Phase-Out Maintenance OptimizationPhase

FT2019

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Project is supported by
VINNOVA, Luleå University of Technology, Saab Support and Services, SAAB Aeronautics and Systecon

Remark: This is a 566 slides presentation done in less than 30 minutes, so please, wait with your questions until the presentation is finished…

Agenda

- Background & Formulation of the optimization problem
- Attacking the optimization problem using two different methods
  - ***Brute Force (time consuming, not recommended)***
  - ***Genetic Algorithm***
- Studying the Genetic Algorithm ability to solve the optimization problem when varying the sampleset size.

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Background

- This work have been done in collaboration mainly between SAAB, Systecon and Luleå University of Technology
  - FLAPS program: 2008-2009
  - NFFP6 program: 2014-2017

- The NFFP6 programme has been supported by VINNOVA, Luleå University of Technology, Saab Support and Services, SAAB Aeronautics and Systecon

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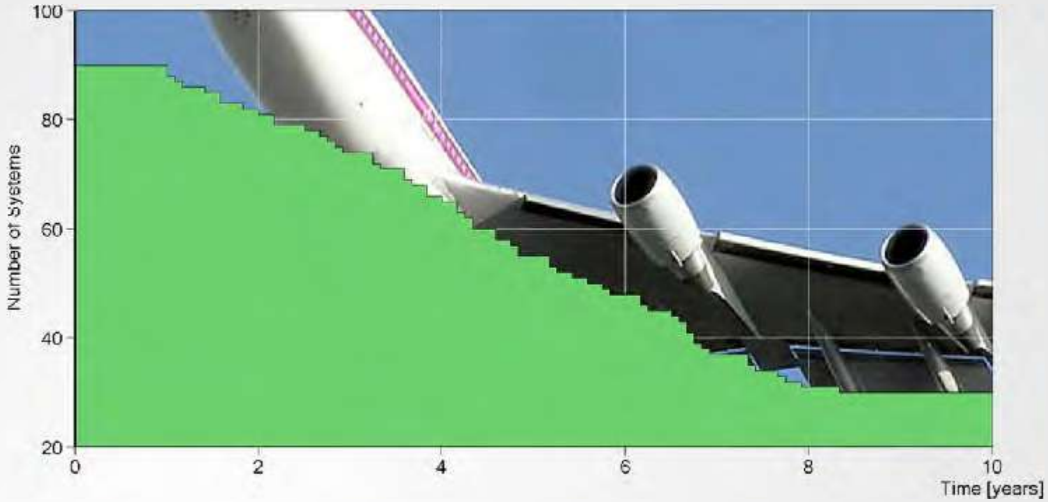
Background

- Phase out scheme:
  - 10 years
  - 90 aircraft



- Item data:

Item ID	Quantity per aircraft	Initial stock	Fail rate $[1/10^3$ fh]	CM TAT [Days]	CM Cost [SEK]	PM Interval	PM TAT [Days]	PM Cost [SEK]	Recov cost [SEK]
Warning Beacon	[redacted]								
Relief Valve	[redacted]								
Transducer	[redacted]								
Cut-Off Valve	[redacted]								
A/C - Start Generator	[redacted]								
Hydraulic Generator	[redacted]								
Electric Motor	[redacted]								
Electric Jack	[redacted]								
Oxygen Hose	[redacted]								
Cooling Turbine	[redacted]								

Optimization

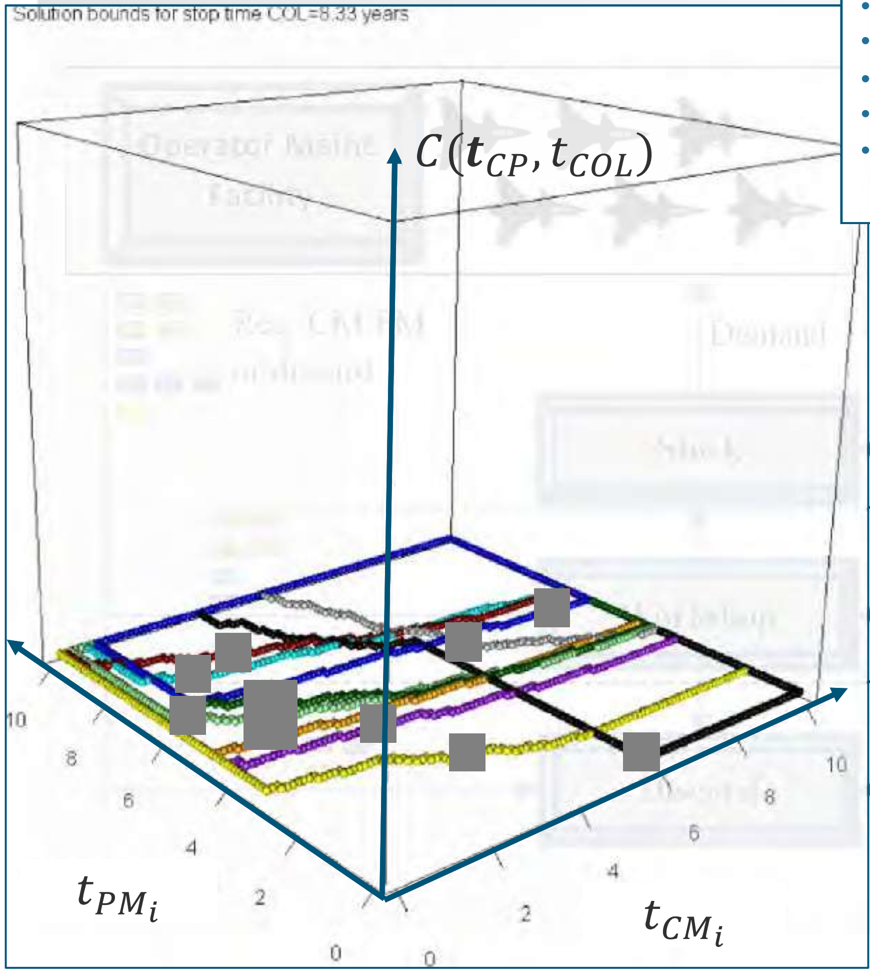
Optimization problem:

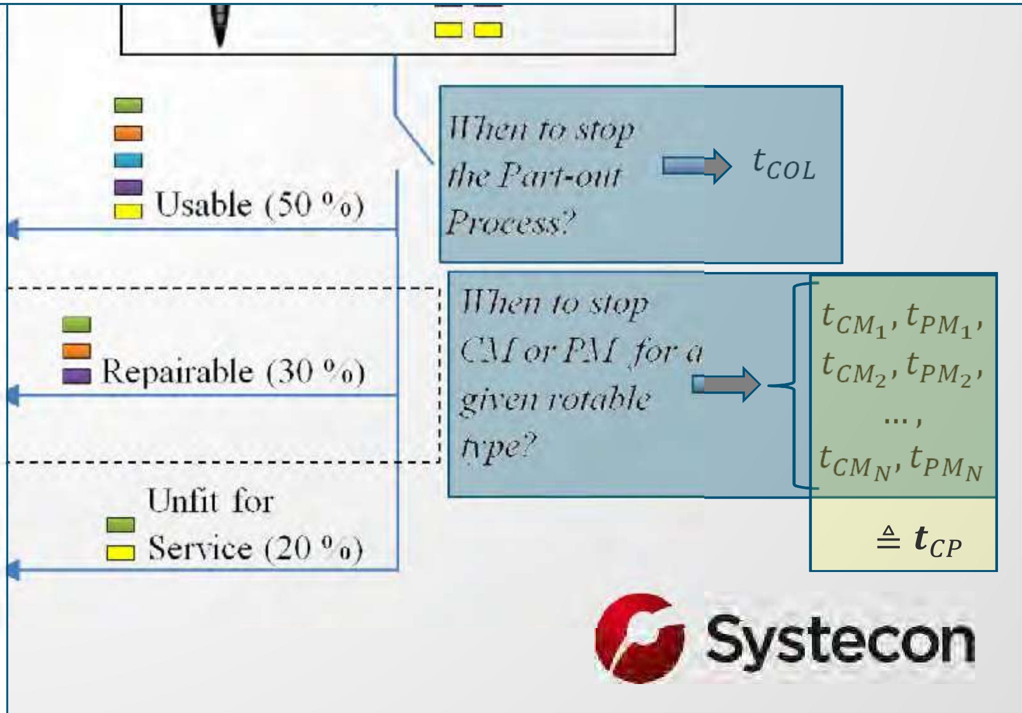
$$\min C(\boldsymbol{t}_{CP}, t_{COL})$$

$$\text{s.t. } \sum_{i=1}^{N} B_i(t) = 0$$

$C(\boldsymbol{t}_{CP}, t_{COL})$ can be chosen freely to fit reality. In this presentation, we use:

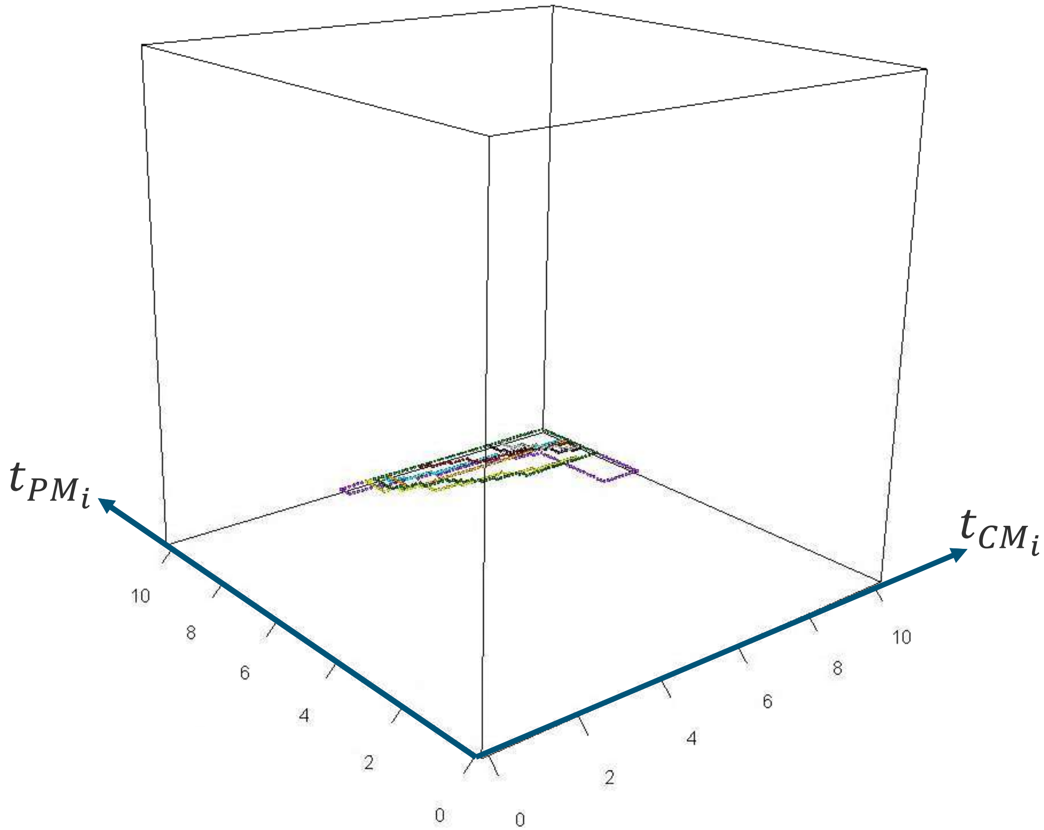
- $C = C_K + C_M + C_O$, where
- $C_K = c_K \max(\boldsymbol{t}_{CP}, t_{COL})$
- $C_M = \sum_{i=1}^{N} \left[\sum_{j=1}^{k_i} c_{a_{ij}} a_{ij} + \sum_{j=1}^{m_i} c_{b_{ij}} b_{ij} \right]$
- $C_O = \sum_{i=1}^{N} c_{o_i} o_i$
- o_i is the number of LRU_i that are recovered from disposed aircraft
- c_{o_i} is the cost for recovering LRU_i from disposed aircraft
- k_i and m_i are the number of CM and PM maintenance types that exists for LRU_i
- a_{ij} is the number of CM activities of type j that are done on LRU_i
- $c_{a_{ij}}$ is the cost of carrying out CM activity of type j in LRU_i
- b_{ij} is the number of PM activities of type j that are done on LRU_i
- $c_{b_{ij}}$ is the cost of carrying out PM activity of type j on LRU_i
- c_K is the maintenance capacity cost (500 000 SEK/year)





Matrix simulation results $t_{COL} = 0.00$ years

The boundaries of the solution spaces $S_1, S_2, \dots, S_{10}$ obtained by applying matrix simulations are shown below with a unique color



When not recovering any items from phased out aircraft ($t_{COL} = 0.00$) we are forced to continue with PM and CM longer time in order to meet the backorder requirements in the optimization problem… but if we increase t_{COL} then we can stop CM and PM earlier…

Slide 7

Matrix simulation results $t_{COL} = 1.00$ years

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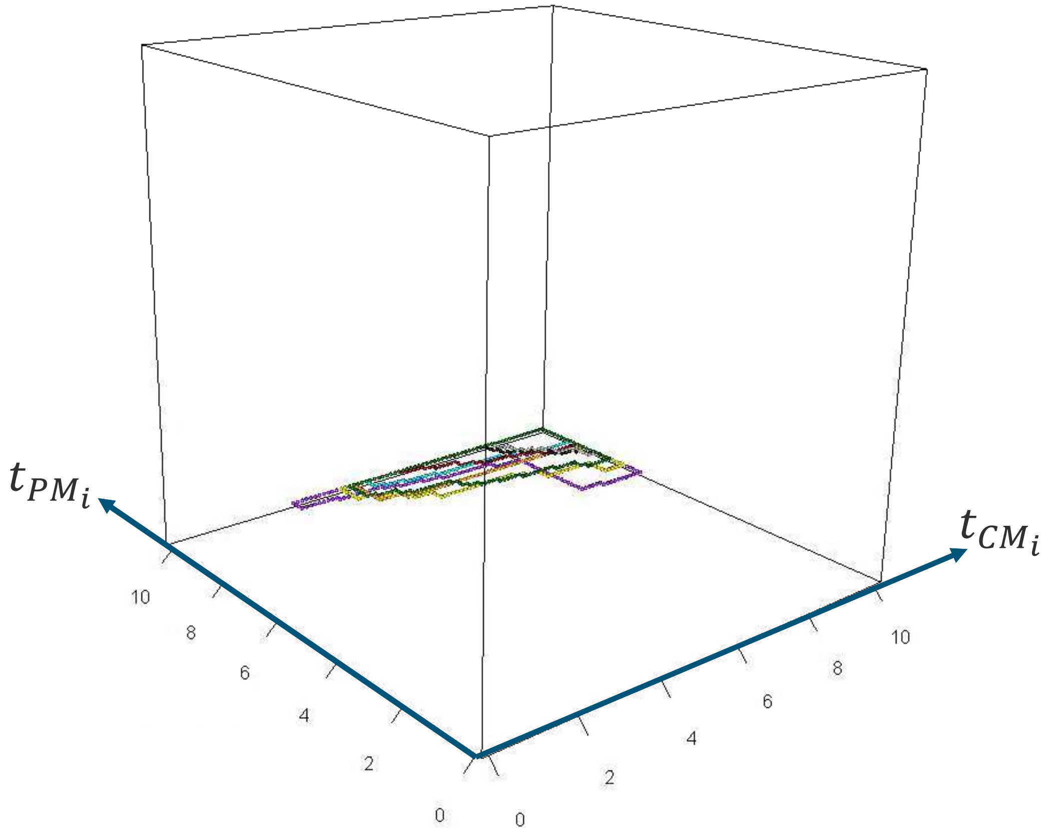

Slide 8

Matrix simulation results $t_{COL} = 1.08$ years

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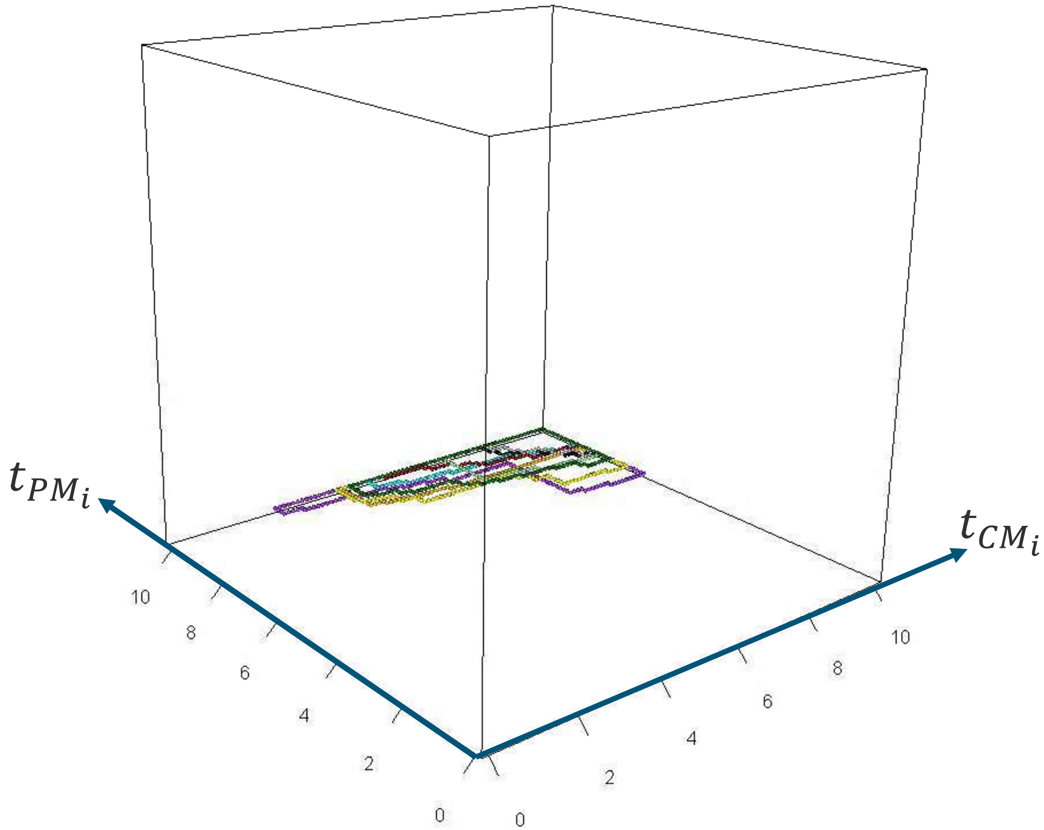

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Slide 9

Matrix simulation results $t_{COL} = 1.17$ years

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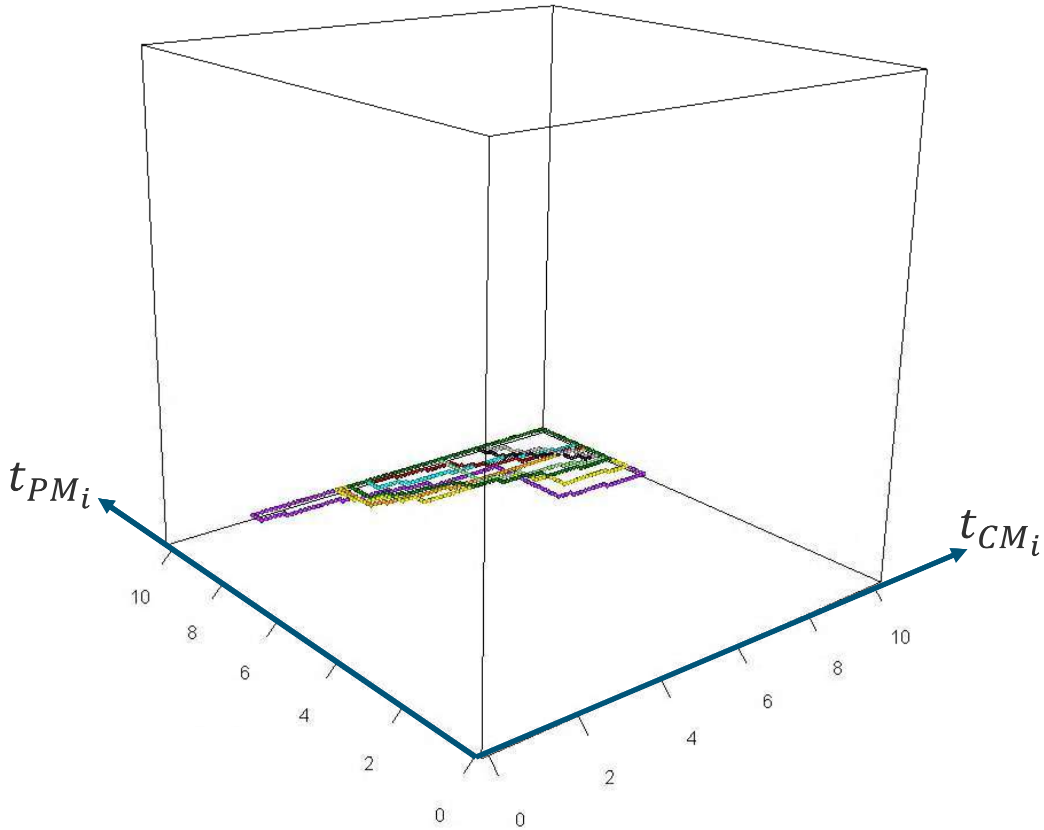

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Matrix simulation results $t_{COL} = 1.42$ years

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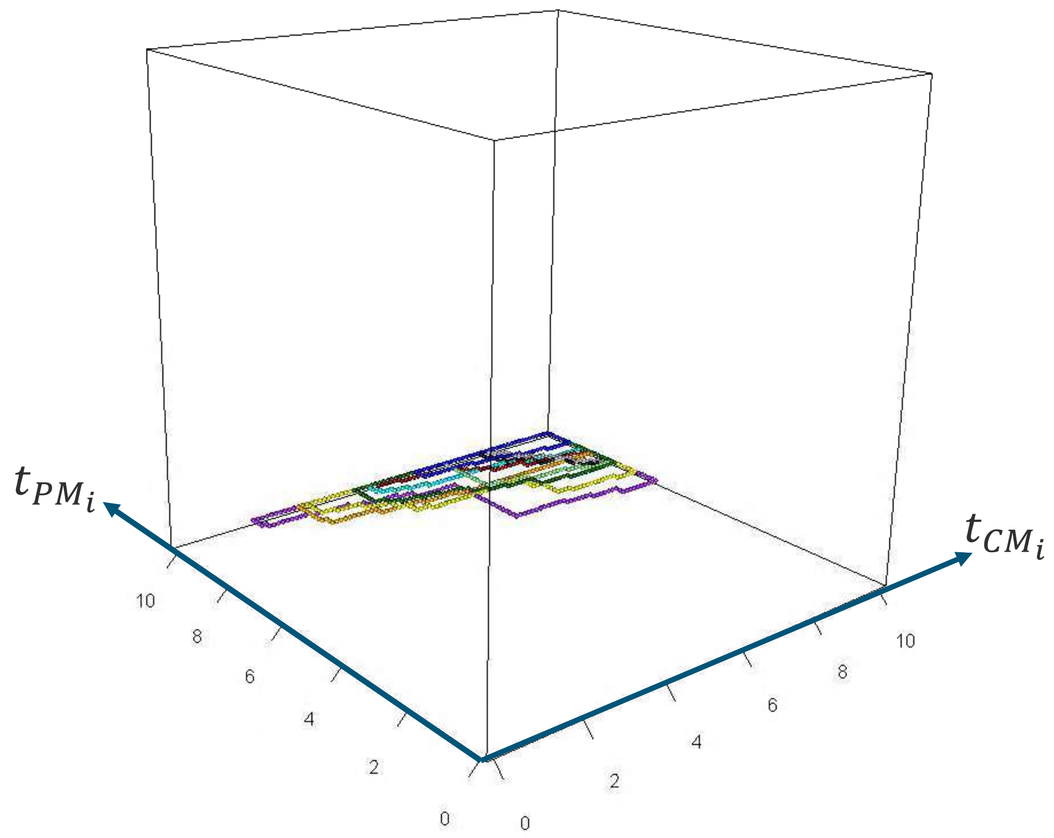

Matrix simulation results $t_{COL} = 1.58$ years

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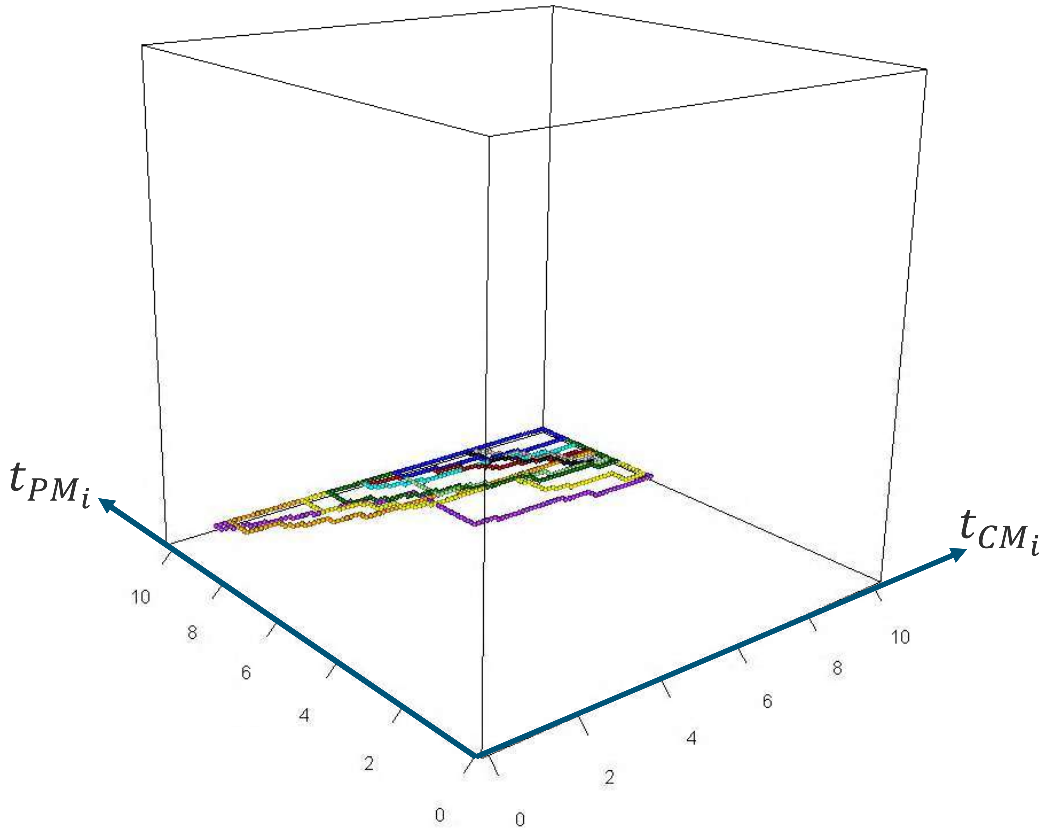

Matrix simulation results $t_{COL} = 1.83$ years

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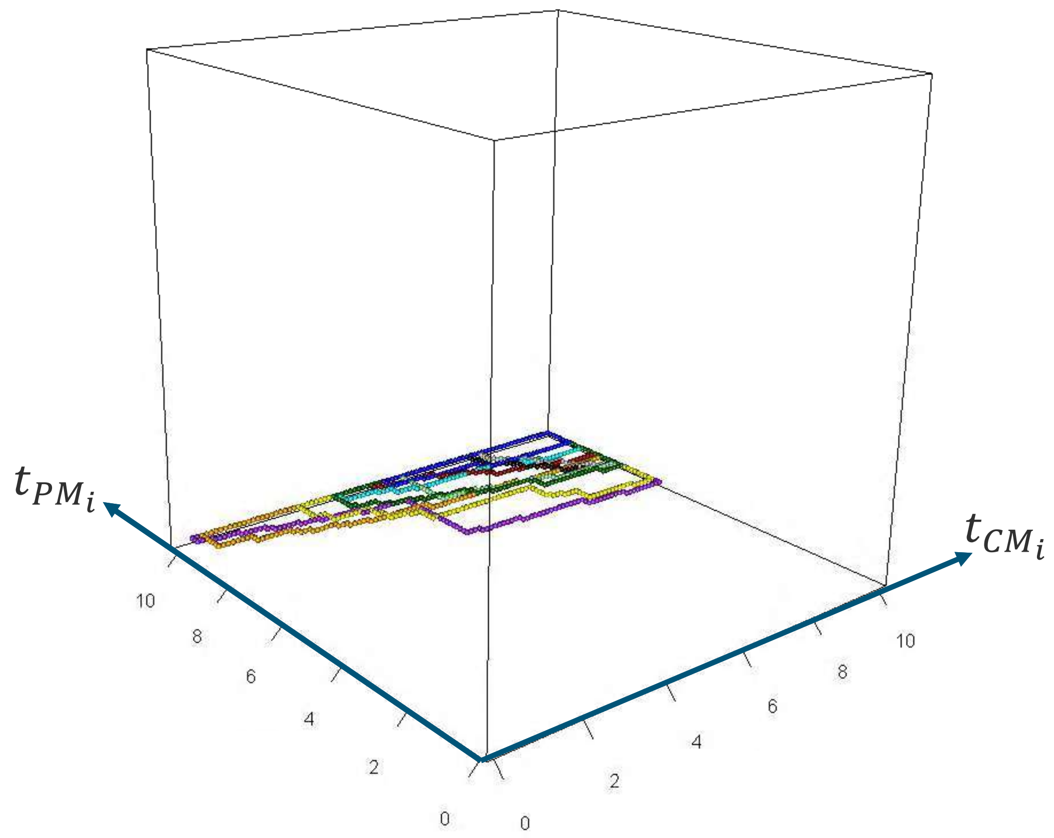

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Matrix simulation results $t_{COL} = 2.00$ years

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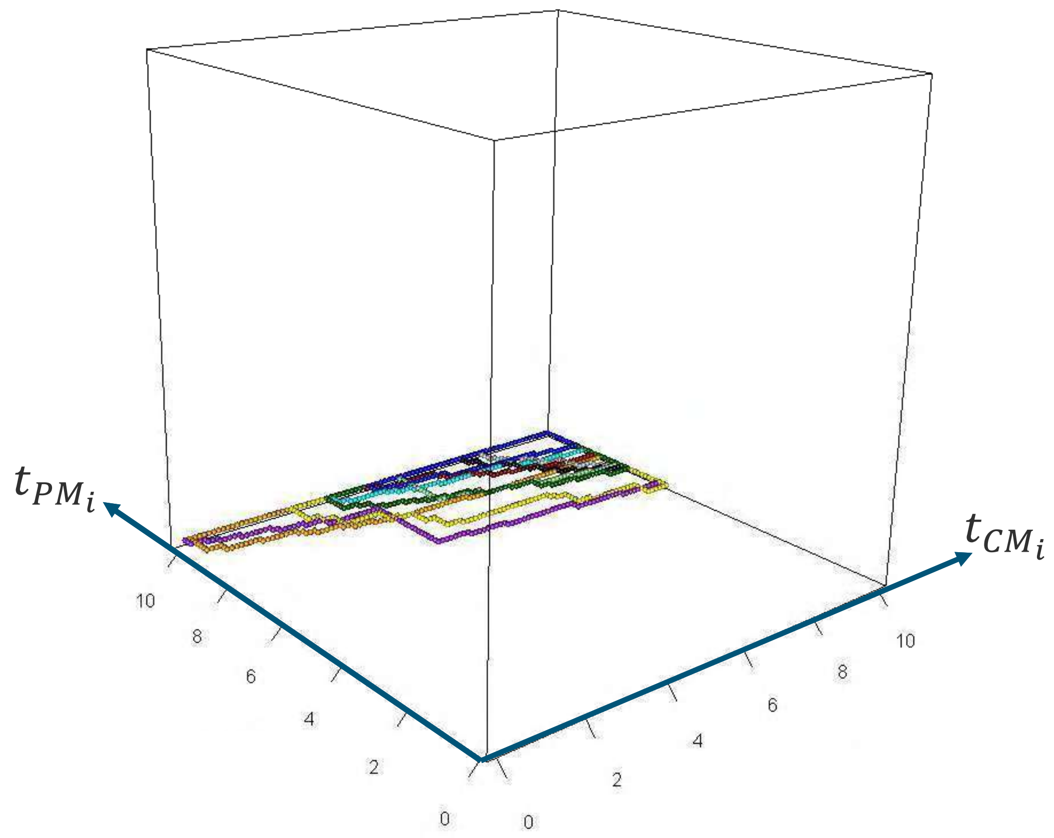

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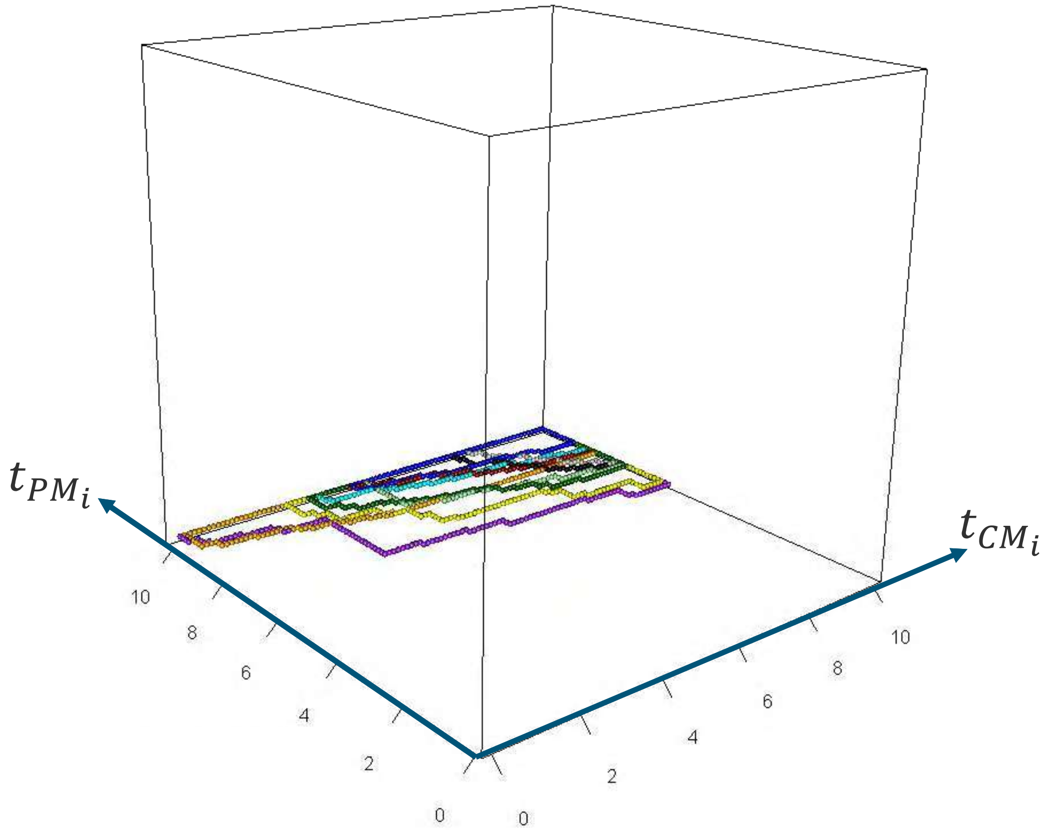

Matrix simulation results $t_{COL} = 2.50$ years

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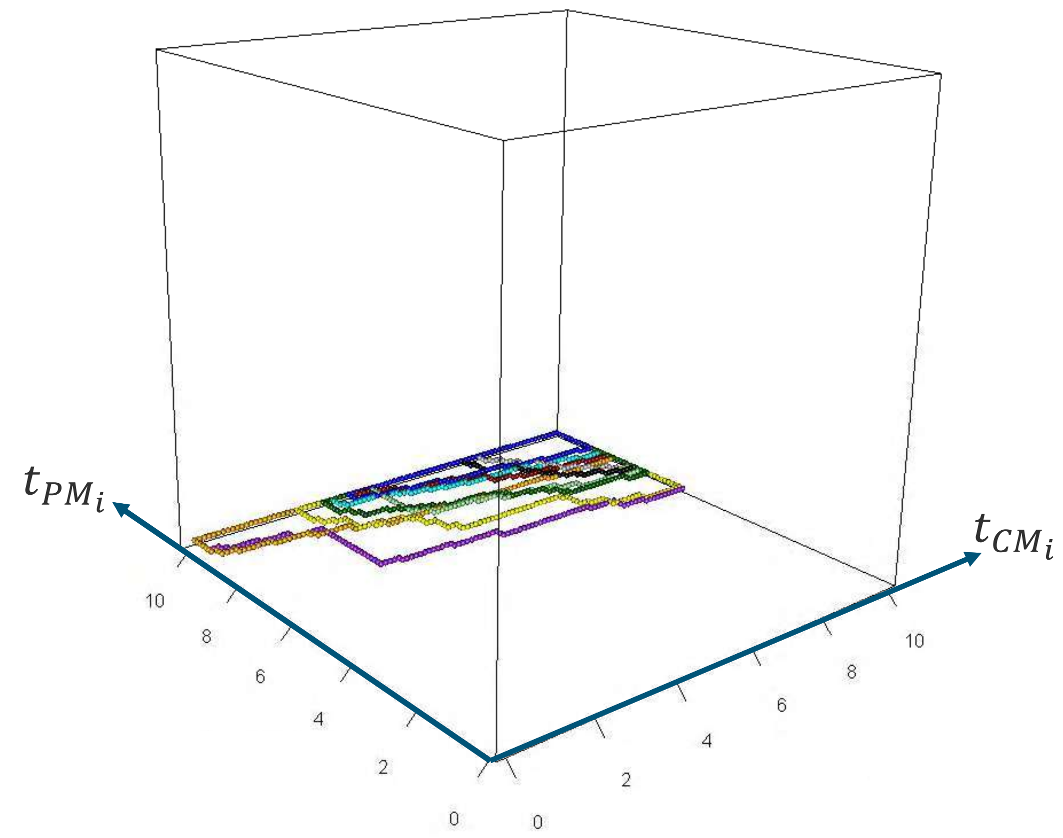

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Matrix simulation results $t_{COL} = 2.67$ years

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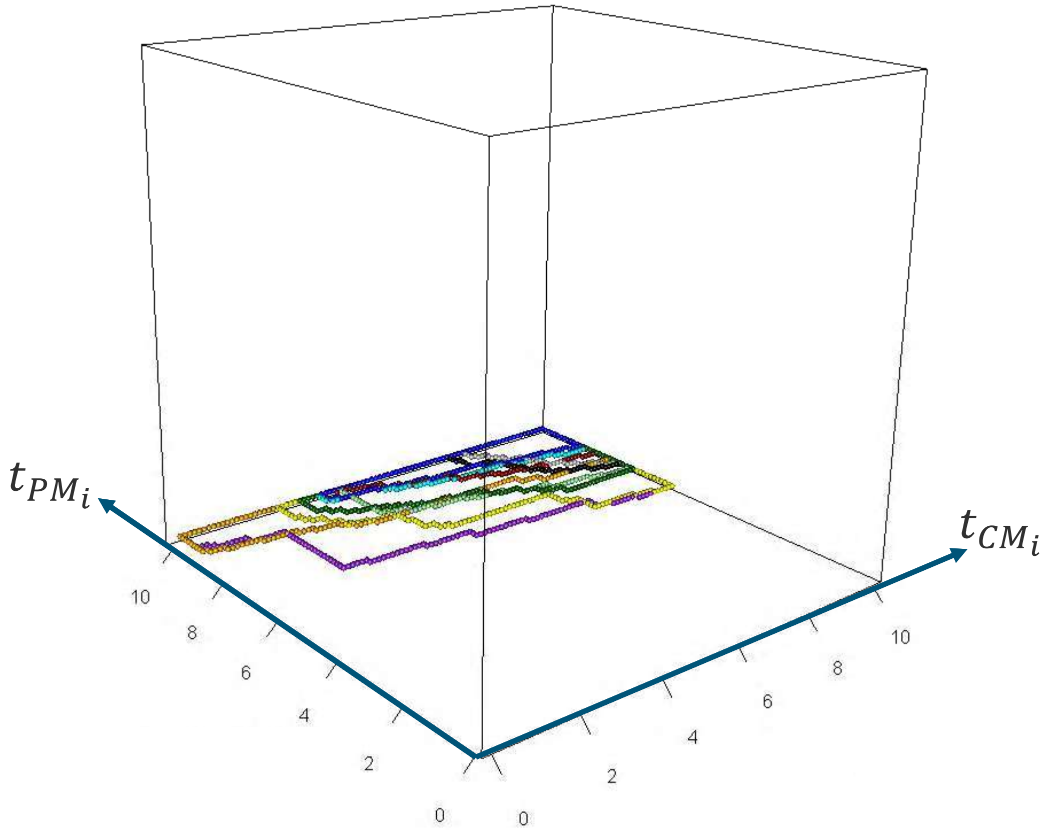

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Slide 17

Matrix simulation results $t_{COL} = 2.75$ years

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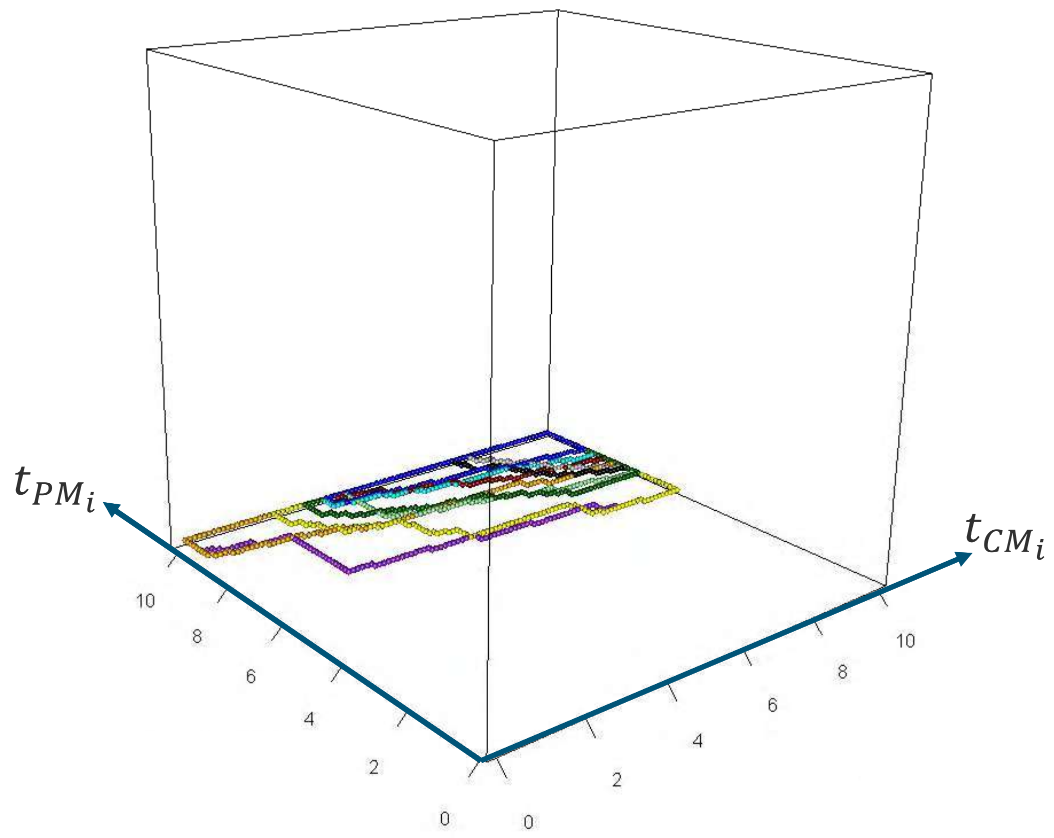

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Slide 18

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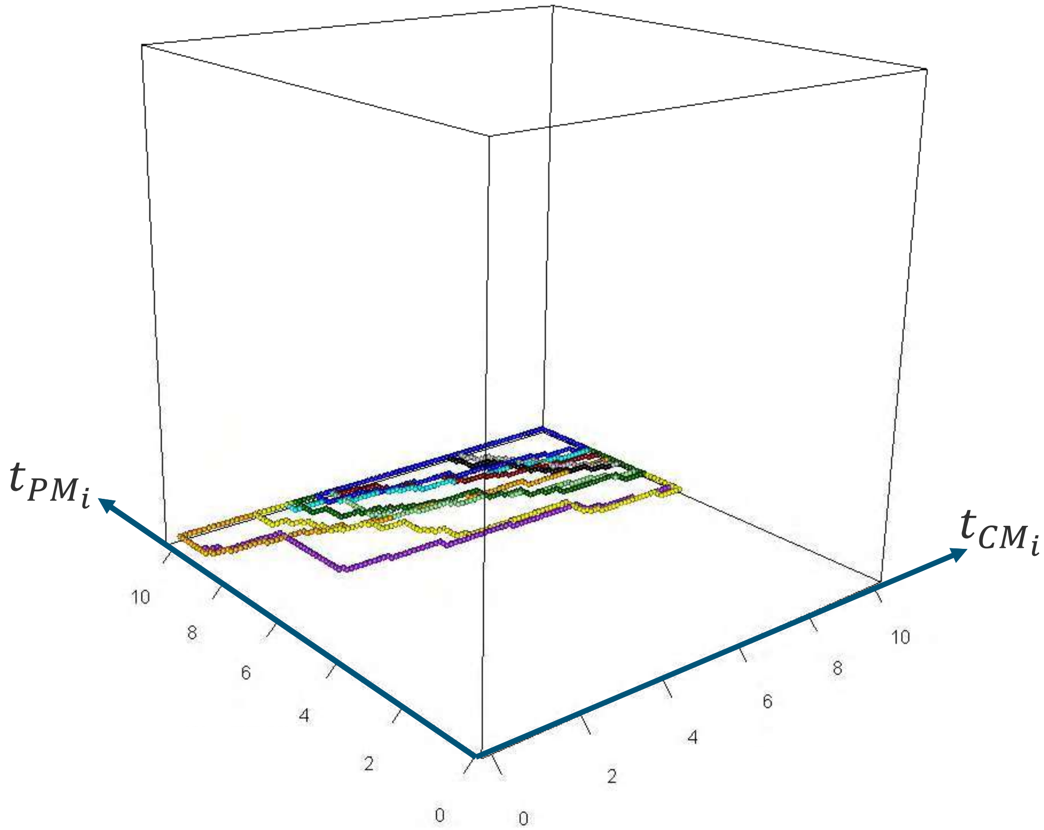

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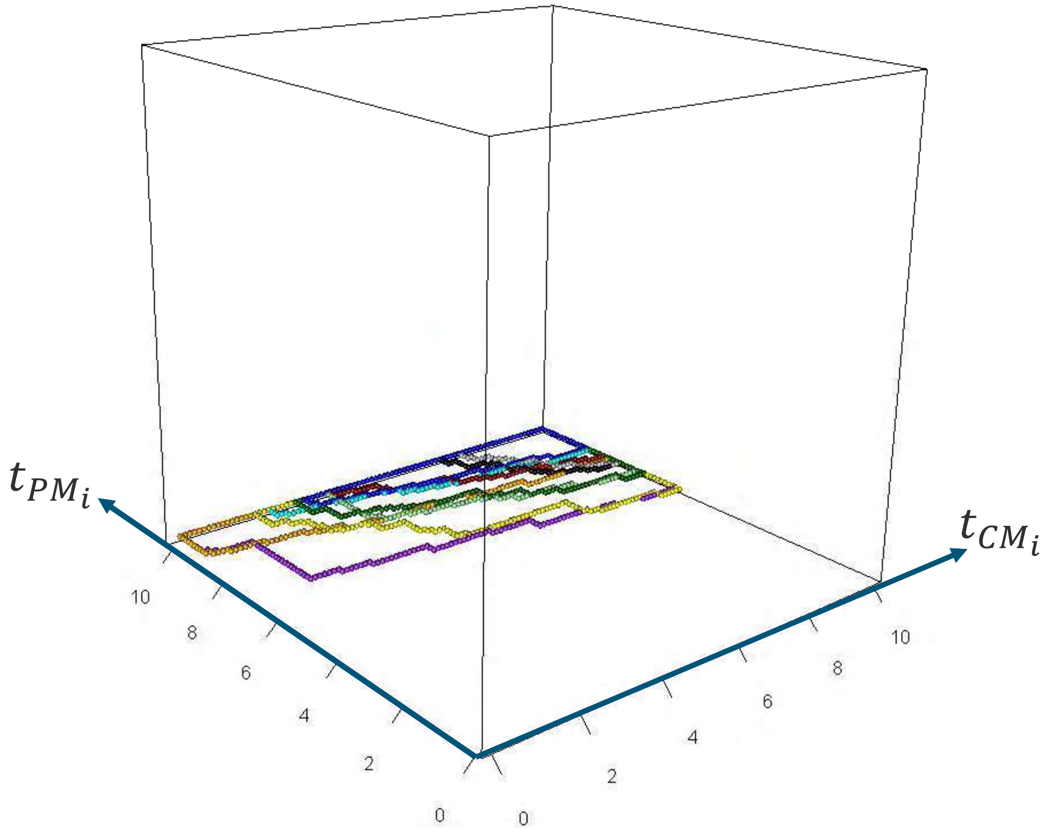

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Matrix simulation results $t_{COL} = 3.25$ years

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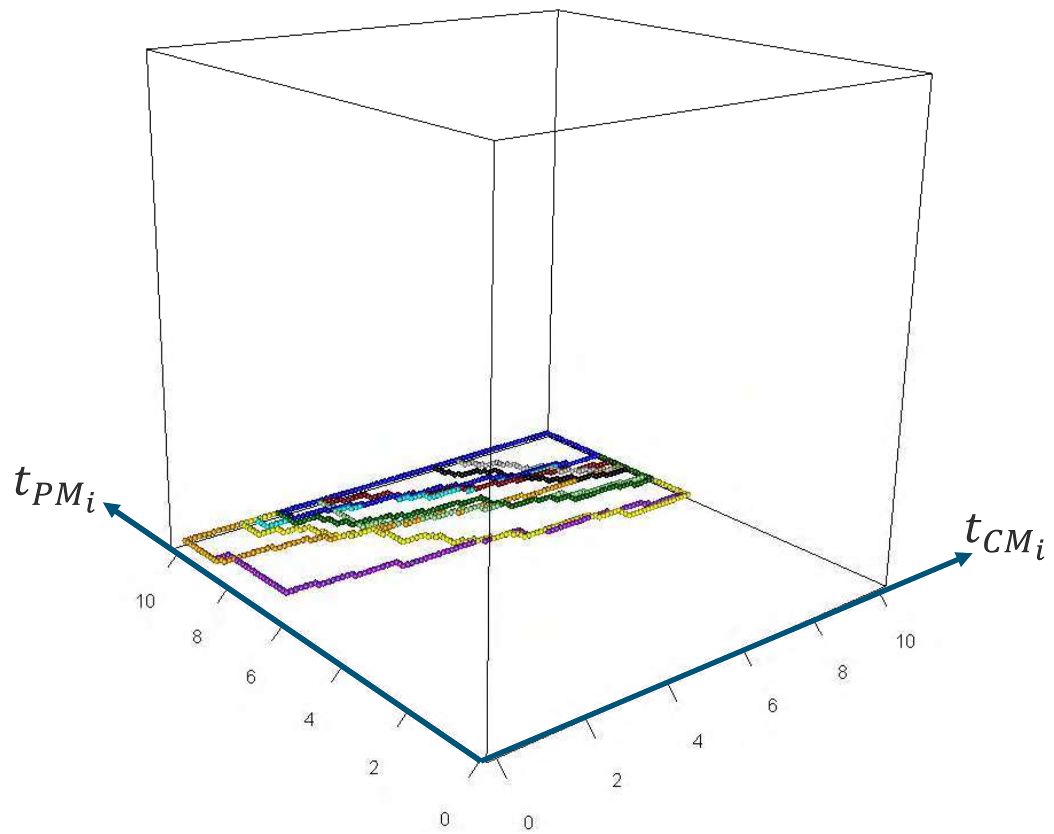

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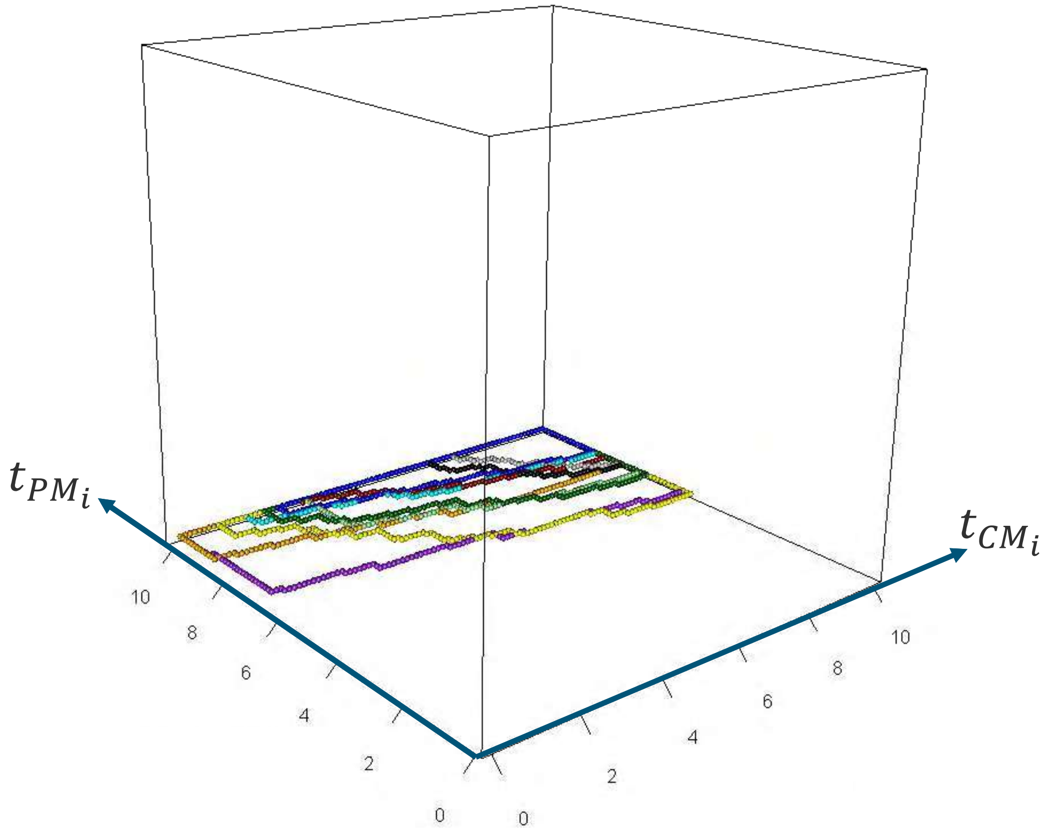

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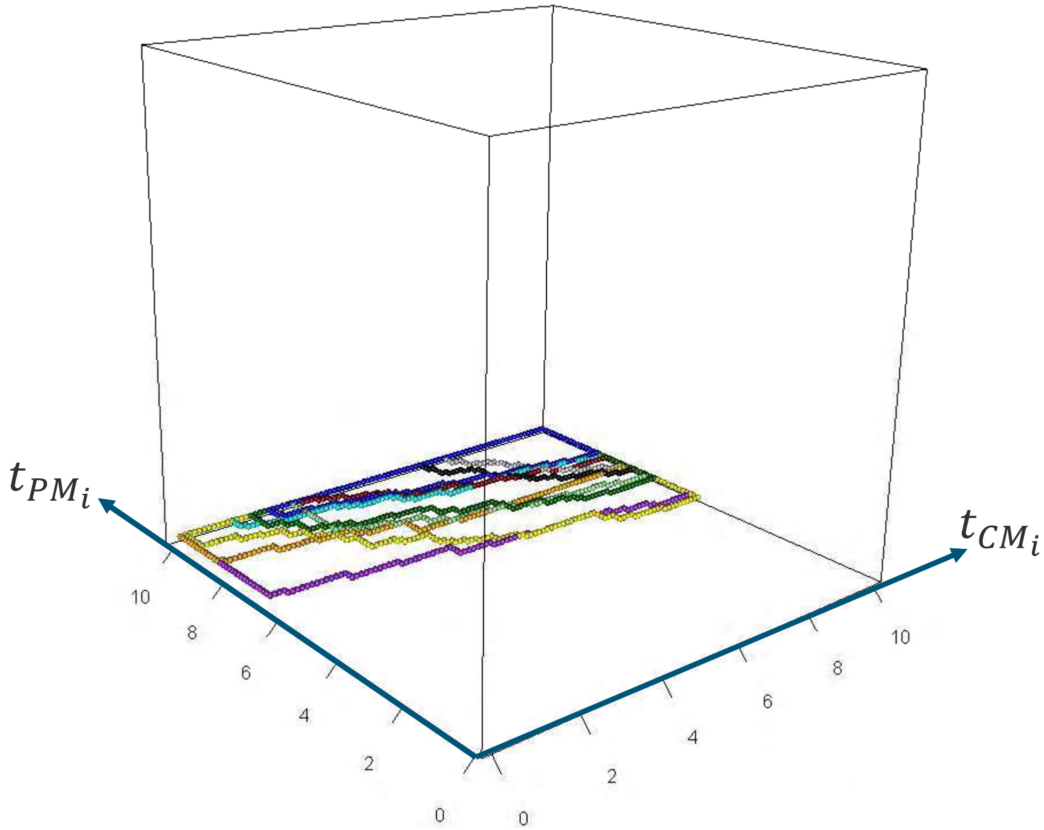

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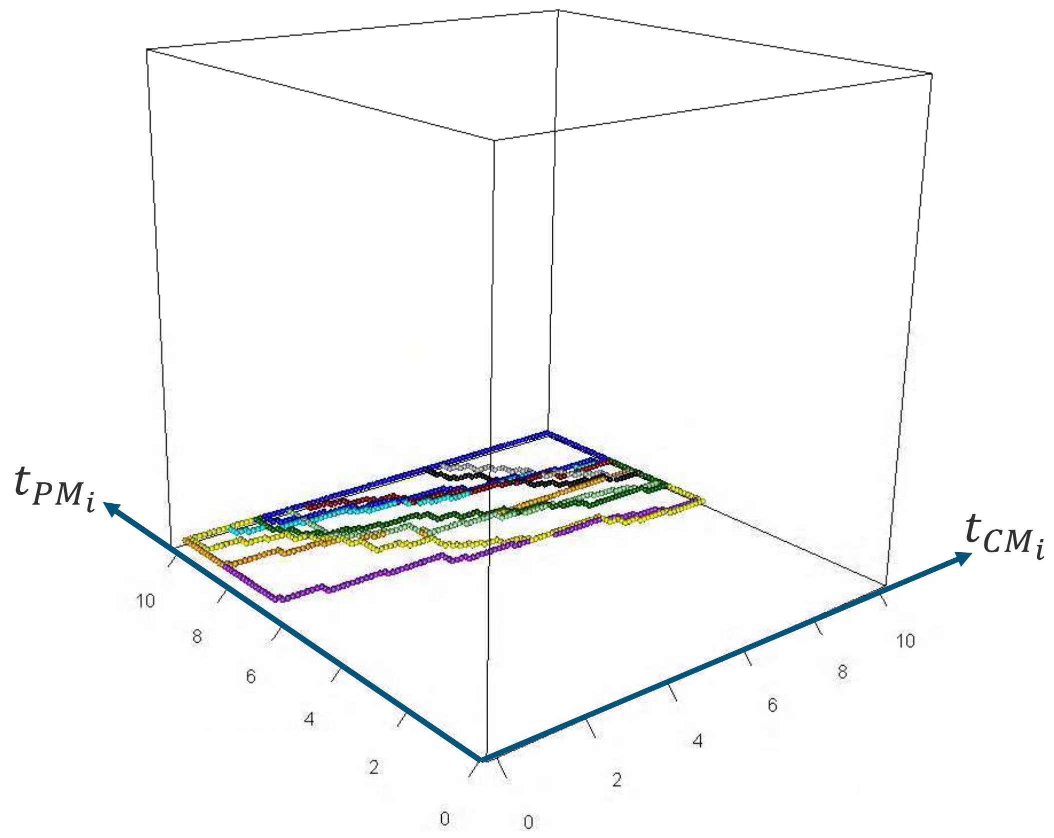

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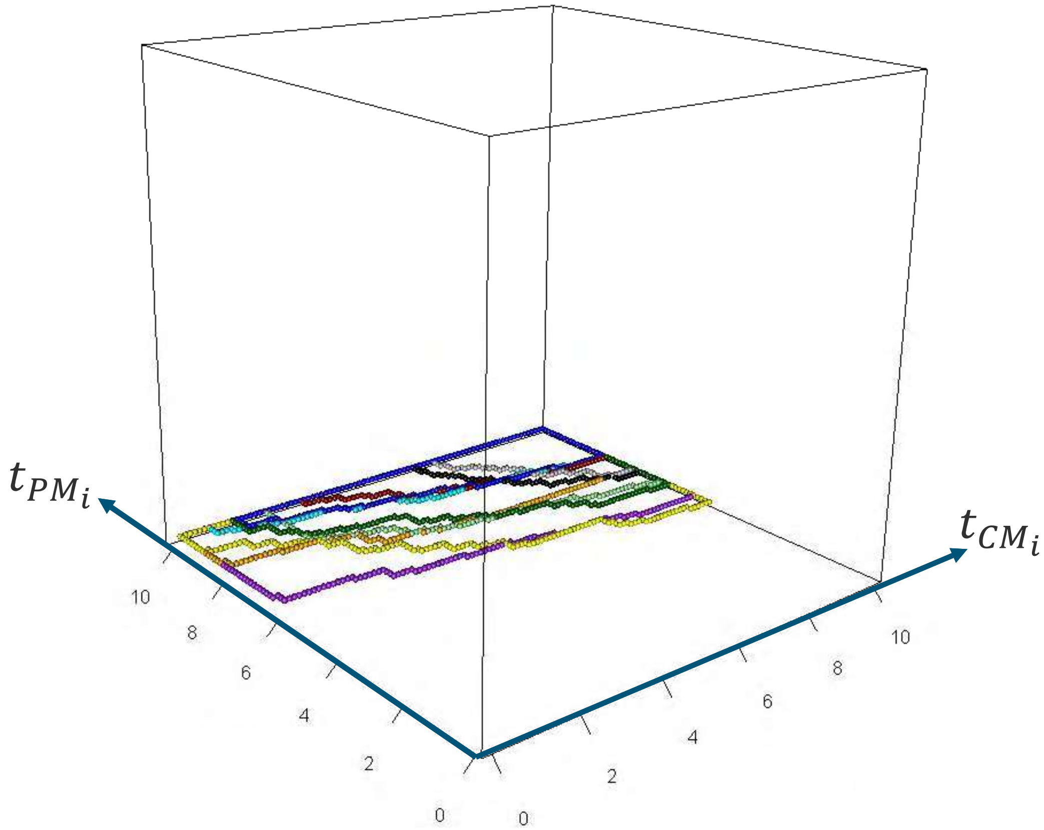

Matrix simulation results $t_{COL} = 4.00$ years

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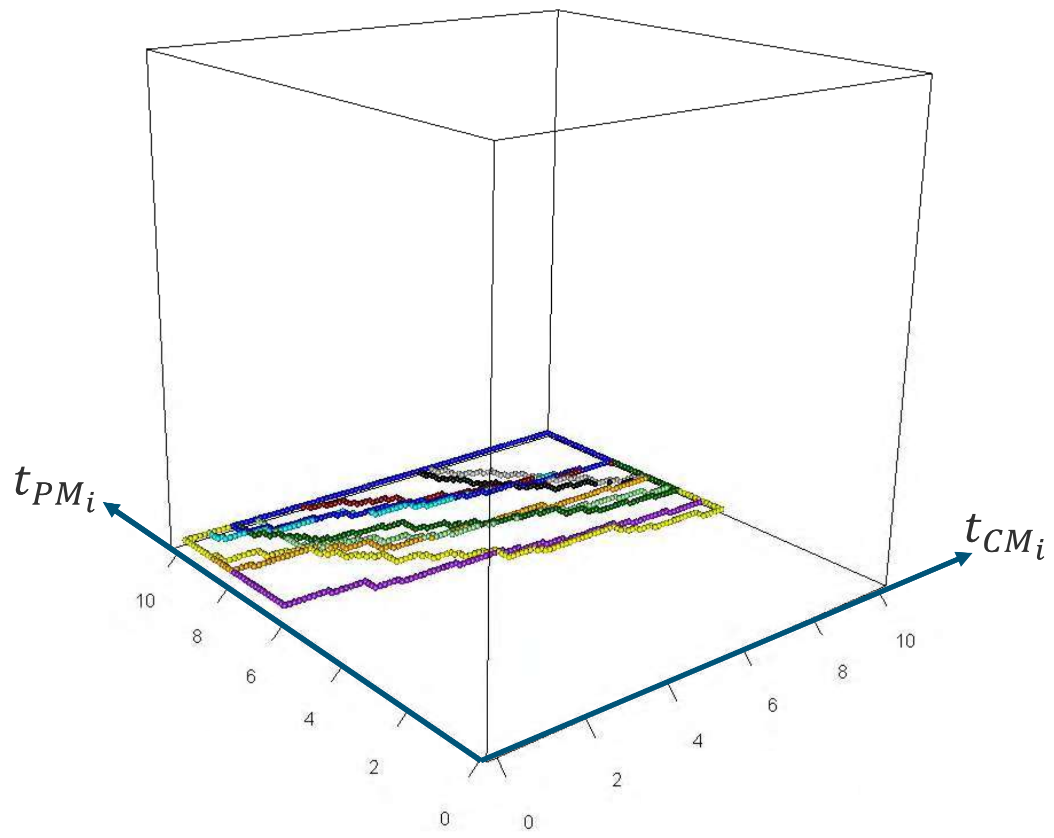

