A Socio-Technical Foundation for Collaborative Engineering

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Improving Productivity with Advanced Collaboration Technology

Decision-making Productivity of Engineering Design Teams:

- quality
- speed
- cost
Key Points of This Presentation

- With globalization, collaborative engineering (CE) is in!
  - What is collaboration, and what is collaborative engineering?
- CE research needs a new intellectual foundation
  - The determinism versus constructionism philosophy
  - The purely technical versus socio-technical paradigm
- Group decision is the key challenge of CE research
  - Many types of group decisions
  - A old myth of group decision making
- A socio-technical foundation (STF) for participative joint decisions in collaborative engineering (CE)
  - Organization behavioral theory to model engineering teams
  - Social construction theory to achieve common understanding
  - Social choice model to rate continuous alternatives
  - Collaborative negotiation to support joint decisions
- STF/CE posts many challenging CS research questions
What is Collaboration?

Collaboration is a human Activity

- The Cultural and Historical Activity Theory (CHAT)
  - Activity is the basic unit of analysis to study human endeavor
  - Subject, Object, and Community
- Three types of Collaboration Activity
  - Coordination
    - Uni-directional dependencies
  - Cooperation
    - Multi-directional dependencies
  - Co-construction
    - Un-defined dependencies

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<thead>
<tr>
<th>Level</th>
<th>Oriented Towards</th>
<th>Carried Out by</th>
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<tbody>
<tr>
<td>Activity</td>
<td>Motives (long-term)</td>
<td>Community</td>
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<tr>
<td>Action</td>
<td>Goals (short-term)</td>
<td>Individual (or united group)</td>
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<tr>
<td>Operation</td>
<td>Conditions</td>
<td>Routinized human (or automated machines)</td>
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What is Collaborative Engineering?

Collaborative engineering is a socio-technical group decision-making process whereby a team of engineers, who share a common commitment, engage in collaborative activities to:

- resolve conflicts,
- bargain for individual or collective advantages,
- agree upon courses of action,
- craft joint decisions that serve their mutual interests.
Engineering Lifecycle Activities

- Sequential Engineering
- Concurrent Engineering
- Collaborative Engineering

Product Opportunity Gap Identification/Understanding
Concept Development
Product Design
Process Design
Commercial Production

Degree of Concurrency (Activity Overlapping)
Degree of Collaboration (Decision Coupling)

Partly Overlap
Largely Overlap
No Overlap

How do we make decisions for these overlapping activities?

Multiple stakeholders interact to make multiple decisions
Multiple stakeholders interact to arrive at a single agreement

Product Design
Process Design
Commercial Production
An Old Myth of Group Decisions

٣ Arrow’s theorem of ImPossibility

Kenneth Arrow proved the intransitivity of individual preferences to a group preference, which led to the traditional myth of group decision making.

Customers express their preferences via ordinal ranking of discrete alternatives

<table>
<thead>
<tr>
<th>Individual Customer</th>
<th>Preference Rankings</th>
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<tbody>
<tr>
<td>I</td>
<td>( a &gt; b &gt; c ), and ( a &gt; c )</td>
</tr>
<tr>
<td>II</td>
<td>( b &gt; c &gt; a ), and ( b &gt; a )</td>
</tr>
<tr>
<td>III</td>
<td>( c &gt; a &gt; b ), and ( c &gt; b )</td>
</tr>
</tbody>
</table>

Democratic decision making (or social choice) by simple preference aggregations

<table>
<thead>
<tr>
<th>Customer (when asked)</th>
<th>Decisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a vs. b)</td>
<td>b vs. c</td>
</tr>
<tr>
<td>I</td>
<td>a</td>
</tr>
<tr>
<td>II</td>
<td>b</td>
</tr>
<tr>
<td>III</td>
<td>a</td>
</tr>
<tr>
<td>Group Result</td>
<td>a &gt; b</td>
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</tbody>
</table>
Demystify the Old Myth!

If group decisions are indeed irrational, then a true collaborative engineering is impossible
- let the leader to make autocratic individual decisions
- Become multi-objective, multi-attribute decision problems

We challenge this old myth with a new approach

<table>
<thead>
<tr>
<th>Collaborative Engineering</th>
<th>Old Thinking</th>
<th>New Approach</th>
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<tbody>
<tr>
<td><strong>Philosophy</strong></td>
<td>Scientific Determinism</td>
<td>Social Constructionism</td>
</tr>
<tr>
<td><strong>Paradigm</strong></td>
<td>Pure-Technical</td>
<td>Socio-Technical</td>
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<tr>
<td>Group Decision Making</td>
<td><strong>Style</strong></td>
<td><strong>Decision</strong></td>
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<tr>
<td></td>
<td>Autocratic</td>
<td>Individual</td>
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<tr>
<td></td>
<td></td>
<td>Joint</td>
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</table>
Determinism vs. Constructionism

Determinism: Any event can be rationally and precisely predicted, if a complete and accurate description of the event with all the needed laws of nature is given.

Constructionism: An idea which may appear to be obvious to those who accept it, but in reality is just a creation or artifact of a particular culture or society. Social constructs are human choices, rather than laws of the nature.

