CIFE Research Questions and Methods

How CIFE Does Academic Research for Industrial Sponsors

John Kunz, Martin Fischer, CIFE
Construction Management Today

• Large unique projects
• Lots of
  – stakeholders
  – different types of info
  – Need to relate data
  – Paper
  – Time for coordination
• Time and cost pressures

➢ Needs: implemented, tested theory w/
  • Power
  • Generality
**CIFE research agenda**

- **Broad motivating engineering problems:**
  - Engineering practice
    - Has many problems for which a solution is knowable, but the person with the knowledge is not a timely participant
    - Has many aspects of a (repeated, one-off) craft

- **Research questions**
  - What fundamental principles characterize civil engineering design and management?
  - How can we operationalize new ones in the computer
  - How good are they?
CIFE research agenda

In 2010, CIFE members
• Operate with a strategic plan to implement VDC broadly and will manage by public and explicit model-based process metrics in latency, safety, quality, schedule, cost and sustainability;
• Use Integration of VDC confidently and serve >= 5 business purposes on >=10 major projects/year, e.g., architecture, safety, schedule, space use, energy;
• Pilot Automation stage of VDC and automate >30% of routine design and construction activity (wrt 2006 baseline) on > 2 pilot projects/year; and
• Staff each project with four VDC trained engineers
CIFE research agenda

- **Research methods**
  - Careful observation of practice
  - Computational models of products and processes
    - Symbolic (non-numeric)
    - Graphical (4D, Gantt, tables, many specialized views)
  - Carefully designed validation studies to show evidence of power and generality
    - Demo that does not break not a mouse
    - Every good engineer solves hard problems; solving a hard problem is not a mouse
    - “One mouse is no mice”
CIFE “Horseshoe” Research Method

- Observed Problem
- Intuition
- Theoretical POD
- Research Questions
- Research Method
- Validation Results
- Claimed Contributions
- Predicted Impact
- Impact
- Intellectual Merit
- Evidence?
- Power
- Generality
- Testable?

Legend:
- Leads to
- Compare

Einstein:
The only real valuable thing is intuition.

1/23/2007 Research Methods
Example of Horseshoe in Use

Ryan Orr

<table>
<thead>
<tr>
<th>Observed Problem</th>
<th>Theoretical POD/ Gap</th>
<th>RQs</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>It takes firms many years to evolve a good strategy. What are they learning?</td>
<td>- Lack an integrated theoretical framework for why firms adopt different entry &amp; staffing strategies.</td>
<td>(1) What strategies do firms use?</td>
<td>(1) Case studies w. 3 firms: Kone, Fluor, Hines</td>
</tr>
<tr>
<td></td>
<td>- Literature tells us strategy selection is discretionary.</td>
<td>(2) How do they select these strategies?</td>
<td>(2) Asia data</td>
</tr>
<tr>
<td></td>
<td>- Classic mgmt theory has been overlooked.</td>
<td></td>
<td>(Melin quote about deep understanding)</td>
</tr>
<tr>
<td>Recommends a concrete OD strategy &amp; show that not all strategies are appropriate for all firms.</td>
<td>'Identifies framework to describe environment&gt;</td>
<td>&lt;- Actors, scripts, set, props&gt;</td>
<td>(1) GT</td>
</tr>
<tr>
<td></td>
<td>-(1) Recognize set of strategies that firms adopt</td>
<td>- (1) Strategies: incr. KS, decr. KD, incr. except handling, knowl. integration</td>
<td>(2) Inference</td>
</tr>
<tr>
<td></td>
<td>- (2) Implies a KBV contingency approach to strategy</td>
<td>- (2) Strategy = F(EMB, KD)</td>
<td>&lt;copy the paper b/w US &amp; Canada&gt;</td>
</tr>
<tr>
<td>Predicted Impact</td>
<td>Contribution</td>
<td>Findings</td>
<td>Data Analysis/Presentation</td>
</tr>
</tbody>
</table>
Agenda