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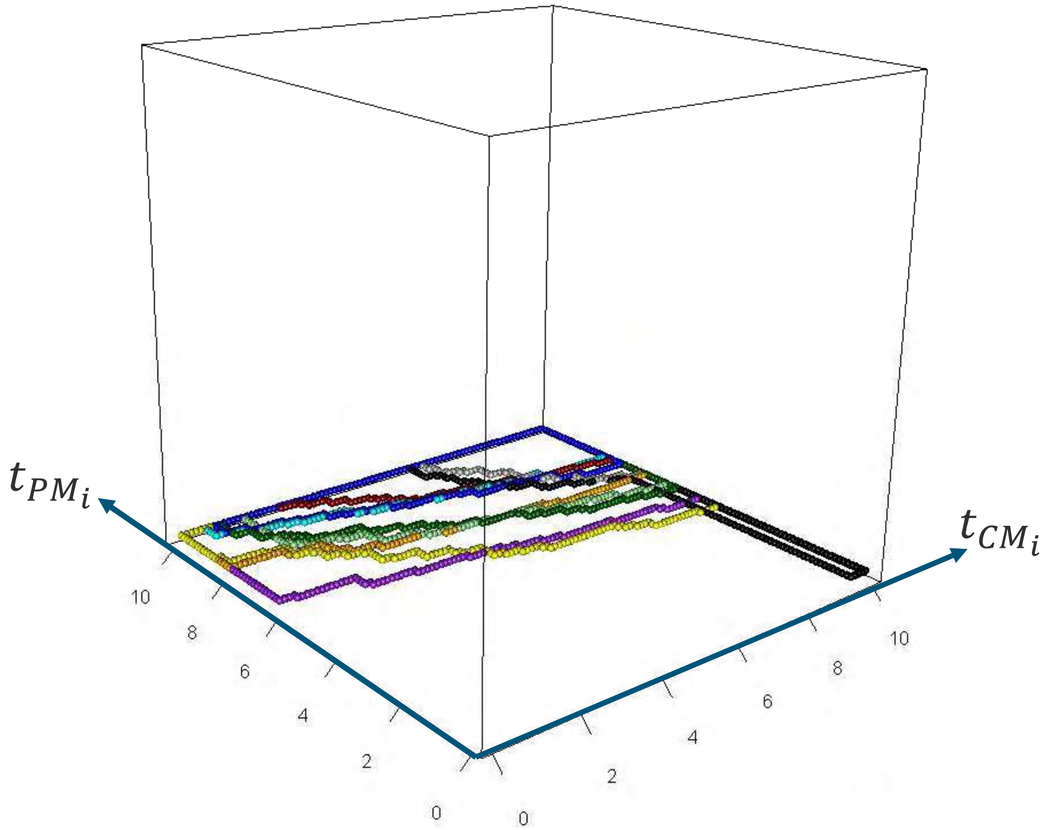

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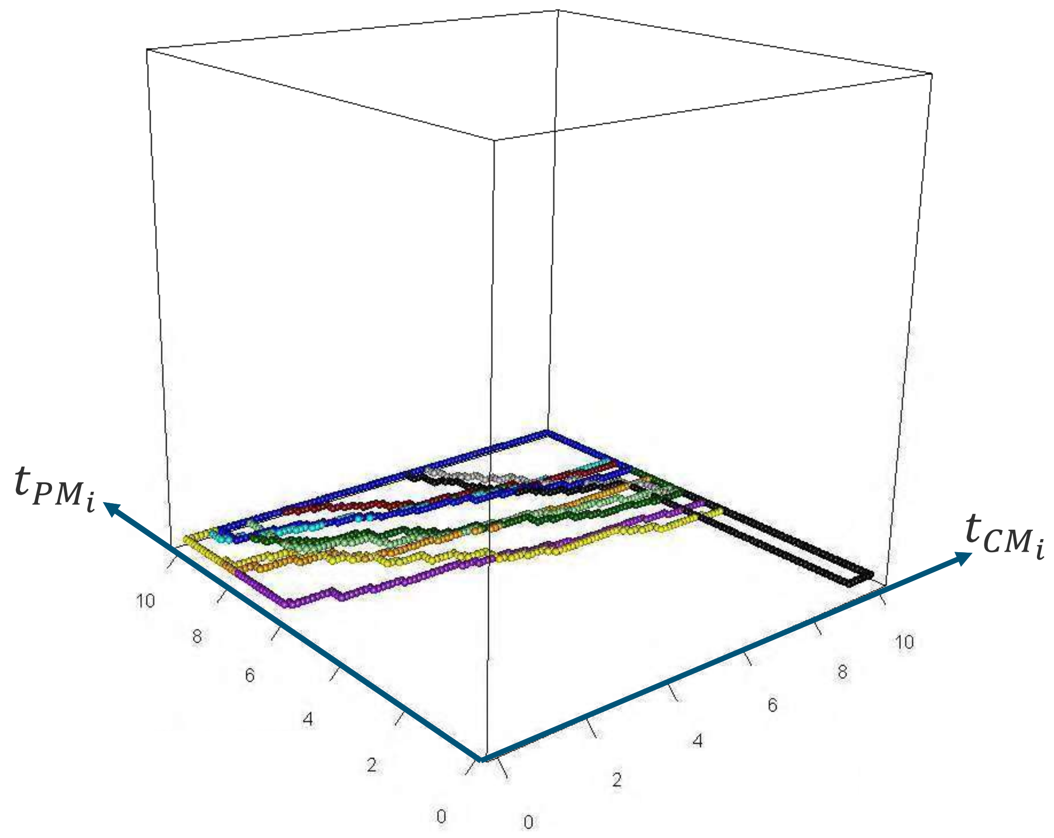

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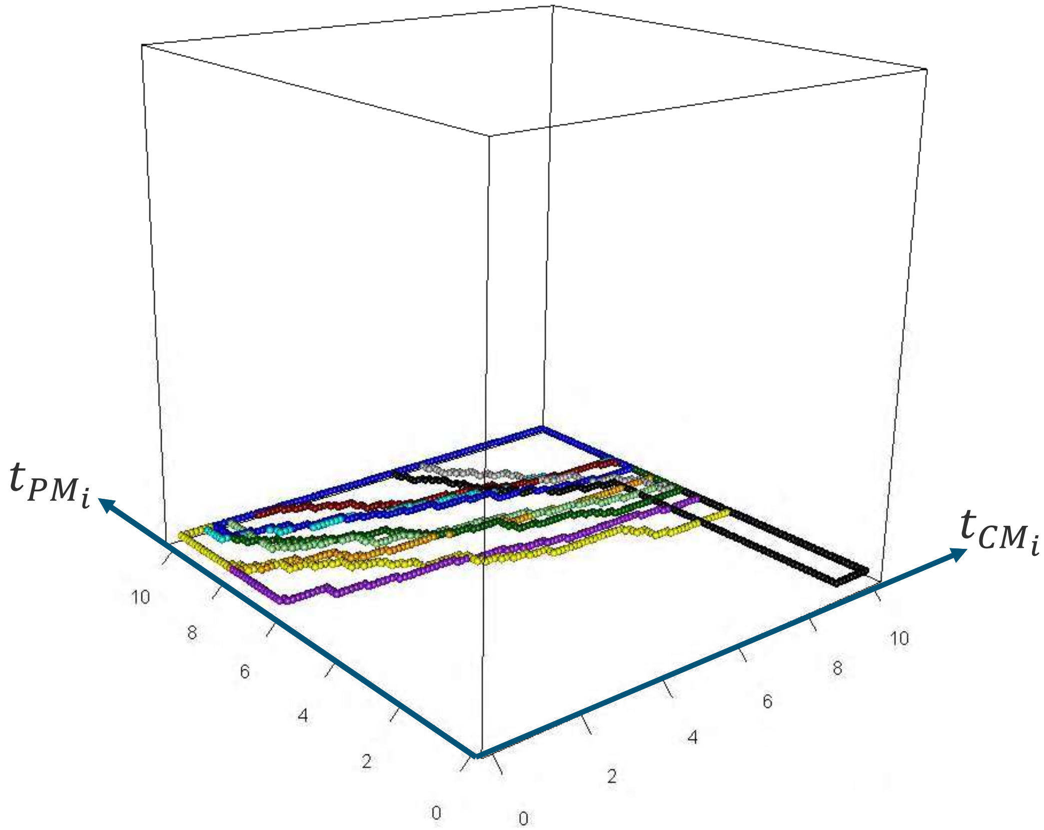

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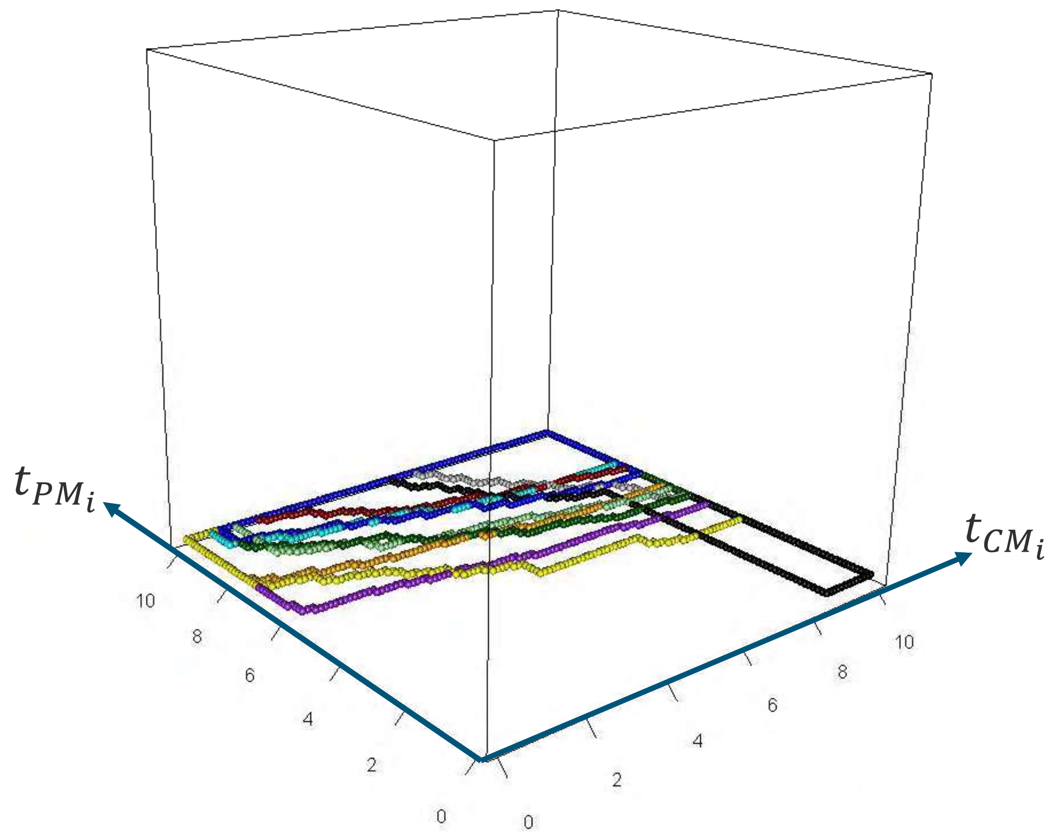

Matrix simulation results $t_{COL} = 4.75$ years

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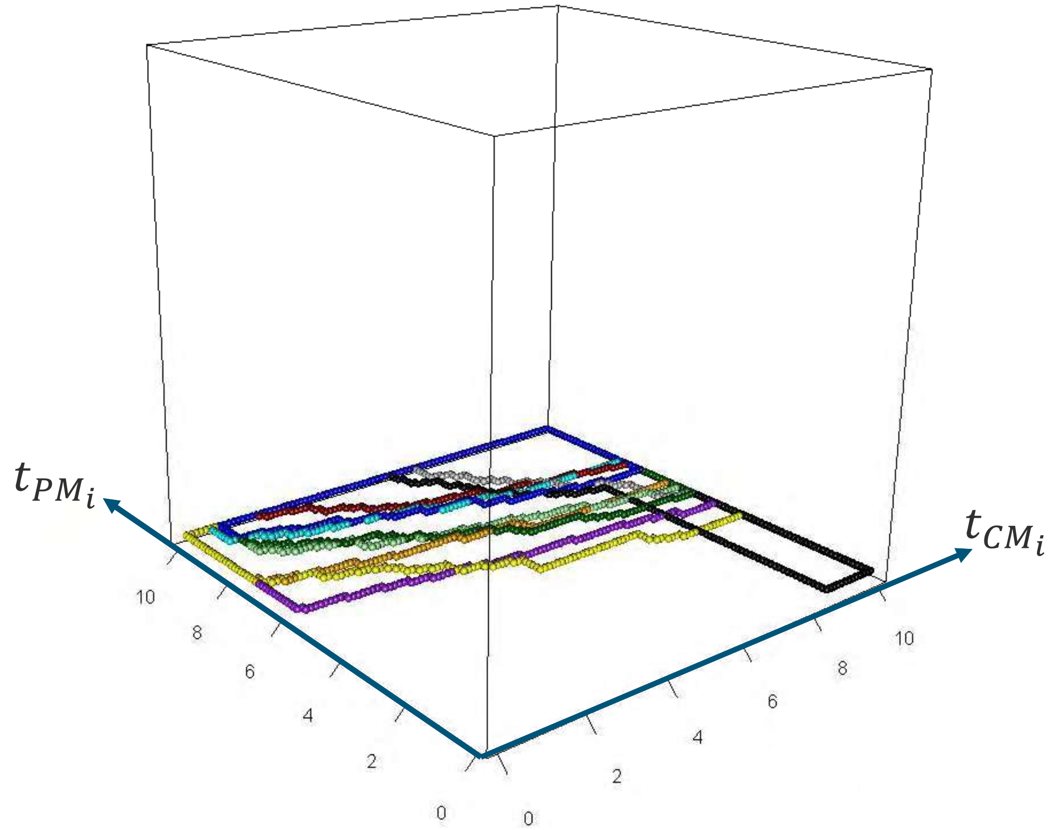

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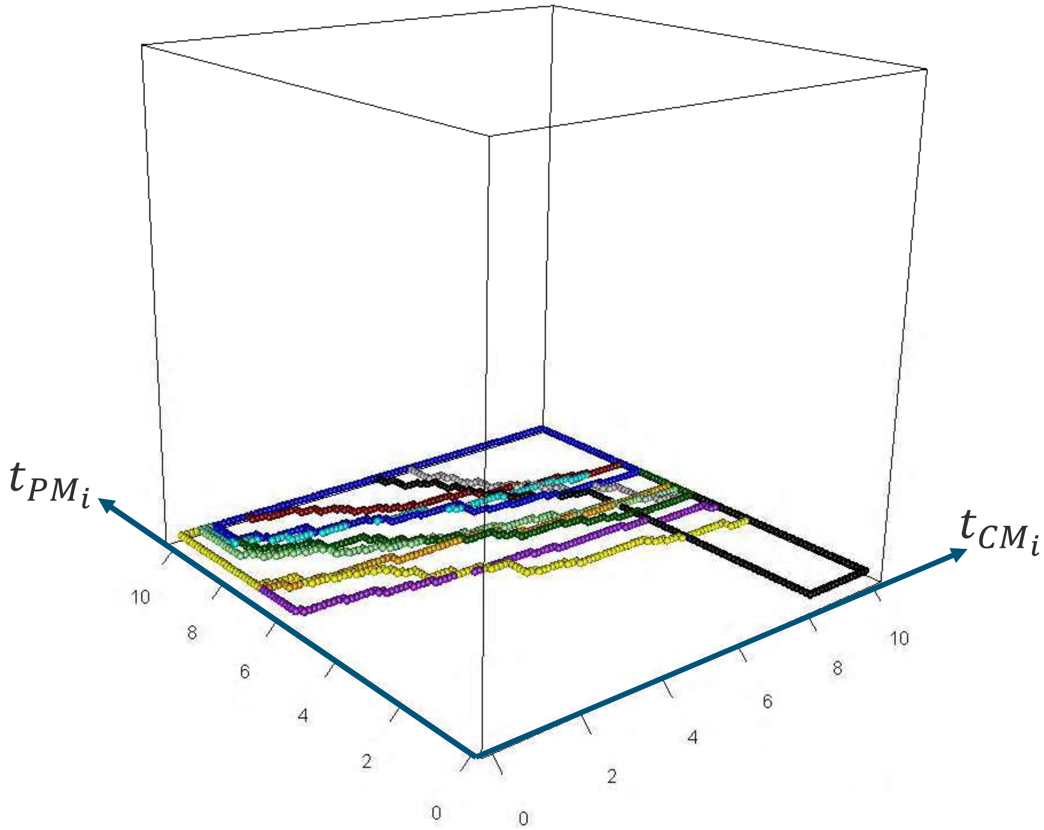

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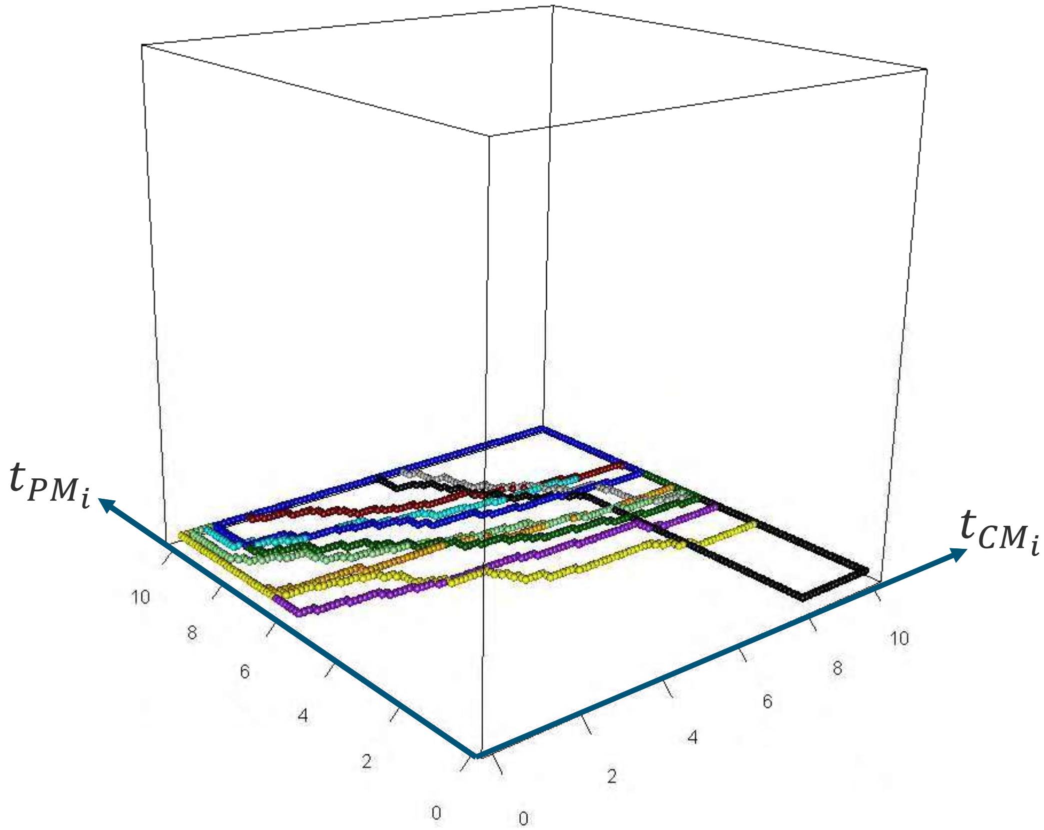

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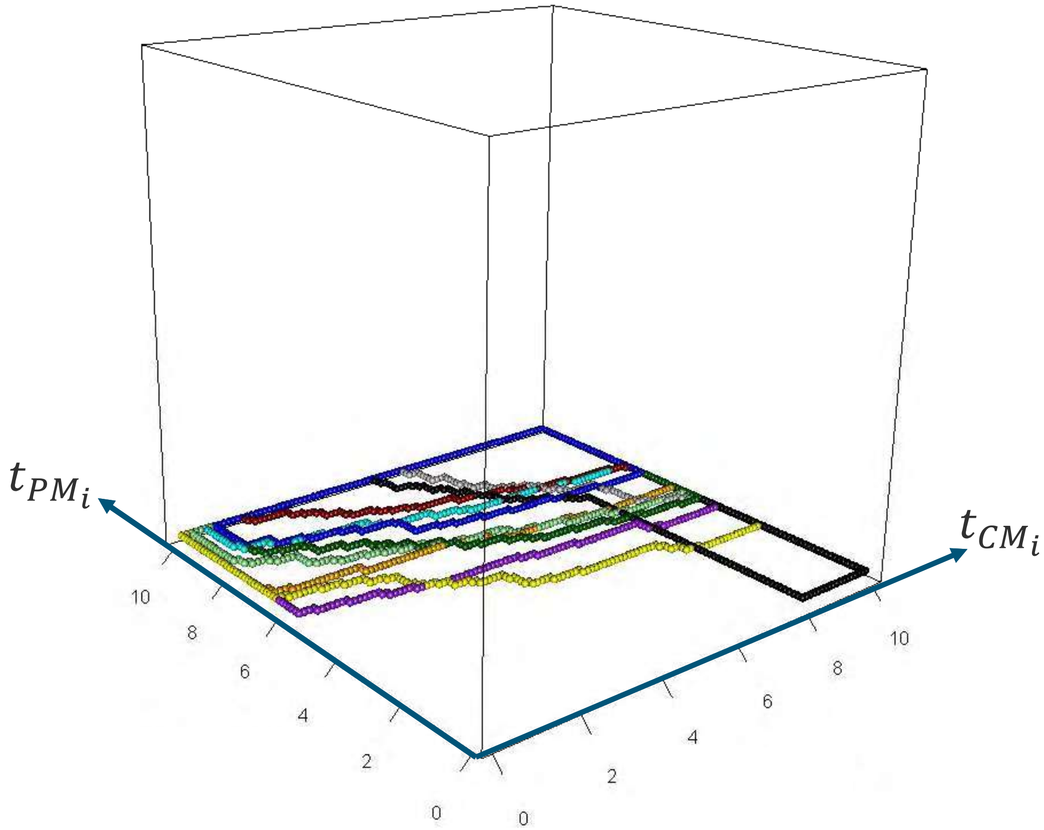

Matrix simulation results $t_{COL} = 5.42$ years

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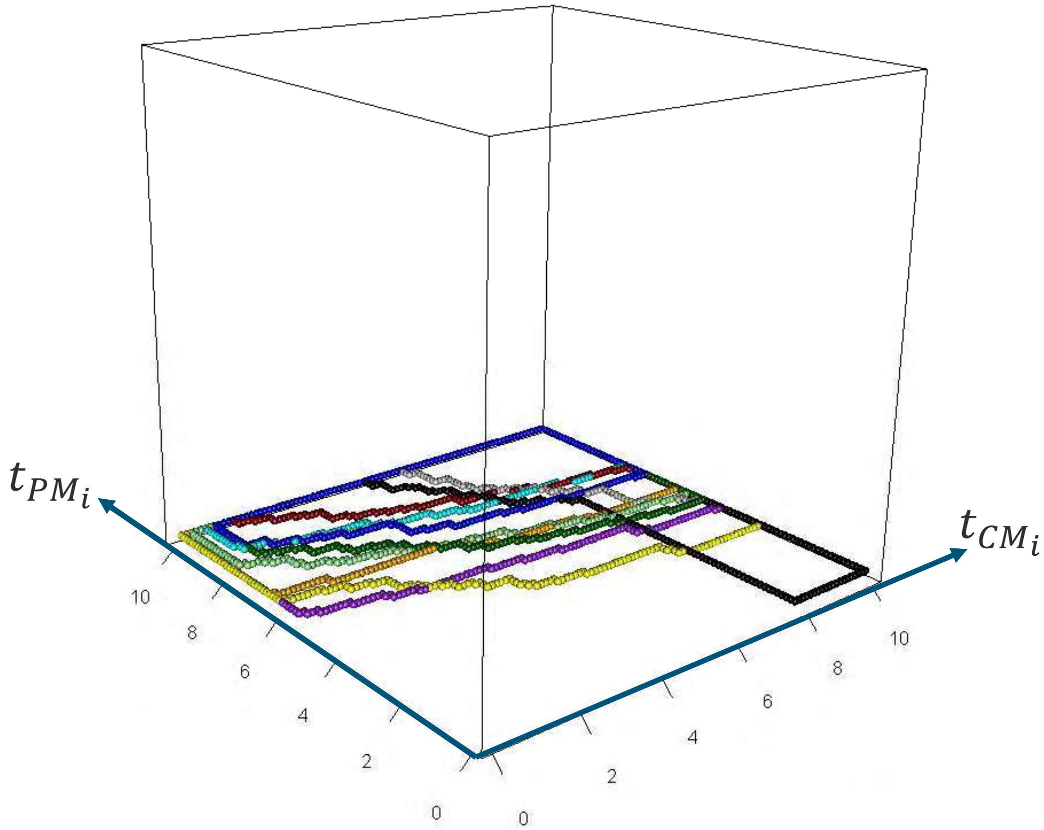

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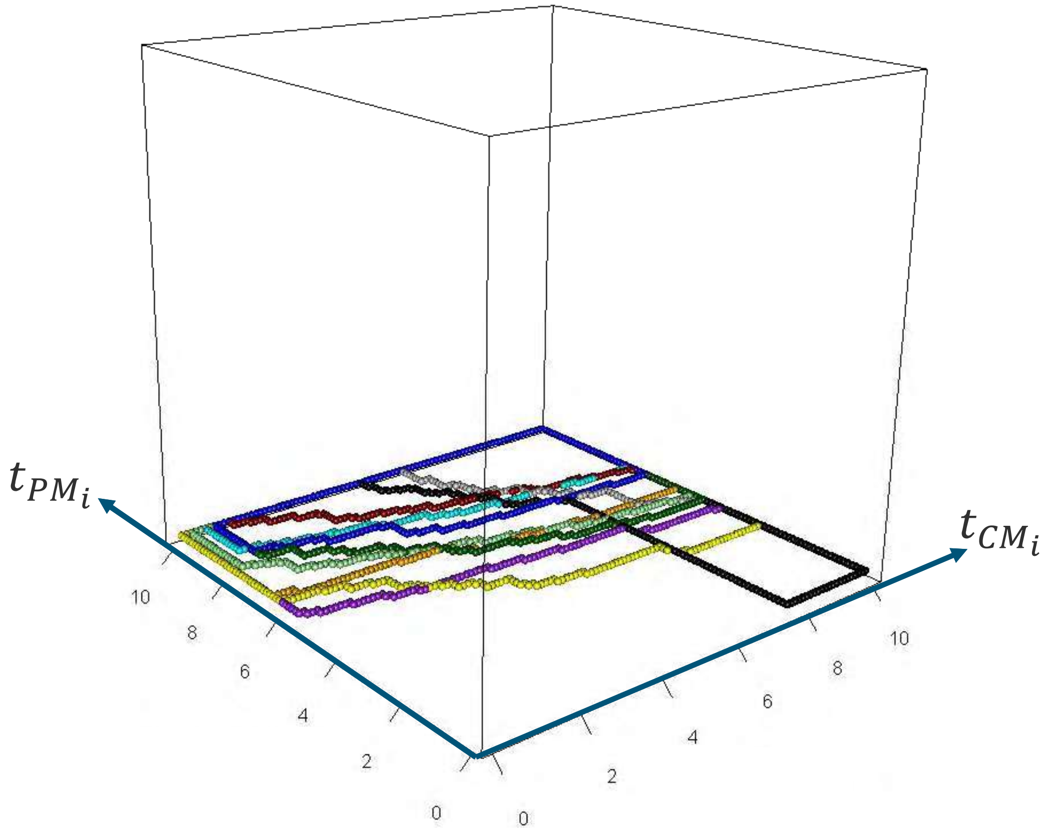

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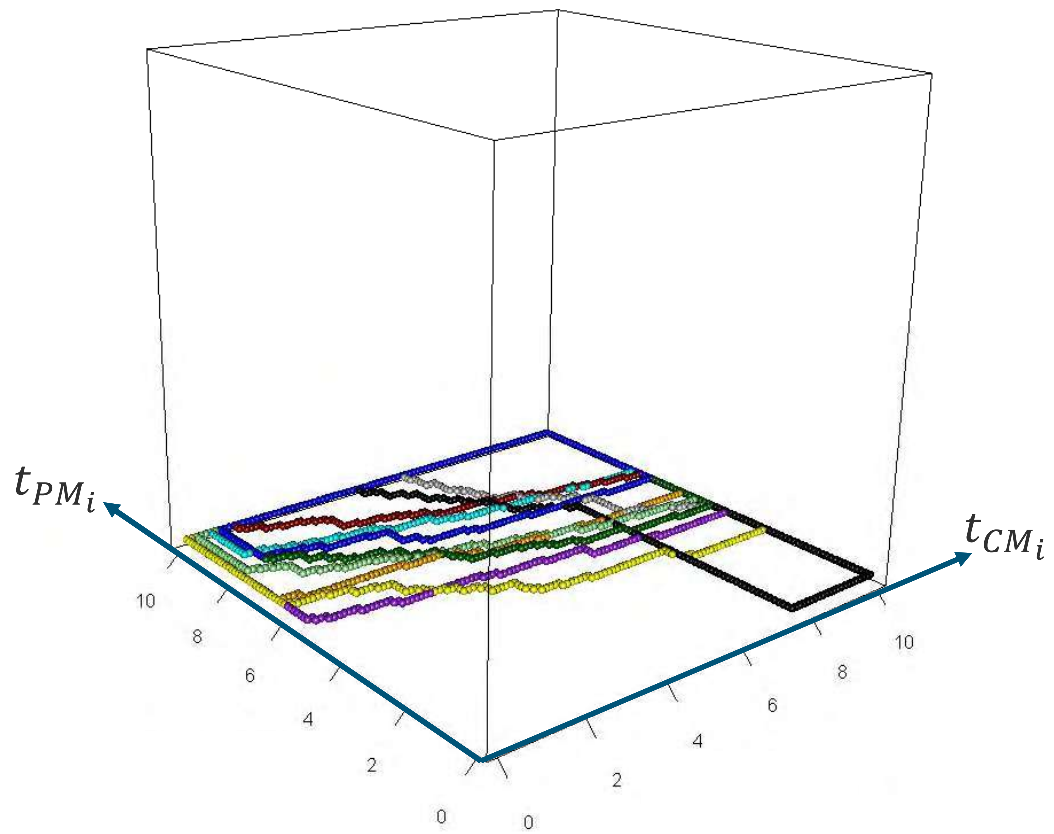

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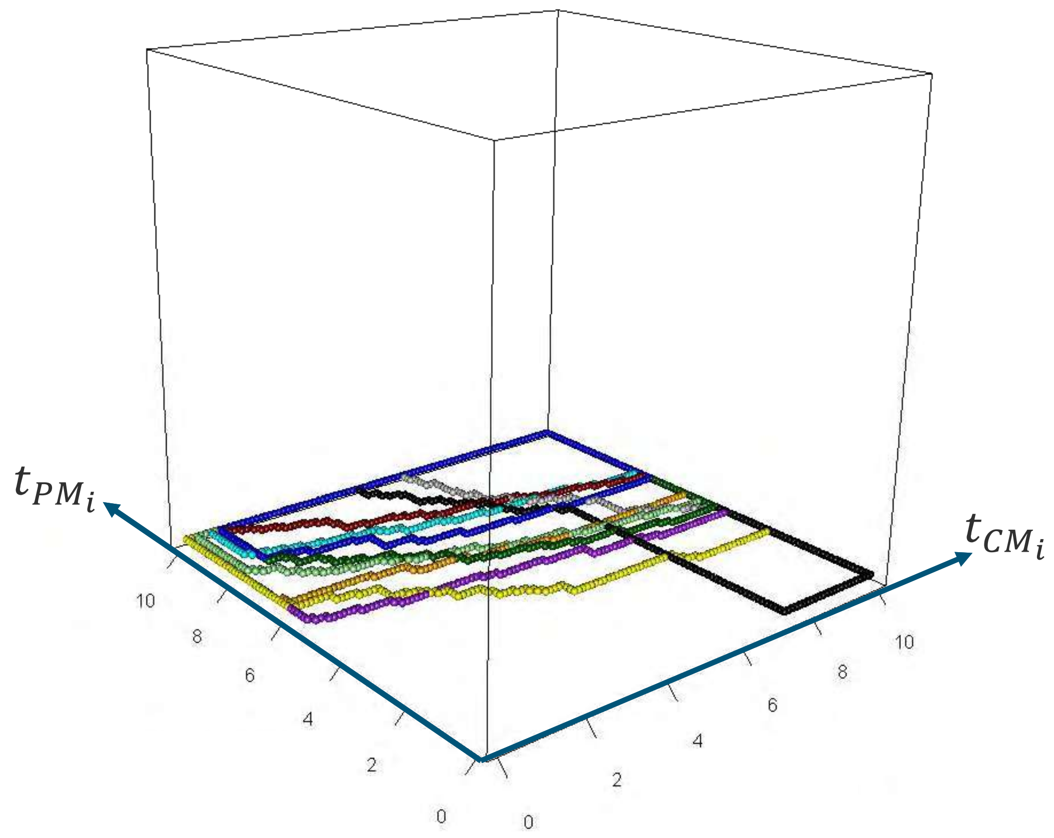

Matrix simulation results $t_{COL} = 6.17$ years

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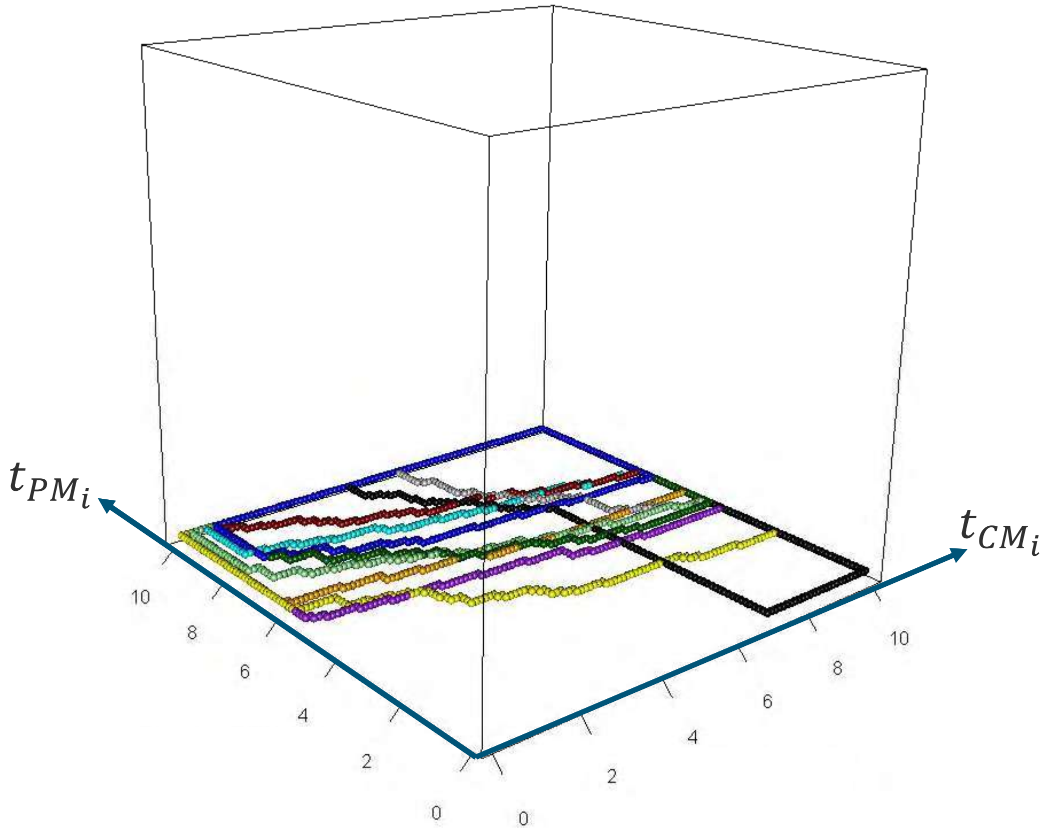

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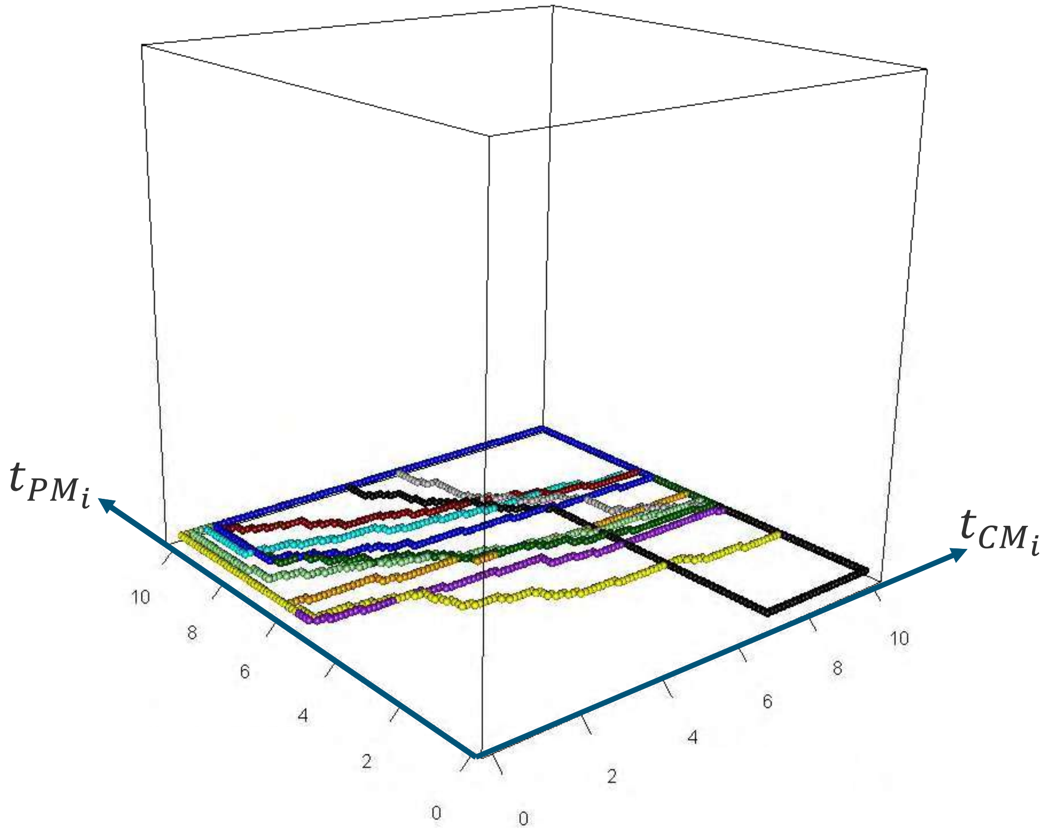

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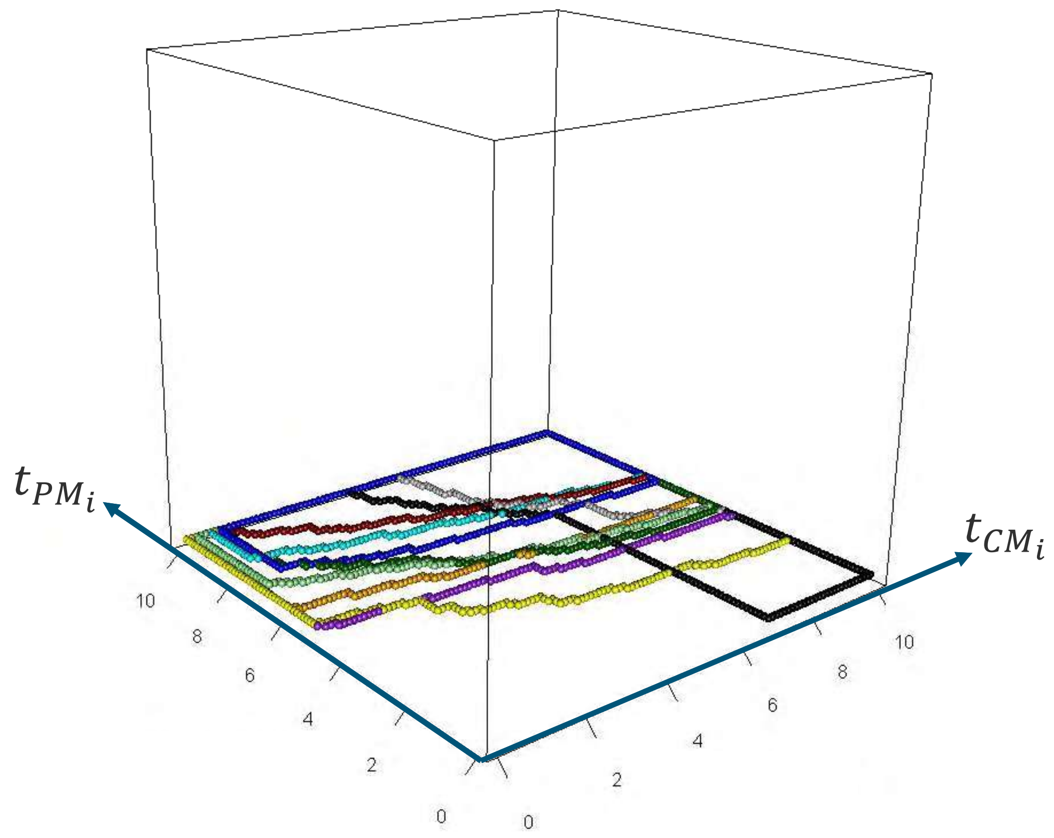

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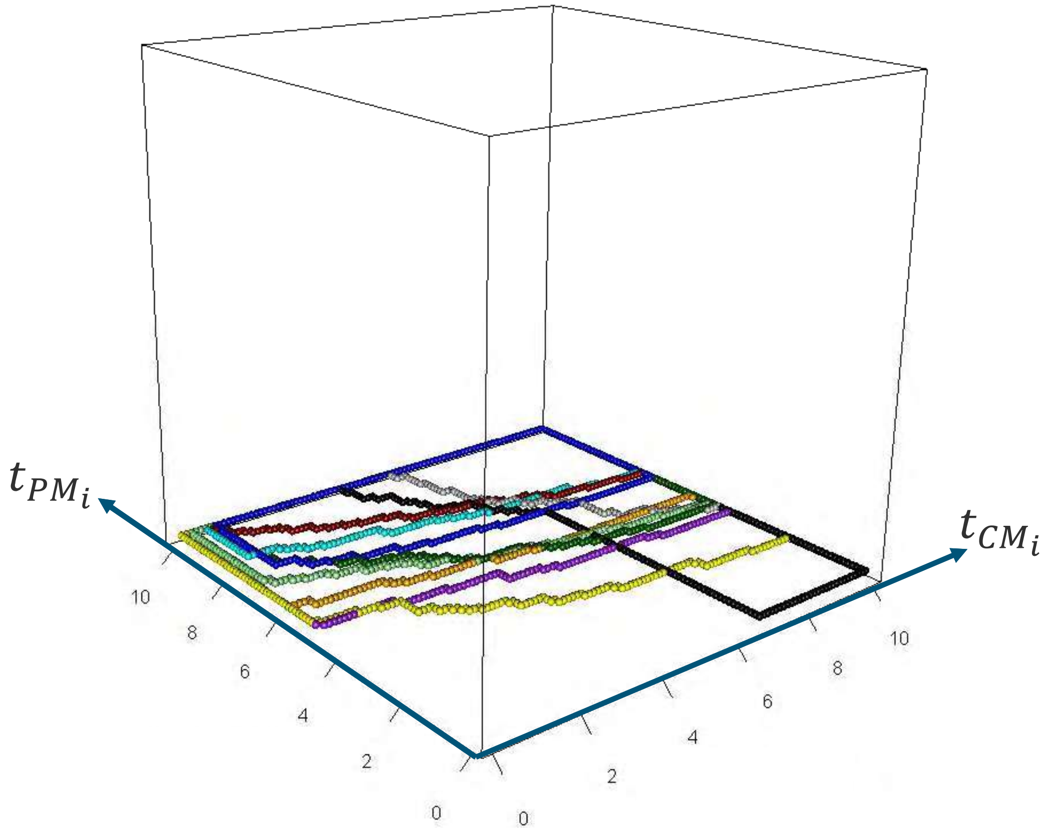

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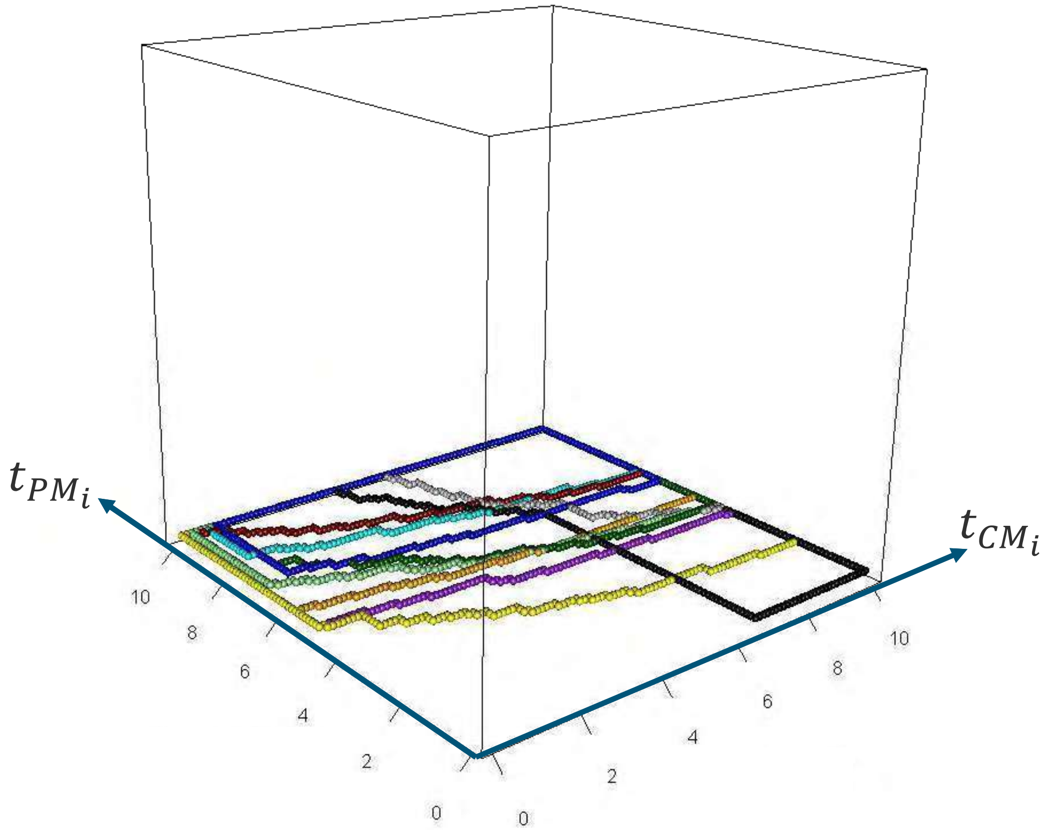

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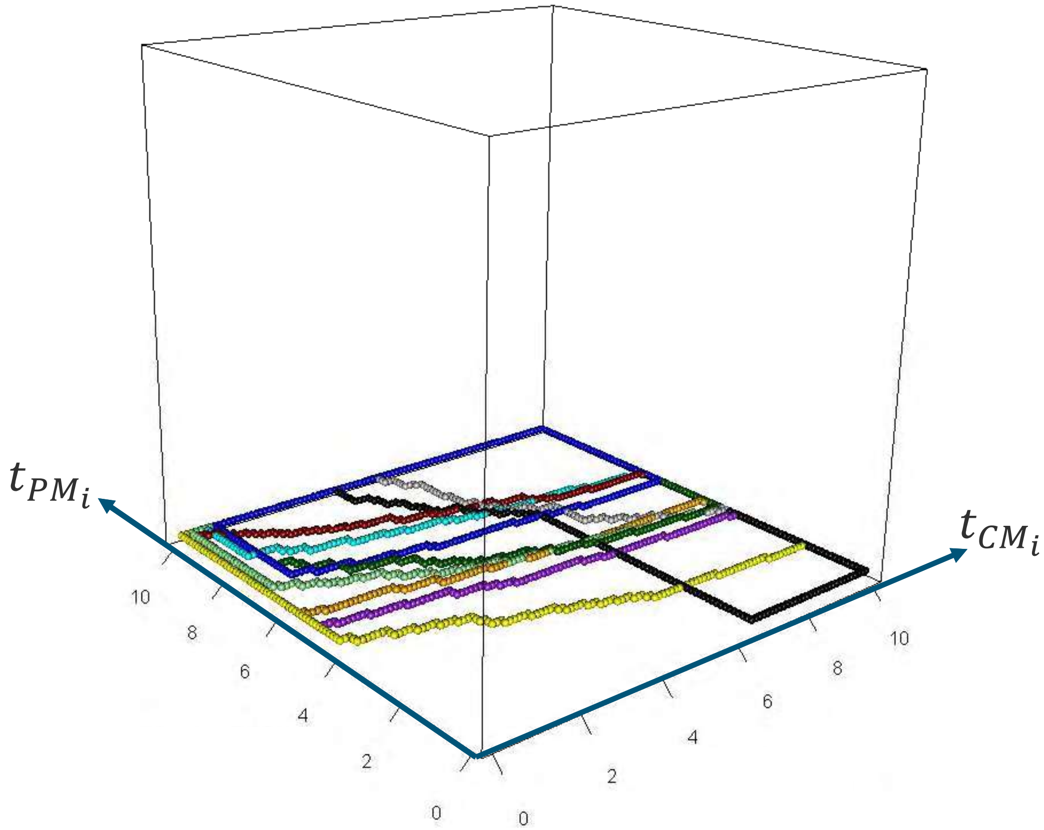

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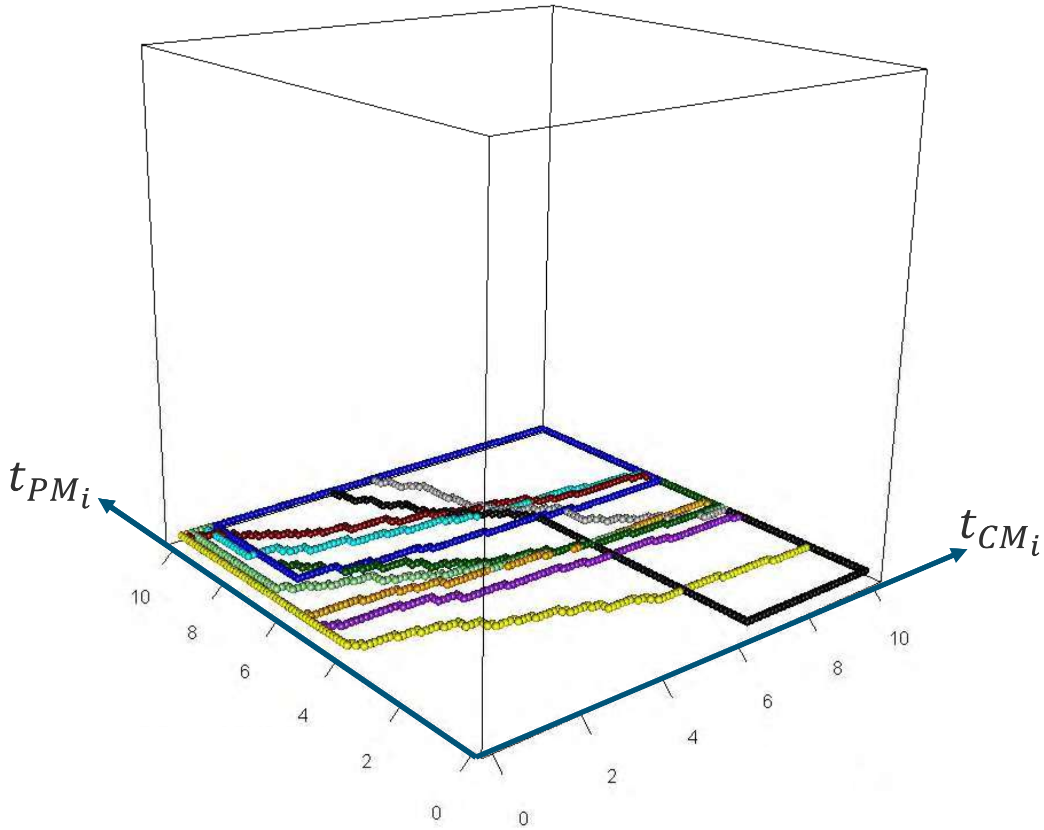

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Slide 45

Matrix simulation results $t_{COL} = 6.92$ years

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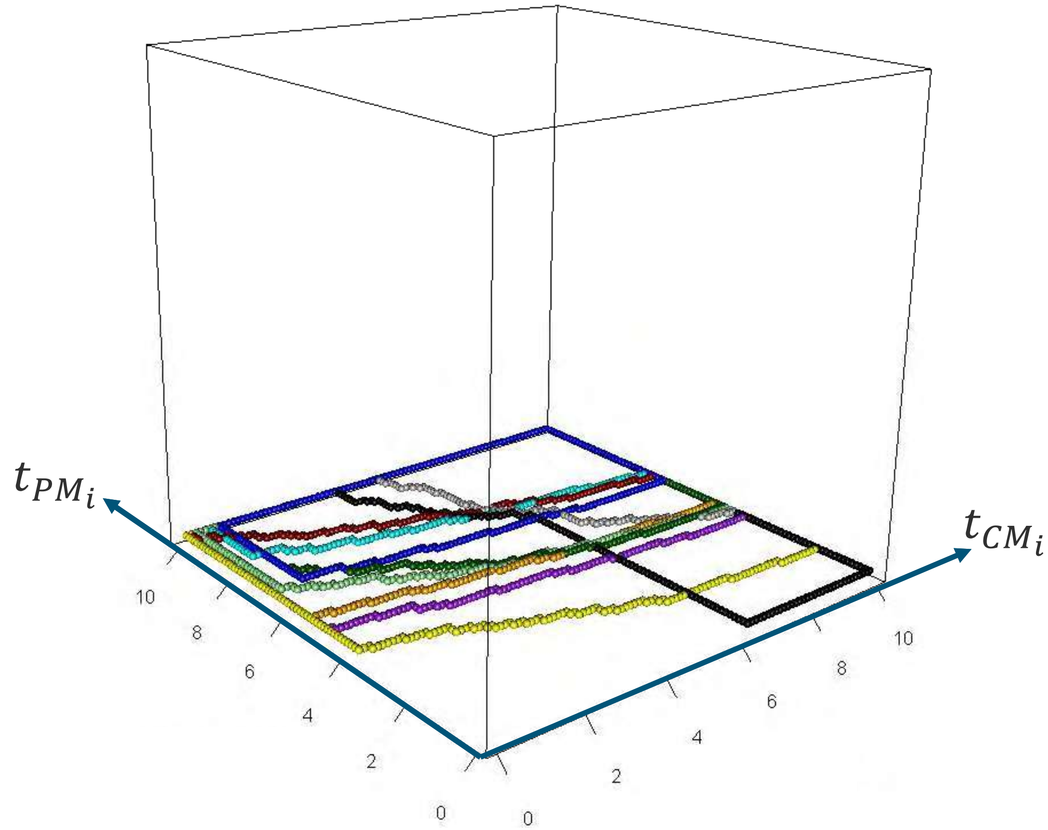

Slide 46

Matrix simulation results $t_{COL} = 7.33$ years

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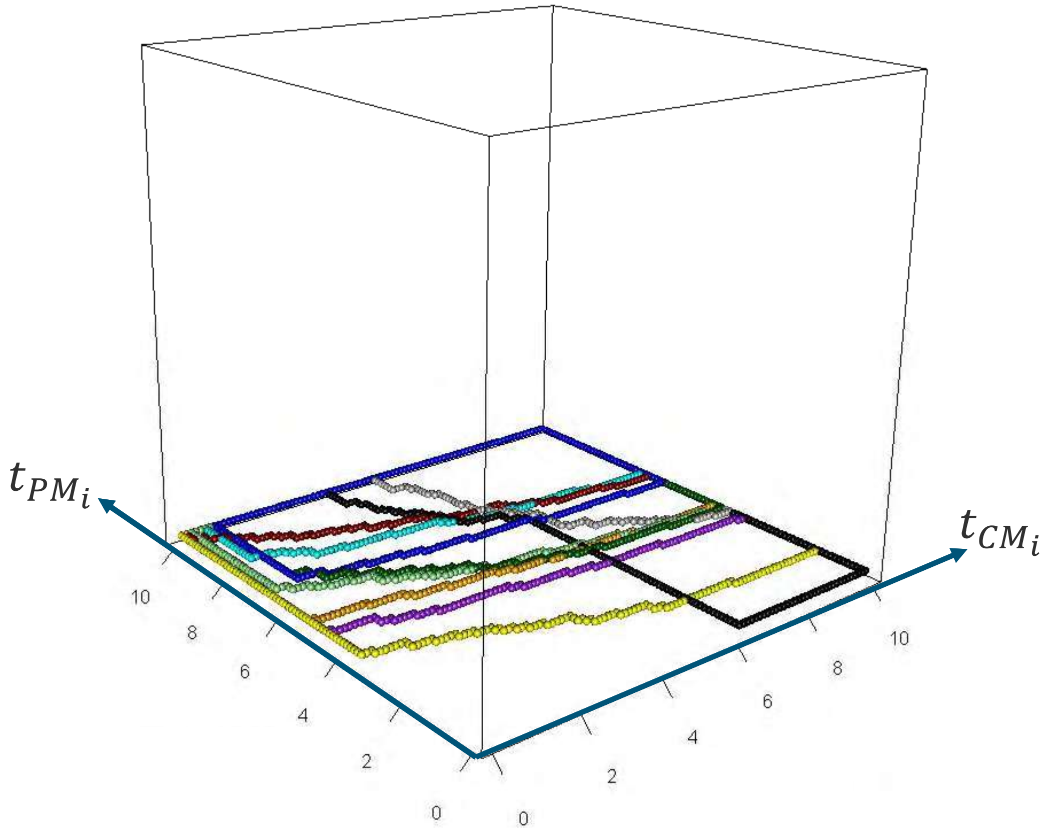

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Matrix simulation results $t_{COL} = 7.42$ years

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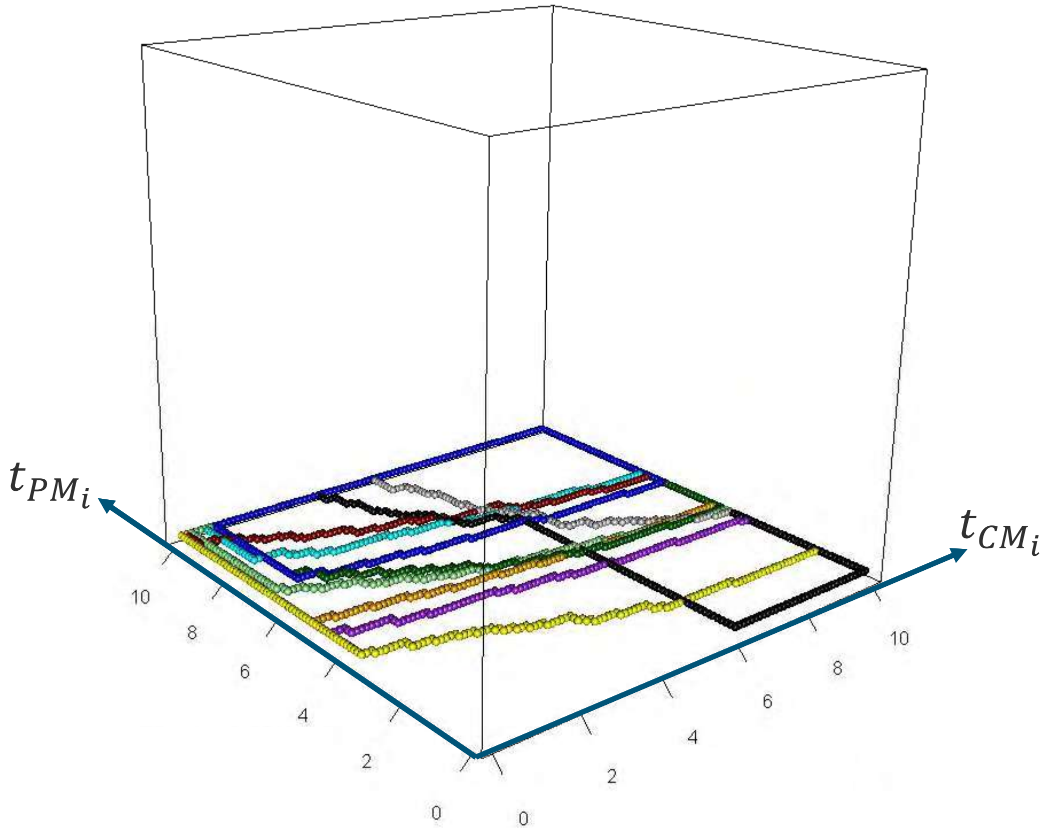

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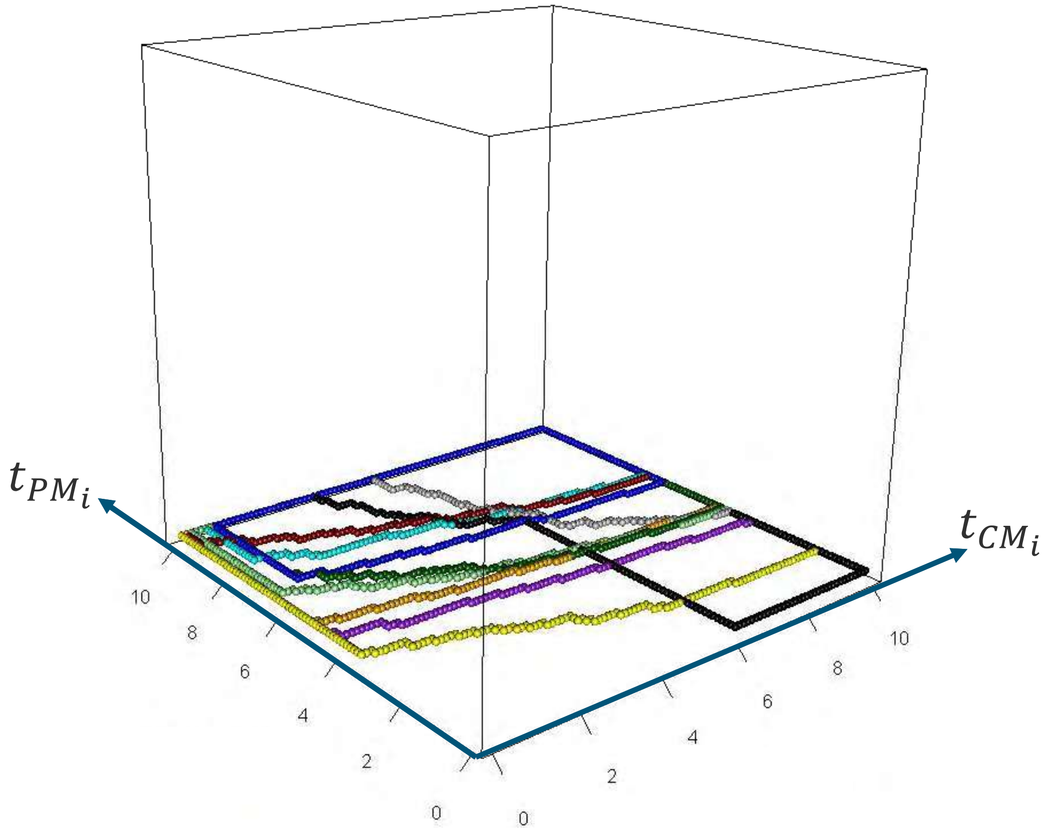
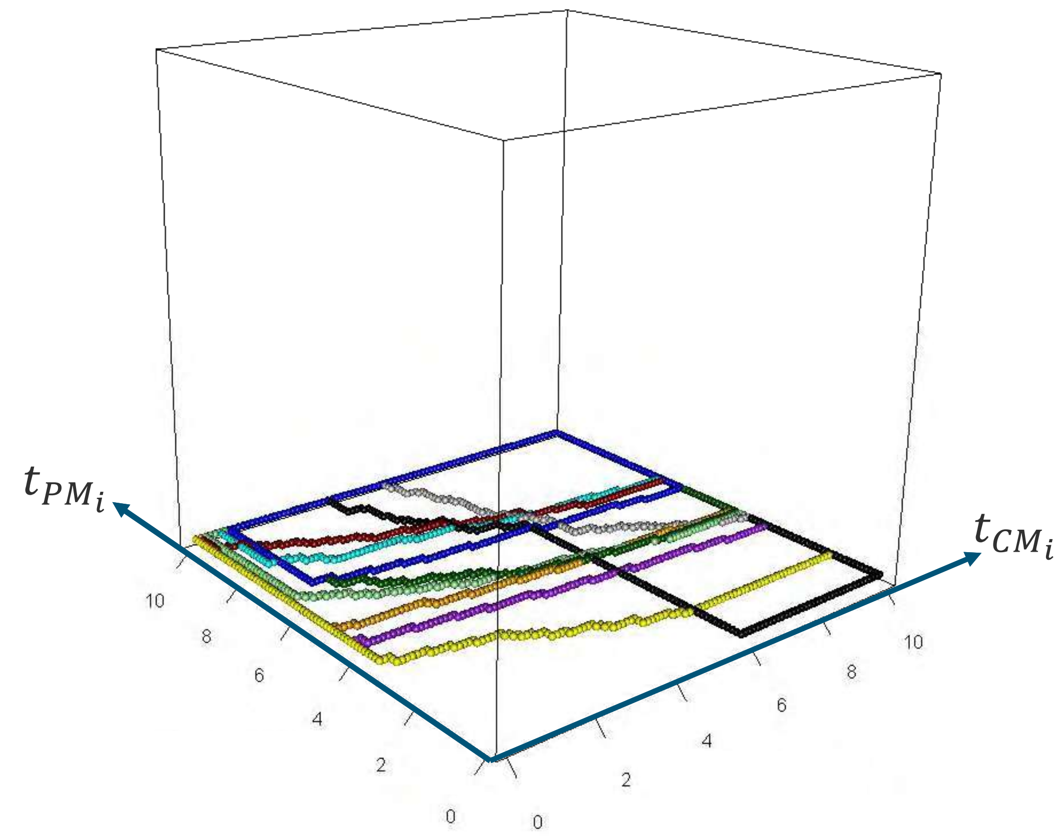


