Modeling the Drift to Unsafe State
Connecting STAMP and System Dynamics

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Aim

The study explores the impact of each of the unsafe control actions (UCAs), as well as of their combination, on the dynamics of drift from safe to unsafe states.
Motivation

- Ever-changing
- Prone to delays
- Dynamic drift to unsafe states

MIT STAMP 2016

- Where is the system dynamics?
- How short/long the loops are?
- How long does it take to recover?

STPA

UCA

SD
Outcome

• By manipulating the UCA variables:
  (1) understand how long it takes for the system to drift to unsafe state,
  (2) which UCAs lead to the quickest drift,
  (3) which UCAs interact

• Dynamic analysis of a healthcare process with the STPA results as an input to the SD model
Previous work with STAMP & System Dynamics

• DuLac, N. PhD Thesis 2007
  – “A framework for dynamic safety and risk management modeling in complex engineering systems”
  – http://hdl.handle.net/1721.1/42175

• Coutier, M. MS Thesis 2010
  – ”A case study of Vioxx using STAMP”
  – http://hdl.handle.net/1721.1/59557

• Leveson, et al 2012
STPA Results

• Accident: *Deaths or deterioration of condition, while waiting to see specialist*

• Hazard: *Waiting time to see specialist extends too long*

• CAs: Hospital ED (7); GP (2); Radiology (2)

• 50 UCAs in total; 3 UCAs are used as variables in the SD model for demonstration
Input to the SD model

- UCAs considered in the SD model
  - [DR] [CA4] [UCA18] Does not send/give discharge letter
  - [DR] [CA6] [UCA27] Does not send referral proforma
  - [MA] [CA1] [UCA51] Cuts number of specialists
Waiting for Specialist & Treatment Model

Stocks

Queue: Waiting for referral to specialist

Patient referred to Specialist

Flows

Queue: Waiting for treatment

Patient visits Specialist

Patients die while waiting

Number of Specialists

Patients die while waiting

Pressure to increase number of specialists
Adding UCAs to the Model

Patients die while waiting

Number of Specialists

Pressure to increase number of specialists

Queue: Waiting for referral to specialist

Patients visit Specialist

Queue: Waiting for treatment

Queue: Waiting for treatment

UCA

[DR] UCA18

[DR] UCA27

[MA] UCA51

Patient referred to Specialist

Patients die while waiting

Specialists Leaving
Factorial Experimental Design
2^3 = 8 runs

<table>
<thead>
<tr>
<th>Run Number</th>
<th>[MA] UCA51</th>
<th>[DR] UCA18</th>
<th>[DR] UCA27</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BASELINE</td>
<td></td>
<td></td>
<td></td>
<td>Baseline</td>
</tr>
<tr>
<td>MDUS-2</td>
<td>X</td>
<td></td>
<td></td>
<td>Single Factor</td>
</tr>
<tr>
<td>MDUS-3</td>
<td></td>
<td>X</td>
<td></td>
<td>Single Factor</td>
</tr>
<tr>
<td>MDUS-4</td>
<td></td>
<td></td>
<td>X</td>
<td>Single Factor</td>
</tr>
<tr>
<td>MDUS-5</td>
<td>X</td>
<td>X</td>
<td></td>
<td>Two Factor</td>
</tr>
<tr>
<td>MDUS-6</td>
<td>X</td>
<td></td>
<td>X</td>
<td>Two Factor</td>
</tr>
<tr>
<td>MDUS-7</td>
<td></td>
<td>X</td>
<td>X</td>
<td>Two Factor</td>
</tr>
<tr>
<td>MDUS-8</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Three Factor</td>
</tr>
</tbody>
</table>

X → CHANGE FROM BASELINE VALUE
## Model Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
<th>Source</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients referred to specialist</td>
<td>1000</td>
<td>Patients/week</td>
<td>Assumption</td>
<td>Chosen to balance demand and capacity*</td>
</tr>
<tr>
<td>Specialist Productivity Rate</td>
<td>20</td>
<td>Patients seen/week</td>
<td>Assumption</td>
<td></td>
</tr>
<tr>
<td>Number of Specialists</td>
<td>50</td>
<td>Specialists</td>
<td>Assumptions</td>
<td></td>
</tr>
<tr>
<td>Rate of dying while waiting</td>
<td>3/100000</td>
<td>Deaths/100k patients/week</td>
<td>Fraser Institute Canada 2014</td>
<td>All cause mortality</td>
</tr>
</tbody>
</table>

*Nominal Capacity (20 x 50) = Nominal Demand (1000)
# UCA SD Model Values

<table>
<thead>
<tr>
<th>UCA</th>
<th>Variable</th>
<th>Parameters</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>[MA] UCA51</td>
<td>Managers cut number of specialists</td>
<td>Number of specialists cut</td>
<td>10% cut, pulse at 50 weeks for 50 weeks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Duration of cut</td>
<td></td>
</tr>
<tr>
<td>[DR] UCA18</td>
<td>Doctor send/give discharge letter</td>
<td>Percentage of patient flow receiving discharge letter</td>
<td>95%</td>
</tr>
<tr>
<td>[DR] UCA27</td>
<td>Doctor send referral proforma</td>
<td>Percentage of patient flow receiving referral pro forma</td>
<td>98%</td>
</tr>
</tbody>
</table>
System Dynamics Model (Vensim)

[Model Output]

- [DR] [CA6] [UCA27] - does not send referral proforma
- [DR] [CA4] [UCA18] - does not send/give discharge letter

- Patients waiting for referral
  - Patients dying while waiting for referral
  - Patients waiting for referral rate

- Patients waiting for appointment
  - Patients dying while waiting
  - Patients leaving for treatment