Our STF to Collaborative Engineering: Socio-Technical

Individual: Purely-Technical

Group: Socio-Technical

Traditional Engineering Focus

Collaborative Engineering Focus

A Socio-Technical Foundation for Collaborative Engineering

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Traditional Technical Paradigm

WHAT → ? → HOW

Engineering Decision Making

(Why) → (Why) → (How)
(Who) → (Who) → (How)

Marketing → Engineering → Service
New Socio-Technical Paradigm

The **Technical** Dimension of Engineering
- Interaction
  - Dynamic Collaborations
- Decision
  - Collaborative Negotiations

The **Social** Dimension of Engineering
- Understanding
  - Shared Interpretations
- Preference
  - Collective Choices

**WHAT**
- (objective)

**WHY**
- (decision)

**HOW**

How can we integrate these two dimensions together scientifically?

The Science Base of Collaborative Engineering

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Different Decision Making Styles

The Leader Decides
1. Autocratic or directive style of problem solving
2. Autocratic with group information input
3. Autocratic with group's review and feedback
4. Individual Consultative Style
5. Group Consultative Style

The Group Decides
6. Group Decision Style (based on leader’s definition)
7. Participative Style (by all interested stakeholders) Our Focus
8. Leaderless Team

CE research must support the “Group-decide” styles
- Classical decision theory is only good for styles 1 – 5
- Our research is targeted at styles 6, 7 and 8
Individual vs. Group/Joint Decision

**DECISION MAKING**

*by Individual*
- Sole or Multiple Decision(s)
  - Descriptive
    - Alternative-Focused Thinking
    - Uncertainty & Risk Analysis
  - Prescriptive
    - Value-Focused Thinking
    - Preference & Value Analysis
  - Normative

*by Group*
- Interacting Multiple Decisions
  - (Game Theory)
    - Non-repeating Game
    - Repeating Game
  - (Negotiation Analysis)
    - Distributive Negotiation
    - Integrative Negotiation
- Joint Single Decision

**TRADITIONAL ENGINEERING**

**LIFE-CYCLE ENGINEERING**

A Socio-Technical Foundation for Collaborative Engineering
Socio-Technical Paradigm for CE

The **Social** Dimension of Engineering Design

- **WHO**
  - Interaction
    - Dynamic Collaborations
  - Decision
    - Collaborative Negotiations

The **Technical** Dimension of Engineering Design

- **WHAT**
  - Understanding
    - Shared Interpretations
  - Preference
    - Collective Choices

- **HOW**

- **WHY**
Alternative Theories and Models

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<tr>
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<tbody>
<tr>
<td>Team Behavior</td>
<td>Neo-Classical Economic Man in Open Large Groups</td>
<td>Modern Organizational Man in Small Teams with Incentives</td>
<td>(WHO) Interaction</td>
</tr>
<tr>
<td>Social Interaction</td>
<td>Self-Interested Rationality with Static Perspective</td>
<td>Social Construction Theory with Dynamic Perspective</td>
<td>(WHAT) Understanding</td>
</tr>
<tr>
<td>Joint Decision</td>
<td>Classic Decision Analysis, and Game Theoretic Approach</td>
<td>Collaborative Win-win Negotiation Framework and Analysis</td>
<td>(HOW) Decision</td>
</tr>
</tbody>
</table>
Economic vs. Organizational Man

Economic Man (and Rational Man)
- Based on neoclassical economic theory (and decision theory)
  - Economic Man has a complete/consistent system of preferences to choose correctly among entire set of available alternatives
    - all the alternatives of choice are given,
    - all of the consequences of each alternatives are known, and
    - a complete utility ordering for all possible set of consequences

Organizational Man
- Based on modern organization theory (Simon, Cyert, March)
  - While Economic Man optimizes, Organizational Man satisfices to look for a course of action that is satisfactory or good enough
    - choice is always exercised with respect to limited resources, time, information, and approximate model of the real situation, and
    - the elements of alternatives are not given but are the outcome of a psychological and sociological processes, including the choosers’ own activities and the activities of others in the choosers’ environments

Our research is based on organizational behavior theory
- “satisficing” and “bounded rationality”
Social Construction of Reality

- Social construction of reality is an interactive and dynamic process of socially shape an agreement and/or artifact by a group of interested stakeholders
  - Interpretive Flexibility
    - SC (e.g., CE) results are always under-determined
  - Relevant Social Group
    - All members of a social group share the same set of meanings (i.e., interpretations) attached to a specific design
  - Closure and Stabilization
    - The SC process continues until all conflicts are resolved, and the artifact no longer posts a problem to any relevant social group
  - Wider Context
    - Background conditions of social interactions matter

We use this process to achieve a common understanding among team members

- Preferences are expressed w.r.t a common understanding
Spatial Social Choice Model

- **Group preference** can be rational and consistent
  - Ordinal rankings of discrete alternatives of individual preferences leads to the Arrow’s paradox of group decisions
  - Ordinal ratings of continuous (spatial) alternatives of individual preferences can result in rational and consistent procedures of aggregating preferences of many to a group preference

