CH2M HILL Today

We are an industry leader in consulting, design, design-build, operations, and program management.

- Headquartered in Englewood, Colorado
- More than 30,000 employees
- US$6.4 billion in revenue
- 100 percent owned by our employees
- Broadly diversified across multiple business sectors
- Performing work in more than 140 countries
Presenter

- James Godfrey
  - Electrical Engineer with 15 years experience in manufacturing, critical system design, and system integration. He has been with CH2M HILL for 13 years and currently works with CH2M HILL’s Industrial & Advanced Technology clients.

- On LinkedIn
  - James Godfrey Industrial Automation Technologist
Industrial Automation Software UML

• Projects - Tool
  ▫ Applied to MES/utility systems for solar client - EA
  ▫ Applied to utility systems for datacenter client - Visio
  ▫ Applied to MES for chemical manufacturing clients - EA
  ▫ Applied to MES for consumer product manufacturing - EA
## Factory Functional Area Matrix

<table>
<thead>
<tr>
<th>Area/Process</th>
<th>MES Function</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Area</td>
<td>Process Step</td>
<td>Material Handling</td>
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<tr>
<td></td>
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<tr>
<td>Receiving</td>
<td></td>
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<tr>
<td>Mix</td>
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<tr>
<td>Fill</td>
<td></td>
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<tr>
<td>Lab</td>
<td></td>
<td></td>
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<tr>
<td>Warehouse</td>
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</tbody>
</table>
UML Analysis Diagram for Chemical Manufacturing

- **Mix Batches**
- **Batch Complete**
- **Fill Containers**
- **Containers Filled**
- **Ship Orders**
- **Order Shipped**

**Data Flows:**
- **Production Data**
- **Quality Data**

**External Inputs:**
- **Raw Materials**
- **Containers Arrive**

**Processes:**
- **Process Incoming Containers**
- **Dip Tube**
- **Spent Material Disposal**

**Internal Data:**
- **Containers Ready for Fill**
- **Production Schedule**

**Outputs:**
- **Containers Filled**
- **Order Shipped**
UML Sequence Diagram for Vendor Interface
UML Experience

- **Good**
  - Enables system discussion
  - Involves stakeholders
  - Accessible

- **Bad**
  - Doesn’t address continuous processes
  - Labor intensive to develop
  - Not for simple systems
SysML Interest

• Motivation
  ▫ Abundance of continuous systems
  ▫ Need for industry standards
  ▫ Improve knowledge transfer
  ▫ Alignment with A3 process (Lean effort)
  ▫ System focus vs. building

• Training Courses
  ▫ PSU 591 Systems Engineering Approach
  ▫ GA Tech 101/201 SysML
SysML vs. Construction Documents

**SysML**
- Model Based
  - OMG SysML
    - Open source general purpose modeling tool for systems
  - Diagrams (9 total)
    - Package
    - Requirements
    - Activity
    - Block Definition
    - Internal
    - Parametric

**Construction Documents**
- Document Based
  - Specs
    - CSI Construction Specification Institute – maintains standardized construction language for building specifications
  - Engineering Drawings
    - P&IDs
    - Piping/layouts
Construction - Domain Perspective

- Design development focused on documenting components
- Performance and functional descriptions limited to getting systems through start-up and fully deployed
- Operations documents typically managed separately by sustaining staff
- Operations documents may or may not influence/feedback to construction documents for the next development cycle
- Multiple documents owned by different staff describe the system requirements and behavior
Construction - Stick Built Systems

- Non-packaged, i.e. no performance spec document
- Some components described independent of system specific documents
- Information documented in over 20+ specifications and drawings
- System specific requirements limited to datasheets, SOO, and drawings
- Non-functional requirements may not be documented
- Requirements may be a challenge to align between documents
Construction - Typical Challenges

- Systems of systems – power failure restart
- Systems with multiple owners – backup power, network systems, sumps
- New requirements – security, first of kind systems
- Operational – organizational issues, start-ups, expectations
Construction - PCW Example Specs

• Process cooling water (PCW) is a typical semi/PV factory utility system
• Components: pumps, heat exchanger, tank, piping, filters, drives, controls, and motors
  ▫ Each component has at least one specification and associated component datasheets
• Operations: controls/drive specifications
  ▫ Sequence of Operations describes automation requirements
  ▫ Start-up and testing documents
Construction - PCW Example Dwgs

- P&IDs – process industry diagram which shows the interconnection of process equipment and the instrumentation used to control the process
- Piping
- Layouts
- Electrical
MBSE - Domain Perspective

- Alternative to document-based systems engineering
- Formalized application of modeling to support system requirements, design, analysis, verification and validation activities for all phases of the lifecycle
- Goal is to enhance design specification and quality, reuse, and team communication
- Output of the process is a coherent model of the system with tools and methods for continuous refinement and evolution
Vision (InterCAX)
Collaborative System M&S Framework

Design
- CAD
  - Mentor, Cadence, Zuken, AP210
- mCAD
  - NX, ProE, CATIA, AP203

Analysis
- FEA/CFD
  - ANSYS, Abaqus
- Math
  - MATLAB/Simulink, Mathematica, Excel

Design
- Excel
- MS Project

Project Management
- DOORS
  - CORE
- REQTIFY

Requirements

SysML

Risk/Monte Carlo Simulations

Trades/Sensitivity/Optimization

PDM
- TeamCenter
- Windchill
- Isight
- ModelCenter
Model vs. Diagrams

Reality
- Envisioned or actual

Model
- Computer-oriented
- Master repository
- Complete for intended scope

Diagrams
- Human-oriented
- Subset views

Tools
- Authoring, viewing, executing, ...

