Cost Effective O&M through Efficient Mirror Cleaning, Condition Monitoring and Reliability Modelling

ASTRI Symposium on The Future of Concentrating Solar Thermal Technology

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Node Overview – Significance and aim

O&M significance in CSP

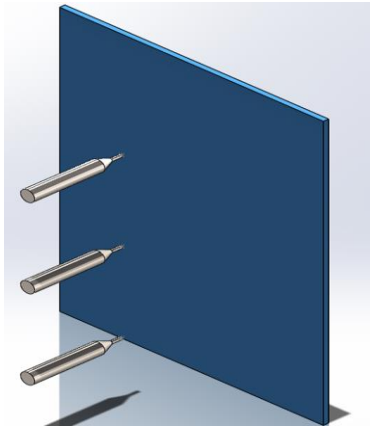
- O&M (incl. cleaning) represent a significant component of LCOE (10-15%)
- IRENA identifies O&M as a key area for feasible cost reduction (~23% in tower CSP)
- Mirror cleaning improvement of 2% results in 0.2-0.25 c/kWh reduction (Sandia/NREL)
- O&M costs for Solar Field of about 0.3-0.5 c/kWh (Kutscher et al. NREL, IRENA)

Aims

- Increase the productivity of the plant by reducing reflectivity losses due to soiling of heliostats
- Reduce the O&M component of LCOE by optimizing O&M tasks and schedules in CSP power plant

Optimisation of Solar Field O&M

- Optimisation of cleaning technology
  - Optimised cleaning system
    - Best nozzle design and parameters
    - Low water consumption
    - Automated cleaning without human operators



- Optimisation of O&M schedule
  - Optimised cleaning schedule
    - Which mirror has priority
    - Optimal sector cleaning sequence and timing
    - Automated reflectivity assessment
    - Assessment of soiling impact in design phase
  - Optimisation of maintenance

High direct O&M $
(over-serviced assets)

Optimal O&M balance

High failure/downtime $
(under-serviced assets)

Cleaning technology – State of the art

- Mirror Cleaning Technology
  - Trucks or hosing systems : Abengoa Solar's Albatros manned trucks
  - Sprinkler-like systems with fixed nozzles: Heliotex and KNE
  - Cleaning robots
    - Sener's Heliostat Cleaning Team Oriented Robot HECTOR
    - Greenbotics's CleanFleet robots
    - eSolar's Automatic Heliostat Cleaning Robot
    - Novatec Fresnel robots
    - OCS Energy's SolarWash
    - No-Water Mechanical Automated Dusting Device NOMADD in Saudi Arabia)
- Proposed Technology

  Linear array of small nozzles utilising a fluid flow/mechanical automated traverse mounted on each mirror.

Optimisation of cleaning technology
CFD for optimisation of nozzle and water spraying

Optimisation of key design parameters

Nozzle

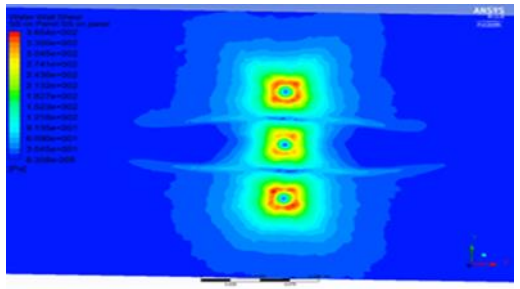
- Type
- Diameter
- Numbers
- Interaxial distance
- Angle of impingement

Fluid

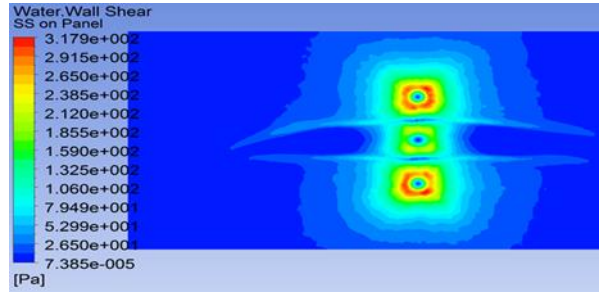
- Pressure
- Flow
- Temperature
- Quality

