engineering laboratory

Applying visual variables to manufacturing data for enhanced decision-making

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Outline

- Visual variables & information visualization (InfoVis)
- Three visualization-related projects
  - Mapping MTConnect data to solid models
  - Exploring functional relationships of KPIs
  - Representing similarities for manufacturing processes
- Moving forward
  - Data Information Visualization & Exploration (DIVE) Lab

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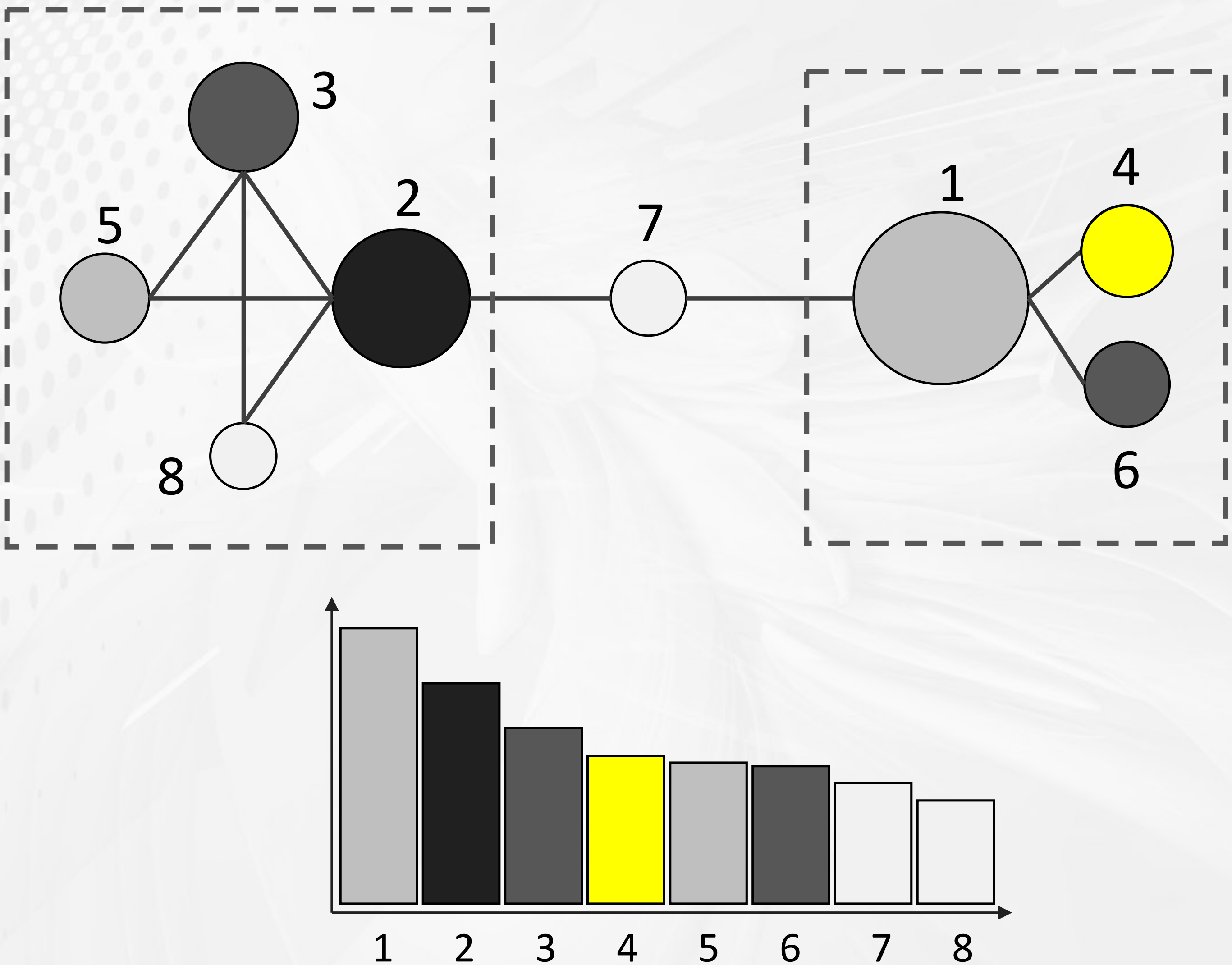
Example



Bernstein WZ, Ramanujan D, Kulkarni D, Tew J, Elmqvist N, Zhao F, Ramani K, Mutually coordinated visualization of product and supply chain metadata for sustainable design, *Journal of Mechanical Design*. 137(12). 2015

Selecting the right visual variable

Visual Variables		Characteristics				
		Selective	*Associative*	*Quantitative*	*Order*	*Length*
	Position					Theoretically Infinite
	Size					Selection: ~5 Distinction: ~20
	Shape					Theoretically Infinite
	Value					Selection: <7 Distinction: ~10
	Color					Selection: <7 Distinction: ~10
	Orientation					Theoretically Infinite
	Texture					Theoretically Infinite

Adapted from Prof. Sheelagh Carpendale, Dept. of CS, University of Calgary

Bernstein WZ, Ramanujan D, Kulkarni D, Tew J, Elmqvist N, Zhao F, Ramani K, Mutually coordinated visualization of product and supply chain metadata for sustainable design, *Journal of Mechanical Design*. 137(12). 2015

Distilling design patterns

Goal: Suggest design patterns for InfoVis-based tools used in manufacturing

Task-by-type taxonomy	Example of design patterns for sustainable product design
T1: Overview	P1: Indicator-overviews P2: Eco-prominence P3: Eco-persistence
T2: Zoom	P4: Intent-based aggregation P5: Multiscale design exploration
T3: Filter	P6: Emphasis on design similarities P7: Collaborative pruning
T4: Details-on-demand	P8: Interactive detailing of hidden dimensions
T5: Relate	P9: Co-ordination of lifecycle views P10: Linking eco-indicators through the lifecycle
T6: History	P11: Eco-location P12: Shareable exploration trails
T7: Extract	P13: Exploration snippets

Ramanujan, D., Bernstein, W. Z., Ramani, K., 2017. "Design patterns for visualization-based tools in sustainable product design." *Proceedings of the ASME 2017 IDETC/CIE*. To appear.

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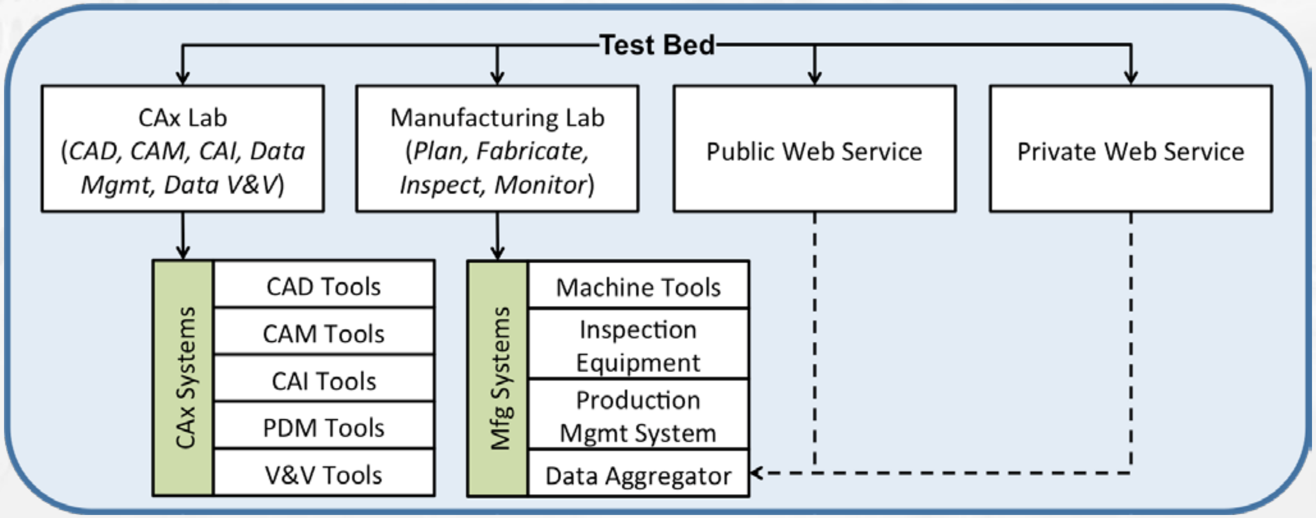
NIST Smart Mfg. Systems Test Bed

