FIELD GUIDE TO INTERPRETING ENGINEERING TEAM DESIGN BEHAVIOUR WITH SENSOR DATA

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Challenge: Potential for Measurement of Systems Teams Performance

Problem Statement

To reveal the mechanisms inside teams working on complex systems problems, a sociotechnical physics

Inspired ethnography, great thinkers and insightful writers are relevant guides, yet we cannot be sure without uncovering the underlying phenomena with reproducible experiments. Indeed, insightful case studies might be only shadows of the underlying phenomena.

This work is an early attempt to seek the underlying science of teamwork for complexity, and the first principles of sociotechnical systems.

Related Research Insights

1. Frame problems by well-articulated systems models, increased interactive visualization for real-time exploration, and new sensors for data capture.

2. Detect how team attention and activities map to the problem, solution, and social spaces

3. Overcome difficulty to reproduce and scale to industrial teams of teams.
Fig. 1. A nomenclature for the design process, which consists of a design walk & events occurring simultaneously in the problem, solution, and social spaces - which forms the context for problem, solution & teamwork.
Challenge: Maritime Transition to New Fuels

An OPM systems model for this challenge, cutting across many actors in the maritime industry

Maritime Multi-Stakeholder Decisions for LNG

<table>
<thead>
<tr>
<th>Decision</th>
<th>Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Ships fueled with HFO</td>
<td></td>
</tr>
<tr>
<td>Number of Ships fueled with LSFO</td>
<td>0</td>
</tr>
<tr>
<td>Number of Ships fueled with LNG</td>
<td>5</td>
</tr>
<tr>
<td>Number of Ships fueled with HFO/LNG</td>
<td>15</td>
</tr>
<tr>
<td>Number of Ships fueled with LNG</td>
<td>20</td>
</tr>
<tr>
<td>LNG Bunkering Location</td>
<td></td>
</tr>
<tr>
<td>Persian Gulf</td>
<td>Singapore</td>
</tr>
<tr>
<td>Japan</td>
<td></td>
</tr>
<tr>
<td>LNG Bunkering Method by Location</td>
<td></td>
</tr>
<tr>
<td>Truck to Ship</td>
<td>Ship to Ship</td>
</tr>
<tr>
<td>Shore to Ship</td>
<td></td>
</tr>
<tr>
<td>Number of LNG Bunkering Facilities by Location</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

**Objective or -lility**

<table>
<thead>
<tr>
<th>Objective</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions Reduction</td>
<td>NOx Emissions [Ton/ Ton Cargo * km]</td>
</tr>
<tr>
<td></td>
<td>SOx Emissions [Ton/ Ton Cargo * km]</td>
</tr>
<tr>
<td></td>
<td>CO2 Emissions [Ton/ Ton Cargo * km]</td>
</tr>
<tr>
<td>Schedule</td>
<td>Waiting Time [%]</td>
</tr>
<tr>
<td>Cargo Moved</td>
<td>Initial Cost [MUSD]</td>
</tr>
<tr>
<td>CAPEX</td>
<td>Fuel Cost Efficiency [USD/ Cargo Ton * km]</td>
</tr>
</tbody>
</table>

**Diagram Description**

- LNG Bunkering Plant connected to LNG Loading Terminal.
- Liquefaction Plant and LNG Carrier (Loading) shown.
- Port and Ship locations indicated.
- Gas Fields and Pipeline diagrammatic representations.

**World Map**

- Port and Ship locations marked on world map.
Instrumented Teamwork Experiment

• Problem framework, key decisions, and info. on options provided
• Simulation and expert’s judgement for evaluation of decisions
• Stages of individual and team discussions, decisions, interpretation
• Capture interactions with models and model changes
• Audio, Video, and Written communication among participants

UX + SysofSys Model + Instrumented Teamwork

MaritimeDSS v1.0

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**Process to Generate Narratives**

Fig. 3. Overview of the experimental framework and procedure. The current work is in grey, concerned with integrating data to generate holistic design walk narratives.