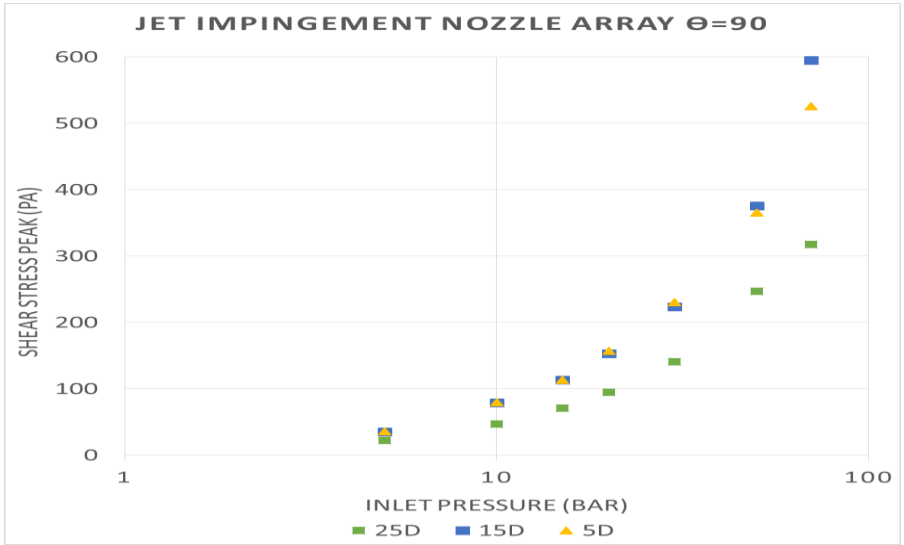
Standoff distance

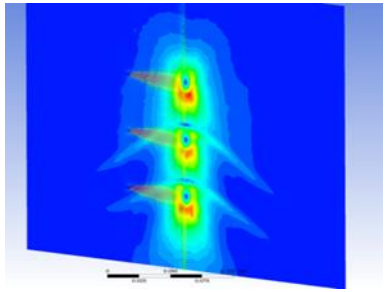
15D , 50 Pa



25D , 70 Pa







Optimisation of cleaning technology
Experimental testing setup

Equipment (set up):
- High Speed Camera
- Camera Tripod
- Flash, Diffuser x3
- White Screen

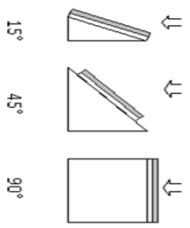
- Water Pump
- Water Pump Controller
- Pressure Gauge x2

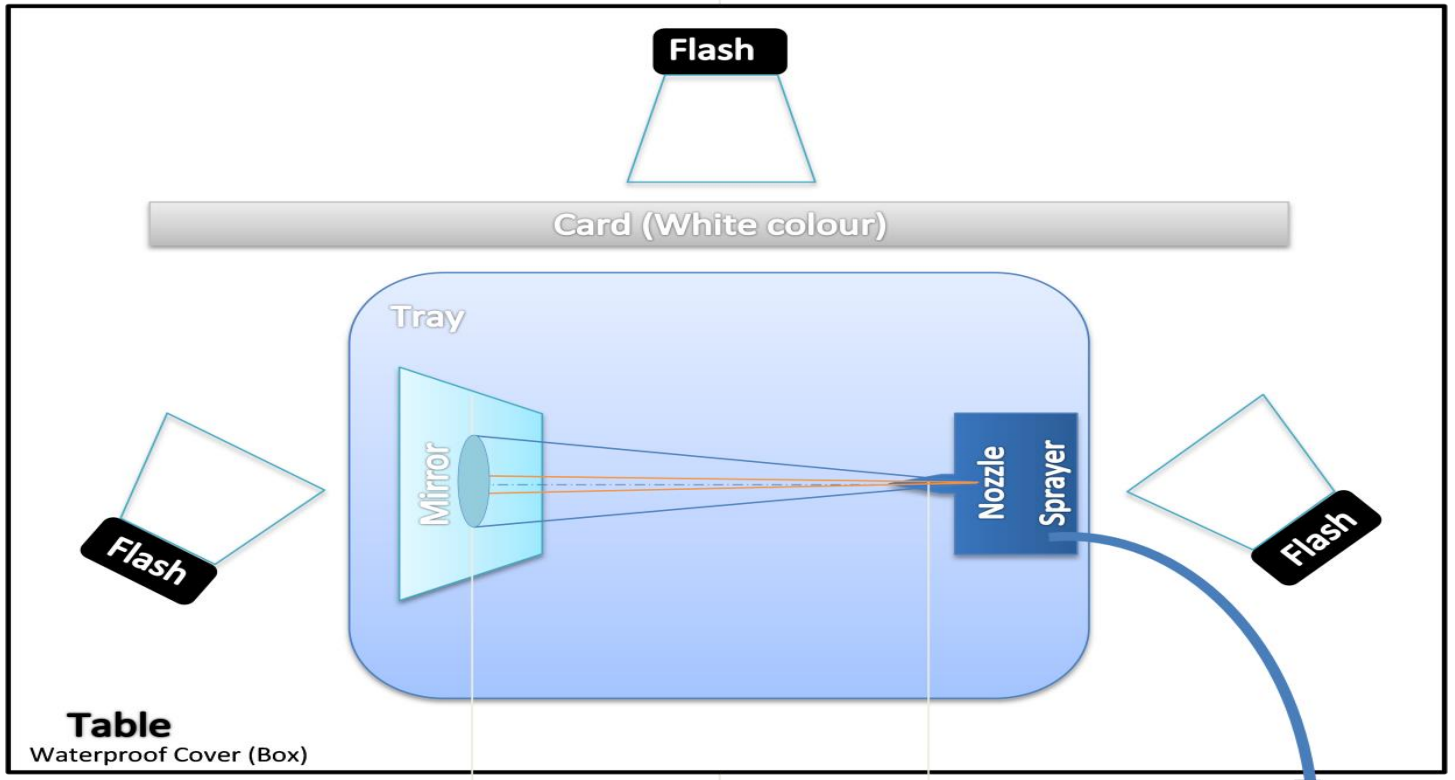
- Mirror

- Cold Light Source

- Nozzles

Mirror Sitting:
100mm x 100mm
400mm x 400mm
Mirror Angle Sitting:
< 90° 45° 15 °

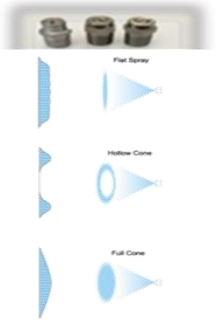




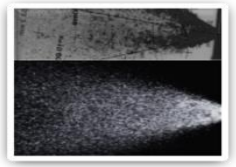
Outputs
Impact Surface (Mirror):
- Spray Patterns
- Pressure Patterns
- Pressure Distribution