- Specialists entering field
- Specialists leaving field

- Specialist departure
- Patient scheduling rate

- Pressure to reduce deaths

UCA

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SD Modeling Results
Rates of dying while waiting

patients dying while waiting

Time (week)
Rates of dying while waiting
Specialist Cuts vs Baseline
(No Referral Reduction)

patients dying while waiting for treatment

-1.9e-5
-0.01499
-0.02999
-0.045
-0.06

Time (week)

0 80 160 240 320 400 480 560 640 720 800

patients dying while waiting for treatment : BASELINE
patients dying while waiting for treatment : MDUS-2
Rates of dying while waiting
Referrals reductions vs Baseline
(No Specialist Cuts)

patients dying while waiting for treatment

patients dying while waiting for treatment: BASELINE
patients dying while waiting for treatment: MDUS-7
Rates of dying while waiting
Specialist Cuts and Referral Reductions vs Baseline

patients dying while waiting for treatment

patients dying while waiting for treatment: BASELINE
patients dying while waiting for treatment: MDUS-8
Modeling Observations

• Specialist Cuts more impactful than Referral Reductions
• UCAs modify flows
• Model structure is not changed by including UCAs
• Some UCAs take longer to recover from than others
  – Should be noted in designing mitigations
• Need to make sure you look at total system losses
  – Deaths while waiting for treatment and Deaths waiting for referral
## Drift Rate vs Recovery Rate
(Possible Prioritization Method)

<table>
<thead>
<tr>
<th>Drift Time</th>
<th>Recovery Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td>2</td>
</tr>
<tr>
<td>Long</td>
<td>4</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Recovery Time</th>
<th>Short</th>
<th>Long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Long</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>
Can this model be generalized?

Resources required to keep system in control

Controlled Process

Contribution to Safe State

Contribution to Unsafe State

Inputs

Pressure to return to safe state

[MA] [CA1] [UCA51] cut specialists

Specialist departure

Pressure to reduce deaths

Specialists entering field

specialists leaving field

[DR] [CA6] [UCA27] - does not send referral proforma

[DR] [CA4] [UCA18] - does not send/give discharge letter

specialist productivity rate

patient scheduling rate

patients leaving for treatment

patients dying while waiting

rate of dying while waiting

Patients waiting for appointment

Patients waiting for referral

Patient arriving for evaluation

Patients dying while waiting for referral

[Image]
Generalized Model

Pressure to return to safe state

Resources required to keep system in control

Inputs

Controlled Process

Contribution to Unsafe State

Contribution to Safe State

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Final Remarks

1. Bring dynamic analysis to STAMP
2. STPA Step 1 & SD to model the dynamics of the drift from safe to unsafe states
3. Linkage by using the UCAs as variables in the SD model
4. Each UCA can trigger other UCAs
5. Manipulation of each UCA in combination with other UCAs at the same time to assess the speed of drift into failure
6. STAMP and SD combination gives insight on rate of drift and recovery time for systems
7. UCAs impact flows between stocks but not structure of the model
Future Work

• Validate the model
  – SD models are illustrative, not predictive.
  – Interview experts to get better estimates of values of flow and fixed constants
  – Review SD literature for “pressure” models
• Assess the drift into failure and the recovery of the system based on more than one hazard
• Consider all UCAs and group them
• Generalize to other domains
  – Food Safety
  – Perhaps other problematic fields, i.e. Mining, Railways
Thank you!

Contact
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## Model Variable Relationships

<table>
<thead>
<tr>
<th>Model Variable</th>
<th>Value</th>
<th>Units</th>
<th>Init</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specialists</td>
<td>Specialists entering – specialists leaving</td>
<td>Specialists</td>
<td>50</td>
</tr>
<tr>
<td>Patients waiting for appointment</td>
<td>Patients arriving – patients scheduled – patients dying while waiting</td>
<td>Patients</td>
<td>0</td>
</tr>
<tr>
<td>Patients dying while waiting</td>
<td>Patients waiting x Rate of dying while waiting</td>
<td>Patients/week</td>
<td></td>
</tr>
<tr>
<td>Patient scheduling rate</td>
<td>Specialists x specialist productivity</td>
<td>Patients/week</td>
<td></td>
</tr>
<tr>
<td>Patients leaving for treatment</td>
<td>Max (patient scheduling rate,0)</td>
<td>Patients/week</td>
<td></td>
</tr>
<tr>
<td>Pressure to reduce deaths while</td>
<td>Patients dying while waiting</td>
<td>Dimensionless</td>
<td></td>
</tr>
<tr>
<td>waiting</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Specialists entering</td>
<td>Pressure to reduce deaths</td>
<td>Specialists/week</td>
<td></td>
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</tbody>
</table>
## Run Values

<table>
<thead>
<tr>
<th>Run Number</th>
<th>[MA] UCA51</th>
<th>[DR] UCA18</th>
<th>[DR] UCA27</th>
<th>Result</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>BASELINE</td>
</tr>
<tr>
<td>2</td>
<td>50,50</td>
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<td>0</td>
<td>MDUS-2</td>
</tr>
<tr>
<td>3</td>
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<td>.95</td>
<td>0</td>
<td>MDUS-3</td>
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<td>4</td>
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<td>MDUS-4</td>
</tr>
<tr>
<td>5</td>
<td>50,50</td>
<td>.95</td>
<td>0</td>
<td>MDUS-5</td>
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<tr>
<td>6</td>
<td>50,50</td>
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<td>MDUS-6</td>
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<tr>
<td>7</td>
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<td>.98</td>
<td>MDUS-7</td>
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<td>8</td>
<td>50,50</td>
<td>.95</td>
<td>.98</td>
<td>MDUS-8</td>
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