On the impact of operational uncertainties on water distribution system design

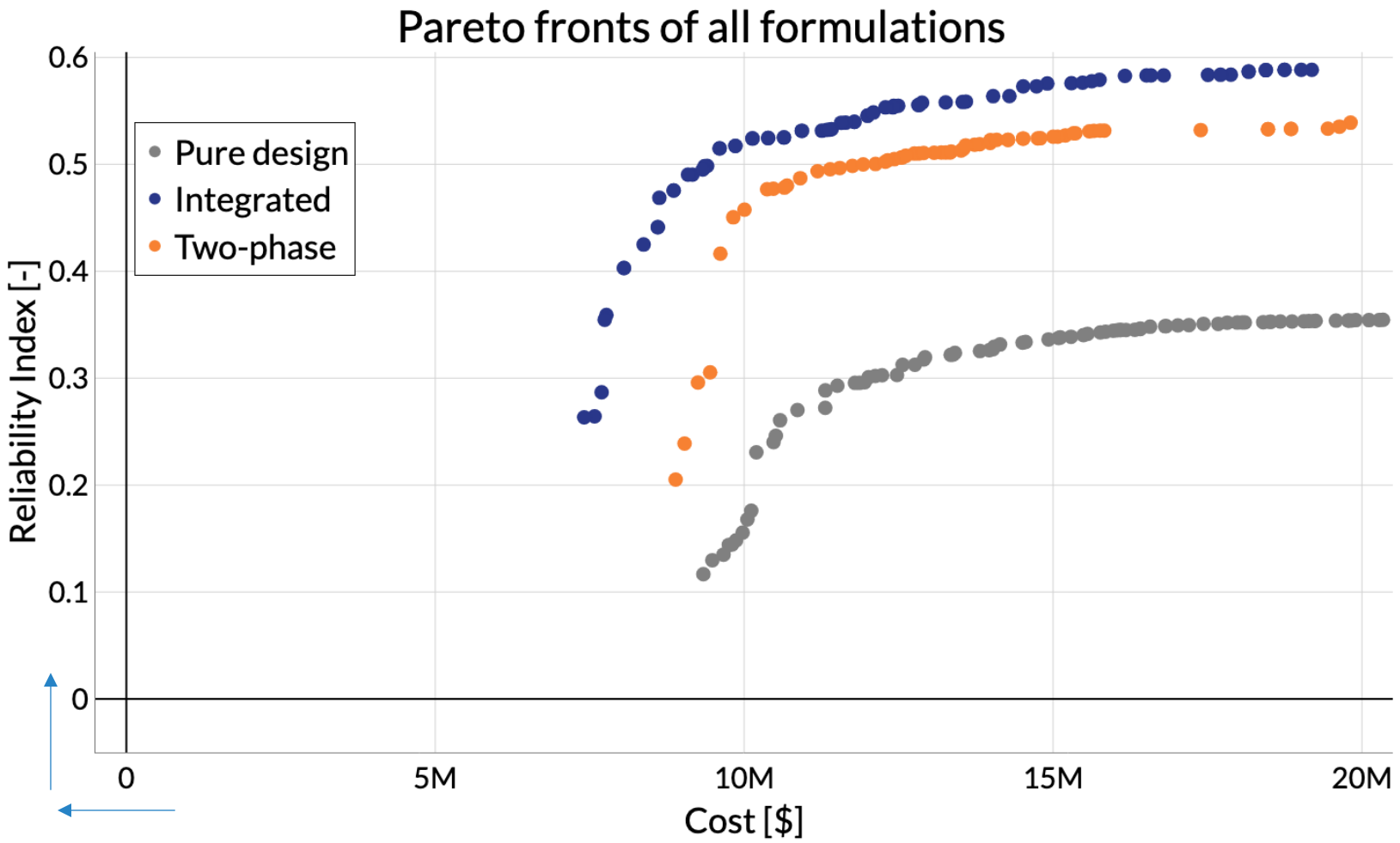
Preliminary insights on Anytown

Dennis Zanutto, 2nd year Ph.D candidate
Prof. Andrea Castelletti,
Prof. Dragan Savić

water futures

This project has received funding from the European Research Council (ERC) under the ERC Synergy Grant Water-Futures (Grant agreement No.951424).

Uncertainty or Flexibility?



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Research Objectives and Motivation

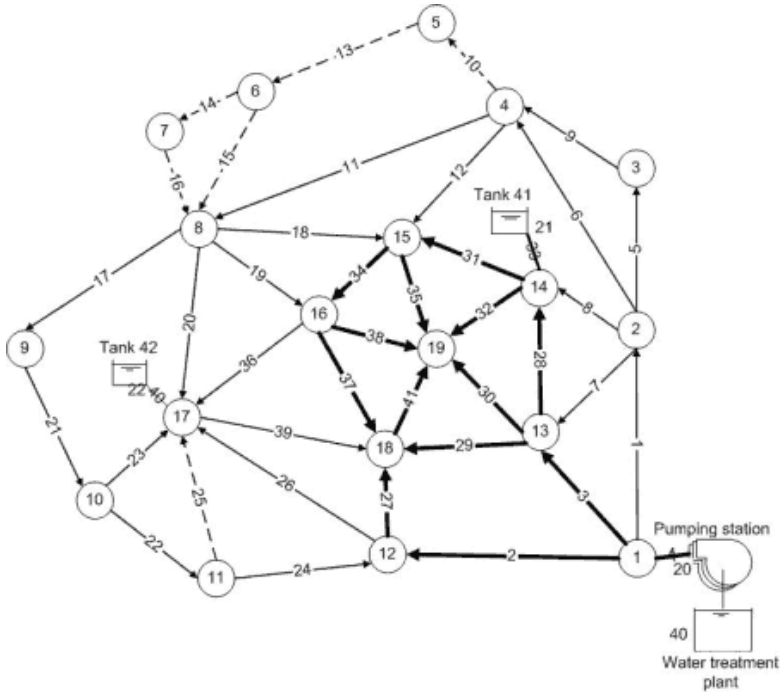
Long-term PhD research question:

Can we **introduce flexibility in WDS planning**/long-term design **through the operations** of the active elements?

Steps:

1. Why ”operational flexibility”?
2. Does this hold in other contexts?
3. **How do we introduce operational flexibility in WDS planning?**
    1. **How sensitive are WDSs to operations?** Today's focus!
    2. How do we quantify operational flexibility?
    3. How do we exploit operational flexibility?