Spray Area:
- Droplet Size
- Droplet Velocity
- Patterns
- Distribution

Nozzle Sitting:
Full, Hollow, Flat Cone



Flash Sitting:
1/16th power
105mm zoom



Camera Sitting:
Apertures f11
Shutter Speed
1/250

Camera Fujifilm X-T1

Distance 300mm – 600mm – 800mm

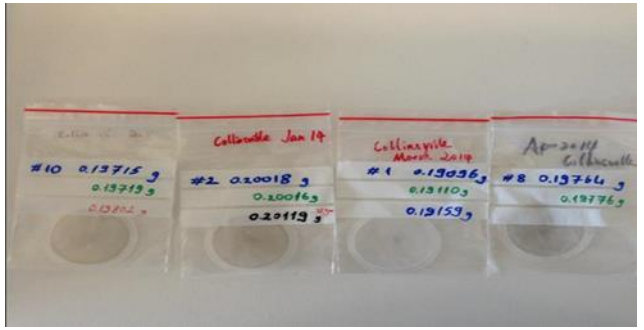
Pressure Control
Pump Sitting:
30 bar
60 bar
100 bar

Optimisation of cleaning technology
Soil Characterisation

Dust accumulation (Collinsville, QLD)

- Airborne dust monitor: filters collected months of dust accumulation
- Filters are analysed by SEM and XRD analysis at QUT laboratories to identify chemical compounds & particle size

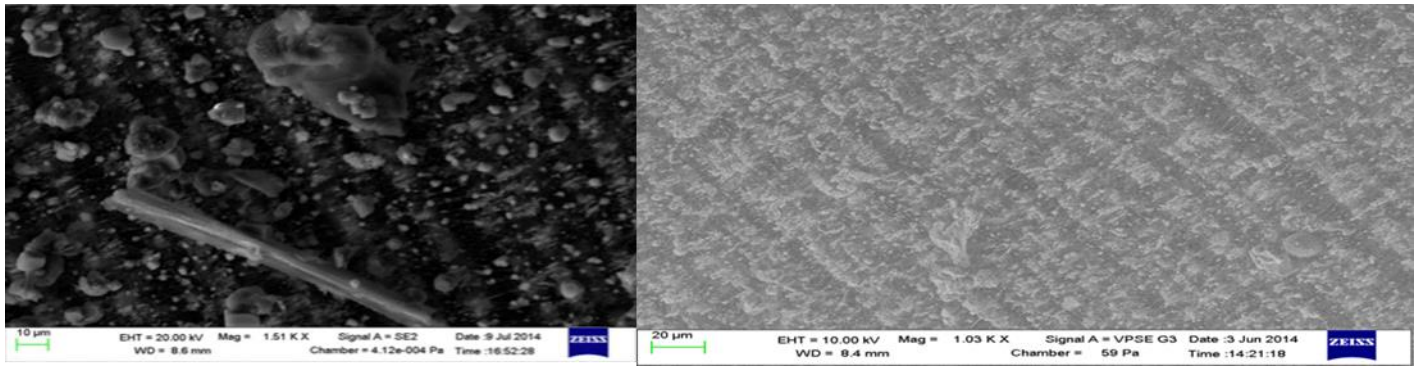
Real time monitor



Filters collected at Collinsville with different dust concentration

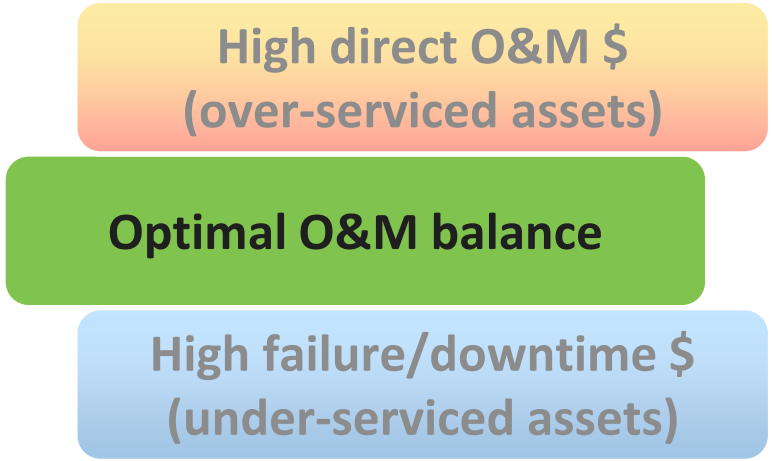
Soil class results:

- Average of dust particle size is around 10µm
- Most particles are albite or silicon dioxide
- Major composition: sodium and silicon



Optimal O&M schedule

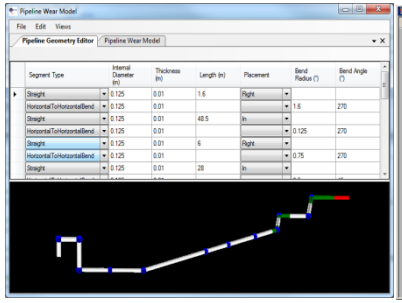
- Optimal O&M schedule
  - Balances direct costs with loss of productivity due to degradation/failure
  - Balance changes in time according to degradation rate, availability and cost of O&M, etc.
  - Requires continuous degradation modelling, degradation assessment and optimisation



