Predictive Performance Monitoring of Material Handling Systems Using the Performance Spectrum
Baggage Handling Systems

Check-In → X-Ray → Screening & identification → Final sorting → Happy path
Re-Circulation Causes Significant Delays
Insufficient Number of Screening Machine Operators

Check-In

X-Ray

Screening & identification

Final sorting
Unavailability of Outgoing Conveyors

Check-In

X-Ray

Screening & identification

Final sorting

[Diagram showing the process of luggage handling at an airport]

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Predictive Performance Monitoring of Material Handling Processes

What is the required **number of operators** in +x minutes from now?

What is the **amount of re-circulation** in +x minutes from now?
What Are Relevant Features?

**Intra-case features**

**Bag properties**
- Bag color: *red*
- Final destination: *Amsterdam*
- Dimensions: 550x450x250mm
- Weight: 15kg

_Bag properties_ is an example of _intra-case features_.

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**Inter-case features**

**System properties**
- Utilization of the Loop Sorter: 90%
- Utilization of conveyors around the Sorter: 60%
- Current load on the X-Ray Screening Machine: _15 bags/min._
- Number of bags in the system: 8000

One bag = one case

What is the load on the screening machines?  What is the amount of re-circulation in +x minutes from now?
Performance Spectrum [1]

Sub-trace: \((e_i^{(a, t_a)}, e_{i+1}^{(b, t_b)})\)

Bins:
- cases **started**
- cases **stopped**
- cases **pending**

Development of Problem Instance 2: Re-Circulation because of Unavailability of a1-a3

Check-In → X-Ray → Screening & identification → a1 → b1 → c1 → a2 → b2 → c2 → a3 → b3 → c3 → Loop

Severity

Time
Extracting Features from Performance Spectrum

Now

Target spectrum

Prediction horizon

Historic spectrum

v/ = [8, 2, 5]
Multi-Channel Performance Spectrum

- Channel 1: Speed
- Channel 2: Screening result
- Channel 3: Sortation status

Now Prediction horizon Time

X-Ray:a2
a2:b2
b2:c2
a3:b3
b3:c3

X-Ray:a1
a1:b1
a1:loop

Multi-Channel Performance Spectrum
Multi-Channel Performance Spectrum

In the paper:
✓ **Generic definition** of the Multi-Channel Performance Spectrum
✓ **Generic method** for Performance Spectrum-based feature extraction
Sliding Window over Performance Spectrum

Training & test sets

Model training

ML Model
Problem Instances and Datasets

**Problem Instance 1**
Load on the X-Ray Screening Machines

**Problem Instance 2**
Extra re-circulation because of unavailability a1-a3

<table>
<thead>
<tr>
<th>Property</th>
<th>Simulation model [2]</th>
<th>Real BHS of a major European airport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time period</td>
<td>7 days</td>
<td>4 month</td>
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<tr>
<td>Activities</td>
<td>25</td>
<td>850</td>
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<td>Cases per day</td>
<td>1600</td>
<td>25,000-50,000</td>
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<tr>
<td>Events per day</td>
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<td>1,000,000-2,000,000</td>
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<tr>
<td>Events, total</td>
<td>134,000</td>
<td>148,000,000</td>
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</table>

Implementation: Performance Spectrum Miner [3] and Scripts on Top of PyTorch

Computational environment:
• a single-machine configuration
• 40 CPUs
• 6 GPUs
• 400GB RAM
• the Performance Spectrum Miner in ProM 6.9
• the PyTorch Framework

http://www.promtools.org/doku.php?id=prom69
https://github.com/processmining-in-logistics/psm/tree/ppm

Models and Baselines

Models:
• Logistic Regression (LR)
• Feedforward Neural Network (FFNN)

Baselines:
• Naïve baseline: current load
• Data-driven inter-case feature encoding (DDICFE) [4] [5]

Experimental Results

**Problem Instance 1**
Load on the X-Ray Screening Machines

- Observed spectrum
- Predicted spectrum
- Baseline spectrum
- Error (%)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Approach</th>
<th>Model</th>
<th>RMSE, % of max</th>
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</thead>
<tbody>
<tr>
<td>Sim. model</td>
<td>PS</td>
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<td>DDICFE</td>
<td>FFNN</td>
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<td>Naïve baseline</td>
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**Problem Instance 2**
Extra re-circulation because of exits a1-a3 unavailability

<table>
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<tr>
<th>Experiment</th>
<th>Approach</th>
<th>Model</th>
<th>RMSE, % of max</th>
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<tbody>
<tr>
<td>Real system</td>
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<td>FFNN</td>
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Conclusion and Future Work

- Processes: cases influence each other
- Performance Spectrum:
  - modelling a variety of performance features over time
  - capturing inter-case dependencies
- Multi-Channel PS: formulating a large class of performance prediction problems as a regression problem
- Generic methodology of solving this problem as a ML task

- Feasibility on MHS → apply to Business Processes
- Feature selection: domain knowledge is required → include a formal process model
- Validation in practice is missing → higher accuracy and longer prediction horizon

Thank you!