Case Study: Anytown*



Objectives

Net Present Value (Cost)

C_0 Immediate capital expenditure
C_t Yearly pumps' electricity cost

$$NPC = C_0 + \sum_{t=1}^{25} \frac{C_t}{(1+r)^t}$$

Todini's Reliability Index

A measure of energy surplus to meet required demand $q^*$and head h^*. Todini, 2000

$$I_r = \frac{\sum_{i=1}^{n_j} q_i^*(h_i - h_i^*)}{\sum_{k=1}^{n_s} Q_k H_k + \sum_{j=1}^{n_p} {}^{P_j}/_{\gamma} - \sum_{i=1}^{n_j} q_i^* h_i^*}$$

Decision variables

Design

New pipes
- Diameter

Existing pipes
- Do nothing
- Clean
- Duplicate

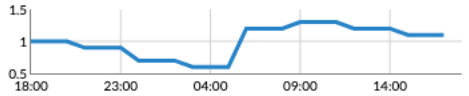
New tanks
- Location
- Volume

Operations

Pumping station
- Schedule

Constraints (Design requirements)

Meet demand and min. pressure at
- ~~instantaneous peak flow~~
- ~~fire flow conditions~~
- average daily pattern



*Full original formulation: Walski et al., 1987

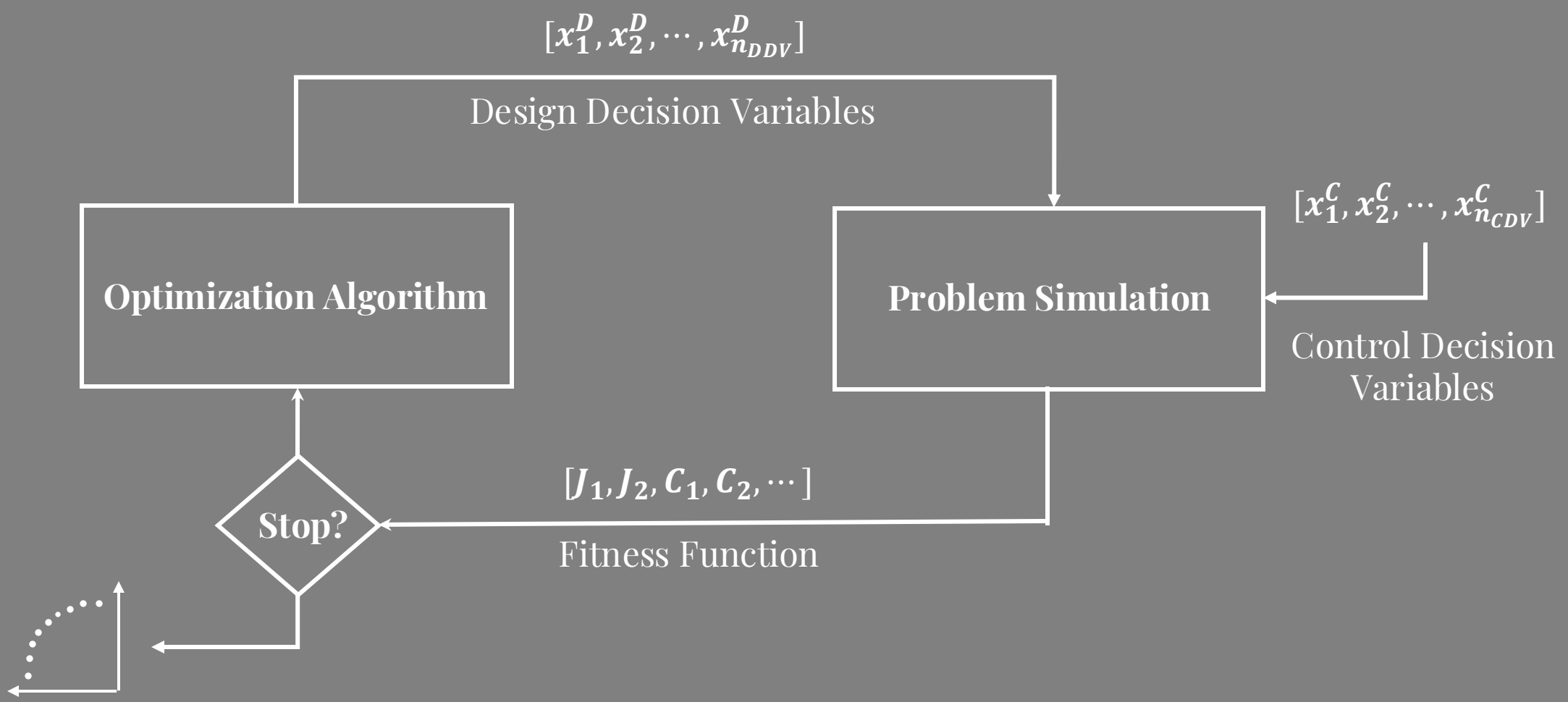
Methodology

Pure design

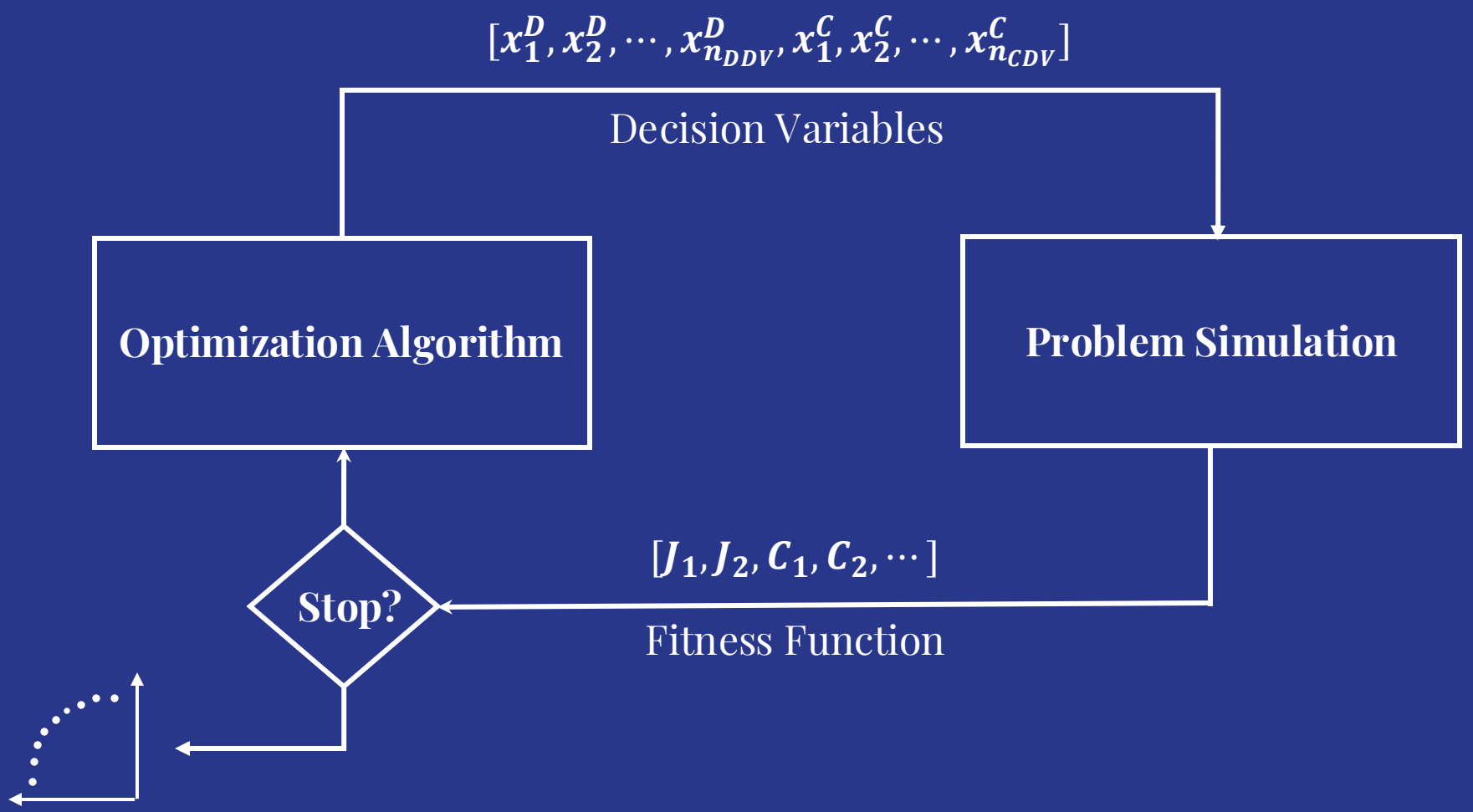
Integrated

Two-phase looped

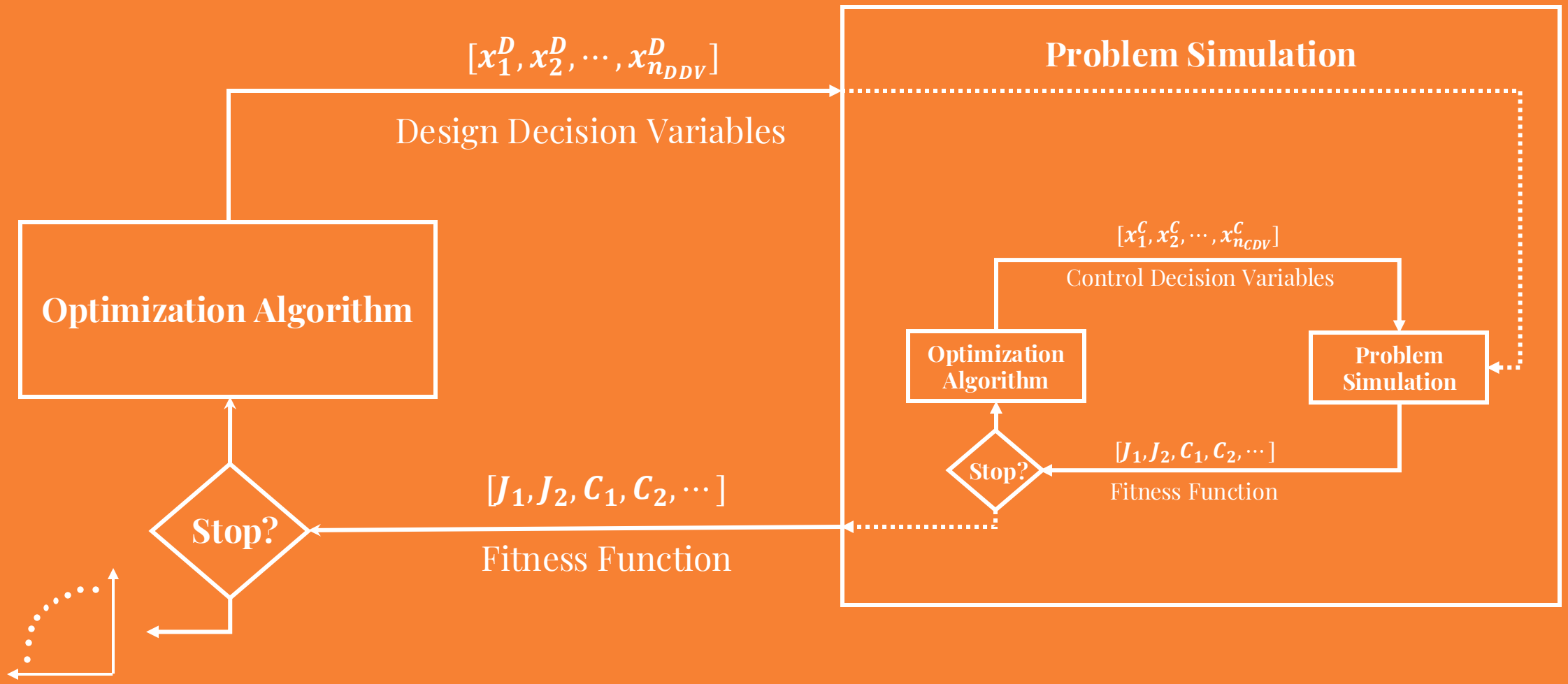
Pure design


$[x_1^D, x_2^D, \cdots, x_{n_{DDV}}^D]$
Design Decision Variables
Optimization Algorithm
Problem Simulation
$[x_1^C, x_2^C, \cdots, x_{n_{CDV}}^C]$
Control Decision Variables
Stop?
$[J_1, J_2, C_1, C_2, \cdots]$
Fitness Function

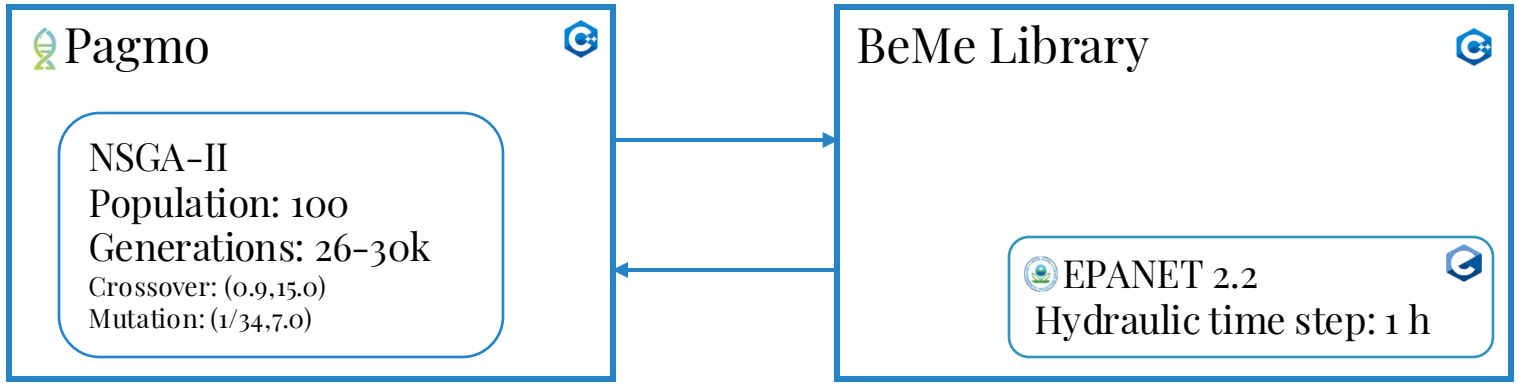
Integrated


$[x_1^D, x_2^D, \cdots, x_{n_{DDV}}^D, x_1^C, x_2^C, \cdots, x_{n_{CDV}}^C]$
Decision Variables
Optimization Algorithm
Problem Simulation
$[J_1, J_2, C_1, C_2, \cdots]$
Stop?
Fitness Function

