CERN

DOCTORAL STUDENT SEMINAR ON FIRE SIMULATION

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CERN, SWITZERLAND

MATERIAL PARAMETER OPTIMISATION FOR CABLE FIRE SIMULATION

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Introduction

Introduction

- Member of the Doctoral Student Programme at CERN
- Work supported by the Wolfgang-Gentner-Programme of the German Federal Ministry of Education and Research (BMBF)
- Supervisor:
  Saverio La Mendola

- Doctoral student at the Bergische Universität Wuppertal
- Department: Computer Simulation for Fire Safety and Pedestrian Traffic
- Supervisor:
  Armin Seyfried
  Lukas Arnold

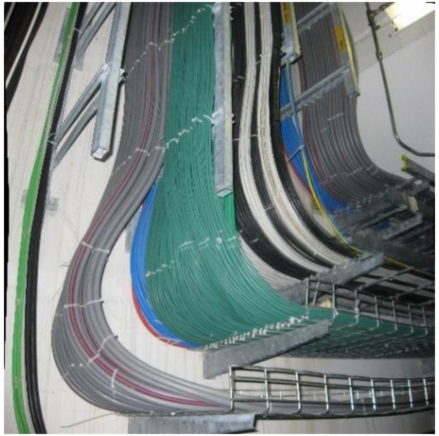
Introduction
Overview

- Where are we?
  - Large amounts of cables at CERN
  - Special facilities (~ 50 km long tunnels, experimental caverns,...)
  - Expensive and unique equipment

- Poses challenges for (fire) safety engineering
  - Design fires
  - Risk assessment
  - ...

Introduction
Overview

- Impressions from CERN facilities



Introduction
Overview

- Desire to study (cable) fire development in detail
- Obtain parameter set, which allows to simulate fire propagation
  - Starting point are bench scale fire tests
    → relavtively inexpensive
  - Utilising mathematical optimisation strategies
    → large number of simulations required
  - Very simplified simulation setup
    → attempt to reduce overall computational power and time demand

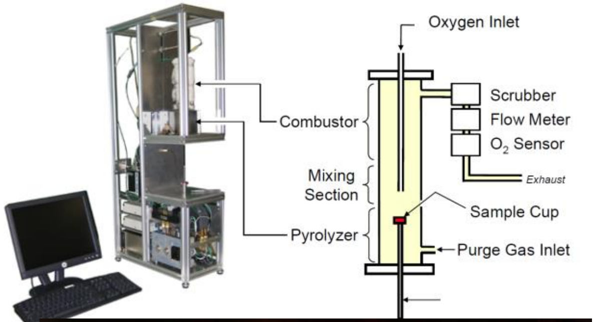
Introduction
Overview

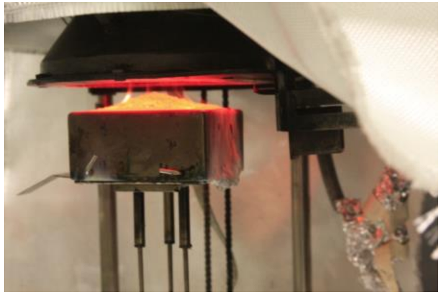
- Starting from ideas/work from Anna Matala, Chris Lautenberger, CHRISTIFIRE, FIPEC
- Using Python 2.7 to setup script environment for automated parameter optimization
- SPOTPY library used as “toolbox” for optimization algorithms
- Fire simulation using FDS 6.x from NIST
- State of the art approach

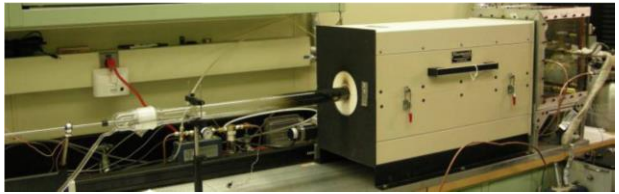
Introduction
Overview

- Cable Heat Release, Ignition, and Spread in Tray Installations During Fire (CHRISTIFIRE)
- Plenty of data recorded, able to be utilised in simulations

