DATA-BASED MODELS FOR ASSESSMENT AND LIFE PREDICTION OF MONITORED BRIDGE WELDED JOINTS

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Agenda

- Introduction
- Case study: SHM of welded bridge joints
  - Strategy undertaken
  - Monitoring system
  - SHM applications
  - Data-based modelling: environmental and operational conditions and loads
  - Methodology for life prediction
  - Methodology for performance assessment
- Concluding remarks

Introduction

Structural type	Component and deterioration mechanism	Asset Management Objectives	Asset Management actions/decisions	SHM strategy and tools
- Short-span bridge - Long-span bridge - Tunnel - Dam - Offshore wind turbine …	**Deterioration**: - Fatigue - Corrosion - Wear and tear - Extreme events,… **Component**: - Welded joint, cable, expansion joint,	- Design verification - Service-life prediction - Abnormal behaviour identification - Support to Operation & Maintenance - Etc…	- Inspection - Repair - Maintenance - Life extension - Traffic disruption	- Type of sensor - Number of sensors - Location of sensors - Data acquisition: permanent/periodic monitoring - Performance indicator - SHM approach: - Data-based / model-based - Global / local - Tools: - Regression models, tim-series models, FFT, SSI, Bayesian networks, SRM, etc,,,

Given for an application

(at the start)

Discussion: infrastructure owner, SHMS designer and structural engineer

Prescribed by SHMS designer

Influenced by cost/budget

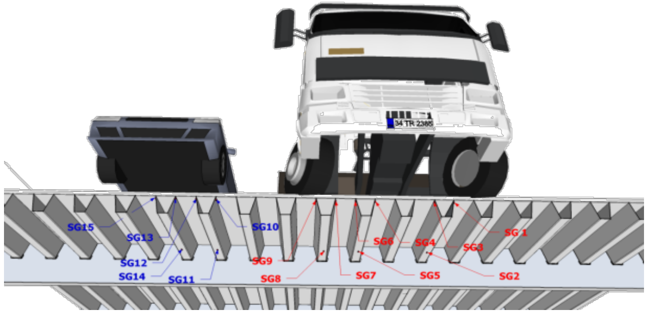
Need a more formal theoretical framework (WG2, WG3,…)

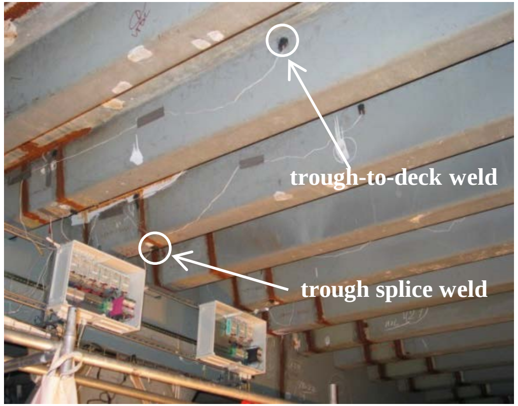
Case study: SHM of welded joints at Great Belt Bridge

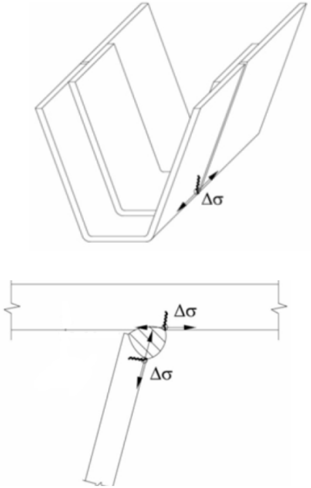
The Great Belt Bridge:

- Inaugurated in 1998 in Denmark
- 1624m main span
- Orthotropic steel deck
- Concrete towers
- 3rd longest suspension bridge in the world
- Instrumented with a SHMS

