On the Role of Numerical Modelling of Reinforcement Corrosion for Sustainable Concrete Structures
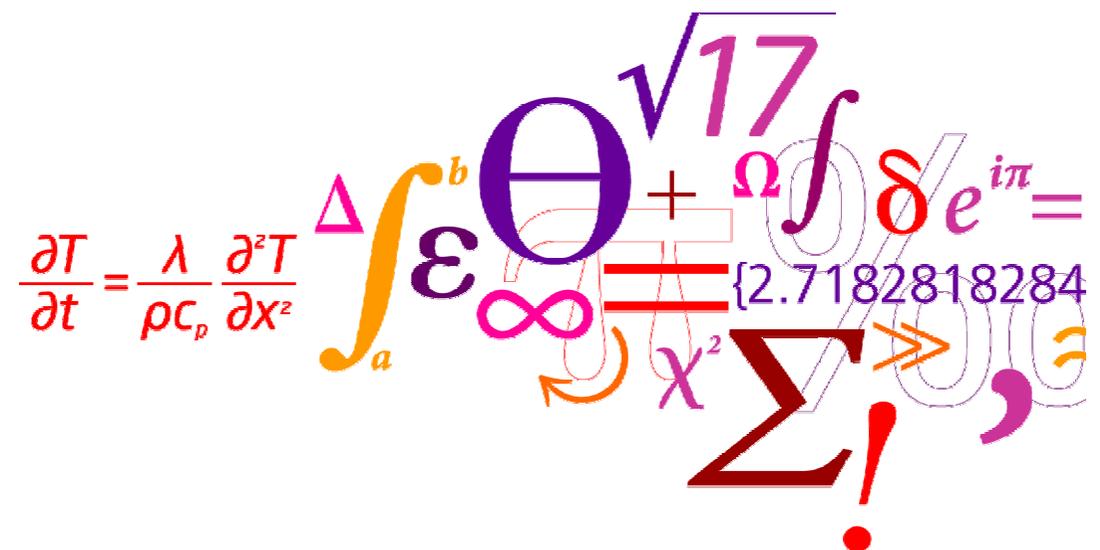
H. Stang, M.D. Lepech, M. Geiker

DTU Civil Engineering
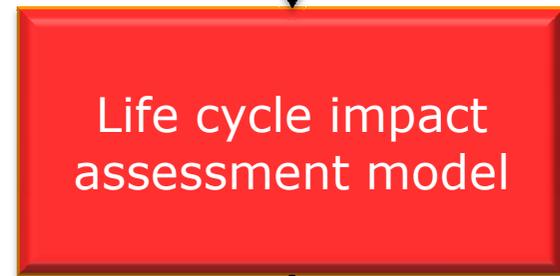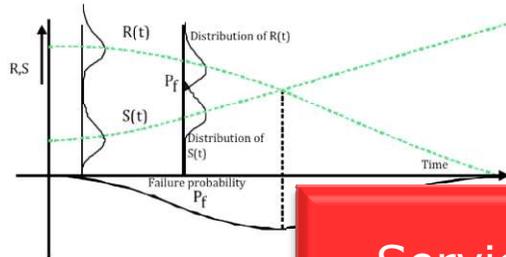Department of Civil Engineering

Outline

- Intro: Durability in a sustainability context
- Service life models – reinforcement corrosion
- Sustainability framework for service life models
- Conclusions and outlook

What is durability?

- This question cannot be answered without *quantitative* tools
- *Service life models* provide such tool
- Service life models represent a *choice* of deterioration *mechanisms* and associated *models* and *limit states*
- Deterioration models involves complex, interdependent (coupled) processes
- Eventually service life models must be formulated in a probabilistic fashion and deal with a range of mechanisms, limit states and loading scenarios to be able to answer a simple question like 'what is the expected increased in service life is the concrete cover is increased with 40 mm?'

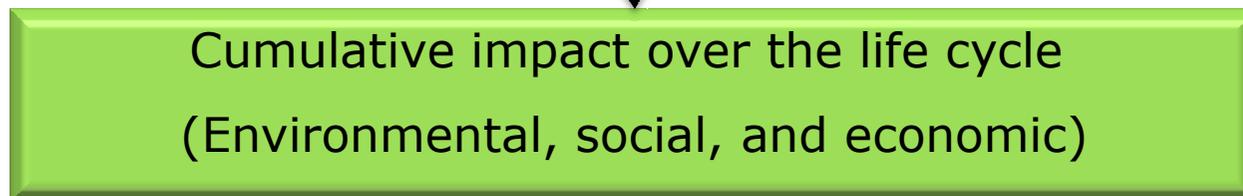# Durability in a sustainability context - what is sustainability?

(Existing *fib* model – or other models)

Service life model

Life cycle inventory model

Life cycle impact assessment model

Involves choice of deterioration mechanisms and limit states

Life cycle assessment model

Involves choice of environmental impact indicators

Cumulative impact over the life cycle (Environmental, social, and economic)
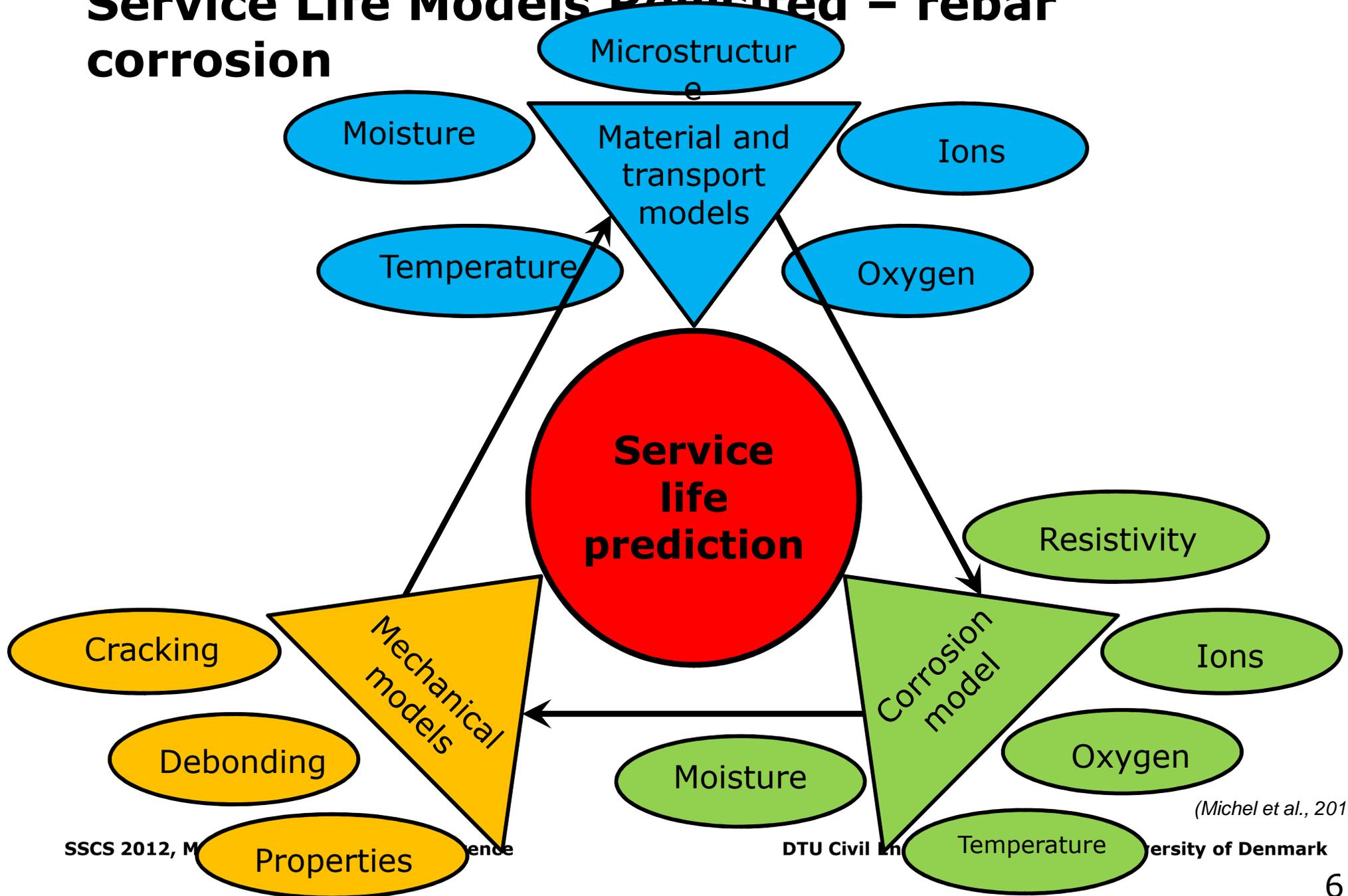
Service Life Models Revisited – Rebar corrosion

