Efficient compliance monitoring:
Comparison of both airborne and landside sniffing and spectrometric methods to provide direct control on the sulfur emission of ships.
Contents

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- Aim
- Analytical techniques
- Statistical techniques
  - Classification with linear boundary
  - Classification using Z-score
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The emission of $SO_2$ over time.

SO$_2$ emissions in the Netherlands

- Total
- Transport
- Shipping

60,000 premature deaths, Corbett

2 year loss, CAFE

Efficient compliance monitoring

Introduction

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Introduction

$40,000 \text{ day}^{-1}$
Fuel Sulfur Content

- \( FSC = \frac{\text{weight of sulphur}}{\text{weight of fuel}} \)

- \( FSC = \frac{16}{64.066} \times M(S) \times \int \left( [SO_2] - [SO_2] \right) dt \)

- \( FSC = \frac{12}{44} \times (M(C)/0.87) \times \int \left( [CO_2] - [CO_2] \right) dt \)

- \( FSC = 0.232 \frac{\int [SO_2] - [SO_2] \, dt}{\int [CO_2] - [CO_2] \, dt} \)
Aim

- Compare different techniques and operators for future use for the inspectorate.
- Explore the measurements performed so far by all inspectorates in Northern Europe.
  - What are the compliance rates?
- What are the type I and type II errors? i.e. how sure are we that a ship is (non-)compliant?
TNO/ ILT sniffer
N = 8049

Efficient compliance monitoring campaigns
What fraction is non-compliant?

Efficient compliance monitoring campaigns
What fraction is non-compliant?
What fraction is non-compliant?

Classification

<table>
<thead>
<tr>
<th>True value</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>✓</td>
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<tr>
<td>6</td>
<td>×</td>
</tr>
<tr>
<td>4</td>
<td>×</td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
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</table>

N = 19
Accuracy = 47%
Intermezzo – type I and type II errors

Classification

True value

Type 1

Type 2

N = 19
Accuracy = 47%

Intermezzo – type I and type II errors

Efficient compliance monitoring
Intermezzo
Intermezzo – type I and type II errors

Classification

True value

N = 19
Accuracy = 47%

Type 1: wrongly accusing

Type 2: overlooking non-compliance
Intermezzo – type I and type II errors

- What do we want?
  - Low type-I error
  - High type-II error
  - Equal type-I and type-II errors
  - High type-I error
  - Low type-II error

Court
Intermezzo – type I and type II errors

- What do we want?

Low type-I error
High type-II error

Equal type-I and type-II errors

High type-I error
Low type-II error

Court

Preselection
Intermezzo – type I and type II errors

- What do we want?

Low type-I error
High type-II error

Equal type-I and type-II errors

High type-I error
Low type-II error

Court
Climate modeling
Preselection
Intermezzo – type I and type II errors

- What do we want?
What fraction is non-compliant?

Low type II error

Low type I error

FSC (% m/m)
**Z-score**

- $H_0$: The ship has a FSC of 0.1 wt. % or less.
- $H_1$: The ship has a higher FSC than 0.1 wt. %.

$Z = \frac{\bar{x} - \mu_0}{s_x / \sqrt{n}}$

- Z-score can be calculated to p-value with a significance level $\alpha$. 

N = 5552 (69%)
Z-score with $\alpha = 0.05$
Z-score with $\alpha = 0.05$

Classification

True value

$N = 19$
Accuracy = 68%
Another approach
What fraction is non-compliant?

- How many port state controls should take place?
- How reliable are climate modellings assuming 100% compliance?
- What is the catch rate?
EM algorithm

- Guess initial parameters
- Calculate responsibility
- Maximize likelihood of all parameters
For each datapoint $i$:

$$\gamma_{i,0} + \gamma_{i,1} = 1$$
EM algorithm

- Guess initial parameters
- Calculate responsibility
- Maximize likelihood of all parameters

\[ \hat{\mu}_k = \frac{1}{n_k} \sum_{i \in k} x_i \]

\[ \hat{\sigma}_k = \frac{1}{n_k} \sum_{i \in k} (x_i - \mu_k)^2 \]
EM algorithm

- Guess initial parameters
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\[ \hat{\mu}_k = \frac{1}{n_k} \sum_{i \in k} x_i \]
\[ \hat{\sigma}_k = \frac{1}{n_k} \sum_{i \in k} (x_i - \mu_k)^2 \]
EM algorithm

- Guess initial parameters
- Calculate responsibility
- Maximize likelihood of all parameters

Iterate until convergence
EM-algorithm

N = 5552 (69%)

$\mu_1 = 0.06 \text{ wt}\%$
$\sigma_1 = 0.04 \text{ wt}\%$

$\mu_2 = -1.1 \text{ wt}\%$
$\sigma_2 = 0.8 \text{ wt}\%$

Efficient compliance monitoring
Another approach
What fraction is non-compliant?

Efficient compliance monitoring
Another approach
EM algorithm

- Guess initial parameters
- Calculate responsibility
- Maximize likelihood

$$\hat{y}_{i,k} = \frac{\text{prior } \pi_k \cdot \text{likelihood } \mathcal{N}(x_i | \mu_k, \sigma_k^2)}{\pi_1 \mathcal{N}(x_i | \mu_1, \sigma_1^2) + \pi_2 \text{Lognormal}(x_i - 0.1 | \mu_2, \sigma_2^2)}$$

Efficient compliance monitoring
Another approach
\[
\hat{\mu}_c = \frac{\sum_{i \in c} x_i}{N_c}
\]
\[
\hat{\sigma}_c = \frac{\sum_{i \in c} (x_i - \mu_c)^2}{N_c}
\]
\[
\hat{\mu}_{nc} = \frac{1}{N_{nc}} \sum_{i \in nc} \log(x_i - 0.1)
\]
\[
\hat{\sigma}_{nc} = \frac{1}{N_{nc}} \sum_{i \in nc} (\log(x_i - 0.1) - \mu_{nc})^2
\]
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Another approach
Efficient compliance monitoring

Another approach
Outlook

- Determine the relation between type I and type II errors more precisely.
- Better instruments will result in better accuracy.
- Better validation makes the introduction of supervised methods possible.