<u>Goals</u>:

- Reference architecture and implementation
- Rich source of data for fundamental research
- Physical infrastructure for standards and technology development
- Demonstration test cases for education

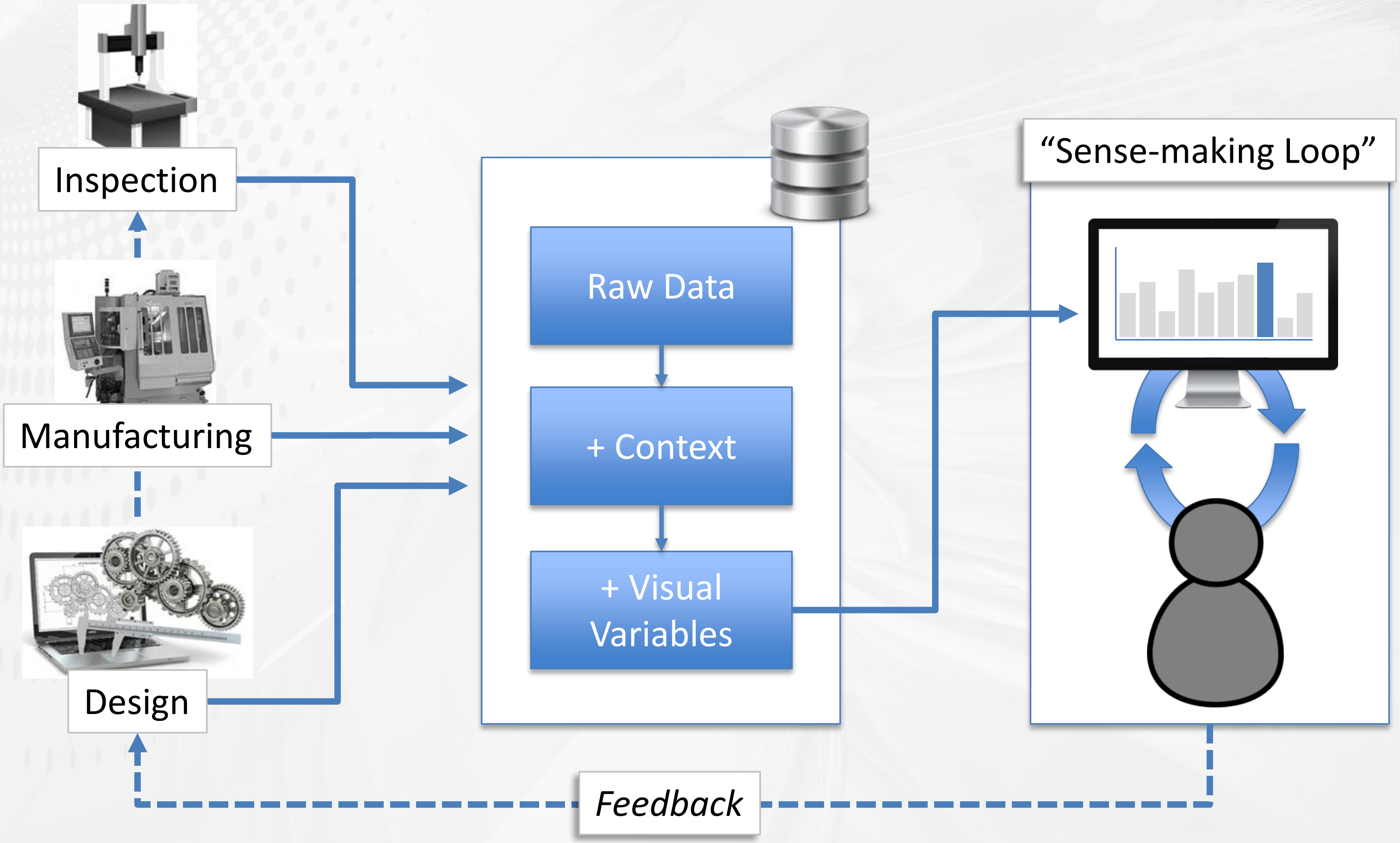


http://smstestbed.nist.gov

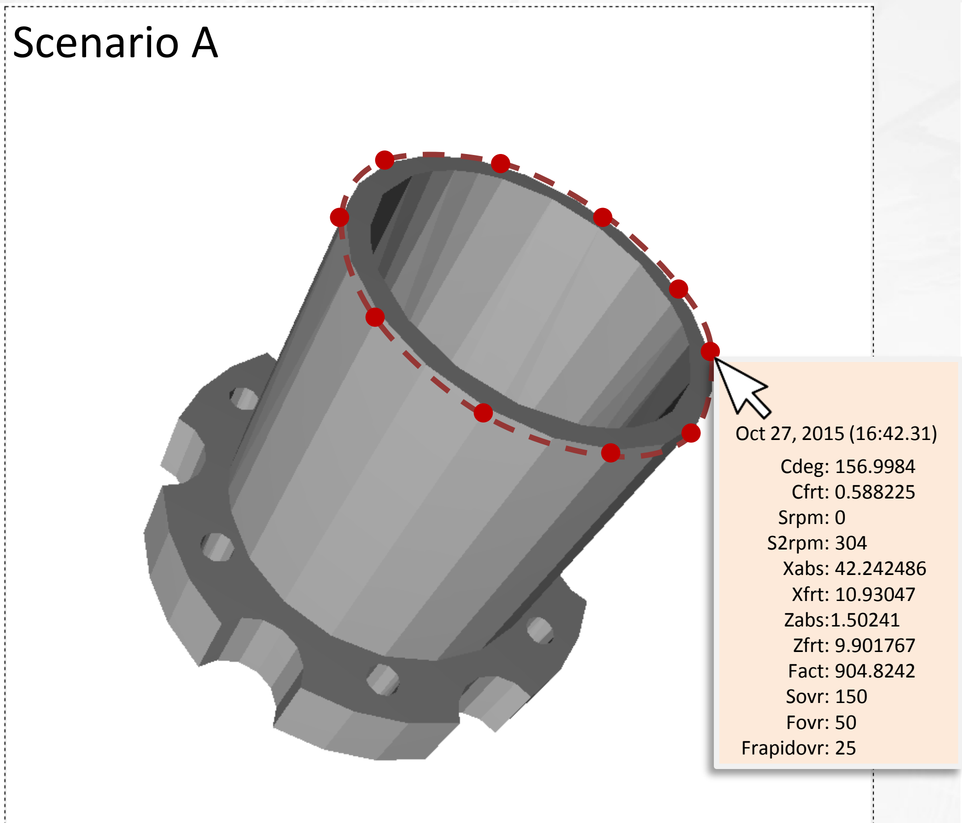
Available data

- Design model data in native and STEP standard format (***as designed***)
- Milling program as NC code in ISO 6983 standard format
(***as planned***)
- Manufacturing execution data in MTConnect standard format (***as executed***)
- Inspection data in QIF standard format (***as inspected***)

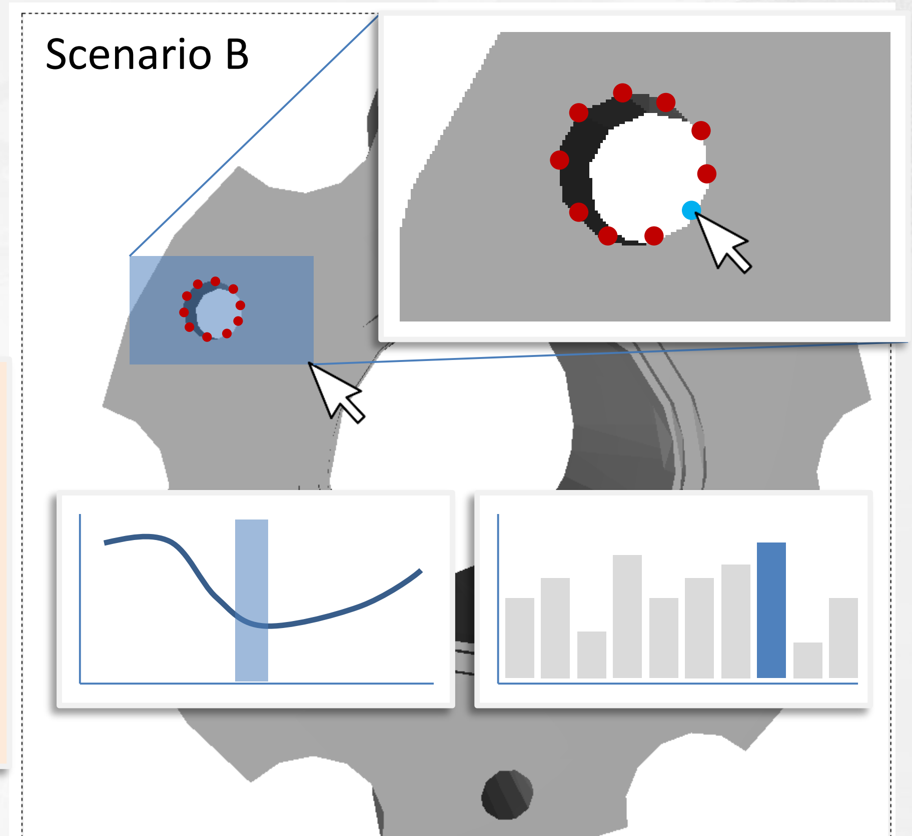
Visualization pipeline for smart manufacturing