Underlying hypothesis:

A service life model, which is able to take into account the conditions of real structures, i.e. the presence of cracks, defects, varying reinforcement surface conditions and more, has to deal with the **propagation phase** as well as the initiation phase and it has to be rest on a probabilistic foundation
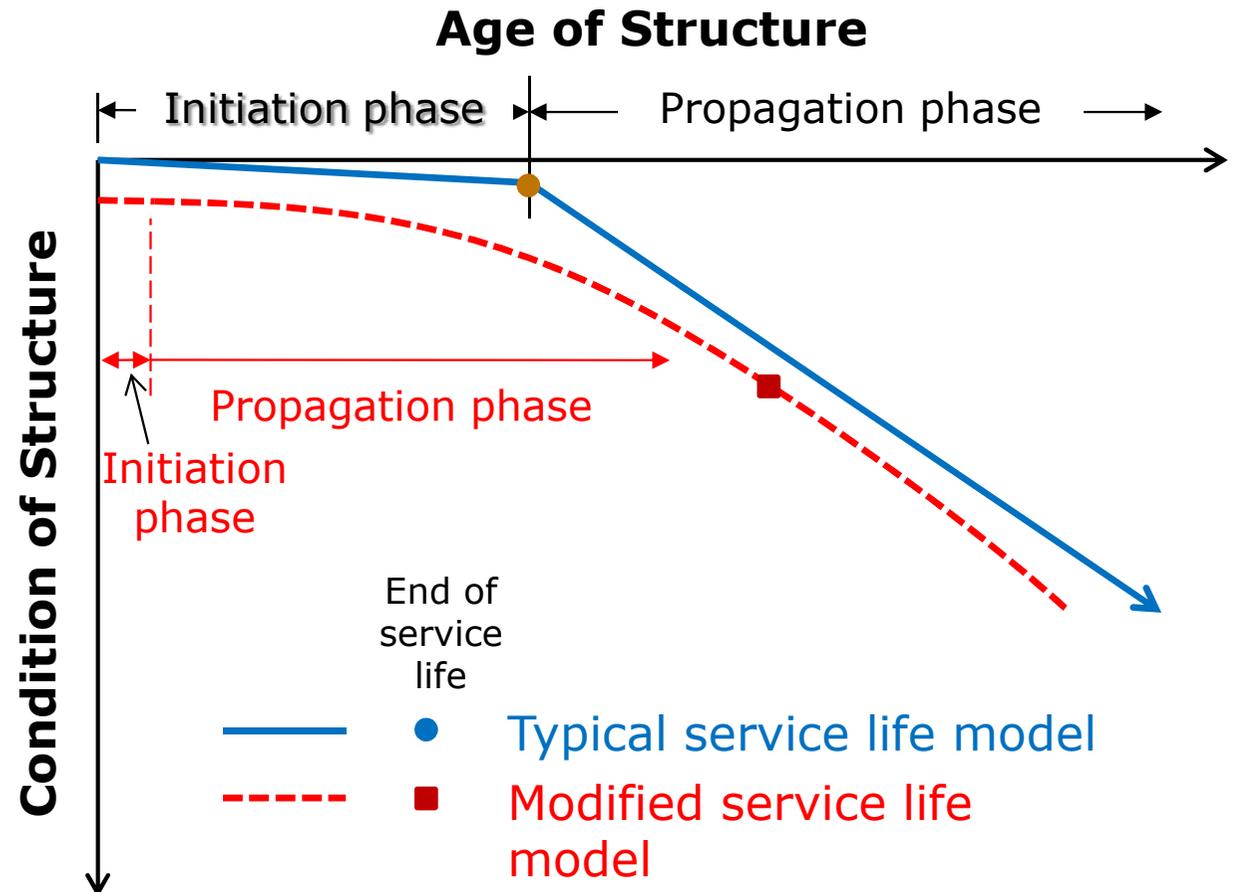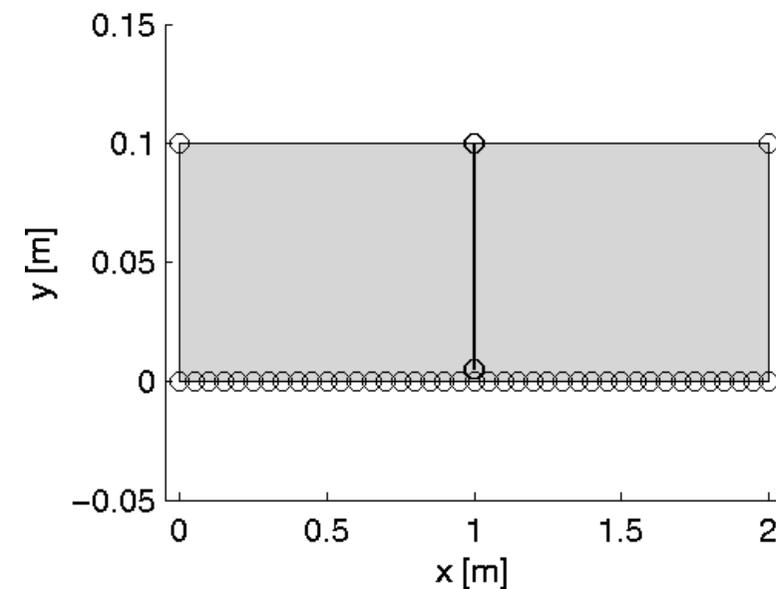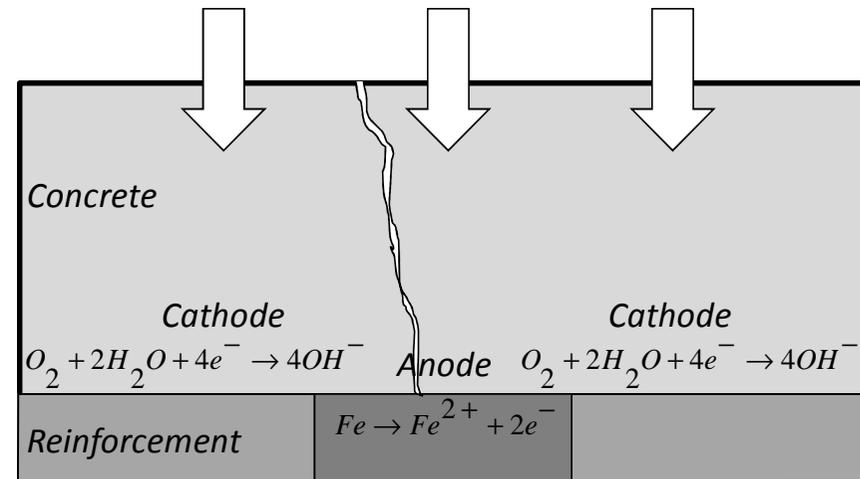

(Pease et al., 2012)

Service Life Models Revisited – rebar corrosion


(Michel et al., 2010)

Service Life Models Revisited – rebar corrosion

Multi-phase model:

- Varying material properties and defects, cracks
- Transport processes
- Material properties
- Anodic and cathodic sites form "randomly"

- Electrochemical processes (preselected)

Moisture, temperature, oxygen, chloride, carbon dioxide

Concrete

Cathode

Cathode

$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ Anode $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