**Experimental Framework**

Fig. 2. A conceptual diagram of the experiment setup and research flow. During design experiments, sensors consist of DSS logs & microphones and “direct feedback” by human participants or observers. Sensor data is displayed, & both are interpreted into narratives.

### Mapping rules (from sensor data to design walk narrative)

<table>
<thead>
<tr>
<th>Narrative fragment</th>
<th>source of narrative</th>
<th>sensor / proposed</th>
<th>mapping rule / proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>model confidence</td>
<td>comments from scratch sheet, post survey</td>
<td>surprise detector, input logy</td>
<td>frequent or early surprises may indicate conflicting mental model; an input log showing OAT model factor</td>
</tr>
<tr>
<td>prioritized preferences for decision</td>
<td>human - design rationale</td>
<td>output log, attention log</td>
<td>avoided or preferred area of problem space: suspect key. Expected attention on key variable</td>
</tr>
<tr>
<td>phases of attention</td>
<td>human scratch sheet comments</td>
<td>surprise detector, input log, output log, attention log</td>
<td>after surprise, “path dependent sequence”: marked change in behavior - use different input levers, attention, maybe output trends</td>
</tr>
<tr>
<td>preferences</td>
<td>human - scratch sheet comments (on surprises), post survey</td>
<td>combined output &amp; attention logs</td>
<td>good result, but no attention paid to this KPI in the log</td>
</tr>
<tr>
<td>key surprises (learning)</td>
<td>human - scratch sheet comments (on surprises), post survey</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(e.g. “1 truck is enough!”)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>accidental result</td>
<td>combined output &amp; attention logs</td>
<td>attention log output log</td>
<td></td>
</tr>
</tbody>
</table>
Decision Making Priorities

<table>
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</tbody>
</table>

- **KPI evaluated**
  - **79%**
  - **48%**
  - **28%**

- **Team 1**
  - Simulator

- **senor / proposed**
  - output log, attention log

- **mapping rule / proposed**
  - avoided or preferred area of problem space: suspect key. Expected attention on key variable

- **Expected attention on key variable**
  - **NOx**
  - **CAPEX**

- **Which performance indicators did you individually consider more often during the design exercise?**
  - Team 1-1: Emissions, OPEX
  - Team 1-2: Emissions, OPEX, Waiting Time, CAPEX
  - Team 1-3: OPEX, CAPEX, OPEX, CAPEX

- **Which performance indicators did your team discuss more during the design exercise?**
  - OPEX
  - CAPEX

- **Team**
  - Team 1
  - Team 2
  - Team 3

- **CAPEX**
- **OPEX**

- **NOx**
- **CO2**
- **SOx**
- **WAIT**

- **KPI evaluated**
  - **79%**
  - **48%**
  - **28%**

- **Time**

- **Team 1**
  - Simulator

- **Sensor / proposed**
  - output log, attention log

- **Mapping rule / proposed**
  - avoided or preferred area of problem space: suspect key. Expected attention on key variable

- **Priority preferences for decision**
  - human - design rationale

- **Narrative fragment**
  - source of narrative
  - sensor / proposed
  - mapping rule / proposed

- **Optimization results**
  - **79%**
  - **48%**
  - **28%**

- **Expected attention on key variable**
  - **NOx**
  - **CAPEX**

- **Which performance indicators did you individually consider more often during the design exercise?**
  - Team 1-1: Emissions, OPEX
  - Team 1-2: Emissions, OPEX, Waiting Time, CAPEX
  - Team 1-3: OPEX, CAPEX, OPEX, CAPEX

- **Which performance indicators did your team discuss more during the design exercise?**
  - OPEX
  - CAPEX

- **Team**
  - Team 1
  - Team 2
  - Team 3

- **CAPEX**
- **OPEX**

- **NOx**
- **CO2**
- **SOx**
- **WAIT**

- **KPI evaluated**
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- **Time**