- **Spatial model of social choice** draws on concepts from geometry, real analysis, and topology to describe the set of continuous alternatives of individual preferences
  - Alternatives are drawn from an ordered set, represented by points in a continuum

- **Our CE research** is based on ratings of continuous alternatives of individual preferences
  - Rating contains richer preference information than ranking
  - It is possible to obtain spatial social choice models (i.e., ratings of continuous alternatives) for most engineering problems
Collaborative Engineering via Negotiation (ECN) with a consistent group preference

1. **Individual Analysis:** each party thinks alone to decide their respective BATNA – organizational behavior theory

2. **Communal Analysis:** two parties get together to establish their initial ZOPA – social construction theory

3. **Mutual Exploration:** both parties jointly explore maximal technical feasibilities – social construction theory

4. **Establish Preference:** parties jointly & collaboratively establish a value structure – spatial social choice model

5. **Initial Agreement:** parties locate initial agreements along the Efficient Frontier within the negotiation feasibility region

6. **Joint Co-construction:** parties work together to dynamically and collaboratively modify their previously constructed value structure to improve initial agreements

7. **Collective Invention:** parties collaboratively probe each other’s knowledge to expand, or invent, new technical feasibilities for even more improved agreements

8. **Collaborative Innovation:** parties simultaneously perform Steps 6 and 7, which is the ultimate goal of ECN
ECN: a Graphical Example

Increasing Win-Win Negotiation Agreements

Group Indifference Curves

Technical Feasibility Curves

Aesthetics (by Engineer B)

Reliability (by Engineer A)
ECN: Dynamic Control System

Combined dynamical system under both external & internal controls
ECN: Socio-Technical Construction

(I) Baseline Process
(from the application domain)

(II) Stakeholder
S1 S2 S3

(III) Concept Structure
(of the Design Campaign)

(IV) Perspective Model @$t$@
(of the participating Stakeholders -- S)

(V) PMSD (Perspective Model State Diagram) for each concept in the Concept Structure

(VI) Perspective Analysis

(VII) Conflict Management

(VIII) Shared Reality

Long-term (Enterprises)
Middle-term (Organizations)
Near-term (Design Campaign)

Baseline Process
(T1 T2 T3 T4)

Time

Activity

Conflict Management

Change Process

Evolve Perspectives

Modify Concepts

Modify Perspectives

Evolve Concepts

Modify Reality

Shared Concepts

Product Model

Shared Perspectives

Long-term (Enterprises)
ECN: Computing the Consensus

For two perspective models toward a concept:

\[ d_{i,j} = \sqrt{\sum_{k=1}^{g} \left[ (x_{ik} - x_{jk})^2 + (x_{ki} - x_{kj})^2 \right]} \]

For two stakeholders' perspective toward a group of concepts:

\[ d_{i,j} = \sqrt{\sum_{r=1}^{g} \sum_{k=1}^{g} \left[ (x_{ikr} - x_{jkr})^2 + (x_{kri} - x_{kjr})^2 \right]} \]

Figure 4: Perspective Model Network and Perspective Interaction Matrix

Figure 6: Mathematical Relations for Computing Perspective Distances and Cluster Analyses
## Summary of Research Journey

<table>
<thead>
<tr>
<th>GOAL</th>
<th>A Socio-Technical <strong>Framework</strong> for Participative Joint Decision Making in Collaborative Design</th>
</tr>
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<tbody>
<tr>
<td>Old Myth</td>
<td>Group decision making is inherently chaotic because it can’t be consistent and rational. The autocratic style by a Supra decision maker is the only way for collaborative design.</td>
</tr>
<tr>
<td>Current Approach</td>
<td>Scientific Determinism - Neo-Classical Economic Theory - Full-Rationality, &amp; Static Perspective - Discrete Social Choice Model - Decision Analysis</td>
</tr>
<tr>
<td>Basic Proposition</td>
<td>Collaborative engineering design is socio-technical group decision making process. Participative joint decision making by all designers can be consistent and rational.</td>
</tr>
<tr>
<td>New Paradigm</td>
<td>(An Integrated Socio-Technical <strong>Paradigm</strong> for Collaborative Design) WHO → WHAT → WHY → HOW</td>
</tr>
<tr>
<td>Research Task</td>
<td>Systematically Model Social Interactions - Consistently Aggregate Group Preferences - Collaboratively Negotiate Joint Decisions</td>
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The BIG Picture – What’s for CS?

**STF/CE**

**Theoretical Foundations**

**Practical Guidelines**

- Social Construction of Reality
- Decision Science
- Management Science

**Analytical Techniques**

- Argument Negotiation Protocols
- CSCW Multi-agent
- Modeling Frameworks

**Supporting Science**

- Decision Making
- Joint Decision Making
- Negotiation Theory
- Social Science

**Example Area of Research**

- Collaborative Decision Making
- Organization Teamwork
- Practical Guidelines
- Negotiation Practice

**STF/CE** — A Socio-Technical Foundation for Collaborative Engineering
Organization by Focus/Foci (CS)

<table>
<thead>
<tr>
<th>Immersion</th>
<th>Interaction</th>
<th>Autonomy</th>
<th>Computation</th>
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