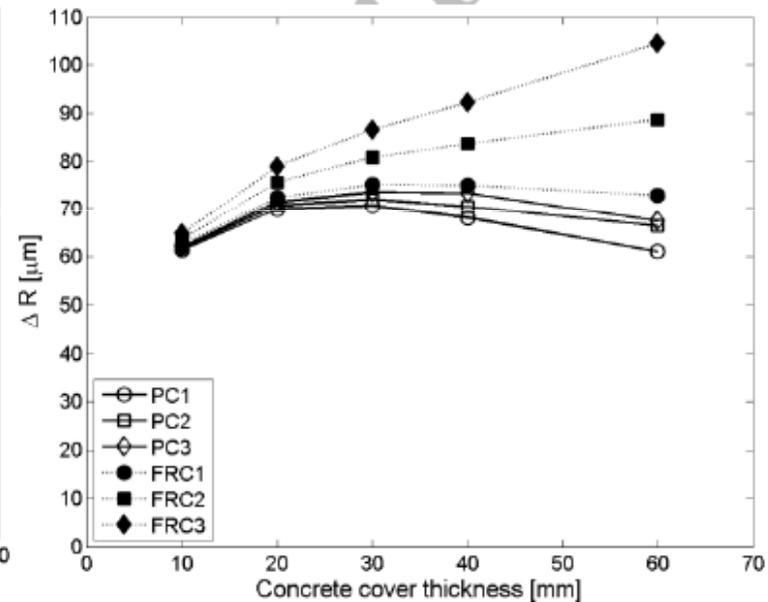Reinforcement $Fe \rightarrow Fe^{2+} + 2e^-$

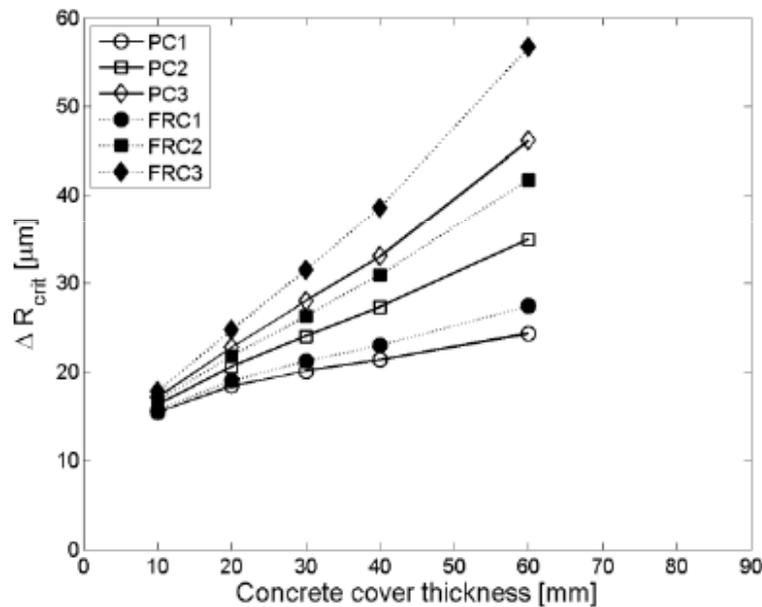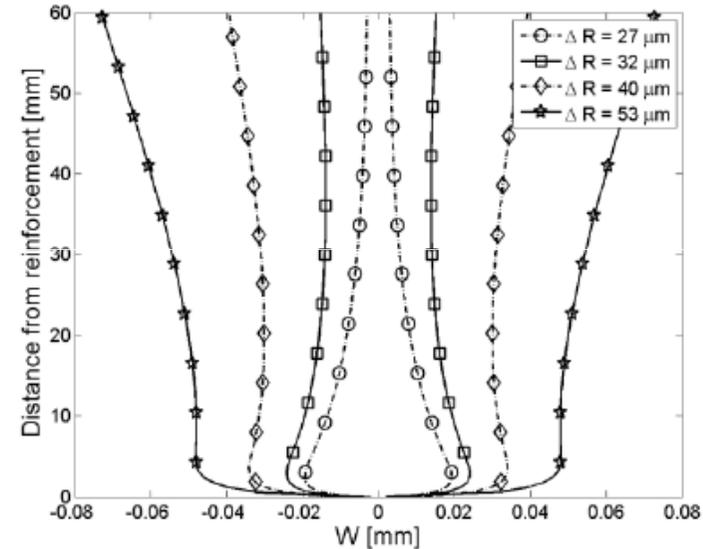# Service Life Models Revisited – rebar corrosion
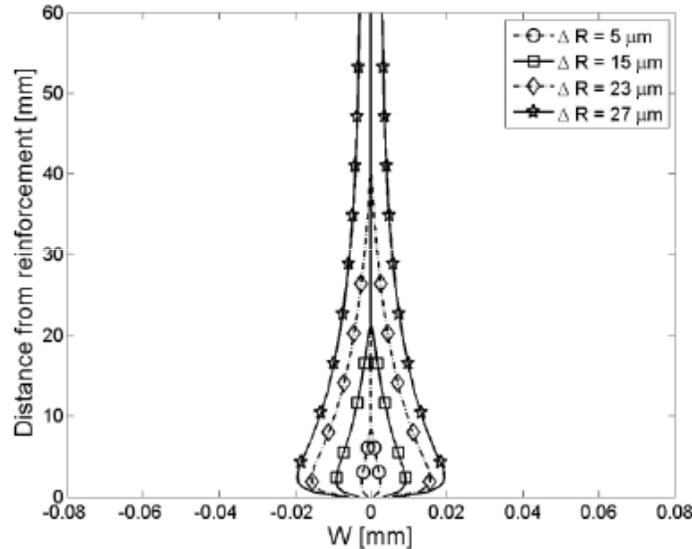
Results for selected times (black - 18.6 years, blue - 21.8 years, red - 24.8 years and green - 37.3 years)
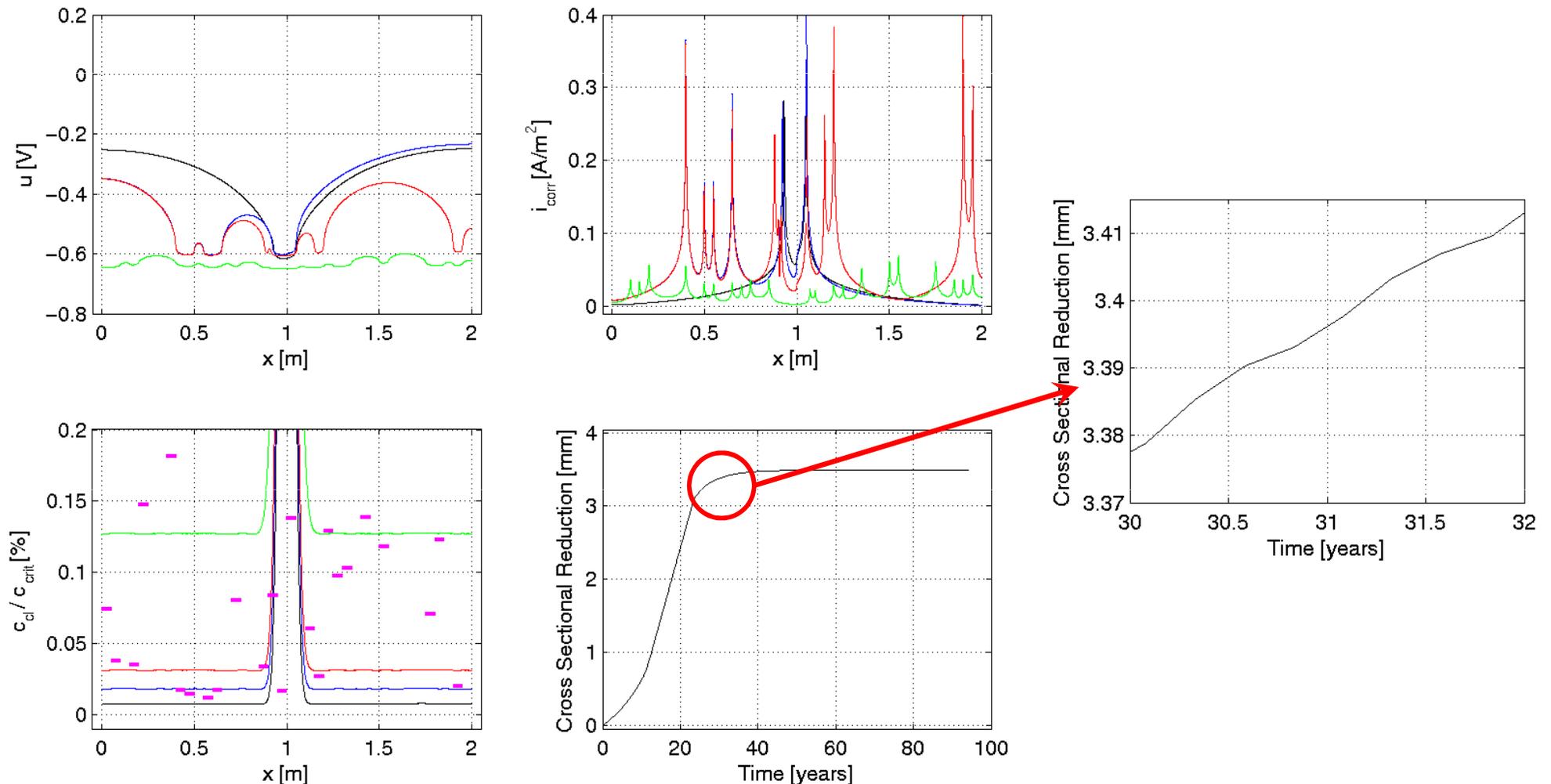
Meso-scale modeling: rebar expansion due to corrosion