Structural component: welded joints of the orthotropic deck







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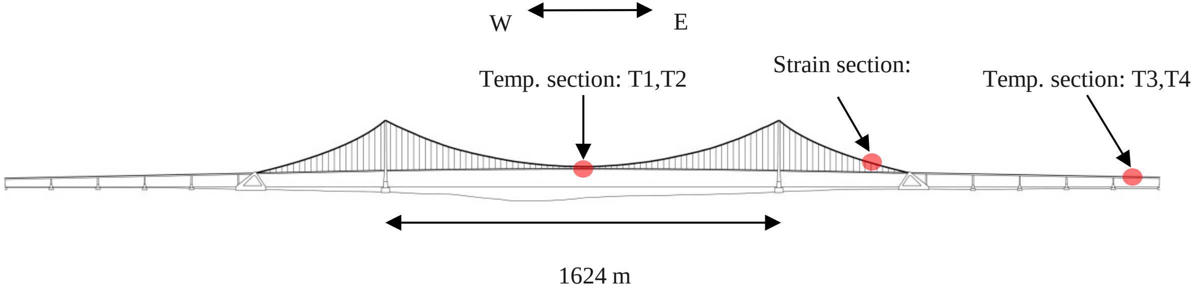
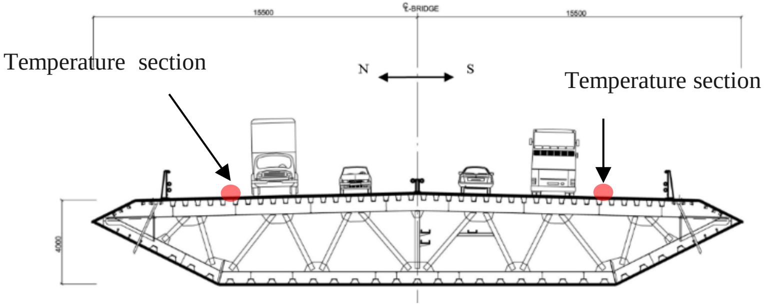
Monitoring system: location of sensors





An overview of the case study

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Structural type

- Short-span bridge
- **Long-span bridge**
- Tunnel
- Dam
- Offshore wind turbine

…

Component and deterioration mechanism

Deterioration:

- **Fatigue**
- Corrosion
- Wear and tear
- Extreme events,…

Component:

- **Welded joint**, cable, expansion joint,

Asset Management Objectives

- Design verification
- **Service-life prediction**
- **Abnormal behaviour identification**
- **Support to Operation & Maintenance**
- Etc…

Asset Management actions/decisions

- **Inspection**
- Repair
- Maintenance
- **Life extension**
- Traffic disruption

SHM strategy and tools

- Type of sensor: **SG, thermometers, traffic classification**
- Number of sensors: **20**
- Location of sensors: **3**
- Data acquisition: **permanent monitoring**/periodic
- Performance indicator: **SN fatigue loading, fatigue lives**

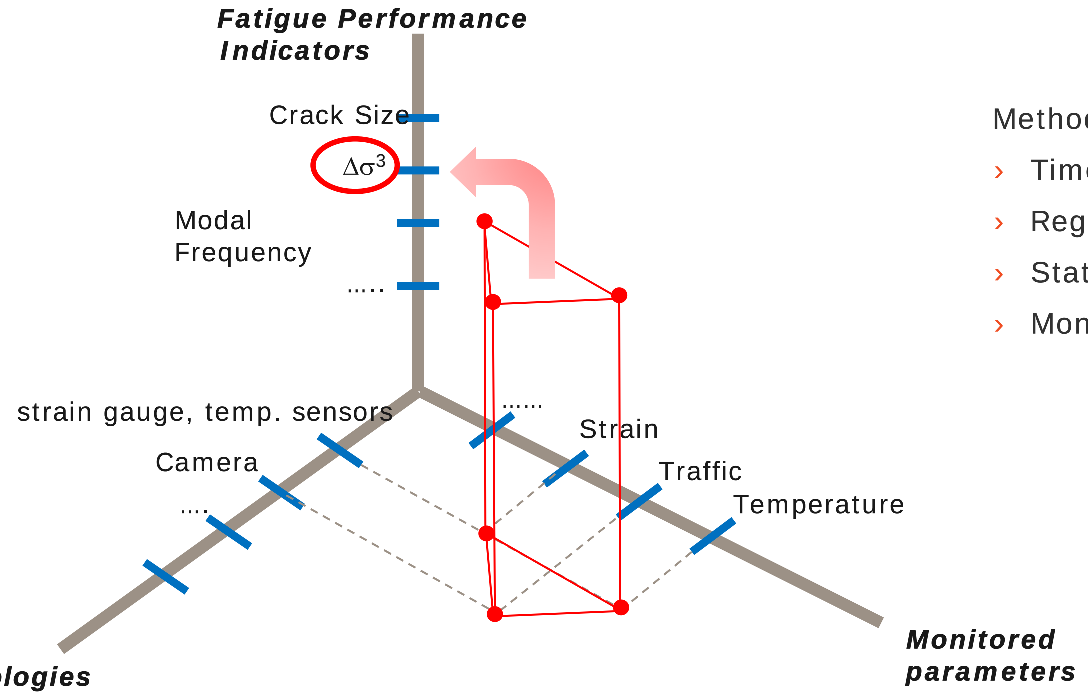
- SHM approach:
  - **Data-based** / model-based
  - Global / **local**
- Tools:
  - **Regression models, tim-series models, MCS**, FFT, SSI, Bayesian networks, **SRM**, etc,,,