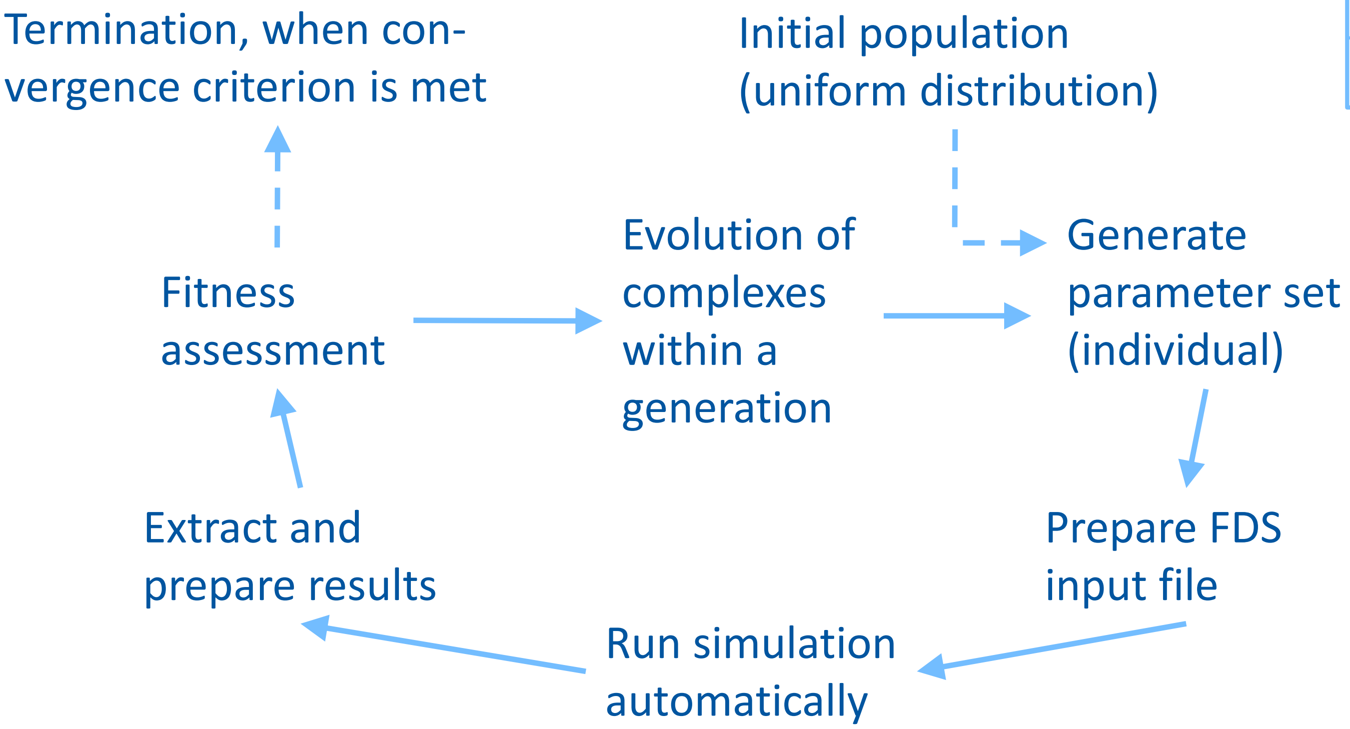
Pictures: CHRISTIFIRE, phase 1







Introduction
SCEUA

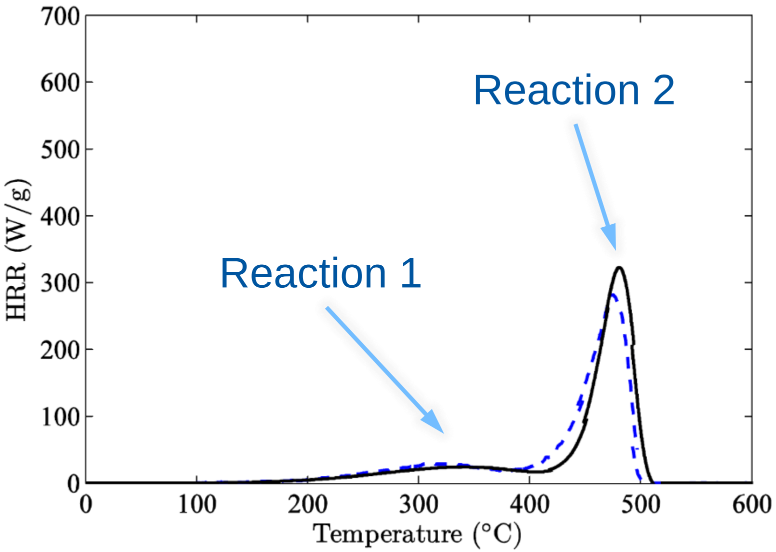


Simulation „cost“
$n_{Gen} \approx n_{Para}{}^{2}$

Introduction
Material Model

- Idea:
  - Perform optimization for materials
  - Build layered cable model
  - Determine layer thickness by optimization

- Starting from small scale material tests
- Two reaction steps per material
  - Arrhenius reaction model in FDS
  - Three parameters: A, E, n



Introduction
Material Model

- Thermo-physical parameters
  - Density, conductivity, specific heat, heat of combustion and reaction
- Thermo-physical parameters of the residue
  - Density, conductivity, specific heat

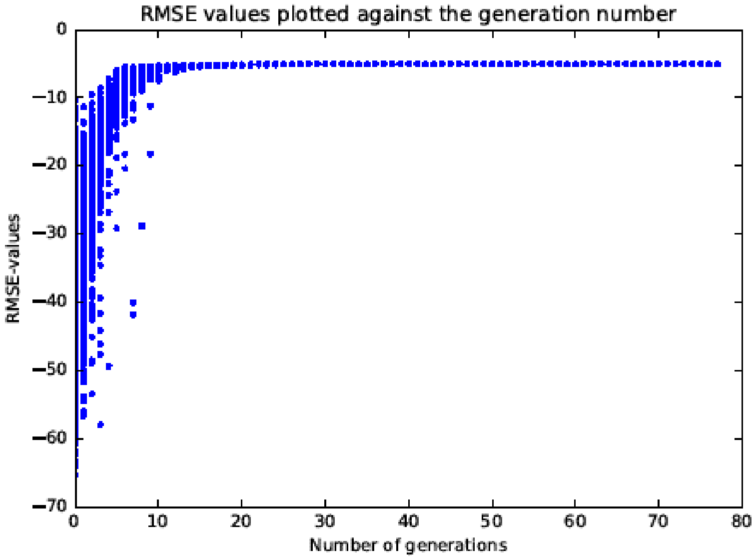
- Leading to 14 parameters in total, per material