Two-phase looped



Experimental Settings



Design Decision Variables $[\underbrace{\langle x_1|d_1\rangle, \cdots, \langle x_i|d_i\rangle, \cdots, \langle x_{35}|d_{35}\rangle}, \underbrace{d_{36}, \cdots, d_j, \cdots, d_{41}}, \underbrace{\langle t_1^{loc}|t_1^{vol}\rangle, \langle t_2^{loc}|t_2^{vol}\rangle}]$

Existing pipes: ⟨action|diameter⟩ New pipes: diameter New tanks: ⟨location'|volume⟩

Control Decision Variables $[\underbrace{z_1, \cdots, z_i, \cdots, z_{24}}]$

Pump station: # active pumps at each hour

Implementation: Zanutto, 2024

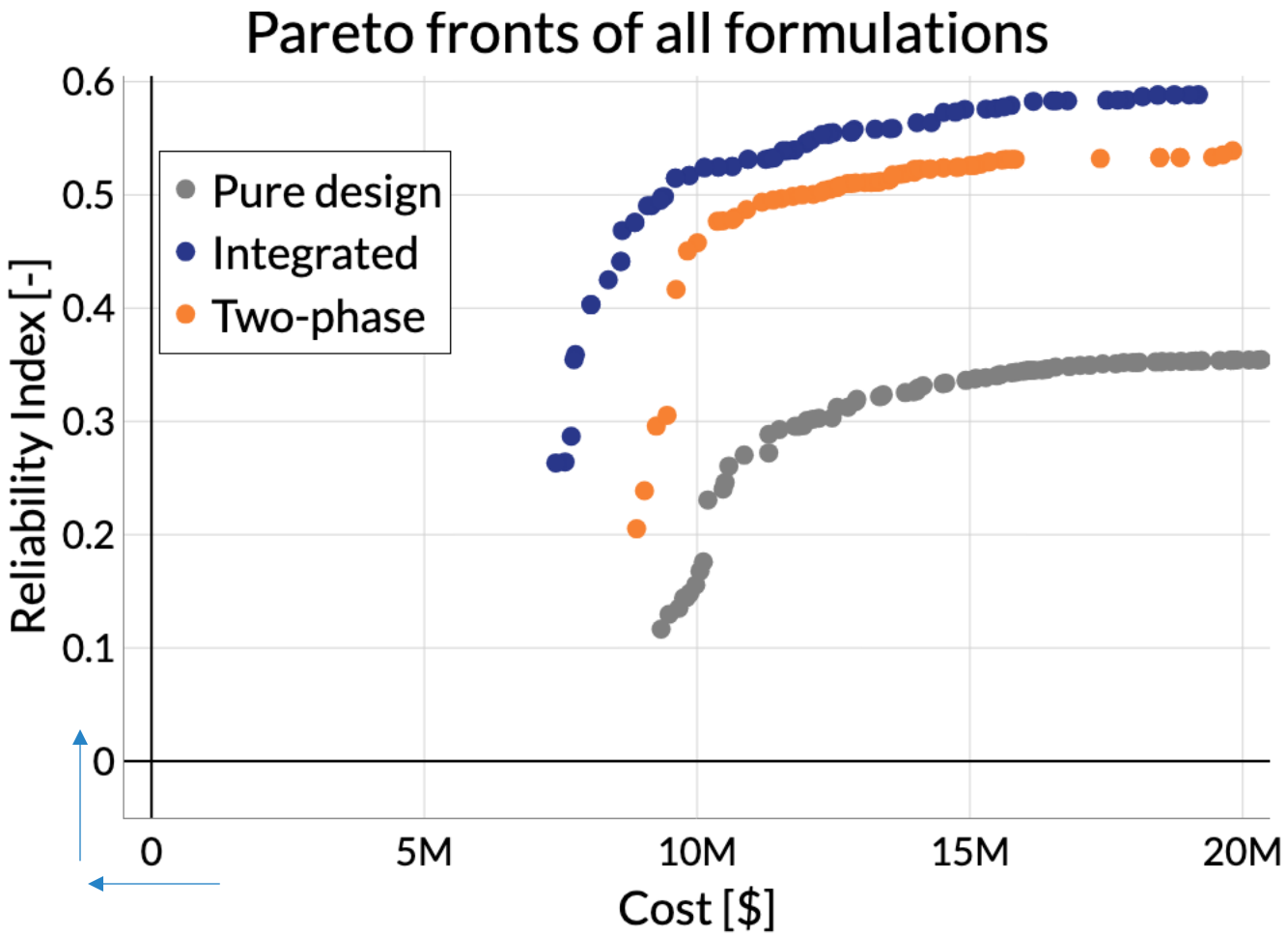
thanks to:

Rossman, 2000

Deb et al., 2002

Biscani and Izzo, 2020

Results



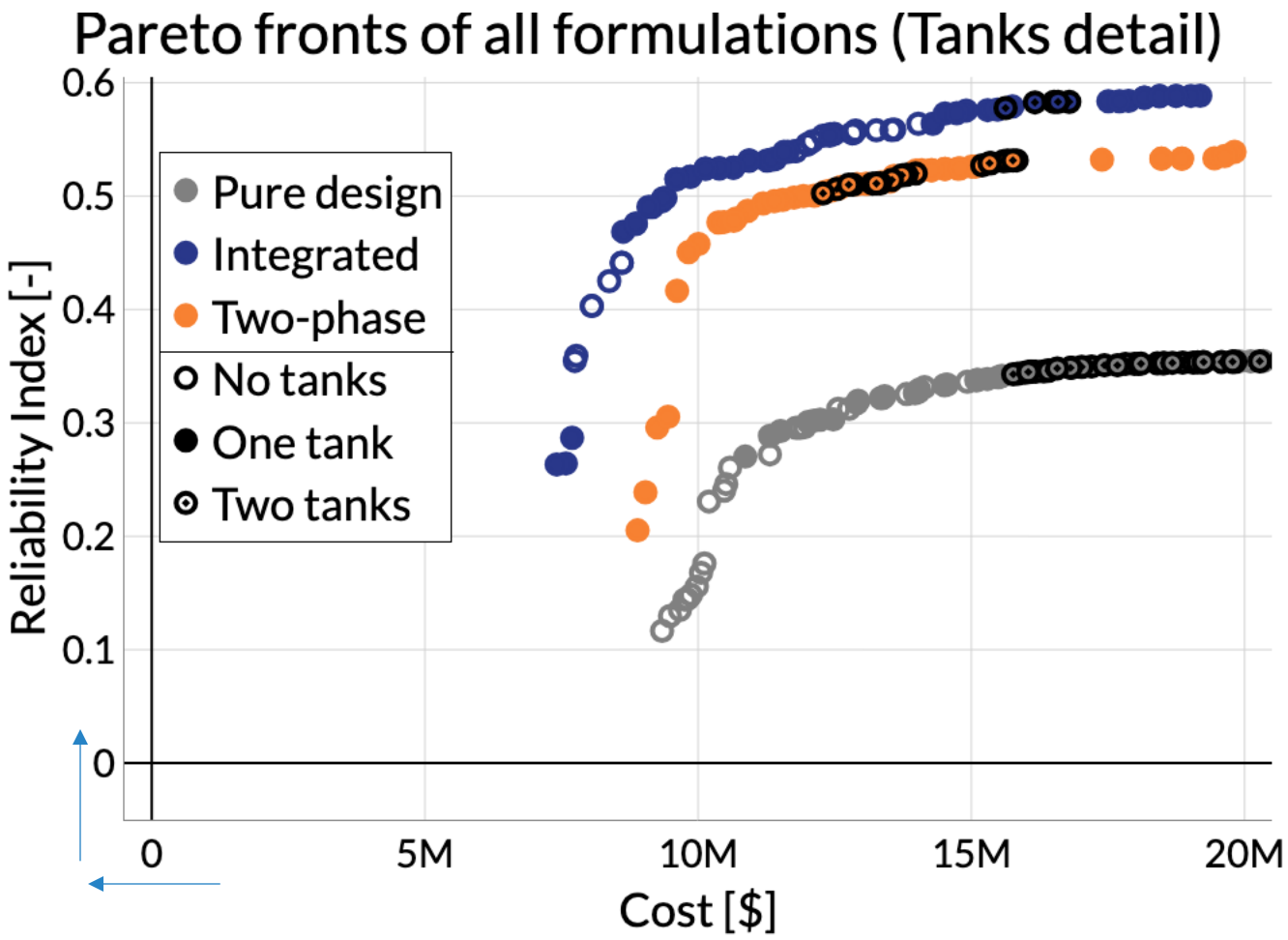
Integrated

- +180% at 10M
- +70% at 15M

Two-phase

- 150% at 10M
- 55% at 15M

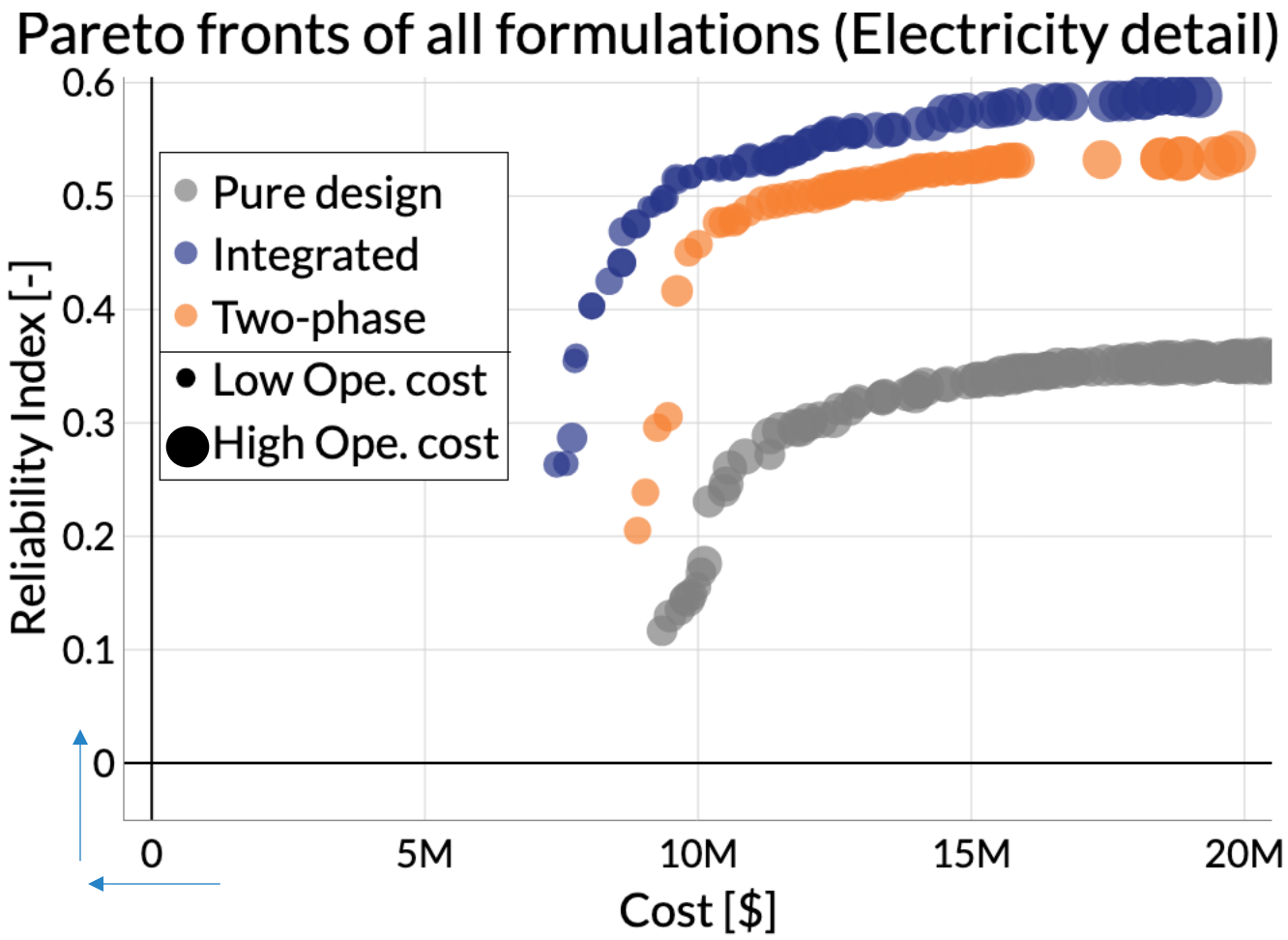
Results- detail-



There is no clear dependence on tanks for the joint approaches.

The pure design needs the tanks for high reliability!