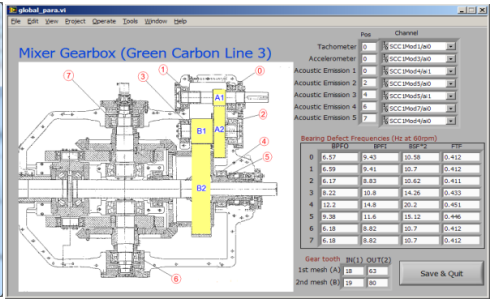
Optimisation of Solar field O&M
First focus of O&M optimisation

- Power Block
  - Largely studied in traditional power generation studies
  - Often highly “constrained” by OEM indications
  - Data-based tools available in O&M team
  - Highly reliant on industry data

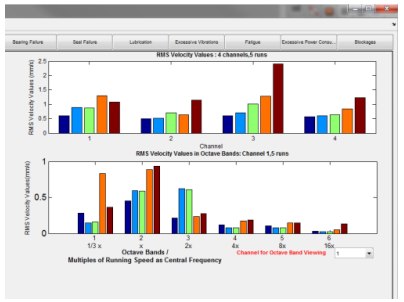
Pipeline wear model



Gear CM



Pump CM



- Solar Field
  - Typical and specific of the industry
  - Cleaning not covered by OEM instructions
  - Plant owners interested in “insights” on appropriate scheduling

First focus of the project

- Greater interest in industry
- Greater specificity
- Greater potential margin for improvement

Mirror cleaning optimisation

State of the art

- Estimate of field-avg. reflectivity loss from reflectivity samples[1]
- Target field-avg. reflectivity[2]
- Cleaning schedule adjusted to keep target time/field-average reflectivity[2]
- Adjustment of field-average possible using reflectivity samples[1]

Proposed approach

- Prediction of reflectivity with ***soiling model***
- Evaluation of economic impact of sector degradation with ***Modelica software integration***
- Optimisation of ***cleaning resources***, ***schedule*** and ***sector priority***
- Continuous update of model prediction with ***automated reflectivity monitoring***

Main advantages

- ***Location-specific*** reflectivity loss before reflectivity samples (plant design phase, planning)
- Optimisation considers soiling and economic impact of different ***sectors*** and includes ***optimal sequence***
- ***Automated process***

1 “Optimum target reflectivity for heliostat washing,” Kattke (Abengoa) et al.
2 “Reflectance measurement in solar tower heliostats fields”, Ferna´ndez-Reche (P. Solar Almeria)

Optimisation of cleaning operations
Soiling model overview

Inputs to the model
- Concentration in air
- Weather conditions (wind, temperature, RH, …)
- Geometry of the solar field

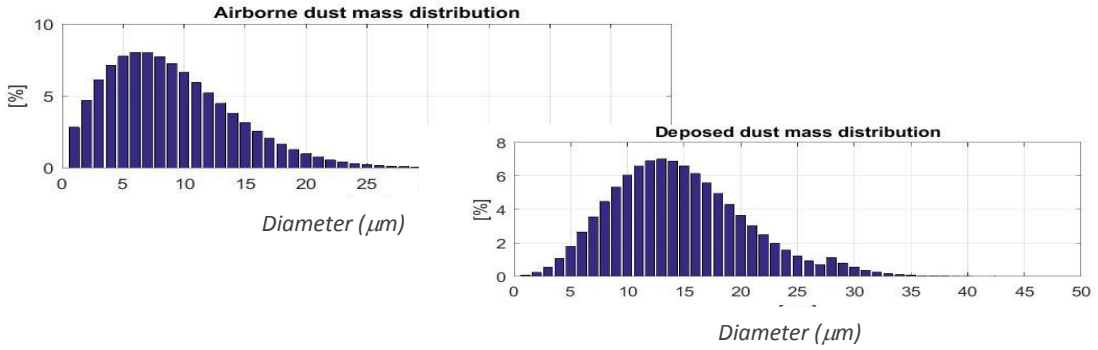
Model output
- Reflectivity loss over time
- Output to be integrated with ASTRI NODE 1 for plant performance effect

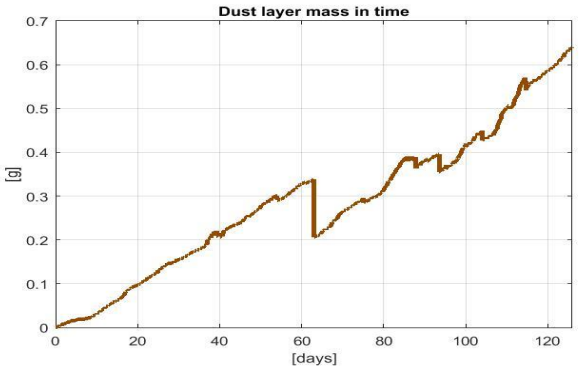
Deposition
- Gravity vs drag
- Turbulence and Inertia

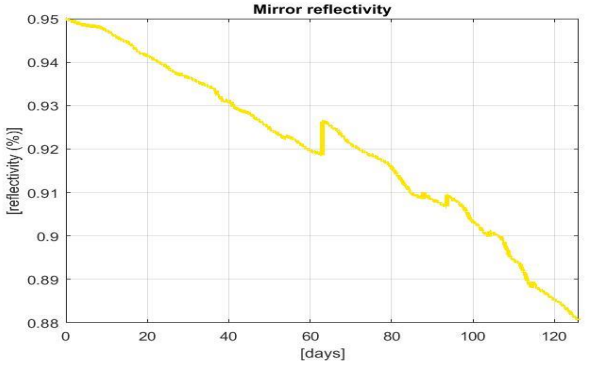
Adhesion
- van der Waals
- Capillary (dew)