Systecon

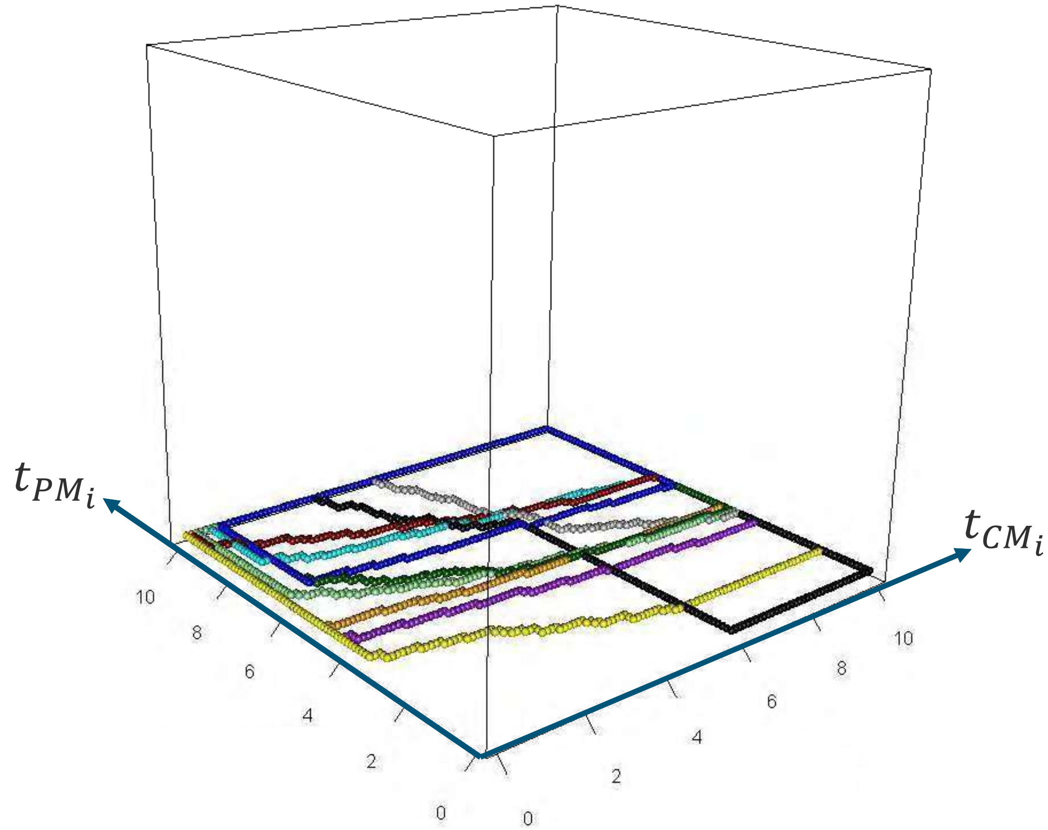
Matrix simulation results $t_{COL} = 7.75$ years

The boundaries of the solution spaces S_1 , S_2 , … , S_{10} obtained by applying matrix simulations are shown below with a unique color



Matrix simulation results $t_{COL} = 7.92$ years

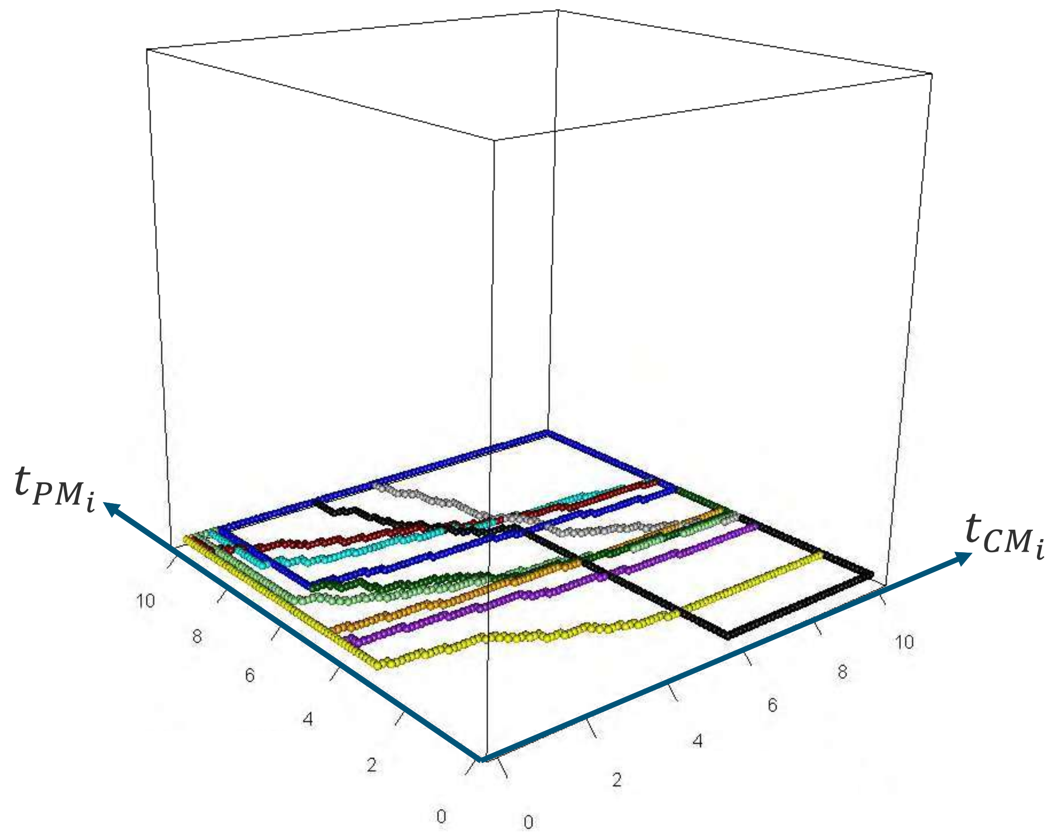
The boundaries of the solution spaces $\boldsymbol{S_1}, \boldsymbol{S_2}, \ldots, \boldsymbol{S_{10}}$ obtained by applying matrix simulations are shown below with a unique color



Systecon

Matrix simulation results $t_{COL} = 8.33$ years

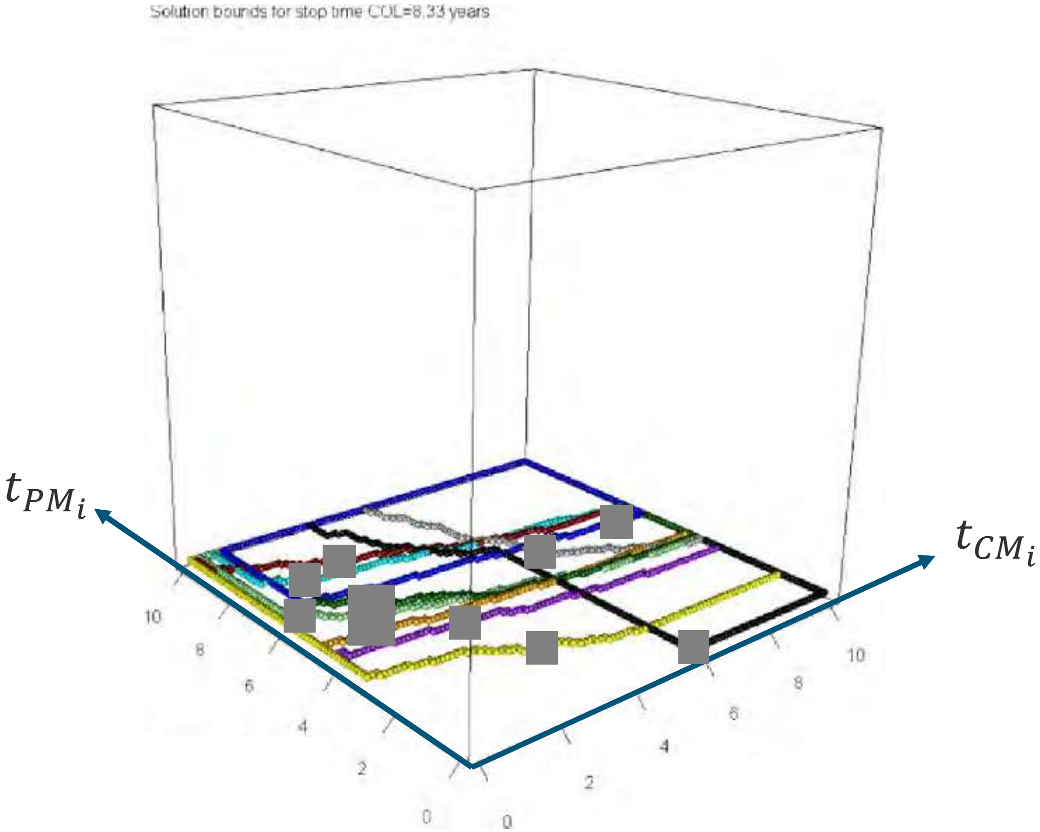
The boundaries of the solution spaces $S_1, S_2, \ldots, S_{10}$ obtained by applying matrix simulations are shown below with a unique color



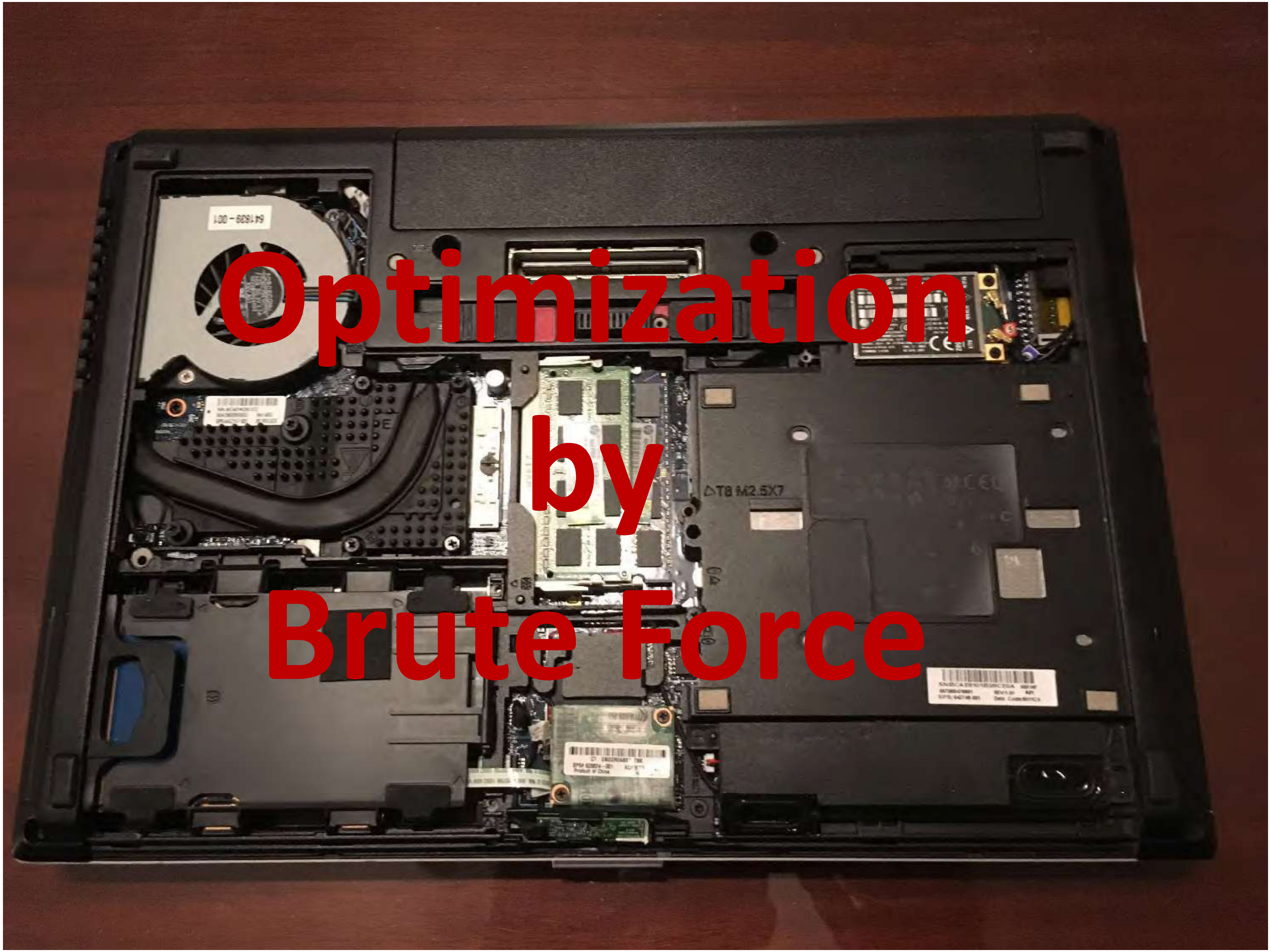
Systecon

Solution subspaces $S_1, S_2, \ldots, S_{10}$

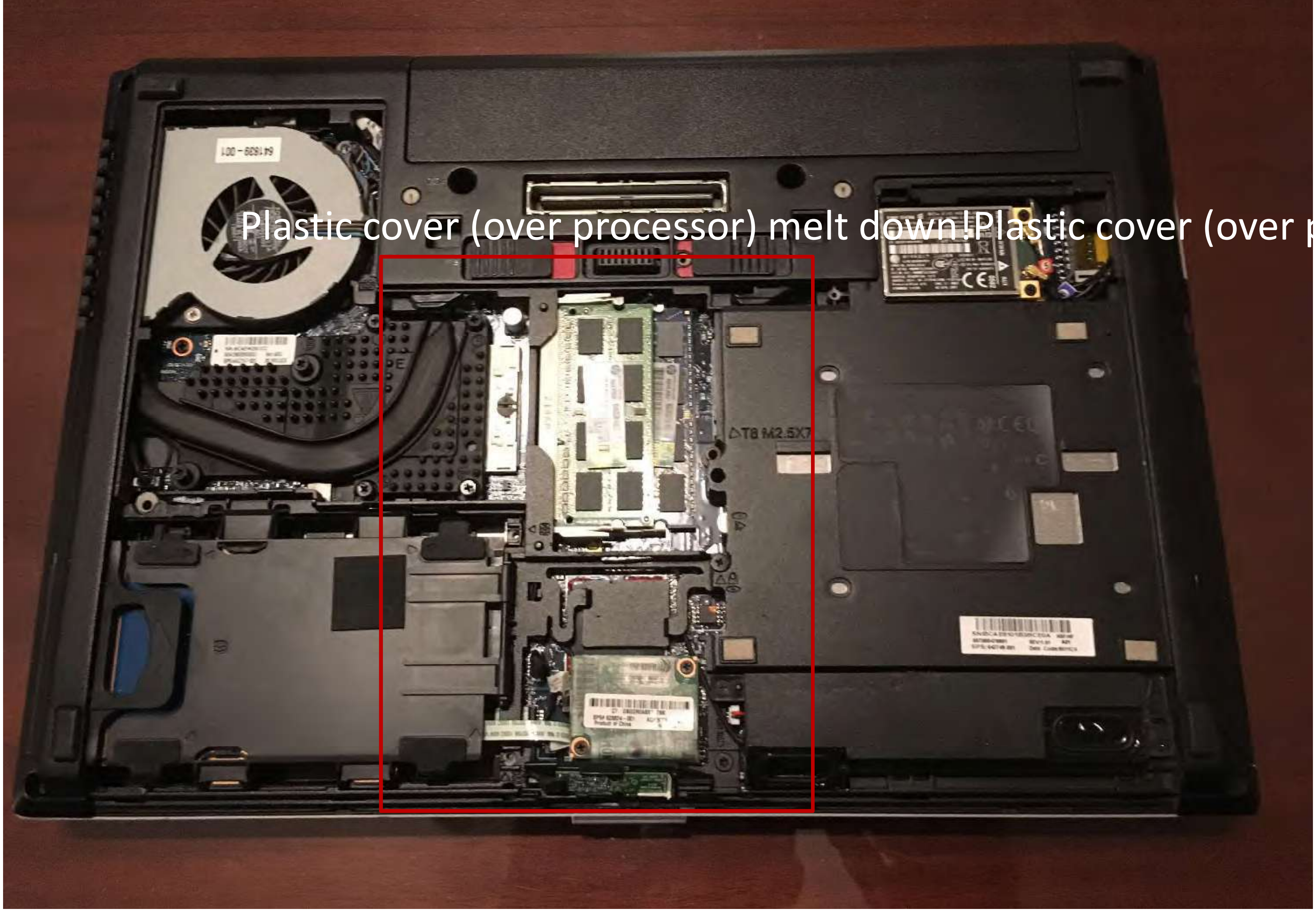
$t_{COL} = 8.33$ years



- Q: How many outer corner point combinations are there in total when ΔT=1000 hours?
- A: 43 866 471 255 357, i.e. approximately 44 trillion!


Optimization
by
Brute Force

HP laptop (2.7 GHz processor)

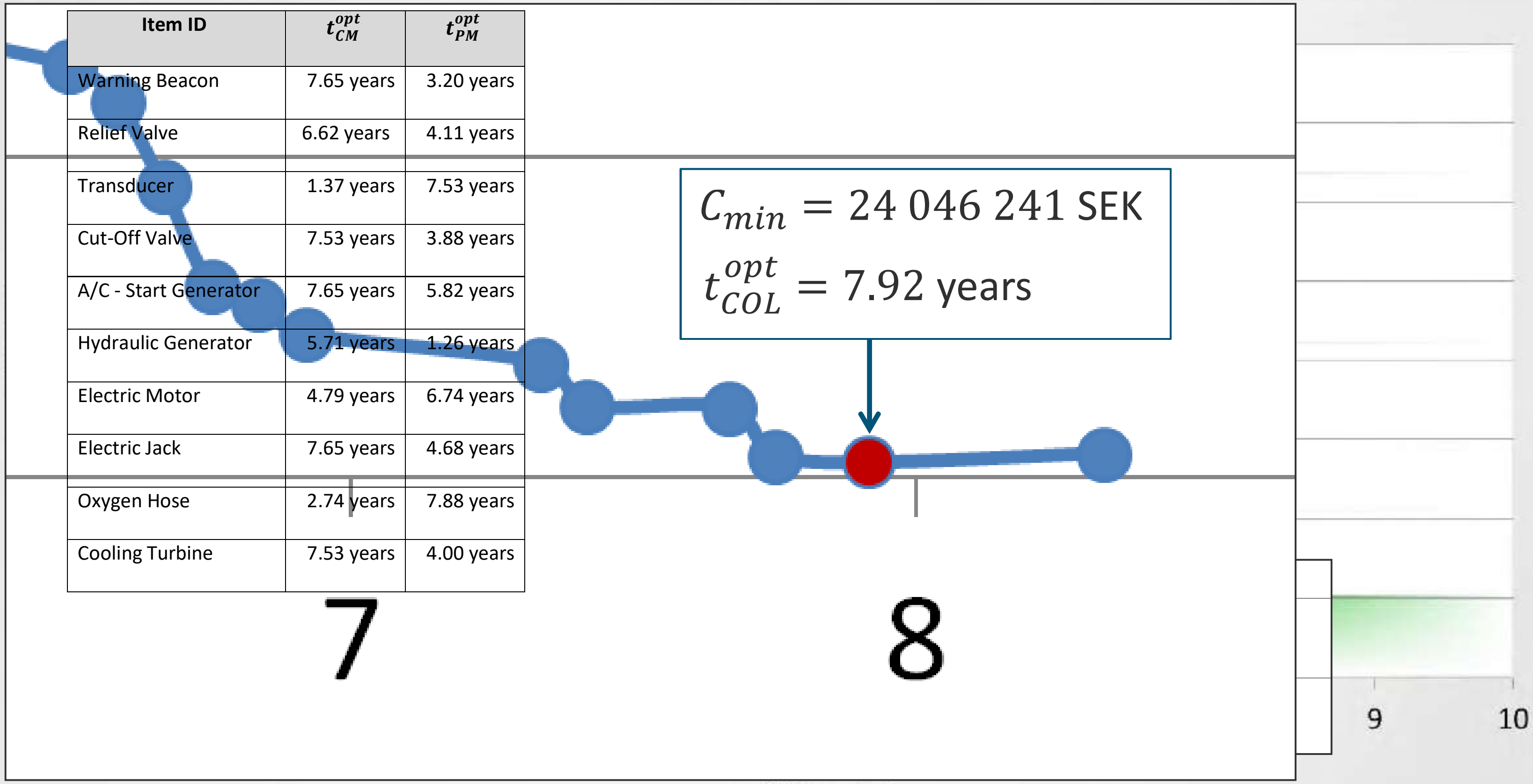


Brute Force (4000 h)

Item ID	t_{CM}^{opt}	t_{PM}^{opt}
Warning Beacon	7.65 years	3.20 years
Relief Valve	6.62 years	4.11 years
Transducer	1.37 years	7.53 years
Cut-Off Valve	7.53 years	3.88 years
A/C - Start Generator	7.65 years	5.82 years
Hydraulic Generator	5.71 years	1.26 years
Electric Motor	4.79 years	6.74 years
Electric Jack	7.65 years	4.68 years
Oxygen Hose	2.74 years	7.88 years
Cooling Turbine	7.53 years	4.00 years

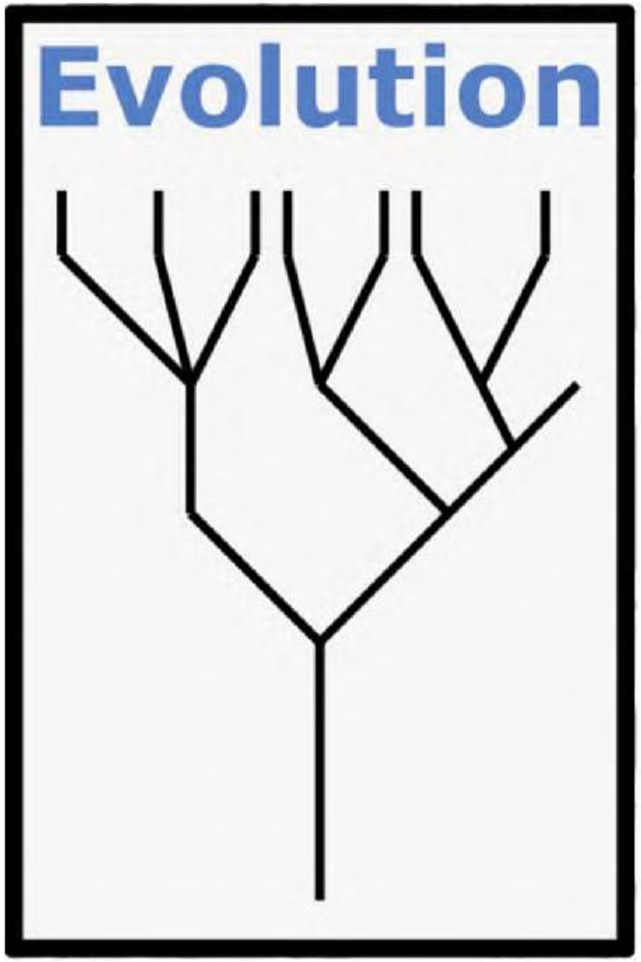
$$C_{min} = 24\ 046\ 241 \text{ SEK}$$

$$t_{COL}^{opt} = 7.92 \text{ years}$$



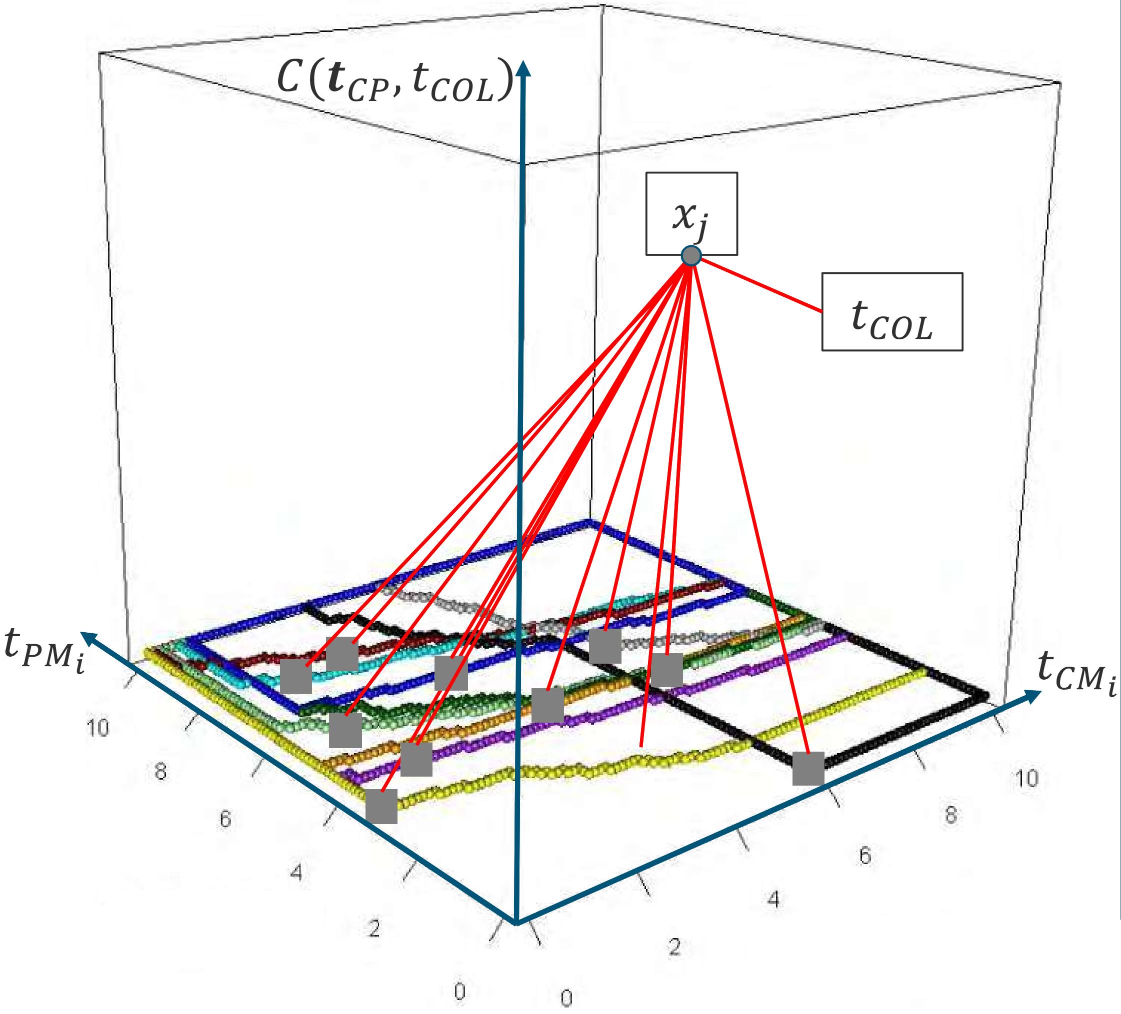
Systecon

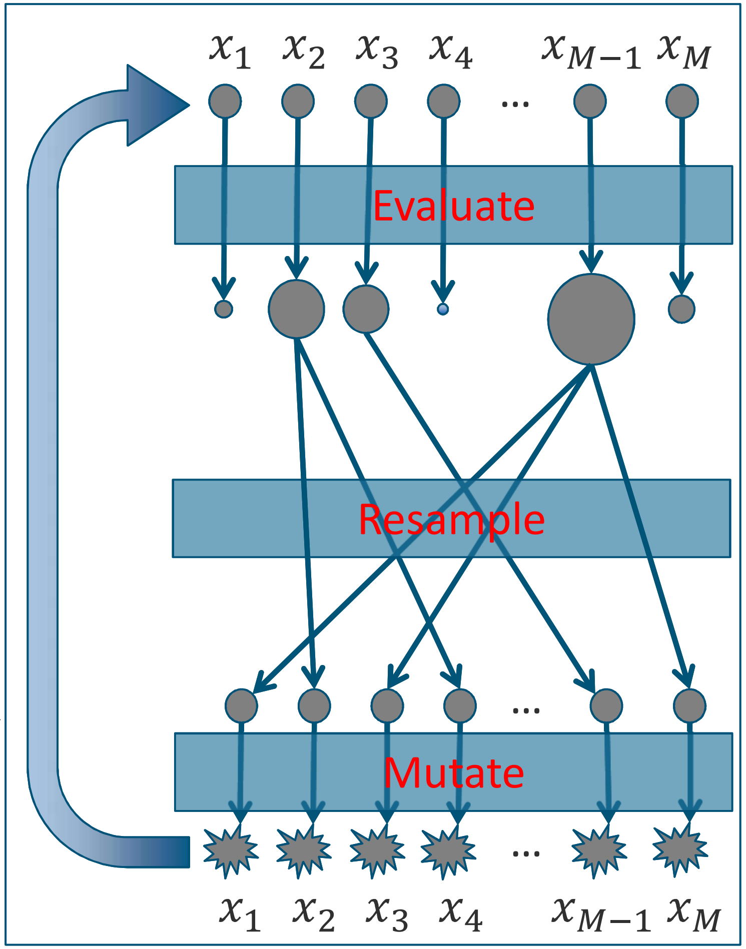
Optimization by using a Genetic Algorithm



Genetic Algorithm

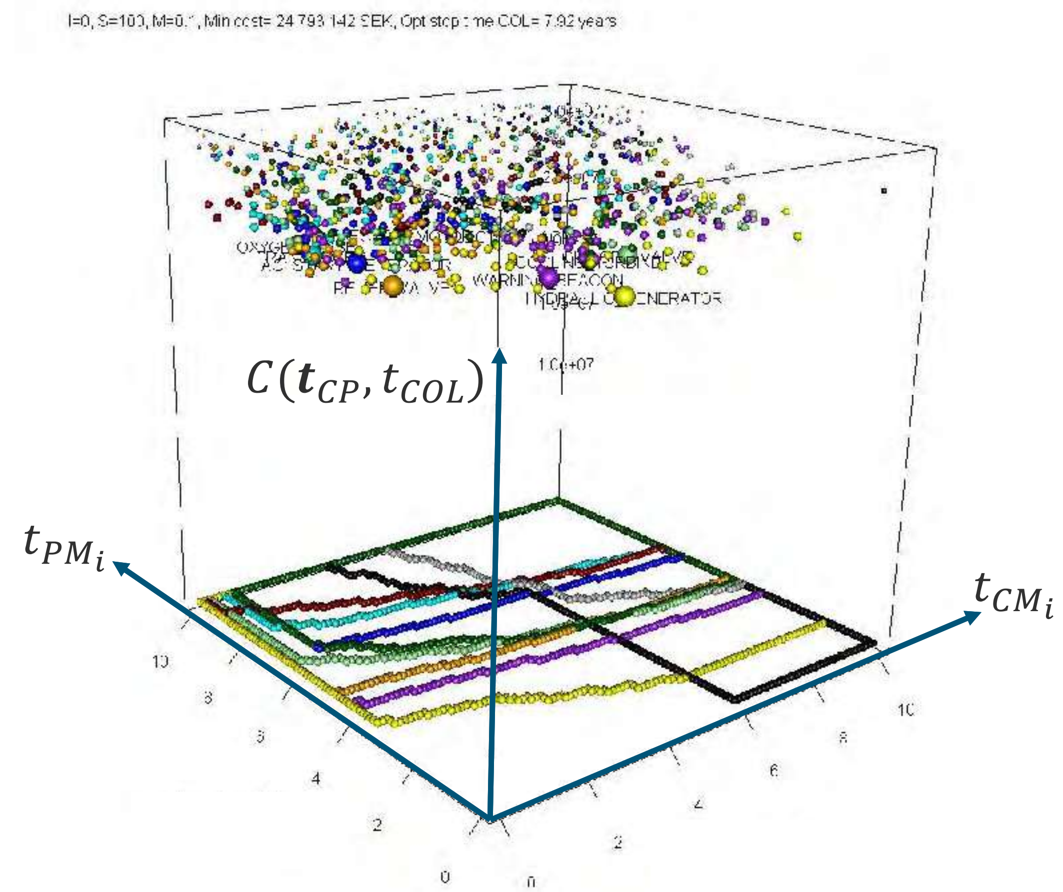
Sample set: $x_j = (\boldsymbol{t}_{CP}, t_{COL}), \quad j = 1,2,\ldots,M$





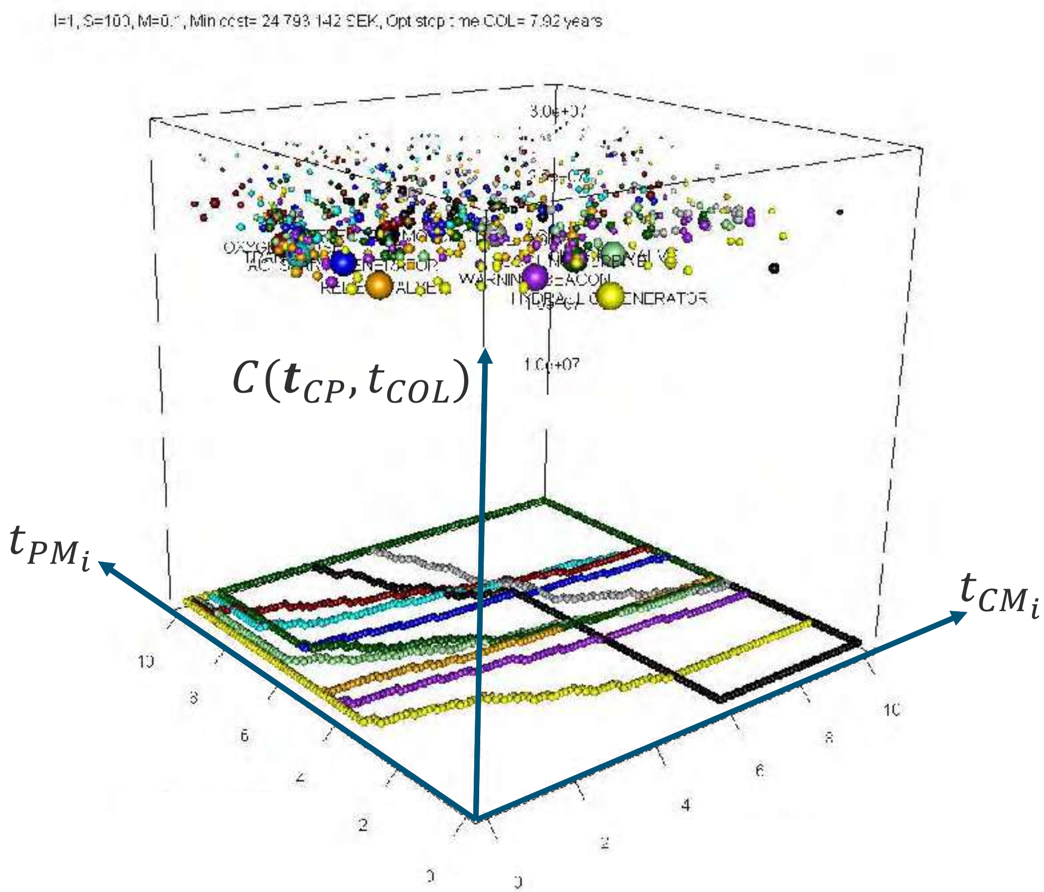
Genetic Algorithm (100 samples)

ΔT=1000 h



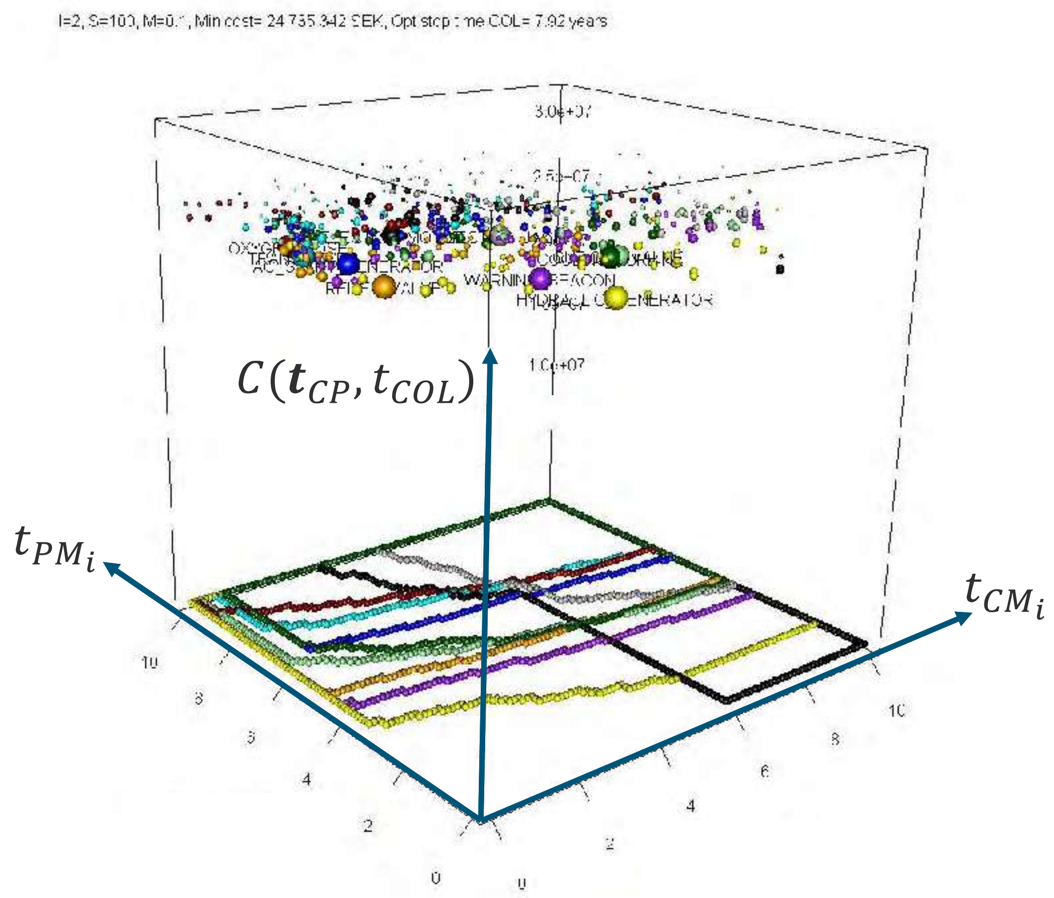
Genetic Algorithm (100 samples)

ΔT=1000 h



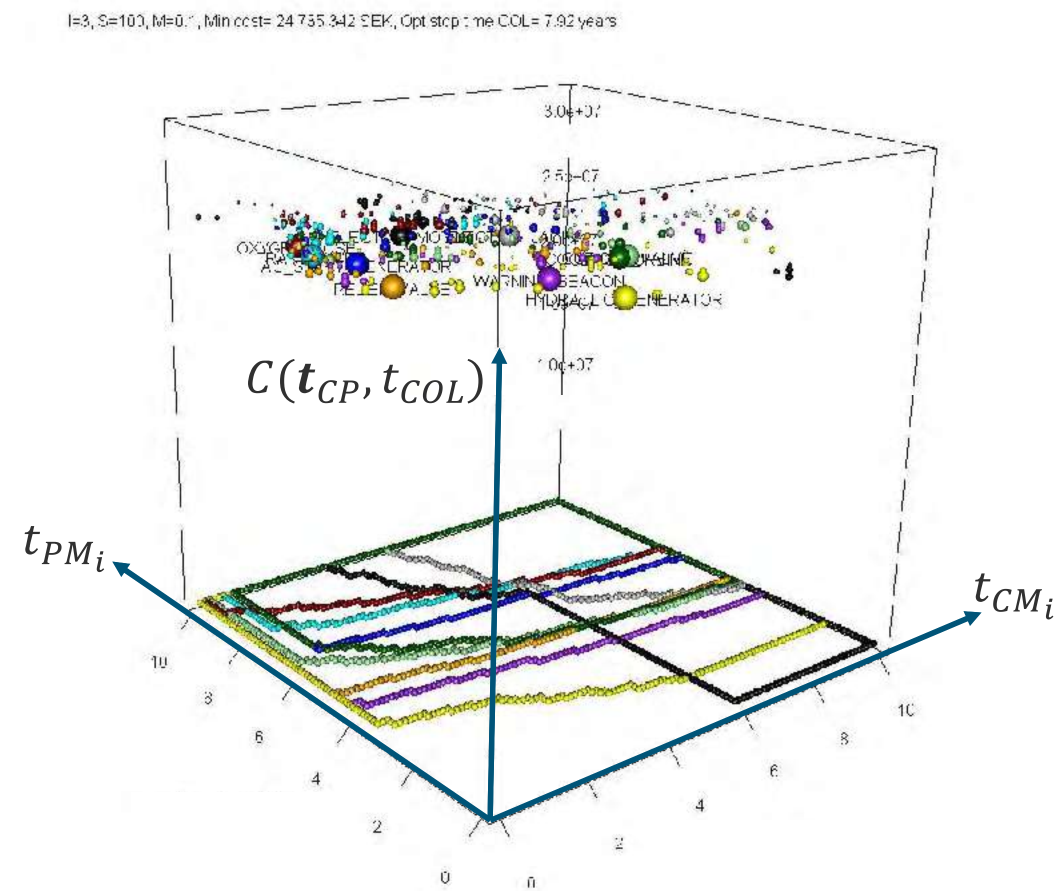
Genetic Algorithm (100 samples)

ΔT=1000 h



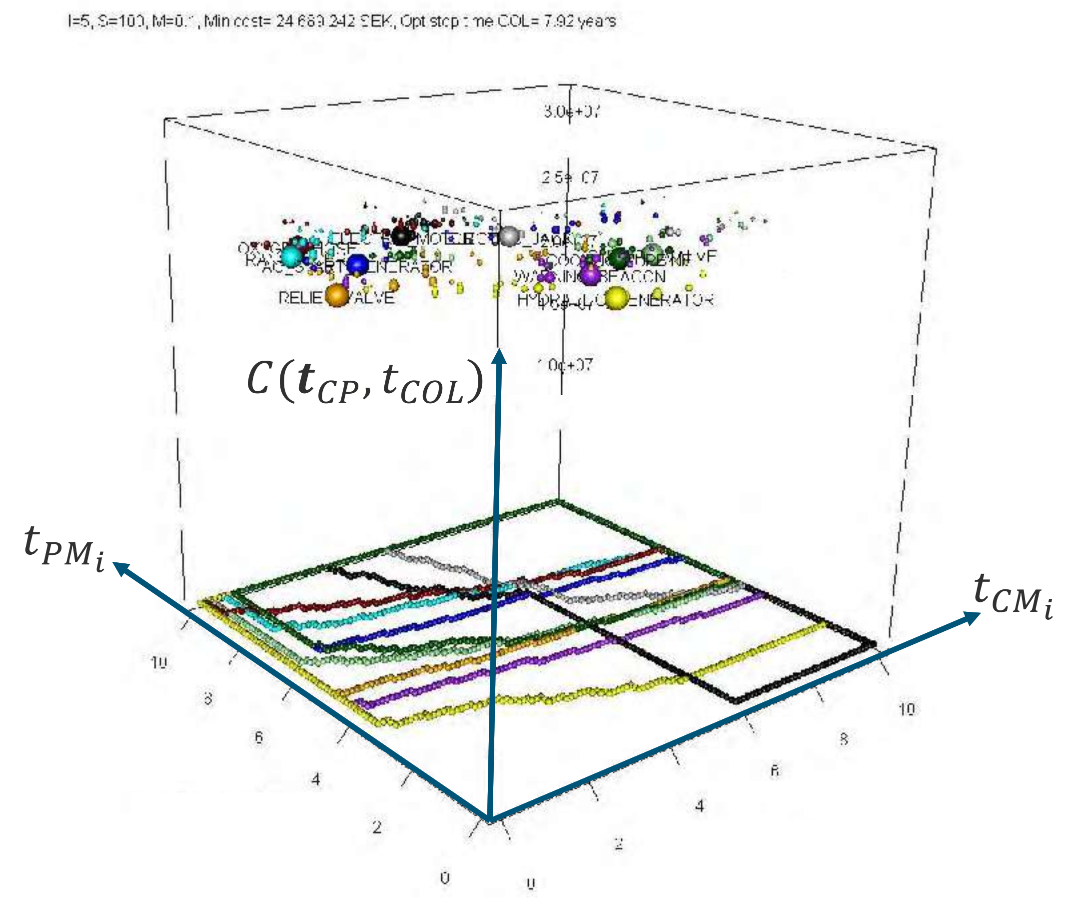
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

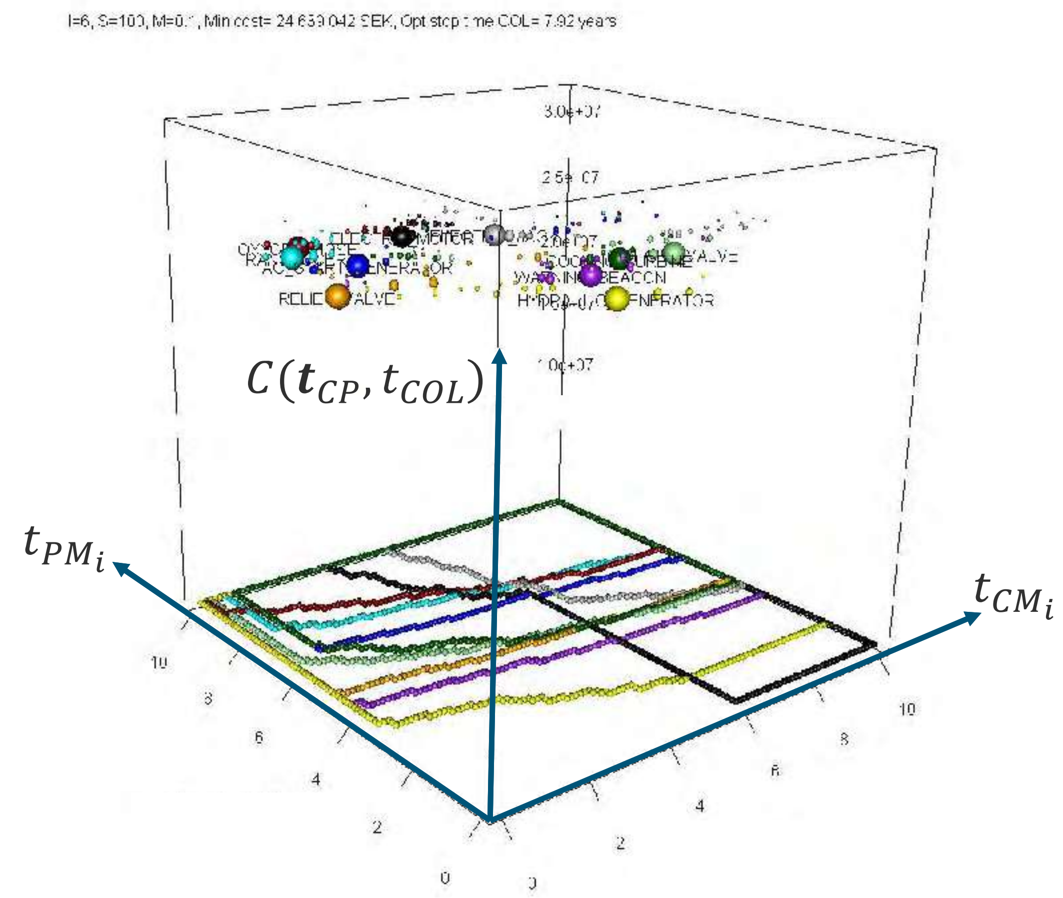
ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

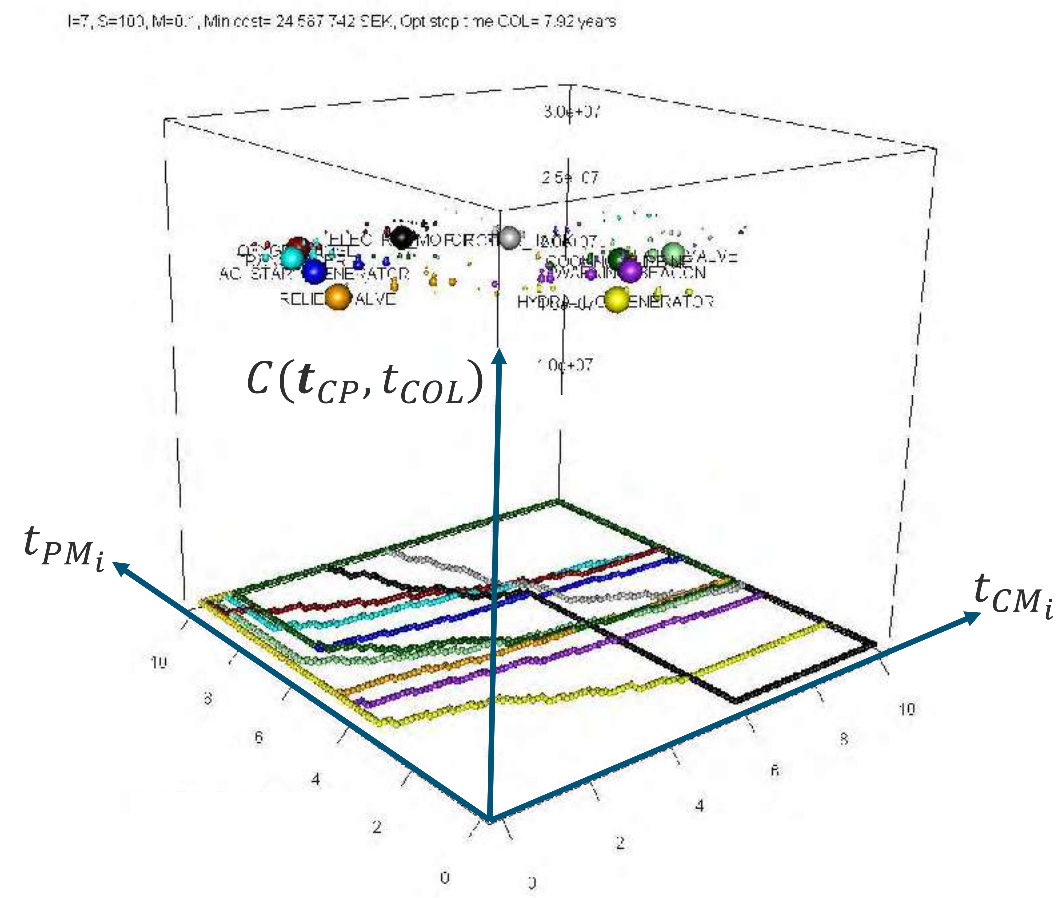
ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

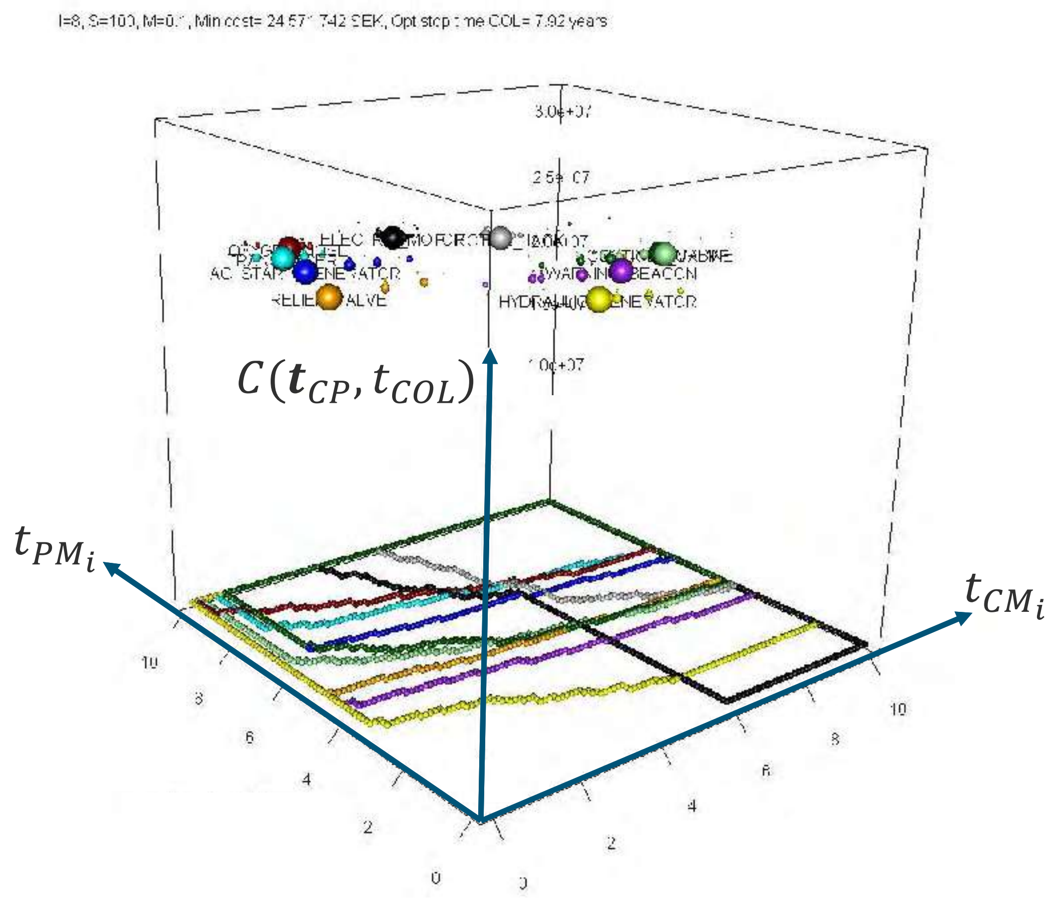
ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

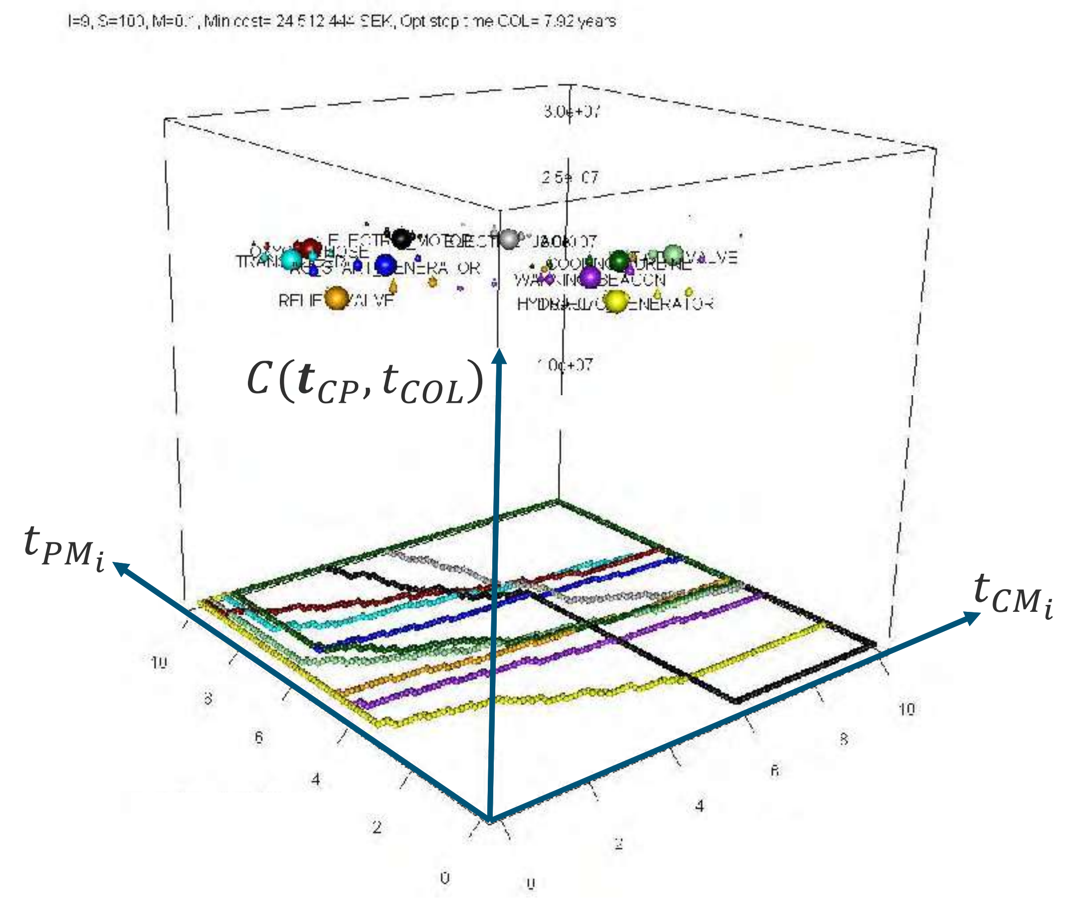
ΔT=1000 h



Systecon

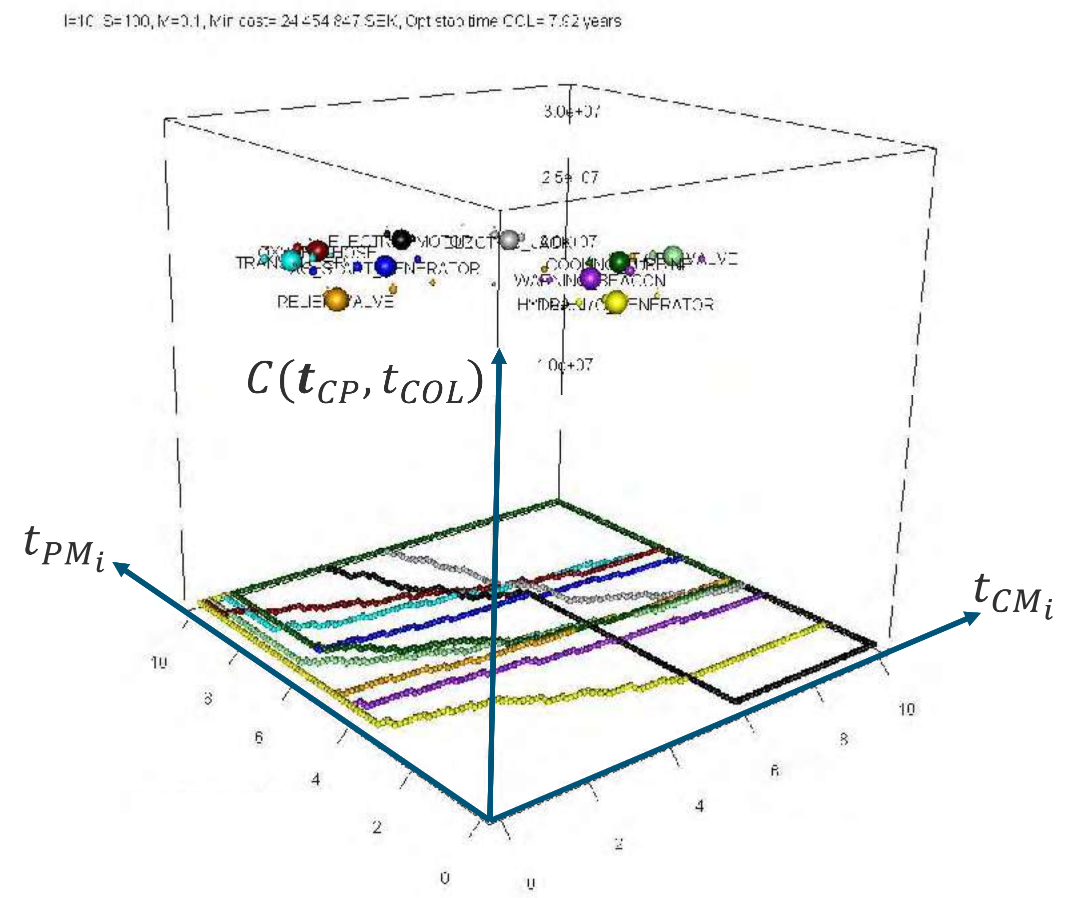
Genetic Algorithm (100 samples)

ΔT=1000 h



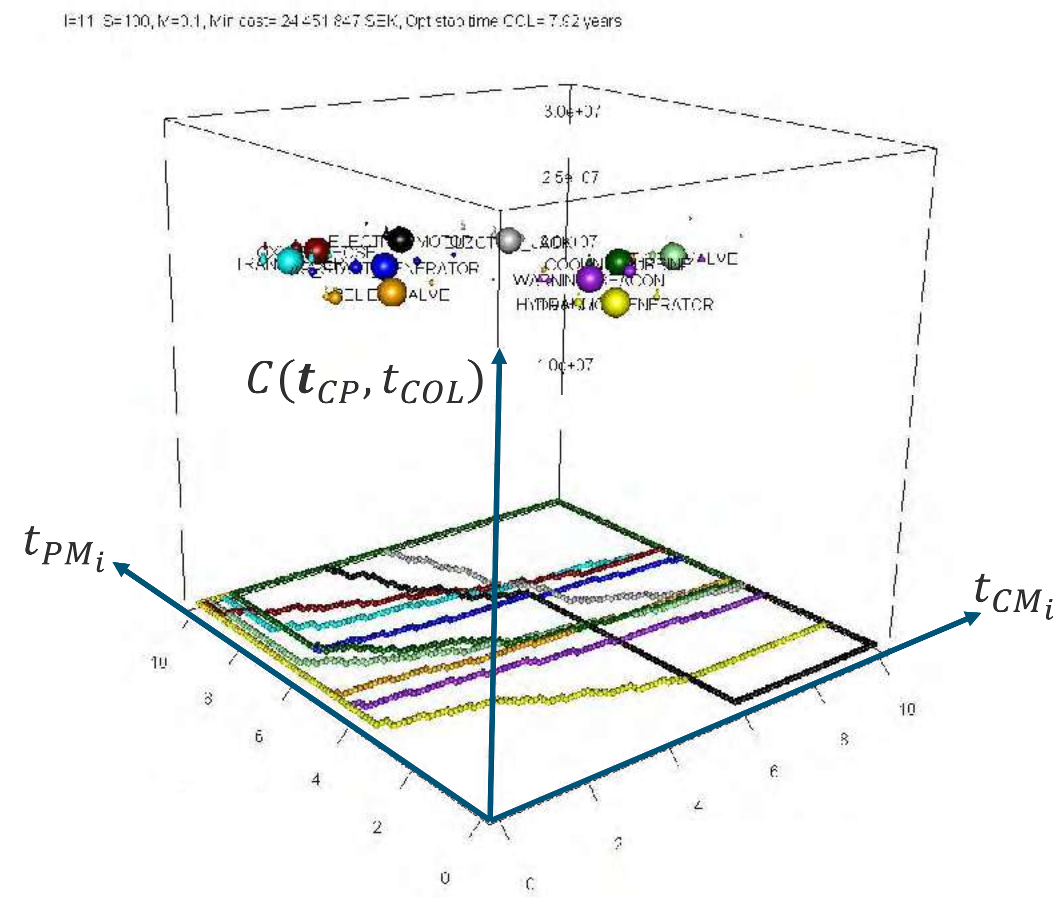
Genetic Algorithm (100 samples)

ΔT=1000 h



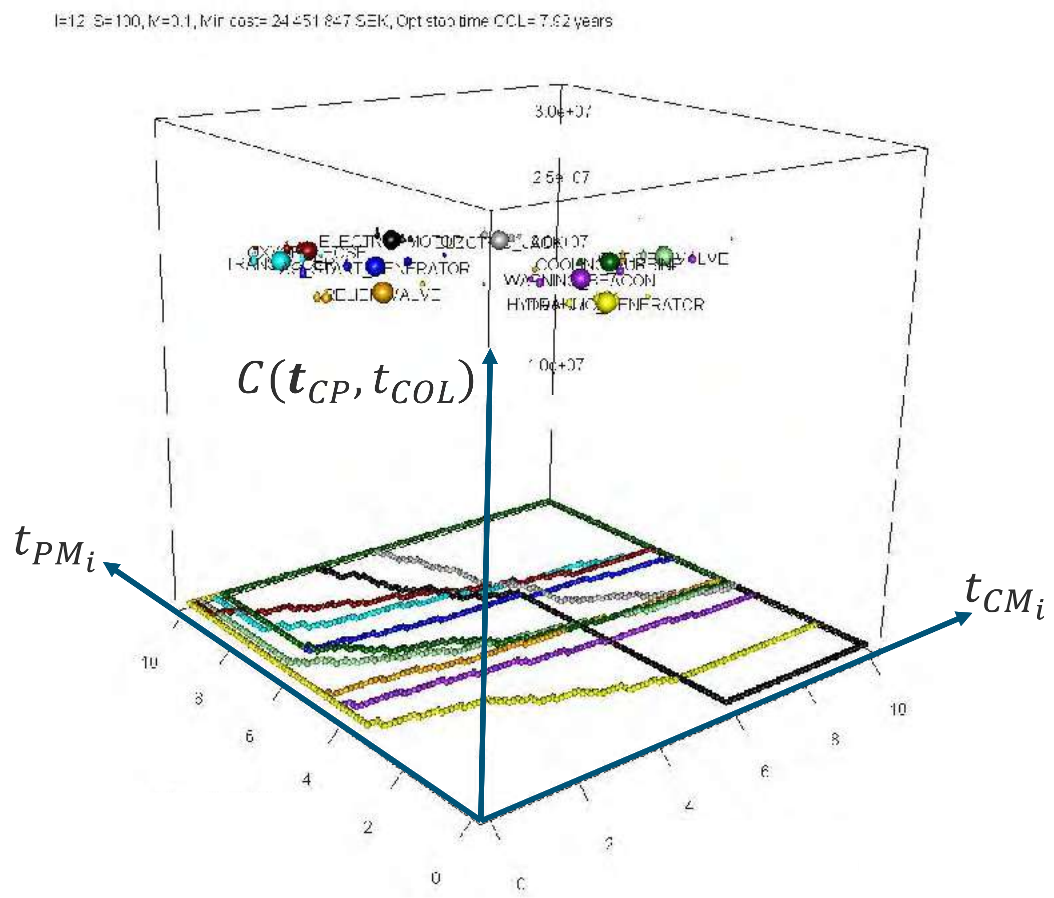
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