- Observations and Intuitions
- What: Research Questions
- How:
  - Research Methods
- Conclusions

- Examples
- Properties
Example-1: Observation  
Sheryl Staub-French

### Hard to (re)estimate costs

△ Wall Height: 8’ → 10.5’
△ Wall Rating: Unrated → Fire-Rated

<table>
<thead>
<tr>
<th>Description</th>
<th>QTY</th>
<th>uom</th>
<th>Prod. Rate</th>
<th>Res. Costs</th>
<th>Total Cost</th>
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<td>Metal Stud Wall, Type A (using Crew C-1)</td>
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<tr>
<td>Install Metal Stud</td>
<td>1550</td>
<td>LF</td>
<td>6.9 lf/hr</td>
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<td>3840</td>
<td>SF</td>
<td>65 sf/hr</td>
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<tr>
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<td>SF</td>
<td>45 sf/hr</td>
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<td>$7,211</td>
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<tr>
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<td>1920</td>
<td>SF</td>
<td>100 sf/hr</td>
<td>$1,440</td>
<td>$2,304</td>
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<td>Framing for Openings</td>
<td>6</td>
<td>EA</td>
<td>75 sf/hr</td>
<td>$450</td>
<td>$476</td>
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<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Cost</td>
<td></td>
<td></td>
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<tr>
<th>Description</th>
<th>QTY</th>
<th>uom</th>
<th>Prod. Rate</th>
<th>Res. Rate</th>
<th>Res. Costs</th>
<th>Total Cost</th>
</tr>
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<tbody>
<tr>
<td>Metal Stud Wall (Crew C-1 &amp; Rolling Scaffolding)</td>
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<tr>
<td>Install Metal Stud</td>
<td>1895</td>
<td>LF</td>
<td>4.3 lf/hr</td>
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<td>$6,474</td>
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<tr>
<td>Hang Drywall</td>
<td>5040</td>
<td>SF</td>
<td>65 sf/hr</td>
<td>$6,978</td>
<td>$8,037</td>
<td></td>
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<tr>
<td>Apply Tape</td>
<td>5040</td>
<td>SF</td>
<td>45 sf/hr</td>
<td>$8,960</td>
<td>$9,464</td>
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<tr>
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<td>2520</td>
<td>SF</td>
<td>100 sf/hr</td>
<td>$1,890</td>
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<tr>
<td>Framing for Openings</td>
<td>12</td>
<td>EA</td>
<td>1 hr/ea</td>
<td>$540</td>
<td>$552</td>
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<td>Apply Fire Caulking</td>
<td>48</td>
<td>LF</td>
<td>40 lf/hr</td>
<td>$54</td>
<td>$222</td>
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<tr>
<td>Cut Drywall</td>
<td>240</td>
<td>LF</td>
<td>60 lf/hr</td>
<td>$180</td>
<td>$180</td>
<td></td>
</tr>
</tbody>
</table>

Prod. Rate
Intuition: *Features* drive costs

```
Features  -->  <Objects Actions Resources>  -->  Cost
```

- **Component Features**
  - Property Set
  - Feature Set

- **Intersection Features**

- **Macro Features**
  - Area
  - Bending Radius
  - Bottom Elevation
  - Curved
  - Fire-rating
  - Fire-rated
  - Height
  - Length
  - Thickness
  - Top Elevation
  - Width
  - Dimension Change
  - Penetrations
  - Direction Change
  - Wall-Beam Intersection
  - Wall-Countertop Connections
  - Grouping (*Similarity*)
  - Openings

**Legend**

- Impacts
- Type Of
- Research Methods
Research questions, *theory*

1. How do product *features* in a building product model affect construction costs?

2. How can the *relationship between product features and construction cost* be formalized in computer models?

3. How can *reasoning mechanisms* leverage the representation in (2) to automatically generate cost-loaded and resource-loaded activities?

*Sheryl Staub-French, 19 December 2001*
What? How?