Mapping machine data w/ virtual models



Time Snapshot Visualization



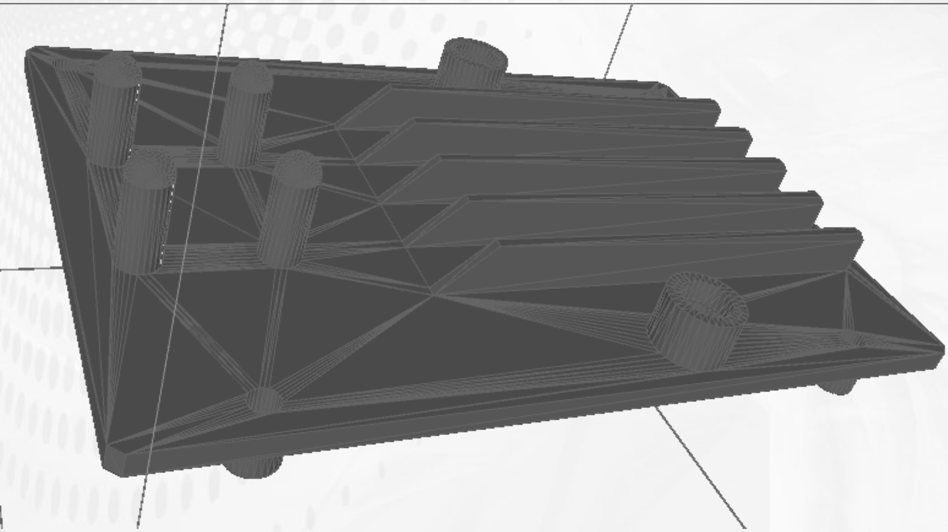
Feature-level Data Retrieval

Virtual Model → *overlay* → Actual Data

Actual Data → *validate* → Virtual Model

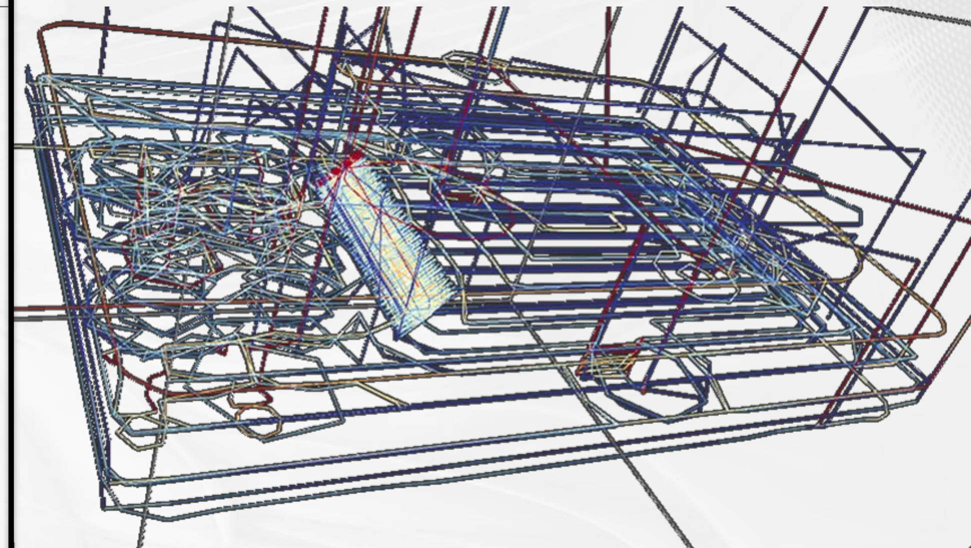
Standard representations of design and manufacturing data

Design Data



```
... ...
#131=DIRECTION(' ',(1.,0.,0.));
#136=AXIS2_PLACEMENT_3D(' ',#126,#121,#131);
#141=PLANE('',#136);
#146=CARTESIAN_POINT(' ',(-8.361367154208E-16...
#151=DIRECTION(' ',(1.087705058168E-16,1.,0.));
#156=VECTOR(' ',#151,1.);
#161=LINE('',#146,#156);
#166=CARTESIAN_POINT(' ',(-8.361367154208E-16...
#167=VERTEX_POINT(' ',#166);
... ...
```

Manufacturing Data



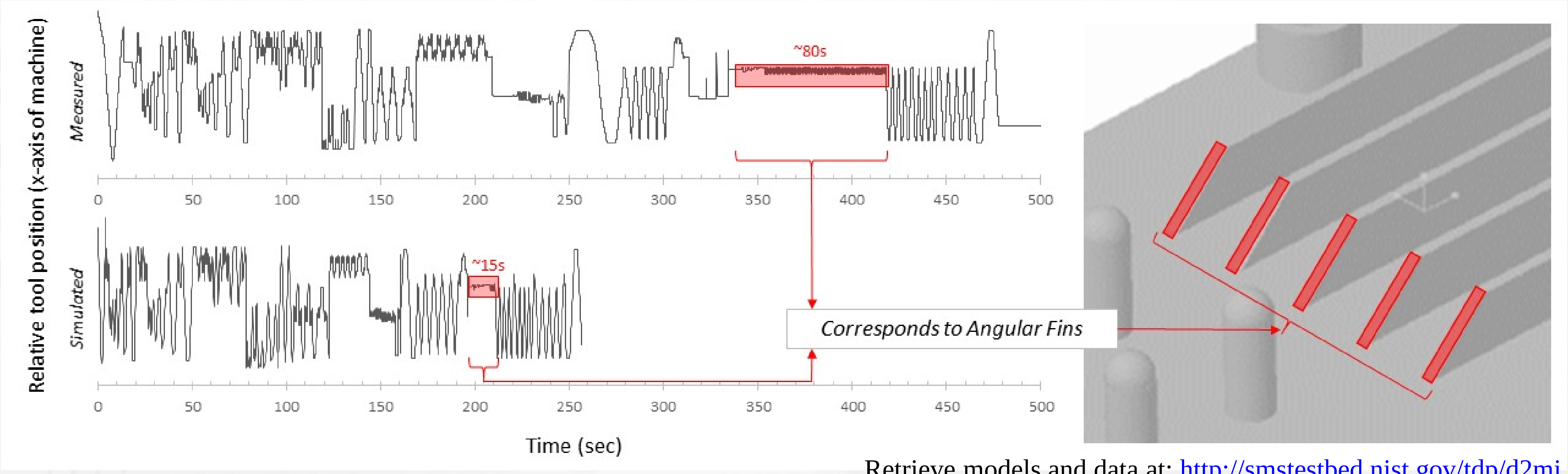
```
... ...
2016-05-09T11:46:51.456188Z|path_pos|15.0998...
2016-05-09T11:46:51.608005Z|path_pos|15.0998...
2016-05-09T11:46:51.752206Z|path_pos|15.0998...
2016-05-09T11:46:52.040056Z|path_pos|15.0998...
2016-05-09T11:46:52.040278Z|Cposition|359.9848
2016-05-09T11:46:52.184104Z|Cposition|359.9847
2016-05-09T11:46:52.616003Z|path_pos|15.0998...
2016-05-09T11:46:52.616184Z|Yposition|-37.80295
2016-05-09T11:46:52.760205Z|path_pos|15.0998...
... ...
```

Video: Initial prototype

Bernstein WZ, Hedberg Jr, TD, Helu, M, Barnard Feeney, A. Contextualizing Manufacturing Data for Lifecycle Decision Making. *International Journal of Product Lifecycle Management.* Under review..