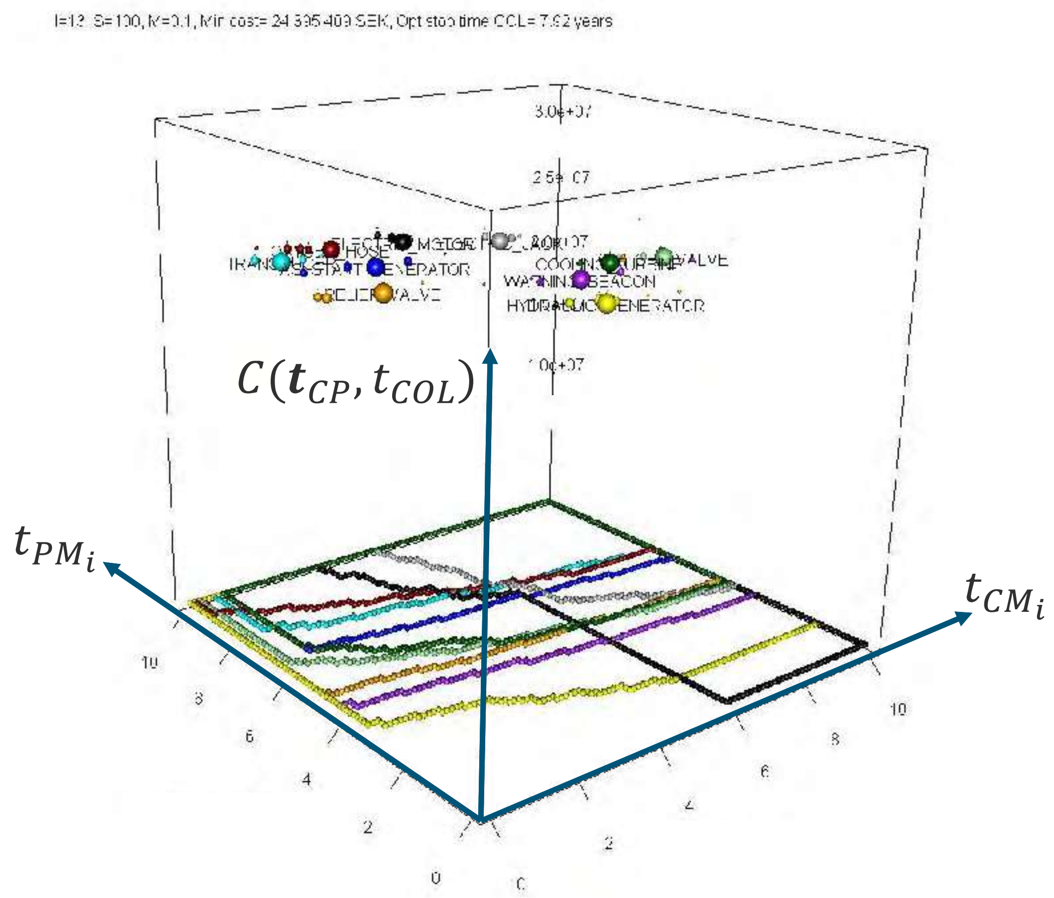
ΔT=1000 h



Systecon

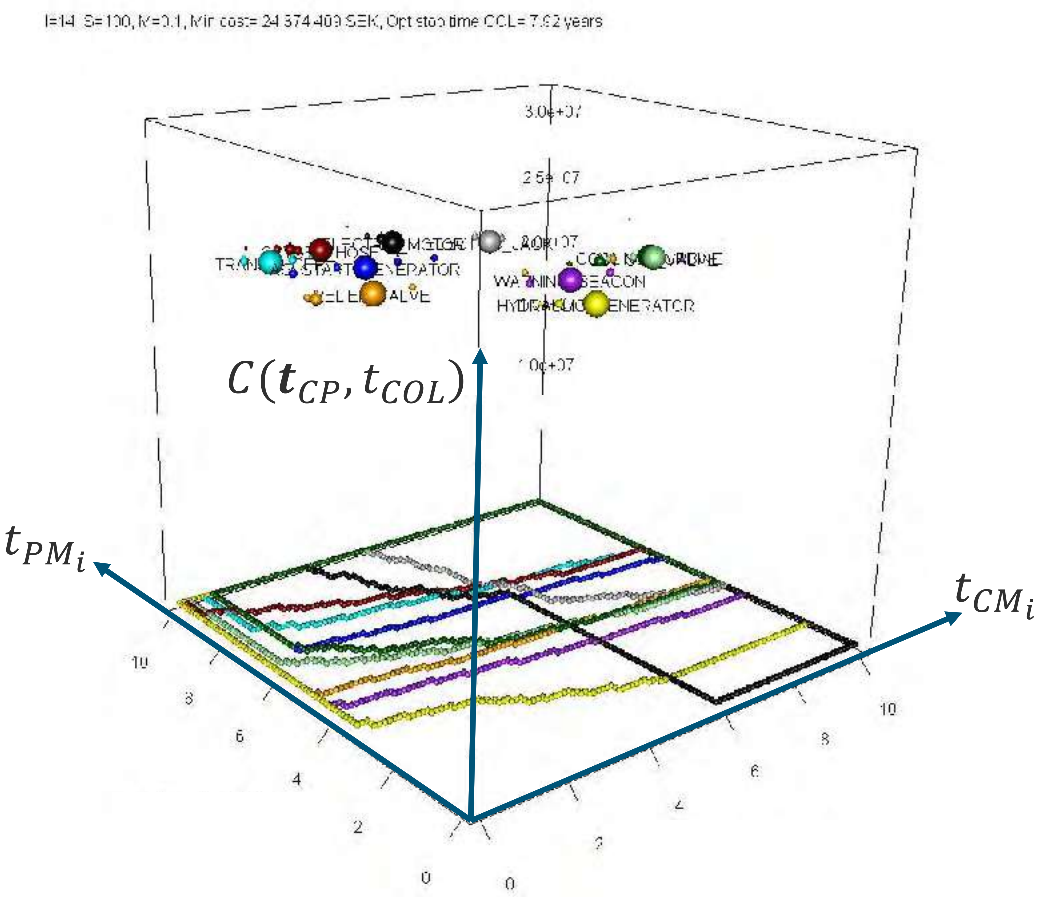
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

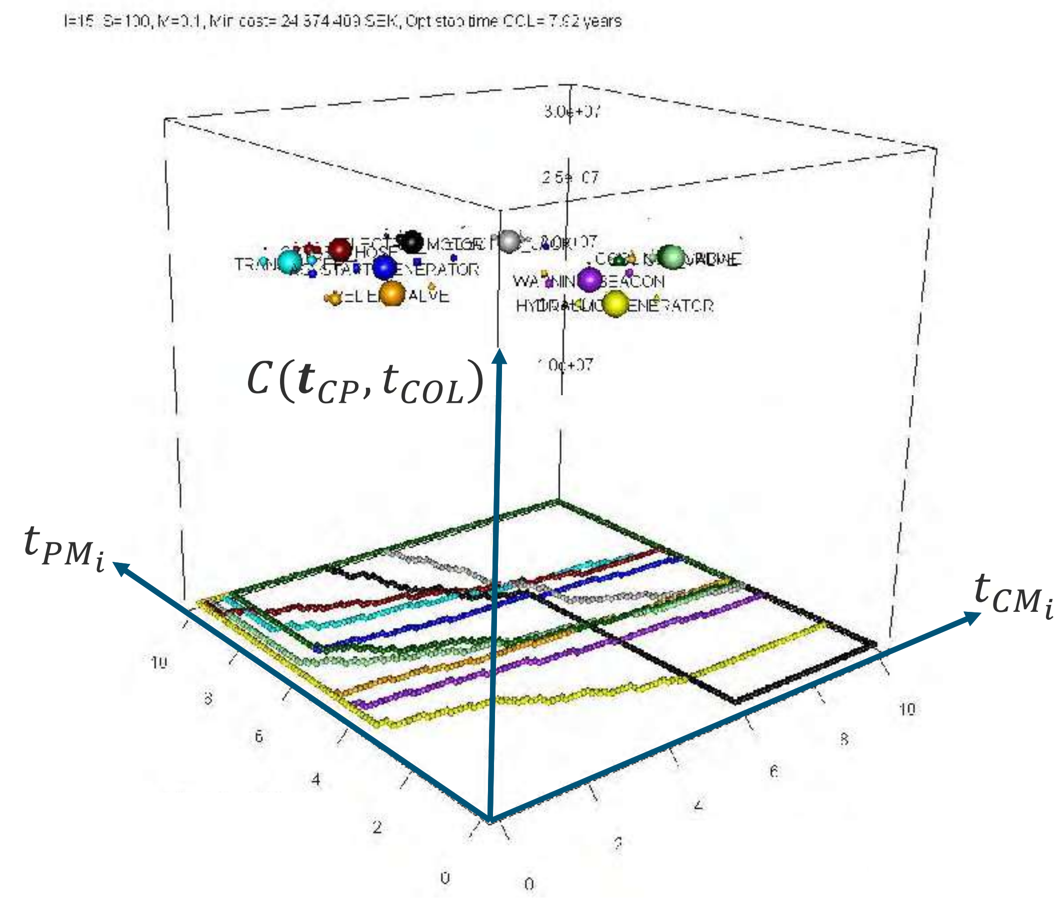
ΔT=1000 h



Slide 72

Genetic Algorithm (100 samples)

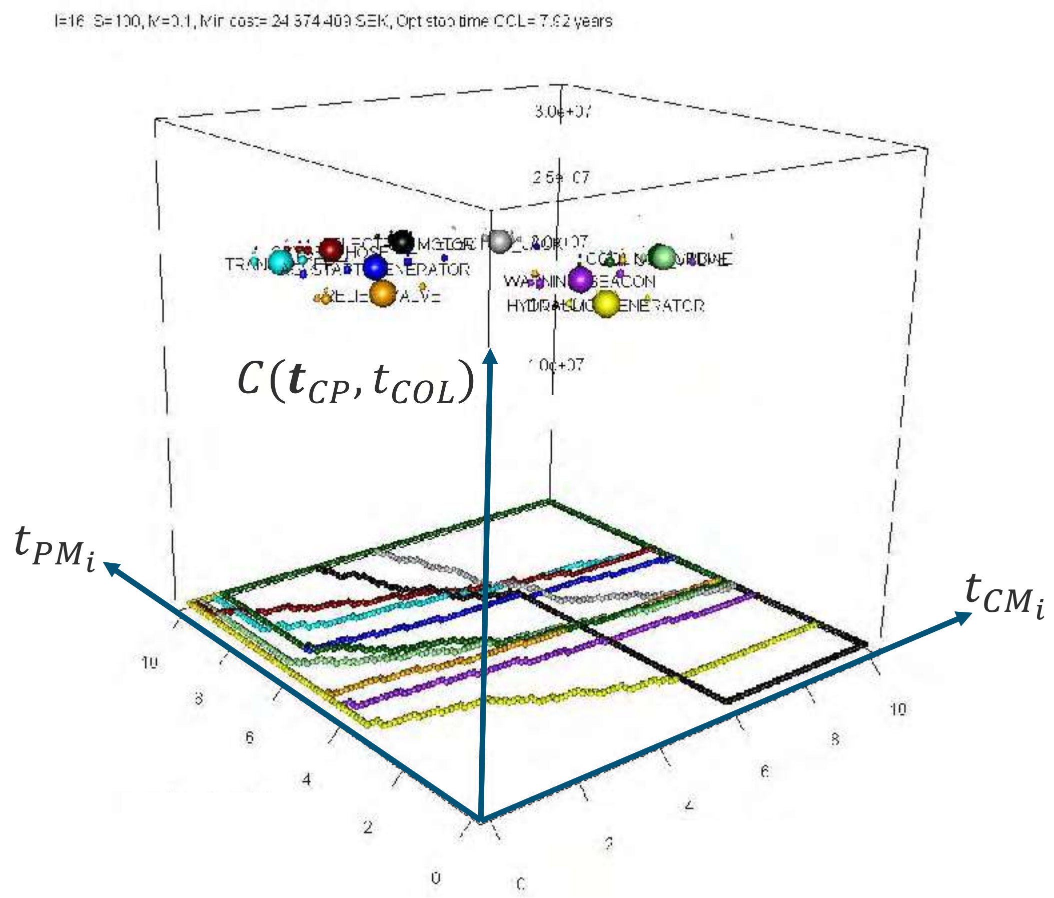
ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

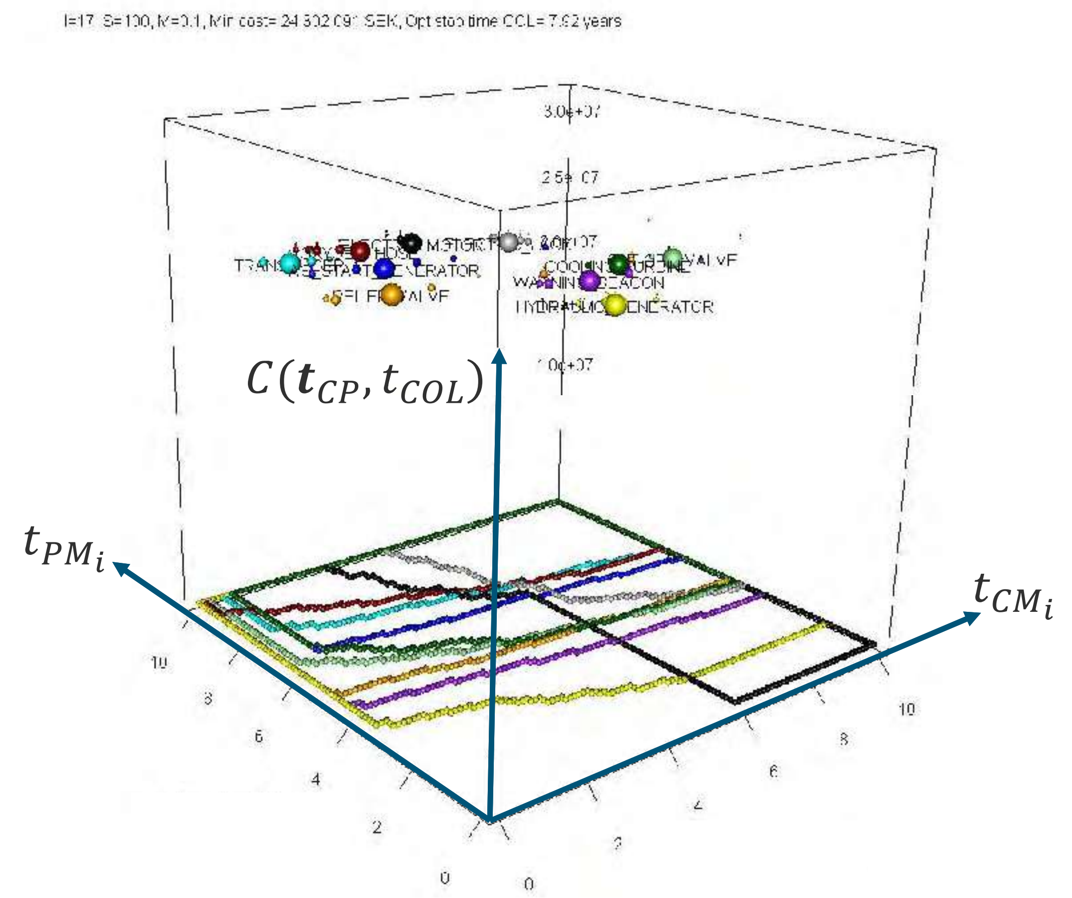
ΔT=1000 h



Systecon

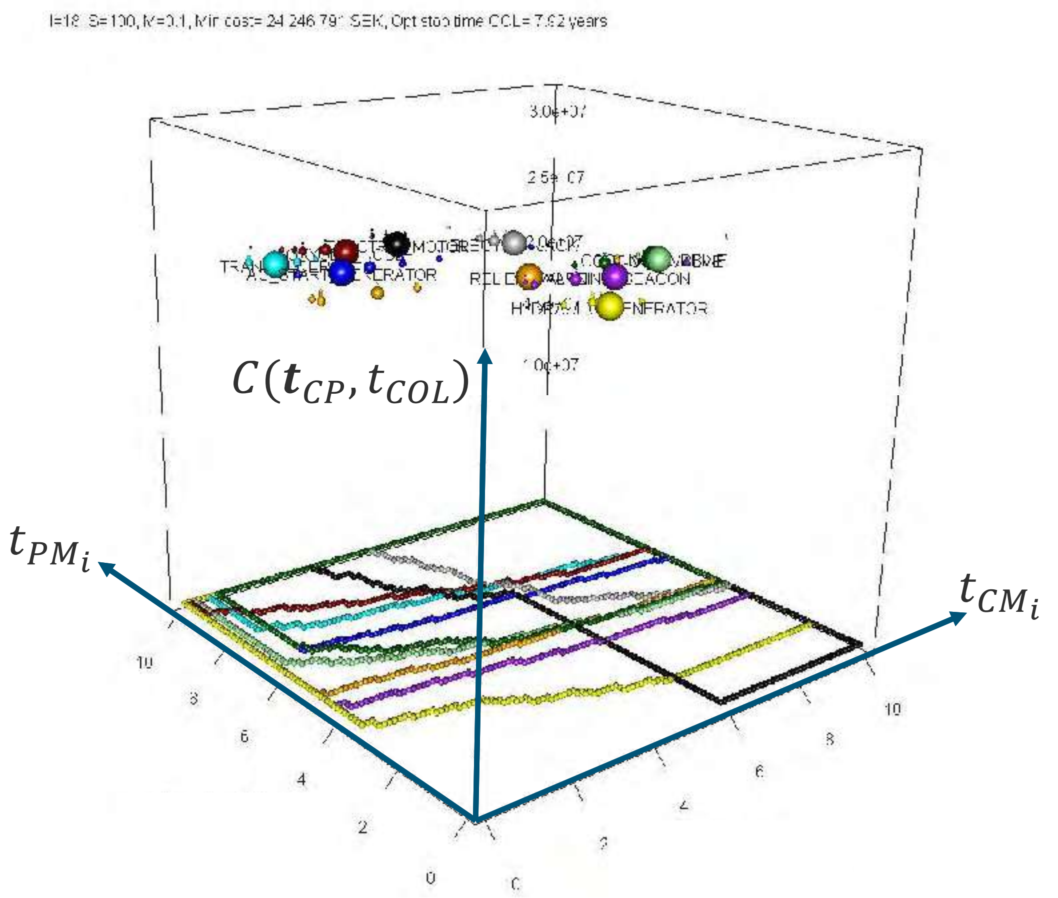
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

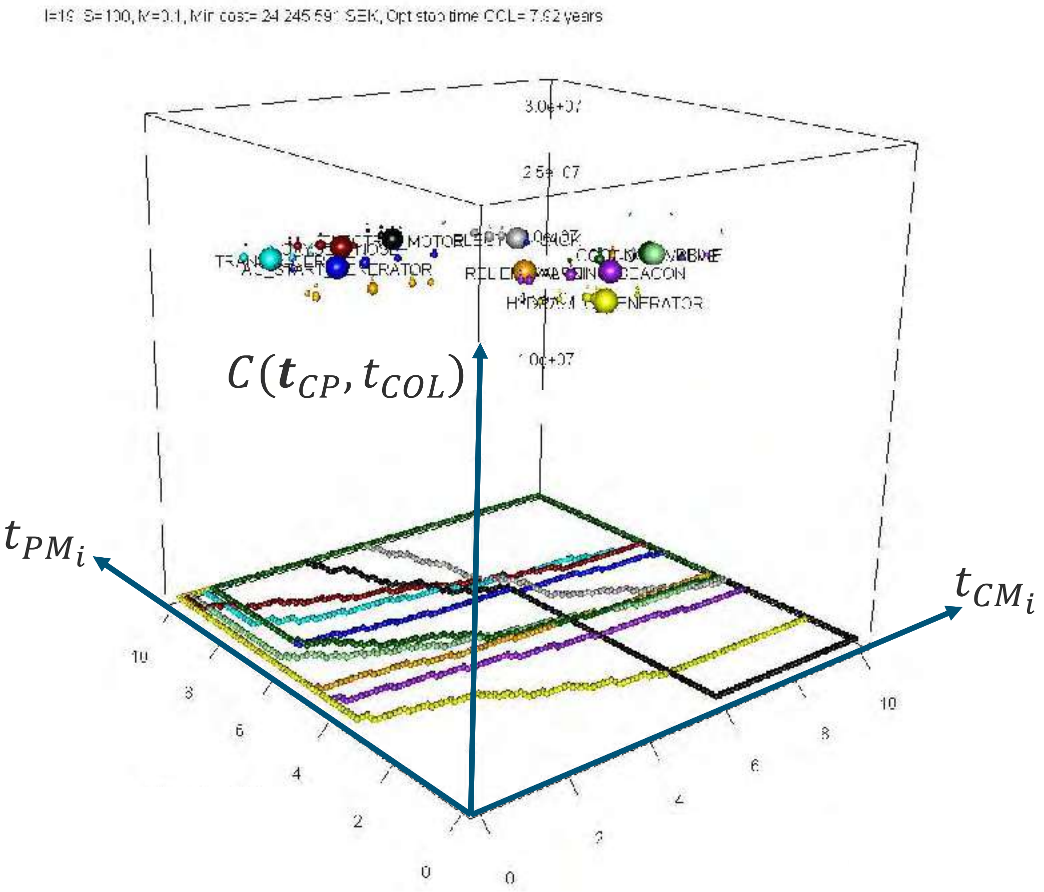
ΔT=1000 h



Systecon

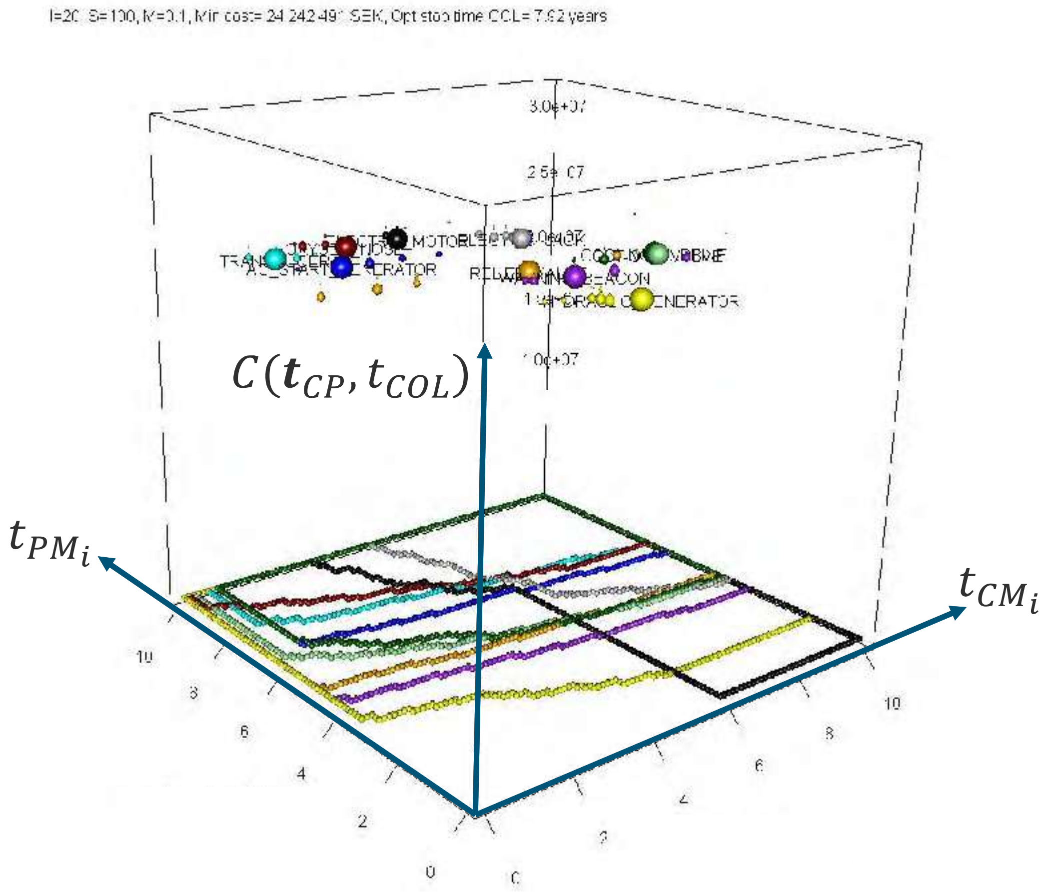
Genetic Algorithm (100 samples)

ΔT=1000 h



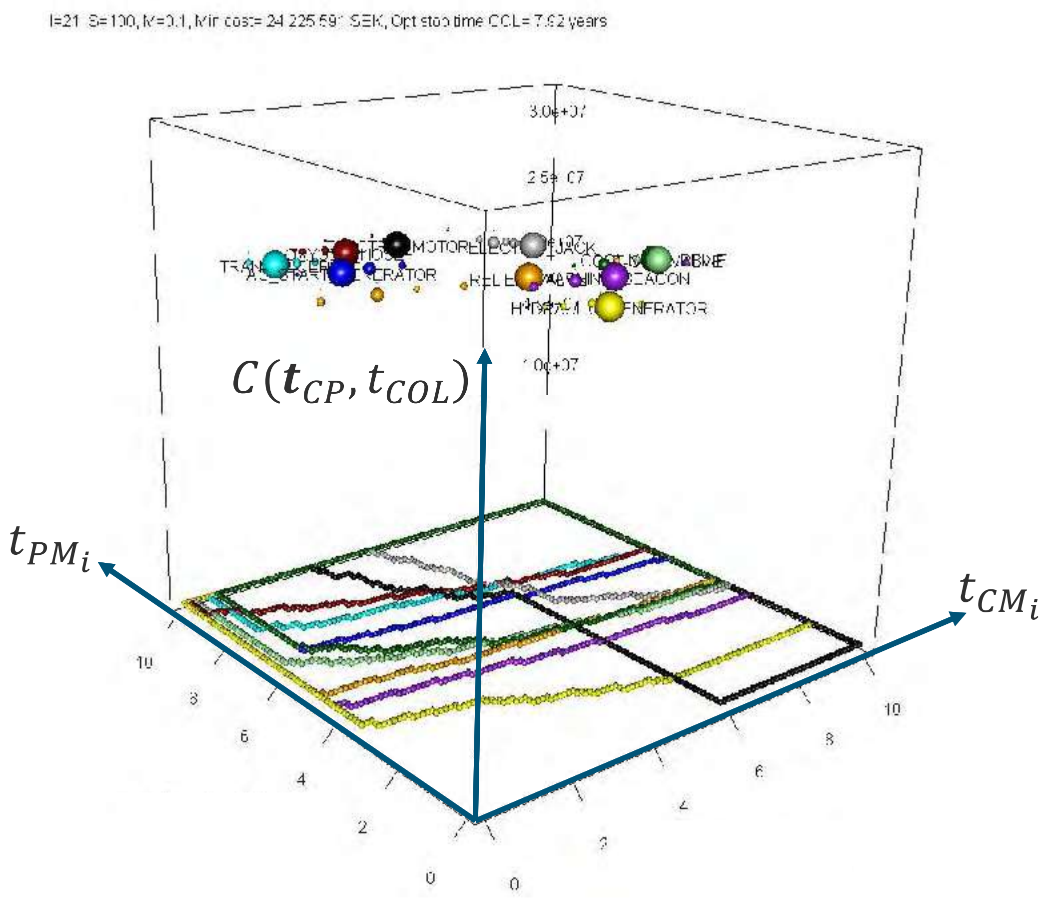
Genetic Algorithm (100 samples)

ΔT=1000 h



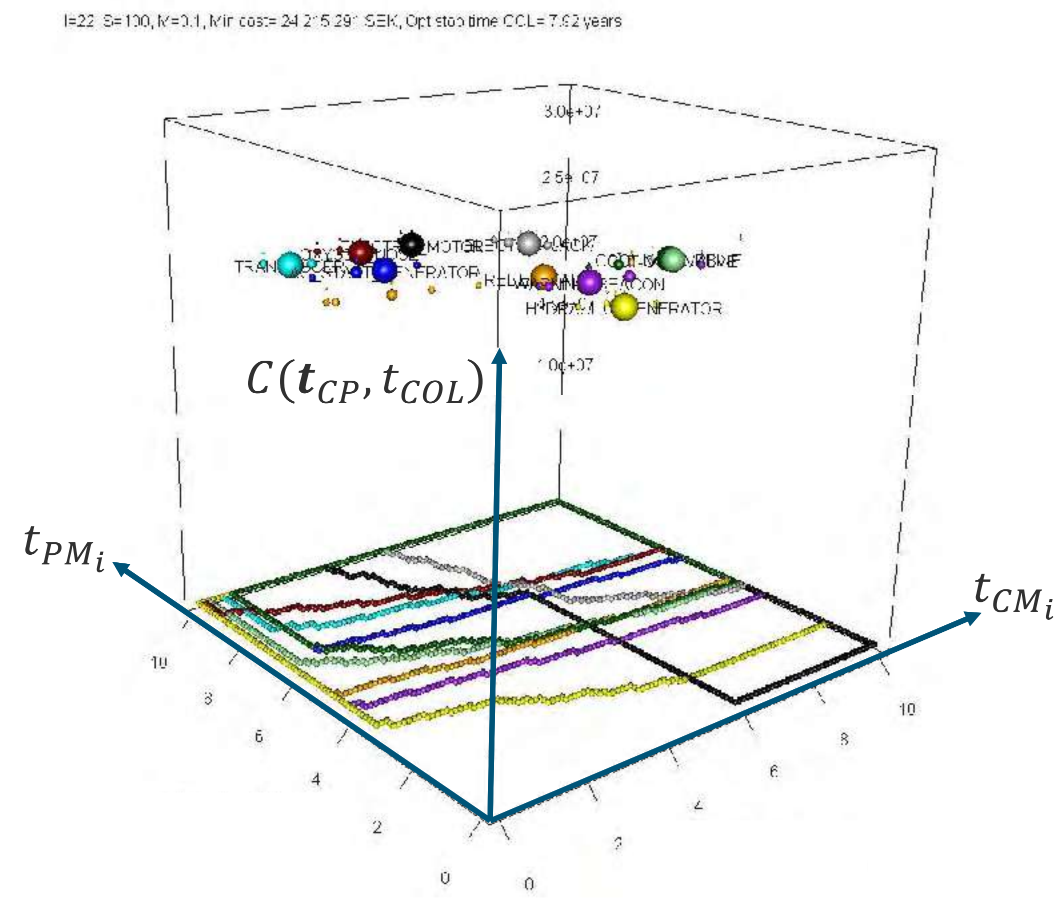
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

ΔT=1000 h



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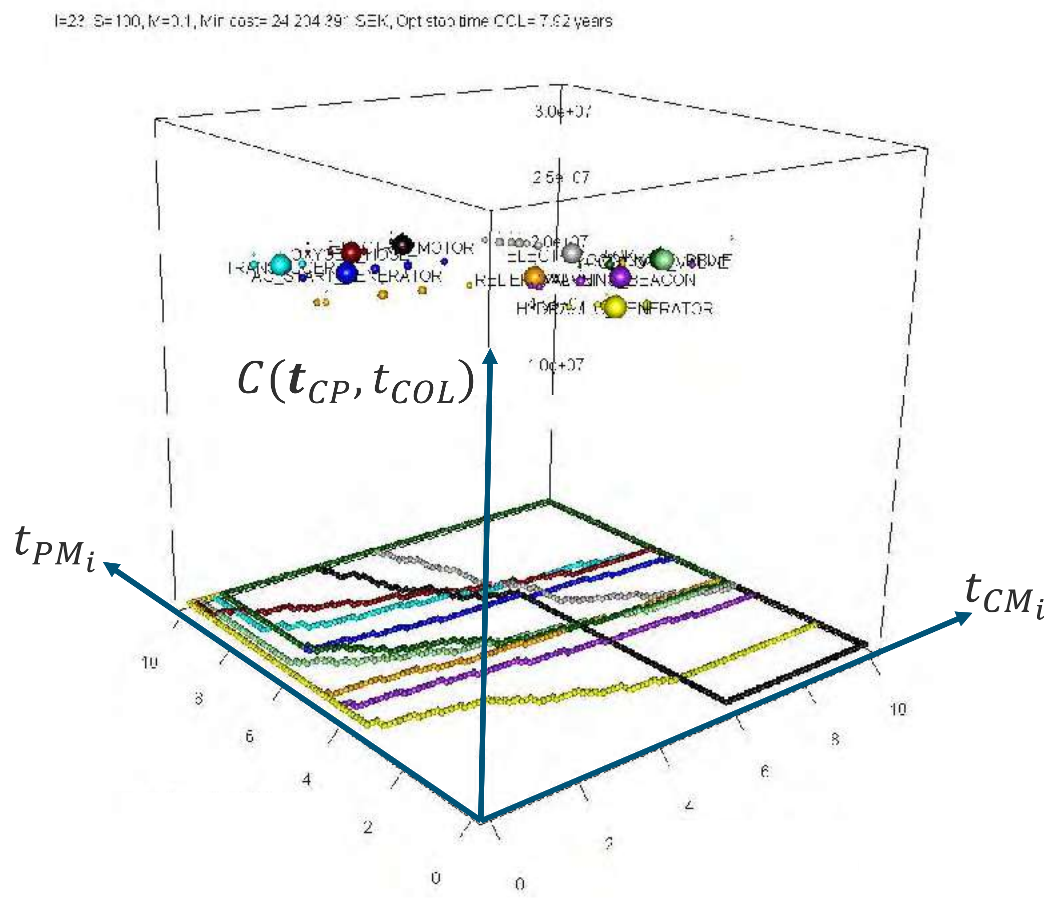
Genetic Algorithm (100 samples)

ΔT=1000 h



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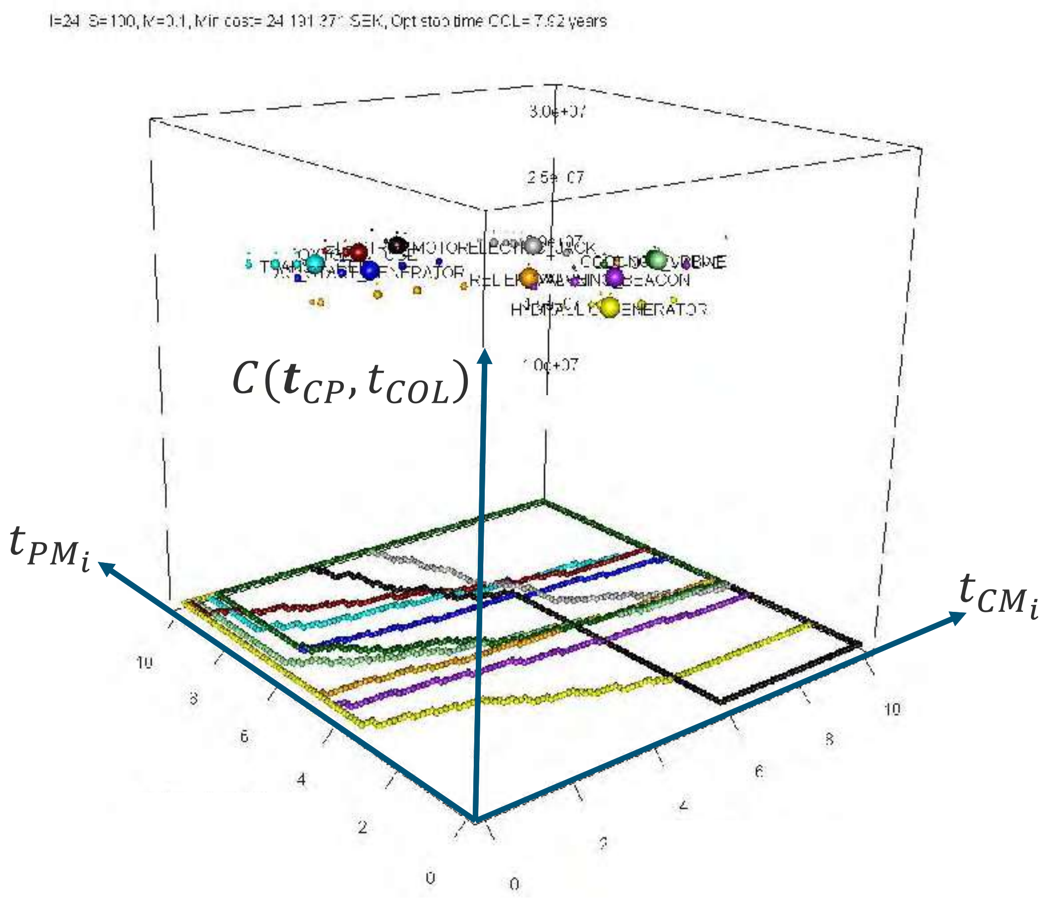
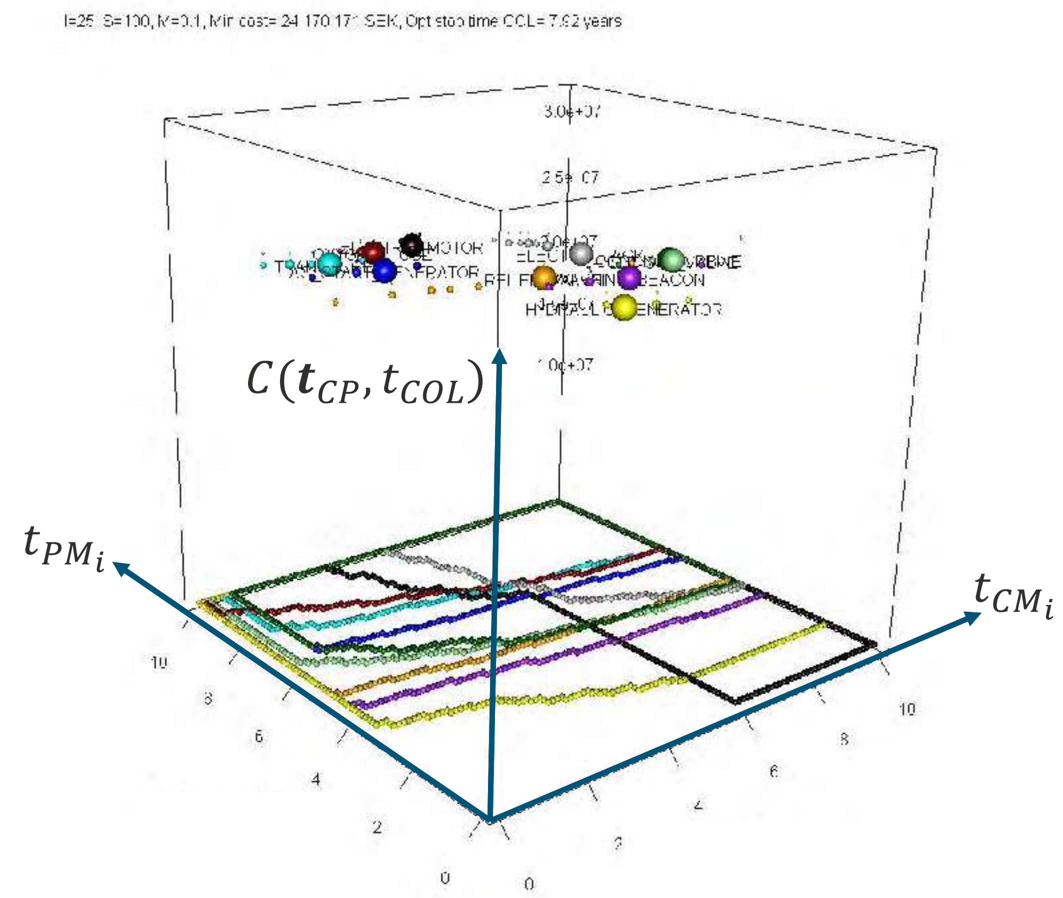
Genetic Algorithm (100 samples)

ΔT=1000 h



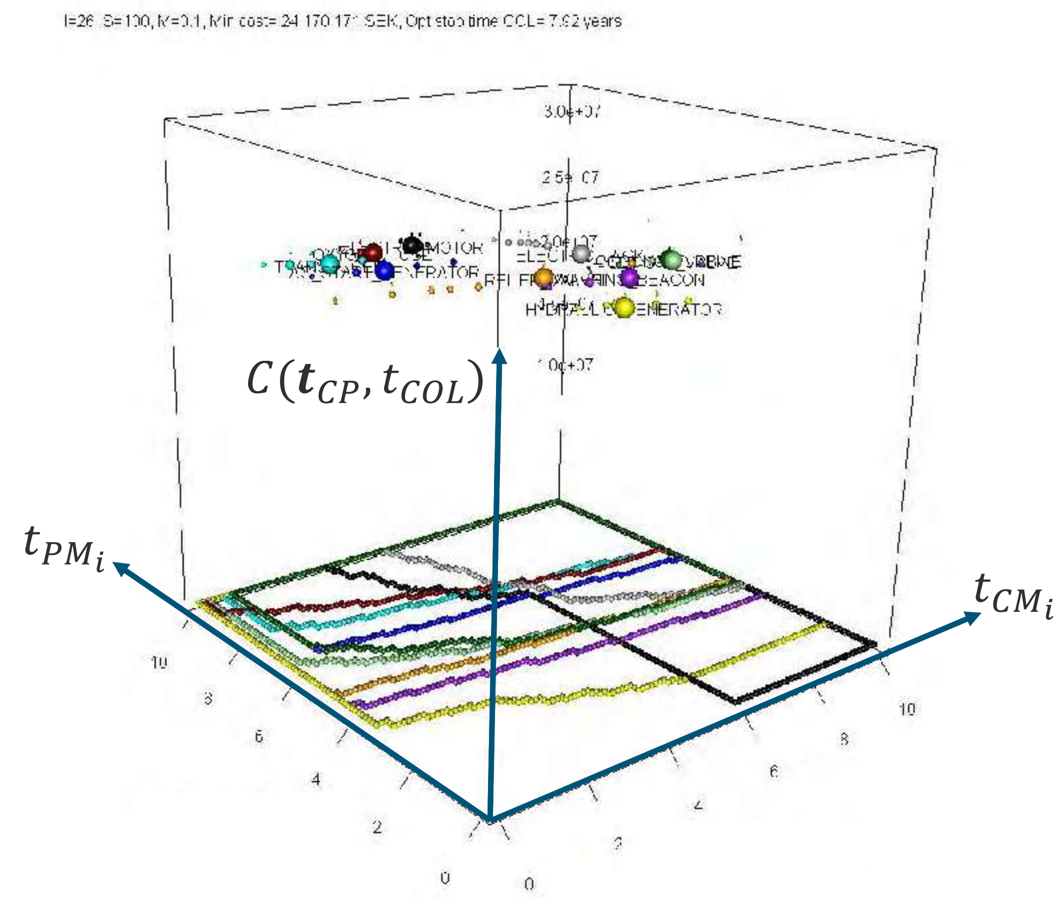
Genetic Algorithm (100 samples)

ΔT=1000 h



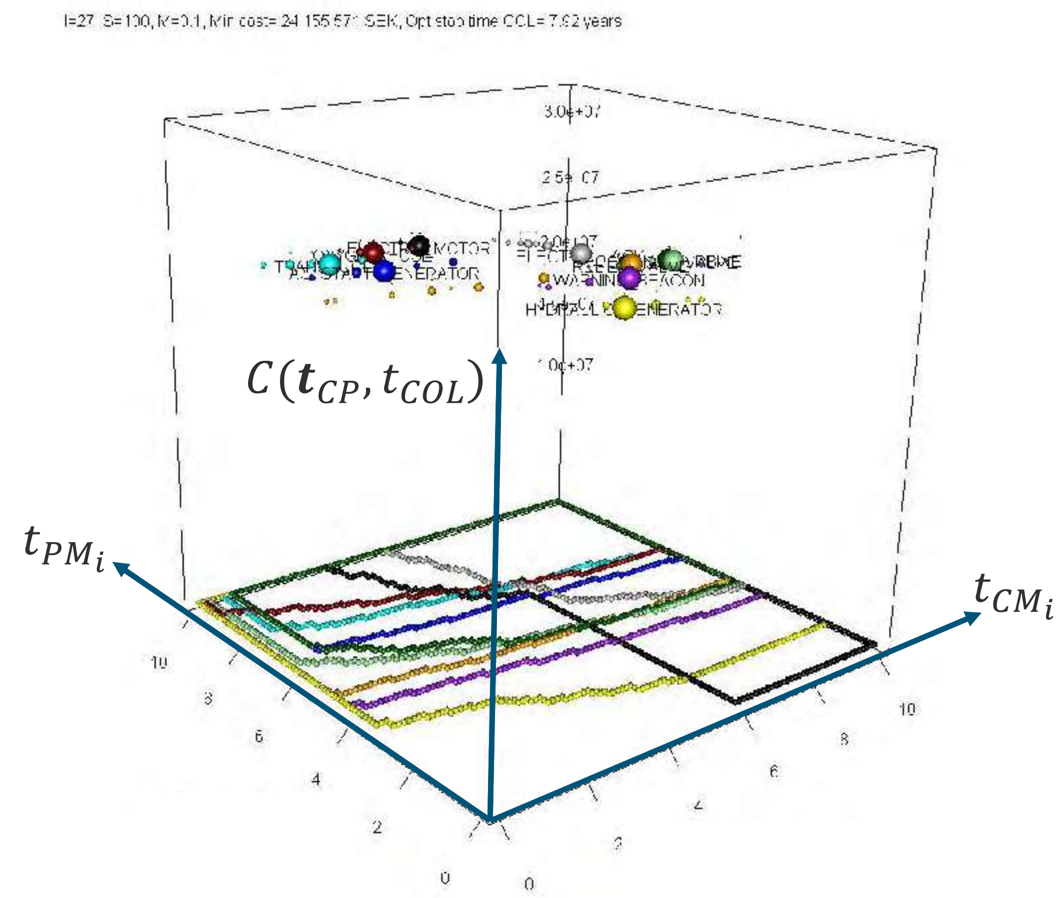
Genetic Algorithm (100 samples)

ΔT=1000 h



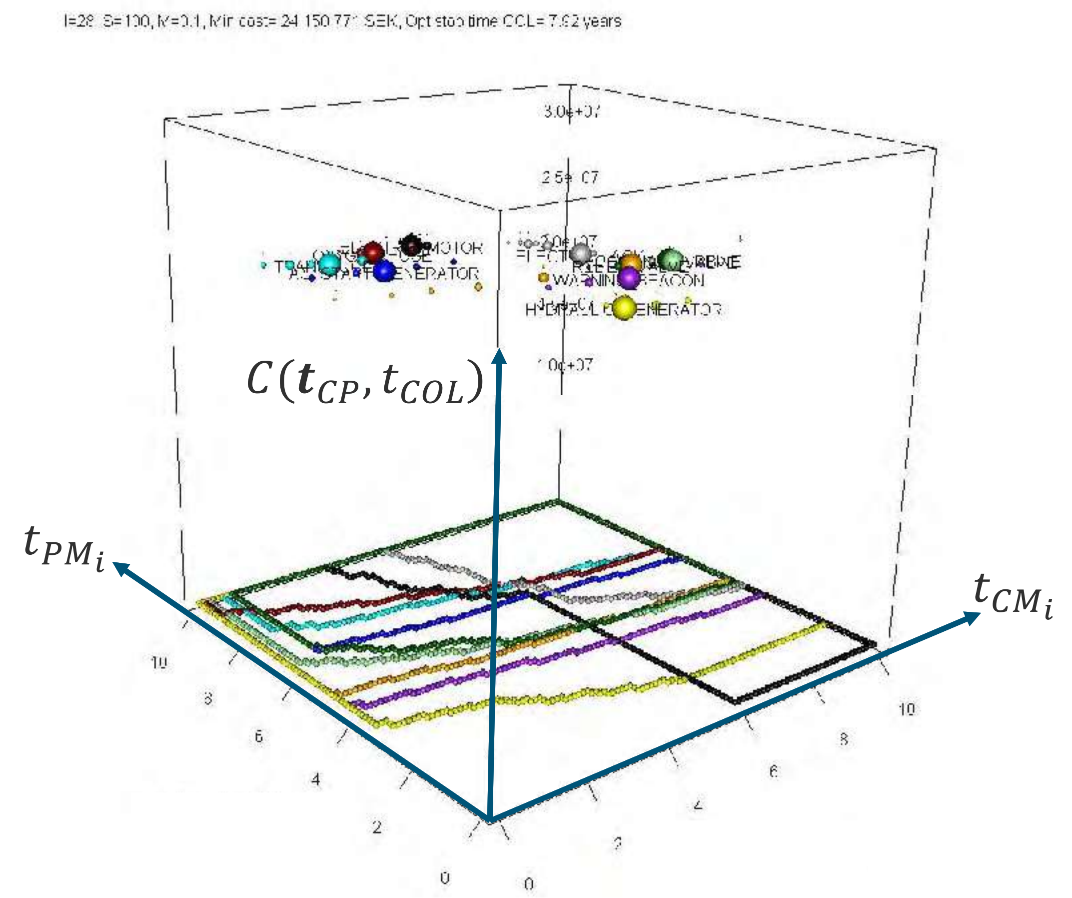
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

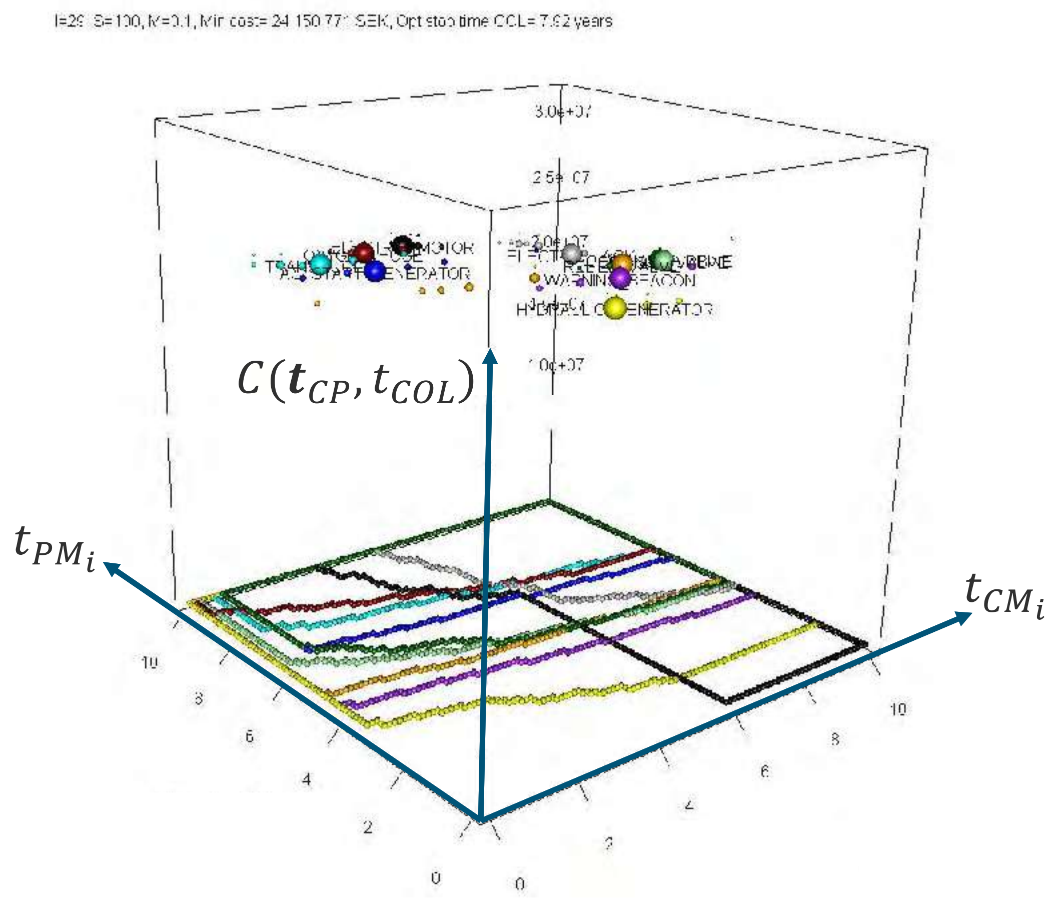
ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

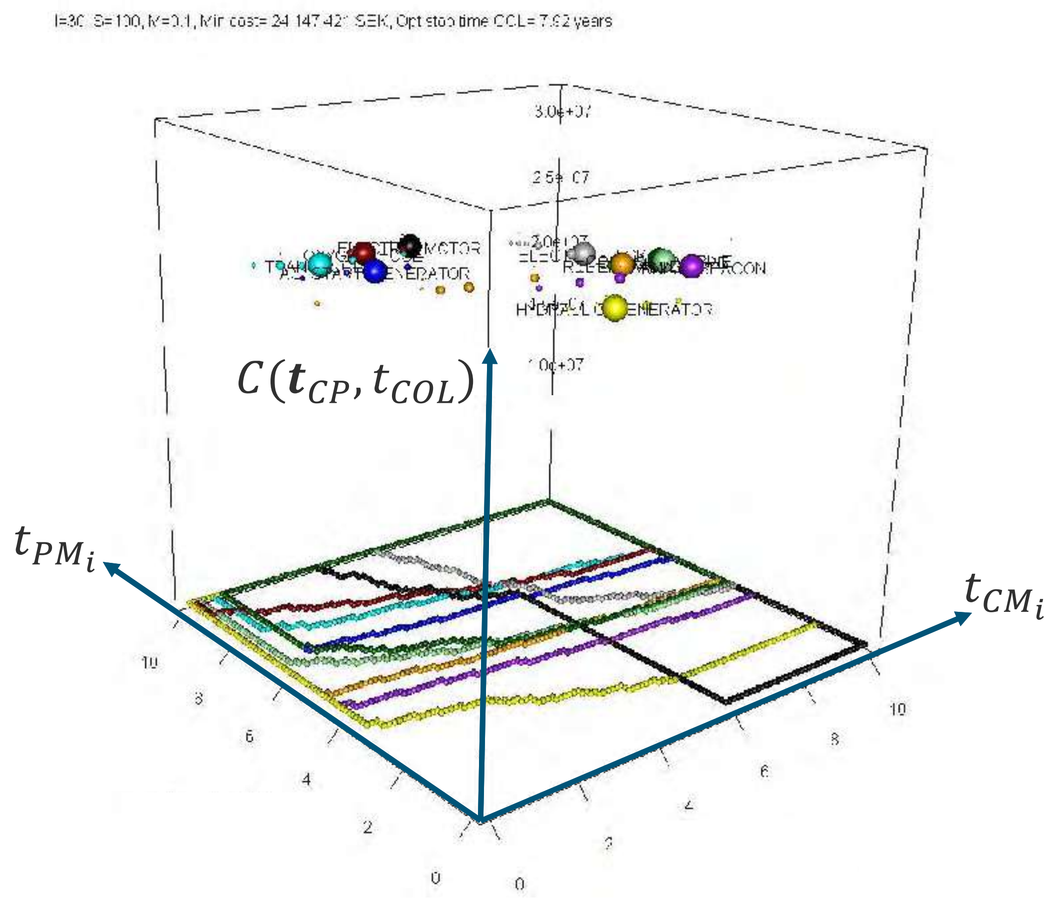
ΔT=1000 h



Systecon

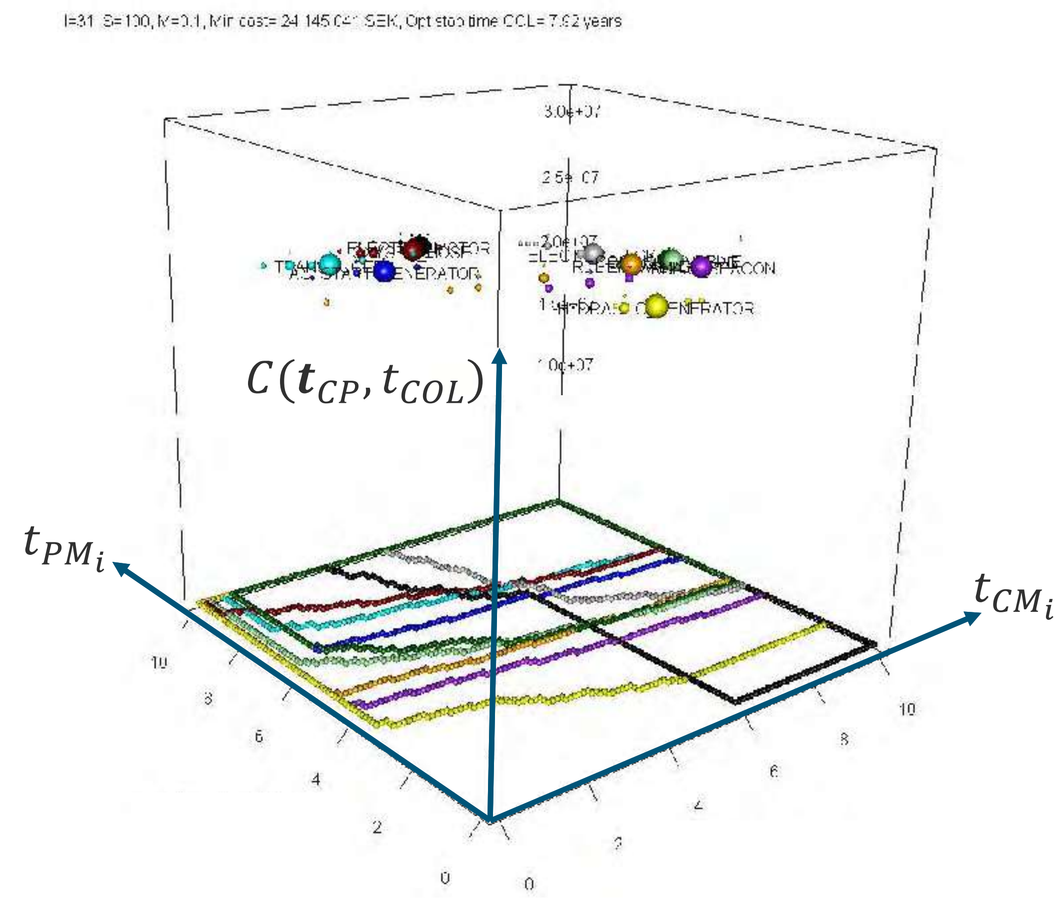
Genetic Algorithm (100 samples)

ΔT=1000 h



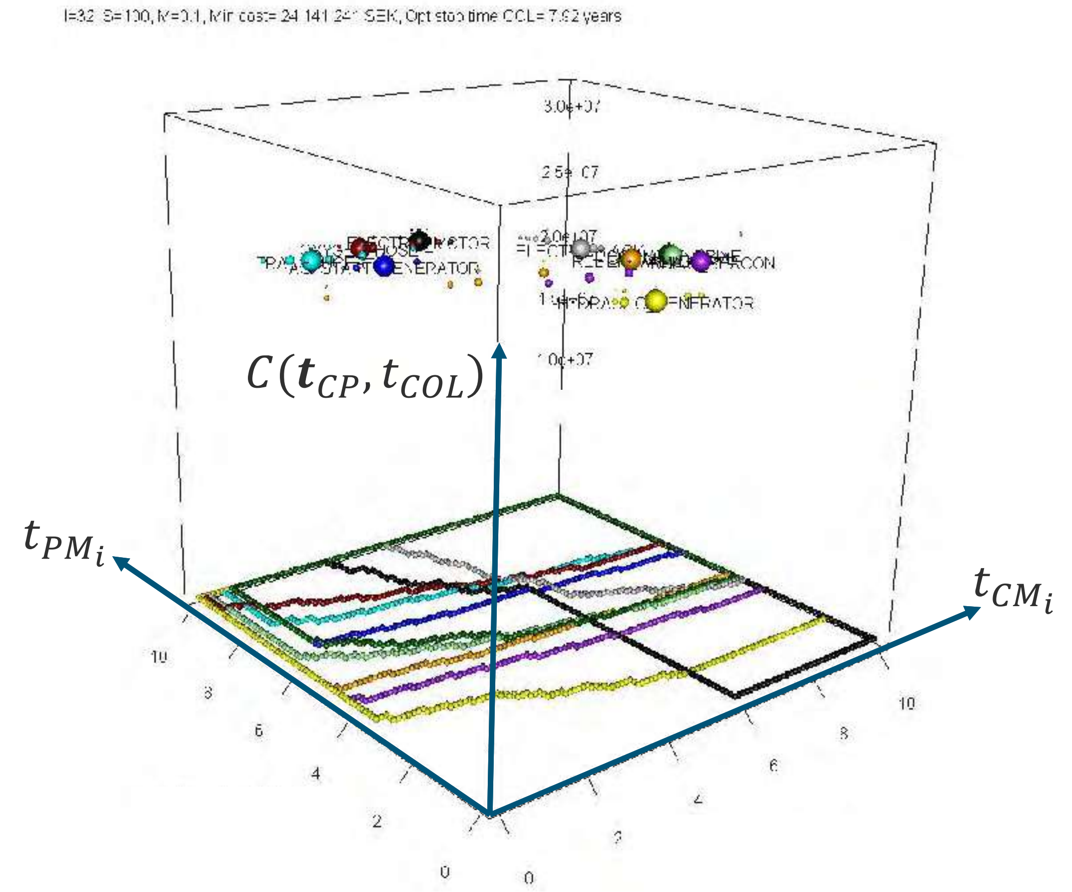
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

ΔT=1000 h



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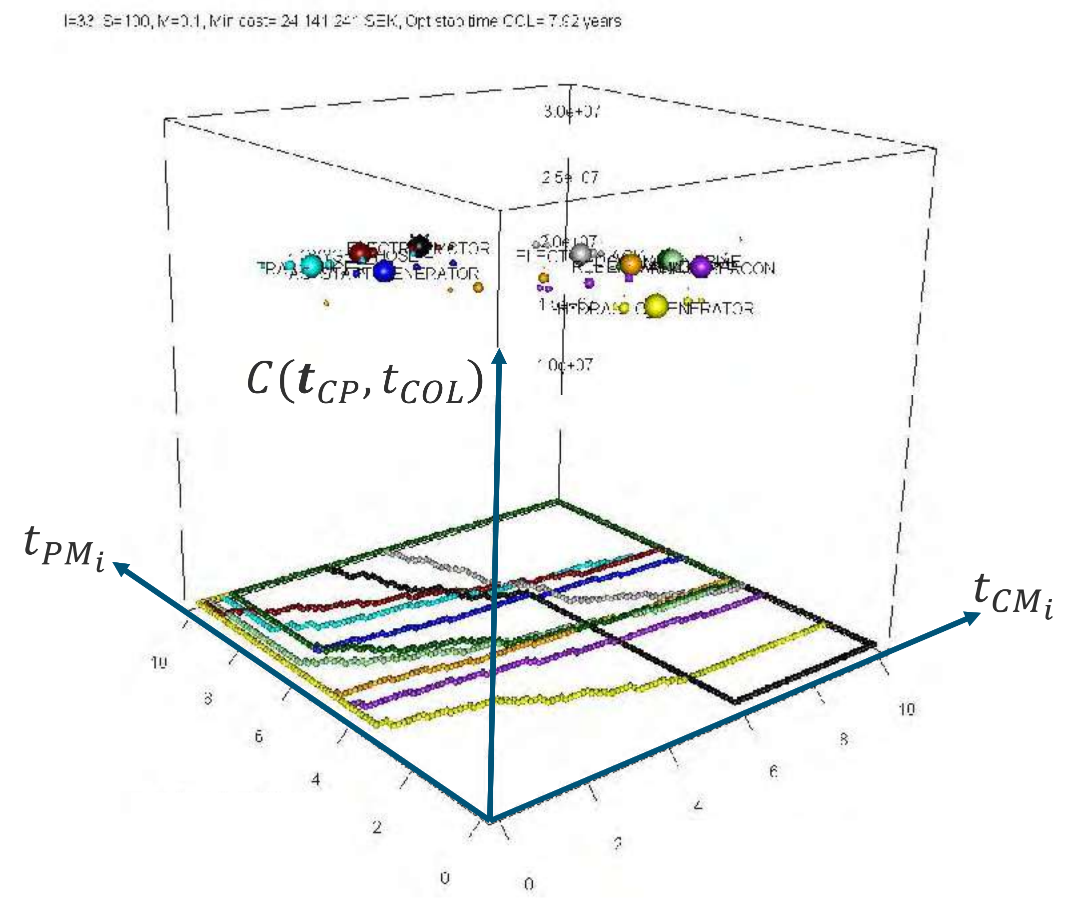
Genetic Algorithm (100 samples)

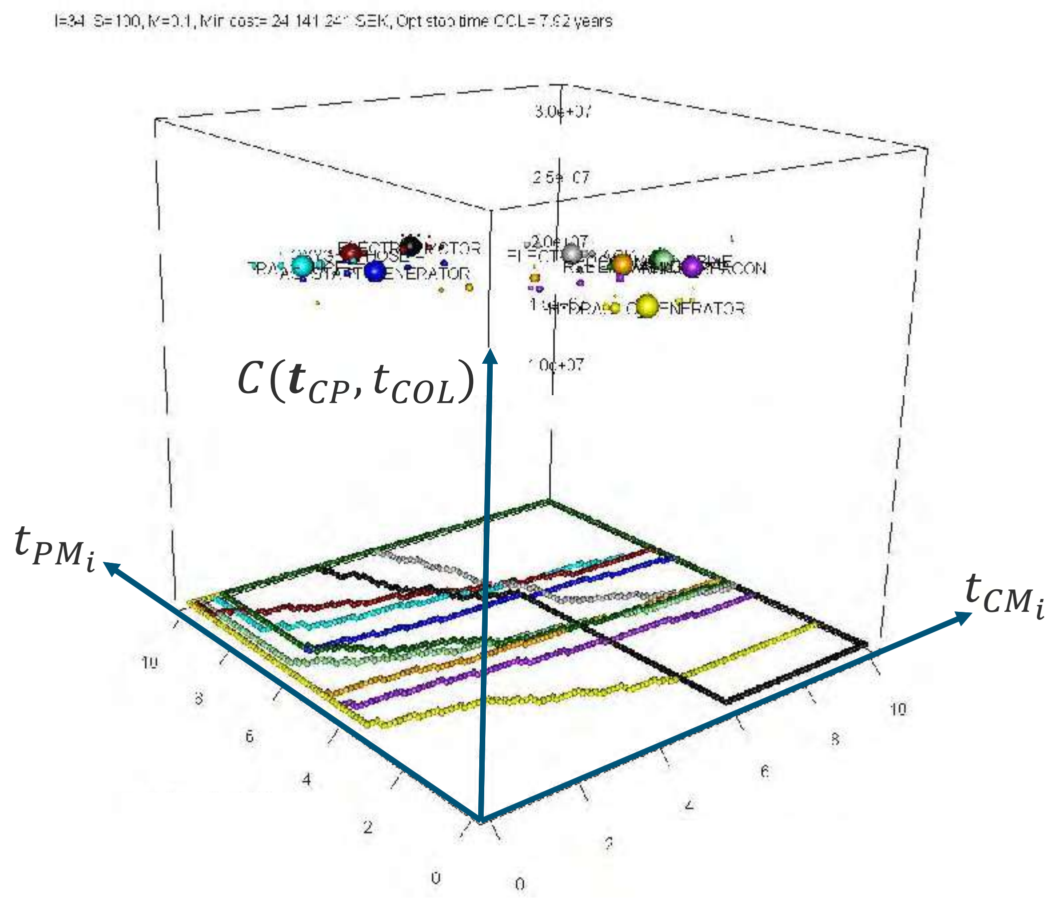
ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