What: Staub-French created
   – Feature and cost ontology (i.e., vocabulary in computer)
   – Model of effects of feature changes on costs

How:
   – Observe: e.g., Hathaway project
   – Model and analyze results
   – Validate, e.g., charrette, realistic example
Research methods: Example-1

- Graphical product model
- Symbolic product model
- Symbolic process model (Cost analysis procedure)
- Retrospective, charrette studies
Validation study results: Example-1
Validation Method: Charrette study

- Realistic engineering problem: 1-2 hours for practitioner to “solve”
- Two studies, same testers
  - Conventional method
  - Experimental method
- Measured performance metrics: time, cost, accuracy, completeness, consistency, …
- Null hypothesis: Performance same for two methods
- Test results provide evidence of power and generality of the feature and relationship representation and associated reasoning method
  → claim that theory of each is a contribution to knowledge
Validation methods

- Evidence for power and generality of theory: “milk-stool” consistency
Validation methods

• Evidence for power and generality of theory: “milk-stool” consistency
Example-2: Observation
Chuck Han

It is hard to ask:
• Does this design comply with building code?
• How do you know?
Intuition

- *Intent* is a crucial issue for compliance
  - Designer: rationale for forms
  - Code: requirements of forms
Research questions, *theory*

1. Can a generalized *analysis framework* be built to support automated architectural building code checking?
   - based on the design-intent of building code

2. What are the *product model* issues to support (1)
   - Considering “IFC” standard
   - Reformulate IFCs to represent intent

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*Chuck Han, 5 October 1998*
Research methods: Example-2

- Graphical product model
- Symbolic product model
- Symbolic process model (Analysis procedure)
- GUI
- Retrospective, Intervention studies
What? How?

What: Han created computer models of
- Process – framework
- Product – building; wheelchair

How:
- Observe: Sunnyvale building permit group
- Model and analyze (simulation) results
- Validate
  - Many what-if animations
  - Stanford career center (intervention study)
- Test results provide evidence of power and generality of the analysis framework and intent model → claim that theory theory is a contribution to knowledge
**Intervention Study Method**

- Observe engineering case
- *Predict* project performance: time, cost, quality, ...
  - With current plan
  - Following possible intervention(s)
- Intervene - at management discretion
- Intervention ⇒ Evidence for “believability”
- Small-sample statistics w/o control
Research methods: Example-3

John Haymaker

- Graphical product model (CAD)
- Formalize a Symbolic Project Model as a Directed Acyclic Graph of formalized dependencies between geometric views
- Retrospective validation studies of WDCH
Example-3: WDCH Concert Hall Cantilever Test Case
Cantilevered Ceiling Panels Perspector Graph
A Generic Perspector:
- Analyzes the source Features in the source Perspective(s)
- Constructs dependent Feature(s) in the dependent Perspective
- Relates the dependent Feature(s) and source Features(s)
Evidence For Power

Deck attachments

- Interpretation by staff

- Perspector interpretation
### Evidence for Power of the Perspective Approach: Deck Attachment Retrospective Test Case

<table>
<thead>
<tr>
<th>field welds</th>
<th>~ 5</th>
<th>total attachments</th>
<th>WDCH</th>
<th>Perspective Approach</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

**Quality**

**Accuracy**
- Found in test case | 0 (shop weld)* | 114 |
- Missed in test case | 86 (field weld)* | 2 |

**Completeness**
- Amount of detail |

**Time**

**to Specify**
- To conceptualize | 0 sec. | 10 hrs |
- To code Perspectors | 0 sec. | 200 hrs |
- To assemble graph | 0 sec. | 120 sec |

**to Construct and Integrate**
- For project | 140 hours | no data |
- For test case | no data | 56 secs |

Significant improvement over current practice is possible. Further improvement possible. Automation could make creating more detail cost-effective. Re-use of Perspectors reduces programming time. Practice can reduce conceptualization time. Once graph is specified, representations can be constructed quickly.
Evidence for generality