$$\Delta R < \Delta R_{crit,c} \qquad \Delta R = \Delta R_{crit,c} \qquad \Delta R > \Delta R_{crit,c}$$
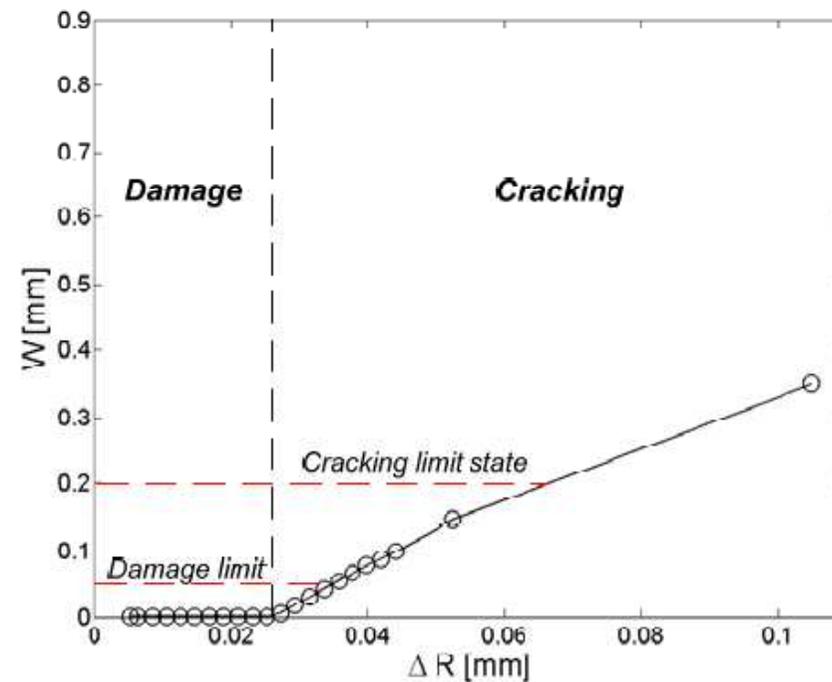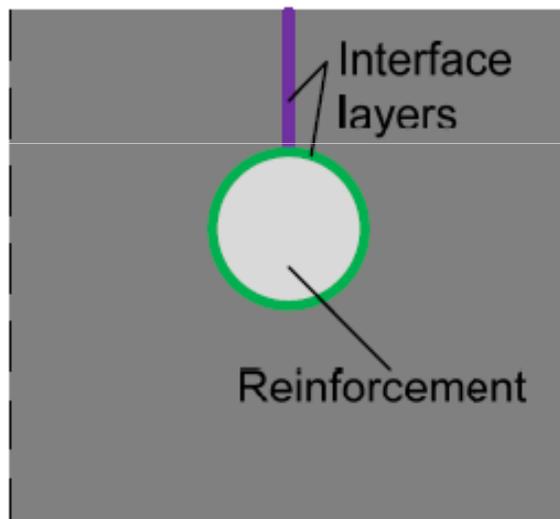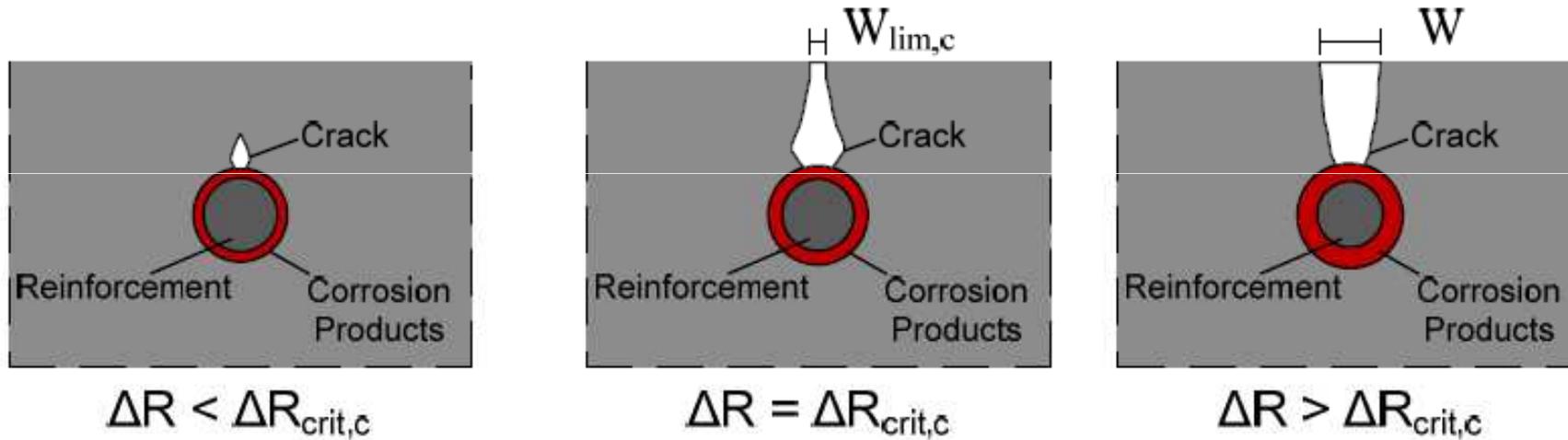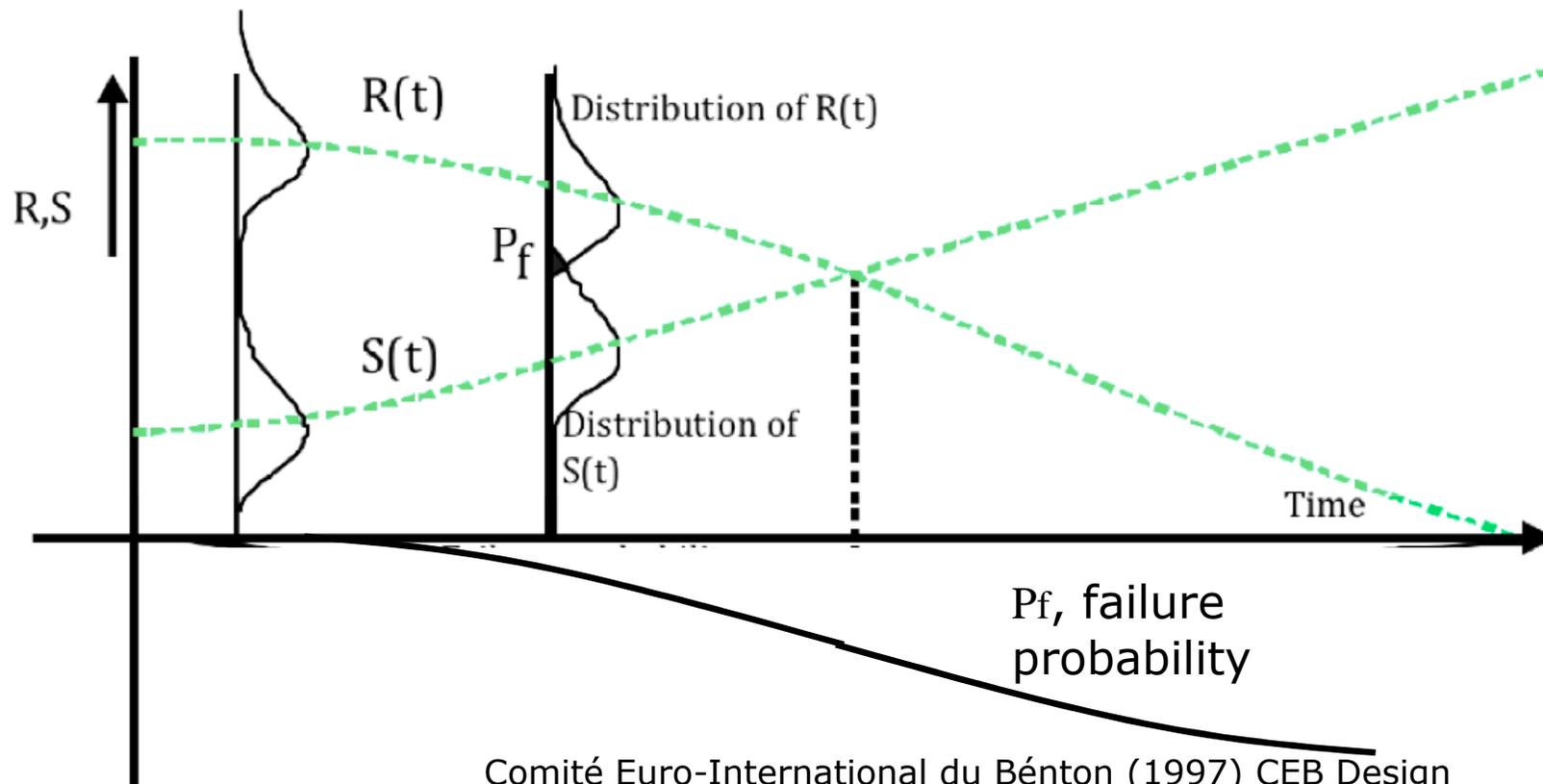