Knowledge generated from case study

- Expected cycle time for one feature was 15 seconds, but measured results show actual time was 80 seconds
- Feed rate mismatch affects production schedule



Retrieve models and data at: http://smstestbed.nist.gov/tdp/d2mi

Feng, S, Bernstein WZ, Hedberg Jr, T, Barnard Feeney, A, Towards Knowledge Management for Smart Manufacturing. *Journal of Computing and Information Science in Engineering.* Under review.

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Background – ISO 22400

KPI description	
Content	
Name	Overall equipment effectiveness index
ID	
Description	The OEE index represents the availability of a work unit (see Table 9), the effectiveness of the work unit (see Table 10), and the quality ratio (see Table 11) KPIs integrated in a single indicator.
Scope	Work unit, product, time period, product, defect types
Formula	OEE index = Availability * Effectiveness * Quality ratio
Unit of measure	%
Range	Min: 0% Max: 100%
Trend	The higher, the better
Context	
Timing	On-demand, periodically, real-time
Audience	Operator. supervisor, management
Production methodology	Discrete, batch, continuous
Effect model diagram	See Figure A.6
Notes	Overall equipment effectiveness (OEE) is an indicator for the efficiency of work units, work centres and areas with several work units or an entire work centre. The OEE index forms the basis for improvements by better production information, identification of production losses, and improvement of the product quality by optimized processes. The calculation of OEE based on the hierarchy structure (see Figure 2) is only useful if the characteristic of the work unit processes would be comparable. Before starting a benchmark based on the OEE index the criteria for comparability should be checked.

ISO 22400: Automation systems and integration – Key Performance Indicators (KPIs) for manufacturing management

Background

$$\text{Overall Equipment Effectiveness} = \boxed{\text{Availability}} \cdot \boxed{\text{Effectiveness}} \cdot \boxed{\text{Quality Ratio}}$$

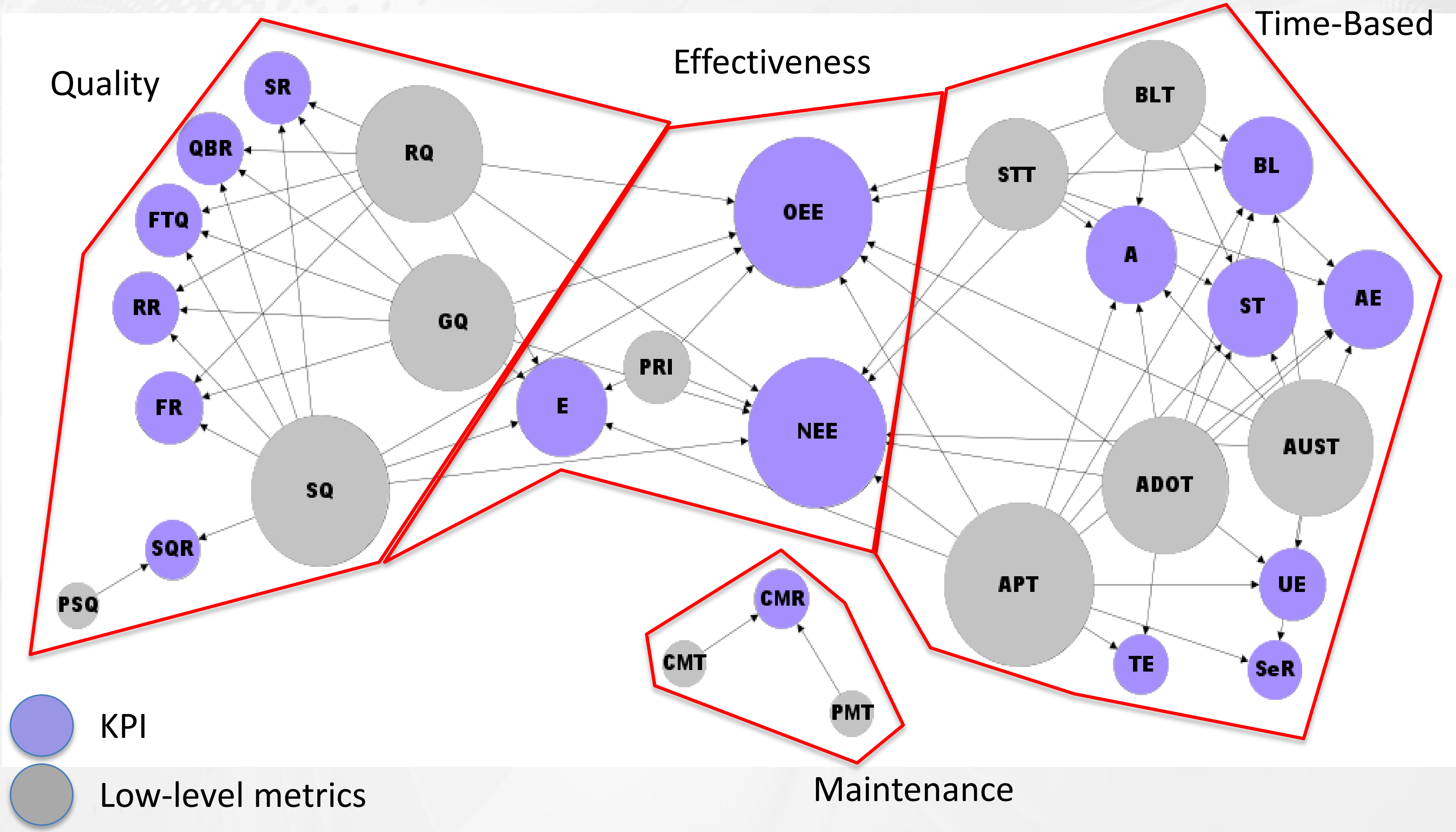
$$\text{Availability} = \frac{\text{Actual Production Time}}{\text{Planned Busy Time}}$$

$$\text{Effectiveness} = \frac{\text{Planned Run time per Item} \cdot \text{Produced Quantity}}{\text{Actual Production Time}}$$

$$\text{Quality Ratio} = \frac{\text{Good Quantity} + \text{Rework Quantity}}{\text{Produced Quantity}}$$