Perspector method for
- Deck Attachments
- Cantilever conditions
Contributions:

Based on evidence of generality and power, Haymaker claims that the underlying mechanisms of his method are a contribution to knowledge, specifically

1. **Project Model Ontology**: dependencies, views, Features, relationships

2. **Perspector**: reasoning to formally construct a new Perspective from other Perspectives

3. **Graph Manager**:
(Empirical) Validation methods

Validation study methods:

1. Retrospective test case(s)
   - “Stress” test ✓ ✓ ✓
   - Engineering test cases ✓ ✓ ✓
2. Prospective (engineering) test case(s)
3. Laboratory study - Charrette method ✓
4. Field intervention study ✓
Summary

• Observations:
  – Engineering practice still has many aspects of a craft
  – Careful observation of practice can inform and test research
• Intuitions:
  – Engineering Principles can guide practice
  – Implementing principles in computer can lead to testable theoretical models
• Research questions:
  – What fundamental principles characterize civil engineering design and management?
  – How can we operationalize new ones in the computer
  – How good are they?
• Build Theory:
  – Processes (e.g., estimate costs, check ADA, plan, create reasoning, …)
  – Products (Buildings, components, systems),
• Model: Object-oriented symbolic and graphical models of products and processes
• Validation to show evidence of power and generality:
  – Many CIFE Ph.D. projects
  – Integration into CEE curriculum: DCI, CEE 100, 111, 222, 241, 242, 243
  – Other Stanford departments: CS, Medicine, Symbolic Systems
Conclusions about Validation

- Serious validation studies are a realistic objective for university research
- Validation motivates students
- Skills
  - Define measurable performance objectives
  - Observe engineering practice
  - Collect data: Formal instrument
  - Analyze data
  - Interpret results
Skills for success

• Good engineer: design, analyze, manage
• Research methods
• Communication
  – Written/Oral
  – Programming
  – Colleagues, sponsors, stakeholders
• Ability to identify, find examples in the chaos of practice, propose “gold standard” methods
• Integrated use of quick-response, careful analysis, reflection
**Research: Benefits for Students**

- Real engineering problems
- Synthesize academic, work experience
- **Methods apply to *big* questions:**
  - What fundamental principles characterize civil engineering design and management?
  - How can we operationalize new ones in the computer?
  - How good are they?
- Research methods necessary for careers in practice & research
- Interesting
- Support
Research: Benefits to Industry

- Industry suggests problems
  - Helps identify big, pre-competitive problems
- University perspective adds value
  - Broad (“integrated”)
  - Theoretical: consistent, repeatable, exportable processes
  - Modern methods
- Unique opportunity to address hard problems
  - Focused effort of gifted graduate students working on industrial-class problems
- Results have been of interest
  - Algorithms (e.g., pipe routing, construction planning)
  - Applications (e.g., org analysis, 4D)
  - Methods (e.g., OOP, 4D, testing, POP, ICE)
  - Successful evangelists within companies
  - (Informal) benchmark evaluation of company processes wrt global best practices
Research Program Status

• Research questions
  ✓ What fundamental principles characterize civil engineering design and management?
  ✓ How can we operationalize new ones in the computer
  ✓ How good are they?

• Research methods
  ✓ Careful observation of practice
  ✓ Symbolic (non-numeric) computer models of products and processes
  ✓ Evidence of power and generality
Research Program Status

Progress

• Practice: small, but real (first VDC users meeting in DC!)

• Academic:
  – Questions and methods now well-validated by CIFE research since 1988, especially last 10 years
  – CIFE still lives, spawns new competition
  – CIFE methods now part of Stanford CEE culture: DCI, CEE 100, 111, 222, 241, 242, 243, …
  – External recognition: “CIFE is the premier academic center for VDC research”
  – External influence: VDC, validation now real issues
Ph.D. student research seminar

- Cifephdstudents -- Ph.D. student research seminar:
- cee320 – CIFE Seminar

- Sign up for both at lists.stanford.edu