Meso-scale modeling: rebar expansion due to corrosion – parametric studies
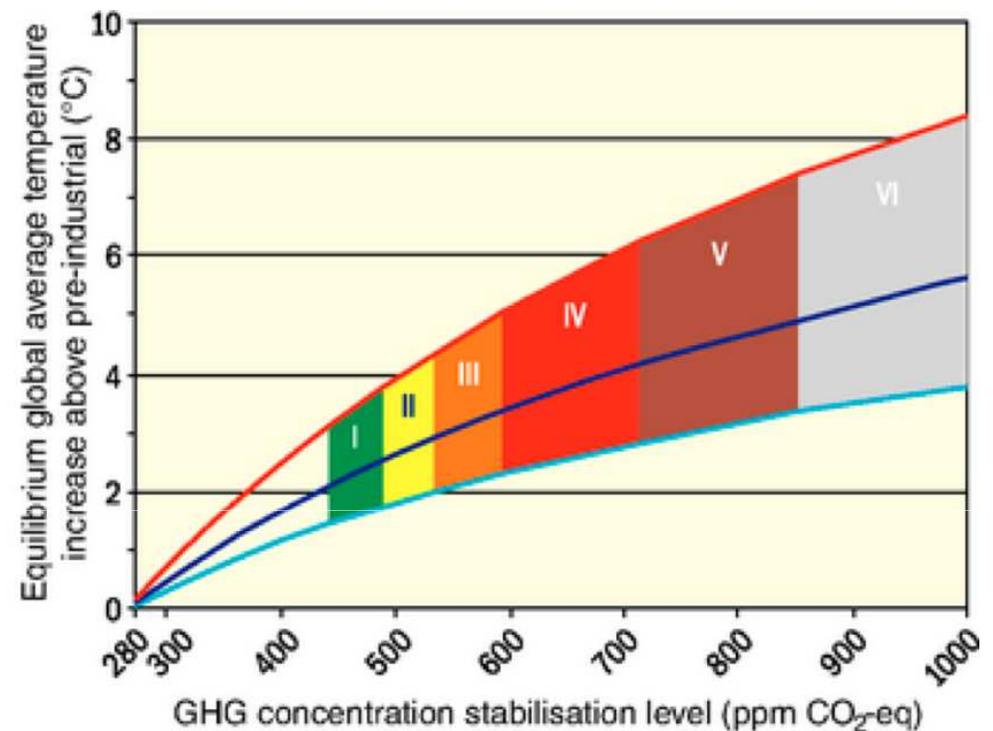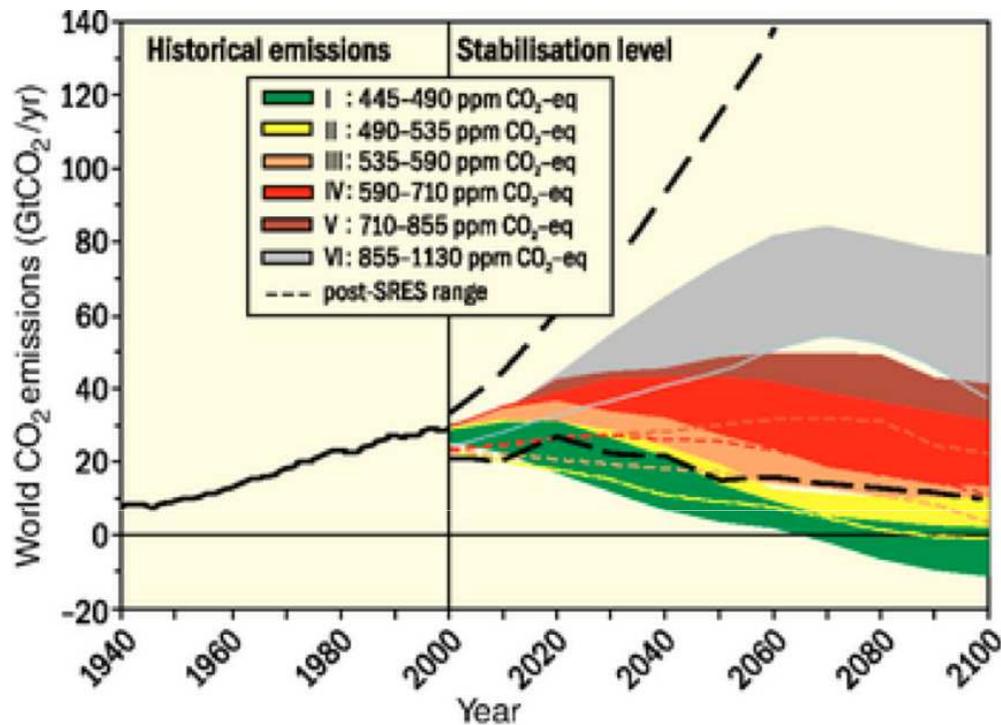
Design for sustainability – the *fib* 2010 Model Code Approach