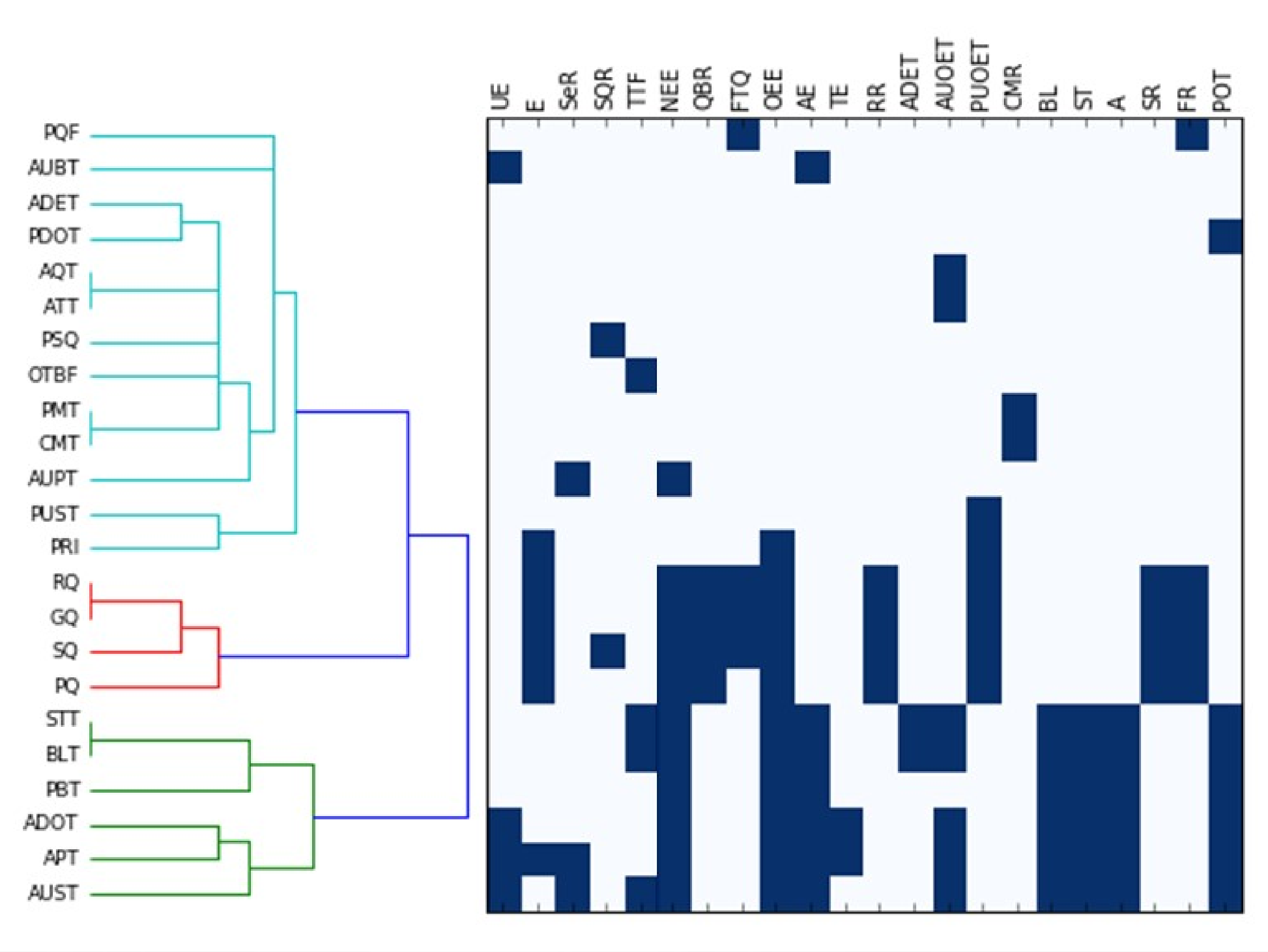
Kang, N., Zhao, C., Li, J., Horst, J.A., A Hierarchical structure of key performance indicators for operation management and continuous improvement in production systems, International Journal of Production Research, 6333-6350, 2015

Node-Link Diagrams



Brundage, MP, Bernstein, WZ, Morris, KC, Horst, JA. Graph-based Visualizations to Explore KPI Relationships. *Proceedings of the CIRP LCE 2017*. To appear.

Matrix-based visualization



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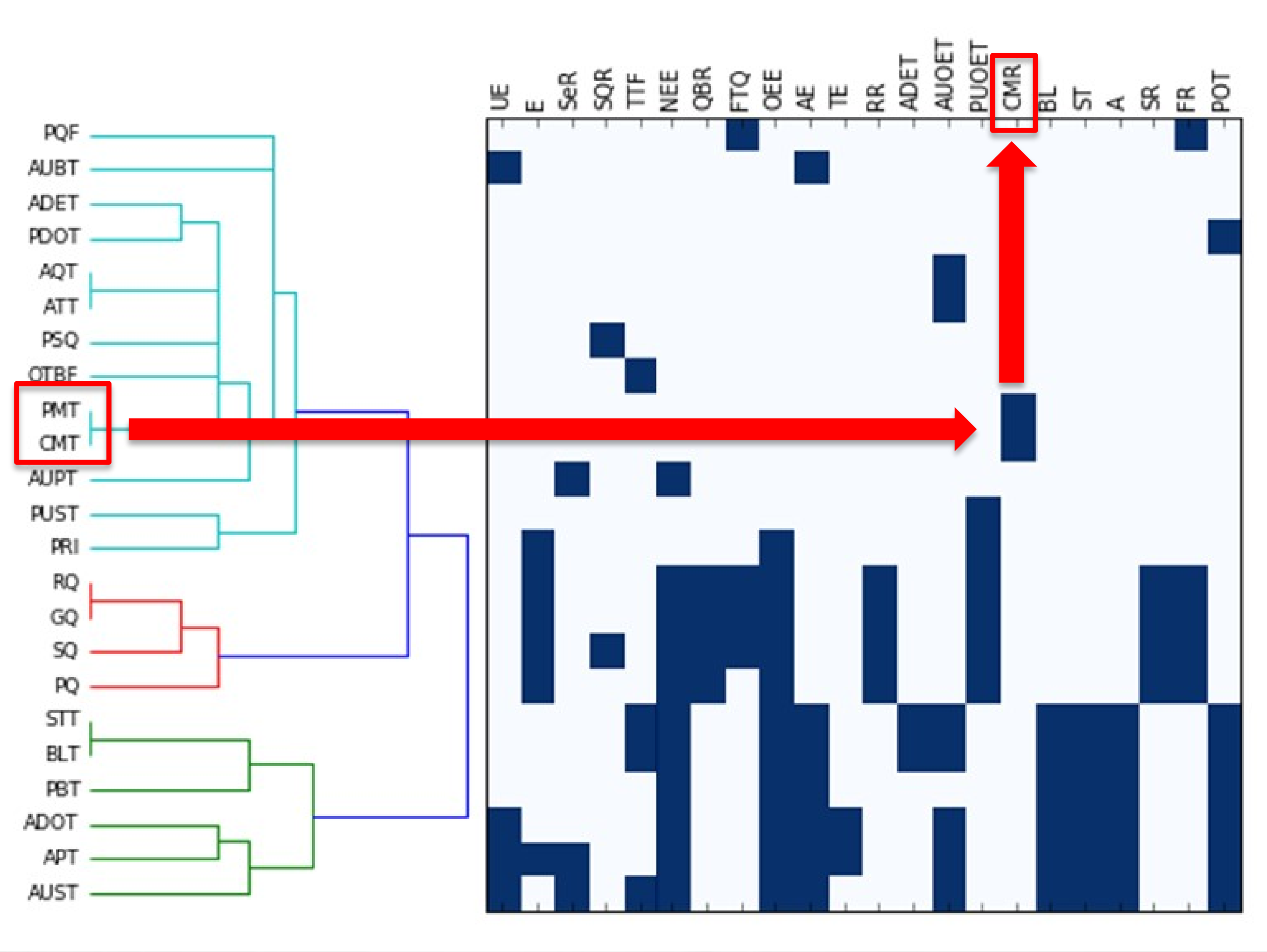

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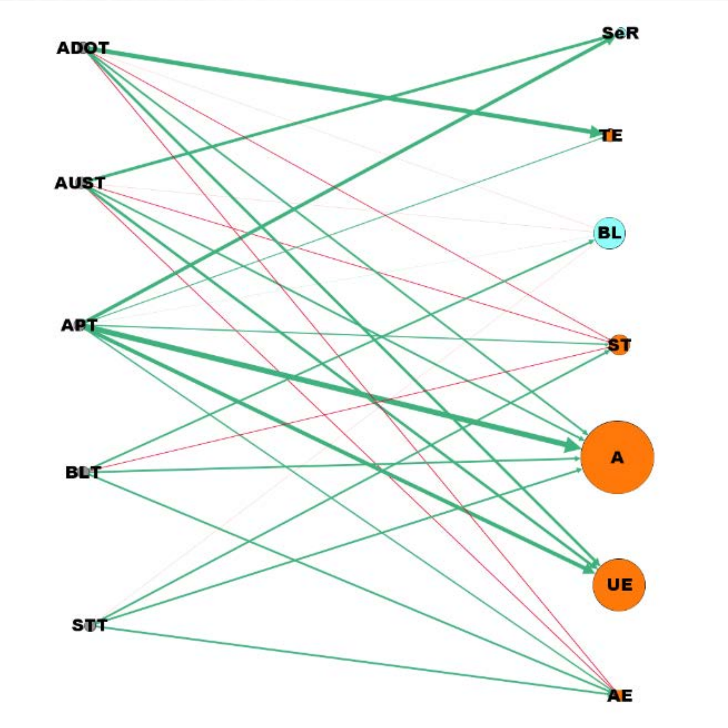
Exploring “what-if” scenarios