MCC Simulation

MCC Simulation
Generations

- Root Mean Square Error (RMSE) used as fitness criterion
- RMSE values plotted by generation
- Good parameter set found after 15 to 20 generations

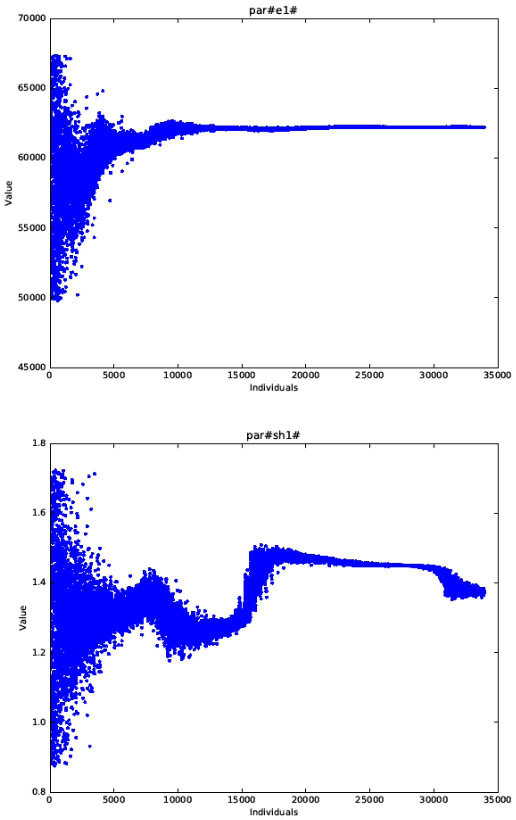
- (For this case: 435 individuals per generation;
  RMSE: 5.048)



MCC Simulation
Parameter Development

- Development of the parameter values over the optimisation run

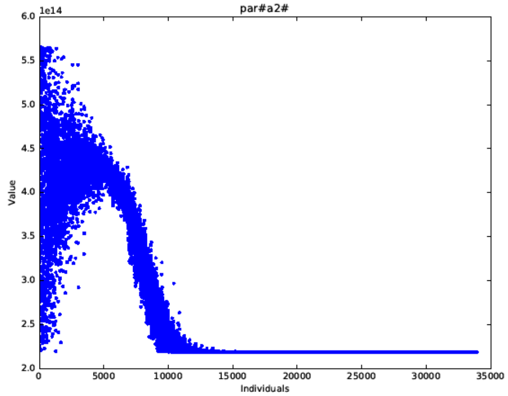
- General behaviour: Parameters converge to a certain value
- This value may change during the optimisation run
    - Presumably due to other parameters approaching limits or local optima

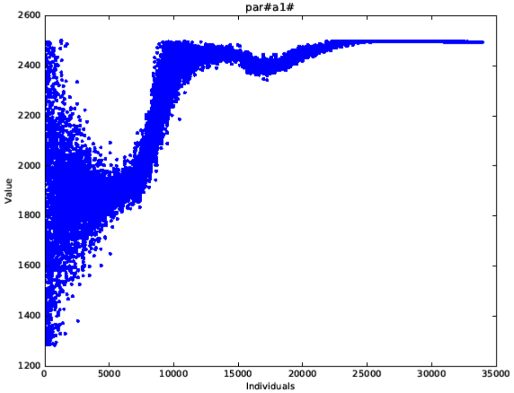


MCC Simulation
Parameter Development

- Parameters which get stuck are converging, too
- Might be able to recover, due to changes in other parameters

- Despite the stuck parameters, a good fit could be acheived for both materials.

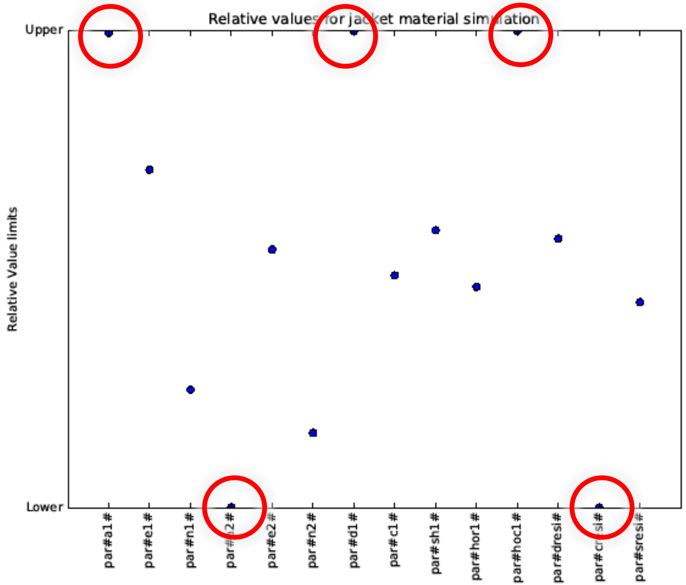




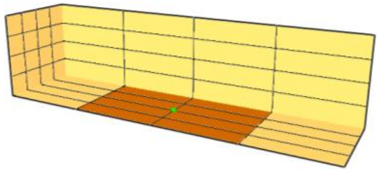
MCC Simulation
Parameter Development

- Relative parameter values due to different magnitudes
  (best parameter set)

