Identifying and Classifying Uncertainties to support Testing of Industrial Elevators

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Industry Context

**Orona**
- Develop and maintain elevators
- SiL testing

**Elevate**
- Performance analysis
- Simulation with visual display
- Building, elevator and passenger data

**Elevator attributes**
- Safety
- Quality of service (QoS)
- ...

What uncertainties do elevators face?
Uncertainties

**Hardware**
- Start delay
- Door dwell
- ...

**Passenger**
- Attributes (e.g., Mass)
- Behaviors (e.g., Arrival, Loading and Unloading)

Rush to an elevator  Uncertain destination  Block the door

How to cost-effectively test elevators in the presence of uncertainties to ensure their dependability?
Practices and Challenges

### Practices
- SiL testing with Elevate manually
- Fixed passenger attributes (e.g., mass)
- Lack of testing of SUT under uncertainty

### Challenges
- Automate SiL
- Classify passenger uncertainties
- Search and RL based testing of elevators under uncertainty

Unpredictable
Our SiL-based Methods

1. Simuloop
   - Uncertain Factors
   - Uncertain Traffic Profile Generator
   - Cynefin Classifier
   - Classified Cynefin Contexts

2. RuCynefin
   - Elevate Config.
   - Uncertain Traffic Profile
   - SiL Test Results

3. GAiEle
   - Genetic Algorithm (GA) (C++)
   - Passenger Traffic
   - Waiting Time
   - GA Config.
   - SiL Test Results

4. GAoEle
   - Genetic Algorithm (GA) (Python)
   - SiL Test Results
   - Traffic Profile
   - AWT
   - State
   - Action
   - Reward
   - Agent
   - SiL Test Results

5. RLoEle
   - Elevate Config.
   - RL Config.
   - SiL Test Results
SiL with Elevate

Testing of Trustworthy Systems

9th UCAAT

(Step-1) Analysis Setting
Select Dispatcher
Set Simulation Parameters

(Step-2) Environment Setting
Configure Building
Configure Elevator

(Step-3) Configure Passenger Traffic
Template Mode?
Yes
Select Traffic Template
No
Upload Passenger File
Set Passenger Details

Execute

Analysis Report
Detailed Report
Simuloop: Automate SiL

Simuloop

Elevate

- Launch Elevate
- Load configuration
- Write to passenger file
- Start simulation
- Wait by listening
- Show results
- Parse results
- Open report in notepad

Notepad
Our SiL-based Methods

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5. RLoEle
   - Agent
     - State
     - Action
     - Reward
     - SiL Test Results
   - RL Config.

Testing of Trustworthy Systems
#UCAAT
Cynefin: Decision Making under Uncertainty

Sketch of the Cynefin framework, by Edwin Stoop
RuCynefin: Cynefin-based uncertain situation generation and classification

Uncertain Factors → (Phase-1) Generate Uncertain Traffic Profiles

CIBSE Guide D → Configurations

→ Uncertain Traffic Profiles → Execute Simulations

QoS → Time List → (Phase-2) Classify Uncertain Situation

Classified Cynefin Contexts → (Phase-3) Assess Robustness

Robustness Scores
The 90 dispatchers exhibit diverse robustness in terms of dealing with uncertainties.
RuCynefin: Cynefin-based uncertain situation generation and classification

- AWT and ATD are impacted relatively less by uncertainties.

- Recommend to optimize a dispatcher’s robustness under uncertainties with respect to a particular QoS of interest.
RuCynefin: Cynefin-based uncertain situation generation and classification

Different uncertain factors have different extents of impact on the robustness of the dispatchers.

Capacity Factor, Mass and their interaction have relatively higher impact on the dispatchers’ robustness than the other uncertain factors.
RuCynefin: Cynefin-based uncertain situation generation and classification

<table>
<thead>
<tr>
<th>QoS</th>
<th>#1</th>
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<th>#3</th>
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<th>#13</th>
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<td>61</td>
<td>54</td>
<td>53</td>
<td>64</td>
<td>63</td>
</tr>
</tbody>
</table>

#1 usC  #2 usL  #3 usM  #4 usU  #5 usC-L  #6 usC-U  #7 usL-U  #8 usM-C  #9 usM-L  #10 usM-U  #11 usC-L-U  #12 usM-C-L  #13 usM-C-U  #14 usM-L-U  #15 usM-C-L-U

Provide feedback on which QoS against which uncertain situation should be prioritized for optimization.

- E.g., focus on LTD when facing uncertainties caused by Capacity Factor itself or its interactions with Mass.
Our SiL-based Methods

1. Simuloop
2. RuCynefin
3. GAiEle
4. GAoEle
5. RLoEle

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- GA Config.
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- AWT
- State
- Action
- Reward
- Agent
- SiL Test Results
- GA Config.
- RL Config.

Testing of Trustworthy Systems
GAiEle: Search-based SiL testing

**GAiEle** generates passengers with specific attributes during SiL, for a given traffic profile, with GA, with the aim of maximizing AWT of passengers.

**Empirical study:**

- Genetic Algorithm (GA) (C++)
- Passenger Traffic
- Orona Dispatcher (C++)
- Waiting Time
- GA Config.
- SiL Test Results
GAoEle: Search-based SiL testing

Objective: maximize AWT of passengers

Difference with GAiEle:
- load standard profile at the beginning
- change all passengers at each generation
- outside of Elevate, not extra engineering work

Empirical study:

<table>
<thead>
<tr>
<th>Attribute</th>
<th>GA</th>
<th>Mass</th>
<th>Cap.</th>
<th>Load.</th>
<th>Unload.</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (kg)</td>
<td>x</td>
<td>90</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>90</td>
</tr>
<tr>
<td>Cap. Fac. Mass (%)</td>
<td>x</td>
<td>x</td>
<td>75</td>
<td>x</td>
<td>x</td>
<td>75</td>
</tr>
<tr>
<td>Loading time (s)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>2</td>
<td>x</td>
<td>2</td>
</tr>
<tr>
<td>Unloading time (s)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>AWT(s)</td>
<td>44.5</td>
<td>40.3</td>
<td>39.0</td>
<td>34.0</td>
<td>30.3</td>
<td>34.5</td>
</tr>
</tbody>
</table>

Individual Waiting times for Passengers
RLoEle: Reinforcement learning based SiL Testing

Environment
- Building configuration
- Elevator setup

State
- Elevator and passenger positions and directions

Action
- Assign arrival and destination floors

Reward
- AWT
Summary and Outlook

Follow-Up Works

- Industrial validation and technology transfer
- Generalize to other domains, e.g., train control

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### State
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### Action
- Assign arrival and destination floors

### Reward
- AWT

\[ x - y = \text{reward} \]
Most models were converged after 1000 cycles.

Given a floor height and a direction, it is straightforward to conclude which action to select.