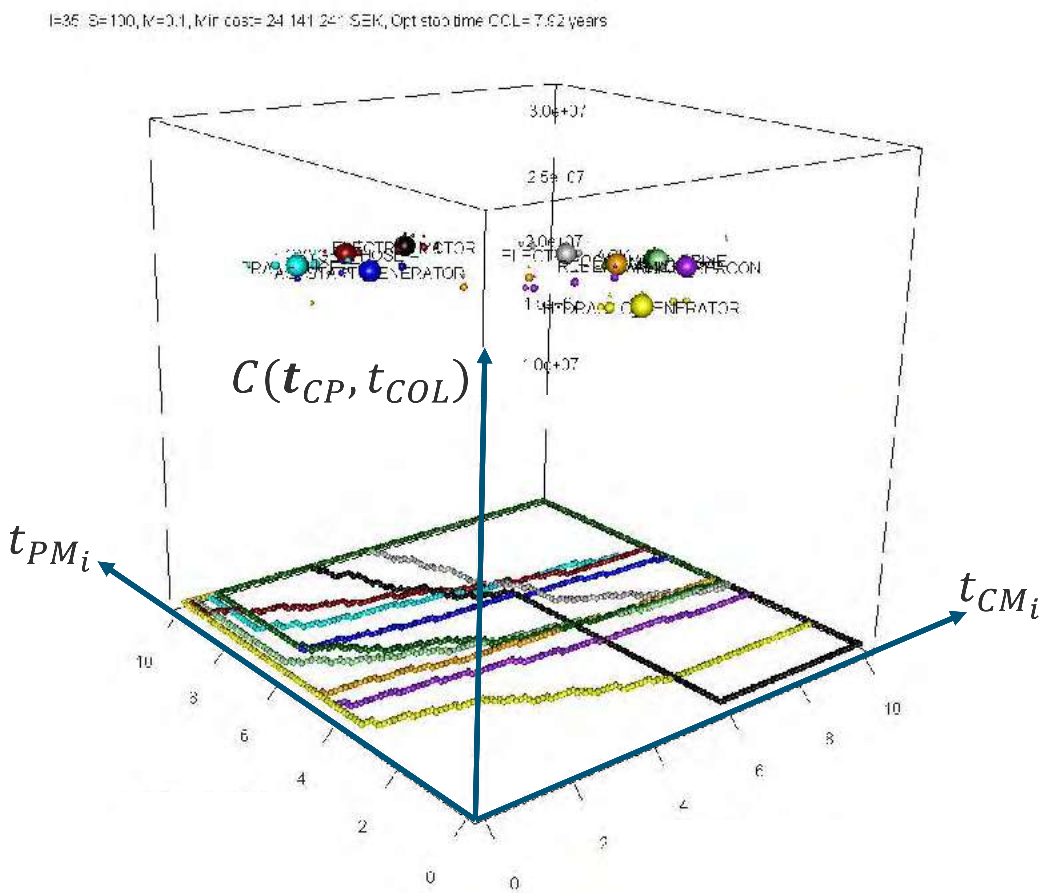
ΔT=1000 h



Systecon

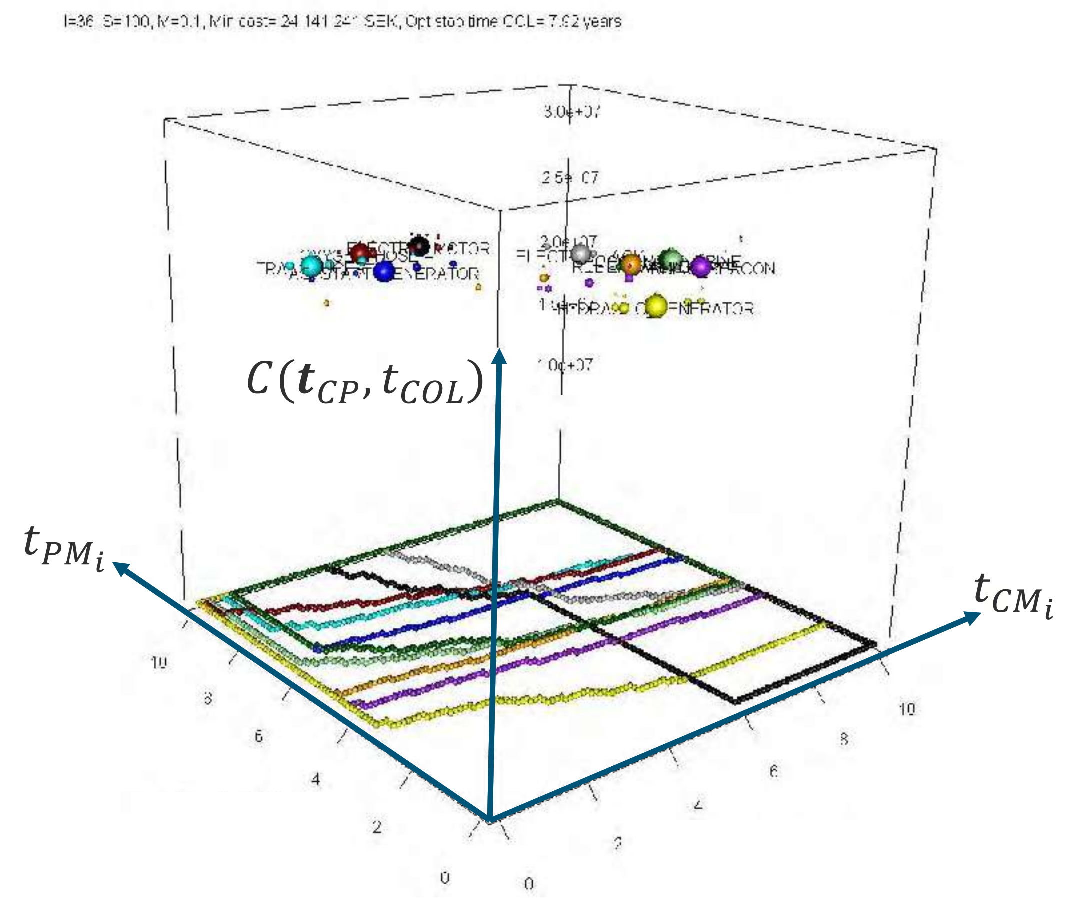
Genetic Algorithm (100 samples)

ΔT=1000 h



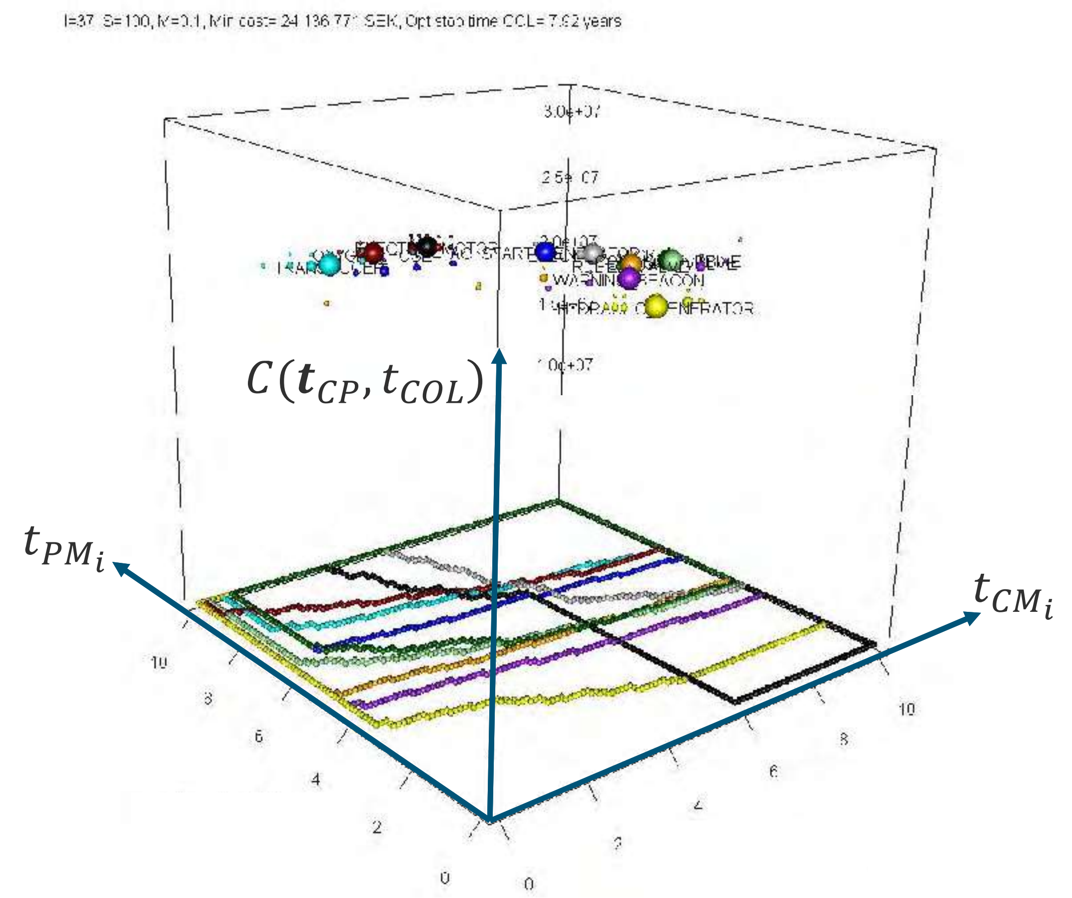
Genetic Algorithm (100 samples)

ΔT=1000 h



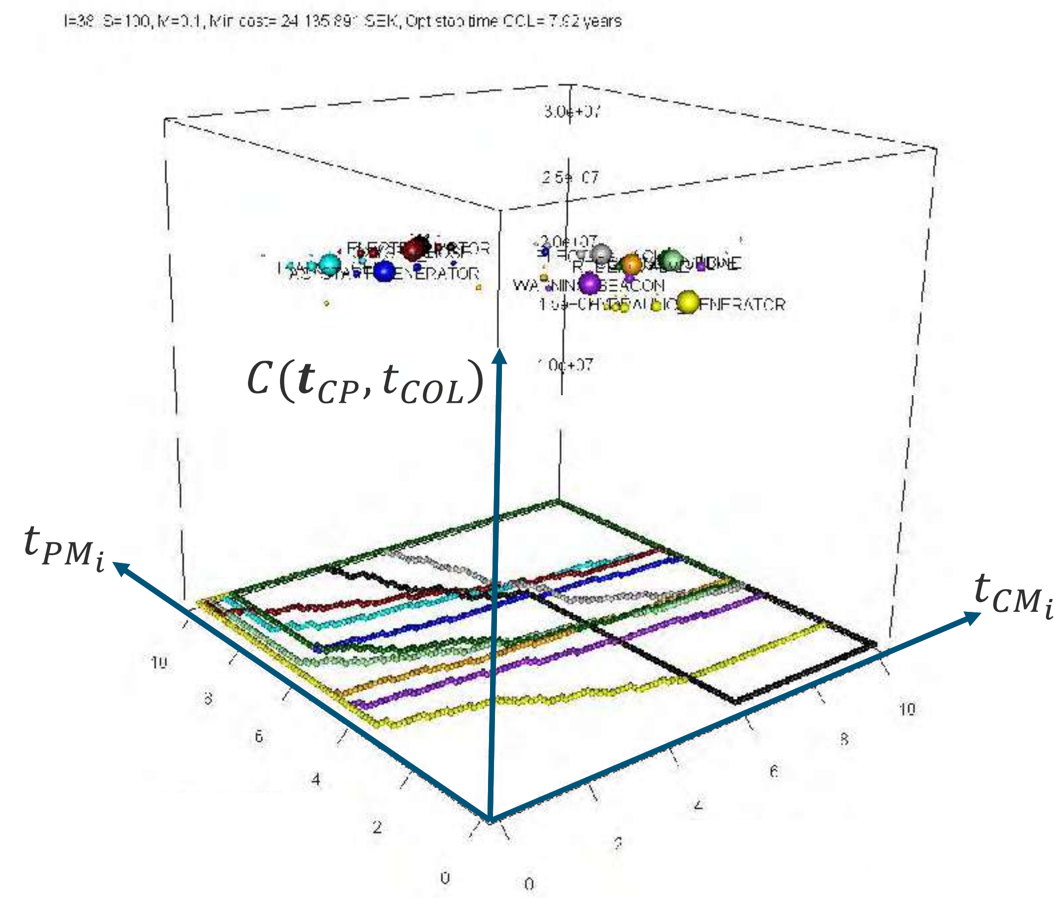
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

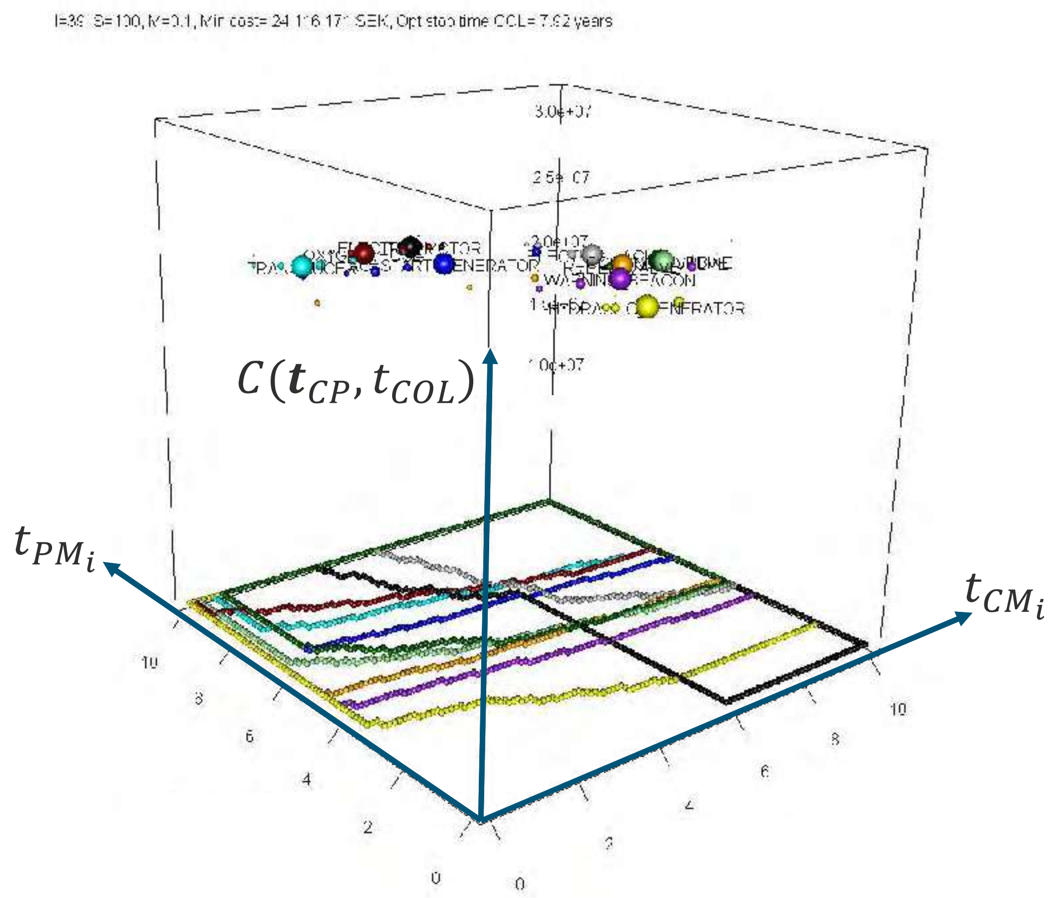
ΔT=1000 h



Systecon

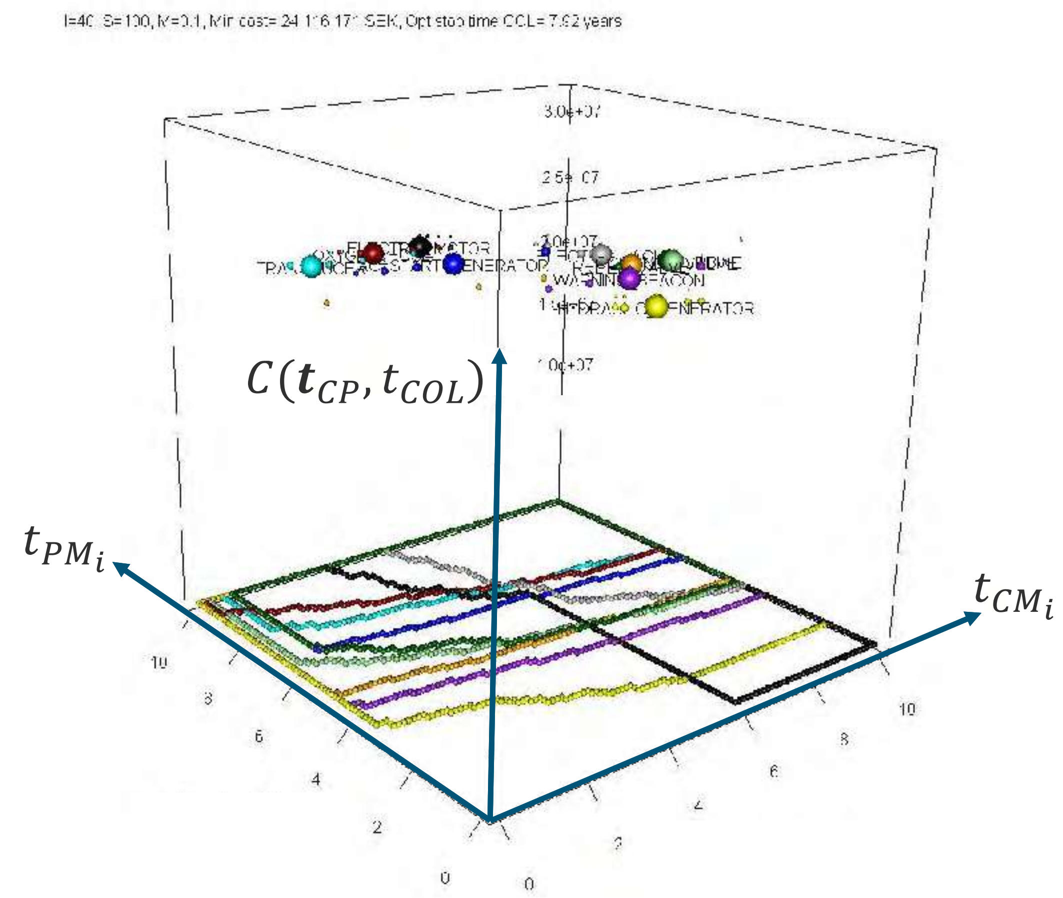
Genetic Algorithm (100 samples)

ΔT=1000 h



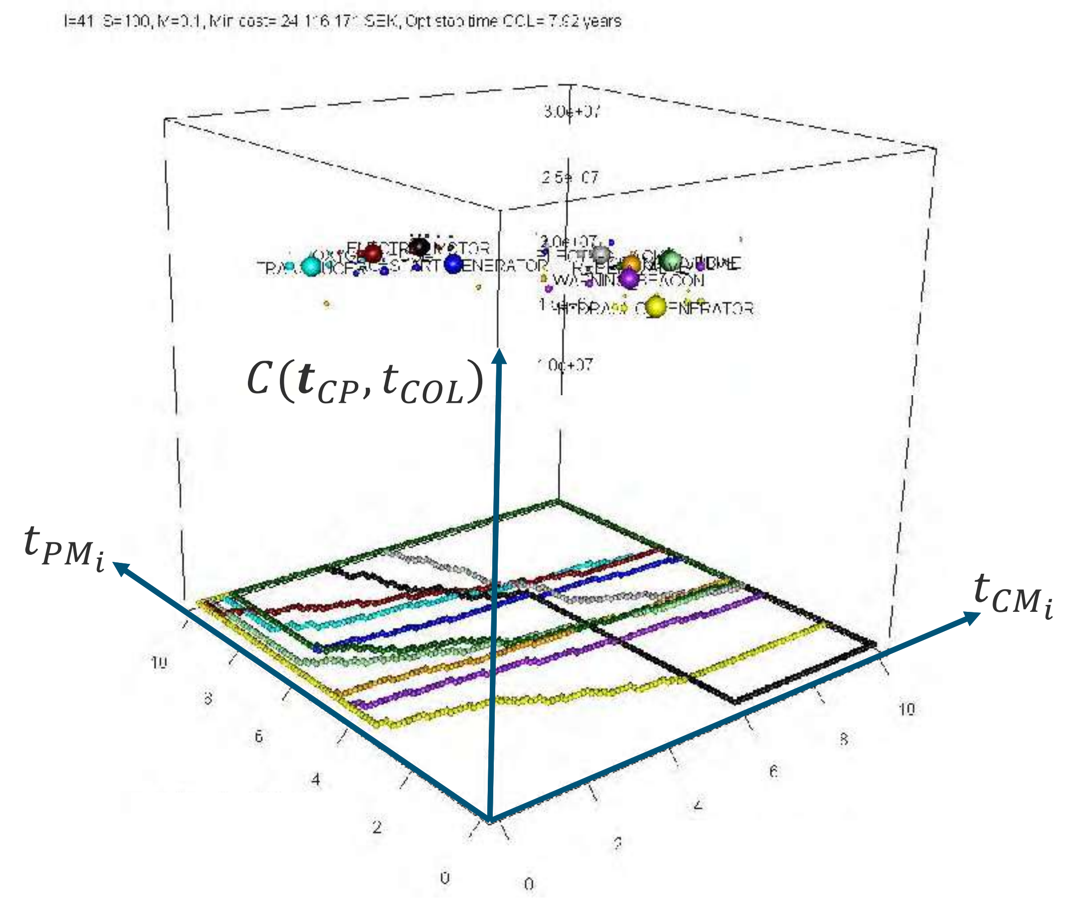
Genetic Algorithm (100 samples)

ΔT=1000 h



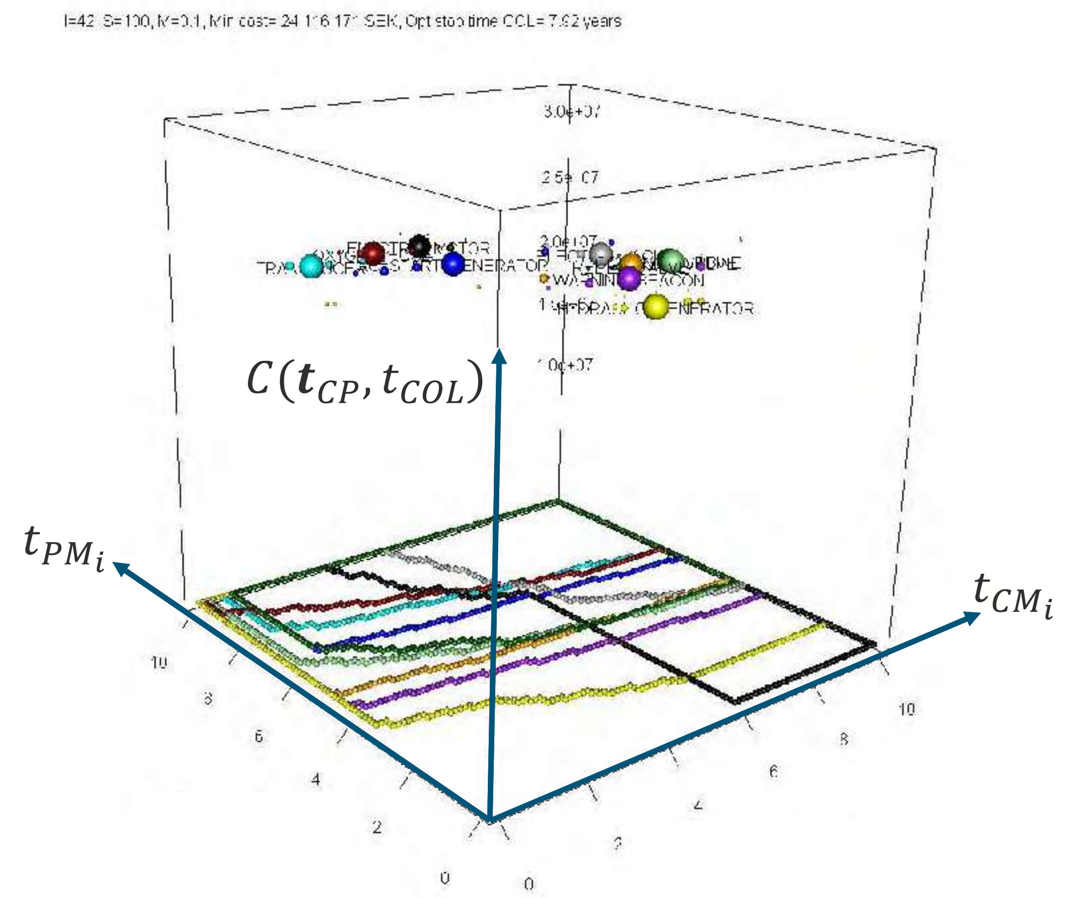
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

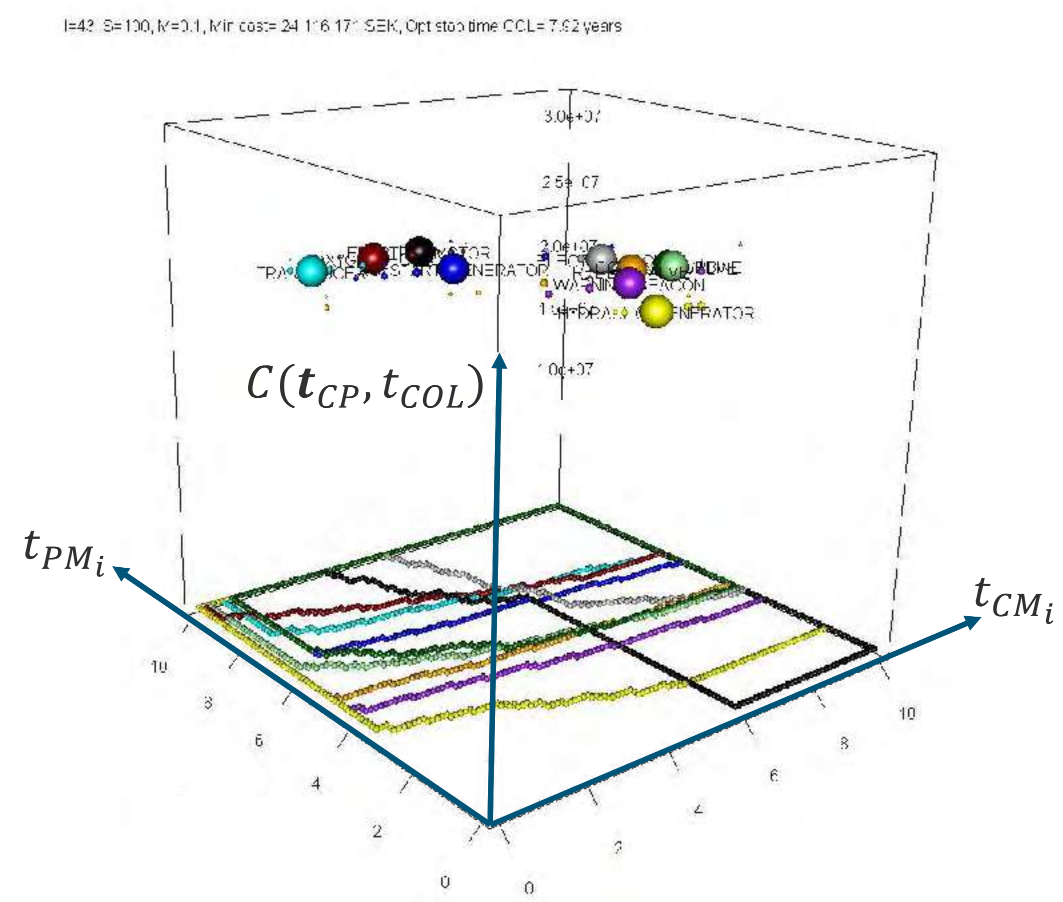
ΔT=1000 h



Systecon

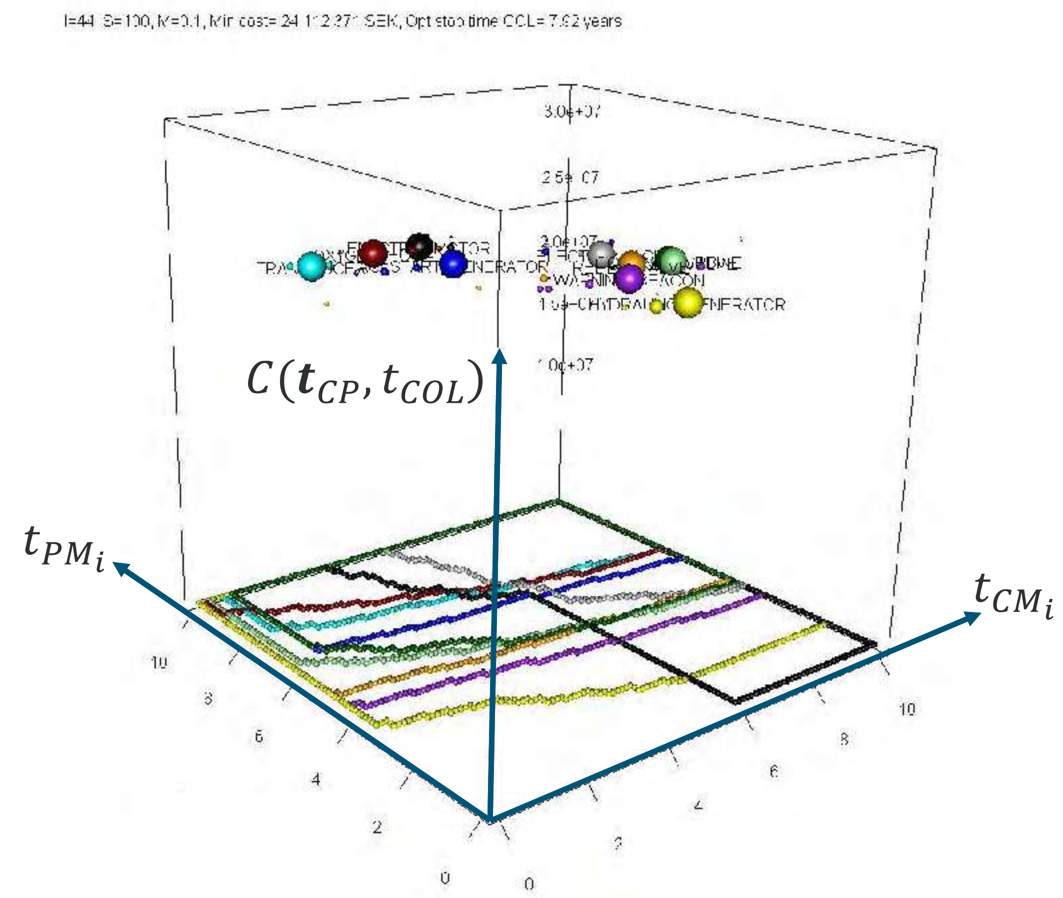
Genetic Algorithm (100 samples)

ΔT=1000 h



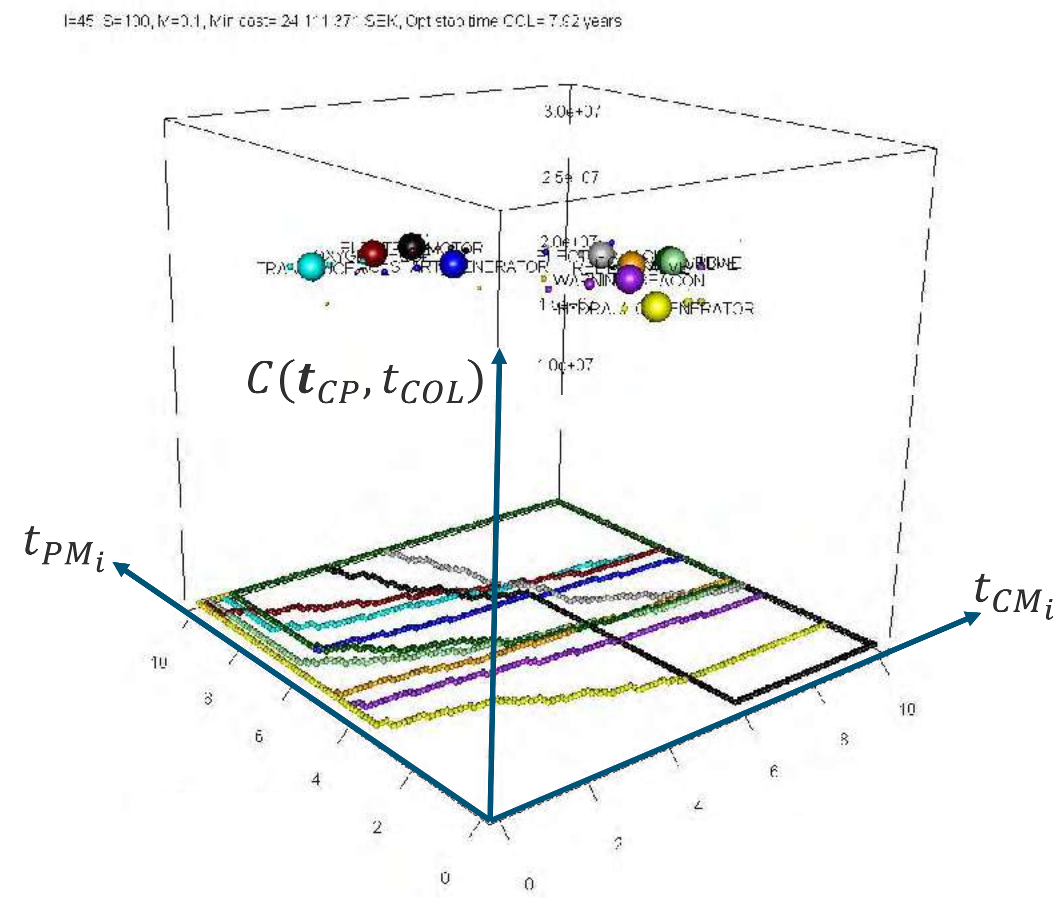
Genetic Algorithm (100 samples)

ΔT=1000 h



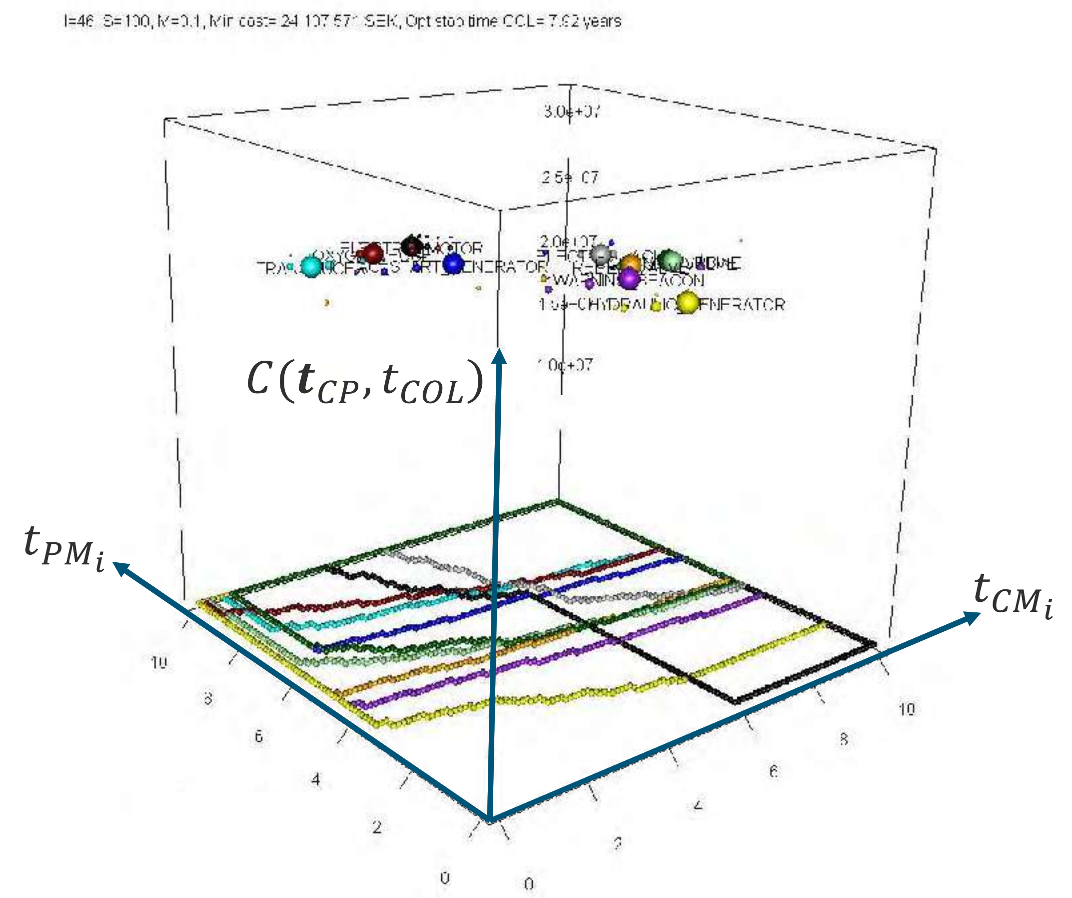
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

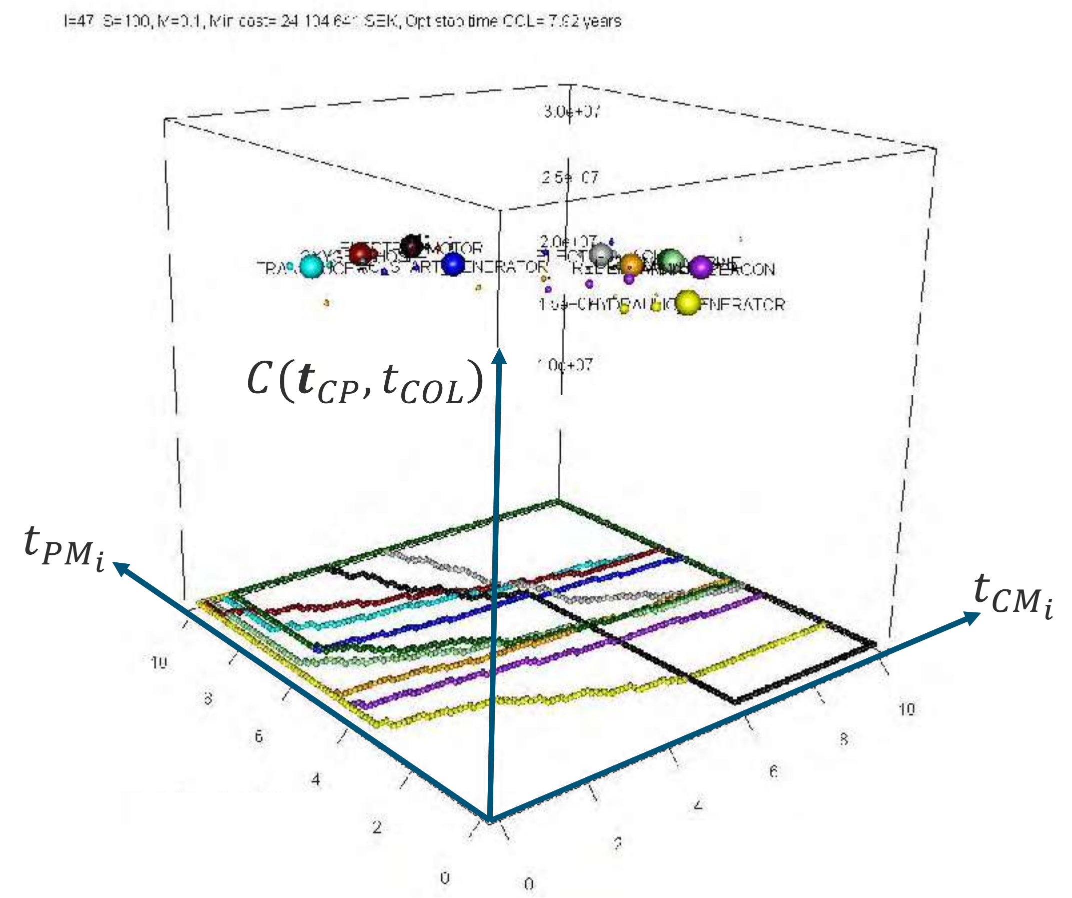
ΔT=1000 h



Systecon

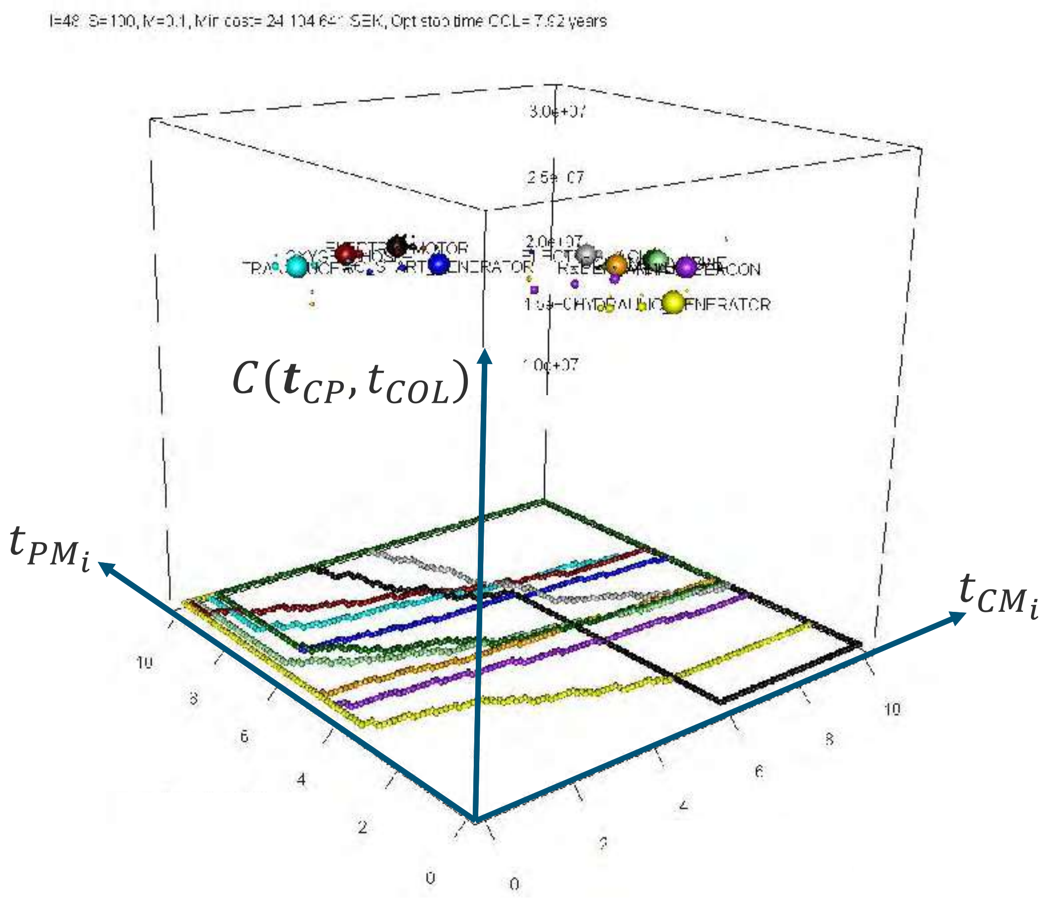
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

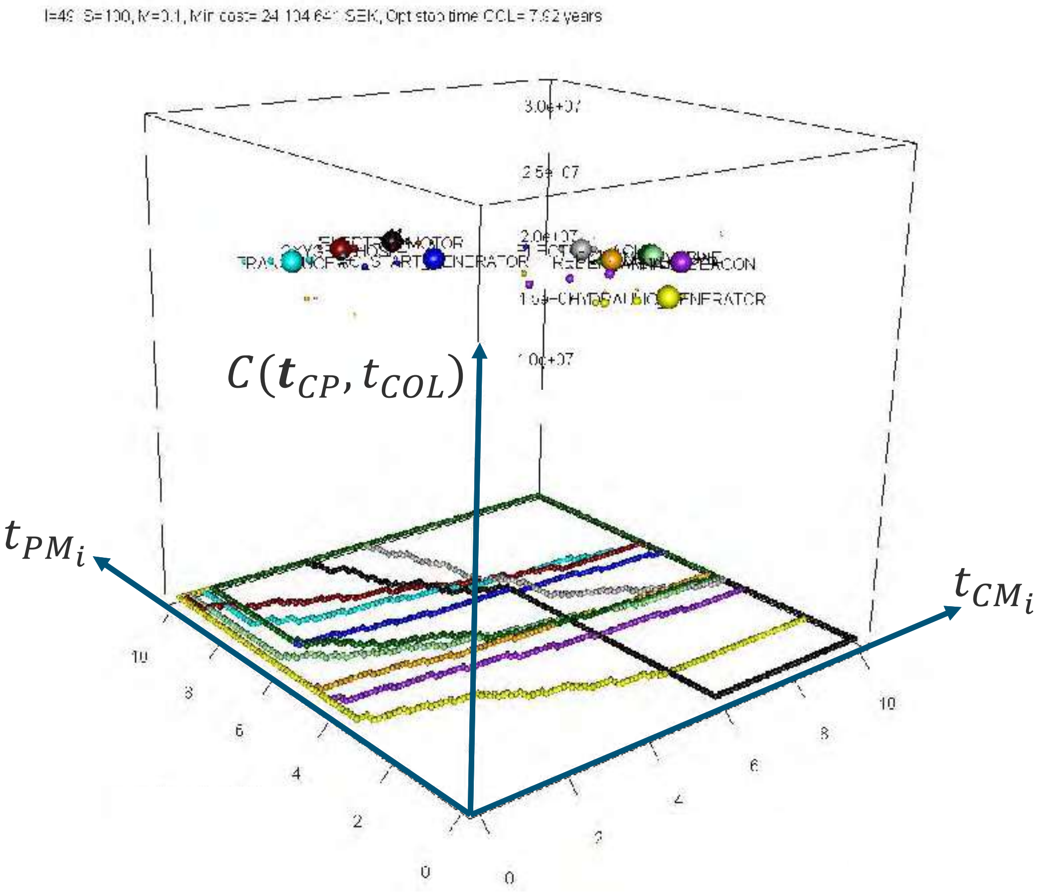
ΔT=1000 h



Systecon

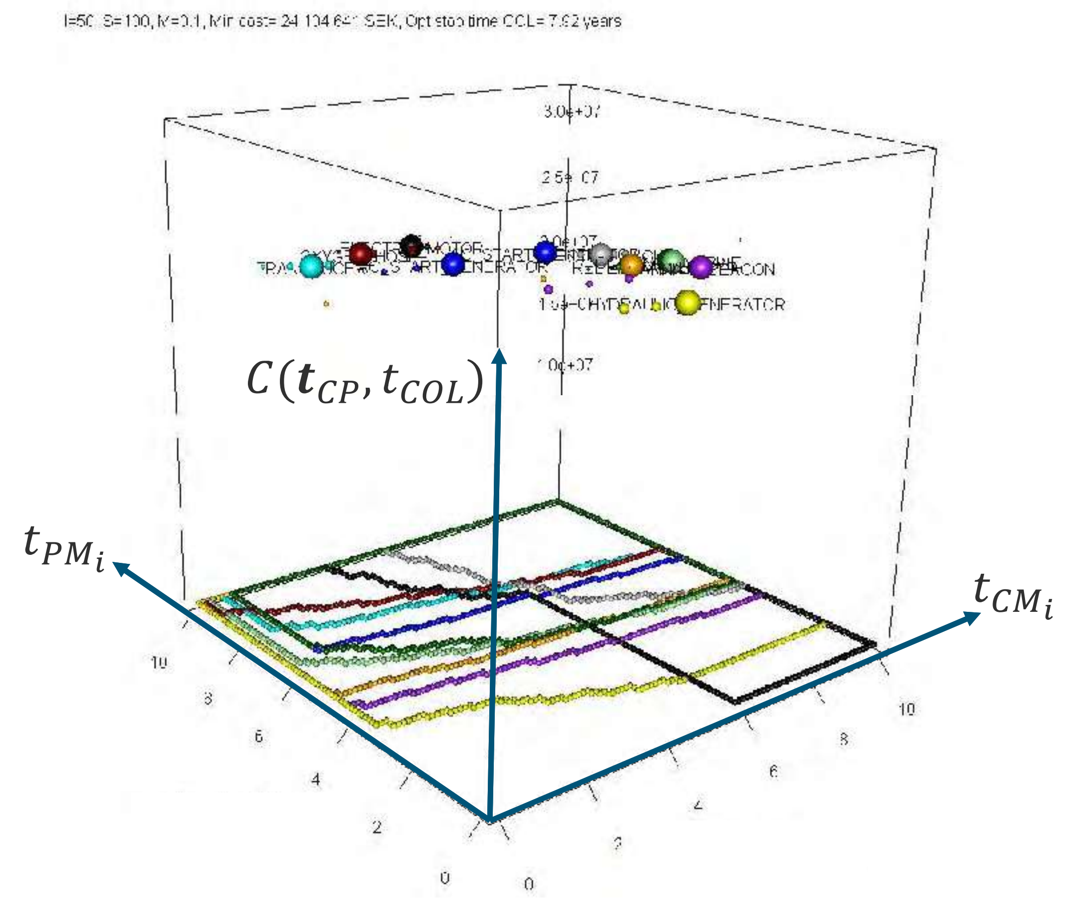
Genetic Algorithm (100 samples)

ΔT=1000 h



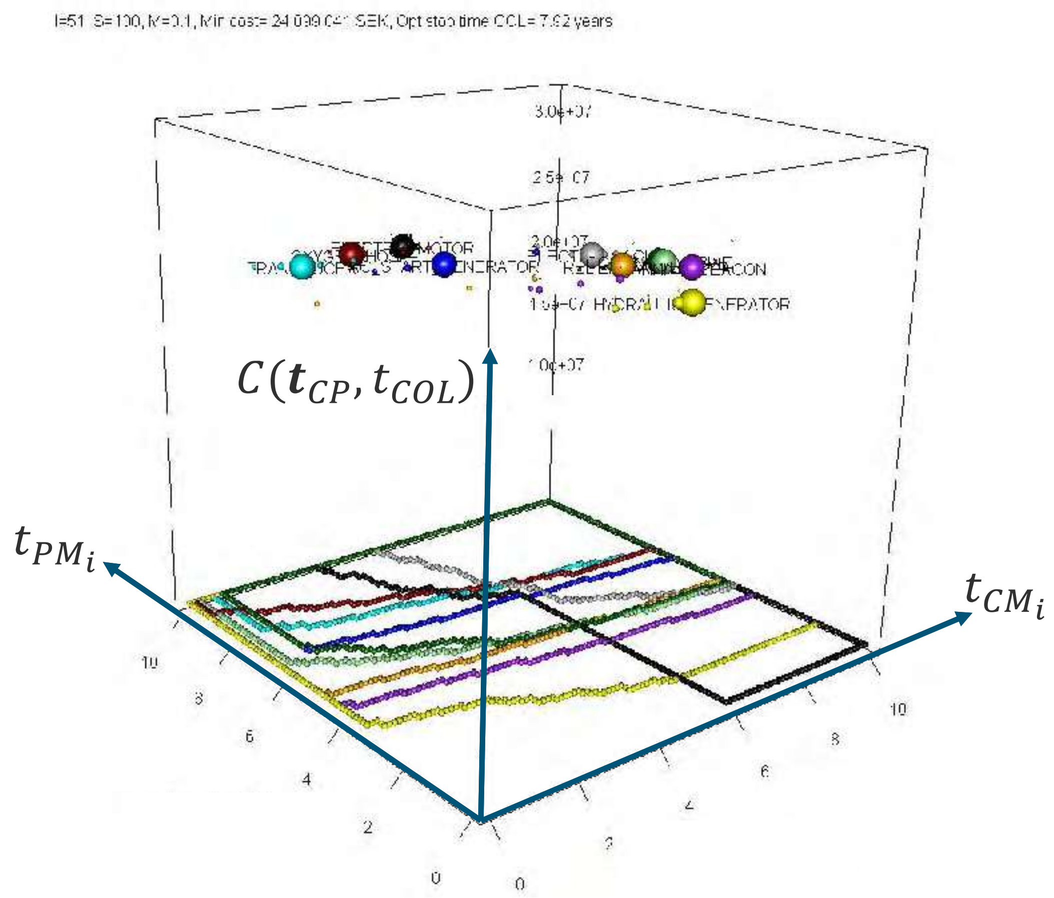
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

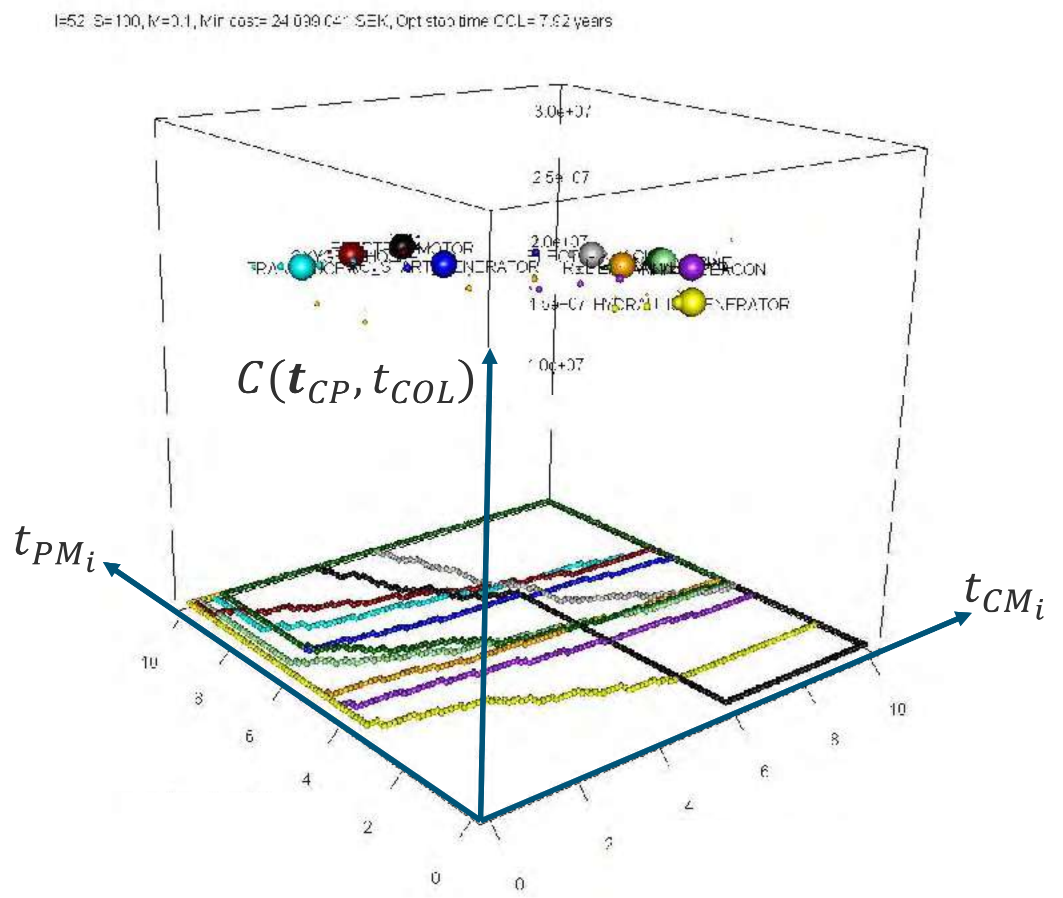
ΔT=1000 h



Systecon

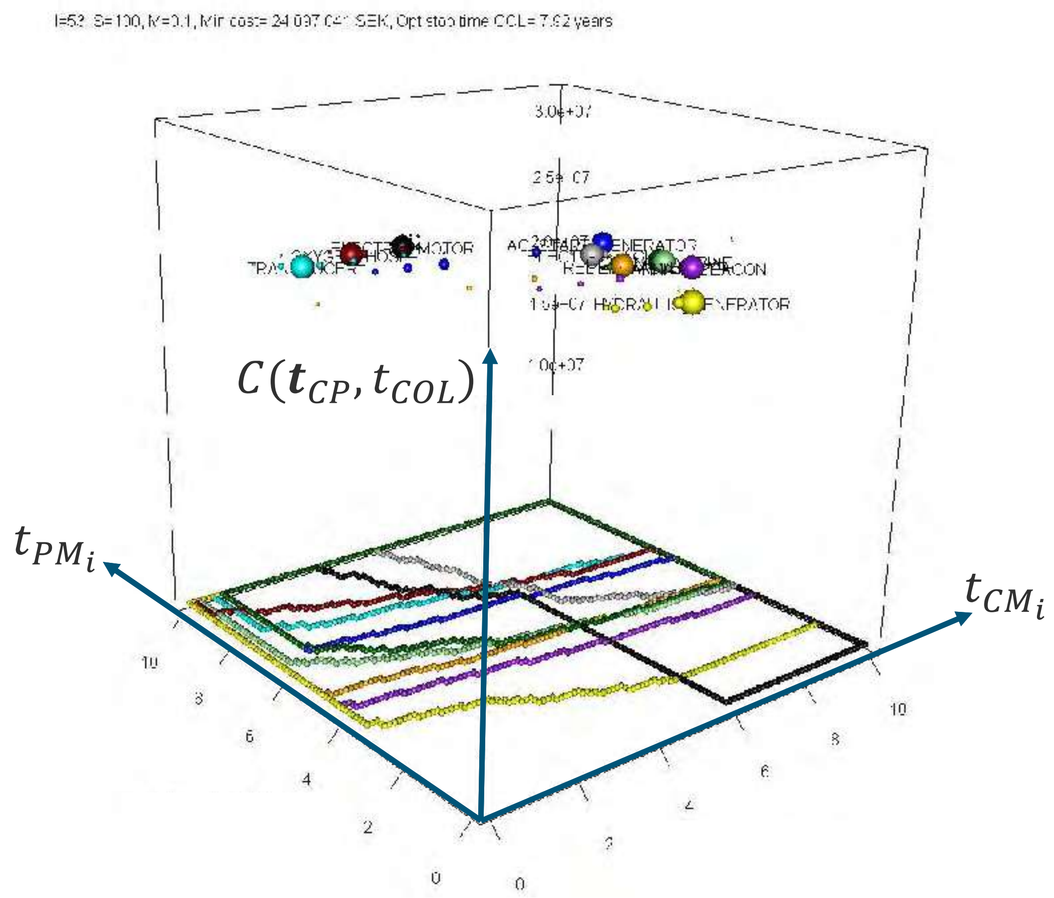
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

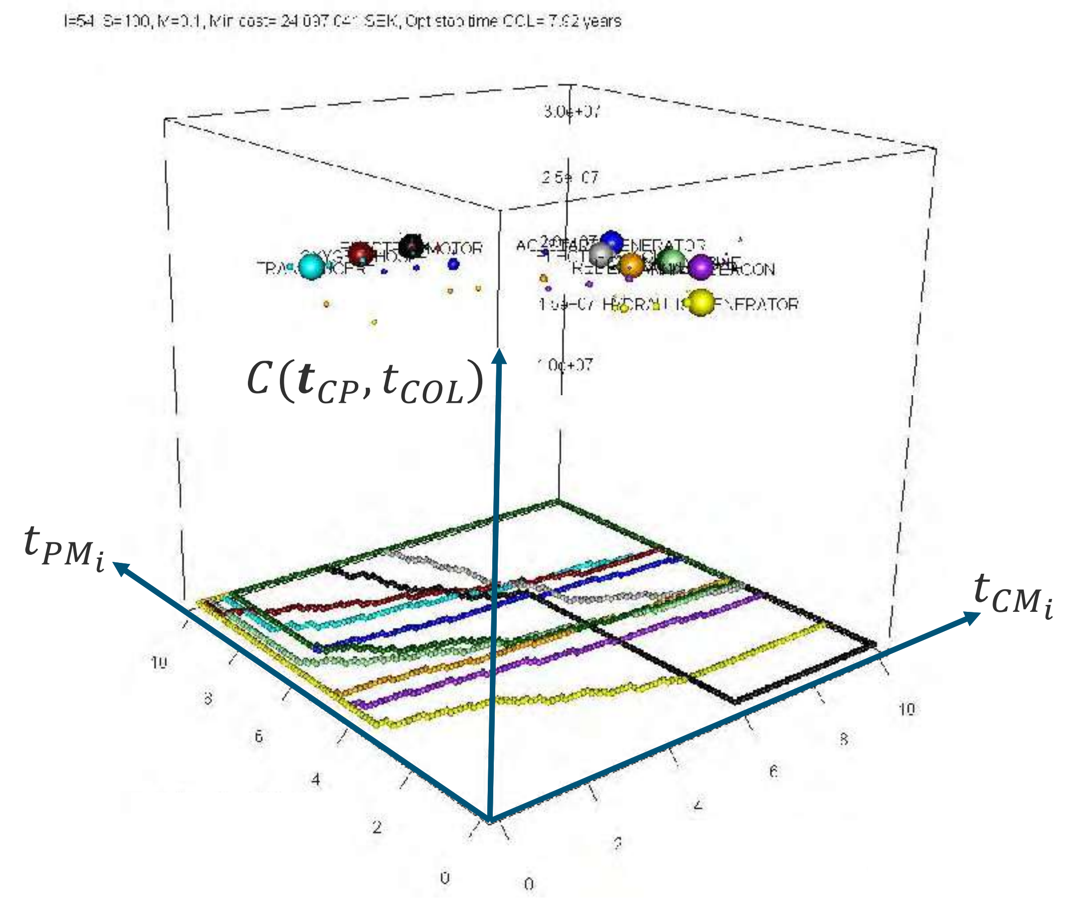
ΔT=1000 h



Systecon

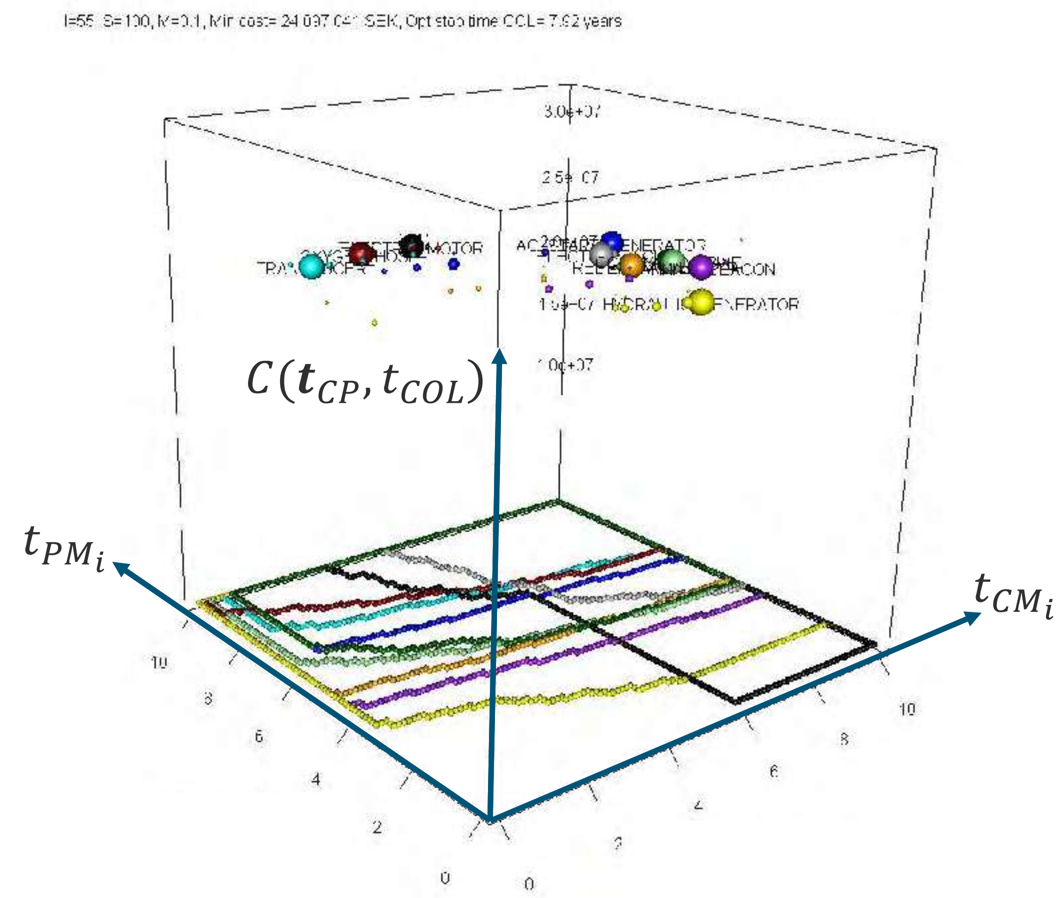
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