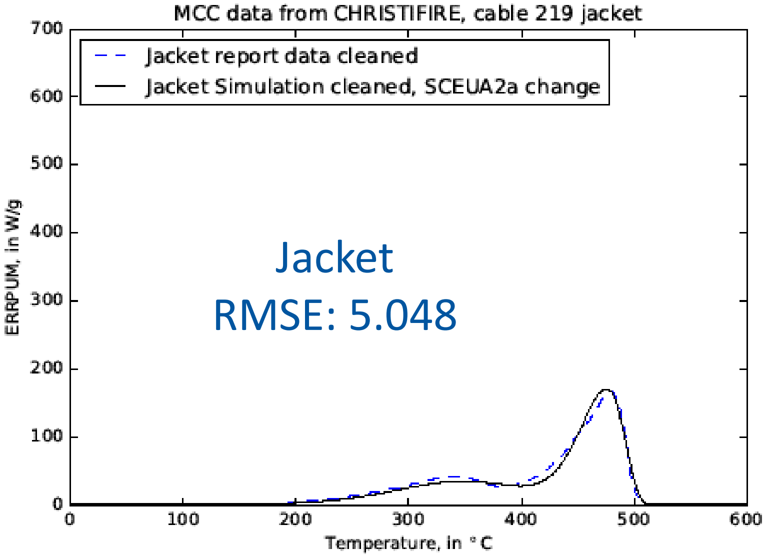
- Some parameters are stuck at their limits
- Investigation of optimisation behaviour with changed parameter limits to be done in the future

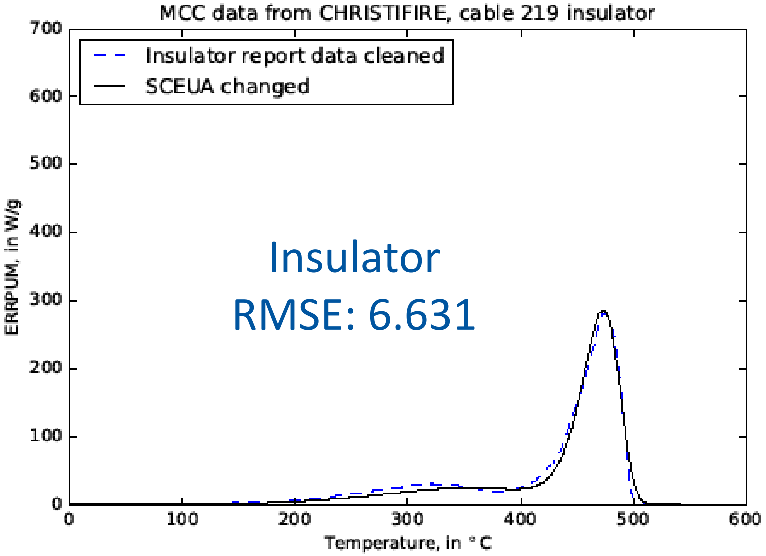


MCC Simulation
Best Parameter Sets



- Best parameter sets from optimisation

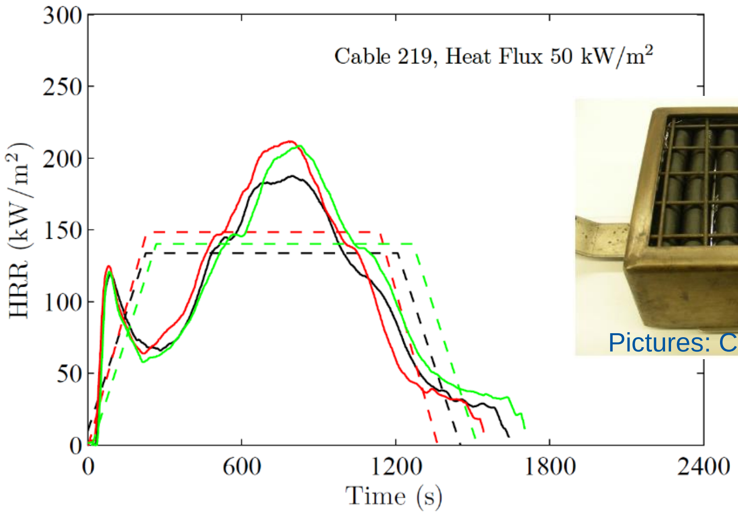




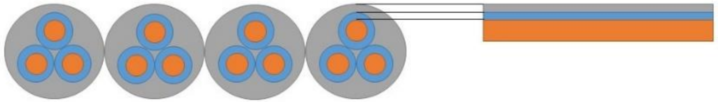
Simple Cone Simulation

Simple Cone Simulation
Cable Model

- Simplified Cone setup
- Cable model with layered structure
- Material parameters from MCC simulations
- Optimised parameters are layer thickness for each material: Jacket, insulator, conductor, backing