Sustainability performance requirement, R, and environmental impact performance, S and ensure that R>S.

Comité Euro-International du Bénton (1997) CEB Design Guide for Durable Concrete Structures *Thomas Telford Services, Ltd*. London.

Design for sustainability – Sustainability performance, R(t)

Design for Sustainability – Environmental impact performance, S(t)
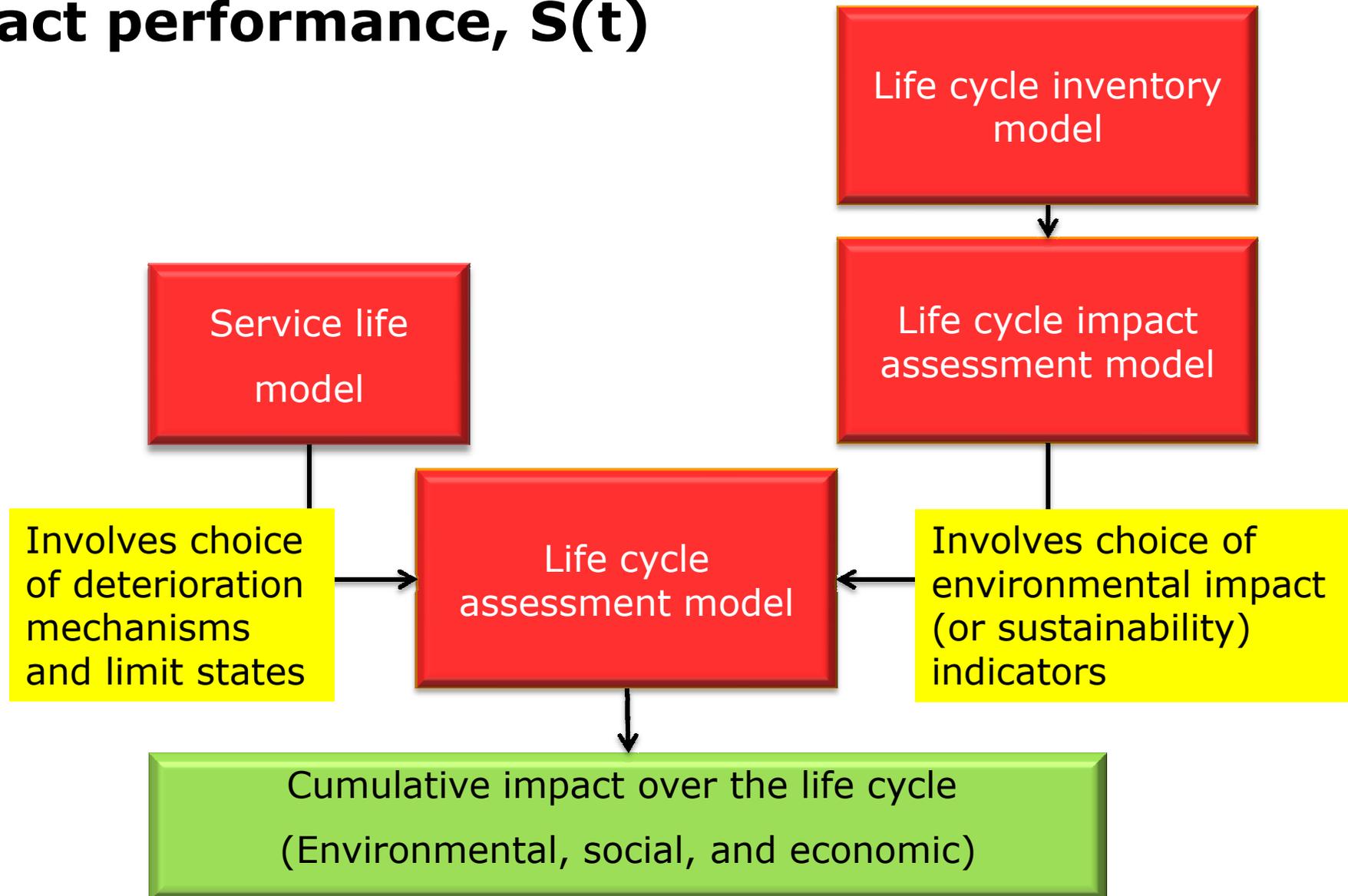
Life cycle inventory model

Service life model

Life cycle impact assessment model

Involves choice of deterioration mechanisms and limit states

Life cycle assessment model

Involves choice of environmental impact (or sustainability) indicators

Cumulative impact over the life cycle
(Environmental, social, and economic)
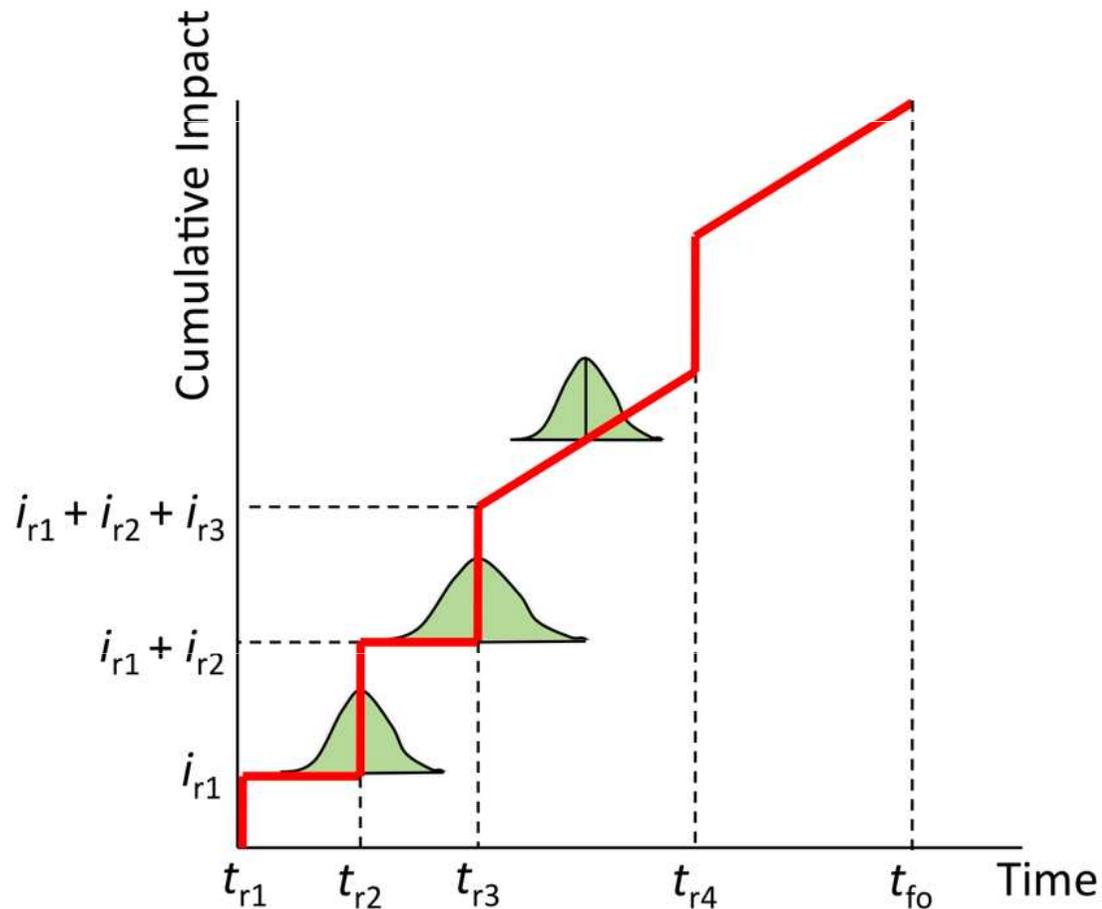
$$I = \sum_{j} i_{rj}(t)$$