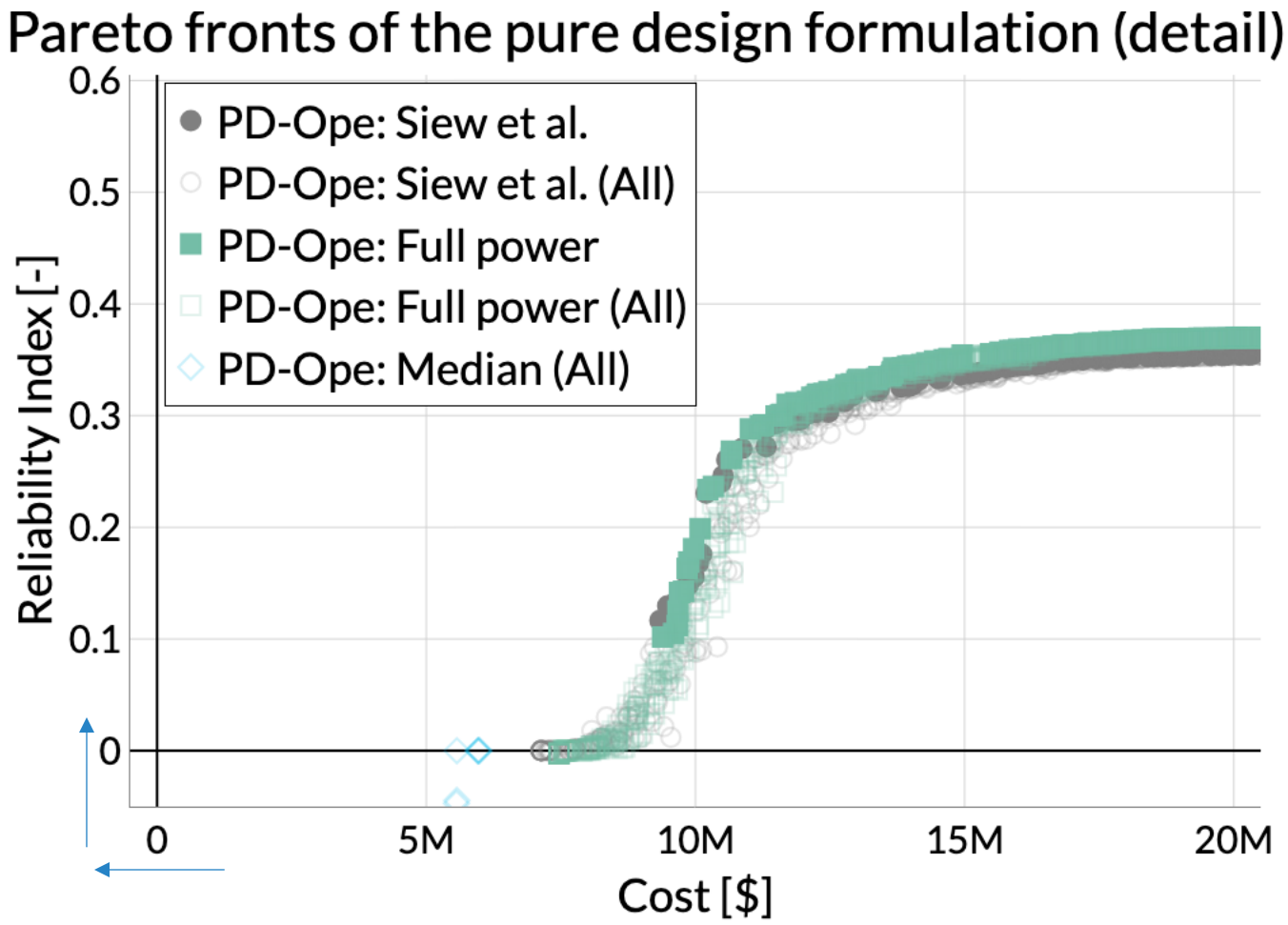
Results- detail-



Similar operational costs.

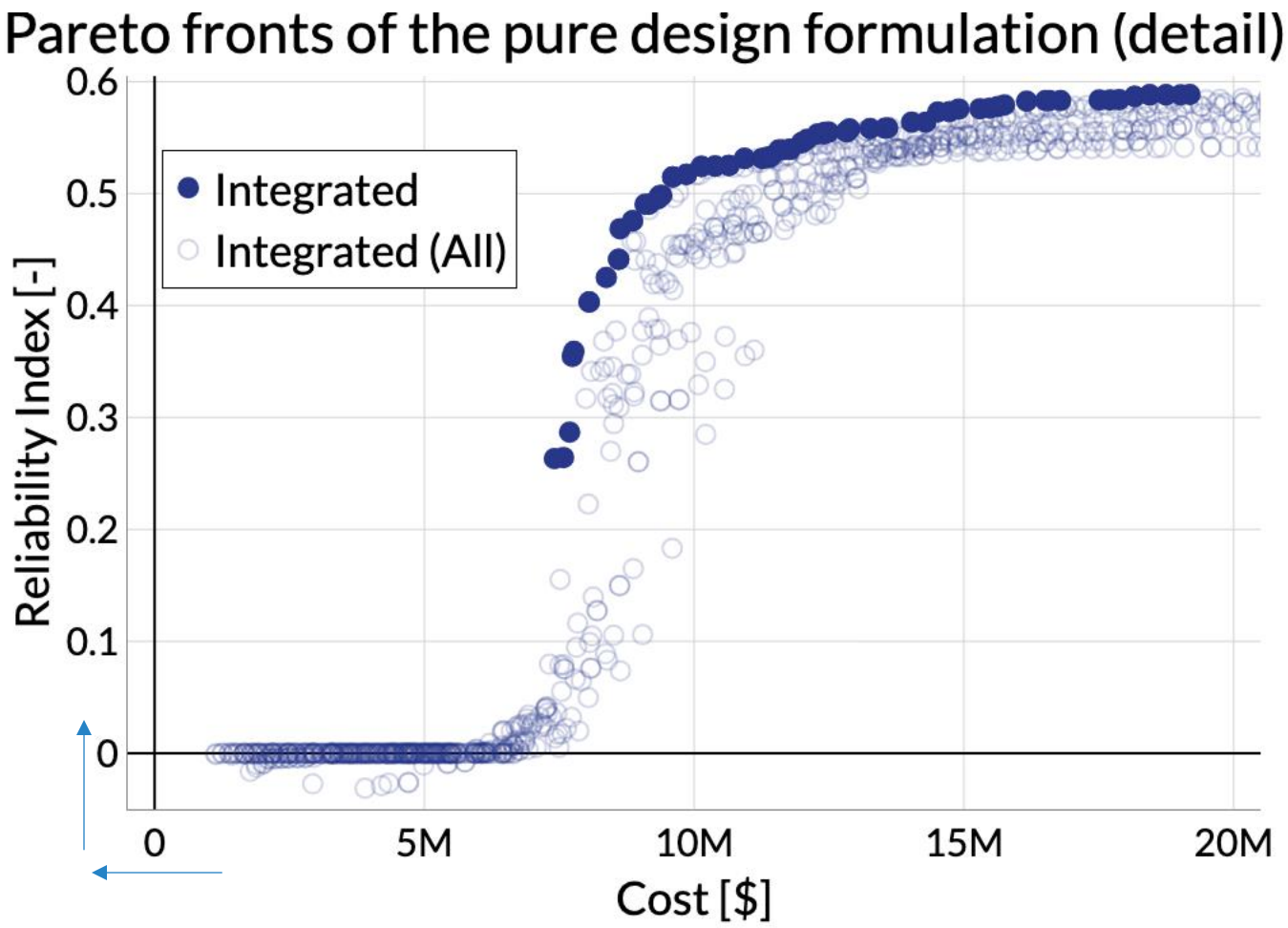
Operations behaviour?

Results- detail-



These are pretty standard results.