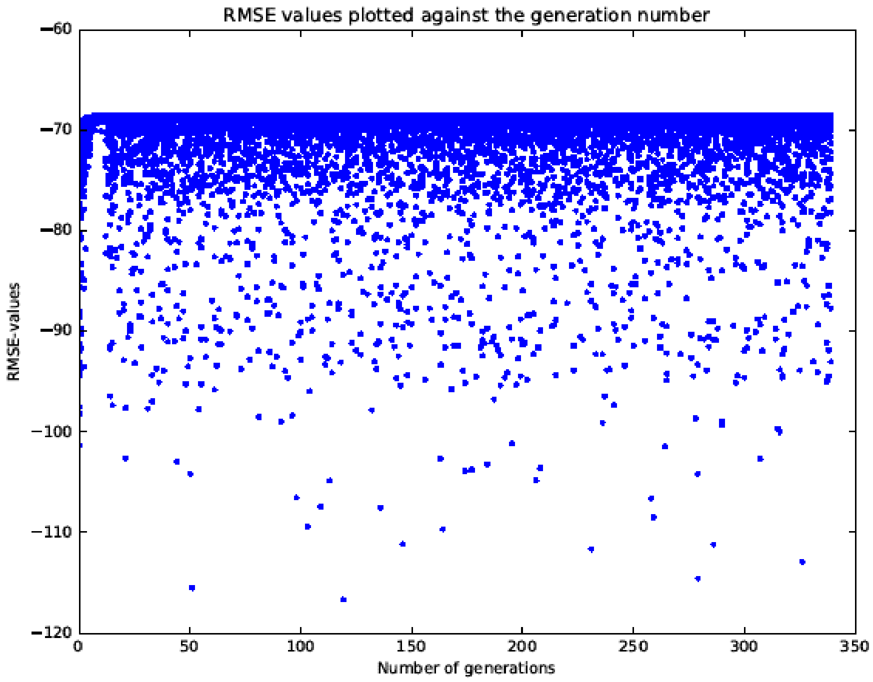
Pictures: CHRISTIFIRE



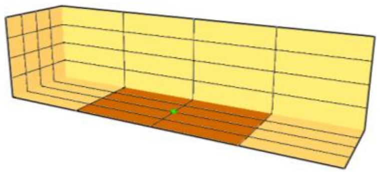
Simple Cone Simulation
Generations

- RMSE values plotted by generation
- No useful fit achieved

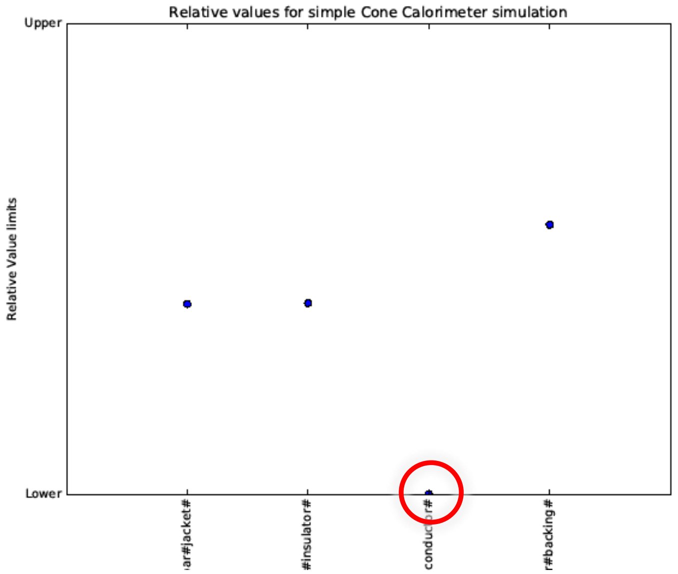
- (n_{Para} = 4, n_{Gen} = 45 ; RMSE: 72.405)



Simple Cone Simulation
Parameter Development



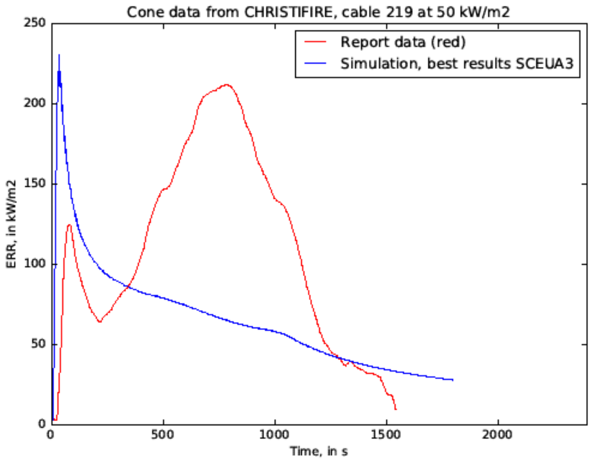
- Conductor thickness stuck at lower limit (best parameter set)



