The predictability of corrosion

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Corrosion cannot be stopped

Can we extend the lifetime of this car?
Preventive maintenance

When should that maintenance be planned?
Solution: Protective coatings

Not all zones of the protective coating have the same efficiency
Solution: Change the environment

Some environments can be made less corrosive
Problem: Corrosion rate depends on many factors

Sensitivity object:
Russian cars vs. American cars

Environment:
Sea water

Sensitivity of objects & corrosivity of environment is variable
Problem: How to predict corrosivity of environment?

Is our current knowledge sufficient?
Alternative approach to estimate corrosion risk

Degradation of materials
- Reduction of performance
- Reduction of reliability
- Reduction of lifespan

**INPUT**

- Hazard: Continuous exposure to environmental parameters
- Hazard: Exposure to a series of undesired situations

**OUTPUT**

- Harm: Continuous increase of harm but with variable rate
- Harm: Incremental increase of harm but step size is variable

Graphs showing accumulated harm over environmental parameters.
Alternative approach to estimate corrosion risk

Degradation of materials
- Reduction of performance
- Reduction of reliability
- Reduction of lifespan

**INPUT**

**Hazard**: Continuous exposure to environmental parameters

**Harm**: Continuous increase of harm but with variable rate

**OUTPUT**

MODEL 1

**Hazard**: Exposure to a series of undesired situations

**Harm**: Incremental increase of harm but step size is variable

**OUTPUT**

MODEL 2

Accumulated Harm

Environmental parameter

Step size
Model 1
Estimate corrosion risk from environmental parameters
1. According to your expertise, what is the highest quantity of a given parameter at which there is no observable corrosion, faintly observable corrosion, or corrosion at an acceptable low rate?

2. According to your expertise, what is the lowest quantity of a given parameter at which the corrosion rate is unacceptable high?
Model: No unique answers due to uncertainty

- Meaning of questions is not completely clear
- Expert has insufficient knowledge to give an exact answer
- Knowledge from laboratory experiments is not valid in the real world
- Differences in material sensitivity between similar objects
- Synergetic effects between parameters vary when parameters change
- Experts do not see themselves as experts and refuse to answer the question
- Experts endure cognitive biases

Given the current knowledge, we cannot do better
Model: Bring the answers of experts together

Use expert intuition to create a quantitative model
1. According to your expertise, what is the highest quantity of a given parameter at which there is no observable corrosion, faintly observable corrosion, or corrosion at an acceptable rate?
   
   **Answers:** 0.5, 0.6, 0.7, 0.8

2. According to your expertise, what is the lowest quantity of a given parameter at which the corrosion rate is unacceptable high?

   **Answers:** 2.3, 2.5, 3

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*Hypothetical example: Collect all the answers*

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*Where was the American Declaration of Independence signed?*

*At the bottom.*

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*Here it is*
Hypothetical example: Statistical processing

Answers contain information about the risk that corrosion occurs
Hypothetical example: Determine risk relation

Determine the nodes of the risk vs. parameter relation
Hypothetical example: Determine average risk

Effects of synergetic effects are considered in the risk trend.
Real case: Air quality in the church of Aalst

Monitor environmental parameters over time
Real case: Air quality in the church of Aalst

Convert measurements into risk assessments
Model 2

Consider environment as a series of randomly occurring stressful moments
Model: Behaviour of the environment

- A hazard generates a series of N stressful moments (undesired situations)
- Every stressful moment is characterized by an apparent force (stressor)
- The apparent force triggers a stress response in objects

Describe environment by N situations each with a random stress
Model: The protection shield

• There can be a protection shield between the objects and environment

• Small stresses below a constant threshold value will not affect the objects

• That threshold describes the fragility of the protection shield

Fragility of protection shield is described by 1 threshold value
Model: Consequence for objects

- Set of $M$ objects is exposed to the same environment
- The object is characterized by a sensitivity towards stress
- The object is characterized by resilience: applied stress has no long-term effect when it is below the resilience threshold
Model: Increment in harm vs. environmental stress

M objects have random sensitivity
Model: Increment in harm vs. environmental stress

M objects have random resilience
Sensitivity, resilience and stress are random variables.

- **Resilience > Stress:** Objects will not be affected by the hazard.

- **Resilience < Minimum stress:** Objects will be affected by all undesired situations.

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**Hypothetical example:** Description of the model
Hypothetical example: Accumulation of harm

Objects accumulate harm over time. The higher the sensitivity, the faster harm accumulates. Accumulated harm increases in jumps.
Hypothetical example: Distribution of harm

Almost all objects have no harm

Objects have similar amount of harm
Hypothetical example: Distribution of harm

Set of M objects have random sensitivity and resilience

- Some objects are not affected by the hazard
- Some objects are affected by all undesired situations

Graph showing the distribution of harm after 160 undesired situations.
Hypothetical example: Distribution of harm

Set of M objects have random sensitivity and resilience
Hypothetical example: Distribution of harm

Set of M objects have random sensitivity and resilience
Hypothetical example: Distribution of harm

Difference between slowest & fastest harm accumulation becomes larger

Some objects accumulate harm extremely slowly

Some objects accumulate harm extremely fast
Hypothetical example: Distribution of harm

First object that reaches the maximum damage (end of lifetime) determines the reliability of the complete set.

Maximum damage & end of lifetime is reached.
Real case: Model resembles a marathon

- Huge amount of people start the marathon
- The leading group becomes smaller over time
- There is only 1 person who will win
- The winner takes it all
- The distance between the slowest & fastest person becomes larger over time

How to use the model in a quantitative way?
Real case: Is this model meaningful?

Environmental parameters show many peaks.
Conclusions
Models are based on expert intuition

Model 1: Estimate corrosion risk from environmental parameters
- Model can be calibrated
- Based on expert intuition
- Corrosion rate $\Rightarrow$ risk for unacceptable corrosion
- Visualize periods with enhanced risk for corrosion

Model 2: Consider environment as a series of stressful moments
- Environmental data show many peaks
- Short moments can dominate the majority of harm
- Both models should be considered at the same time
- Evolution of accumulated harm can be predicted
Some literature

- Anaf W., Leyva Pernia D., Schalm O., 2018, Standardized indoor air quality assessments as a tool to prepare heritage guardians for changing preservation conditions due to climate change, Geosciences, 8:8, 276

- Anaf W., Schalm O., 2019, Climatic quality evaluation by peak analysis and segregation of low-, mid-, and high-frequency fluctuations, applied on a historic chapel, Building and Environment 148, 286–293

Thank you