Acknowledgements: Selected portions from Friedenthal et al. 2008 and MagicDraw samples.

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Model-Based Systems Engineering

Generates a Coherent Set of Documents

Consistency

Coherence

Integrity...
SysML - PCW Example In Progress...
PCW
Package
Diagram

pkg Process Cooling Water Model [Model Organization]

Process Cooling Water Model

Requirements

Use Cases

Behavior

Test Cases

parts
  Pump
  Pump Sequencer
PCW Requirements Diagram
PCW Use Case

- PCW System
  - Improve System Performance
  - Document System
  - Review System Operating Records
  - Operate System

- PCW System Owner
- Process Mechanical System Supervisor
- Operator
PCW State Machine

stm [Package] Behavior [Pump System States]

Initial

Power Available → Not in Auto

Running1

Pump Fault

Not Faulted [< 2 pumps running] /Current On

In Auto

Choice

Not Faulted [>2 pumps running] /Current Off

Running Pump Fault

Idle

Fault Reset

Standby1
CH2M HILL Local Modeling Capabilities

- Replica – Continuous Process Modeling
- Industrial Engineering (IE)
- Airflow/Energy Modeling
Replica™ Dynamic System Modeling

Dynamic System Model

- Unit Process Operations
- Hydraulics
  - Pumps
  - Valves
  - Storage
  - Pipes
- Automation
  - Proper Sensing
  - Control Algorithm
  - Interface
- System Optimization
Replica Opportunities during Project Lifecycle

- **Develop**
  - Standards-based approach and documentation
  - Focus on visualization of information
  - Analyze alternatives/trade-offs

- **Design**
  - Model critical and dependant systems
  - Address operations and start-up issues
  - Transfer model data to programming documentation

- **Sustain**
  - Collect data and optimize
  - Forecast/Analyze Retrofits
  - Transfer data to new plant development

- **Deploy**
  - Deploy modeled systems
  - Calibrate model
  - Capture dependency issues
# IE Material Handling / Manufacturing Modeling

## Type

<table>
<thead>
<tr>
<th>Type</th>
<th>Modeling Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>To – From Analysis</td>
<td>Proprietary (Excel-based)</td>
</tr>
<tr>
<td>Flow Map / Line Balancing Analysis</td>
<td>ProPlanner</td>
</tr>
<tr>
<td>Dynamic Capacity Model</td>
<td>AutoSCHED / AnyLOGIC Simulation Platform</td>
</tr>
<tr>
<td>Static Capacity Model</td>
<td>Proprietary (Excel-based)</td>
</tr>
<tr>
<td>Material Handling Dynamic Model</td>
<td>AutoSCHED / AnyLOGIC Simulation Platform</td>
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<tr>
<td>Process Utility Matrix Model</td>
<td>Proprietary (Excel-based)</td>
</tr>
<tr>
<td>Factory Layout</td>
<td>Revit / AutoCad</td>
</tr>
<tr>
<td>ROI Analysis</td>
<td>Proprietary (Excel-based)</td>
</tr>
<tr>
<td>Manufacturing Flow Diagrams</td>
<td>Proprietary (Visio-based)</td>
</tr>
</tbody>
</table>

- **Pedestrian Dynamics - AnyLogic**
- **Coffee Production - AutoMOD**
- **Flow Mapping - ProPlanner**
- **Flow Mapping - ProPlanner**
IE Representative Experience

- **Industries**
  - Semiconductor Material Handling
  - Solar Manufacturing
  - General MFG
  - Architecture

- **Systems**
  - Conveyors, AGVs, Robotics
  - Bulk Material Handling
  - Pedestrians / Traffic

Cruise Terminal - AutoMOD

Lobby / Elevators System - AutoMOD

Solar MFG - AutoMOD
## Airflow and Energy Modeling

<table>
<thead>
<tr>
<th>Type</th>
<th>Modeling Tool</th>
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</thead>
<tbody>
<tr>
<td>Airflow Modeling</td>
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<tr>
<td>Exhaust Dispersion</td>
<td>FLOVENT</td>
</tr>
<tr>
<td>Cleanroom Laminarity</td>
<td>FLOVENT</td>
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<tr>
<td>Natural and Hybrid Ventilation</td>
<td>FLOVENT</td>
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<tr>
<td>Thermal Analysis</td>
<td>FLOVENT</td>
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<tr>
<td>Complex Geometries</td>
<td>ANSYS FLUENT</td>
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<tr>
<td>Energy Modeling</td>
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<tr>
<td>Whole Building</td>
<td>EnergyPlus and eQuest</td>
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<tr>
<td>System Specific</td>
<td>Proprietary (Excel-based)</td>
</tr>
<tr>
<td>Pipe and Pump System Analysis</td>
<td>PIPE-FLO</td>
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