Towards a Domain-Specific Framework for Predictive Analytics in Manufacturing

David Lechevalier
Anantha Narayanan
Sudarsan Rachuri
1. Motivation
   1. Why Big Data in Manufacturing?
   2. What is needed to apply Big Data in Manufacturing?

2. A Domain-Specific Framework for Predictive Analytics in Manufacturing
   1. Capabilities of the Domain-Specific Framework
   2. Modules of the Domain-Specific Framework
   3. Interactions of the Framework Modules

3. Research Challenges to Develop this Framework

4. Summary

5. Future work
1.1 Why? A Huge Return on Investment

Some sectors are positioned for greater gains from the use of big data

Historical productivity growth in the United States, 2000–08

- Computer and electronic products
- Information
- Wholesale trade
- Manufacturing
- Transportation and warehousing
- Professional services
- Real estate and rental
- Health care providers
- Government
- Accommodation and food
- Arts and entertainment
- Natural resources
- Management of companies
- Educational services
- Other services
- Construction

Big data value potential index

1. Represent the potential associated to a sector to take advantage of Big Data

Bubble sizes denote relative sizes of GDP
1.2 What is needed?

Data

Infrastructure

Solutions to connect Data and Infrastructure

Processes

Data scientists

Manufacturers

Resources

Computing Infrastructure

Analytical models

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2.1 Capabilities of the Domain-Specific Framework For Predictive Analytics

• Be intuitive and easy to use

• Represent physical components and their behaviors

• Generate analytical models

• Handle high volume, velocity and variety of data

• Make results understandable for manufacturers
2.2 Modules of the Framework

- A Domain-Specific Modeling Interface (DSMI)
- Domain-Specific Schema Repository
- Analytical Module
- Data Acquisition Module
- Data Visualization Module
2.3 Interactions between Framework Modules

**Domain-Specific Schema Repository**
- **Die Casting**
  - Input: $x_1, x_2, x_3, x_4$
  - Resource: energy

**Analytical Module**
- Energy function: $f(x_1, x_2, x_3, x_4)$

**Data Acquisition Module**
- XML code:
  ```xml
  <MTConnectStreams xmlns:urn="urn:mtconnect.org" xmlns:datatype="urn:mtconnect.datatype">
    <Header creationTime="2014-05-07T19:17:37Z">
      <DeviceStream name="turning_machine">
        <DeviceSyncStream deviceName="turning_machine">
          <ComponentStream component="Rotary">
            <Samples>
              <Value dataItemId="C_24" timestamp="2014-05-07T19:17:37Z" value="1.23"/>
              <Value dataItemId="C_25" timestamp="2014-05-07T19:17:37Z" value="2.45"/>
            </Samples>
          </ComponentStream>
        </DeviceSyncStream>
      </DeviceStream>
    </Header>
  </MTConnectStreams>
  ```

**Data Visualization Module**
- Graph showing data visualization with lines for $x_1, x_2, x_3, x_4$

**Model Translation**
3. Research Challenges in the Framework

- Domain-Specific Schema Repository
  - DieCasting: $-x_1$, $-x_2$, +energy()
  - Turning: $-x_3$, $-x_4$, +energy()

- Analytical Module
  - Energy = $f(x_1, x_2, x_3, x_4)$

- Data Acquisition Module
  - XML code:
    ```xml
    <MTConnectStreams xmlns:m="urn:mtconnect.org:stream">
      <Header creationTime="2014-05-07T19:17:14Z">
        <DeviceStream device="turning_machine">
          <ComponentStream component="Rotary">
            <Samples>
              <Sample dataItem="C_24" timestamp="2014-05-07T19:17:14Z" />
              <Sample dataItem="C_25" timestamp="2014-05-07T19:17:14Z" />
            </Samples>
          </ComponentStream>
        </DeviceStream>
      </Header>
    </MTConnectStreams>
    ```

- Data Visualization Module
  - Graphs showing $x_1$, $x_2$, $x_3$, $x_4$, and predicted energy.
3. Research Challenges for the Domain-Specific Modeling Interface (DSMI)

- Multilevel modeling
  - Factory level, machine level, process level…

- Multiple viewpoint based on user interest
  - Highlight flows (material, throughput, energy…) 
  - Highlight specific machine
  - Highlight specific process
3. Research Challenges in the Framework

Domain-Specific Schema Repository

Analytical Module

Energy = f(x1, x2, x3, x4)

Model Libraries

Model Translation

Data Acquisition Module

Data Visualization Module

Data management

reuse of

instance of

instance of
3. Research Challenges for the Domain-Specific Schema Repository

• Representation of:
  1. Manufacturing components and their behavior
     • To allow manufacturers to represent their systems
  2. Analytical concepts
     • Optimization
     • Analytics: Bayesian Network, Neural Network…
  3. System states and diagnostic concepts
     • To define a specific problem that needs to be studied
3. Schema examples

Manufacturing components

Analytical concepts

System states

Combination

Schema to represent a factory

Schema to represent machine states

Schema to combine manufacturing component, analytical concepts and system states

Schema to represent a factory
3. Research Challenges in the Framework

- Domain-Specific Schema Repository
  - Data Management
  - Model Libraries
  - Domain-Specific Modeling Interface
  - Model Translation

- Data Acquisition Module
  - Data Visualization Module
  - Data Visualization

\[ \text{Energy} = f(x_1, x_2, x_3, x_4) \]
3. Research Challenges for the Analytical Module

• Model Translation:
  – Automatically generate analytical models that:
    • represent manufacturing system and its behavior
    • are appropriate for the user’s objective
    • are standard-based to facilitate interoperability
4. Summary

Domain-Specific Schema Repository

Manufacturers
- Includes knowledge from
- Uses concepts from
- Model their systems
- Send results and take actions

Data scientists
- Includes knowledge from

Domain-Specific Modeling Interface

Data Visualization Module
- x1
- x2
- x3
- x4
- Energy vs. x1, x2, x3, x4

Energy = f(x1, x2, x3, x4)

Analytical Module

Data Acquisition Module

Manufacturers
- Get analytical models from

Data scientists
- Get data from
- Visualize results and take actions

Uses concepts from

Energy = f(x1, x2, x3, x4)
5. Future work

• Continue working on the schemas to cover additional concepts in manufacturing and analytics

• Define model translation to map between descriptive and analytical models

• Work towards standardized representation of analytical models for manufacturing

• Implement a case study to illustrate the potential of the framework
Questions / Discussion
3. Research Challenges in the Framework

- **Domain-Specific Schema Repository**
- **Data Acquisition Module**
  - `<MTConnectStreams xmlns:m="urn:mtconnect:">
    <Header creationTime="2014-05-07T19:17:45">`
  - `<DeviceStream name="turning_machine">`
    - `<ComponentStream component="TurningMachine">`
    - `<Samples>`
      - `<x3 dataItemId="C_24" timestamp="2014-05-07T19:17:45"/>
      - `<x4 dataItemId="C_25" timestamp="2014-05-07T19:17:45"/>
- **Data Visualization Module**
  - Graph showing energy vs. time for different parameters
  - Chart showing energy and predicted energy over time

**Analytical Module**
- `Energy = f(x1, x2, x3, x4)`

**Model Translation**
- Model Libraries

**Modeling Interface**
- Domain-Specific Modeling Interface
- Instance of DieCastingMachine and TurningFacingMachine

**Model Libraries**
- Model reuse
3. Research Challenges for the Data Acquisition and Data Visualization Modules

- Handle structured and unstructured data

- Handle data flows with:
  - Real-time data
  - Big volume of data

- Handle data with standard-based formats