Removal
- Wind (drag)
- Gravity
- Rain

Reflectivity Loss







Optimisation of cleaning operations
Collinsville data used as input to the model

Available data from Collinsville (QLD) station:

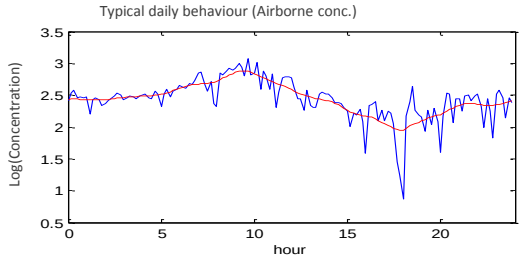
- Weather parameters
- Airborne dust concentration

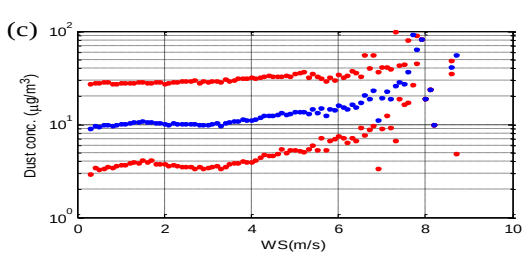
Useful baseline data:

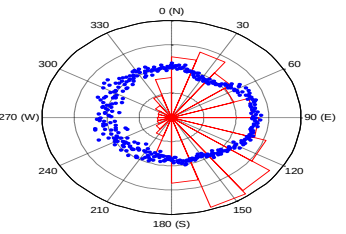
- Input for the model
- Allowed first data processing trials and correlation studies

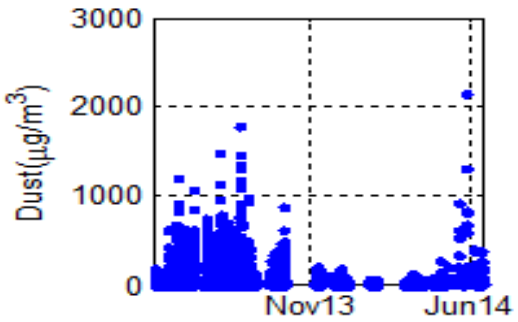
However, data not suitable for model validation:

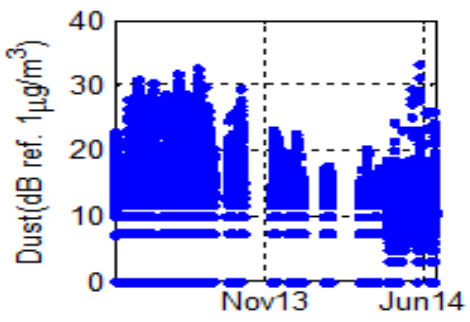
- Not always reliable (highly noisy, variable sampling parameters, missing records)
- Very few measurements of mirrors reflectivity and/or soiling

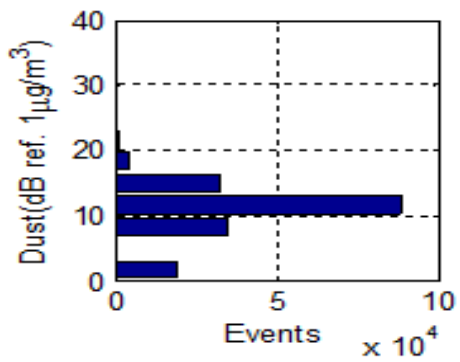












SOURCE: S. Pennetta, S.Yu, P. Borghesani, M. Cholette), John Barry, Z. Guan, An Investigation on Factors Influencing Dust Accumulation on CSP Mirrors, Solar Paces 2015, Oct 13-16 2015, Cape Town, South Africa

Optimisation of cleaning operations
Experimental activity for soiling model validation