Designing for Sustainability - Probabilistic prediction of environmental impacts
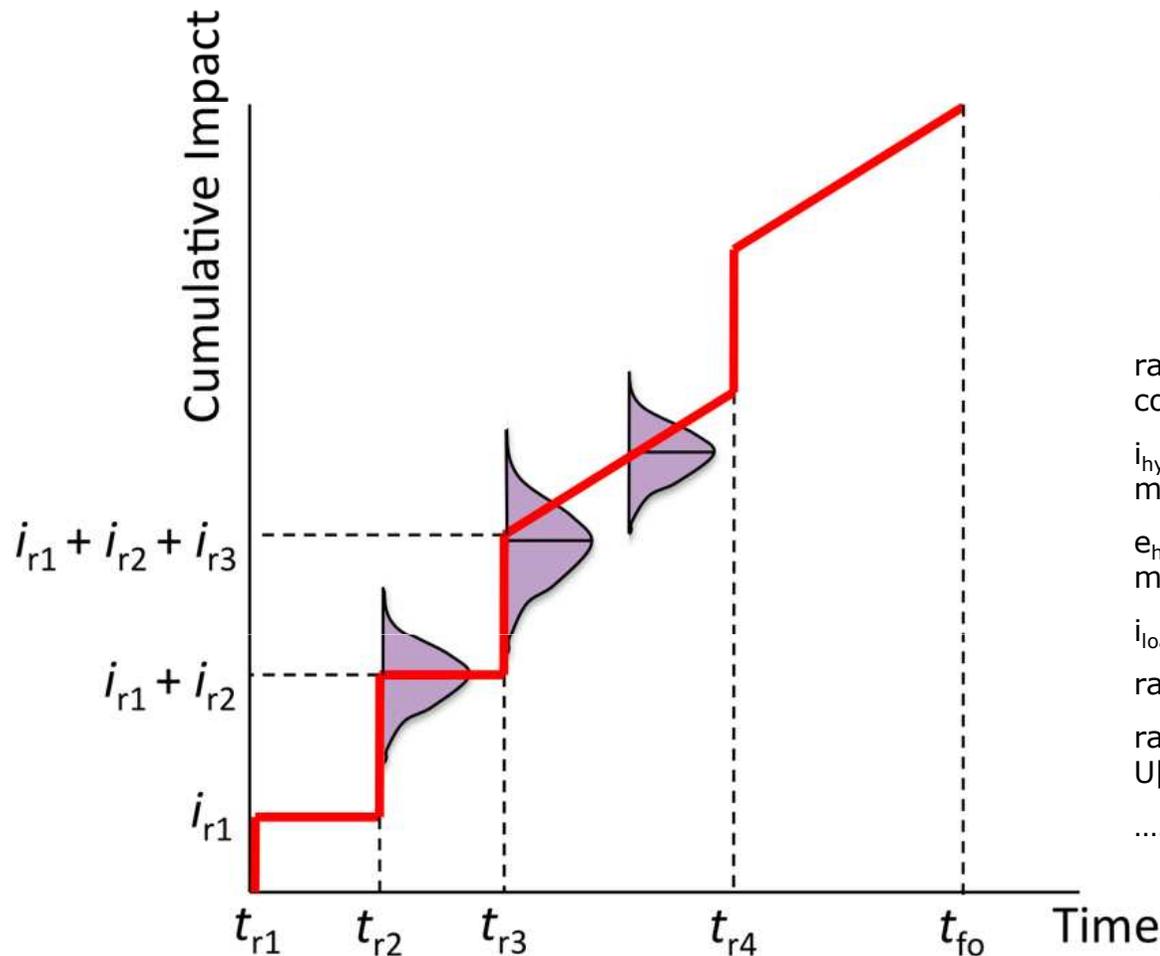
ISO 14040 Life Cycle Modeling:

Scope – Inventory – Database (e.g. SigmaPro)

$rate_{aircompressor}$ = energy consumption of air compressor = U[48,111]hp

$i_{hydromachine}$ = impact of a hydrodemolition machine per m^2 of repair

$e_{hydromachine}$ = power consumption of hydrodemo machine = U[250,750]kW

i_{loader} = impact of a front end loader per m^2 of repair

$rate_{loader}$ = productivity of loader = $150 m^3$/hr
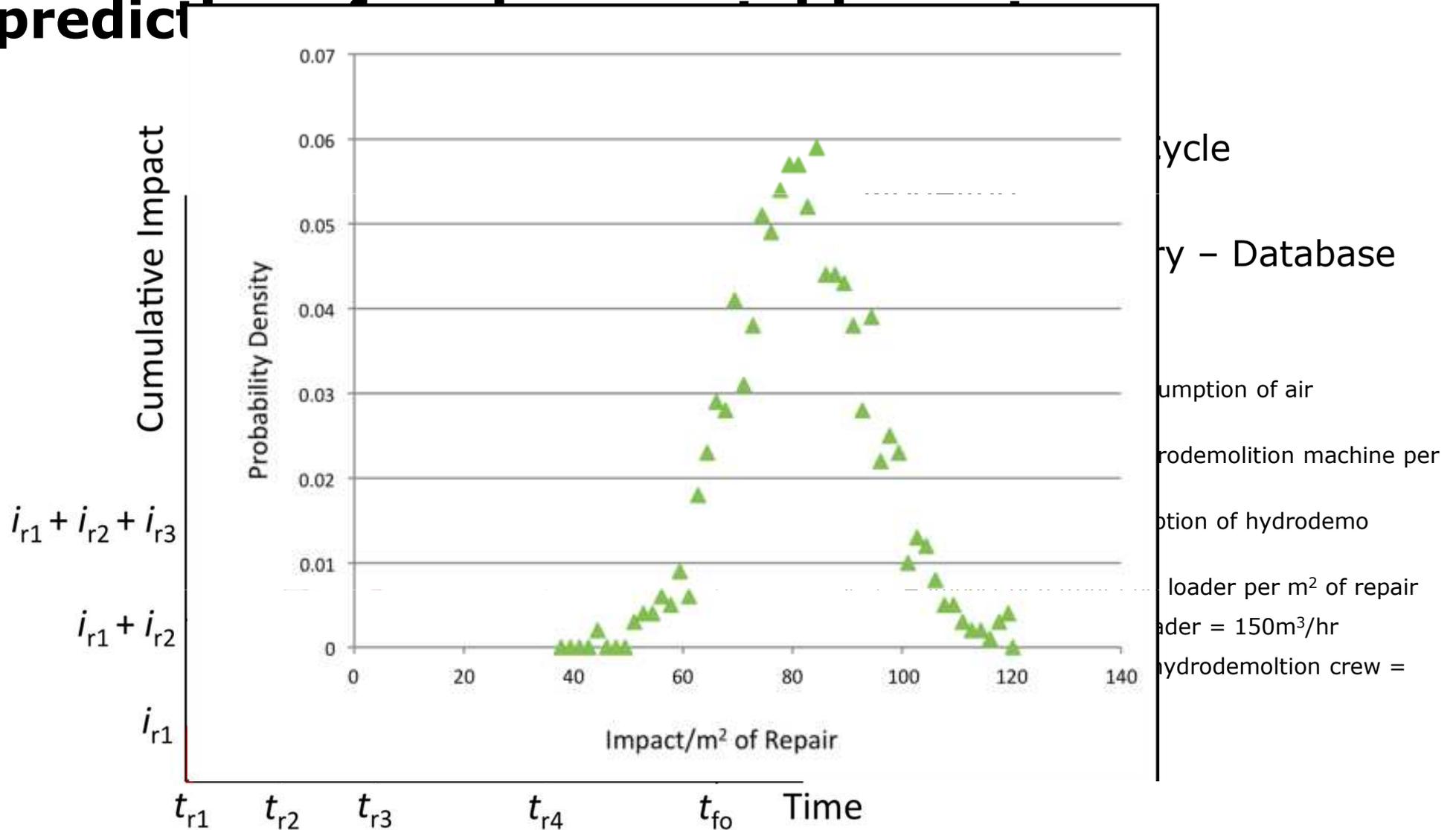
$rate_{hydro}$ = productivity of a hydrodemoltion crew = U[0.24, 0.37]hr/m^2

……….

