)

• Compliance Analyzer
  • Applied in factories lacking full automation
  • After each production shift, for each area (step type), compares moves actually made to schedule goals in order to compute overall schedule efficiency (“OSE”)
  • Compares actual moves made to the portions of goals that were possible considering equipment availability, equipment qualifications, and the available and arriving WIP, in order to compute a performance-to-possible (“Perf-P”) metric for the area. Also computes scores for WIP-feasible portion of goals (“WIP efficiency”) and scores comparing actual moves to feasible moves (“Volume efficiency”)
  • Maintain audit trail and statistics on OSE, Perf-P, WIP efficiency and Volume efficiency
Systems Architecture

Test and QA Data Collection

Engineering Data Collection (EDC)

Recipe Management (RMS)

Advanced Process Control (APC)

Manufacturing Execution (MES)

Cycle Time Analysis (ECT Analyzers)

Equipment Tracking (ET)

Automated Material Handling (AMHS)

Scheduler

Capacity Planner

Production Planner

Compliance Analyzer

Yield Analysis

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Experience

• Leachman & Associates LLC developed and installed in the semiconductor industry the following modules
  • Production Planner (5 companies)
  • Scheduler (3 companies, 1 integrated with AMHS for full automation)
  • ECT Analyzers (3 companies)
  • Capacity Planner (2 companies)
  • Compliance Analyzer (2 companies)
Capacity Planning
ECT vs. Capital Cost of Tool Set, 29.5K WSPW

ECT (days)

Capital $ Spent on Tool Set (millions)
Capacity Planning (cont.)

Entitlement Cycle Time vs. Tool Capital Cost for Various-Sized Fabs

- 12K WSPW
- 14.5K
- 17K
- 19.5K
- 24.5K
- 29.5K
- 34.5K
- 39.5K
- 44.5K
- 49.5K
- 54.5K
- 59.5K

Equipment Capital Cost per WSPW (million $)

Entitlement Cycle Time (days)
Capacity Planning (cont.)

Tool capital cost vs. ECT and fab size

- ECT = 23 days
- 26 days
- 29 days
- 32 days
- 35 days
- 38 days
- 41 days

Fab Size (K WSPW)

Tool capital cost per K WSPW (million $)
Prioritized demands and build rules

Customer Quotation & Order Entry System

Demand Forecast System

Order Board

Prioritized demands and build rules

Factory capabilities and status

Factory Plans (start and out schedules)

Planning Engine

Product Availability

Queries & Orders

Quotes

Raw Materials System

Material availability

Material requirements

Product structure and sourcing rules

Bill of Materials System

Factory Floor Systems

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Results

• In the first company to implement automation of production planning and delivery quotation (1992), *on-time delivery was raised from 75% to 95%,* declining sales and growing losses were transformed into growing sales and profits
  • Won Franz Edelman Award from INFORMS in 1995

• In the first company to implement line scheduling based on IPQ targets (1999), *cycle time was reduced from 3 days per layer to 1.3 days per layer,* market share was doubled, competitors withdrew from market
  • Finalist for Franz Edelman Award in 2001
Results

• In the company implementing full automation (2008): In new factories making leading-edge products operating at world-class equipment utilizations and world-class yields, *cycle time achieved was 1 day per mask layer, operating with a shift crew of only 23 people*
  
  • Competitors fell into bankruptcy
Some Parting Advice

• The most important Industrial Engineering skill is **empathy**
  • Understand challenges and frustrations facing managers and workers
  • Imagine *being in their shoes*

• The second most important skill concerns imagination, vision, and **thinking big**
  • What is the whole scope that matters? What does “optimal” really mean?
  • If the system were re-designed from scratch, what should it look like?
  • What data/information/analysis is needed to design it and operate it efficiently or optimally? What data collection systems and databases are needed to sustain that mode of operation and that analysis?

• The third most important is **communications skill**

• After that come the software and analytical skills you learn in your coursework and in reading the literature