Tube Manufacturing Simulator: A Prototype
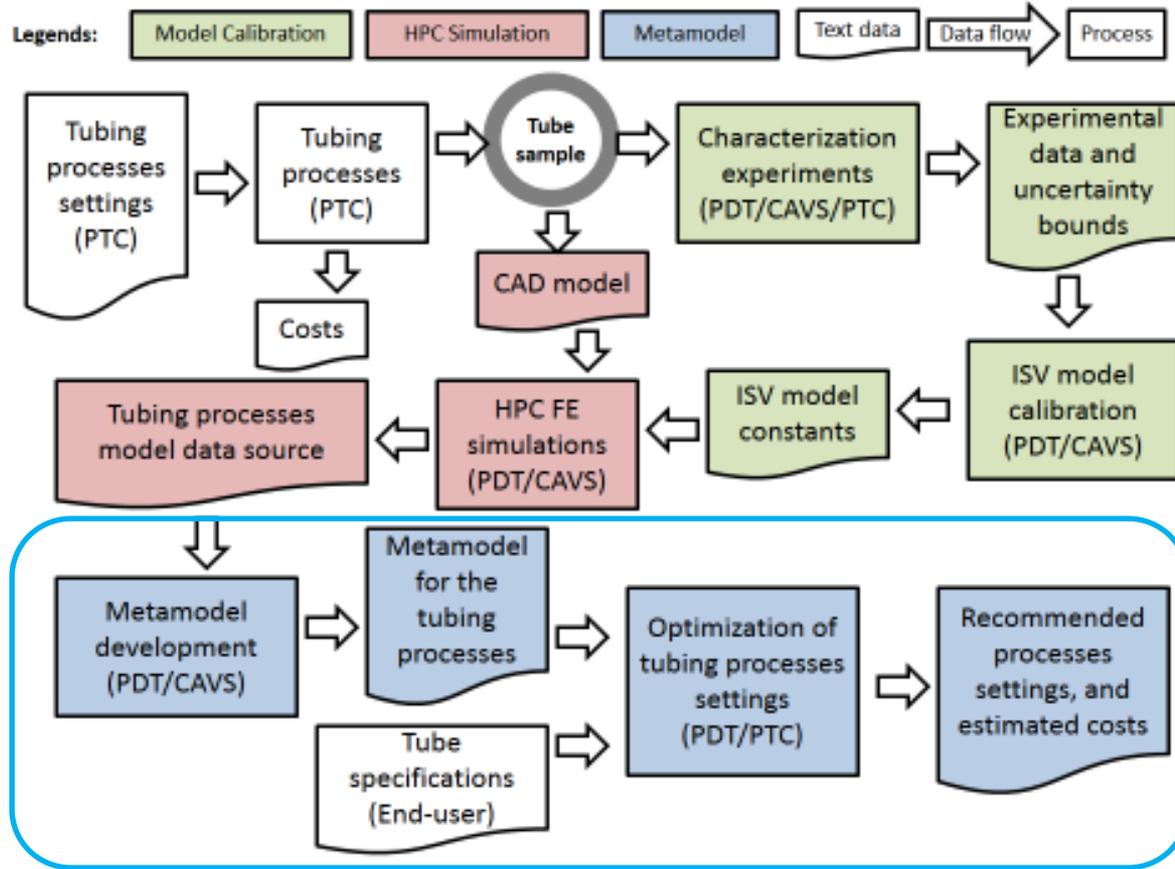
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CONTRIBUTORS

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Predictive Design Technologies, LLC

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PDT-PTC-MSU-CAVS DOE SBIR/STTR Collaboration

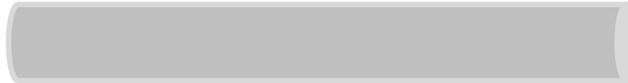# Tube manufacturing simulator (2-draw tubes)

Coil sheet

Tube for pickling & 1st anneal

Tube after 1st draw

Tube after 2nd draw

Tubes for cleaning & 2nd anneal

Finished tubes

❑ **Given client requirements**
  - ➤ L - Length, OD - Outer Diameter, T - Thickness
  - ➤ Yield stress (PSI), Ultimate stress (PSI), Elongation to Failure (in/in), Hardness (HRB)

❑ **Find**
  - ➤ Starting coil sheet
  - ➤ Intermediate L, OD, T
  - ➤ Process settings to achieve required properties