Simple Cone Simulation
Best Parameter Set

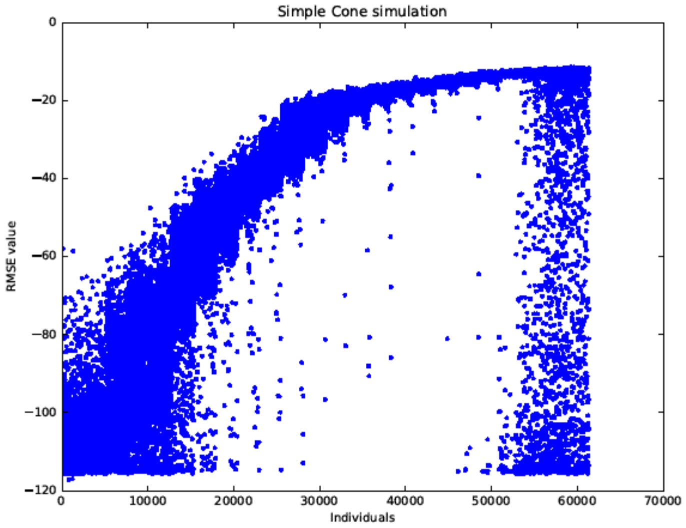
- Simulation results do not match experimental data
- Thickness optimisation alone, seems not to be sufficient

- RMSE: 72.405



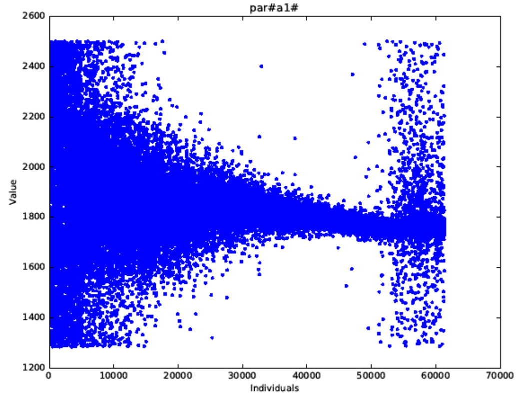
Simple Cone Simulation
More Parameters

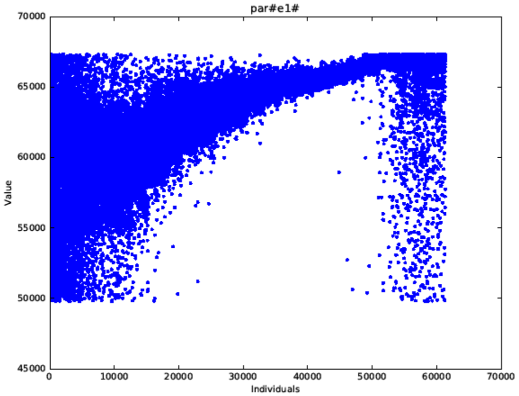
- New optimisation run using more parameters:
  - Material parameters of both components, layer thickness, emissivities (components, residues),
- (n_{Para} = 35, n_{Gen} = 2556 ; RMSE: 11.285)



Simple Cone Simulation
Parameter Development

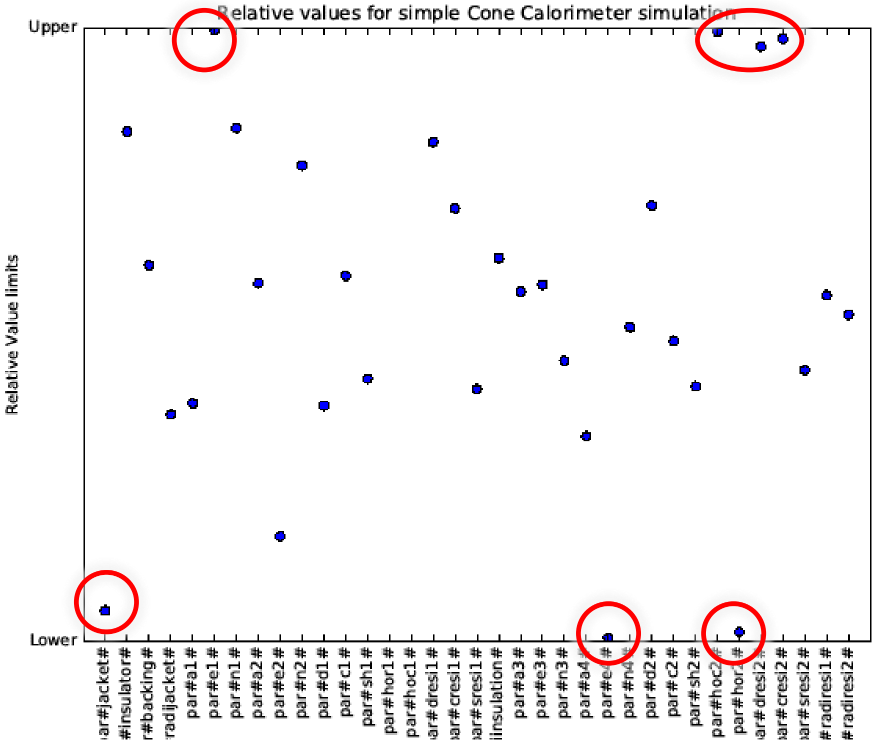
- Similar behaviour is observed
  - Parameters converge
  - Some get stuck at their limits