- **Team 1**
  - Simulator

- **Sensor / proposed**
  - output log, attention log

- **Mapping rule / proposed**
  - avoided or preferred area of problem space: suspect key. Expected attention on key variable

- **Priority preferences for decision**
  - human - design rationale

- **Narrative fragment**
  - source of narrative
  - sensor / proposed
  - mapping rule / proposed

## Model Confidence

### Narrative fragment
- **Source of narrative**: Comments from scratch sheet, post survey, observation
- **Sensor / proposed**: Surprise detector, input log
- **Mapping rule / proposed**: Frequent or early surprises may indicate conflicting mental model; an input log showing OAT model factor testing is low-confidence

### Table: Arch. ID and Rationale

<table>
<thead>
<tr>
<th>Arch. ID</th>
<th>Rationale</th>
<th>Surprises?</th>
<th>Reasons for Surprise and Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Bunkering moethod change to 1 bunker/truck to ship in JP/PG based on sample 2</td>
<td>Better than expected</td>
<td>Waiting time = 0? Why?</td>
</tr>
<tr>
<td>5</td>
<td>Bunkering moethod change to 3 bunker/truck to ship in PG &amp; 1 bunker/truck to ship in JP to ship based on sample 2</td>
<td>Worse than expected</td>
<td>OPEX increases? Why?</td>
</tr>
<tr>
<td>6</td>
<td>Bunkering moethod change to 1 bunker/truck to ship in PG &amp; 3 bunker/truck to ship in JP to ship based on sample 2</td>
<td>Better than expected</td>
<td>OPEX decreases. BUT it indicates PG defined as JP in program because JP LNG &gt; PG LNG. PG and JP is expected to be reversed.</td>
</tr>
<tr>
<td>8</td>
<td>Bunkering moethod change to 3 bunker/truck to ship in JP and 1 bunker/truck to ship in SIN based on sample 2</td>
<td>Worse than expected</td>
<td>In program. PG=JP, JP=Sin, SIN=PG ??? Only LNG cost is switched between JP (PG in program) / SIN</td>
</tr>
<tr>
<td>10</td>
<td>Bunking method change to 3 bunker/truck to ship in SIN based on sample 2</td>
<td>Worse than expected</td>
<td>What happened? Refuel doing in PG in visual. We should forget</td>
</tr>
<tr>
<td>11</td>
<td>Dual fueled ship, bunkering moethod change to 1 bunker/truck to ship in JP and 3 bunker/truck to ship in SIN</td>
<td>Better than expected</td>
<td>Cargo amount increases...</td>
</tr>
</tbody>
</table>

### Diagram: Time vs. Fuel and Bunkering

- **Time**
- **Fuel**
- **Bunkering**
- **Surprise?**

### Chart: Fuel and Bunkering vs. Time

- HFO
- LSO
- LNG
- Dual fuel
- Bunkering Method
- Surprise?
Phases of Design Walk

<table>
<thead>
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<th>sensor / proposed</th>
<th>mapping rule / proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>phases of design walk</td>
<td>time series of aggregated input</td>
<td>input log, output log</td>
<td>look for pattern in input action “macro” time series, results</td>
</tr>
</tbody>
</table>

Fuel

- NOx
- CAPEX
- OPEX

Time series graph showing fuel consumption over time.
### Learning

#### Narrative Fragment
- **Source of Narrative**: Human - scratch sheet comments (on surprises), post survey
- **Sensor / Proposed**: Surprise detector, input log, output log, attention log
- **Mapping Rule / Proposed**: After surprise, "path dependent sequence": marked change in behavior - use different input levers, attention, maybe output trends

#### Surprise Outcomes
- **NOx**
- **CAPEX**
- **OPEX**
- # Ships
- Fuel
- Bunkering

<table>
<thead>
<tr>
<th>Surprise</th>
<th>Architecture</th>
<th>Recorded Reasons for Surprise</th>
<th>Potential Learning and Likely Decision in Course of Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>09</td>
<td>20x LNG-fueled ships, 1x LNG Bunkers in SG, Truck-to-Ship</td>
<td>Better Emissions than anticipated</td>
<td>An LNG fleet works well. Bunkering choices might have limited effect on emissions. Continue exploring bunkering.</td>
</tr>
</tbody>
</table>