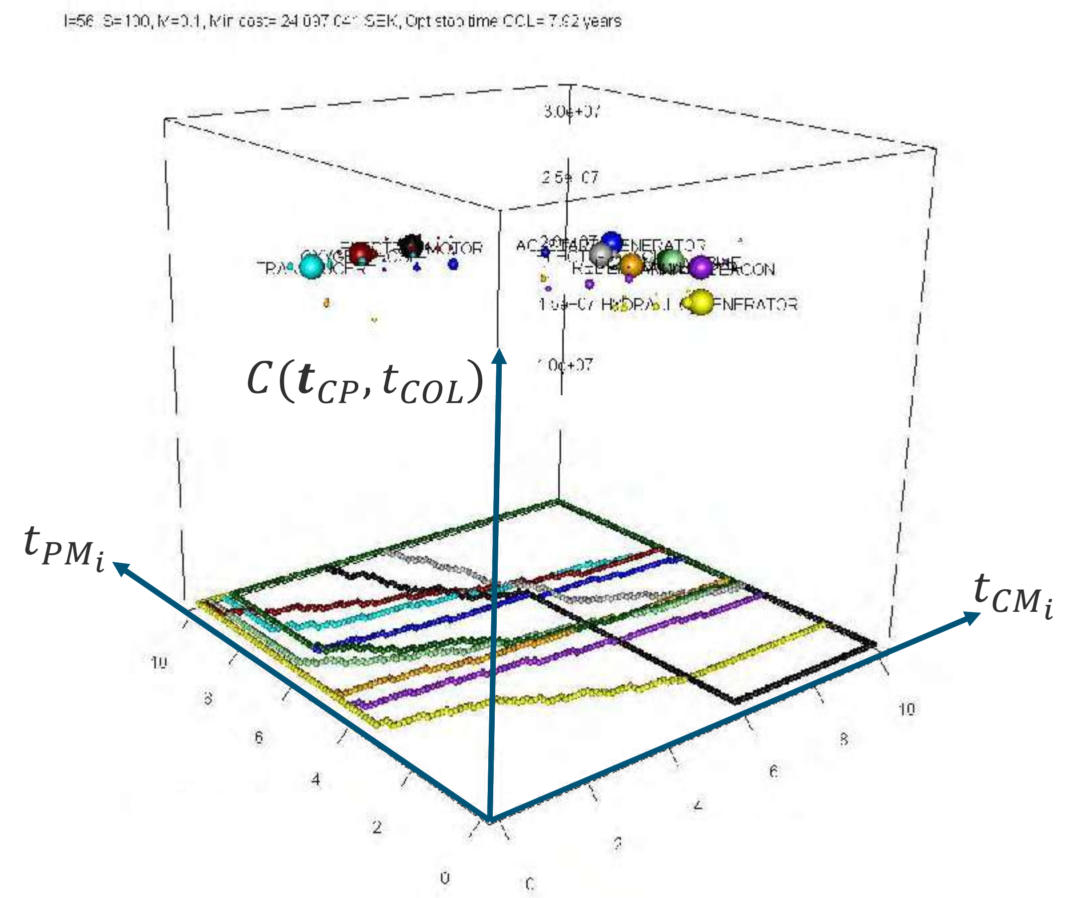
ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

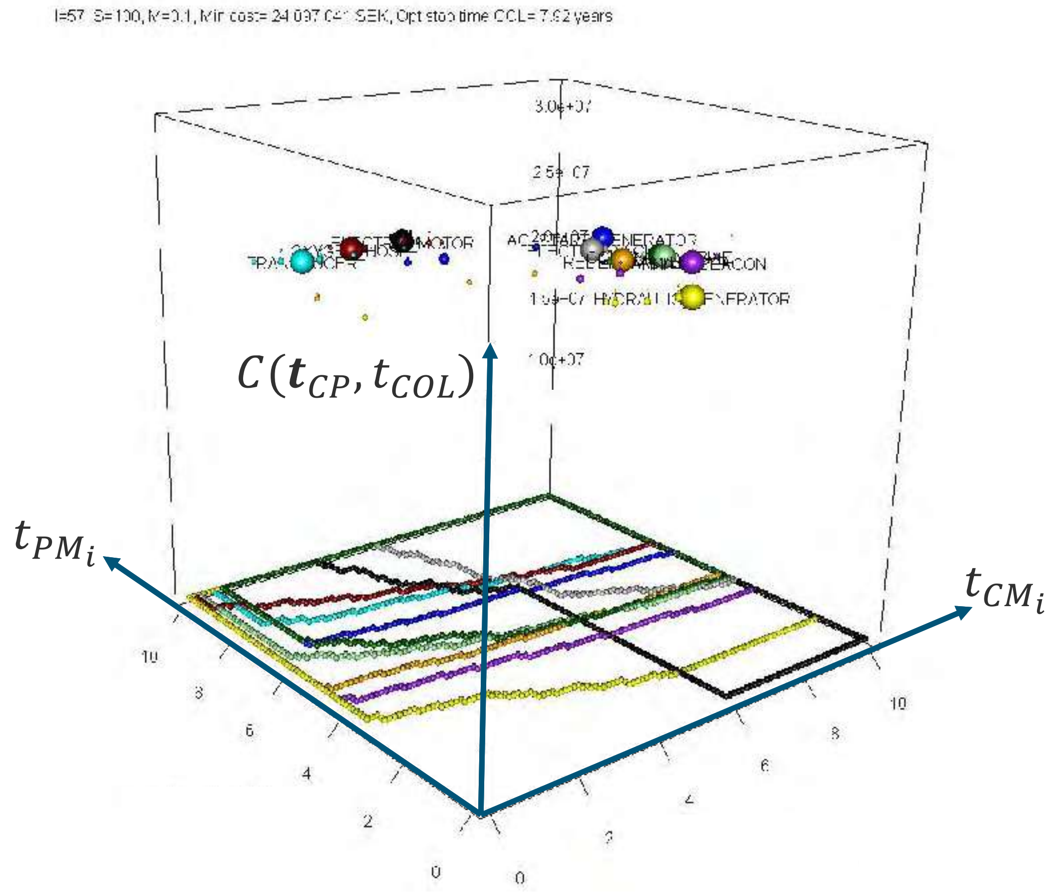
ΔT=1000 h



Systecon

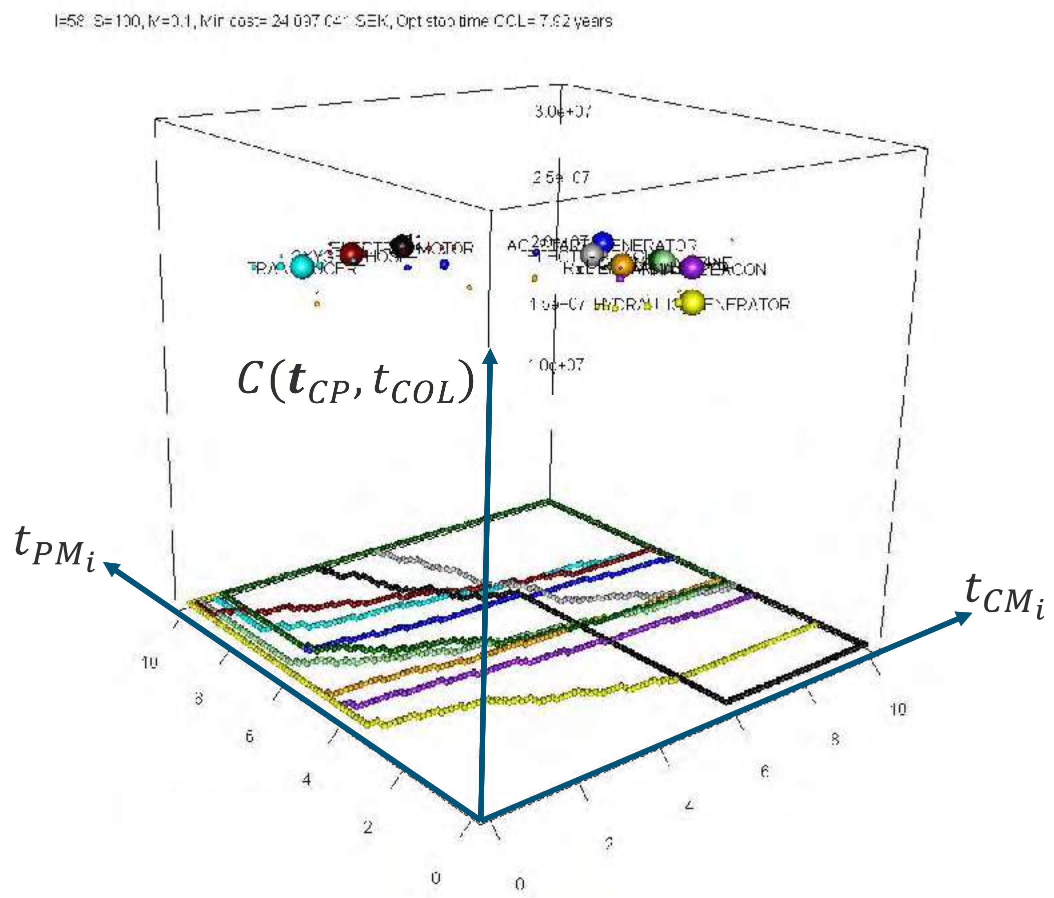
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

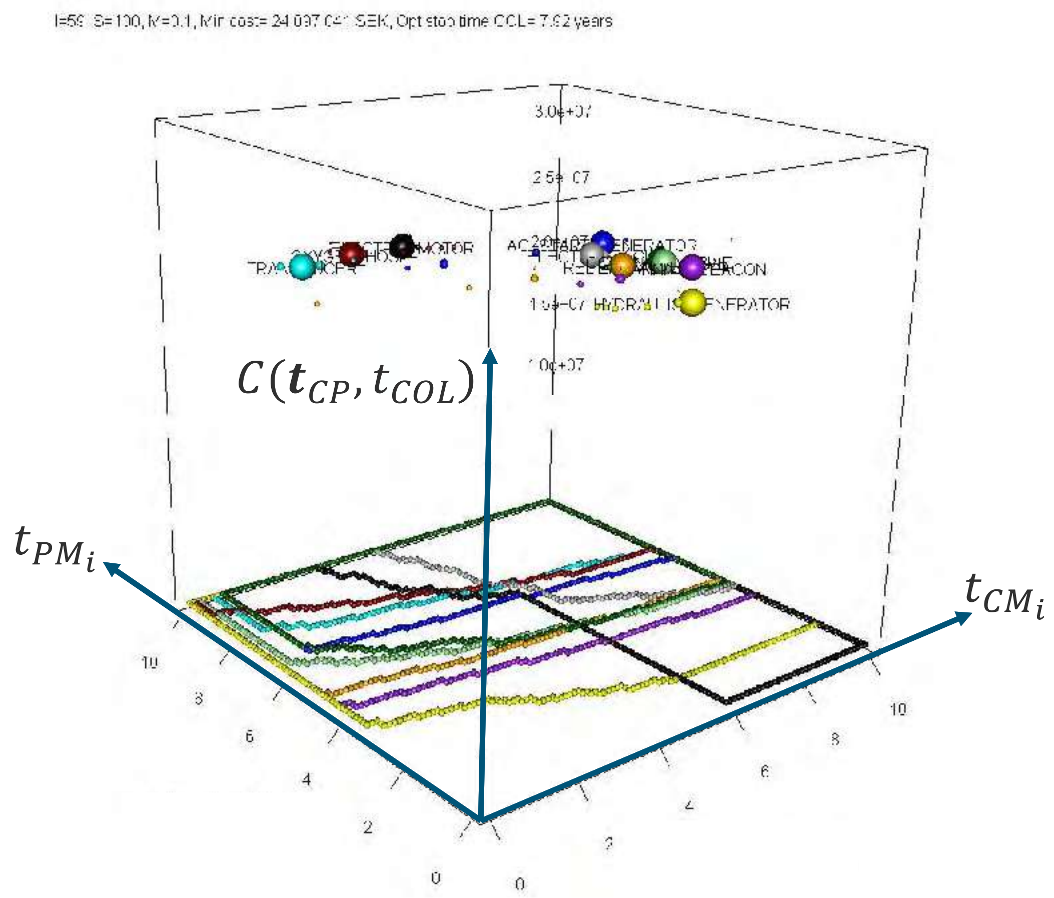
ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

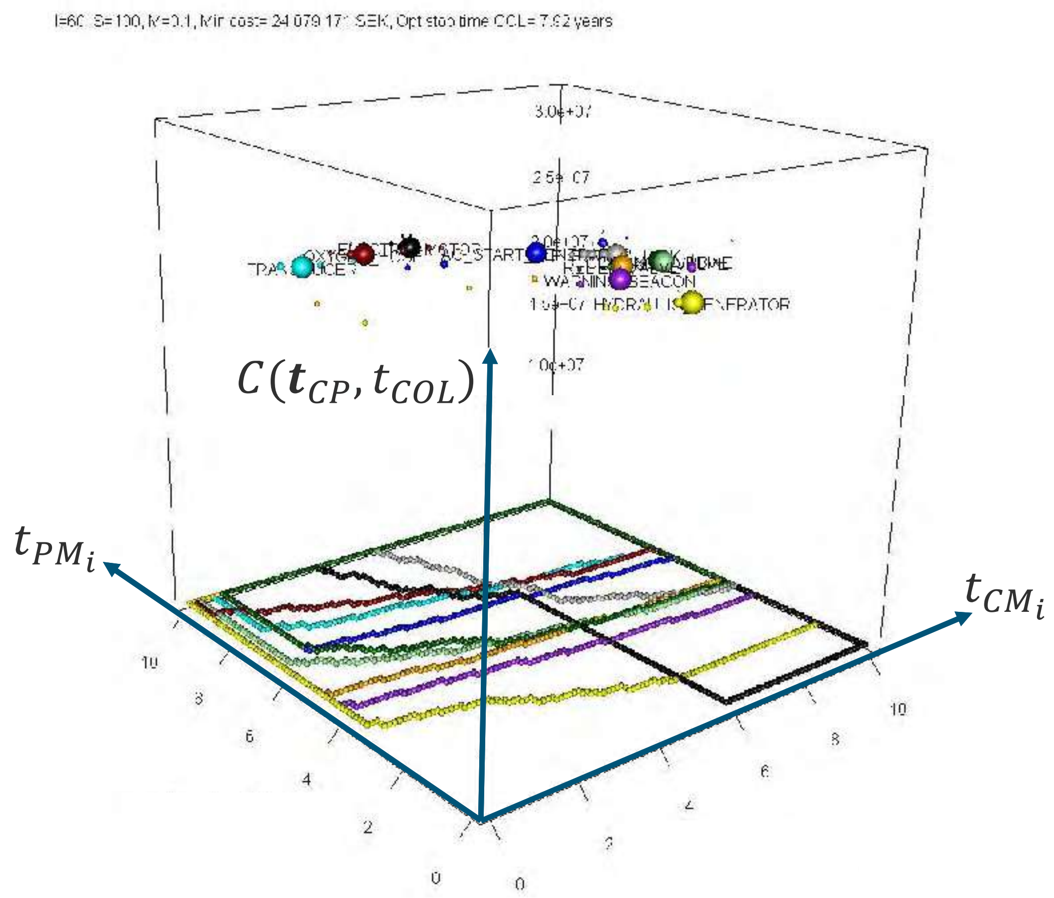
ΔT=1000 h



Systecon

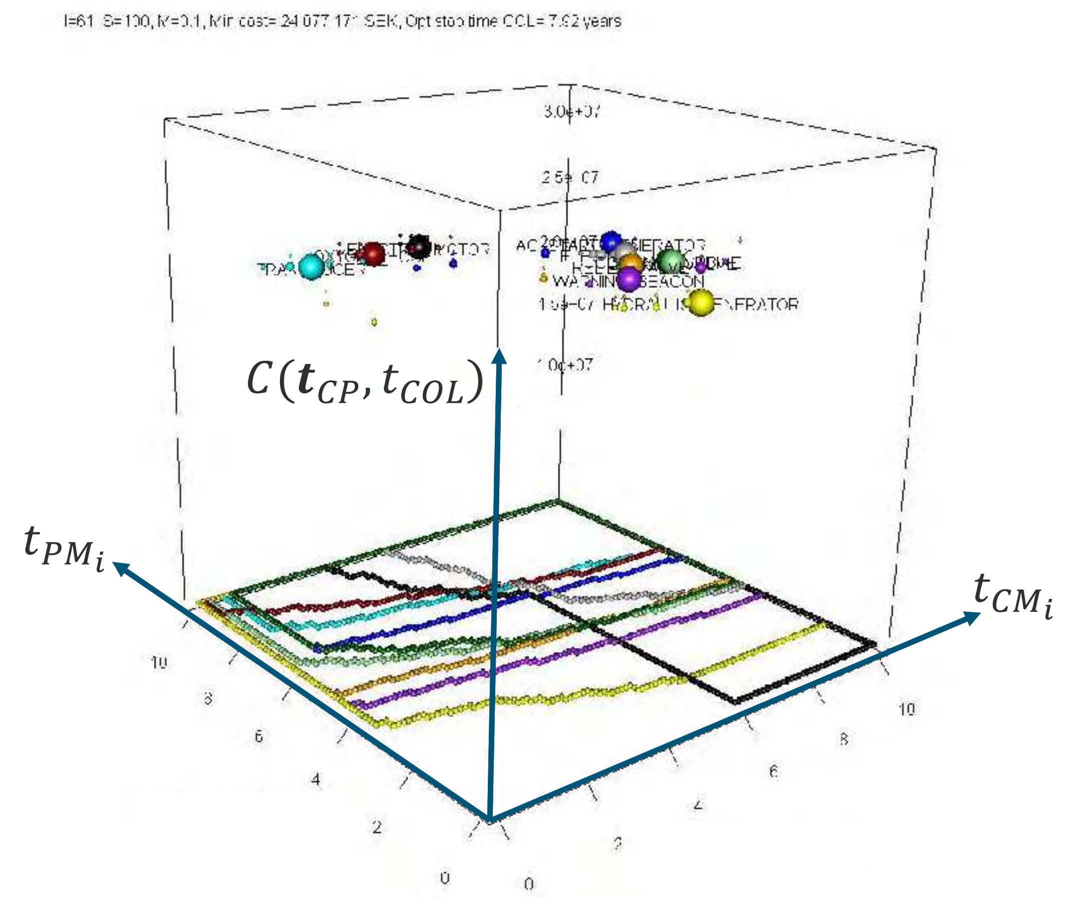
Genetic Algorithm (100 samples)

ΔT=1000 h



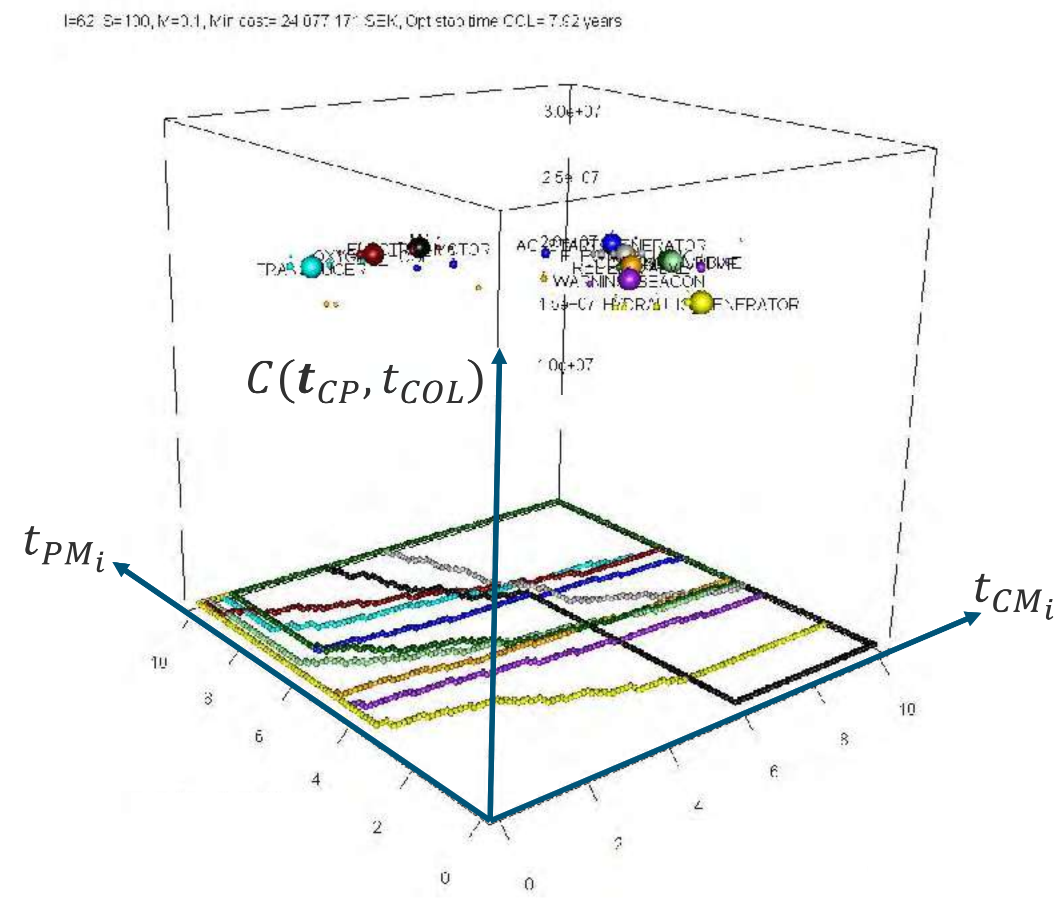
Genetic Algorithm (100 samples)

ΔT=1000 h



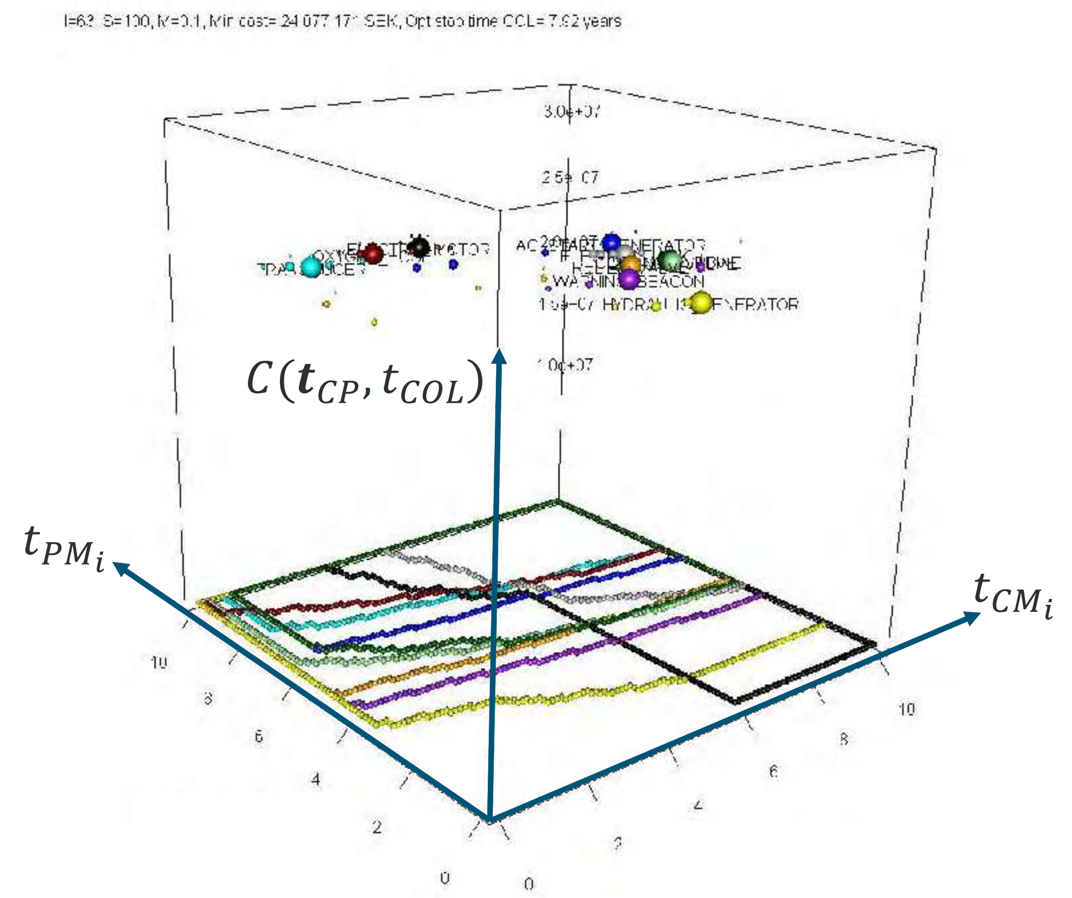
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

ΔT=1000 h



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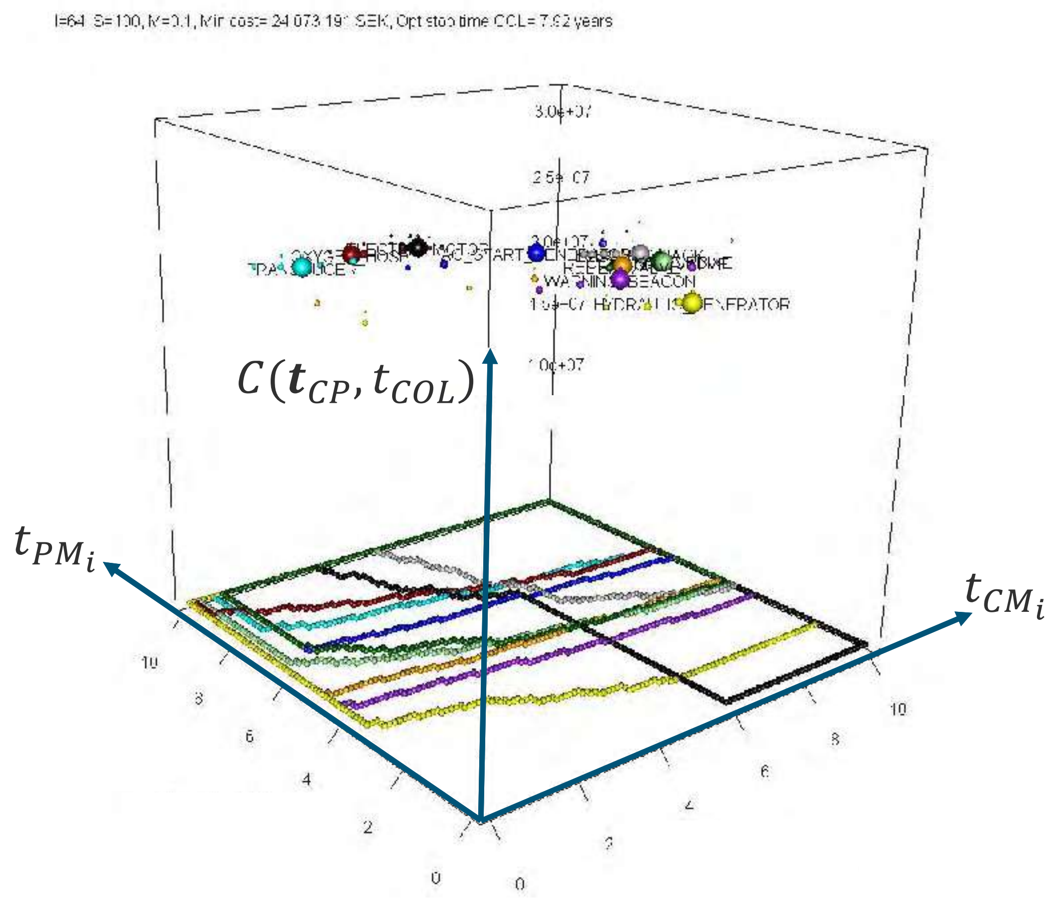
Genetic Algorithm (100 samples)

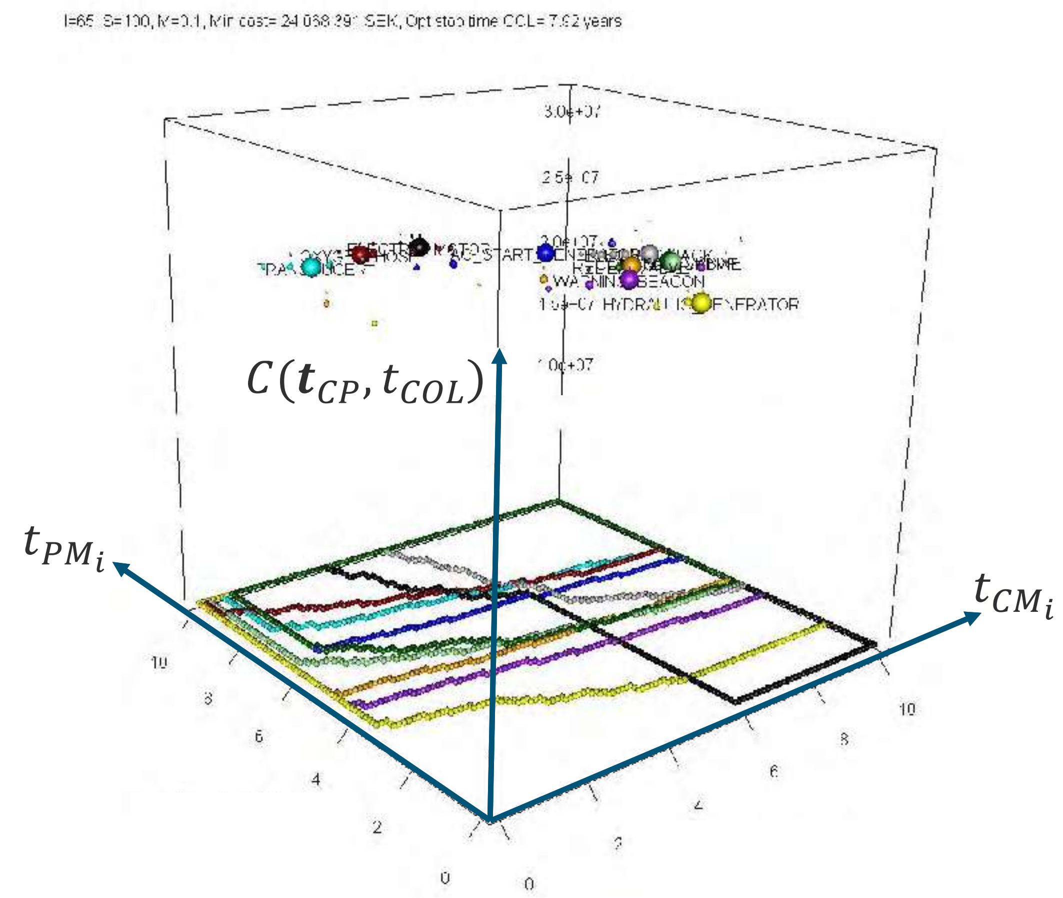
ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

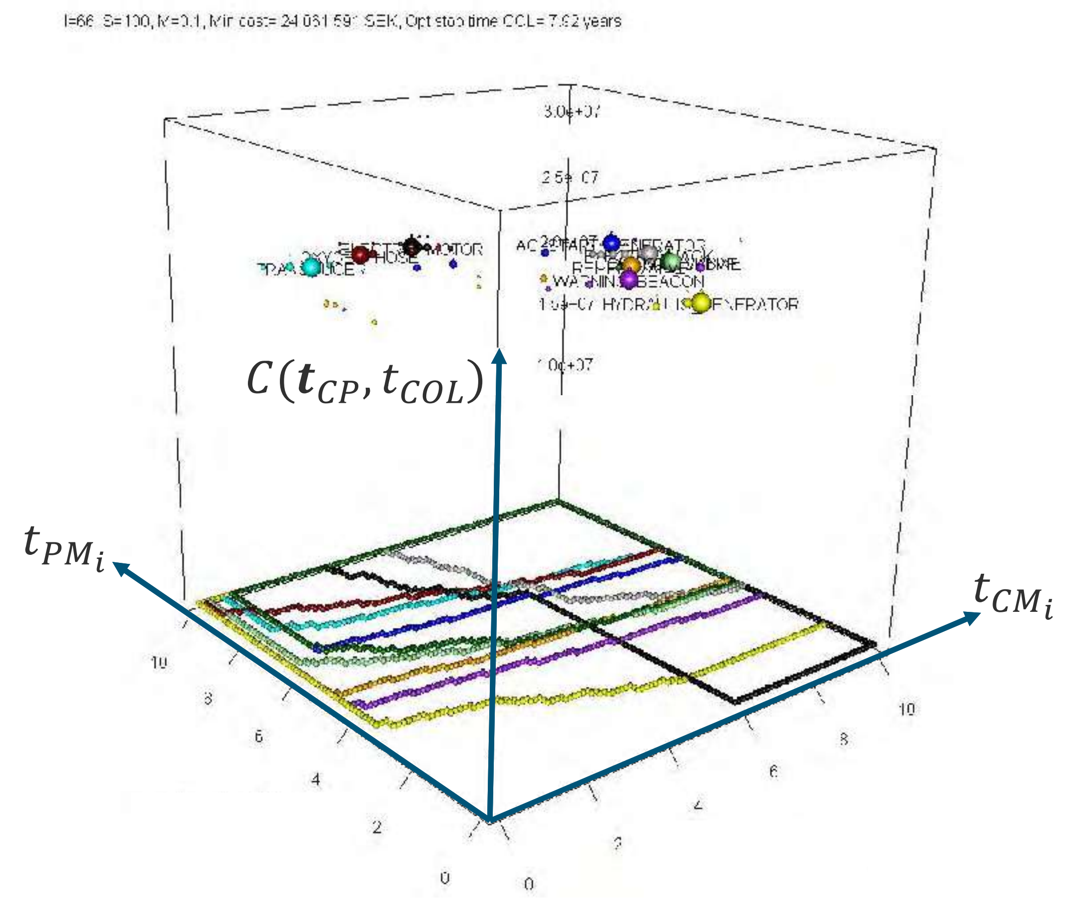
ΔT=1000 h



Systecon

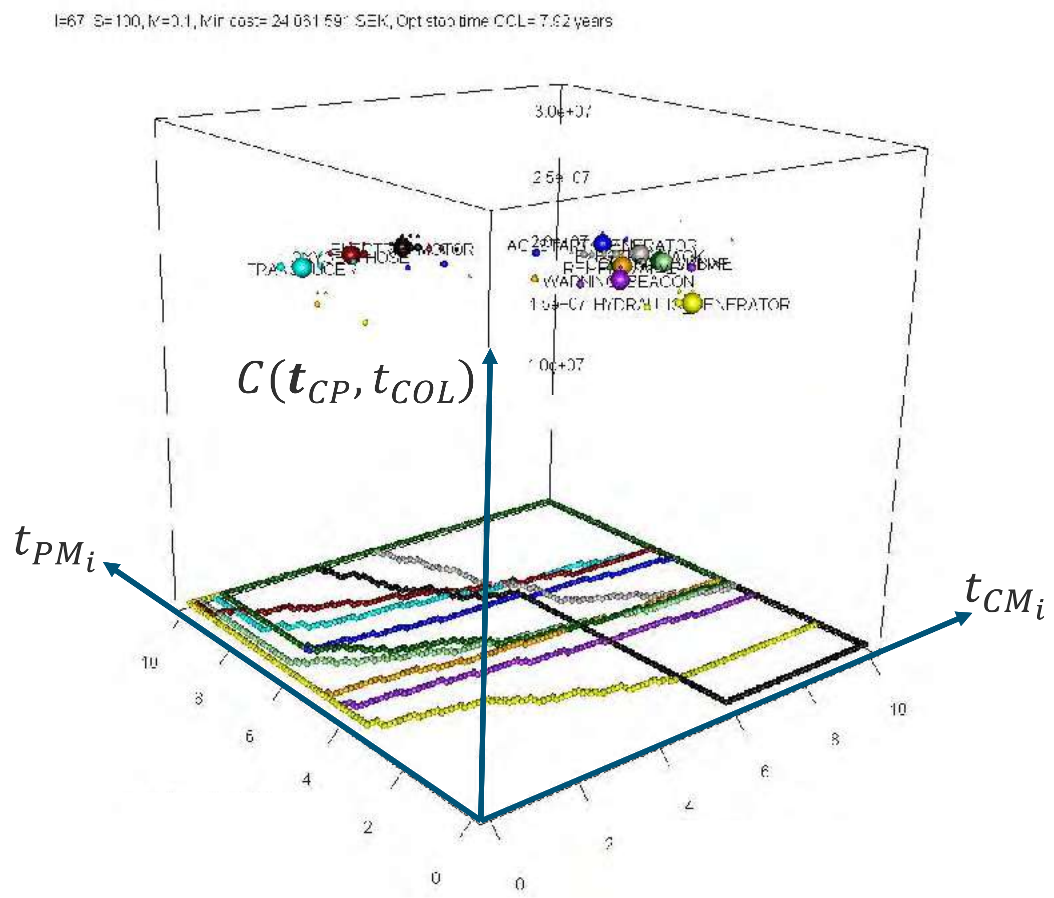
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

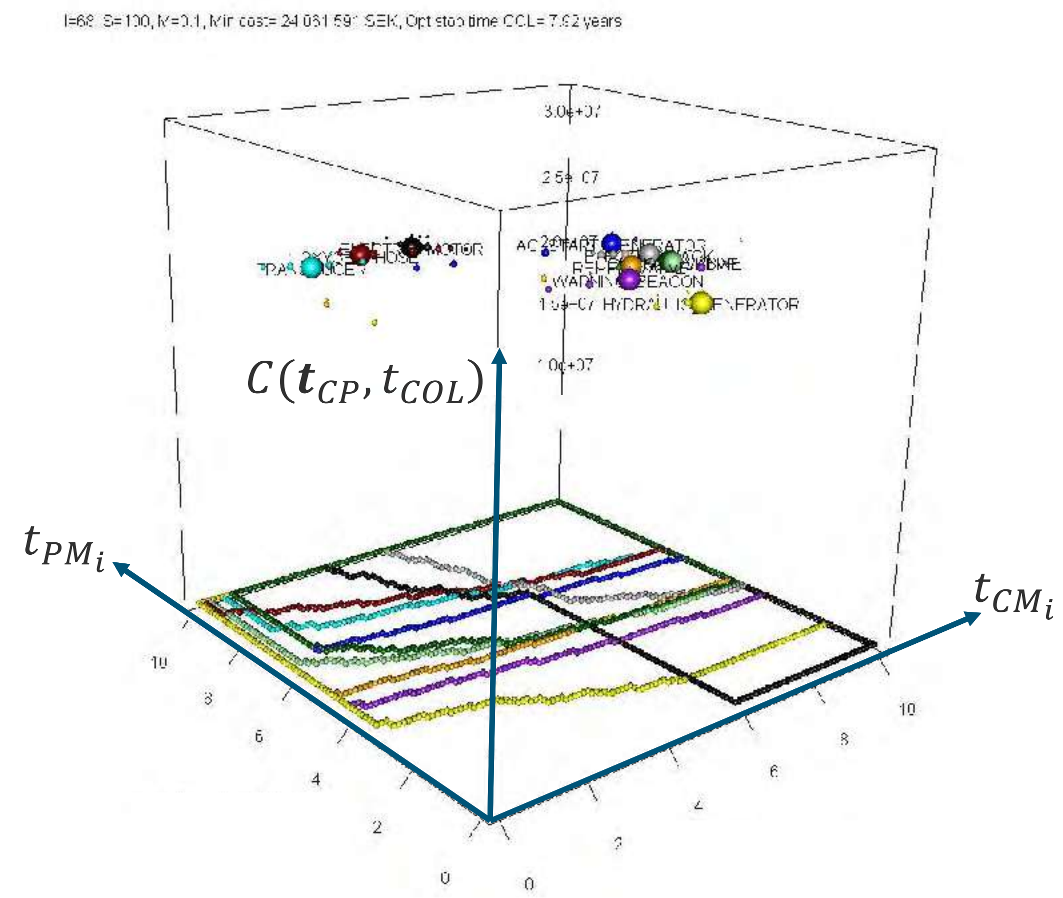
ΔT=1000 h



Systecon

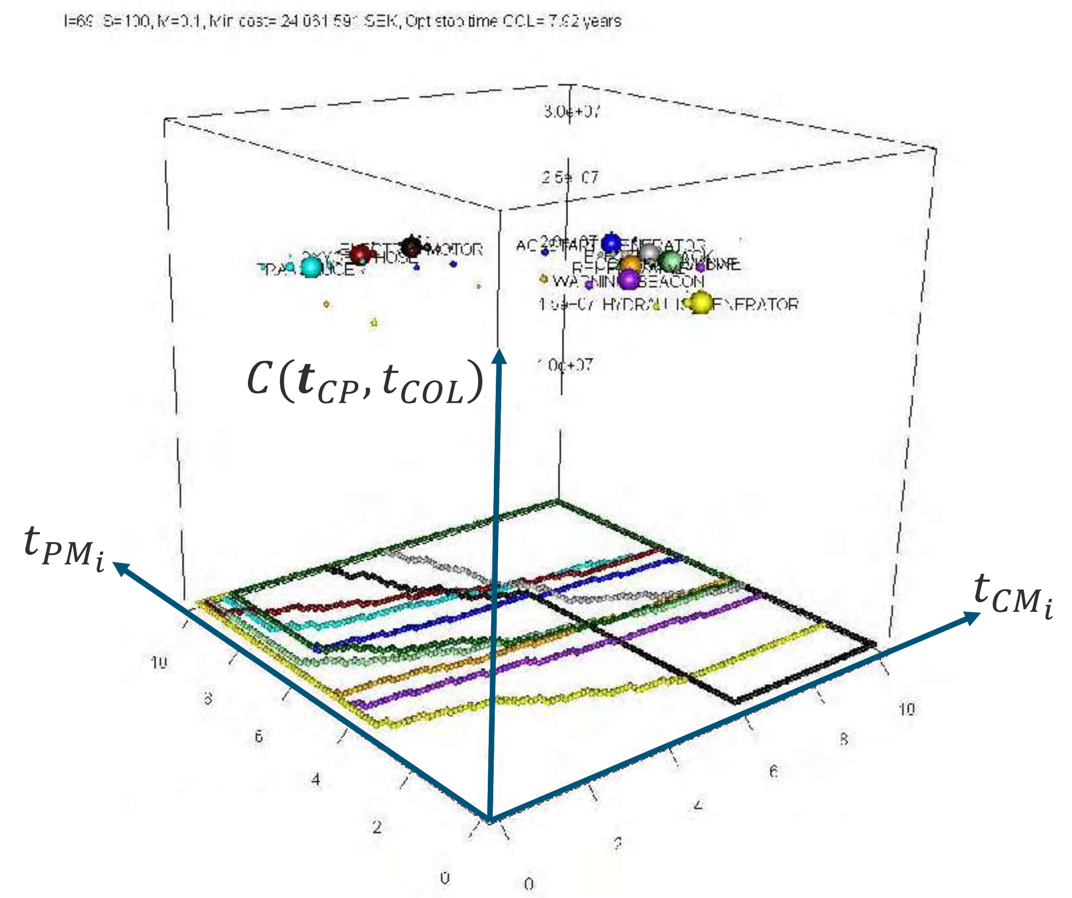
Genetic Algorithm (100 samples)

ΔT=1000 h



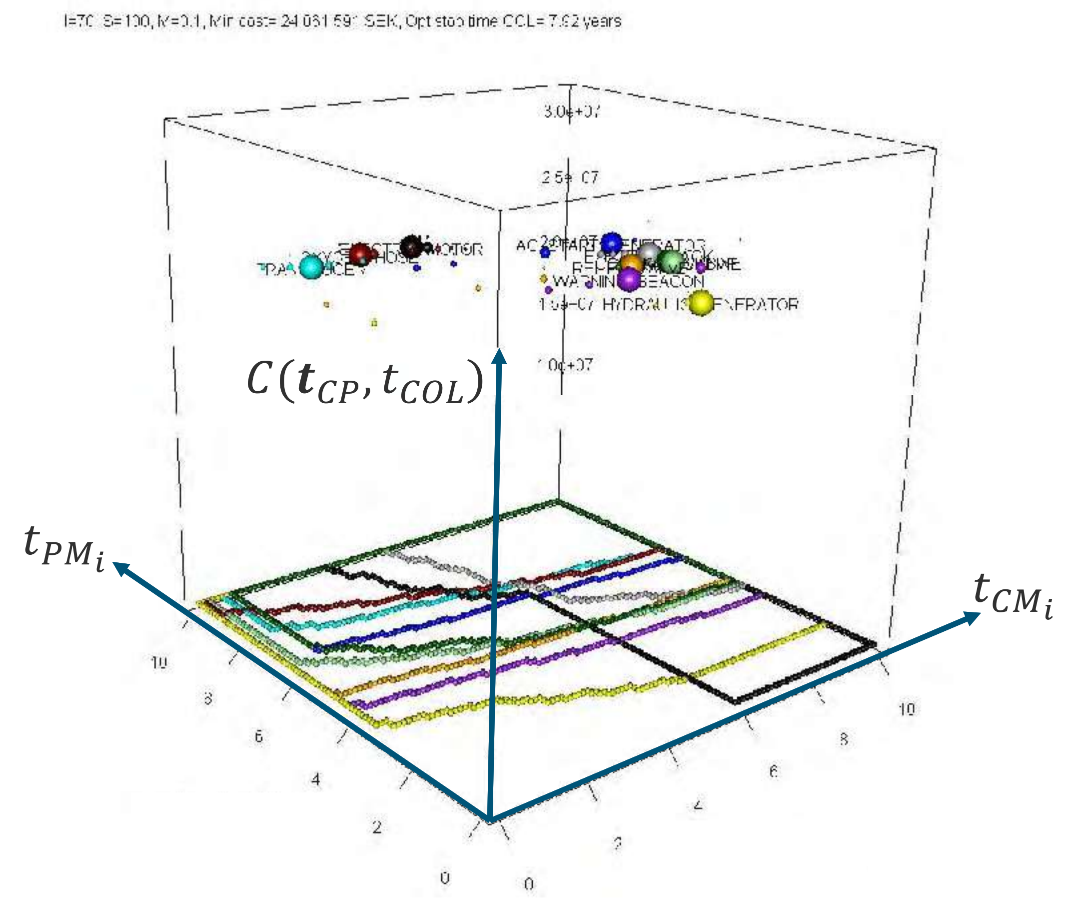
Genetic Algorithm (100 samples)

ΔT=1000 h



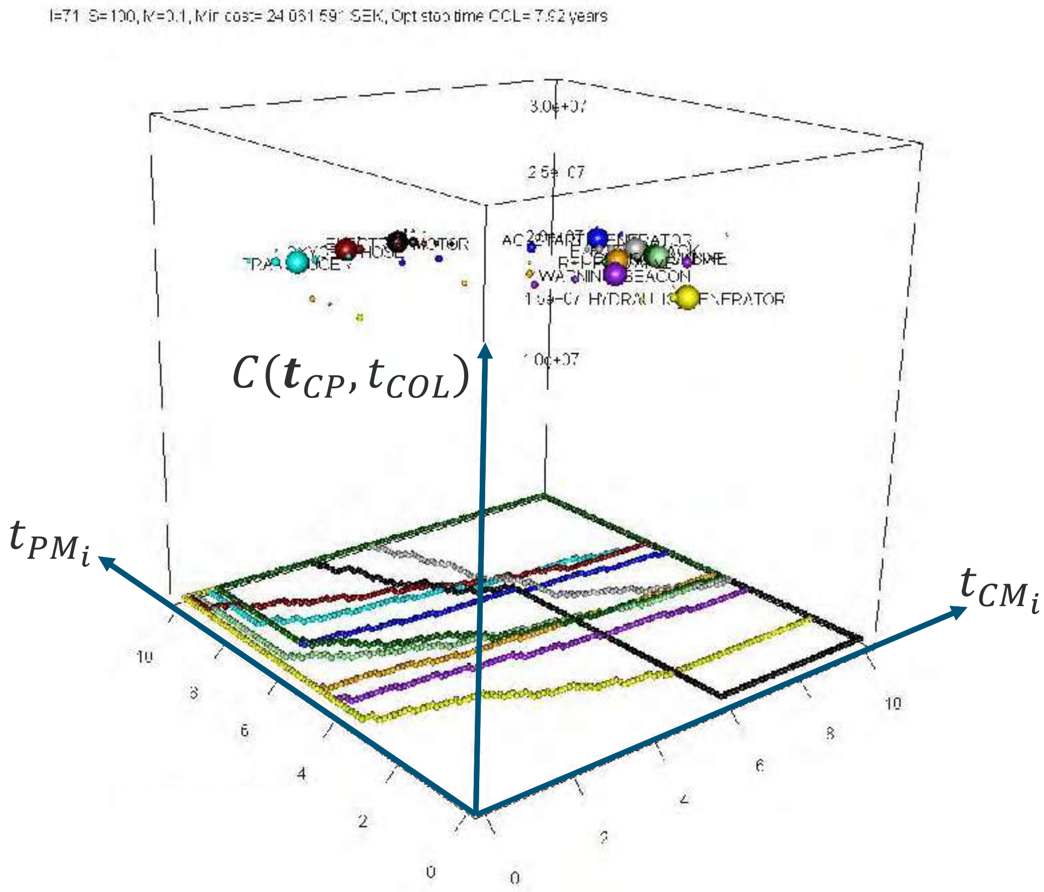
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

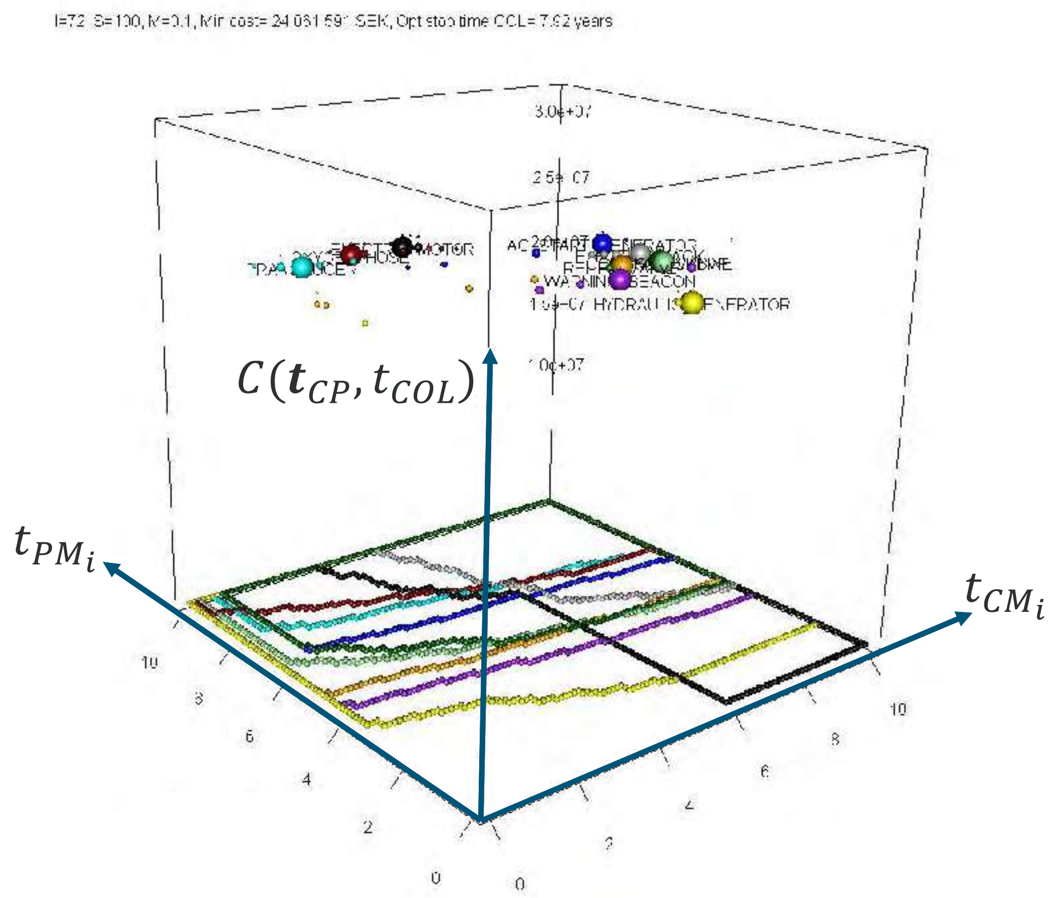
ΔT=1000 h



Systecon

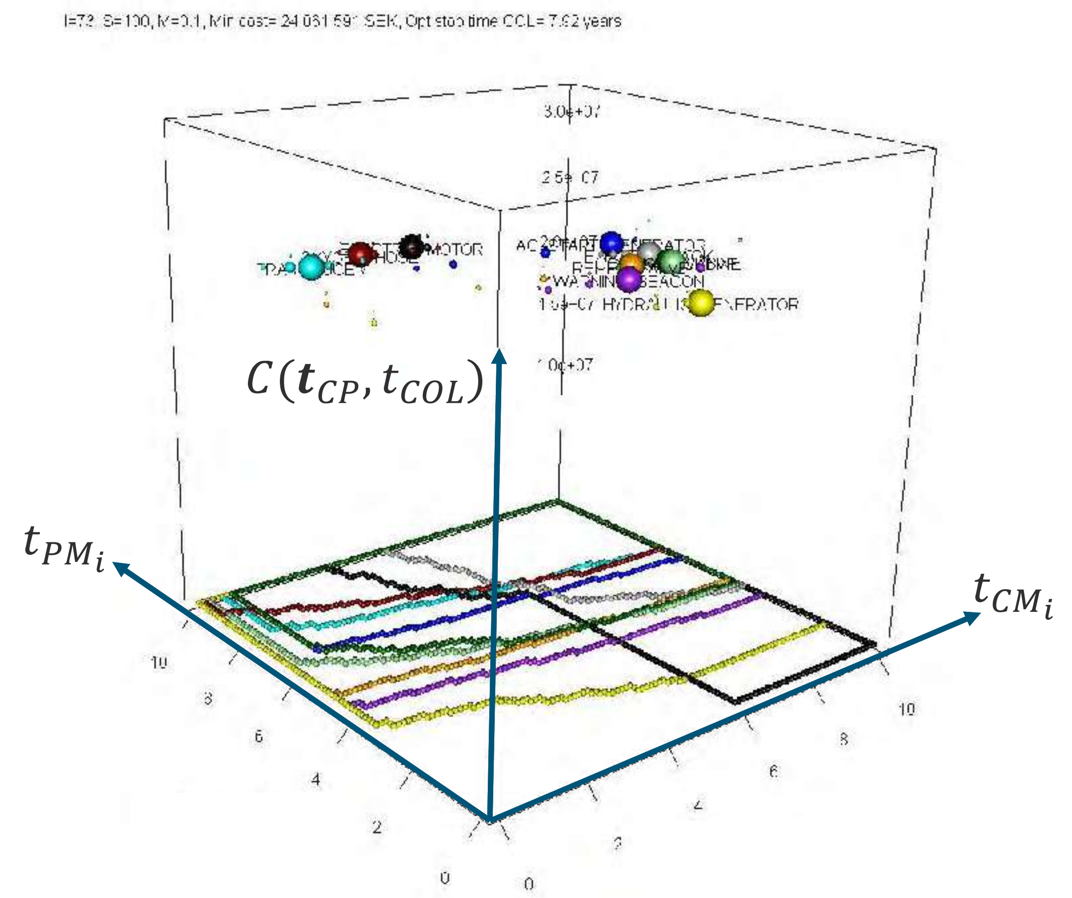
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

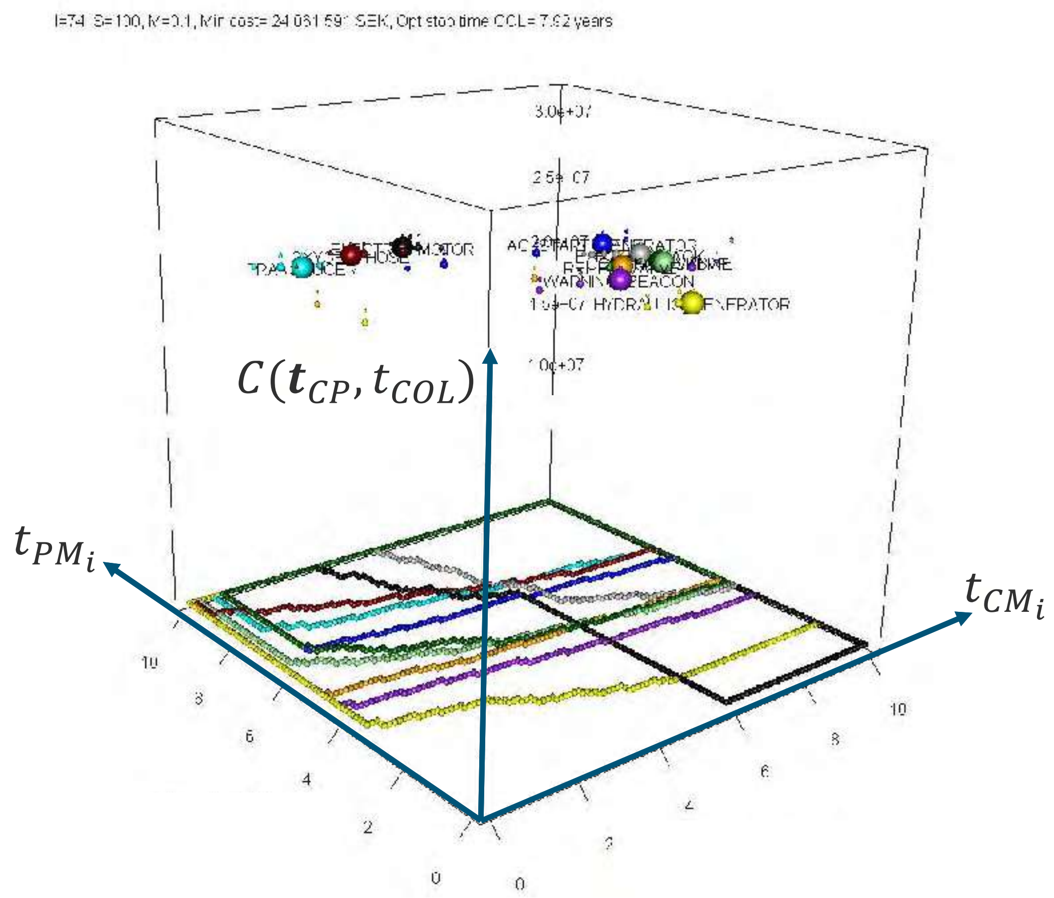
ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

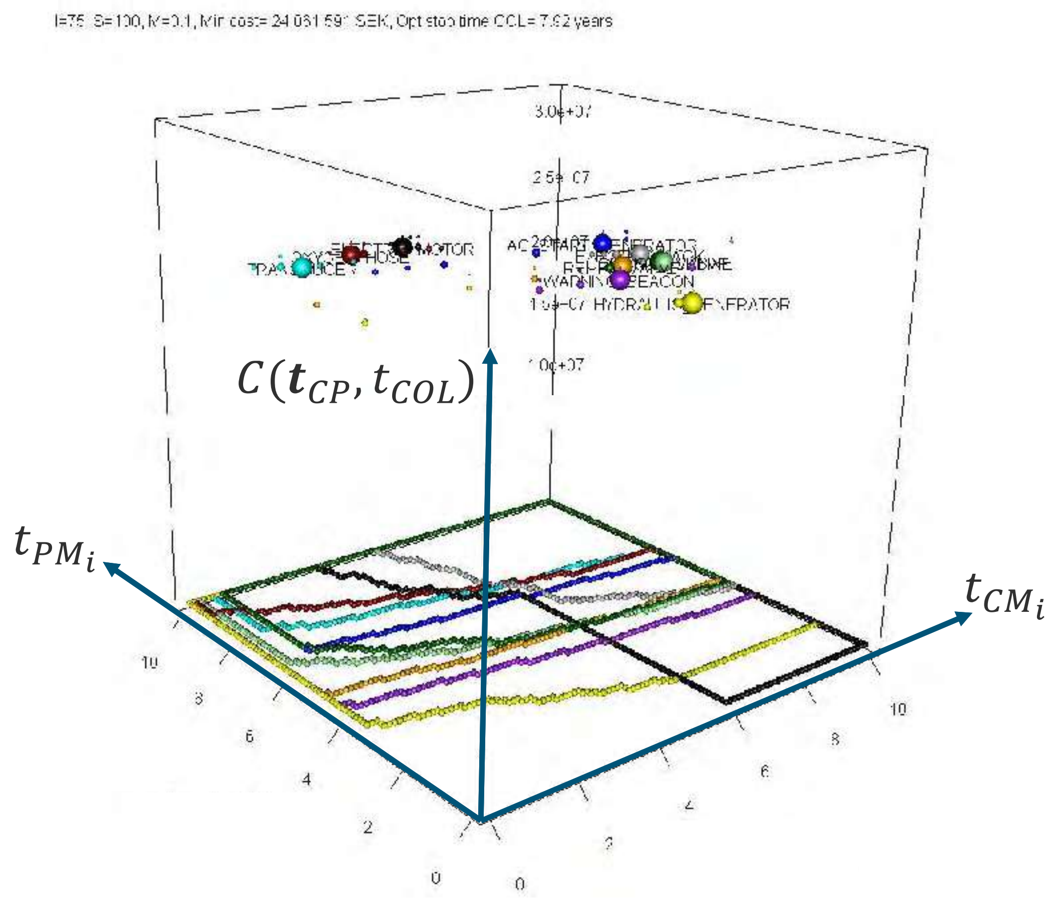
ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

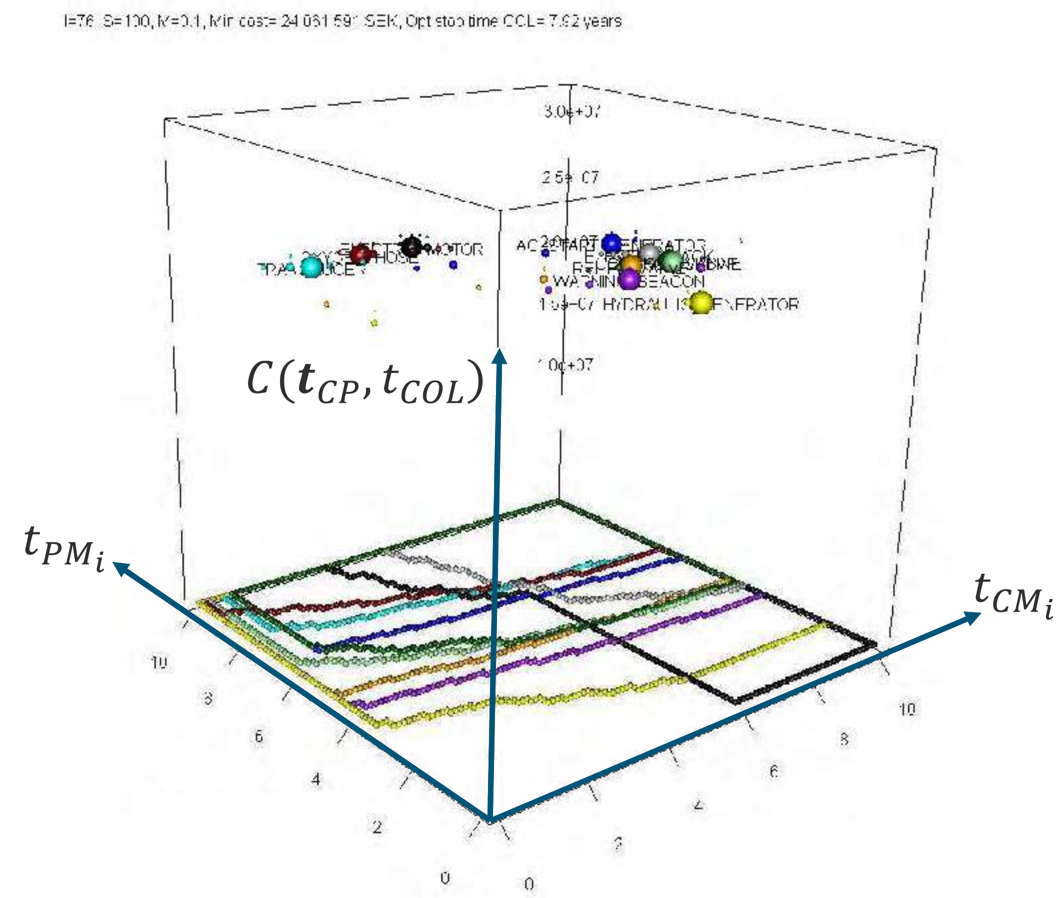
ΔT=1000 h



Systecon

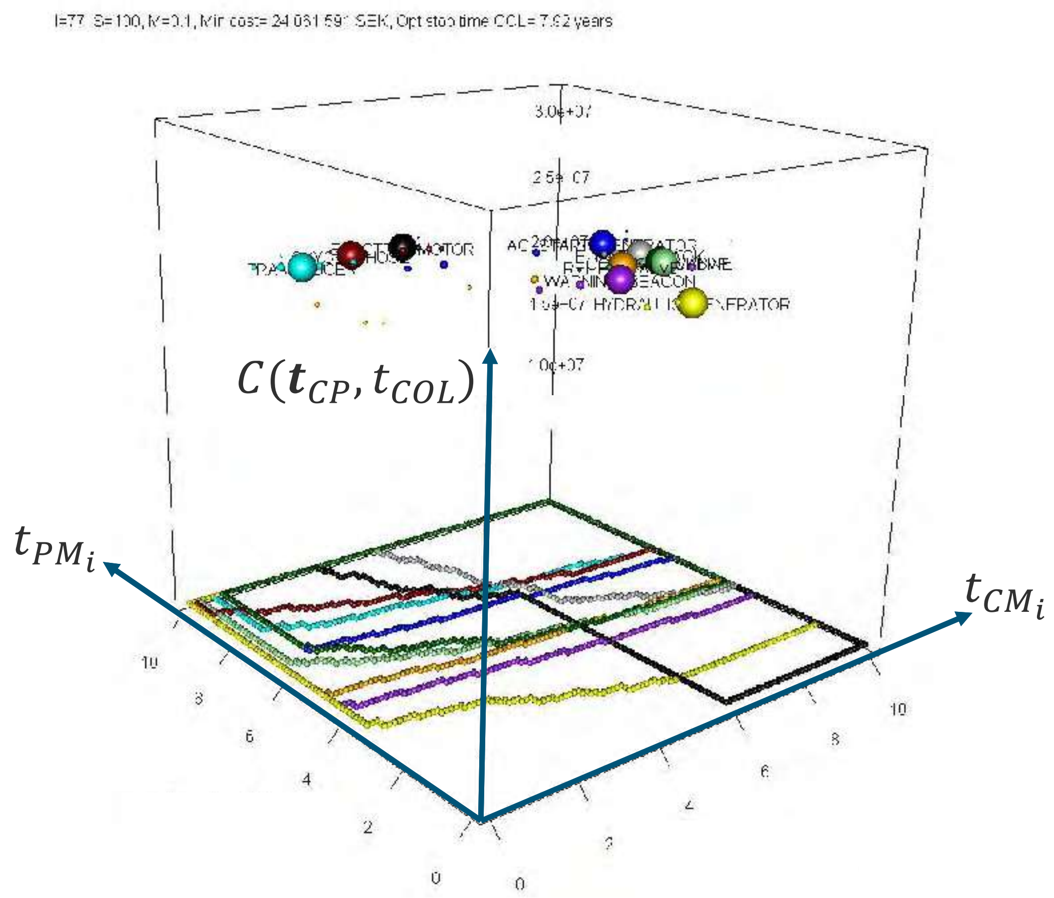
Genetic Algorithm (100 samples)