› A local, data-based approach

› Study of critical components and relevant deterioration mechanisms.

› "Damage" locations are assumed a-priori.

An overview of the case study



SHM strategy

Methods and tools:

- Time-series models
- Regression models
- Statistical control charts
- Monte Carlo Simulation

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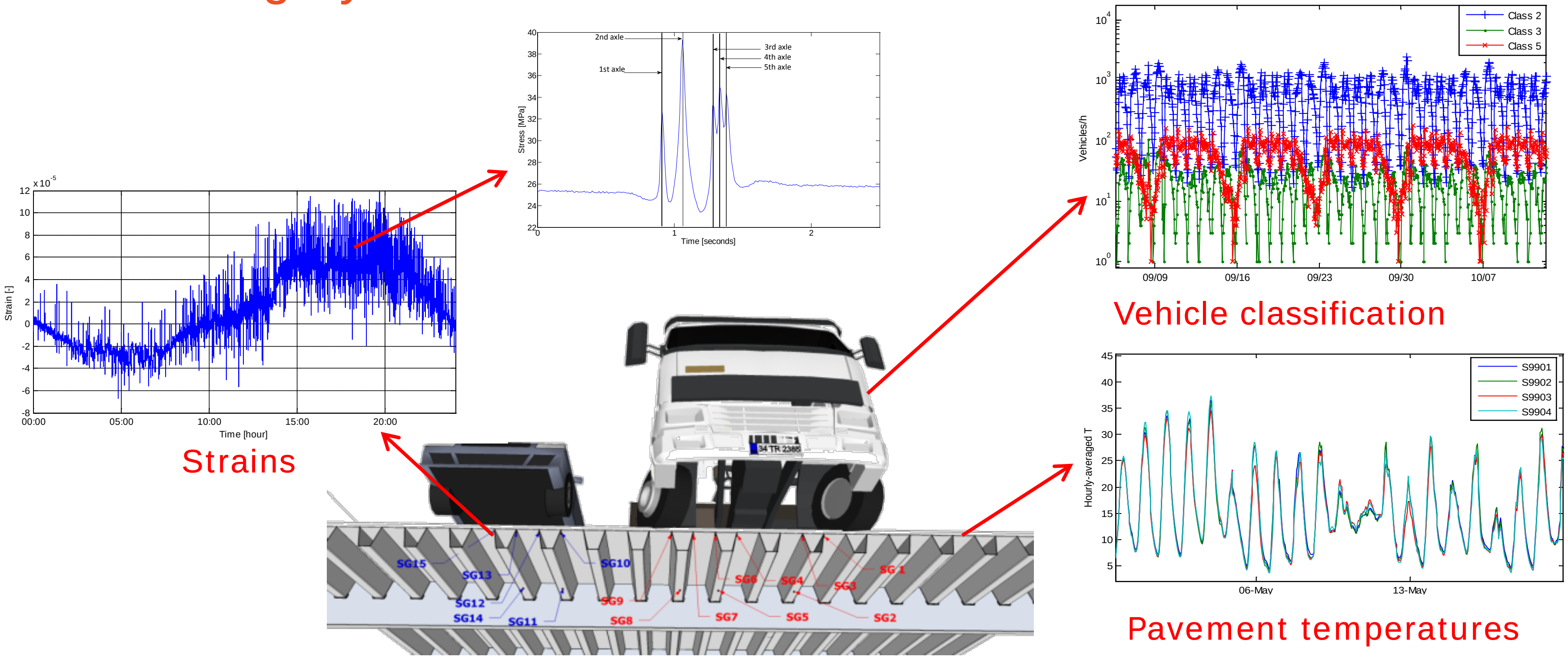
Monitoring system