Simple Cone Simulation
Parameter Development

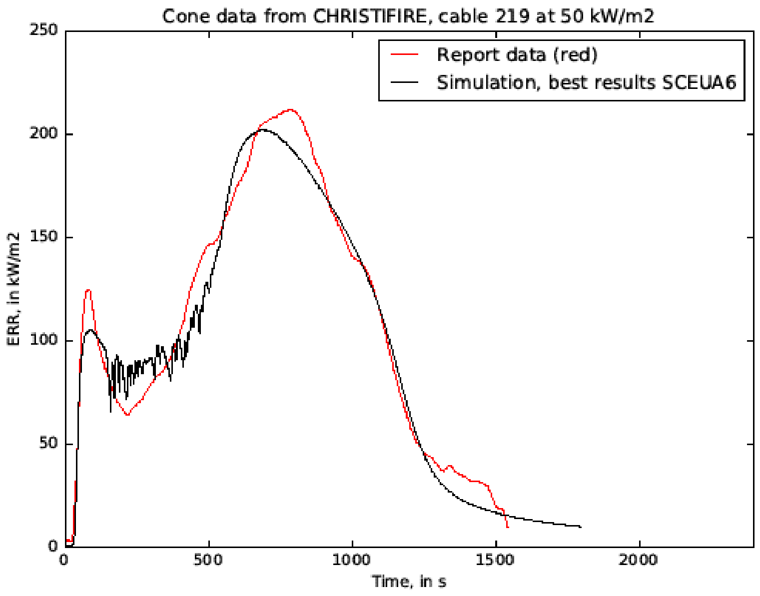
- Again, some parameters are stuck at their limits (best parameter set)



Simple Cone Simulation
Best Parameter Set

- Good fit could be achieved
- Optimisation stopped due to exceeding the simulation limit

- RMSE: 11.285

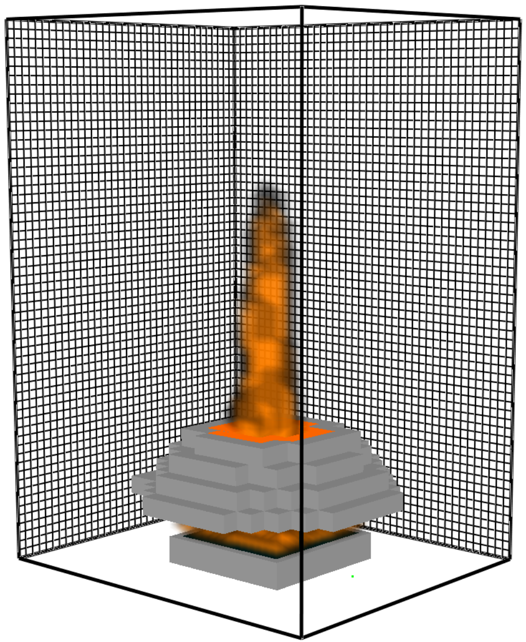


Coarse Cone Simulation

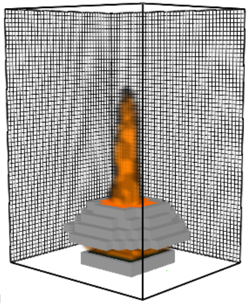
Coarse Cone Simulation
Transfer to higher fidelity

- Best parameter set from Simple Cone setup was tested in higher fidelity Cone simulation

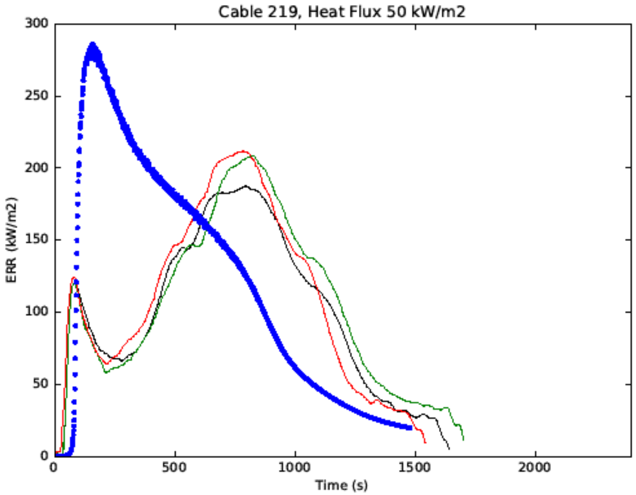
- Again, no good fit was achieved
- Most possibly due to flame heat feed back
  - It was prescribed in the simple cone (&RAMP)



Simple Cone Simulation
Transfer to higher fidelity



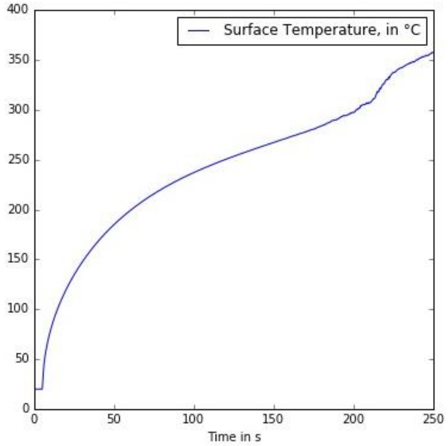
- Conclusion:
  - It seems there are to many simplifications in the simple setups
  - Parameter sets cannot be carried over easily to higher fidelity