ΔT=1000 h



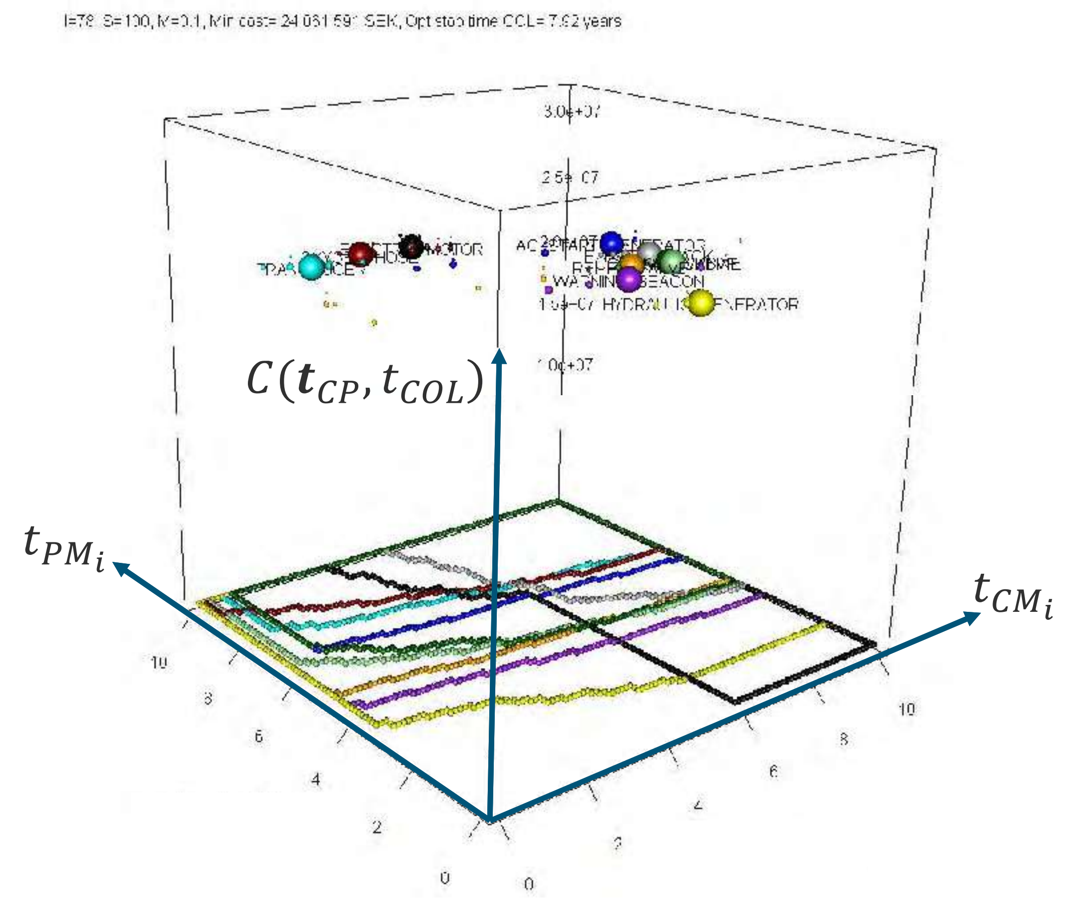
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

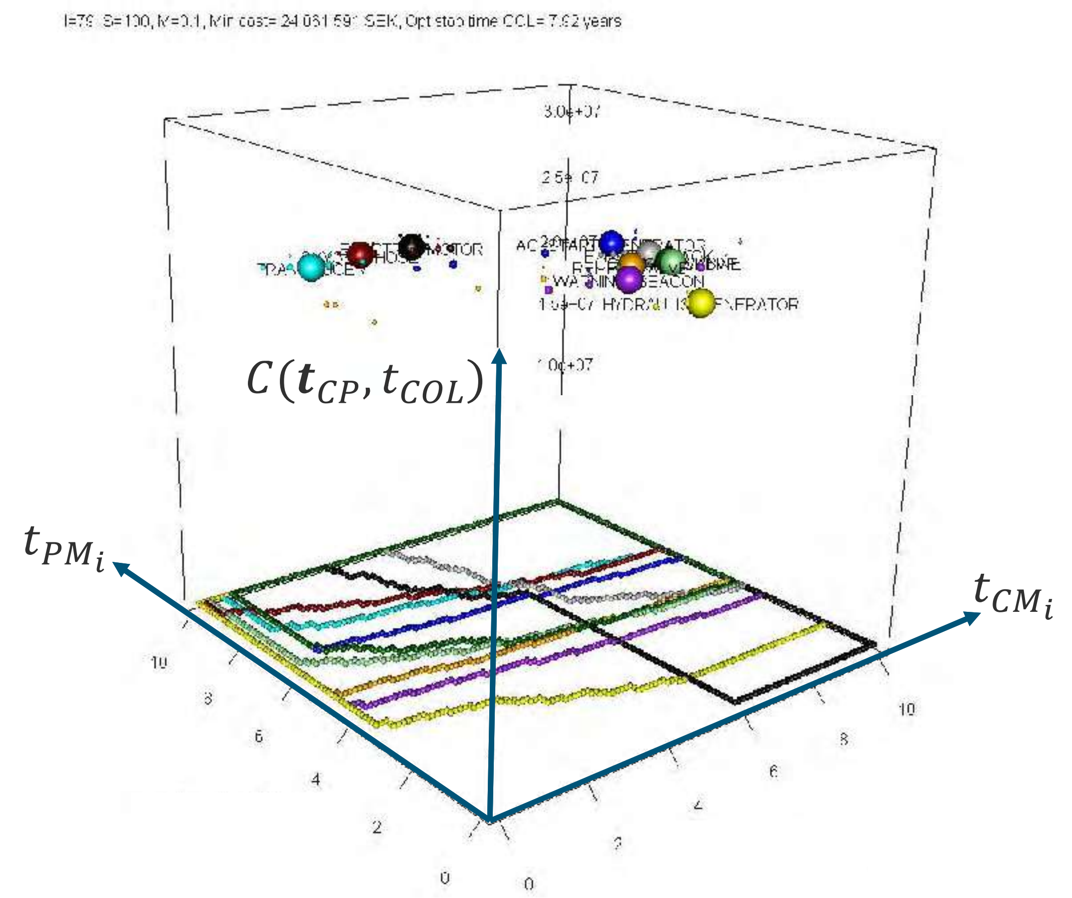
ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

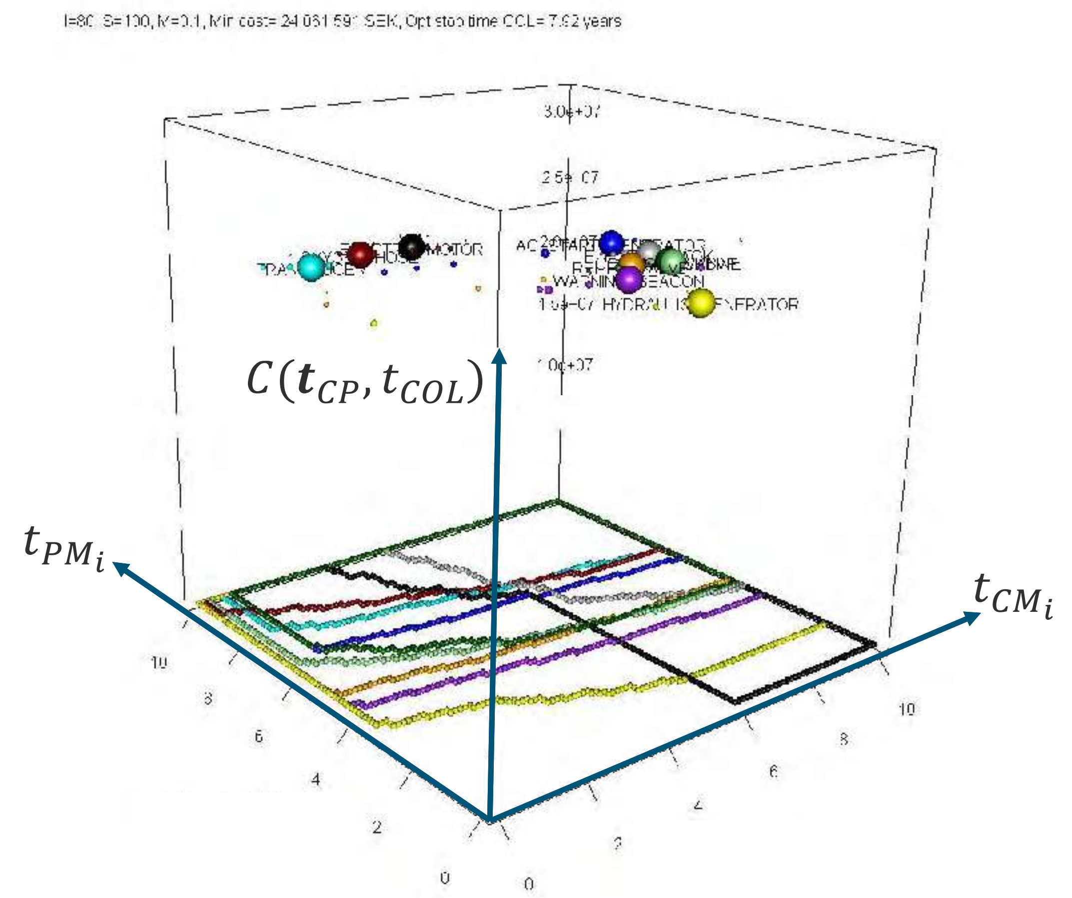
ΔT=1000 h



Systecon

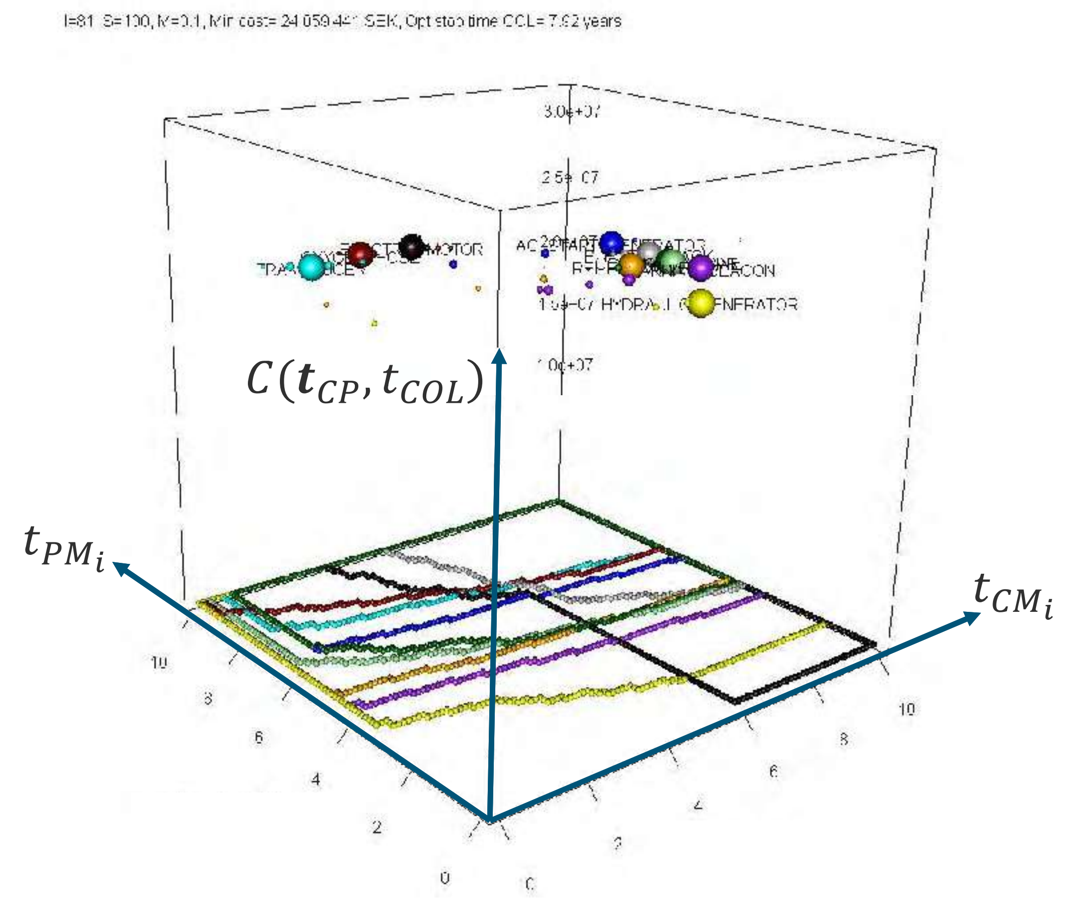
Genetic Algorithm (100 samples)

ΔT=1000 h



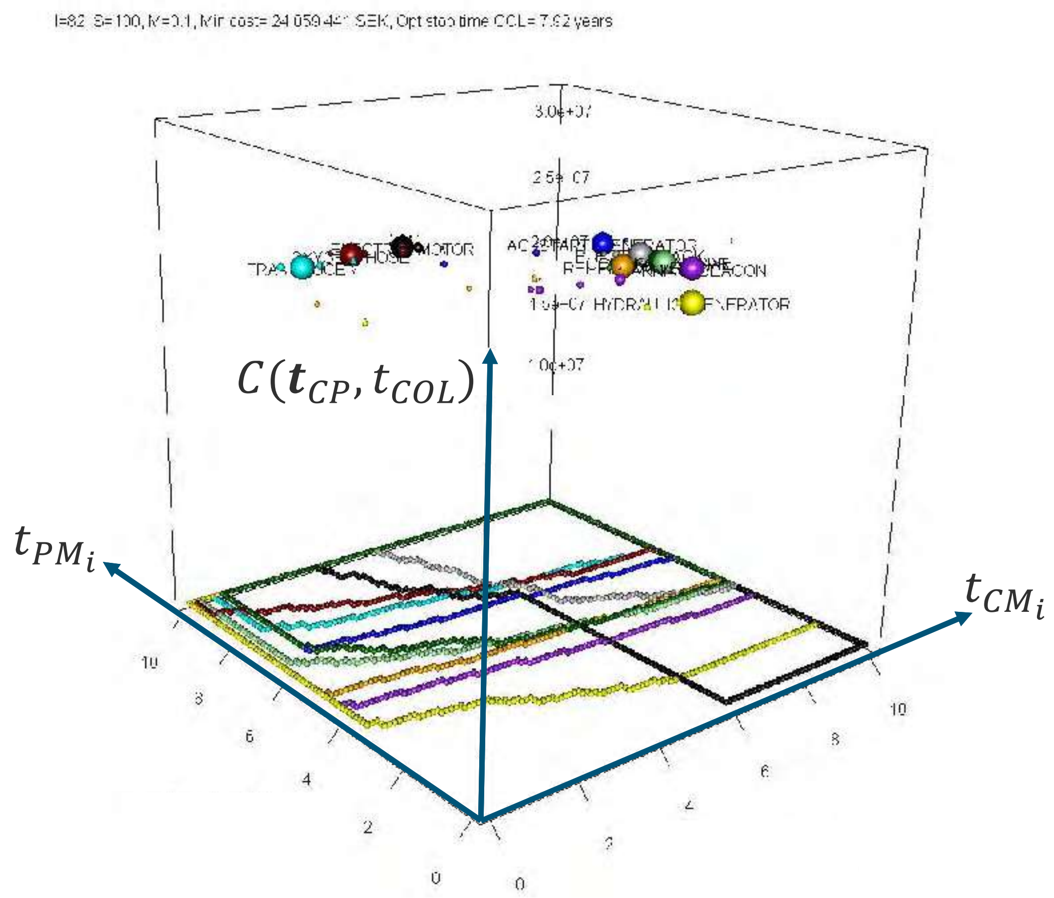
Genetic Algorithm (100 samples)

ΔT=1000 h



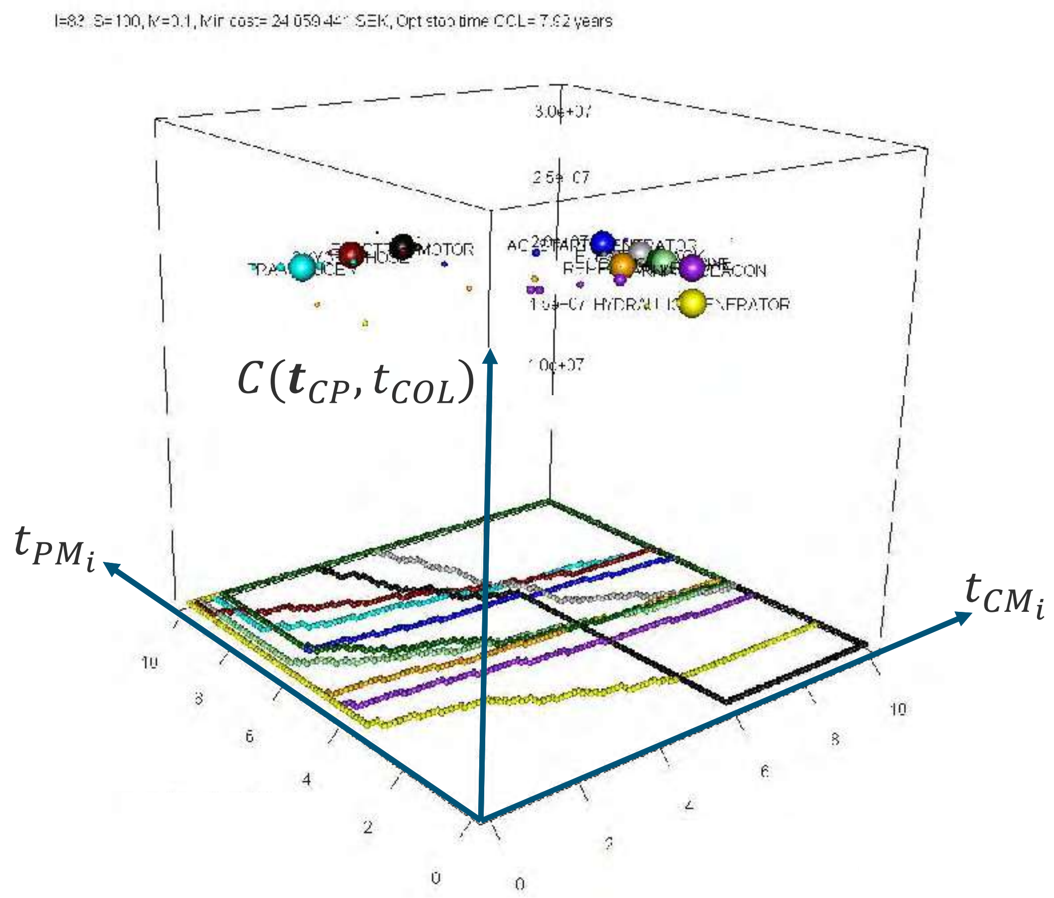
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

ΔT=1000 h



Systecon

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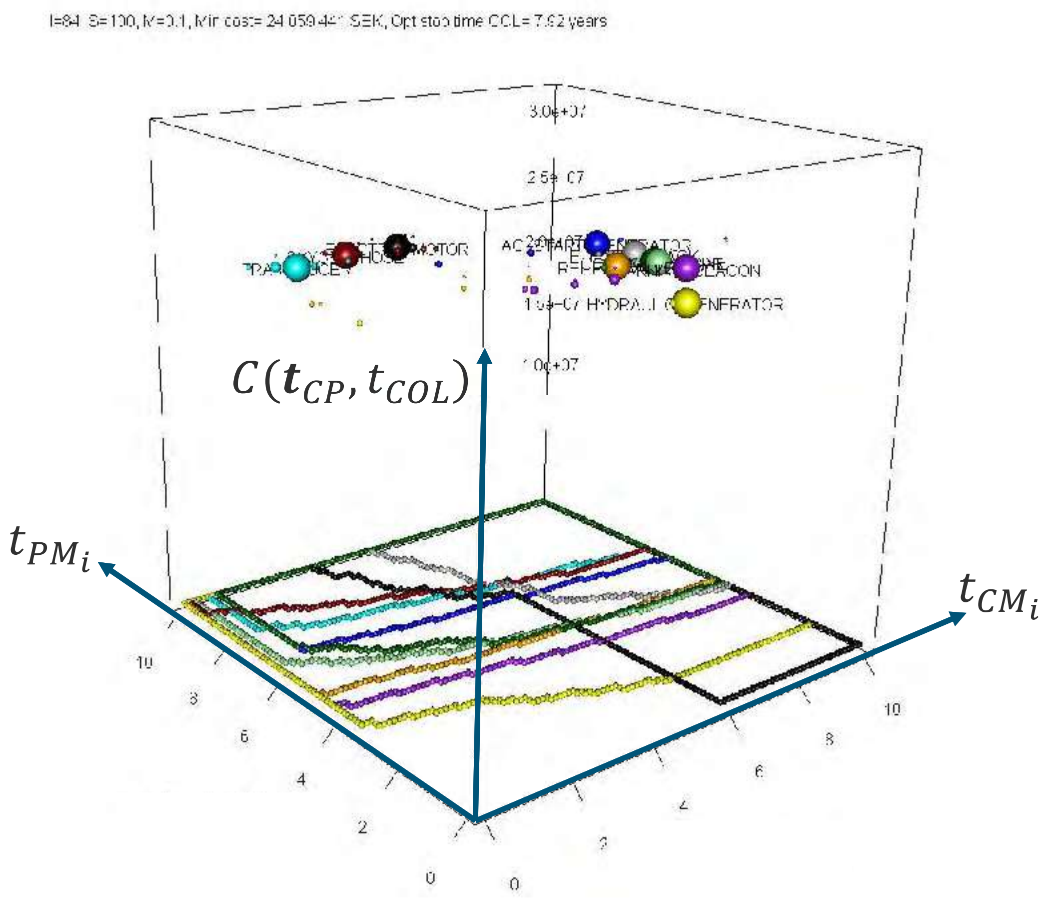
Genetic Algorithm (100 samples)

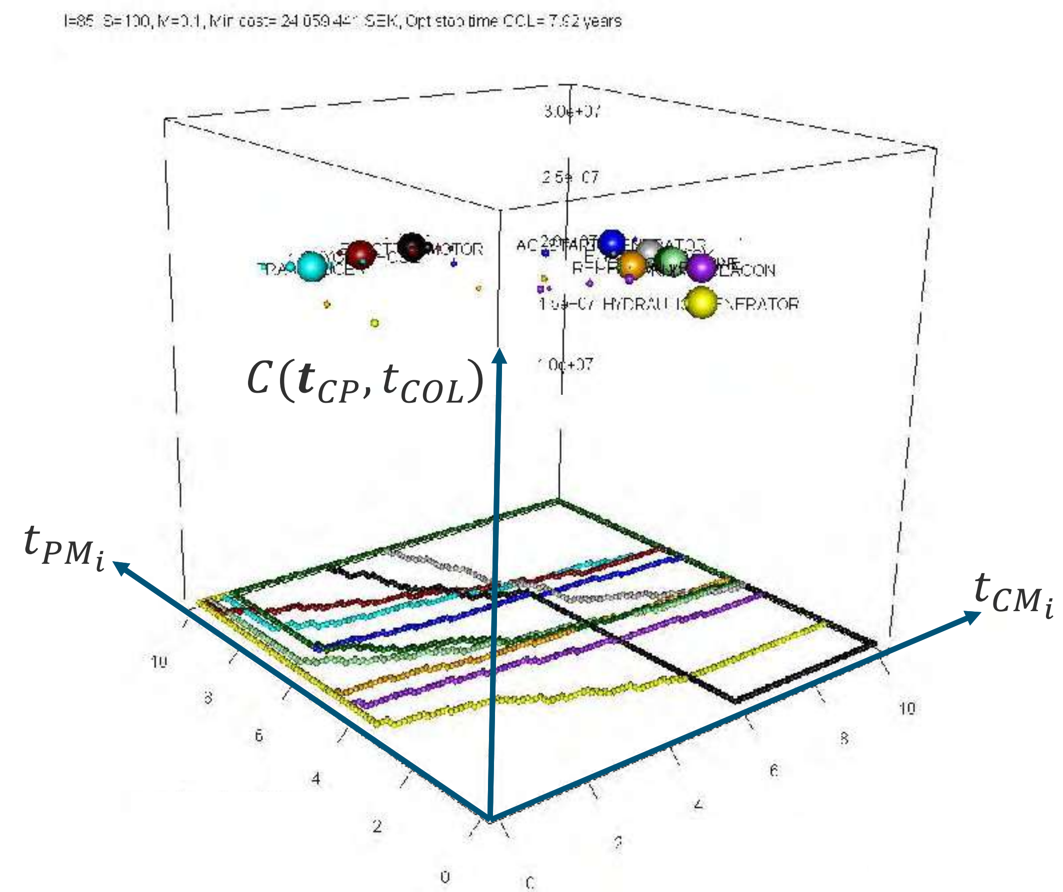
ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

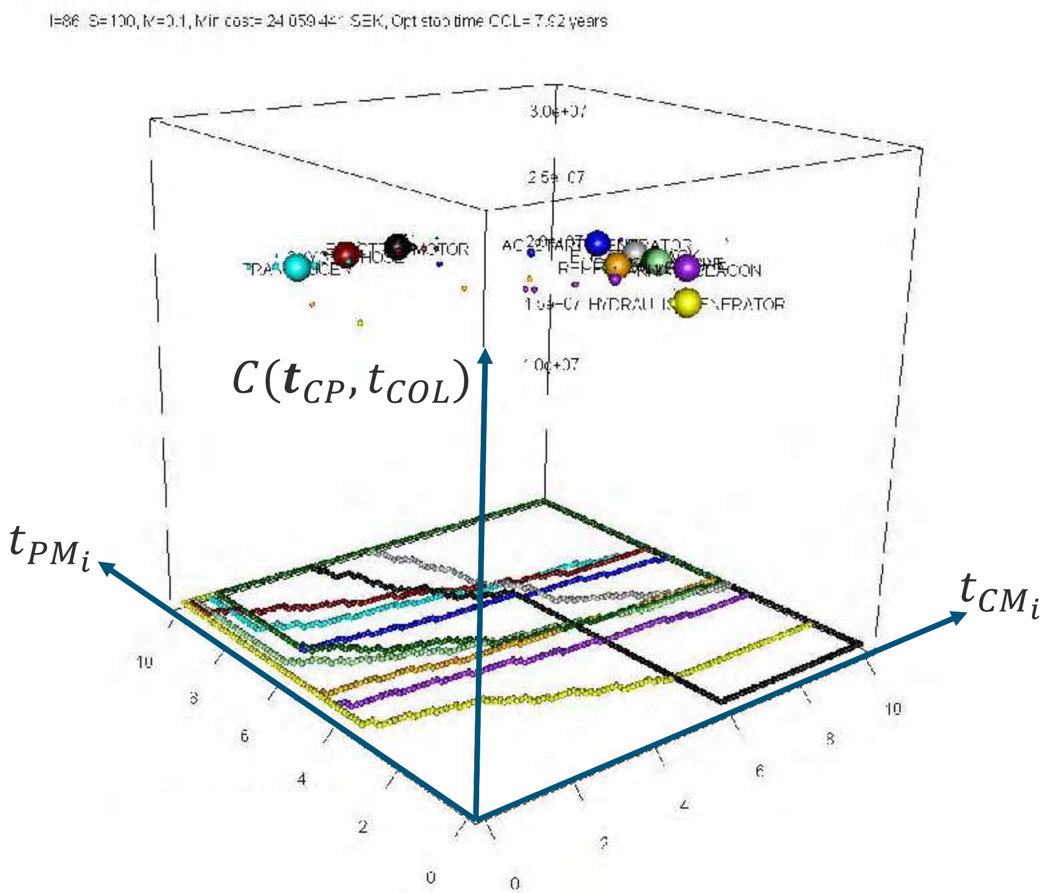
ΔT=1000 h



Systecon

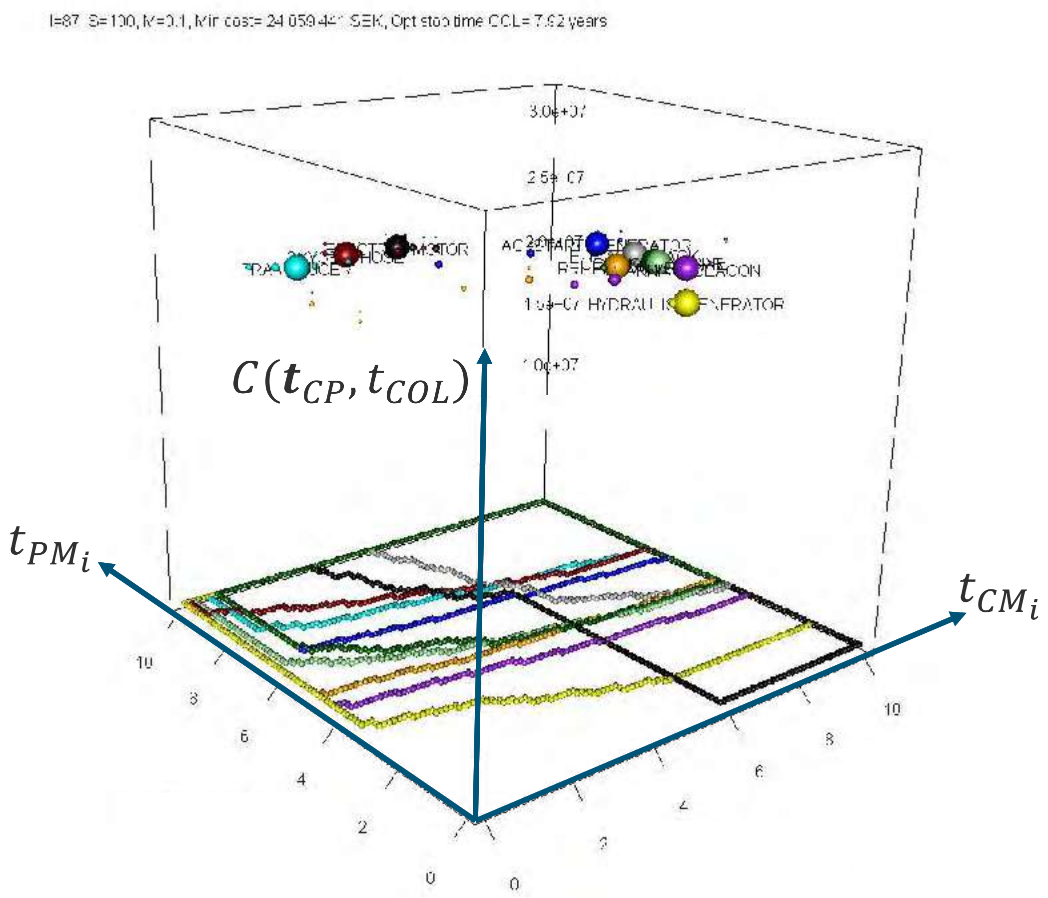
Genetic Algorithm (100 samples)

ΔT=1000 h



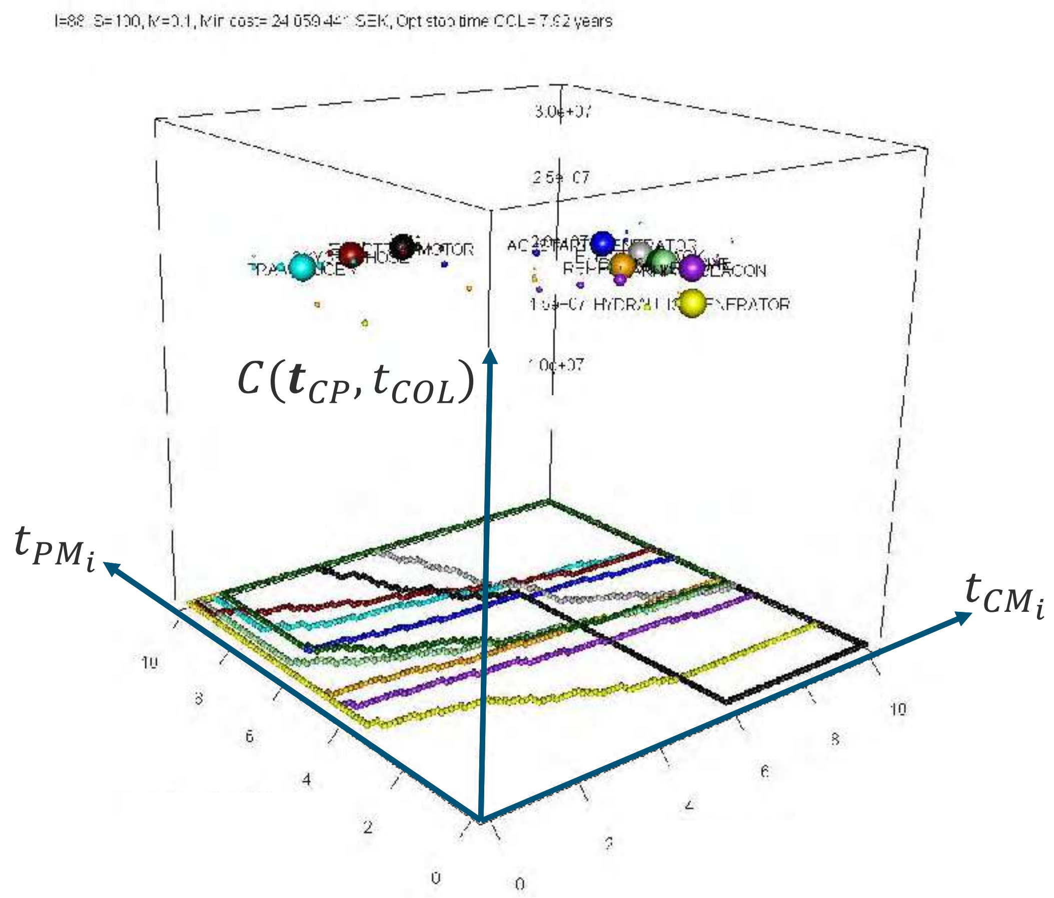
Genetic Algorithm (100 samples)

ΔT=1000 h



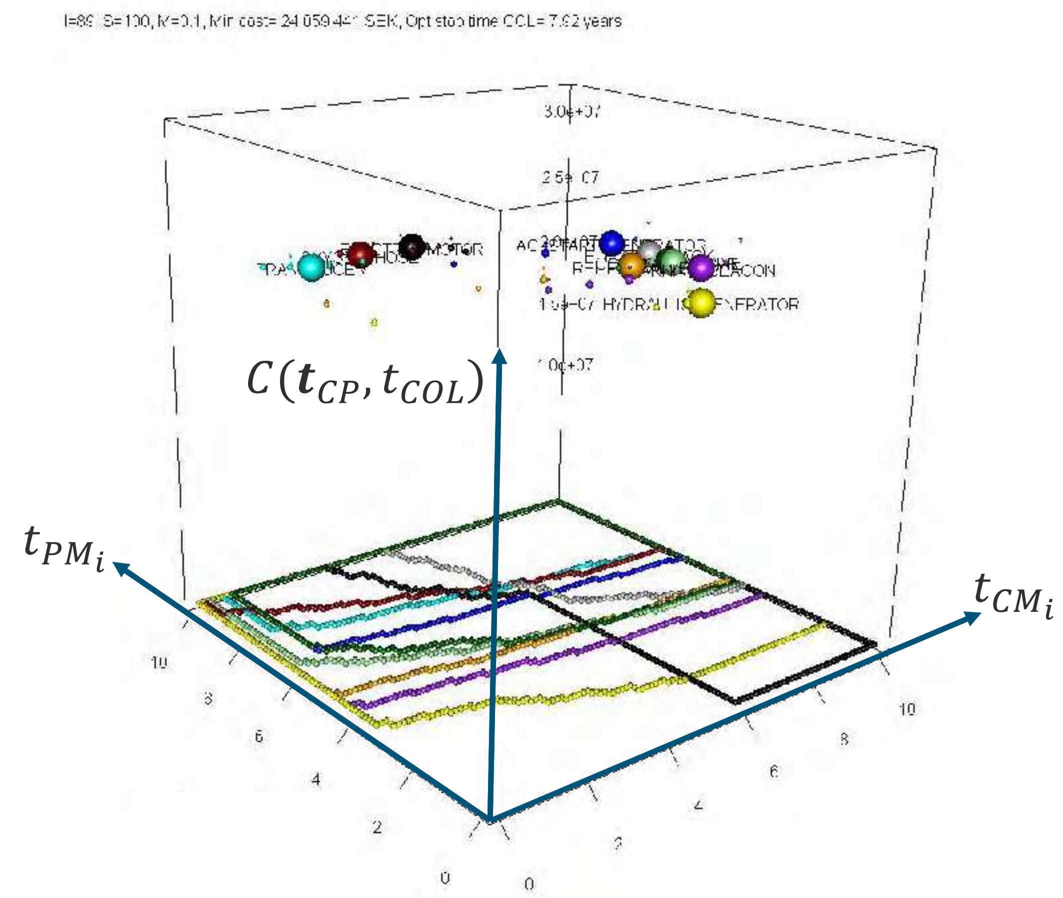
Genetic Algorithm (100 samples)

ΔT=1000 h



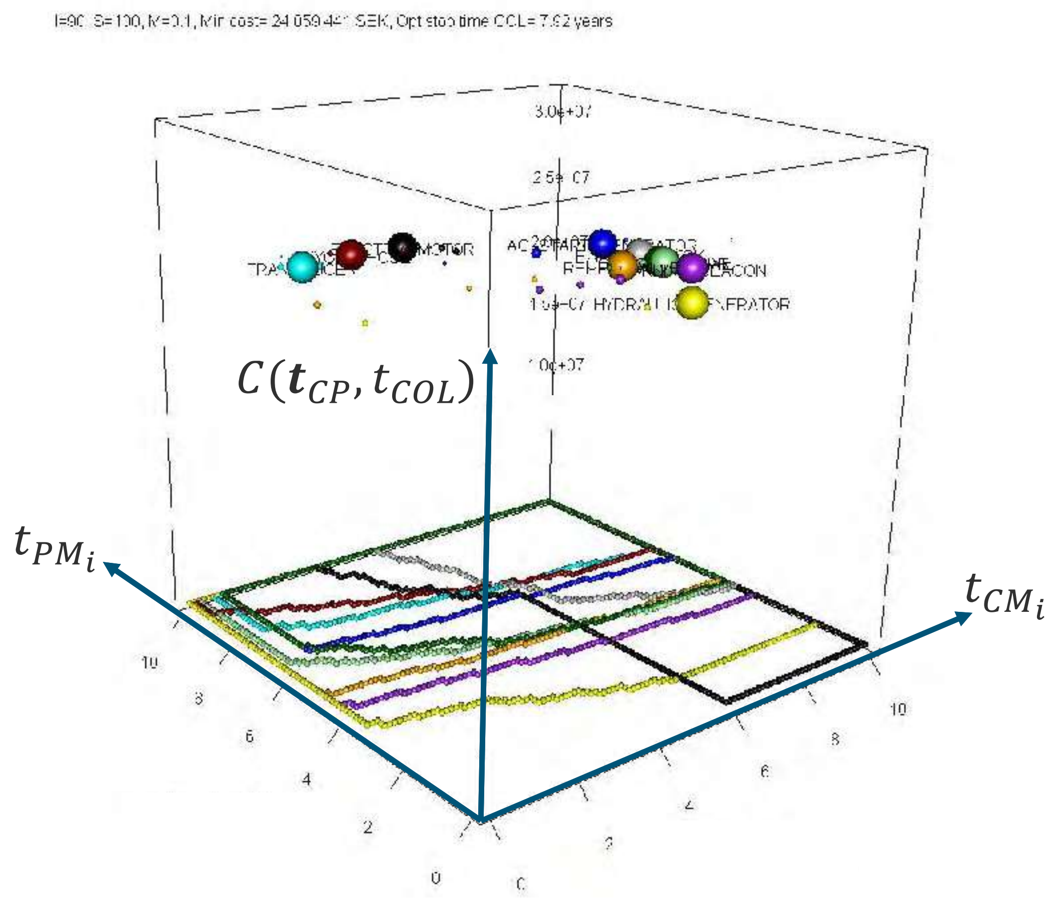
Genetic Algorithm (100 samples)

ΔT=1000 h



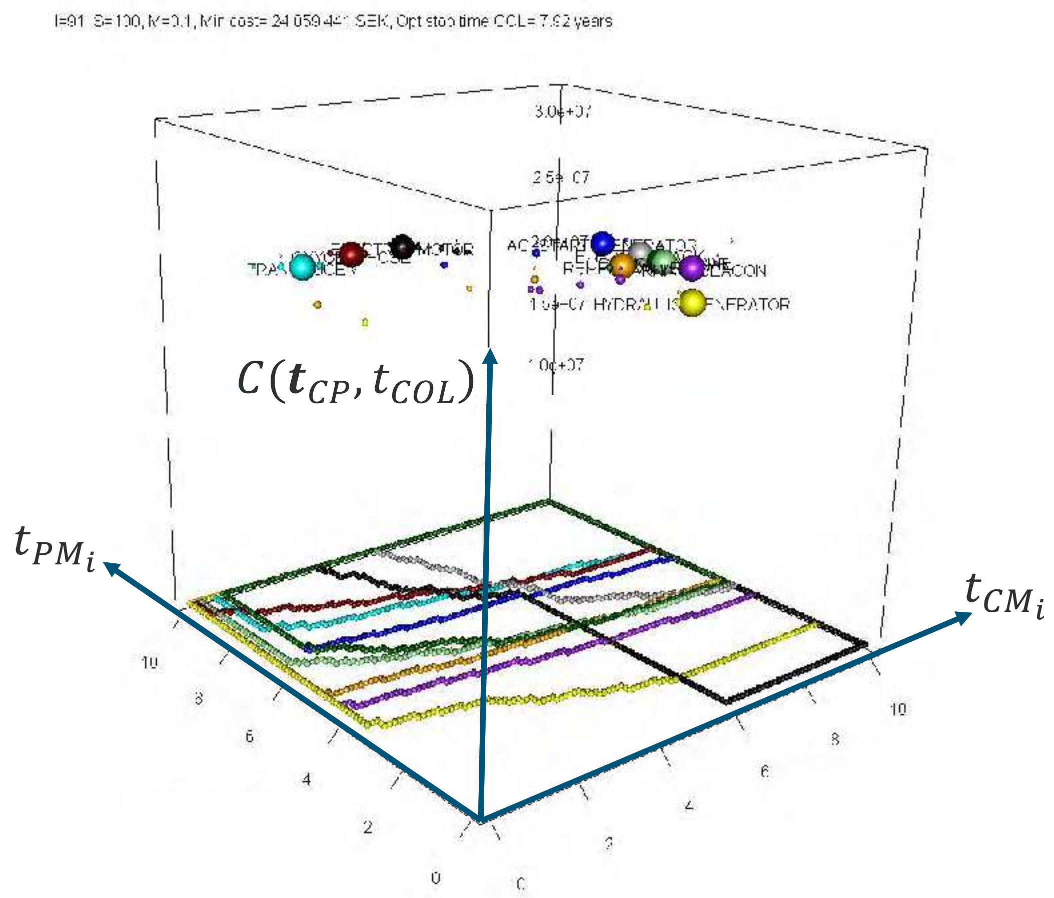
Genetic Algorithm (100 samples)

ΔT=1000 h



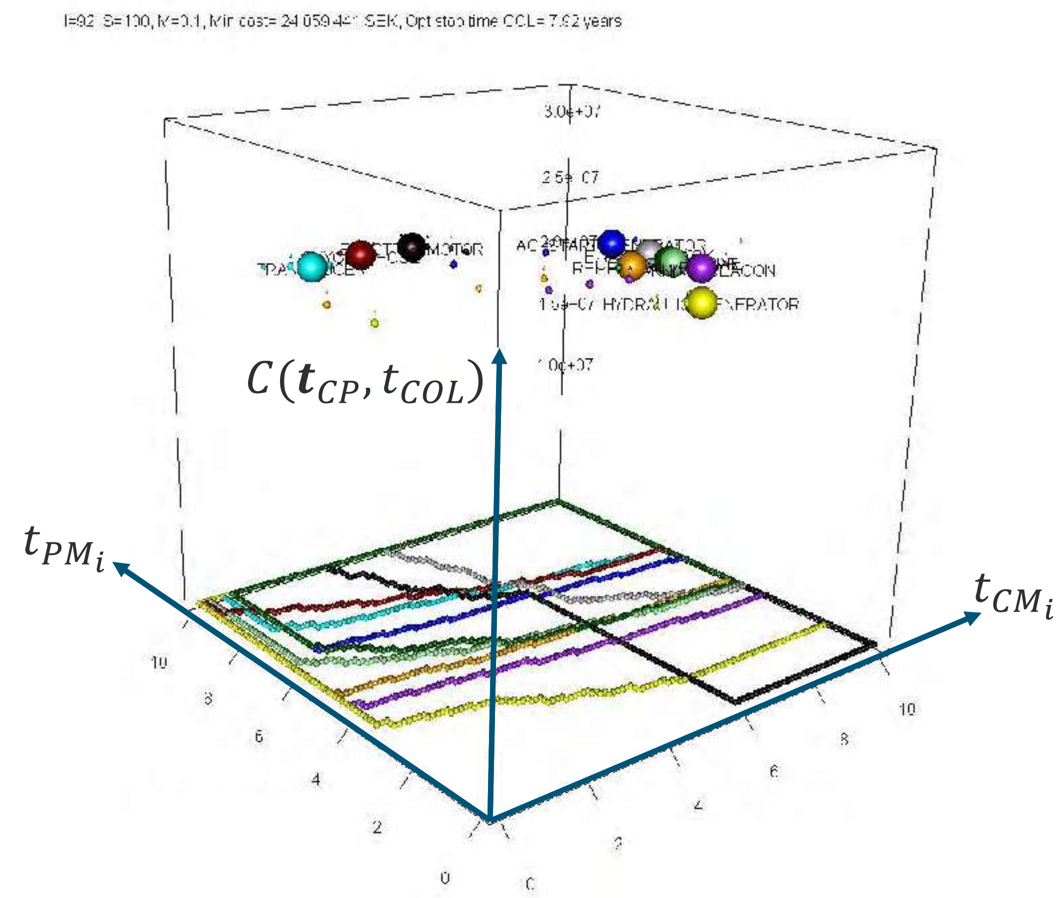
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

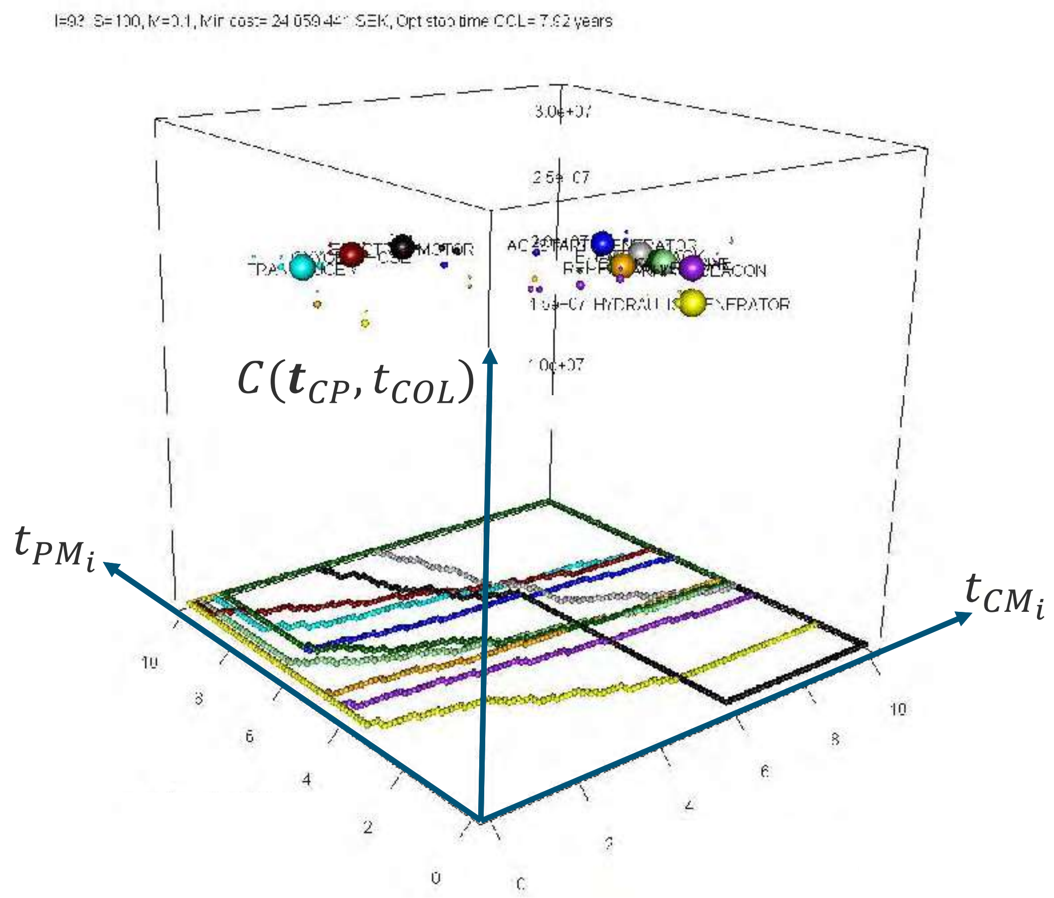
ΔT=1000 h



Systecon

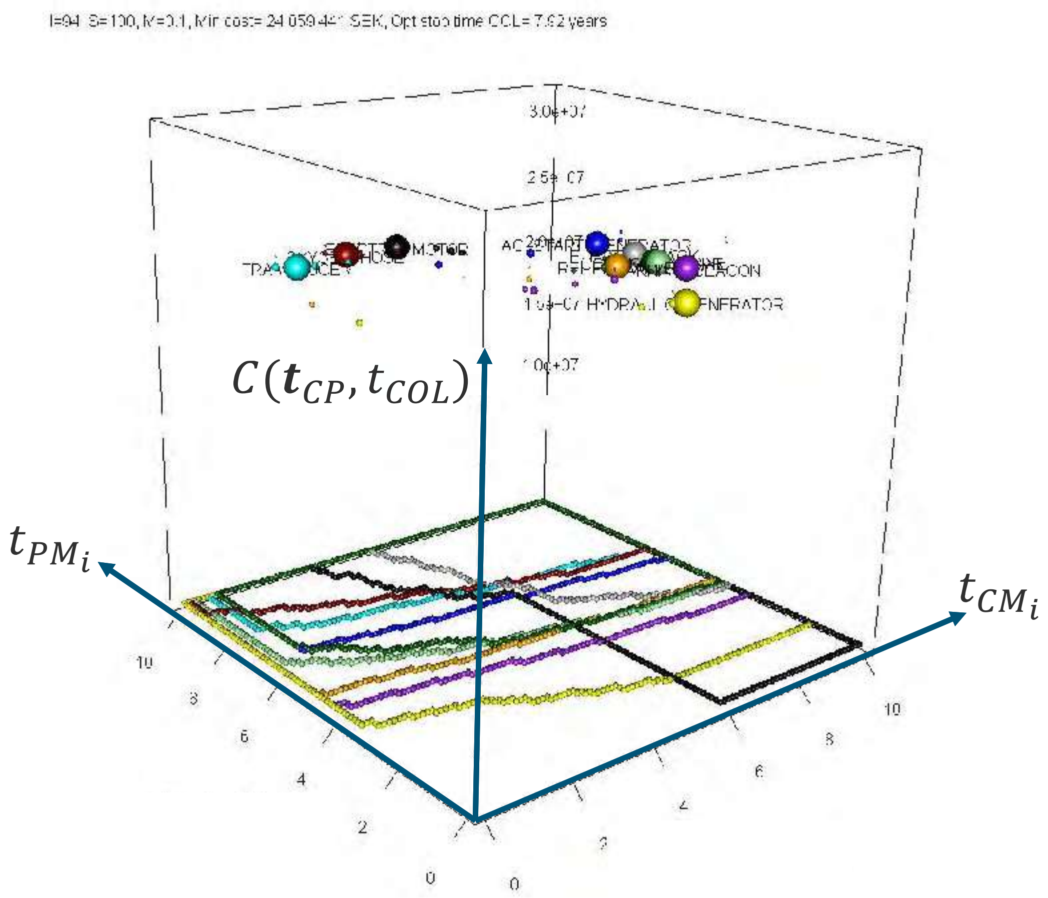
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

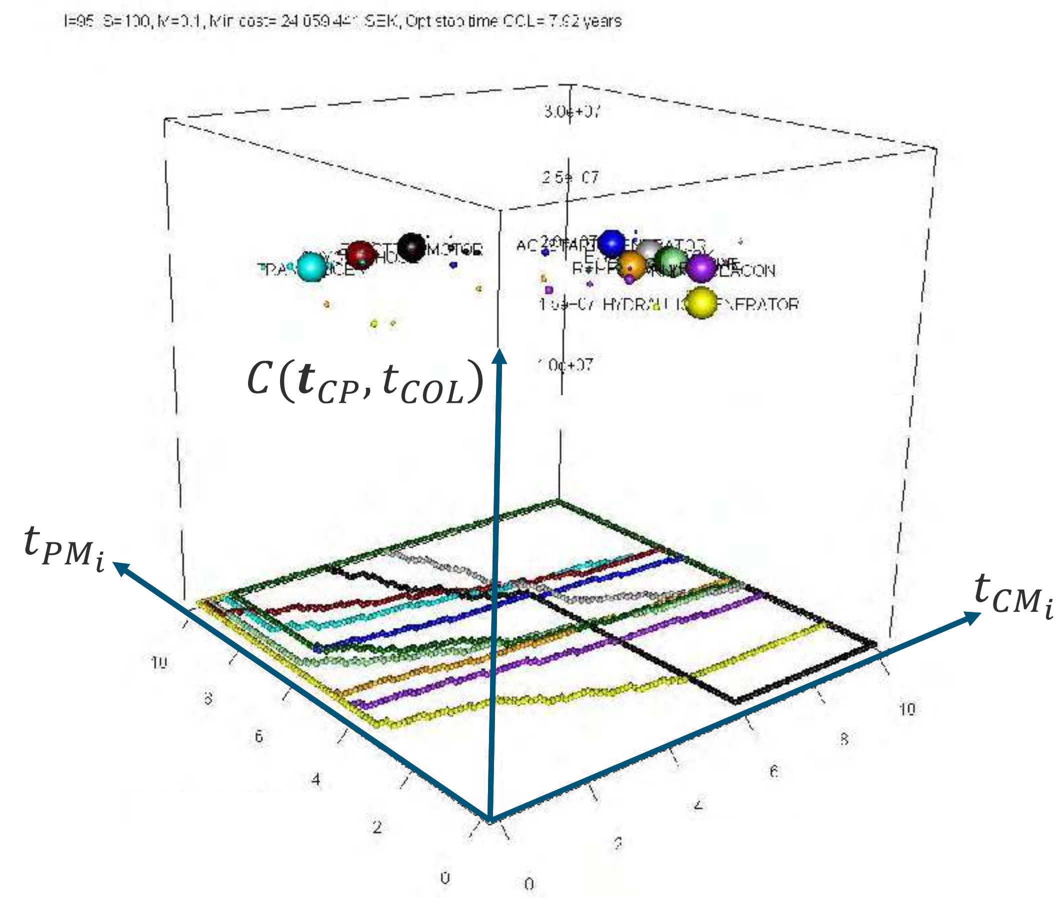
ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

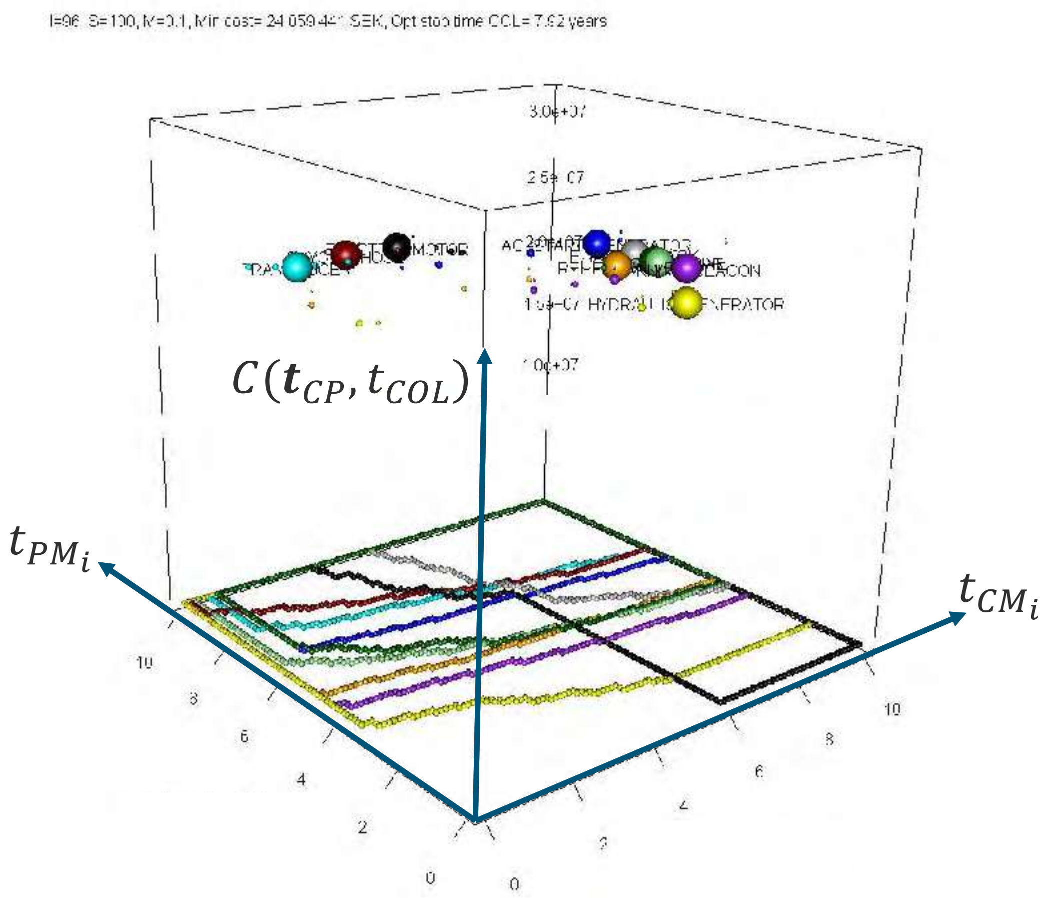
ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

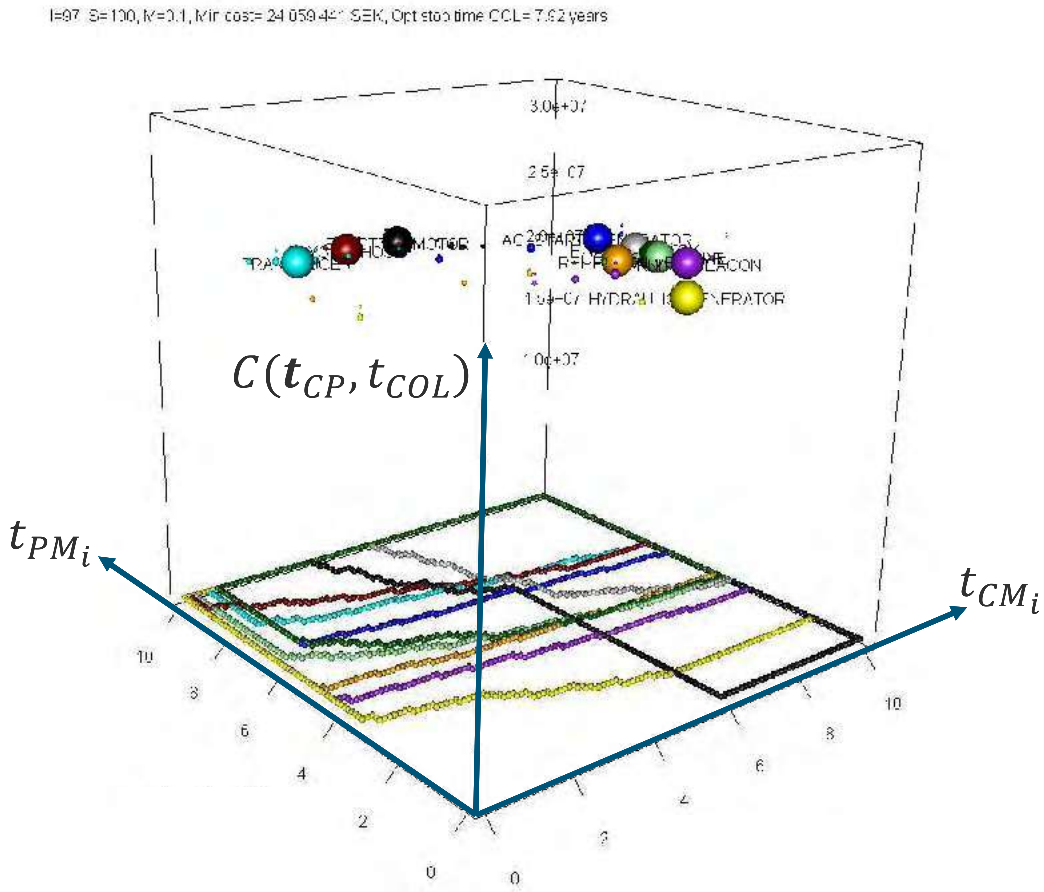
ΔT=1000 h



Systecon

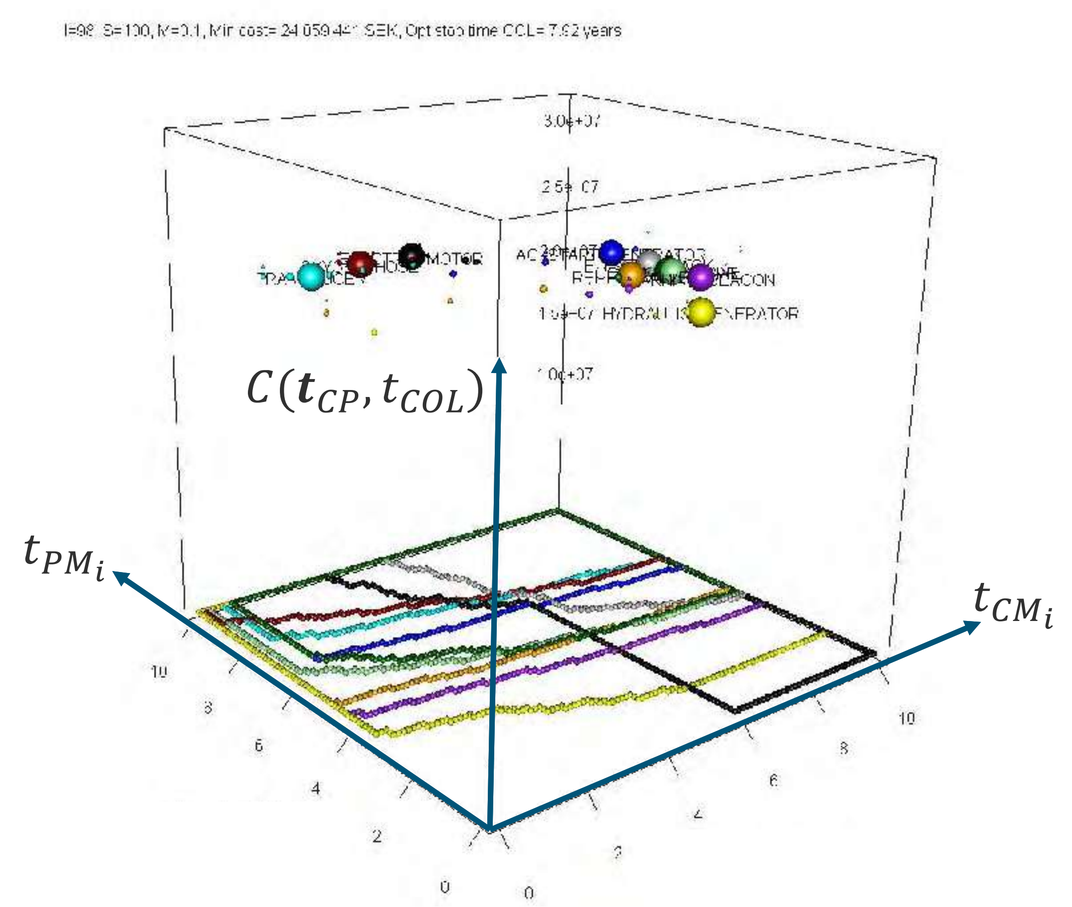
Genetic Algorithm (100 samples)

ΔT=1000 h



Genetic Algorithm (100 samples)

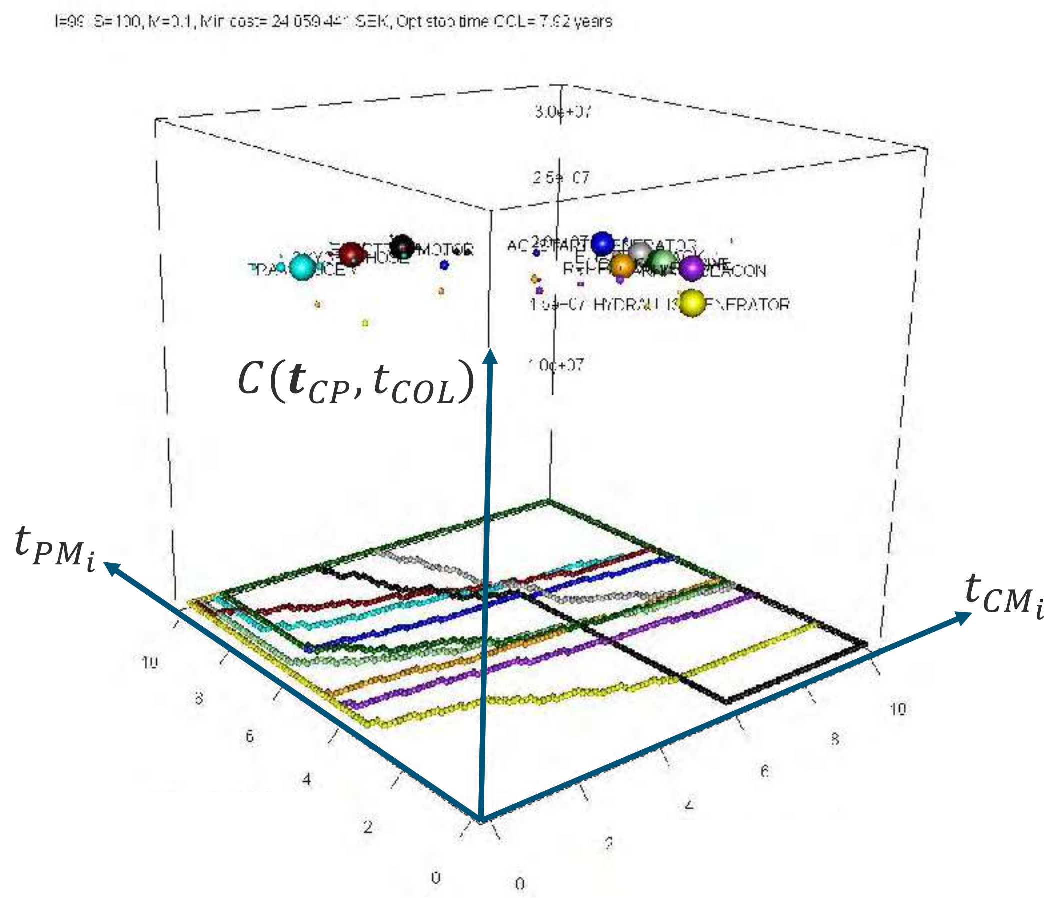
ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