SHM applications

- Performance prediction *(prognostics)*
  - AIM: Determination of remaining fatigue lives.
  - Short-term monitoring campaigns. Long-term infrastructure management.
- Performance assessment *(diagnostics)*
  - AIM: Determine if the component is behaving as expected.
  - Continuous monitoring-data. Short-term infrastructure management.
- Need to develop models (load/response prediction and data interpretation)

Regression models for SHM

- Performance indicator: SN fatigue loading $$D_{\Delta t}(t) = \sum_{i=1}^{N_c} \Delta\sigma_i^3$$

- Characterization of the correlation patern among heavy traffic counts, pavement temperature and fatigue loading at welded joints.

- Daily time discretization

Regression parameters

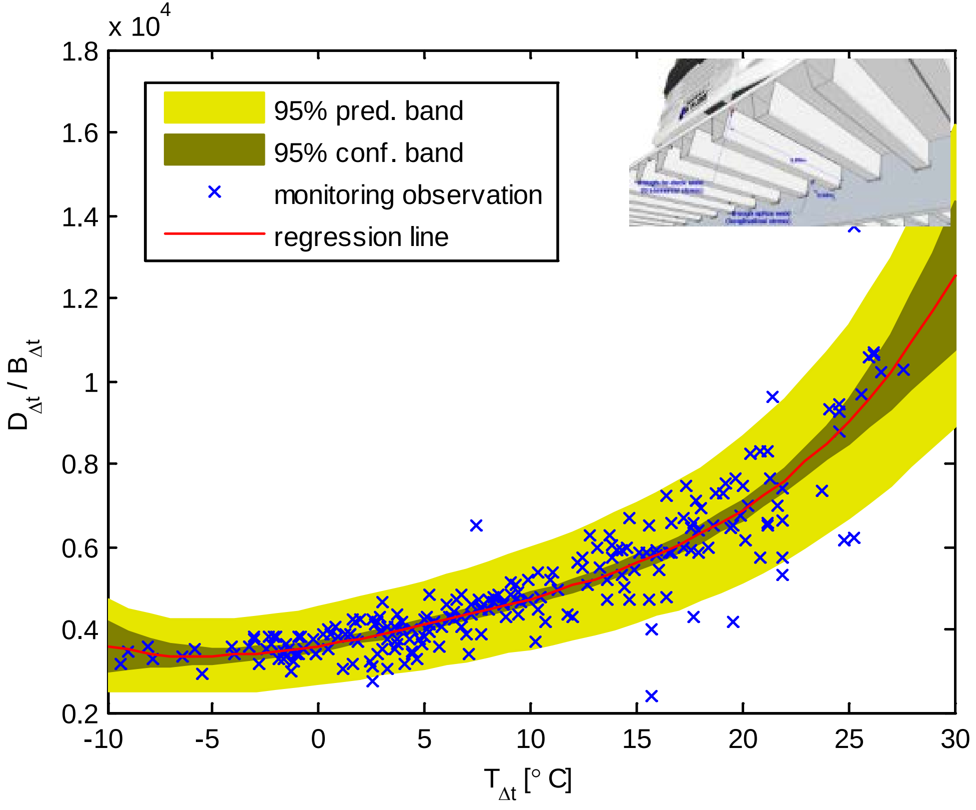
SN fatigue loading

$$\frac{D_{\Delta t}(t)}{B_{\Delta t}(t)} = \left(\sum_{i=1}^{p+1} \theta_{i-1} \cdot T_{\Delta t}(t)^{i-1} \right)$$