Results- detail-

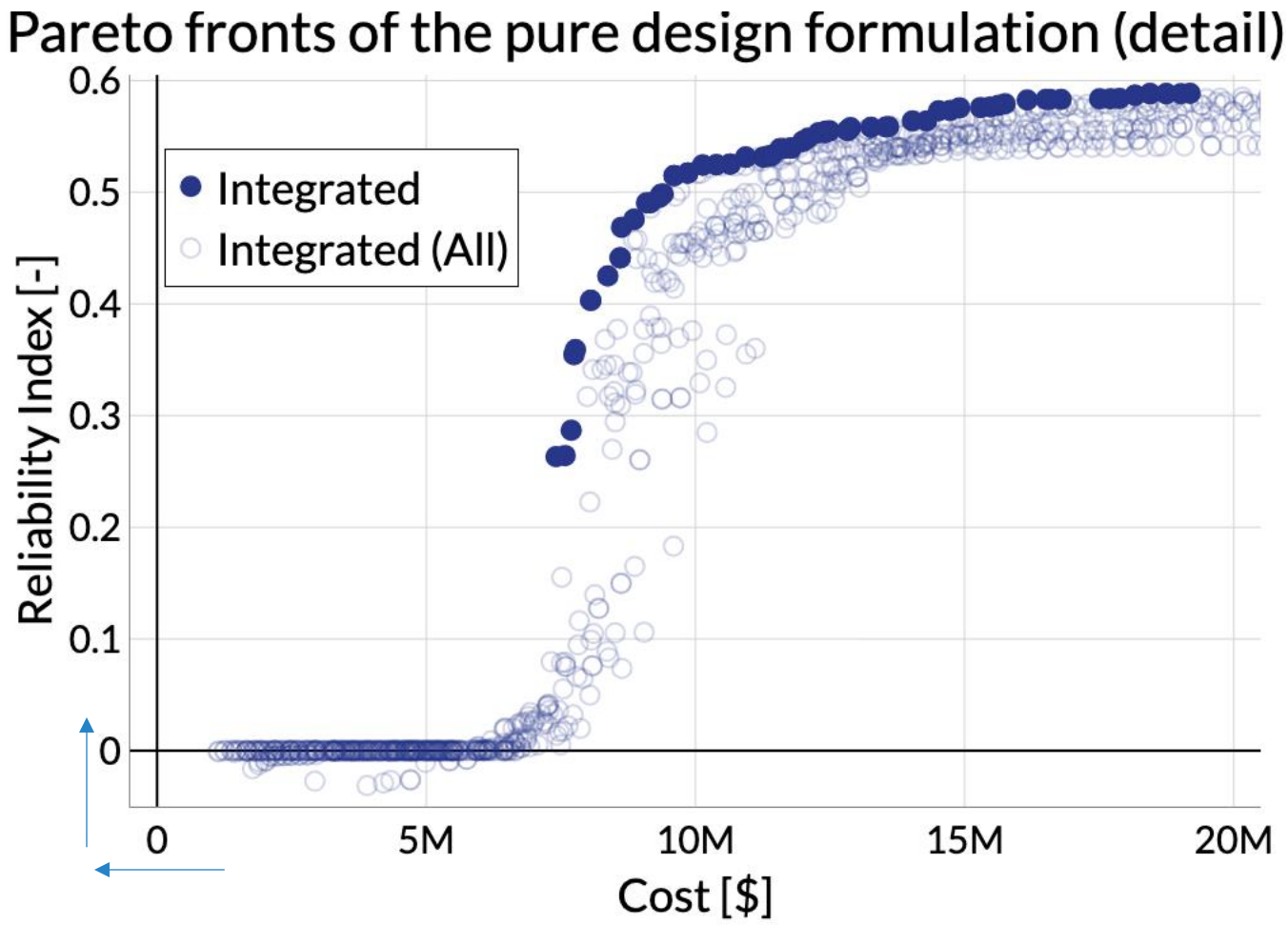


More local optimum.

Big attractor at $I_r = 0$.

Convergence issues.

Results- detail-

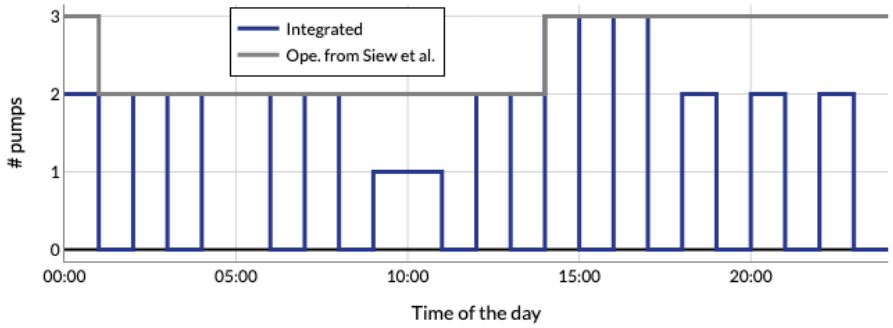


More local optimum.

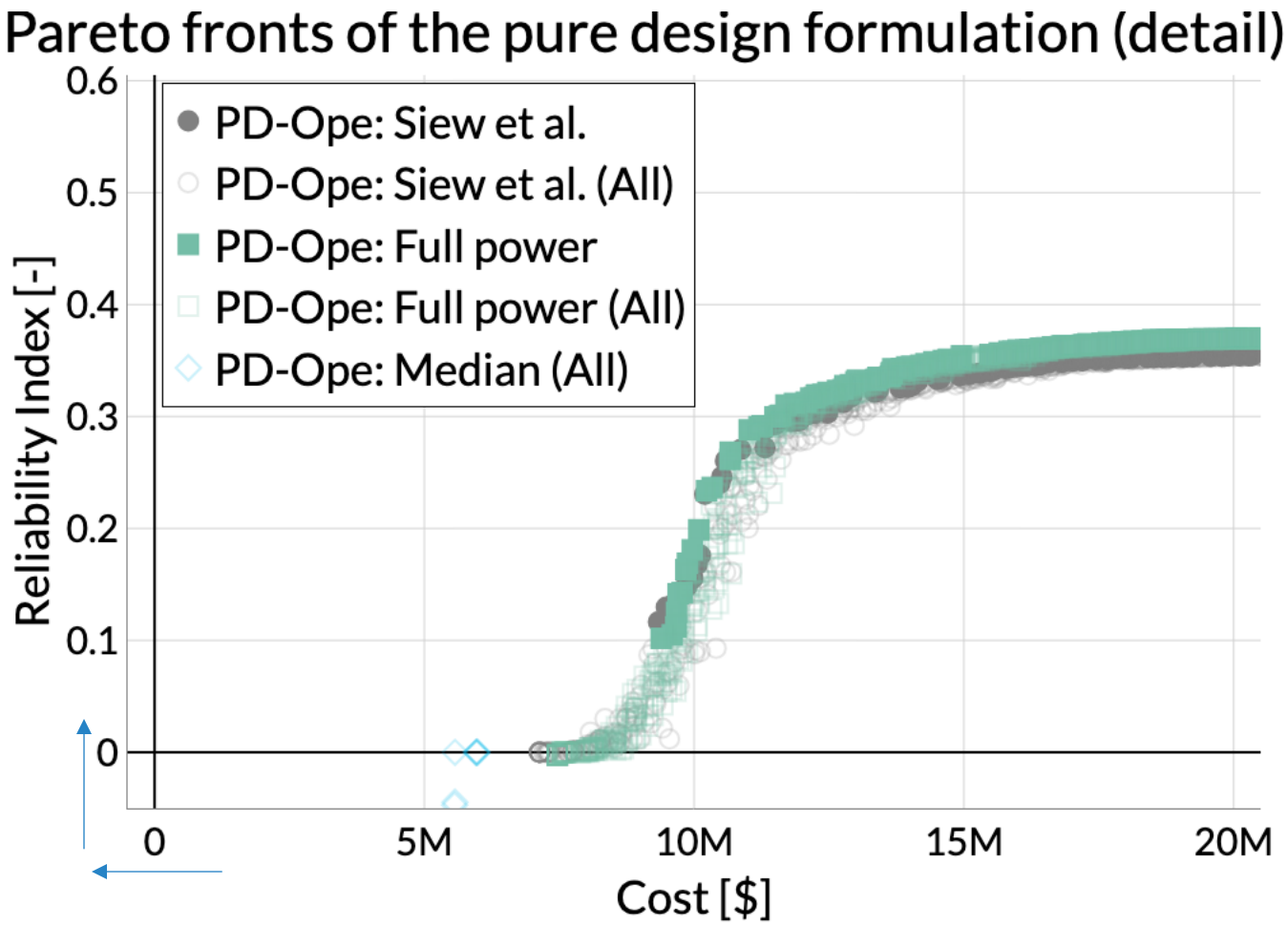
Big attractor at $I_r = 0$.