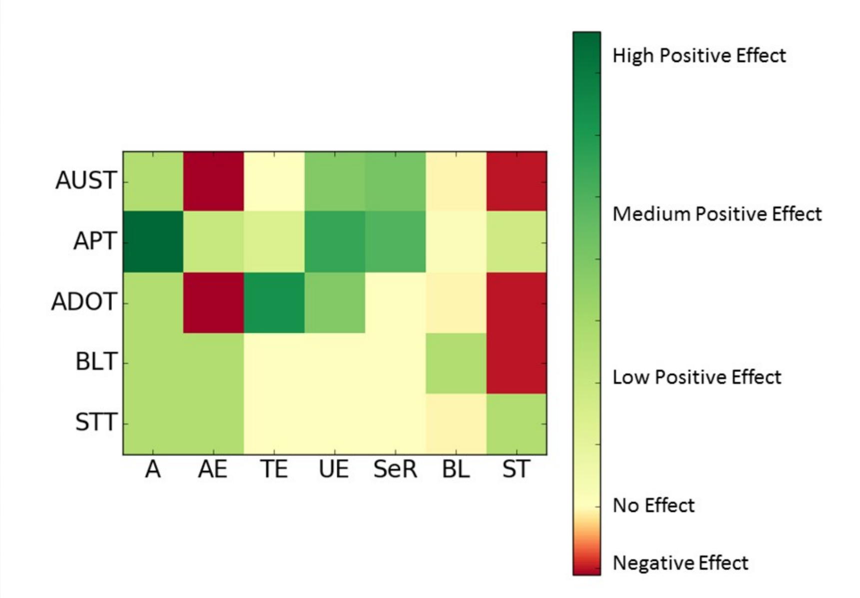
Node Link



Line Thickness show change

Quickly shows KPI performance

Matrix Based

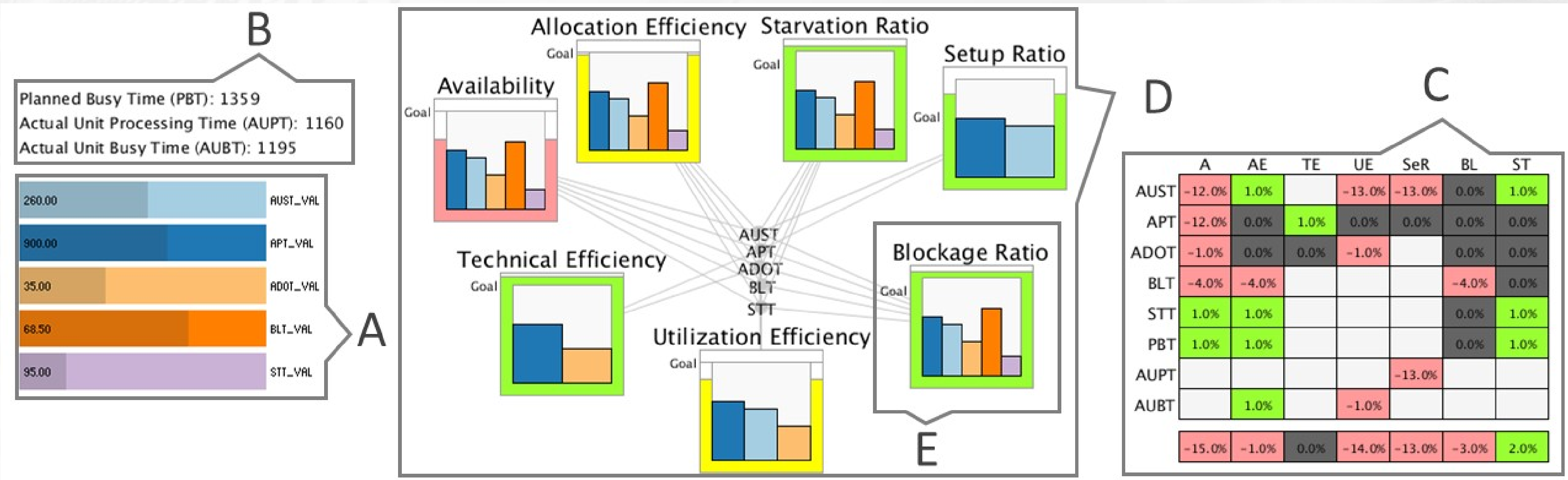


Color map shows change

Only shows change in KPIs with changing metrics

Brundage, MP, Bernstein, WZ, Morris, KC, Horst, JA. Graph-based Visualizations to Explore KPI Relationships. *Proceedings of the CIRP LCE 2017*. To appear.

Prototype interface



(A) Control sliders

(D) Node-link diagram

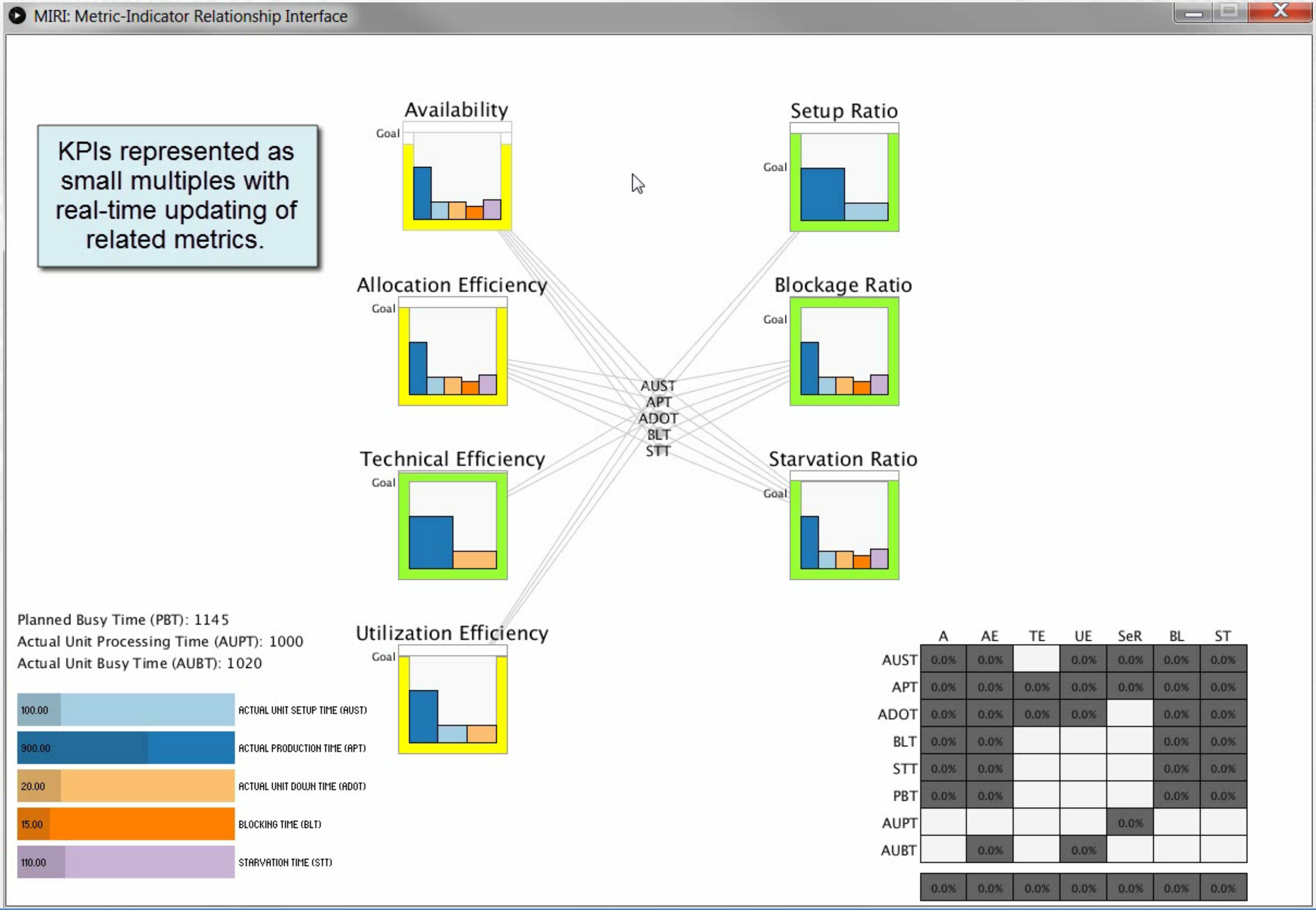
(C) Sensitivity matrix

(B) Dependent metric readout

(E) Small multiples, i.e. nodes

Brundage, MP, Bernstein, WZ, Morris, KC, Horst, JA. Graph-based Visualizations to Explore KPI Relationships. *Proceedings of the CIRP LCE 2017*. To appear.