Daily count heavy vehicles
Daily count heavy vehicles

Daily-averaged pavement temperature

Regression models for SHM



Daily SN fatigue loading

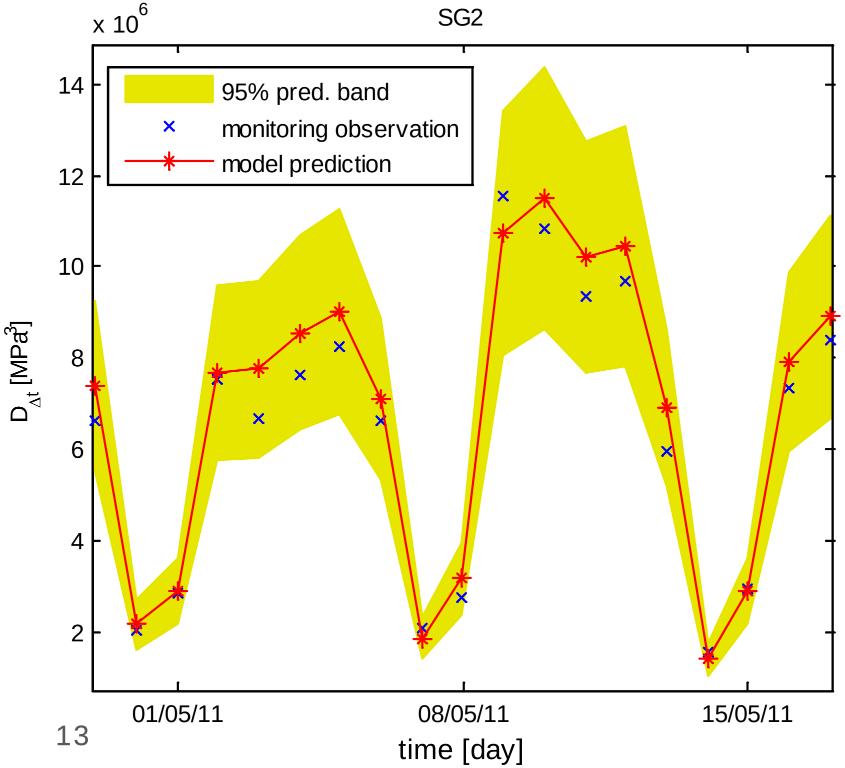
Regression parameters

$$\frac{D_{\Delta t}(t)}{B_{\Delta t}(t)} = \left(\sum_{i=1}^{p+1} \theta_{i-1} \cdot T_{\Delta t}(t)^{i-1} \right)$$

Daily count heavy vehicles

Daily-averaged pavement temperature

Regression models for SHM

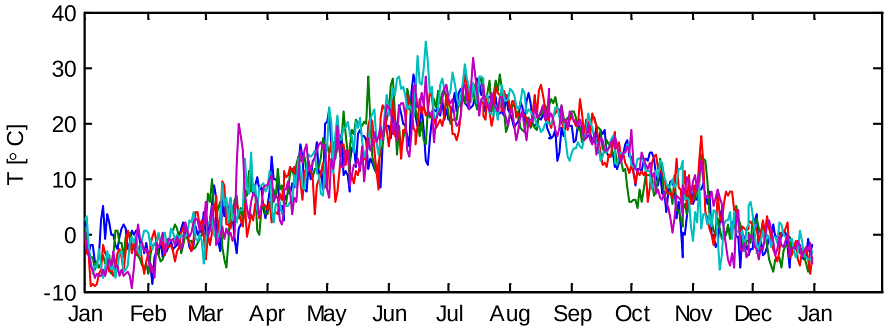


- Normal correlation pattern characterized using a training dataset.
- Under no time-varying effects, structural performance can be predicted by monitoring temperatures and traffic counts (usage monitoring)
- Applications: life prediction, performance assessment.