Weather station

Airborne dust monitor

Solar mirror

Reflectometer

wind
temperature
rainfall
humidity
airborne dust concentration

Reflectivity loss measurement

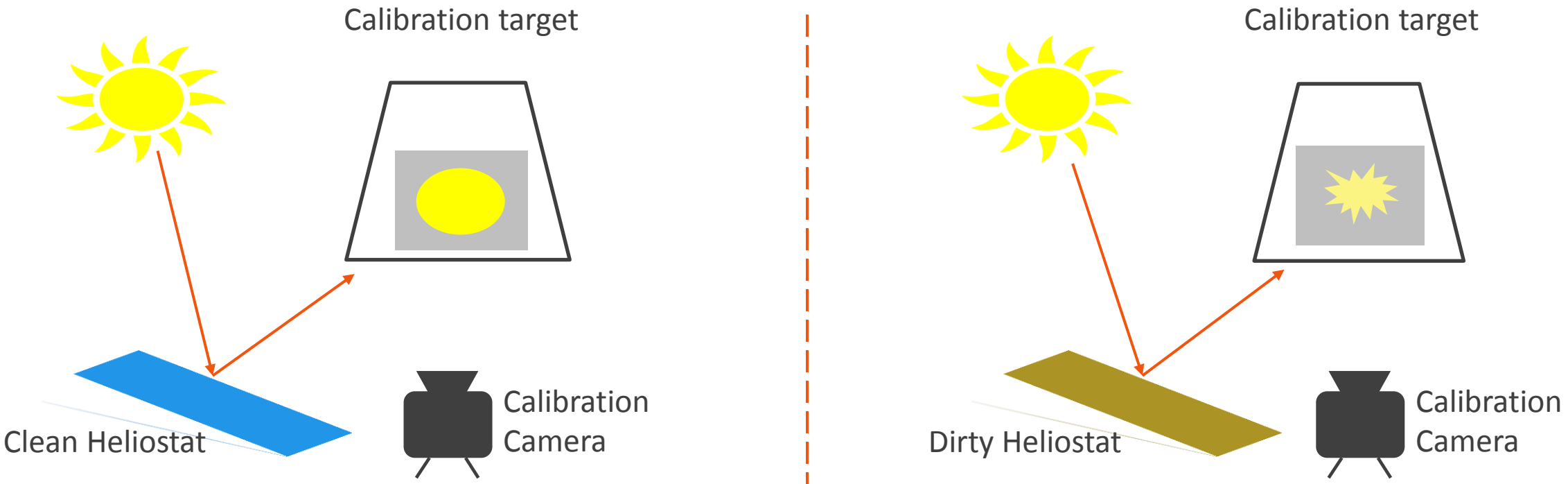
Soiling model

Reflectivity loss prediction

Comparison
Calibration
Validation

Adjusted model parameters

Optimisation of cleaning operations
Reflectivity assessment with calibration cameras



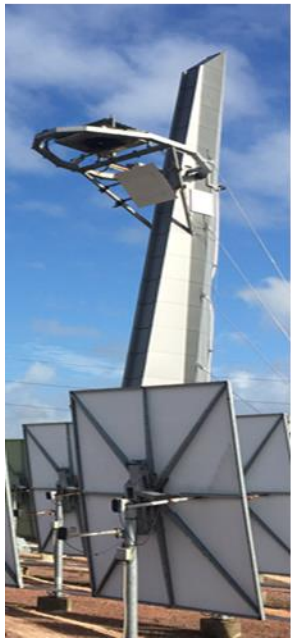
Assessment of heliostat's soiling:

- Comparison of calibration camera image with reference
- Reference obtained by reflectivity measurements
- DNI as control variable to ensure scalability of result

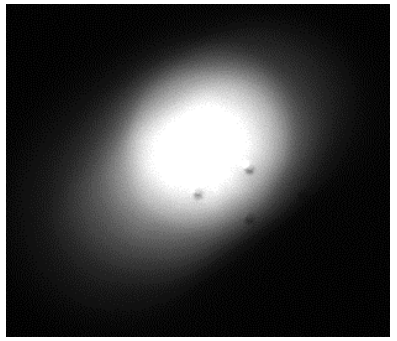
Optimisation of cleaning operations
Reflectivity assessment with calibration cameras

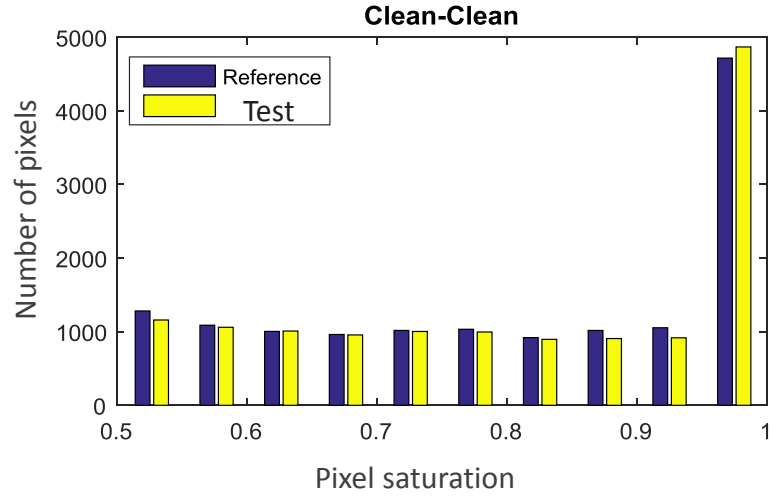
Experiment synthesis

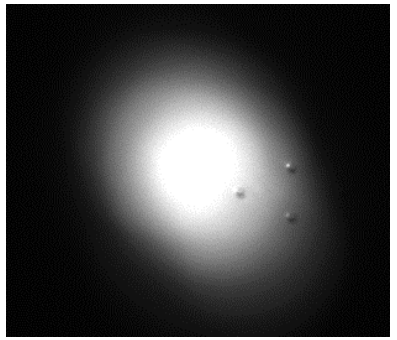
- Two adjacent heliostats (A and B)
- Mirror A kept as reference
- Mirror B progressively soiled using spray gun and suspension of talcum in water
- At each “coating” measurements taken with:
  - Reflectometer (across the reflecting surface)
  - Calibration camera (different exposures)
- Aim is to assess the presence of correlation between calibration camera images and reflectivity of the heliostat surface