Video: Initial prototype



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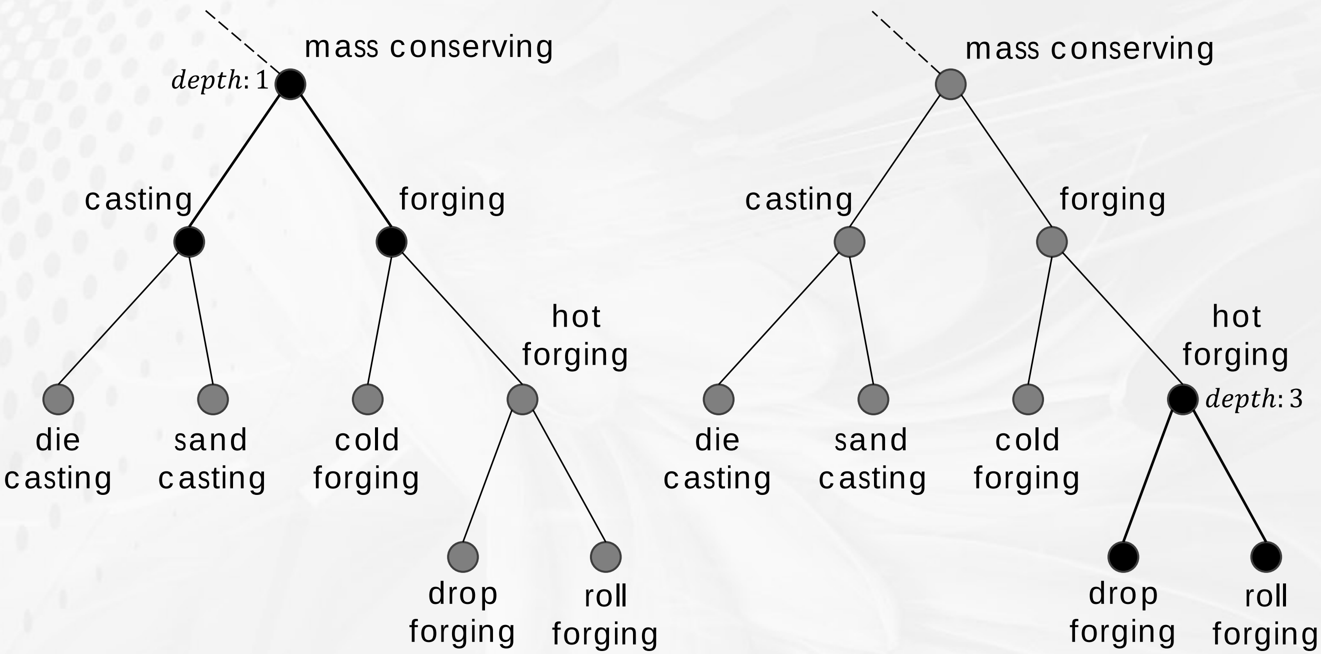
Guiding questions

- How can we visualize the similarities of capabilities of manufacturing processes?
- How can we use these principles for better lookup in a large database?

Li, K and Bernstein, WZ, "Developing a capability-based similarity metric for manufacturing processes," Accepted to ASME MSEC 2017. Best paper finalist.

Similarity based on taxonomic representation



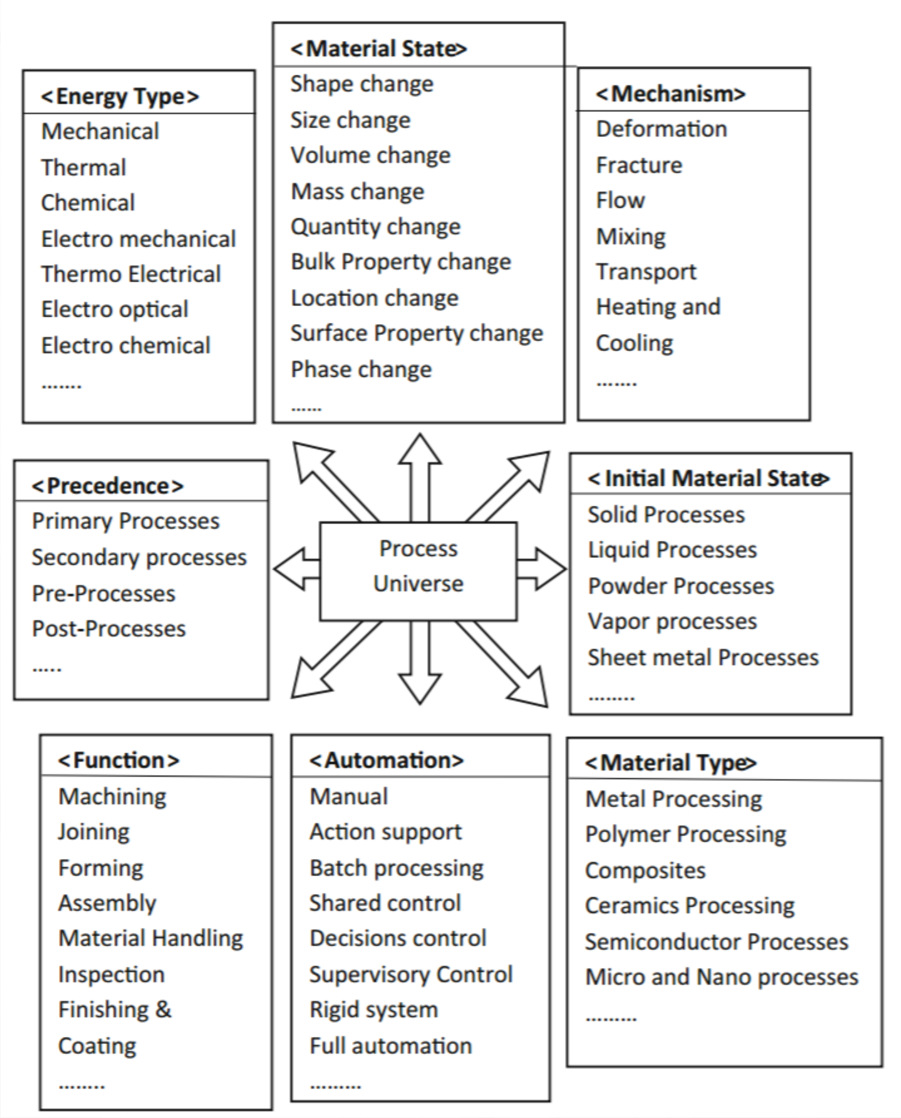
$$D(casting, forging) = \frac{2}{2 + (1 * 1)}$$

$$D(drop\ forging, roll\ forging) = \frac{2}{2 + (1 * 3)}$$

$$D(a_1, a_2) = \frac{pathlength(a_1, a_2)}{pathlength(a_1, a_2) + (k * depthLCA(a_1, a_2))}$$

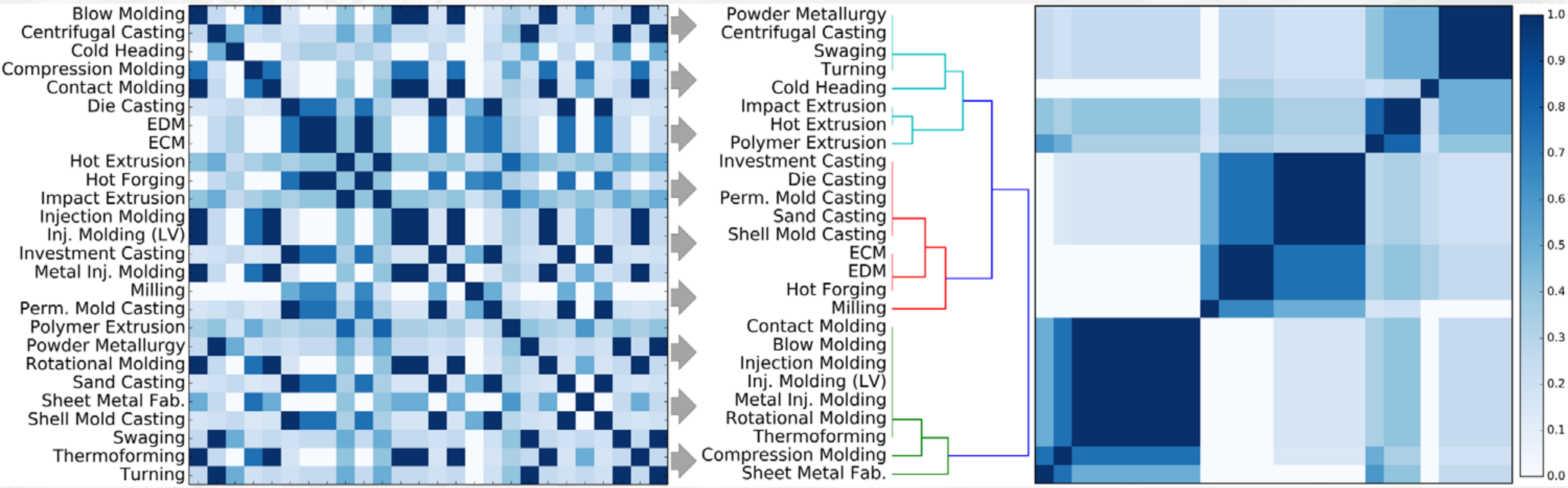
Ramanujan D, Bernstein WZ, Benjamin W, Elmqvist N, Ramani K, Kulkarni D, Tew J, Enabling sustainability-aware design reuse through metadata visualization, *Journal of Mechanical Design*. 2015 (In Review)