Temperature modelling

› Autoregressive models of 1st order to model deseasonalized daily-averaged pavement temperatures

Temperature simulation



$$\bar{T}_t = \alpha_1 \cdot sin(\alpha_2 \cdot t + \alpha_3) + m_T$$

$$T_t^* = \frac{T_{\Delta t}(t) - \bar{T}_t}{\sigma_{T,t}}$$

$$T_t^* = \varphi_{T,1} \cdot T_{t-1}^* + \epsilon_{T,t}$$

Traffic modelling

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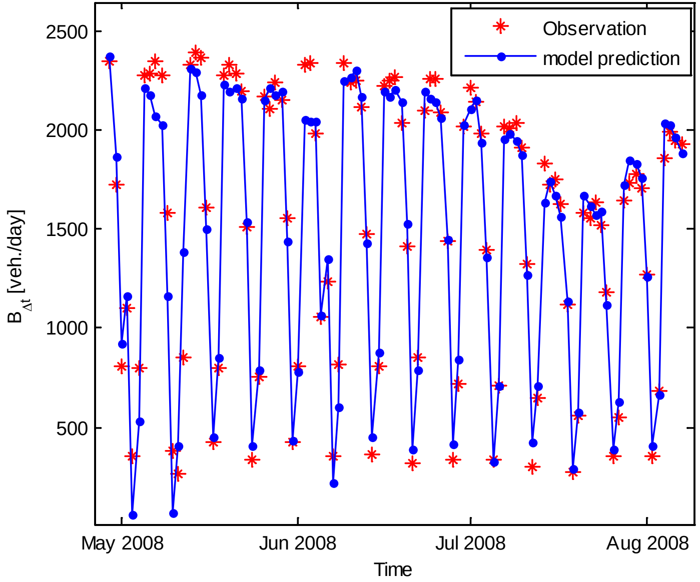
- Deseasonalization of heavy traffic daily counts
- Regression models to account for day-of-the-week and holiday effects
- Autoregressive models are fitted to the residuals of the regression models.



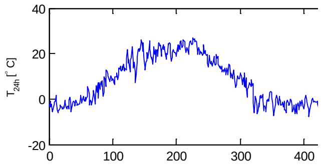
$$B_t^* = \frac{B_{\Delta t}(t) - \mu_{B,t}}{\sigma_{B,t}}$$

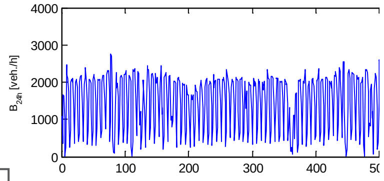
$$B_t^* = \lambda_1 + \lambda_2 X_{2,t} + \cdots + \lambda_k X_{k,t} + \epsilon_{B,t}$$

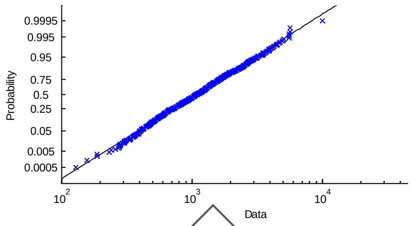
$$\epsilon_{B,t} = \sum_{i=1}^{p} \varphi_{B,i} \cdot \epsilon_{B,t-i} + \nu_t$$

Application 1: Fatigue life prediction

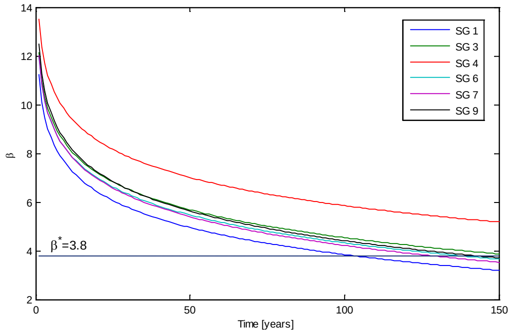
Simulation of actions, i.e. traffic and temperature *(time-series models)*