Designing for Sustainability - Probabilistic predict

Designing for sustainability – Determining satisfaction of sustainability limit state

Impact from old repair plans (at time t_G)

Impact from new repair plans (at time t_G)

$$P_f = P\left(\frac{I_{old}(t_G) - I_{new}(t_G)}{I_{old}(t_G)} - G(t_G) \geq 0\right)$$

Impact reduction goal

Proposed time to meet impact reduction goal
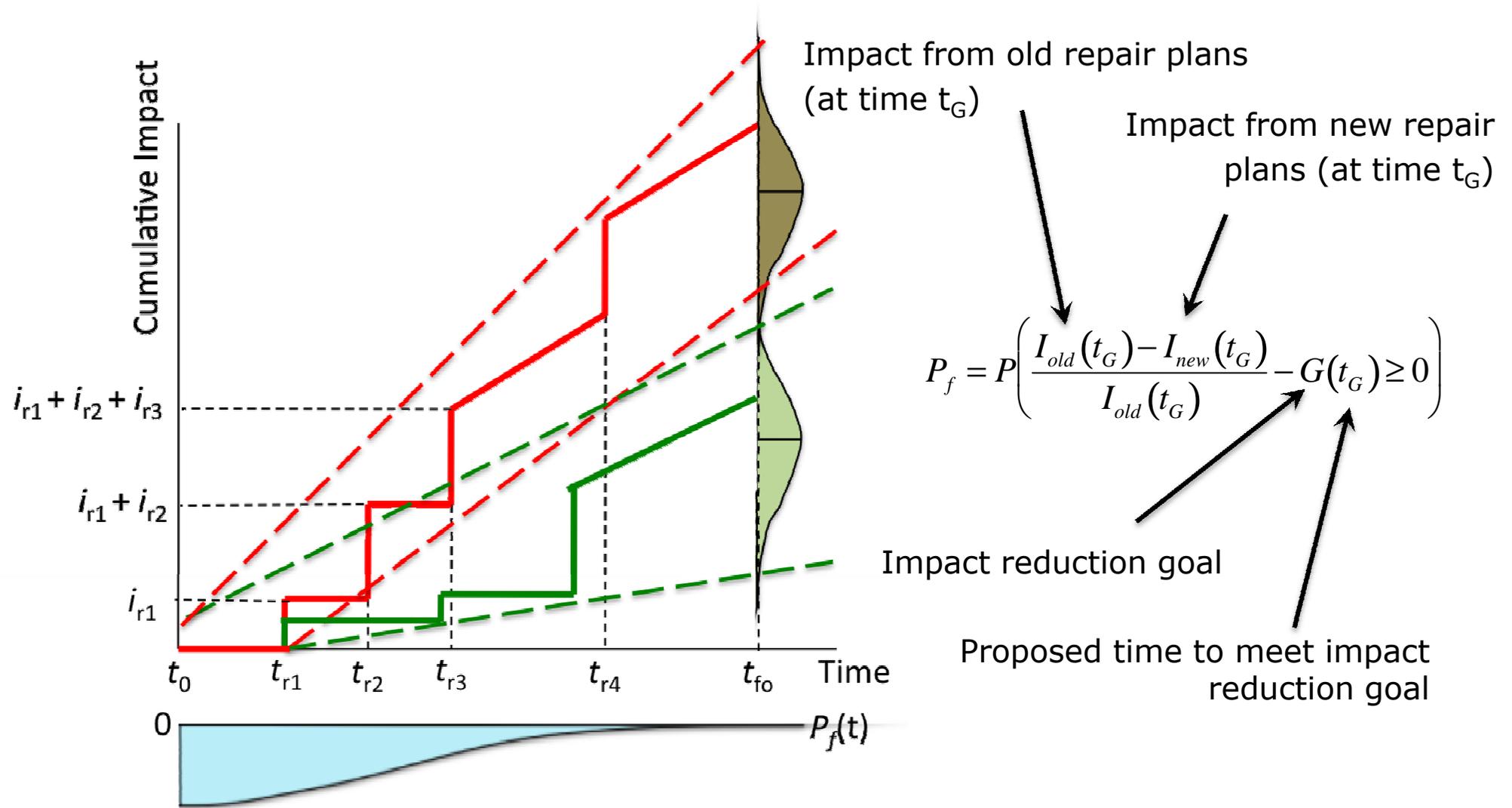
Designing for sustainability – Determining satisfaction of sustainability limit state

Comparing two differene repair scenarios: 40 mm cover and 80 mm cover
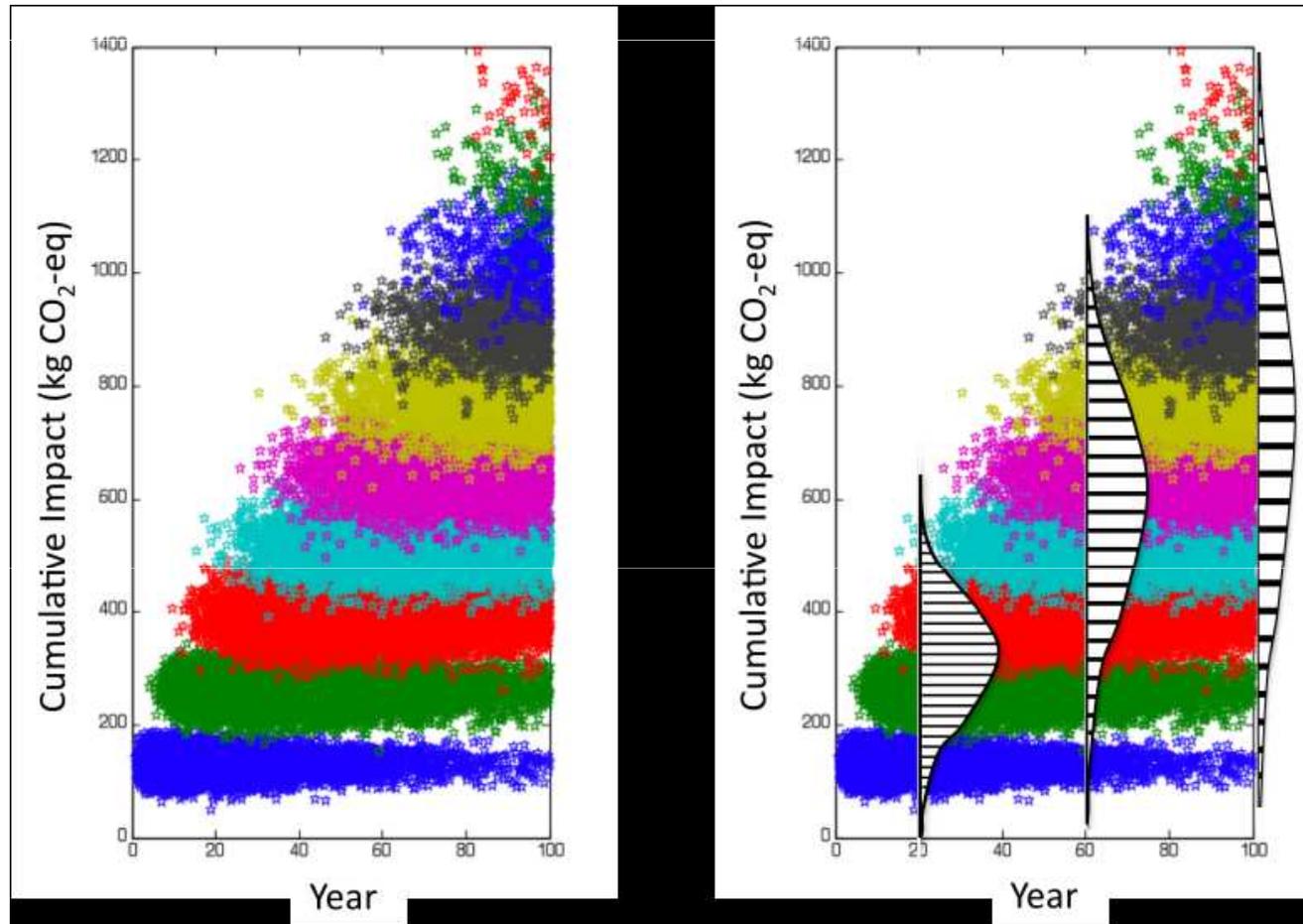
Outlook and discussion

- Methodology of sustainability assessment of infrastructure
  - Probabilistic service life model
  - Probabilistic impact model
  - Policy-based targets for sustainability

- Potential approach to operationalize *fib* Model Code design for sustainability

- Facilitates rational decision-making by infrastructure stakeholders when designing to meet sustainability targets

Outlook and discussion

- Sustainability is just one item in a set of high level parameters in decision making

- Service life predictions (and the associated models) (should) play an important part of all high level decision making tools

- Service life models and their integration in high level decision making tools is an important field for further development and research.

Acknowledgements

- Brad J. Pease (former post doc)
- Anna Emilie Tyboe (PhD student)
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- Alexander Michel (PhD student)