Classification of Manufacturing Processes



Kumaraguru, S., et al., 2014. Faceted classification of manufacturing processes for sustainability performance evaluation. *The International Journal of Advanced Manufacturing Technology*, *75*(9-12), pp.1309-1320.

Visualizing similarities of manufacturing processes



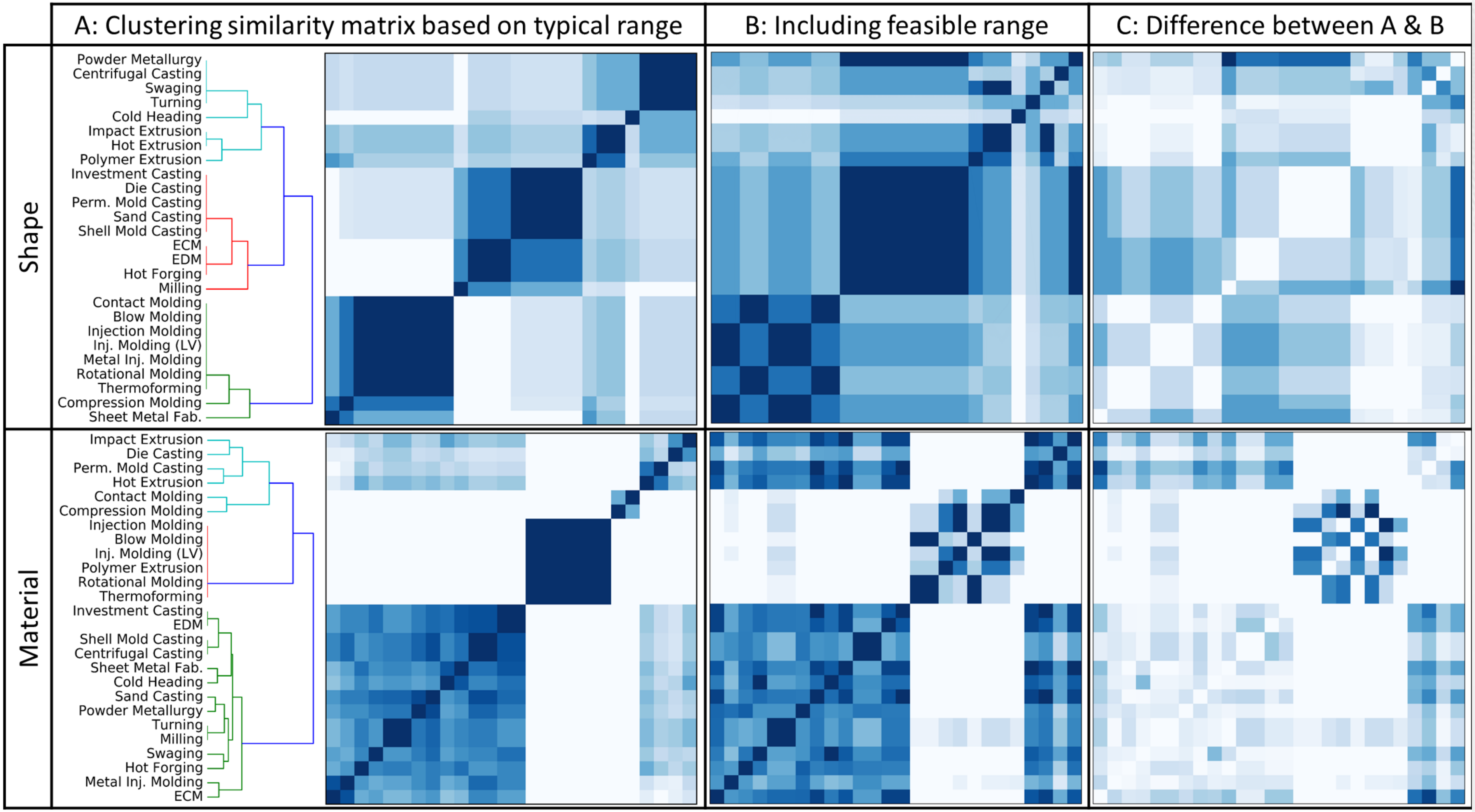
Example:

Blow Molding → {“Thin-walled: Cylindrical”; “Thin-walled: Cubic”; “Thin-walled: Complex”}

Die Casting → {“Thin-walled: Complex”; “Solid: Cylindrical”; “Solid: Cubic”; “Solid: Complex”}

Li, K and Bernstein, WZ, “Developing a capability-based similarity metric for manufacturing processes,” Accepted to ASME MSEC 2017. Best paper finalist.

Visualizing similarities of manufacturing processes



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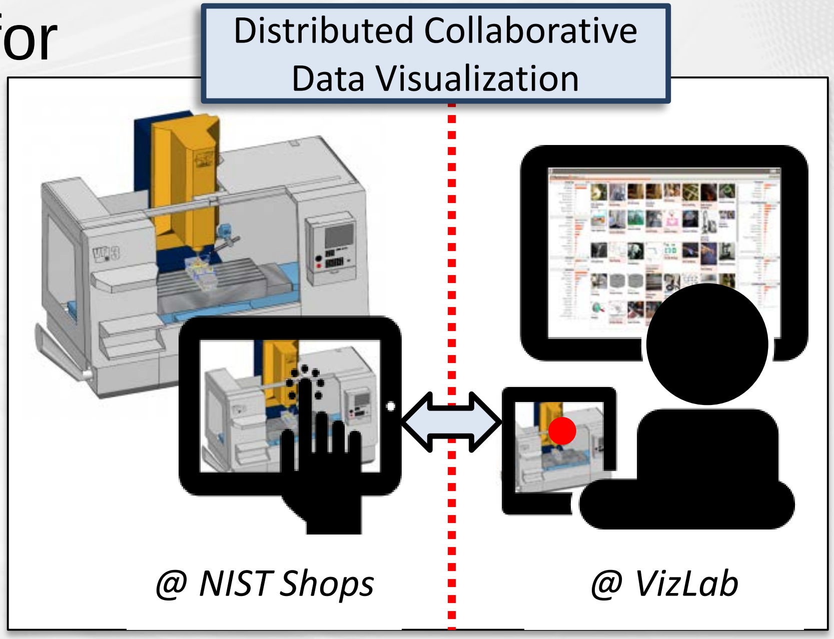
Data Information Visualization & Exploration Lab

- Demonstrate practical use cases for data exploration
- Identify and demonstrate "design patterns" for mfg-based visualizations
- Quicken the design, prototyping and implementation of new interfaces



Hardware & software considerations

Hardware options:

- MSFT Surface Hub
- CINTIQ Pen & Touch
- Intuous Pen & Touch
- MSFT Kinect
- Tablets, etc.
- VR

*Interact with NIST Library

Software options:

- Open: Cytoscape, JigSaw, NodeXL, Processing 3, Gephi, Keshif.js
- Commercial: Power BI, Tableau, IBM Watson

Middleware options:

- Open: libavg, Polychrome, Webstrates, Sage II

Thank you!

Questions?

Comments?

Suggestions?

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