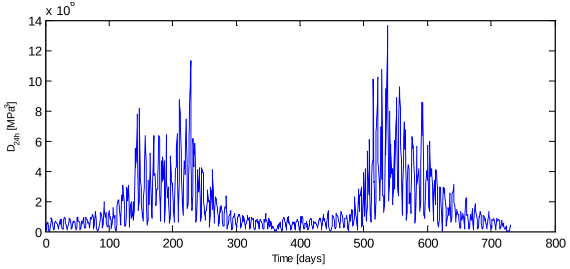




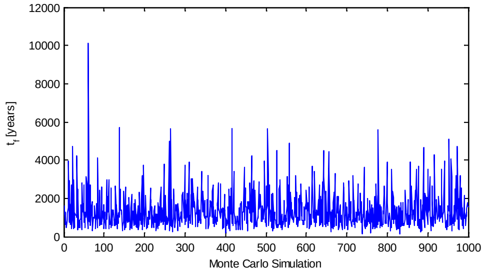
Fatigue life calculation *(reliability profile)*

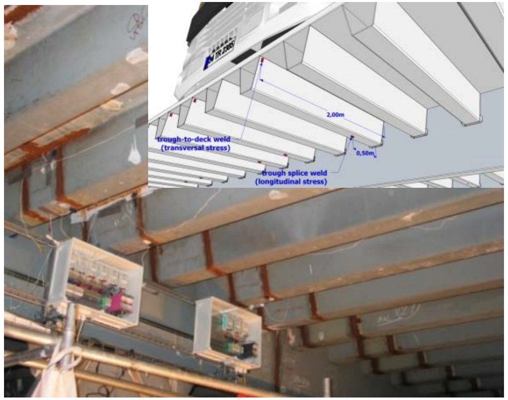


Simulation of fatigue loading *(regression models)*



Monte Carlo simulation: time to failure realizations *(S-N LSF)*



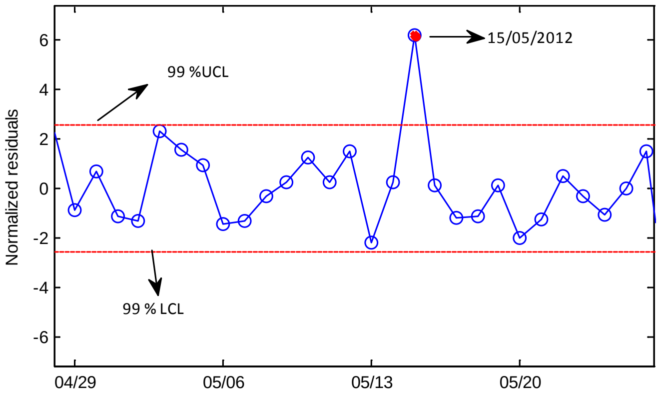


Application 1: Fatigue life prediction

- Assessment of the impact of different scenarios of pavement temperatures (climate change) and heavy traffic intensities.
- Easy-to-understand output: fatigue lives [years]
- Tool for informing long-term infrastructure management decisions (e.g. inspection scheduling).

Application 2: Performance assessment

› Development of an algorithm for identifying abnormal behaviours based on statistical control charts of the regression models.



$$Z \simeq \left(\sum_{i=1}^{p+1} \theta_{i-1} \cdot {T_0}^{i-1} - \frac{D_{\Delta t}(T_0)}{B_{\Delta t}}_{monitored} \right) \cdot \frac{1}{\sqrt{s_{tot}^2}}$$

› *Detection of abnormal behaviour on 15/05/2012.*

› *Cause: Diversion of traffic due to maintenance activities.*

› *Tool for informing short-term infrastructure management decisions.*

Concluding remarks (1/2)

- Case study presented: SHM of welded bridge joints of the Great Belt Bridge
- Strategy followed:
  - Local, data-based approach
  - Focus on critical components under critical deterioration mechanisms, i.e. fatigue
  - Performance indicators chosen: SN fatigue loading and remaining fatigue lives
- Tools:
  - regression models
  - time-series models
  - statistical control charts
  - MCS for fatigue reliability assessment
- Definition of two applications and associated methodologies:
  - life prediction (long-term management)
  - performance assessment (short-term management)

Concluding remarks (2/2)

- SHM strategies and tools depend on the Asset Infrastructure Management aims and on the available budget.
- Need for a formal framework to define SHM strategies and tools.
- Environmental/operational loads and sources of uncertainty to be considered.
- Final output shall be easy to understand
  - Remaining lives [years]
  - Detection of abnormal behaviour [YES/NO]
- Benefit of targeting specific components with known deterioration mechanisms.
- Data-based models have the potential to be scalated to other structures subject to the same deterioration mechanism, but rely highly on the data quality and quantity.