Convergence issues.

How are operations optimised?



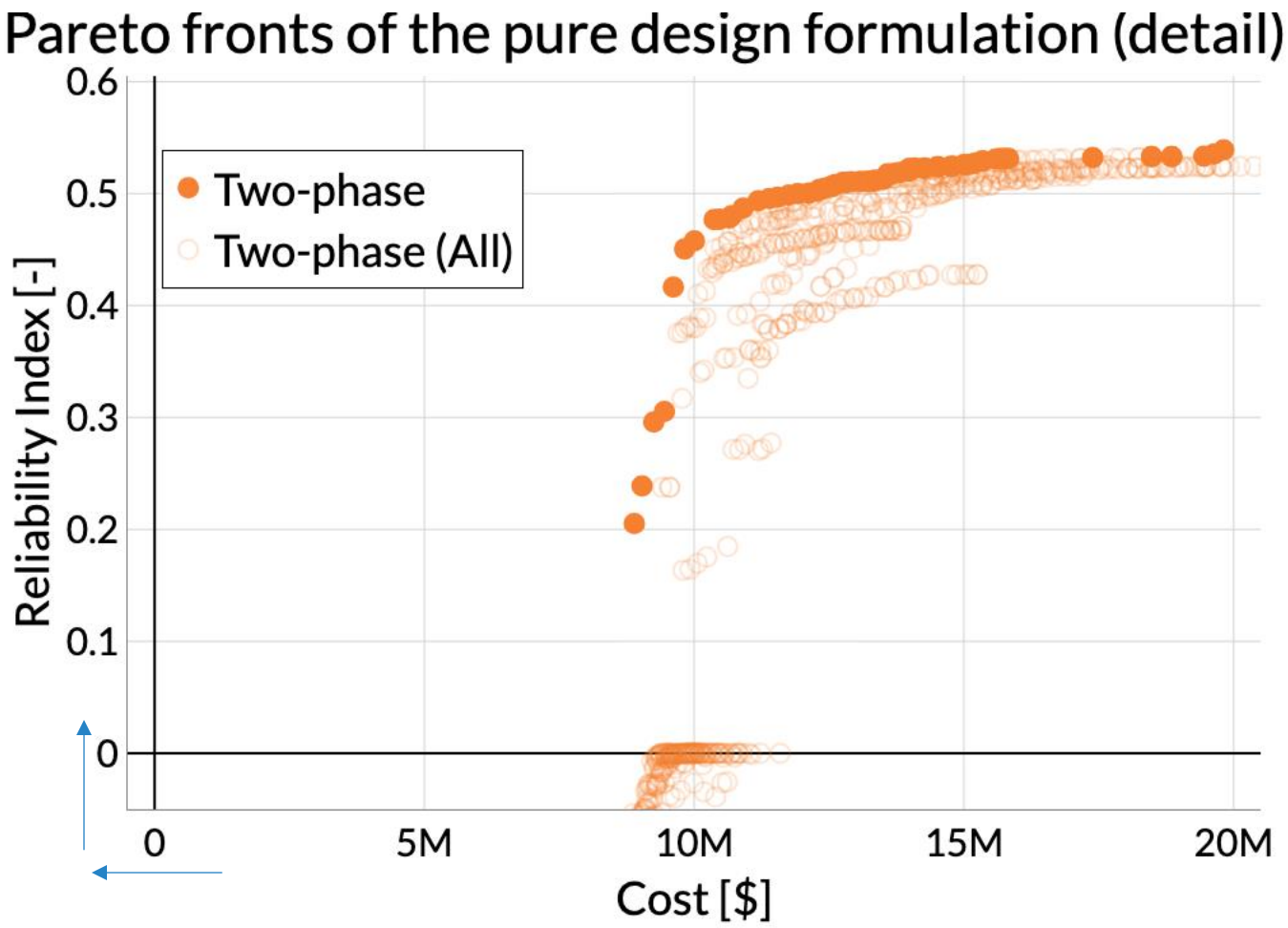
Results- detail-



These are pretty standard results.

These optimised operations don't work!

Results- detail-



Higher stability.

Greater confusion.

Different attractor.

Material and Contacts

Source code (WIP)

Zenodo (results)

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References

Case study:

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- Todini, E. Looped Water Distribution Networks Design Using a Resilience Index Based Heuristic Approach. *Urban Water* **2000**, *2*, 115–122, doi:10.1016/S1462-0758(00)00049-2.

Coding:

- Rossman, L.A. (2000) EPANET 2.0 User Manual. Water Supply and Water Resources Division, National Risk management Laboratory, USEPA, Cincinnati, OH.
- K. Deb, A. Pratap, S. Agarwal and T. Meyarivan, "A fast and elitist multiobjective genetic algorithm: NSGA-II," in IEEE Transactions on Evolutionary Computation, vol. 6, no. 2, pp. 182-197, April 2002, doi: 10.1109/4235.996017.
- Biscani et al., (2020). A parallel global multiobjective framework for optimization: pagmo. Journal of Open Source Software, 5(53), 2338, https://doi.org/10.21105/joss.02338

Other:

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