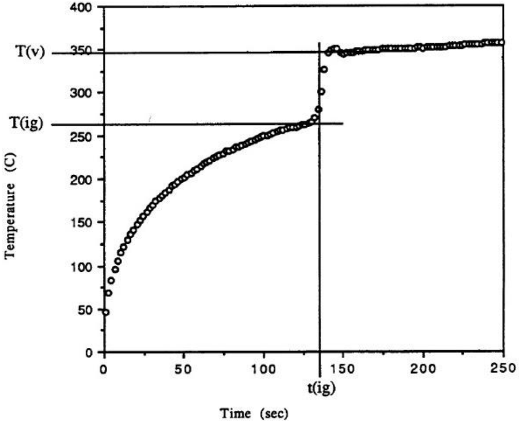
Simple Cone Simulation
Revising Strategy

- Flame heat flux difficult to prescribe
- Strong influence on the burning behaviour

- Picture taken from:
"Burning Rates and Flame Heat Flux for PMMA in the Cone Calorimeter", by Brain T. Rhodes, in May 1994 (NIST-GCR-95-664)



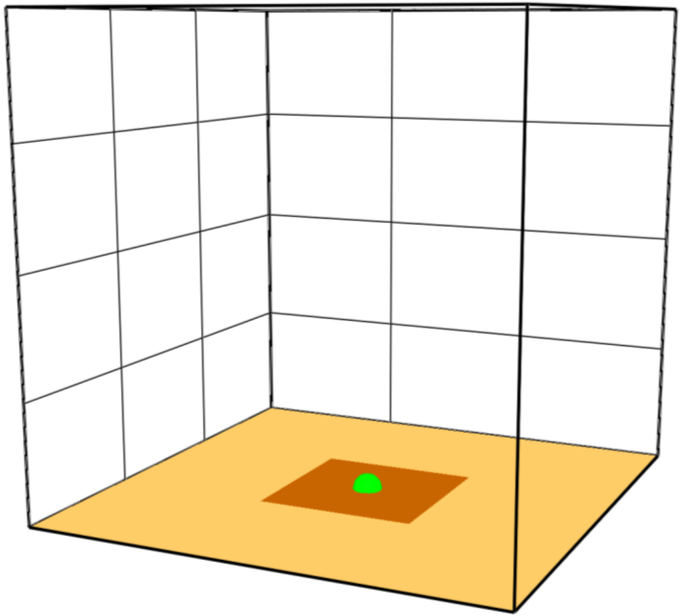
Simulation



Experiment

Simple Cone Simulation
Revising Strategy

- Testing most simple setup with gas phase and flame
- Idea taken from Anna Matala's Dissertation
- Time for optimisation estimated: 4 to 6 weeks (35 parameters)

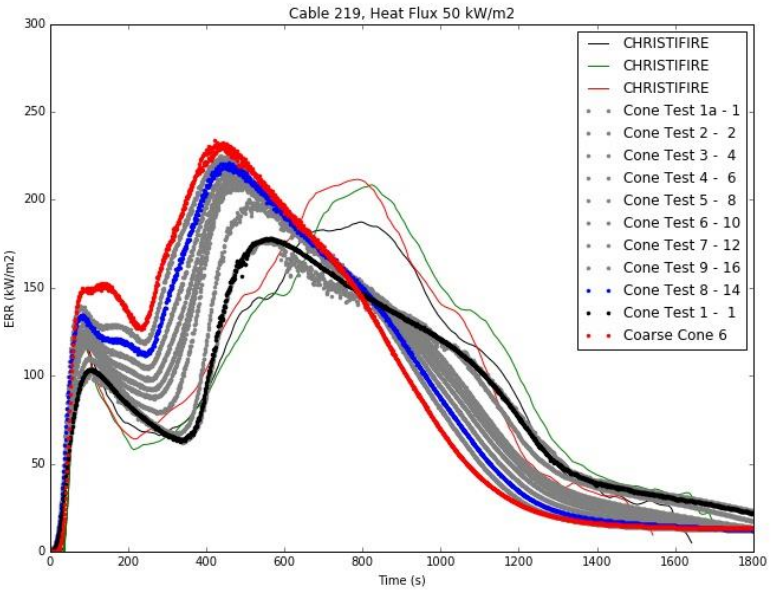


Simple Cone Simulation
Revising Strategy

- Simple setup seems promising
- But it‘s off in Coarse Cone

- Resolution change in simple setup
- For same reolution in simple and coarse setup, results fit better together

- Conclusion:
    - Flame simulation is very important
    - Simple setup is too sipmle



Thank you for your attention!

Do you have any questions?

Parameter Optimisation
SCEUA

- Population devided into groups, called complexes
  - Competitive evolution within the complexes

- Simulation results are compared with target values
  - Creates fitness value
- Complexes are shuffled
  - Population sorted and ranked by fitness value
  - New complexes are generated

Appendix
SCEUA

- Shuffled Complex Evolutionary method developed at the University of Arizona (SCEUA)
- Simulation regarded as individual
- Group of all individuals regarded as population
- Parameter set, describing the simulation, could be regarded as genes
- Genes can have different values (from genetics: allele)

Genes	Alleles
Density	1259.4 kg/m^3
…	…
Emissivity	0.68
…	…
…	…

Appendix
SCEUA

- Population devided into groups, called complexes
  - Competitive evolution within the complexes

- Simulation results are compared with target values
  - Creates fitness value
- Complexes are shuffled
  - Population sorted and ranked by fitness value
  - New complexes are generated