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Thank you for your attention.

Questions?

References:

[2015] Fareras-Alcover, I. Chryssanthopoulos, M.K., Andersen, J.E. Regression Models for Structural Health Monitoring of Welded Bridge Joints based on Temperature, Traffic and Strain Measurements. *International Journal of Structural Health Monitoring*. In press.

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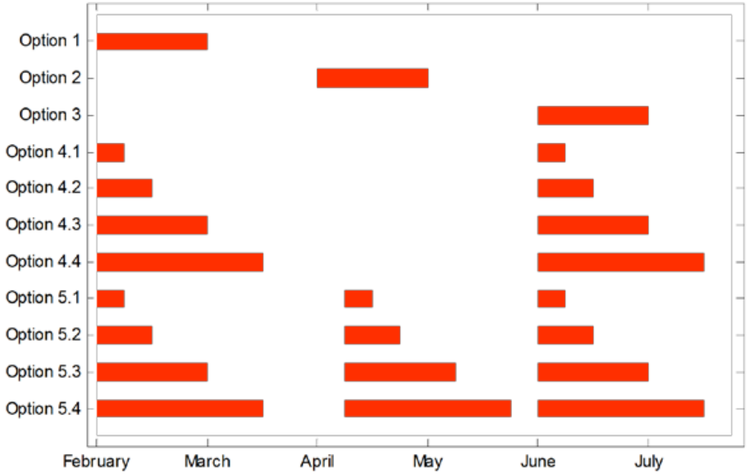
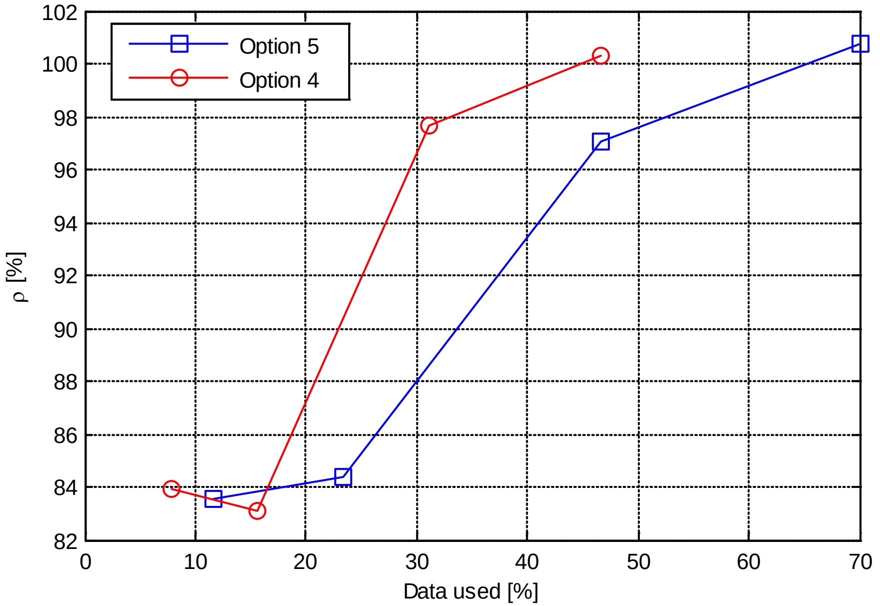
Temporal requirements for fatigue life prediction

› Monitoring options considered



› Accuracy in fatigue life prediction Vs. size of the training dataset used



*Using **33 % of the data leads to a 98 % of accuracy** in determining the fatigue lives.*

Application: Fatigue life prediction

Methodological steps

- Definition of SN limit state function
- Performance of Monte Carlo Simulation
- Simulation of temperatures, traffic and SN fatigue loading based on developed models
- Determination of fatigue-lives realizations
- Calculation of time-varying fatigue reliability profiles