❑ **Constraint**
  - ➤ Tank & bench lengths, max. draw reductions

Tube Geometry and Cutting Problems
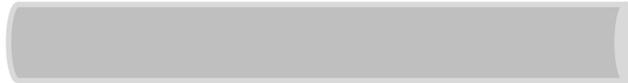
Coil sheet

Select appropriate coil for target tube OD, thickness

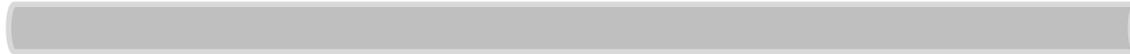**Tube for pickling & 1st anneal**

Adjust for 'forming scrap'
Adjust for 'point scrap'
Adjust for 'clamp scrap' at finishing
Maximize tube length to fit Pickling tank

Tube after 1st draw

Obey cross-section area reduction limit for 1st draw
Conserve mass

Tube after 2nd draw

Maximize tube length to fit drawing bench
Obey cross-section area reduction limit for 2nd draw

Tubes for cleaning & 2nd anneal

Cut 'point scrap'
Maximize longest segment to fit cleaning tank

Finished tubes

Cut segments into finished length
Cut 'clamp scrap'

Mixed-integer programming with nonlinear constraints!

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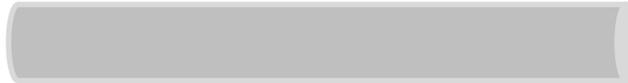# Structure-process-property model

Coil sheet

Tube for pickling & 1st anneal

Tube after 1st draw

Tube after 2nd draw

Tubes for cleaning & 2nd anneal

Finished tubes

MSU Internal State Variable (ISV) Material Model

predicts the following properties of the intermediate and finished tubes:

➢ **Yield stress**

➢ **Ultimate stress**

➢ **Elongation to failure**

➢ **Hardness**

Cost model

- ❑ Definitions
  - ➢ cost = $/ft cost of electricity, gas, etc,
  - ➢ $s_{1,0}$ = factory setting for parameter #1 (Ex. temperature)
  - ➢ $s_{2,0}$ = factory setting for parameter #2 (Ex. Soak time)
  - ➢ c_0 = baseline cost of process at $s_{1,0}$ and $s_{2,0}$
- ❑ Suppose the process runs at setting (x_1, x_2)
  - ➢ $\Delta s_1 = (x_1 - s_{1,0})/s_{1,0}$ *(relative change from factory setting $s_{1,0}$)*
  - ➢ $\Delta s_2 = (x_2 - s_{2,0})/s_{2,0}$ *(relative change from factory setting $s_{2,0}$)*

Cost model *(continued)*

❑ Cost estimate at setting (x_1, x_2)

  ➤ $Cost(x_1, x_2) = c_0 * (1 + c_1*\Delta s_1 + c_2*\Delta s_2 + c_3*\Delta s_1*\Delta s_2)$

  ➤ c_0 = baseline cost of process at $s_{1,0}$ and $s_{2,0}$

  ➤ $c_0 * c_1*\Delta s_1$ = from solitary change in parameter #1

  ➤ $c_0 * c_2*\Delta s_2$ = from solitary change in parameter #2

  ➤ $c_0 * c_3*\Delta s_1*\Delta s_2$ = from combined changes in parameter #1 and parameter #2

Tube manufacturing simulator: Scenarios

❑ **"What-if" changes in:**

- ✓ Material properties of sheet coil
- ✓ Process settings (Ex. Normalization temp. and soak time)
- ✓ Process costs

❑ How to make tubes with acceptable dimensions and material properties while minimizing costs *(cost minimization)*

❑ Investigate trade-offs: processing costs vs. material properties *(multiobjective optimization)*

Software setup

❑ Hardware requirement

➢ Laptop/desktop PC running Windows 7, 64-bit

❑ Installation

➢ Copy the following files to, say, C:\PTMS

✓ MCRInstaller.exe   - MATLAB shared libraries

✓ PTMS.exe   - PTMS executable

➢ Run MCRInstaller.exe (Administrator rights required)

❑ Run simulator

➢ Open Windows Explorer

➢ Navigate to C:\PTMS

➢ Double-click PTMS.exe

Tube manufacturing simulator: User Interface