#### Table: Team No.-arch. | # Ships fueled with | Persian Gulf | Japan | Singapore |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Team 1</td>
<td>HFO, LSFO, LNG</td>
<td>Dual-fuel</td>
<td># LNG Bunkers</td>
<td>Bunkering Method</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td># LNG Bunkers</td>
<td>Bunkering Method</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td># LNG Bunkers</td>
<td>Bunkering Method</td>
</tr>
<tr>
<td>Team 1</td>
<td>20</td>
<td>1</td>
<td>Truck to Ship</td>
<td>1 Truck to Ship</td>
</tr>
</tbody>
</table>

#### Diagram: Global Teamwork Lab
- Bunkering
- Fuel
- Architecture
- Recorded Reasons for Surprise
- Potential Learning and Likely Decision in Course of Action

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**Persian Gulf Port**
- **Japan Port**
- **Singapore Port**
### Primary Narrative

This team interprets the design task literally: to reduce emissions at low cost, though are concerned at the lack of comparison of emissions to regulation. They also realize that waiting time should be considered, but decide to neglect the amount of cargo moved, because of unclear interpretation of this KPI. Thus they consider mostly NOx, CAPEX and OPEX, checking other KPIs also.

### Secondary Narrative

From their attention to KPIs, the team’s goal appears to be interpreted literally: reduce emissions at low cost, but keeping cargo moved nominal. However, emissions attention & outcomes are slightly less disciplined than for cargo moved and OPEX & CAPEX - the team may have made some minor change in goal emphasis (indeed, they often return to check NOx later). But we see no clear sign of perceiving a goal or requirement to be ambiguous or unclear.

+ Based on comments from scratch sheet, post survey, observation
+ Based on digital sensor data

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Discussion: Overall Approach

• The **mapping rules & field guide** are to serve two purposes (Fig. 3): aid data interpretation, and improve experimental setup.

• the **most promising rules** may yield insight on prioritization, model trust, phases/modes of activity, and depth of surprise/learning.

• Some **sensor data may be better than direct** feedback - akin to ”revealed preferences”.

• For now, **ethnography and direct human feedback are still key to intent & the social space**, and to **validate** sensor-based narratives.

• Sensors for social space detection yet to be considered.
Lessons Learned

+ Capability to experiment by experimenting
+ Loosely Constrained, Fluidly Evolving Experiments
+ Real world, multi-actor, multi-attribute challenge

- Expand beyond surprises -- mental model development and validation.
- Latency -- obtaining a new insight through surprise but not changing
- Voice audio not experimentally successful (both implementation and analysis)
Conclusion

To expose dynamics of teamwork, a quasi-experiment to sense and transform data into team narratives was demonstrated:

• a experimental setup based on a systems model and simulation in the maritime industry for fuel transitions

• a formalized concept of a team design walk narrative and a taxonomy for events in the problem, solution, and social spaces

• workshops gather data applied to a set of mapping rules for transforming sensor data into a team narrative

Limitations: not a formally controlled experiment. Better interplay with classic primary (ethnography, survey) approaches needed.
Team of Teams Science for Complex Problems

Platform, experiments and sensors


To analyze events across teams as mapped to problem, solution, and social spaces.

Our goal is real-time detection of framing and re-framing, unlearning and learning, and the overall health of teams of teams work during complex problem solving.
Summary of Recent Experiments

We’re creating:
- platform for repeatable, teamwork experiments across multiple domains
- Sensors for attention and changes to models problem and solution
- reference measure and research protocols for phenomena at the (team of teams) meso-scale.

Just beginning
- To reach sufficient data to correlate performance outcomes to these exposed phenomena.
References