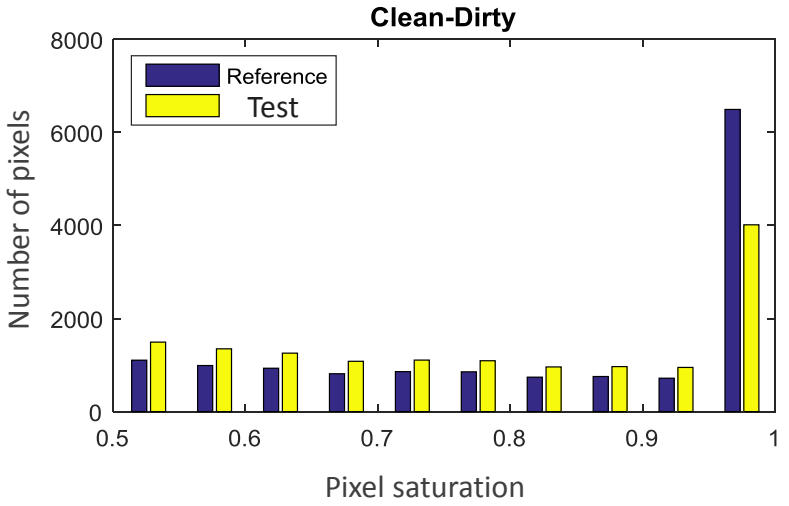


Optimisation of cleaning operations
Reflectivity assessment with calibration cameras



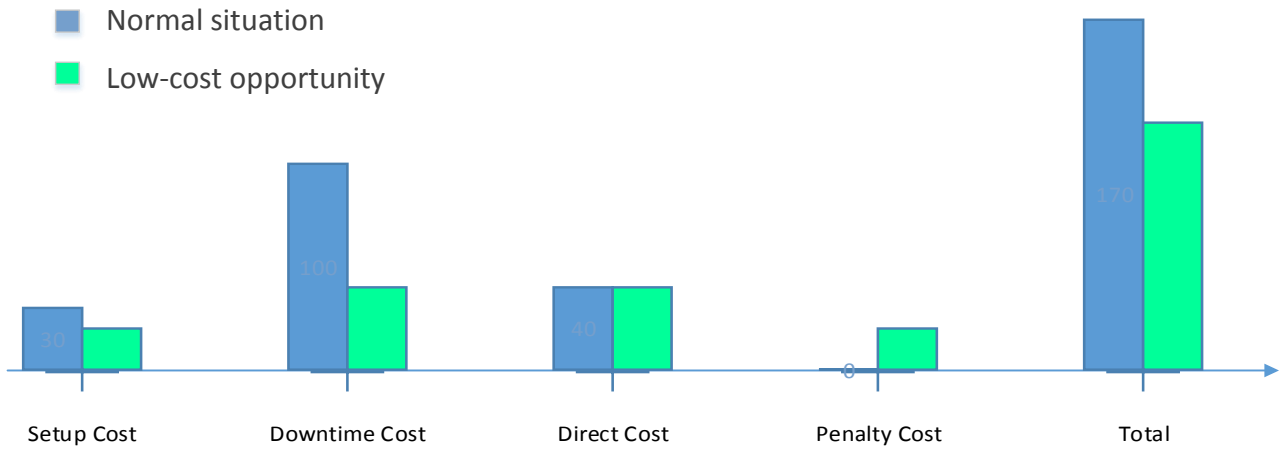


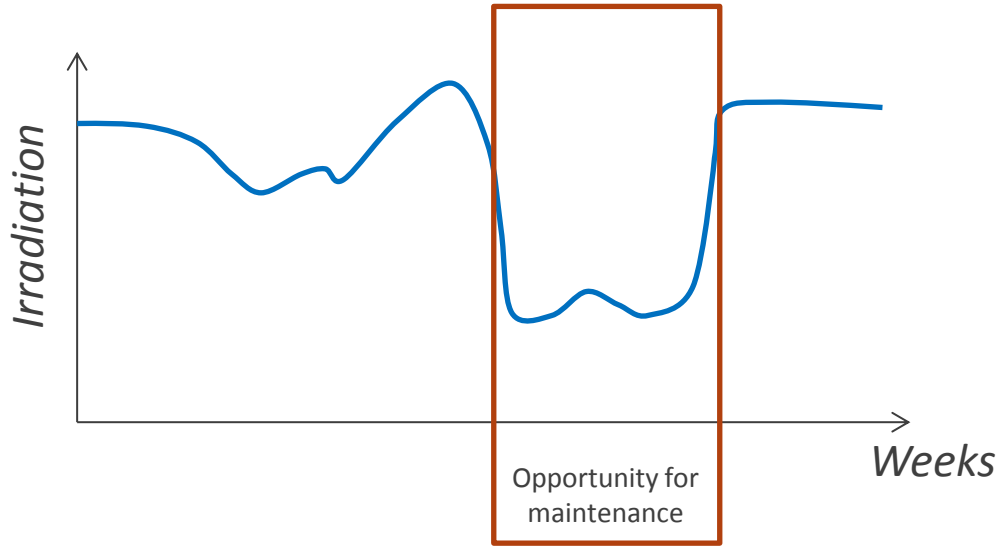




O&M optimisation strategy

- Limited study in this area:
  - Design optimisation: average target reflectivity
  - Constant long-term soiling rates
- Proposed approach:
  - Operational focus for cleaning: when should we clean the mirrors? Which area has priority?
    - Time-varying balance between costs
    - Solar Field sectors: best schedule identifies priority and clustering for cleaning activities
    - Time-varying soiling rates
  - Approach then extended to Maintenance
    - Failure/maintenance data required (VastSolar)
    - Starting from Solar field maintenance





Collaboration map

Development of the soiling model

P41 O&M

ASTRI MODELICA ACTIVITY

Integration of cleaning optimisation in Modelica model

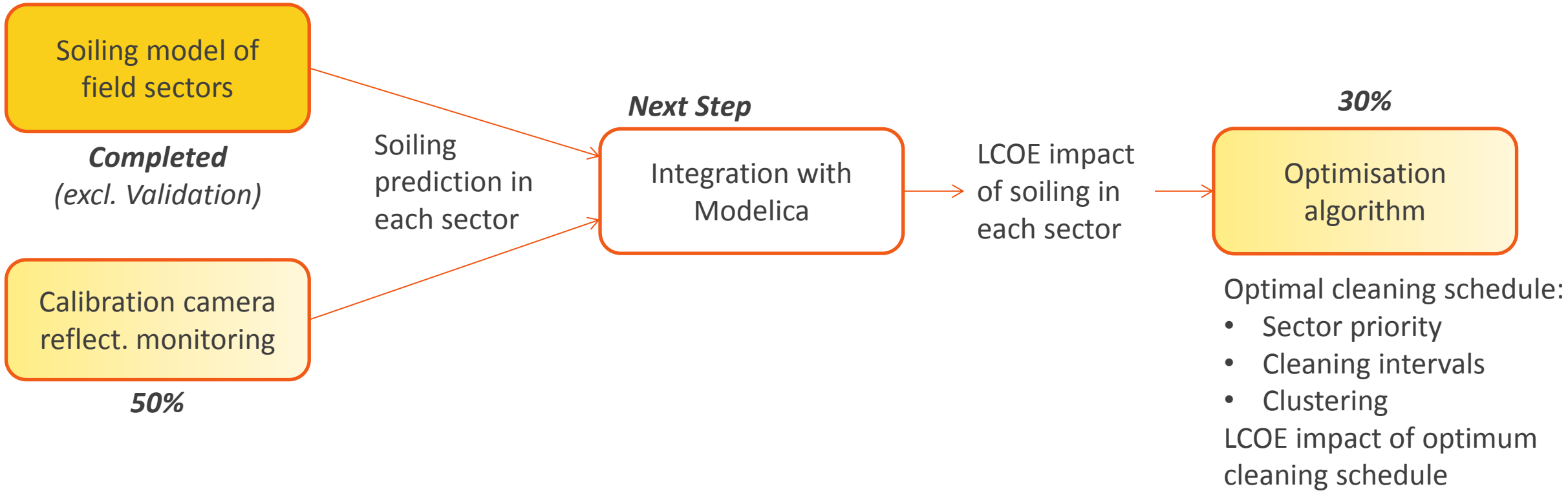
A robotic vision system for automatic inspection and evaluation of solar plants

Alternative assessment of reflectivity and mirror condition

Data from Collinsville installation

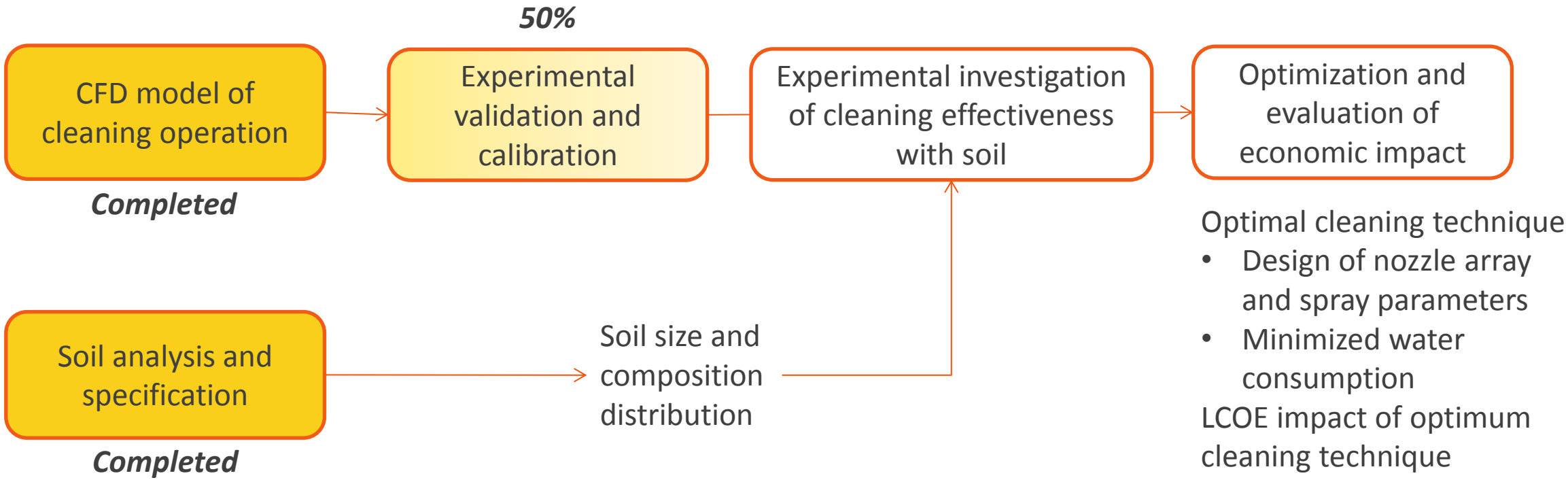
Data, industrial collaboration and piloting

O&M optimisation – Summary



- **Extension of this approach to other equipment and degradation based on industrial maintenance/degradation data**
- **Engagement of industry crucial for this step**

Cleaning technology – Summary



Acknowledgements

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Thank you