ΔT=1000 h



Systecon

Genetic Algorithm (100 samples)

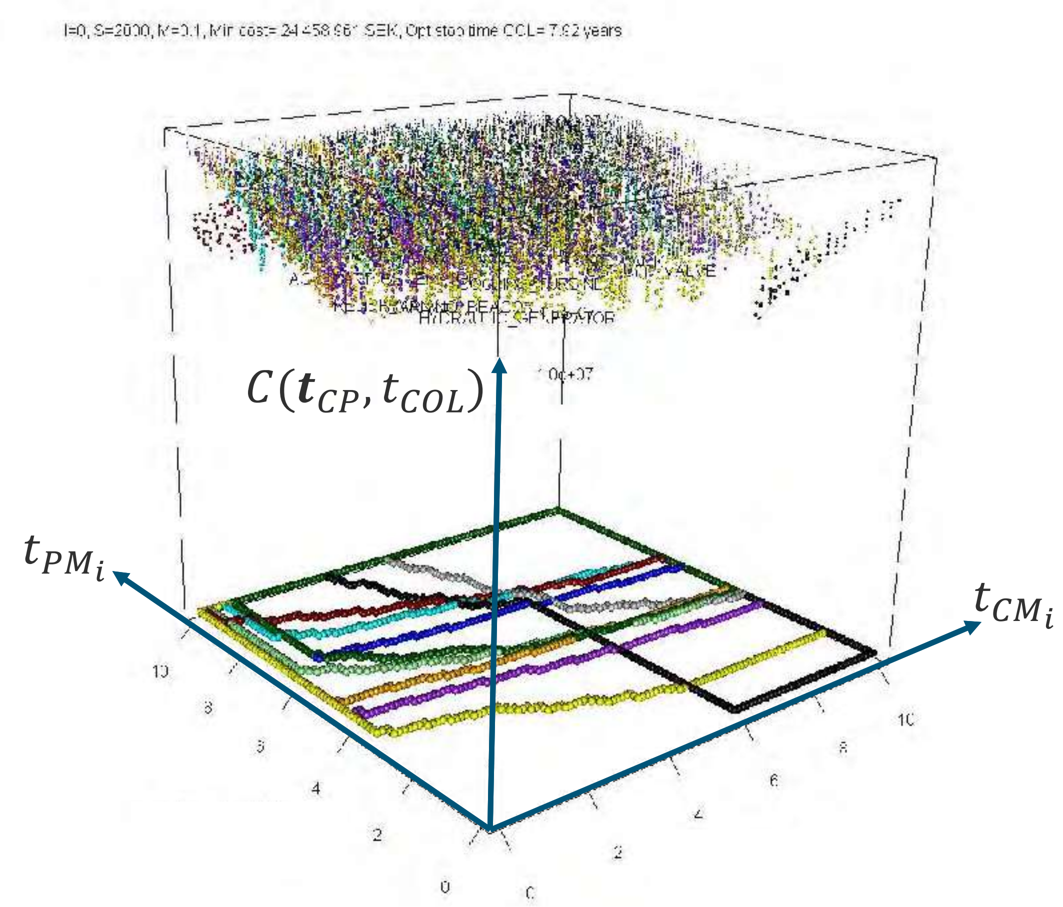
ΔT=1000 h

- Found solution:
  - $C_{min} = \mathbf{24.06}$ **MSEK**
  - $t_{COL}^{opt} = 7.92$ years
- 2 seconds on a laptop with a 2.7 GHz processor
- 0.05 % higher cost than true optimum found by brute force
- Only 10 000 out of 44 trillion solutions investigated

Systecon

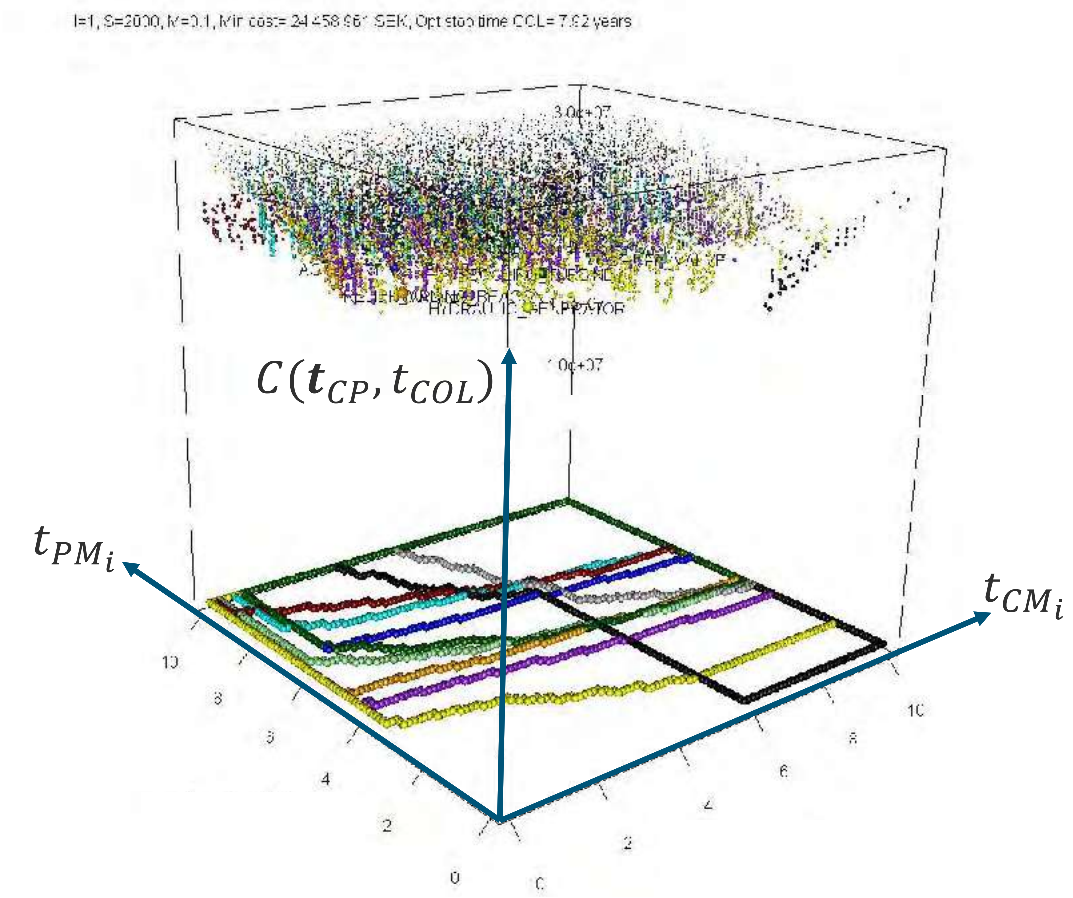
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

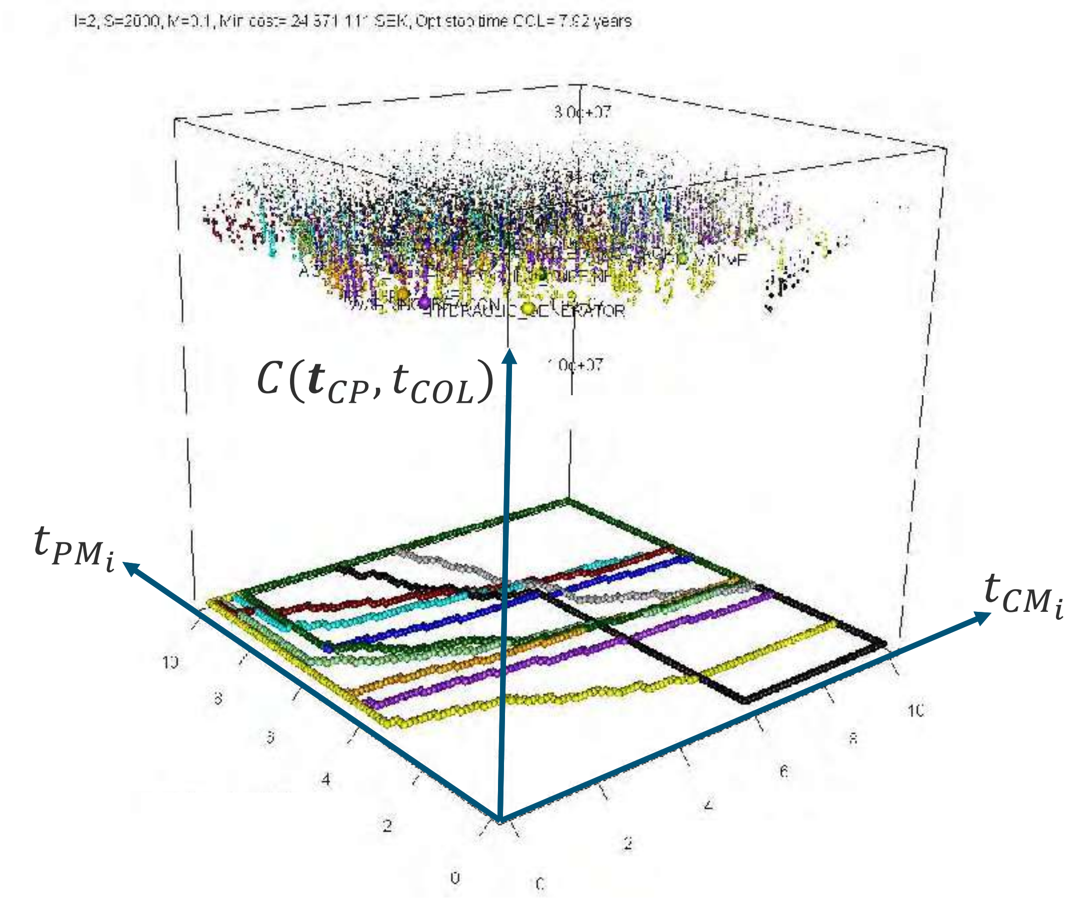
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

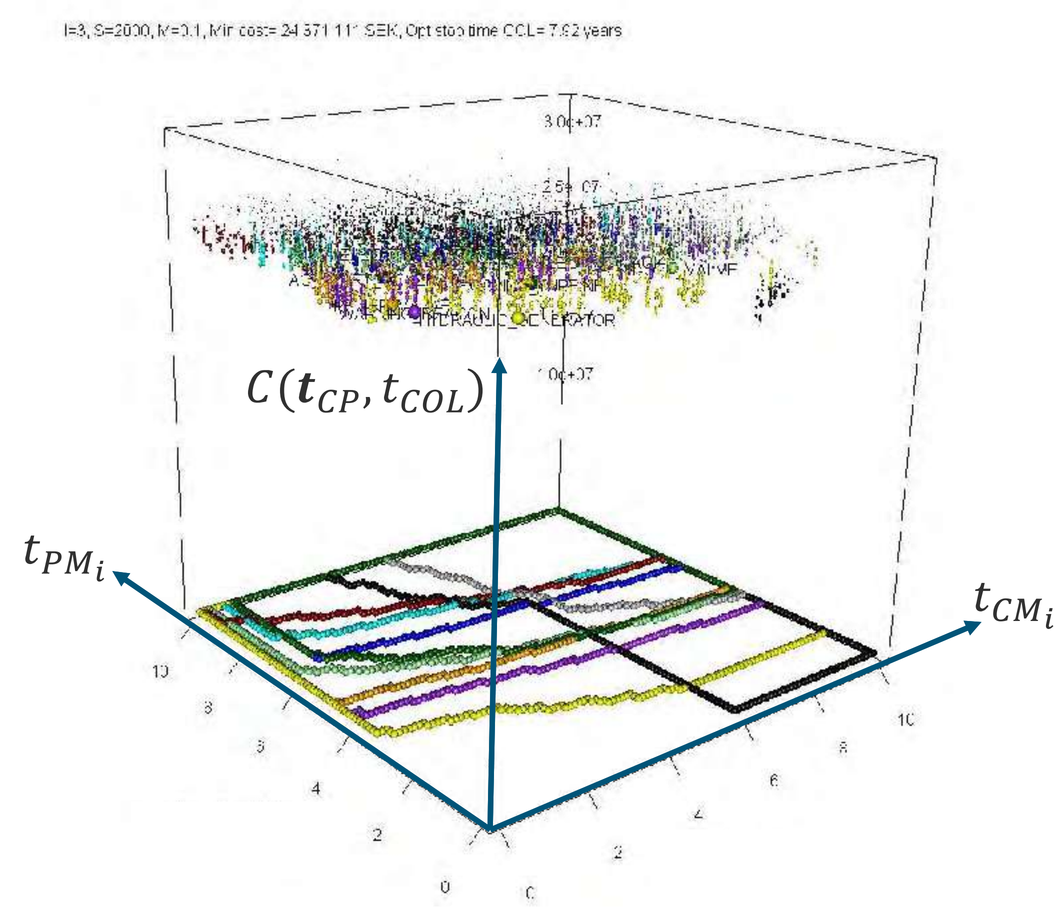
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

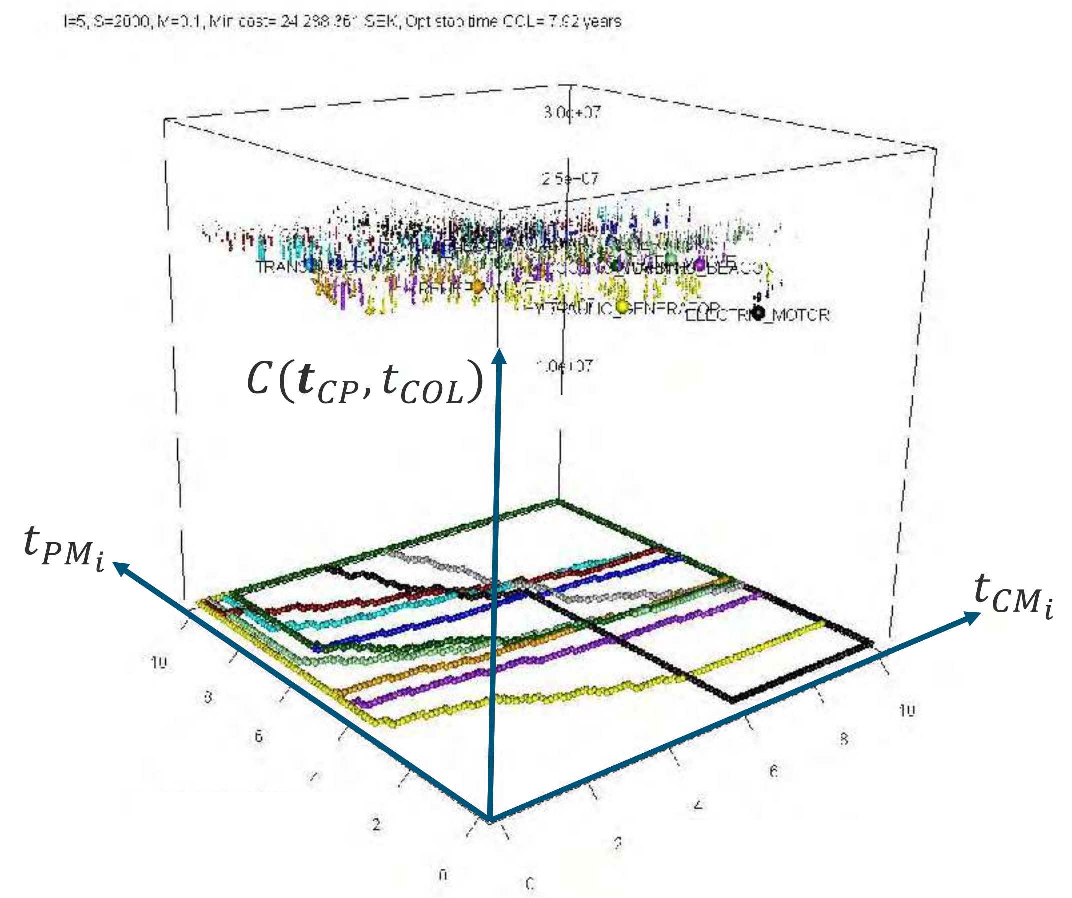
ΔT=1000 h



Systecon

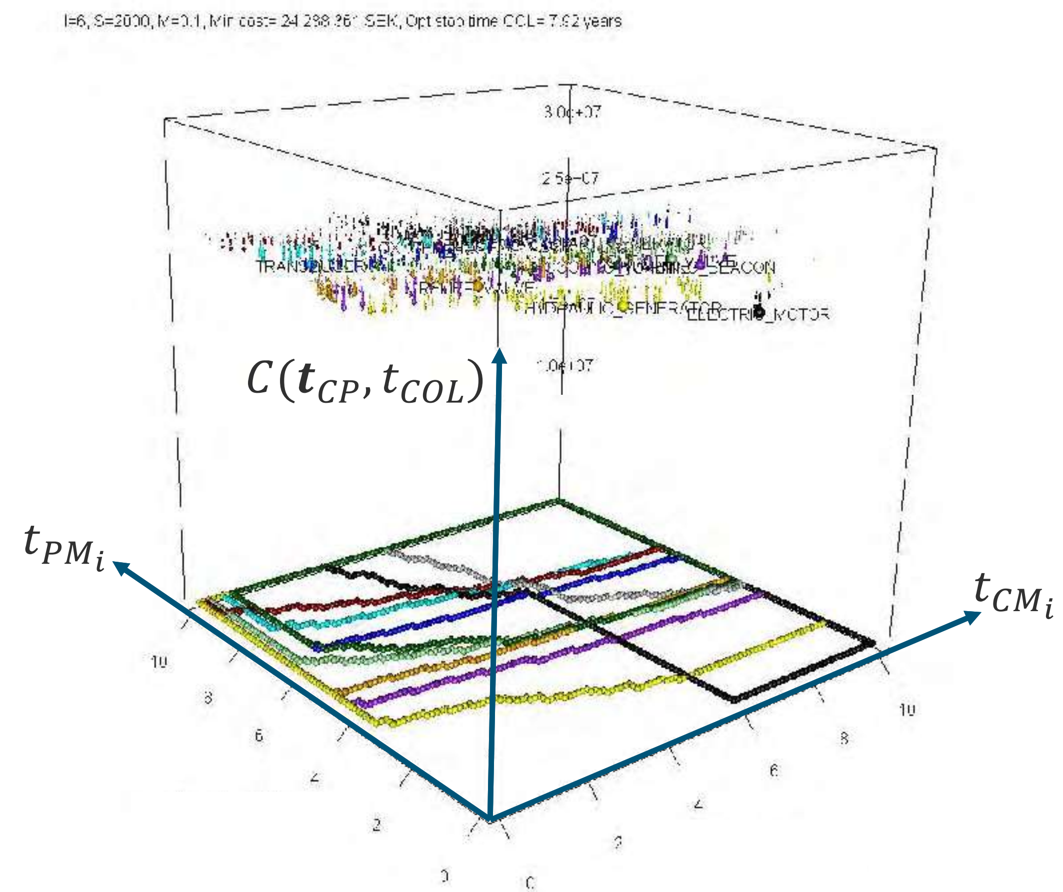
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

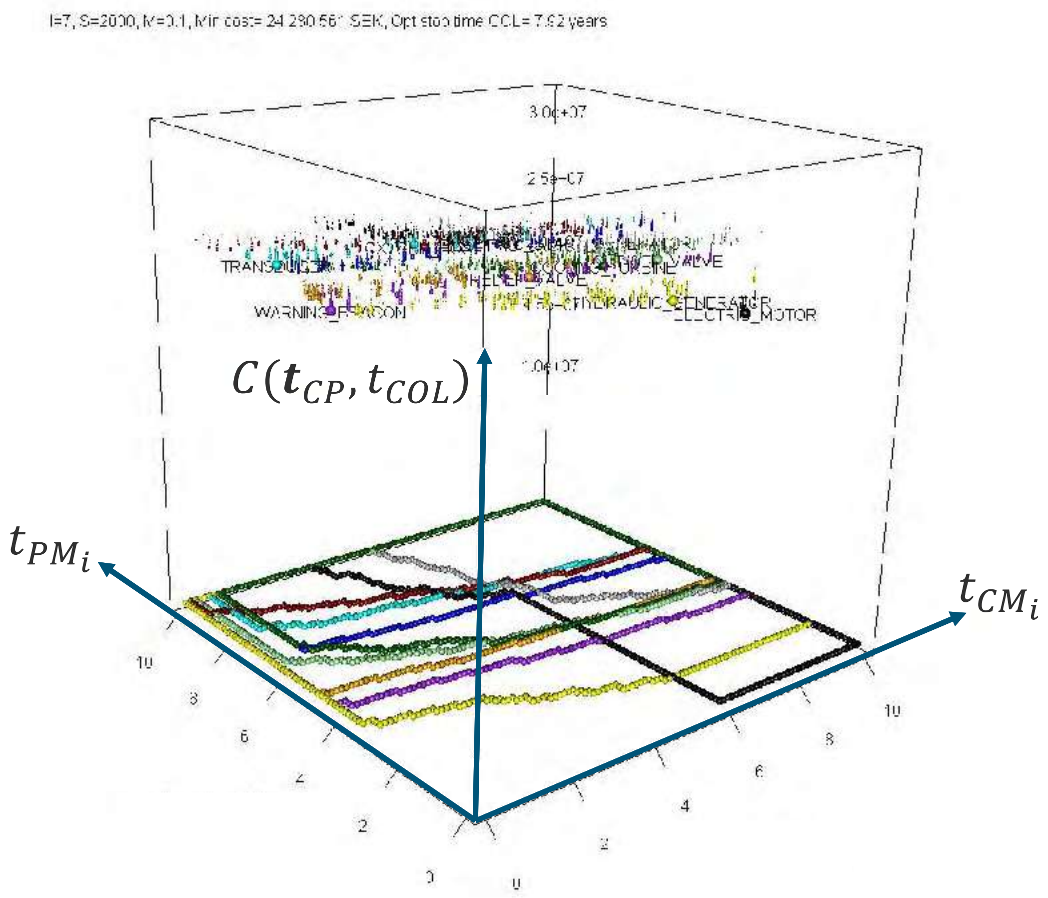
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

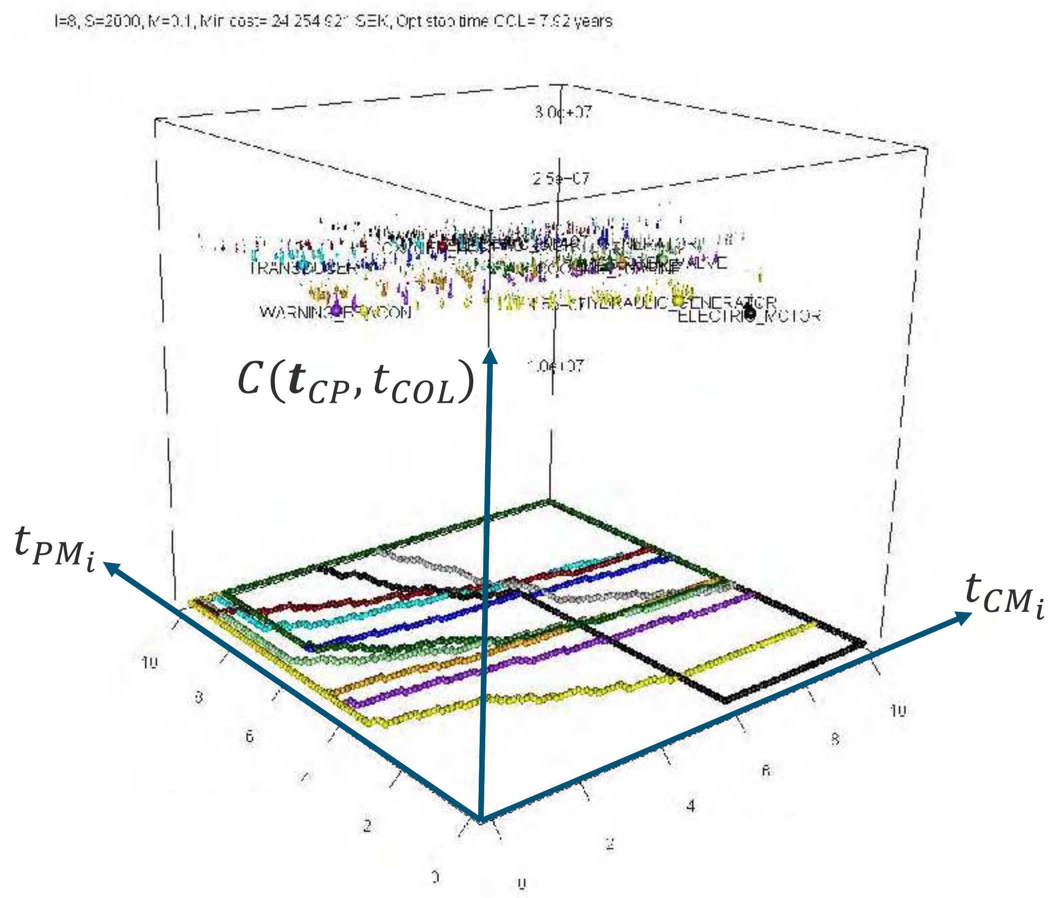
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

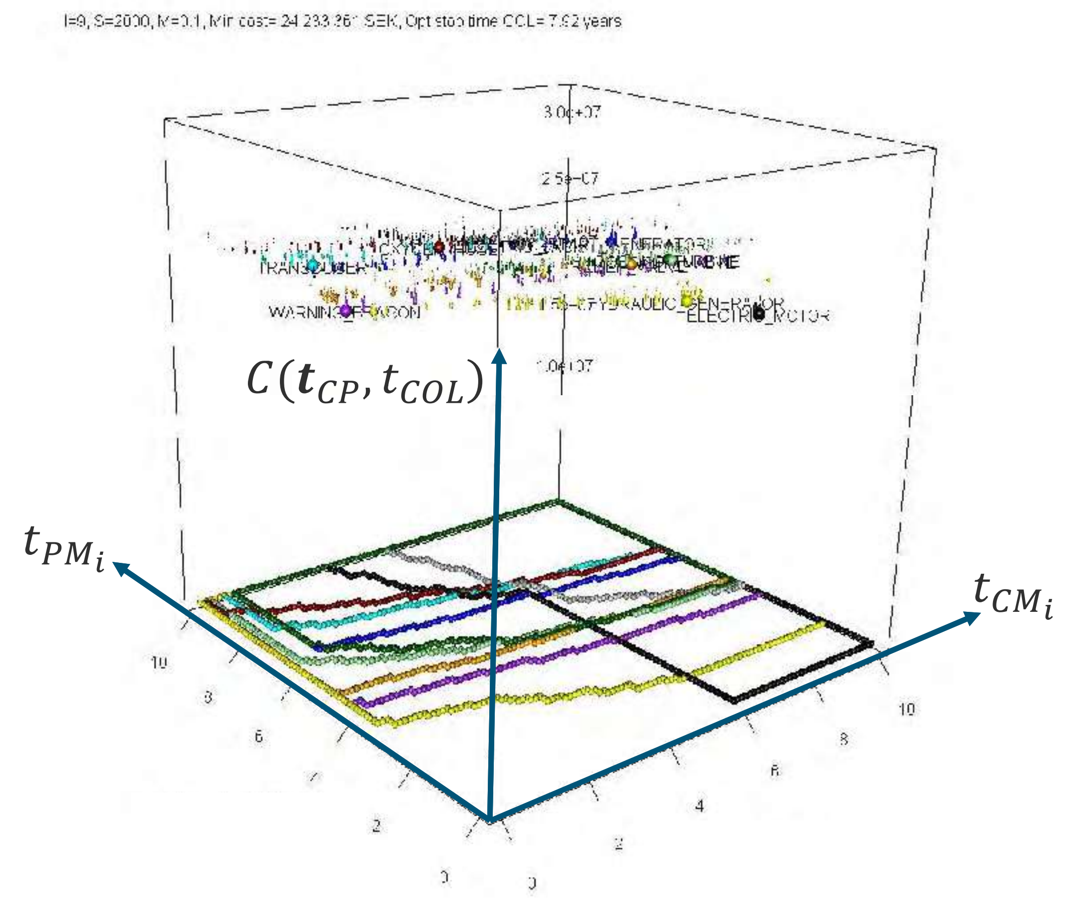
ΔT=1000 h



Systecon

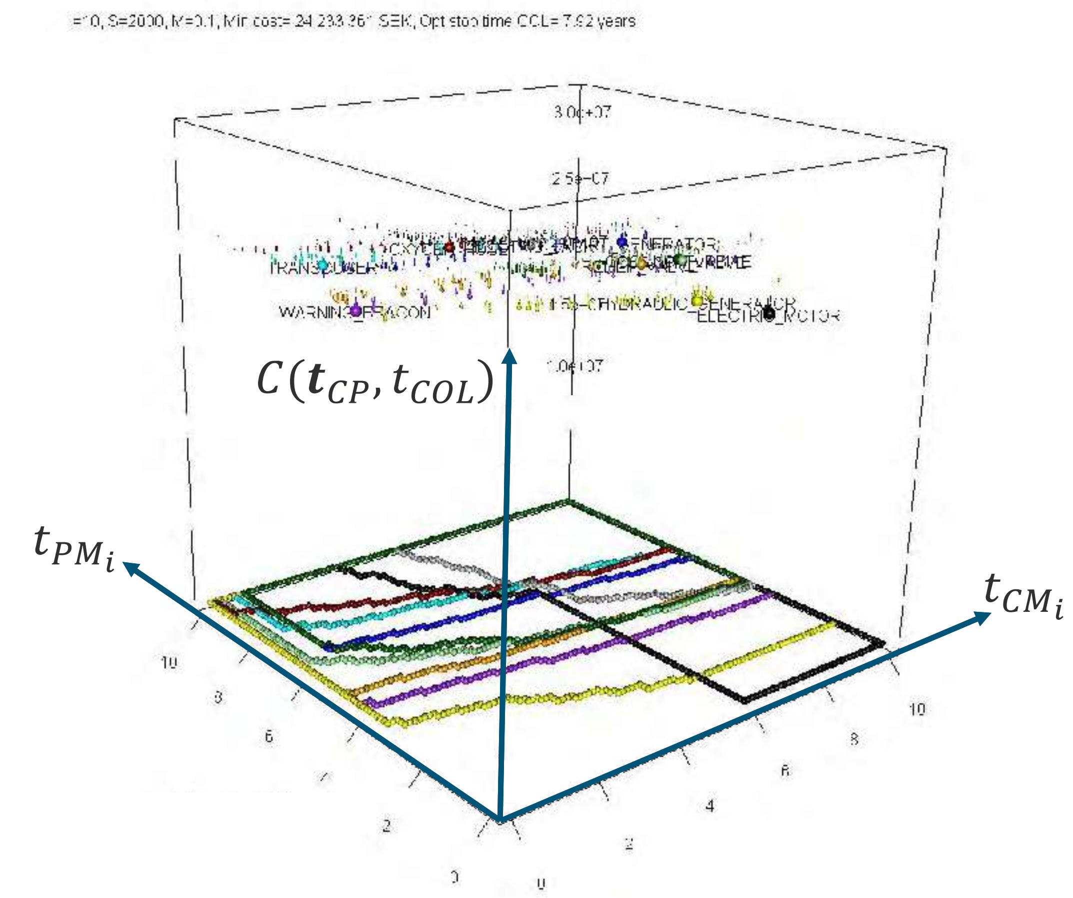
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

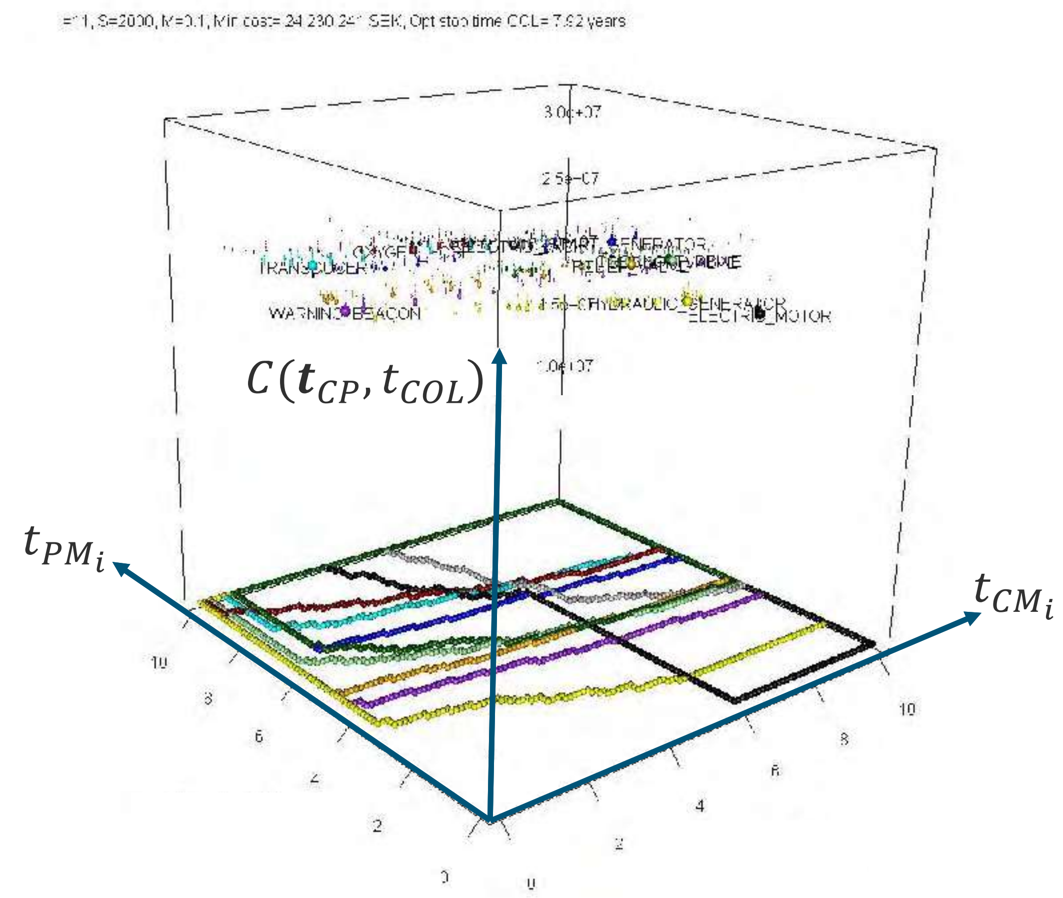
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

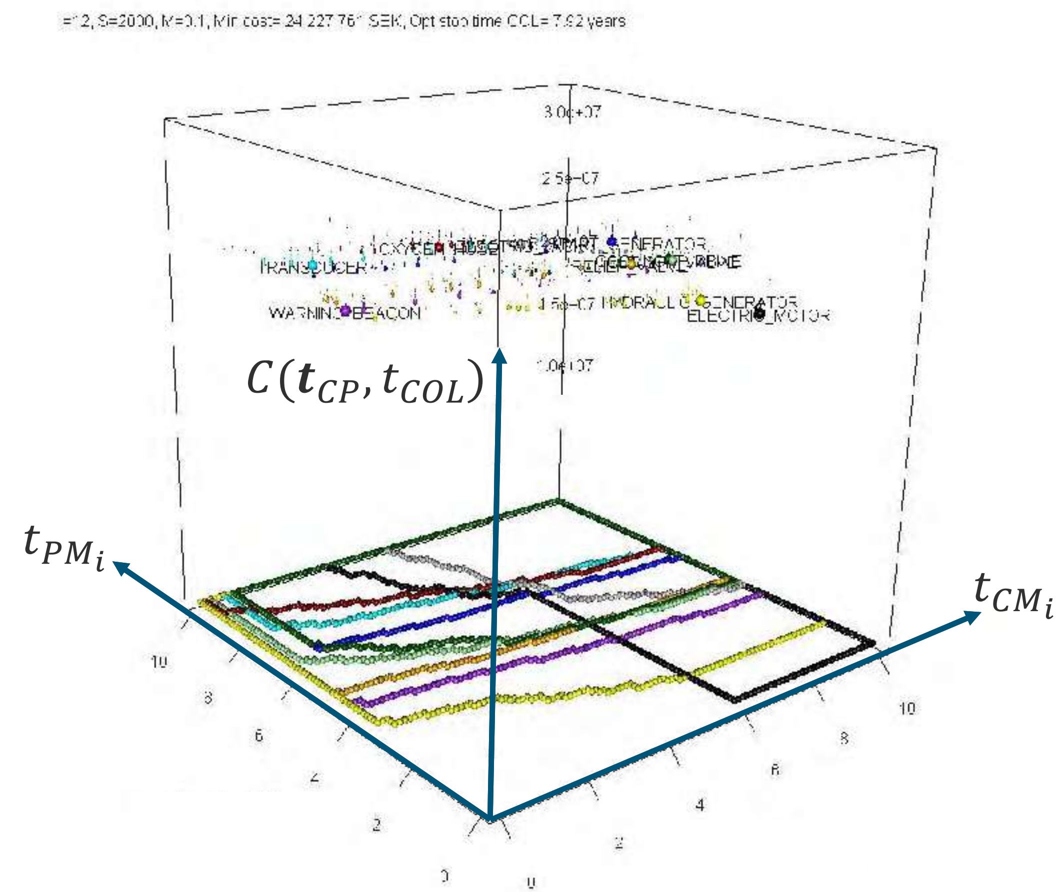
ΔT=1000 h



Systecon

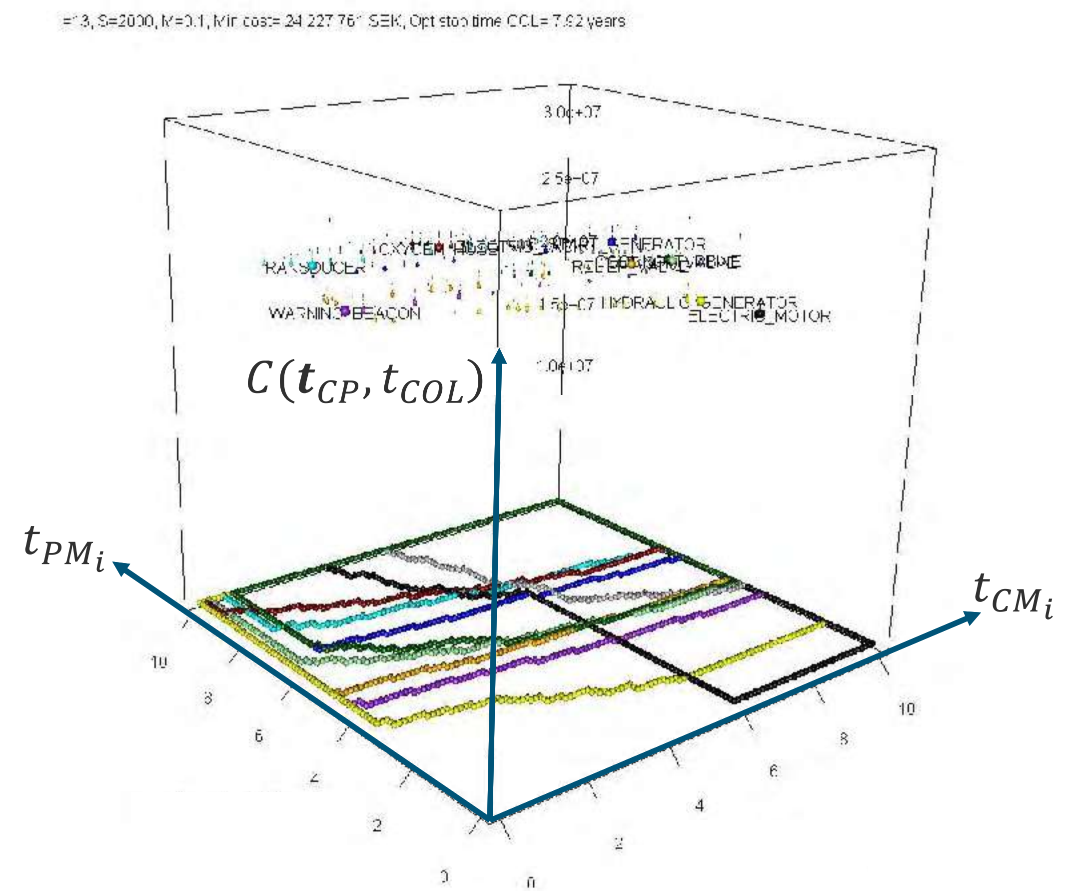
Genetic Algorithm (2000 samples)

ΔT=1000 h



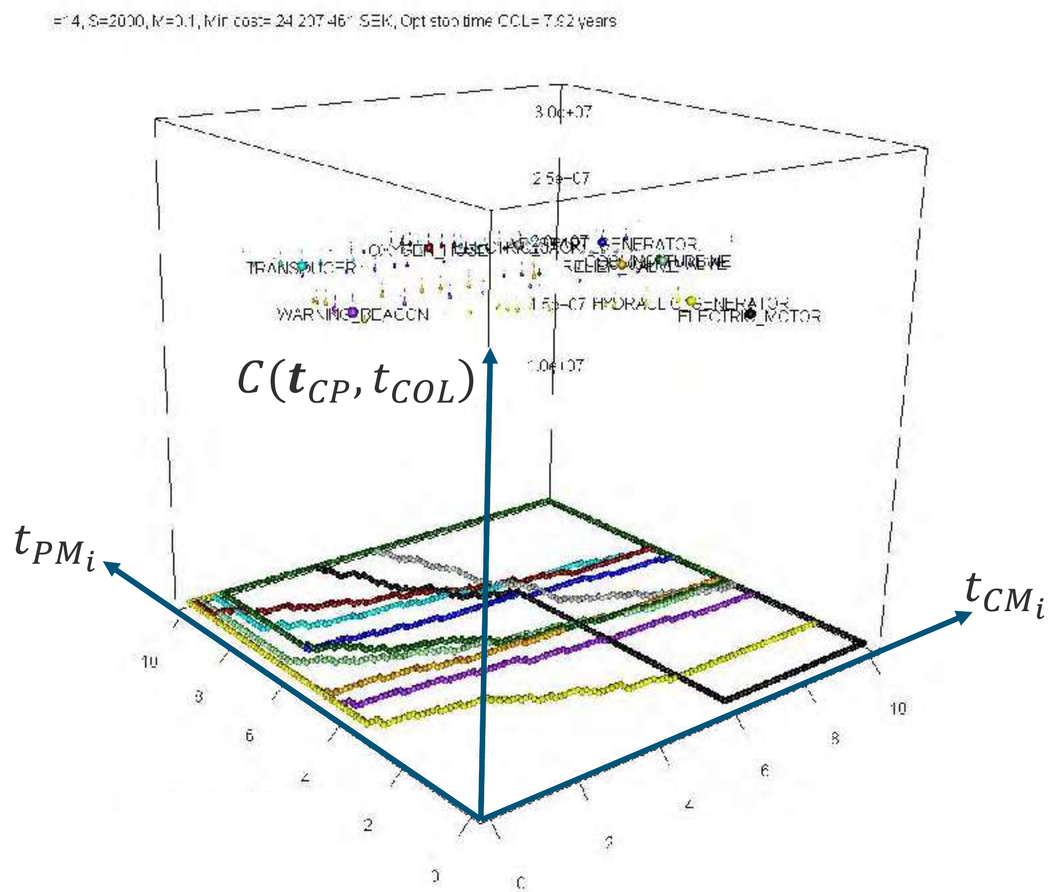
Genetic Algorithm (2000 samples)

ΔT=1000 h



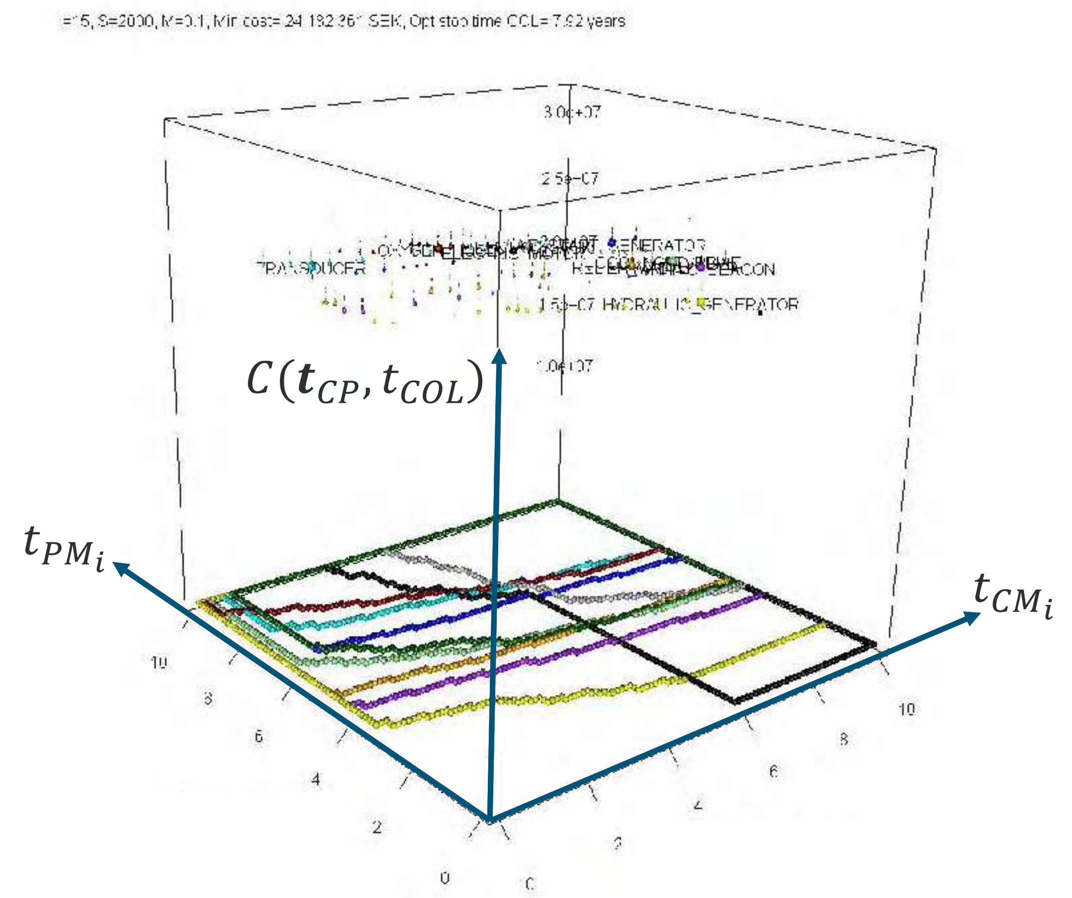
Genetic Algorithm (2000 samples)

ΔT=1000 h



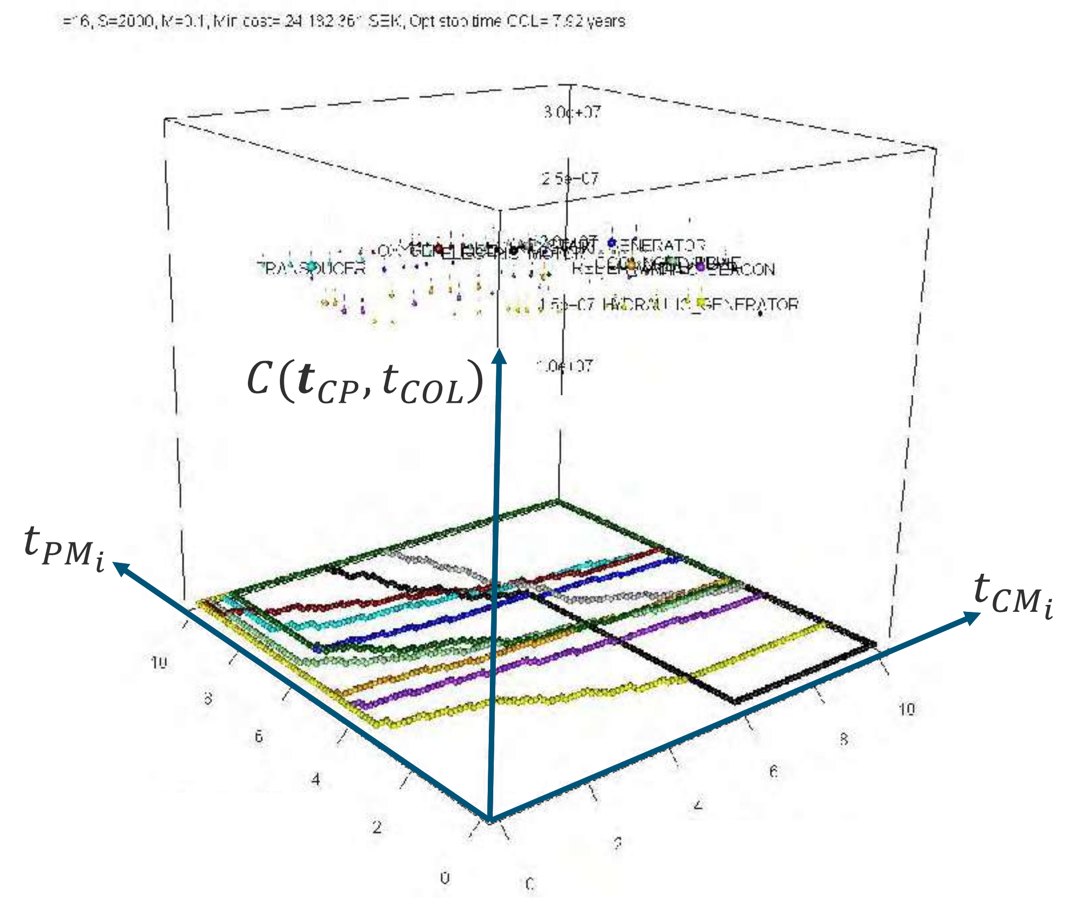
Genetic Algorithm (2000 samples)

ΔT=1000 h



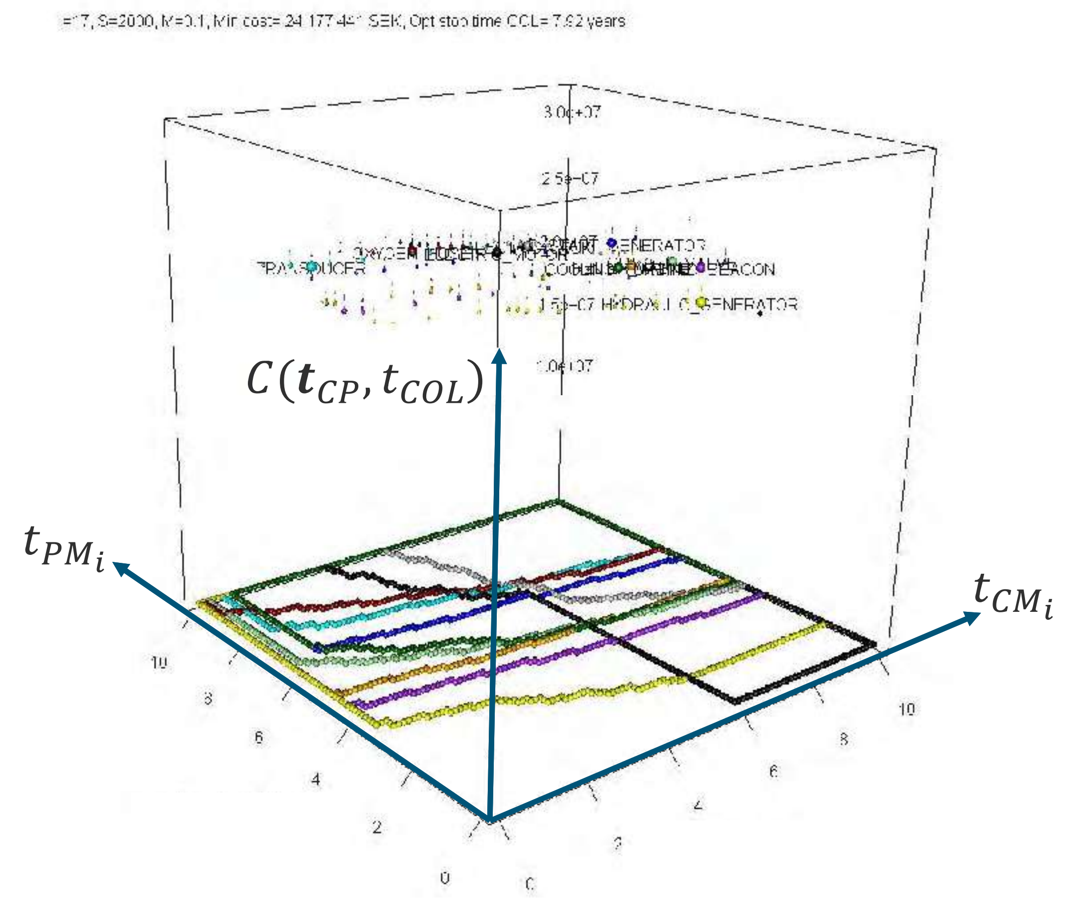
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

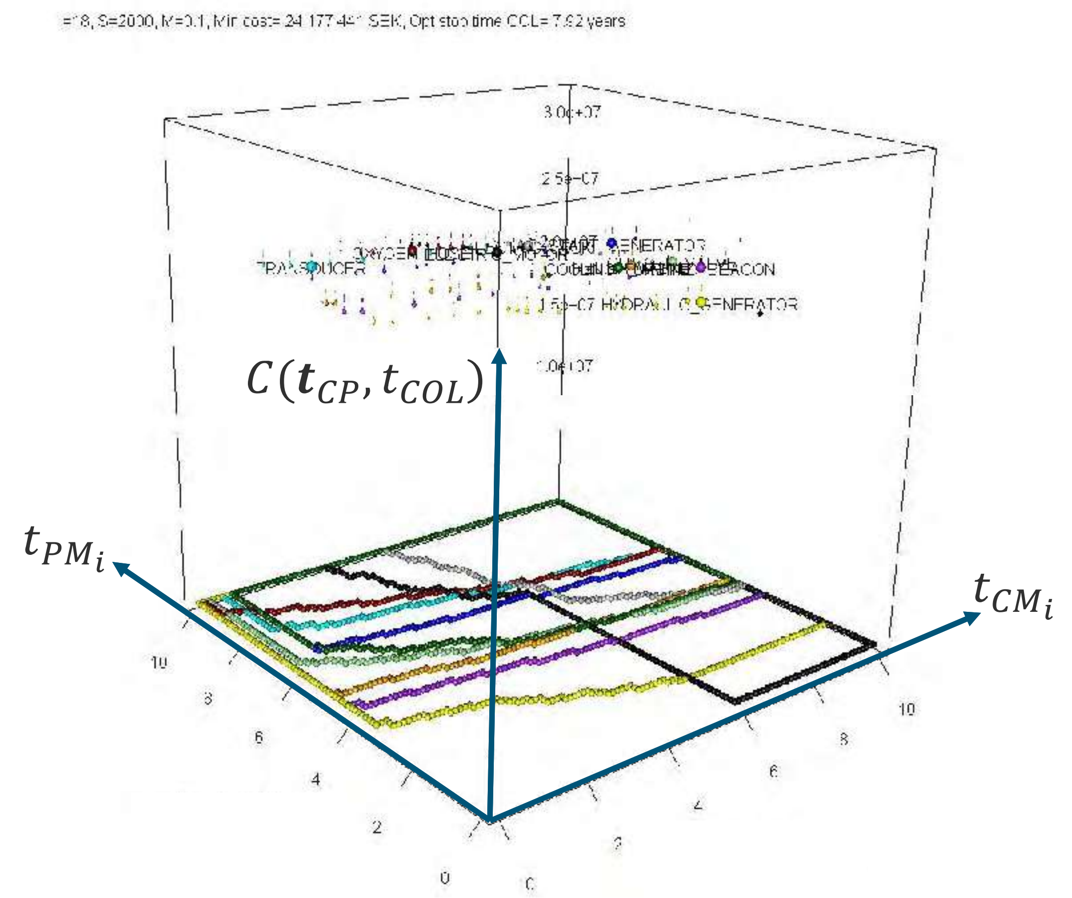
ΔT=1000 h



Systecon

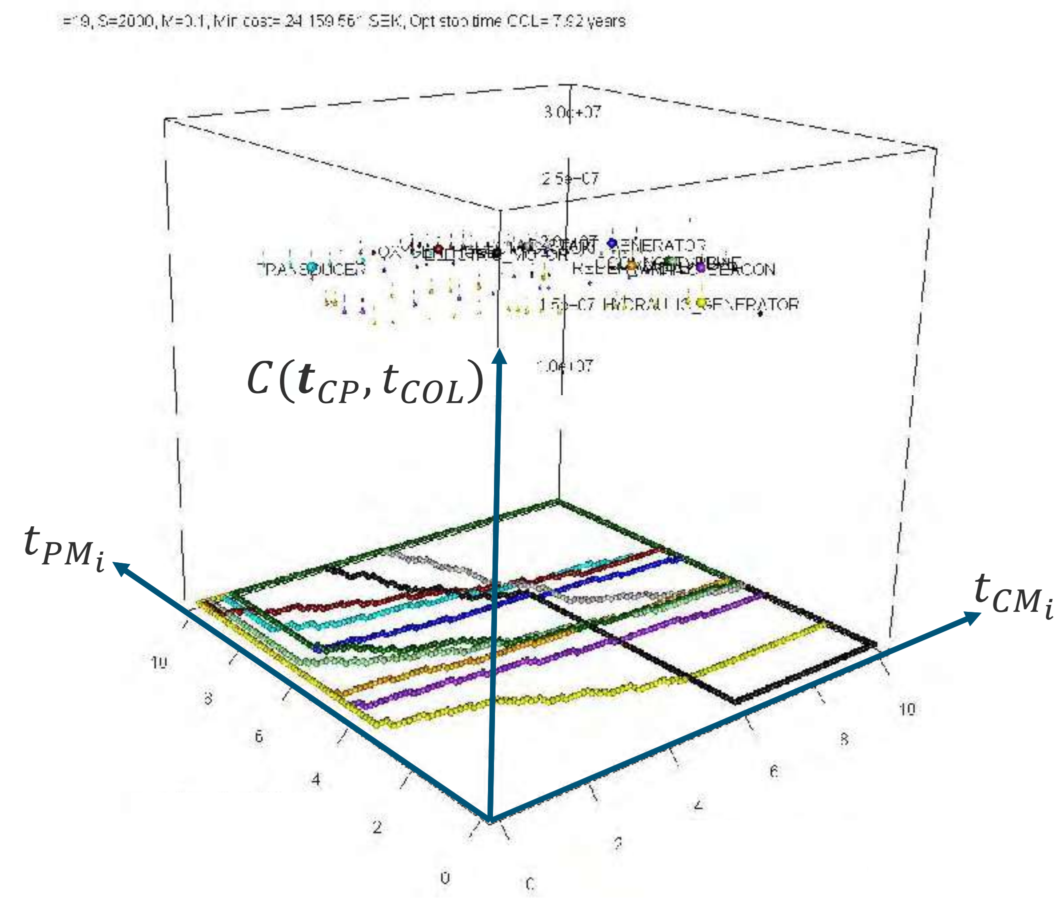
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

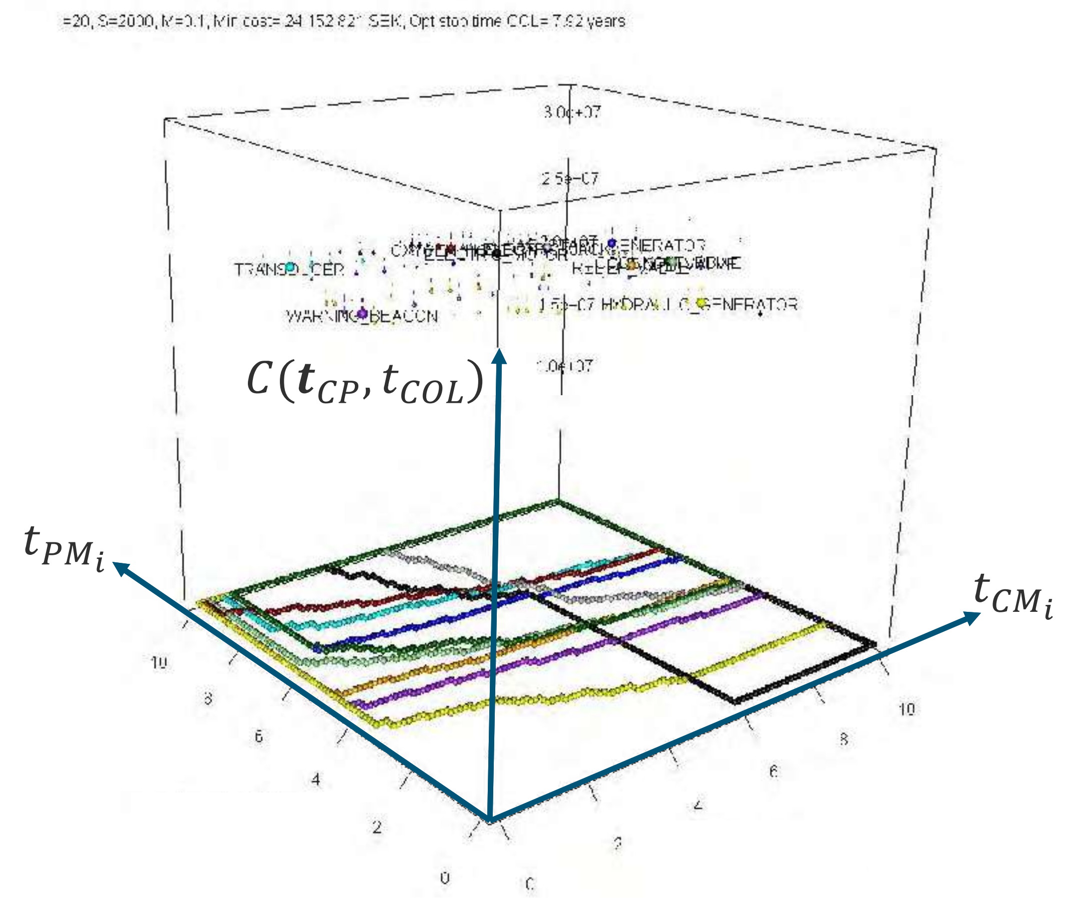
ΔT=1000 h



Systecon

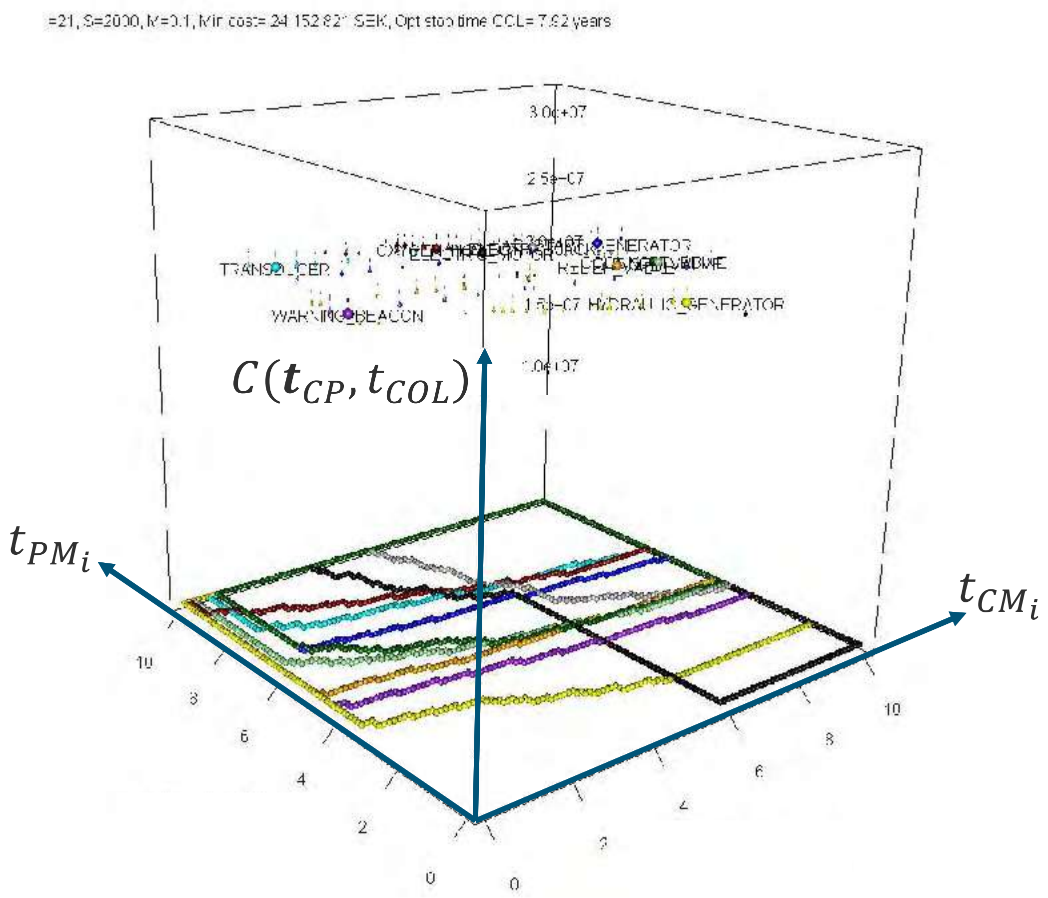
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

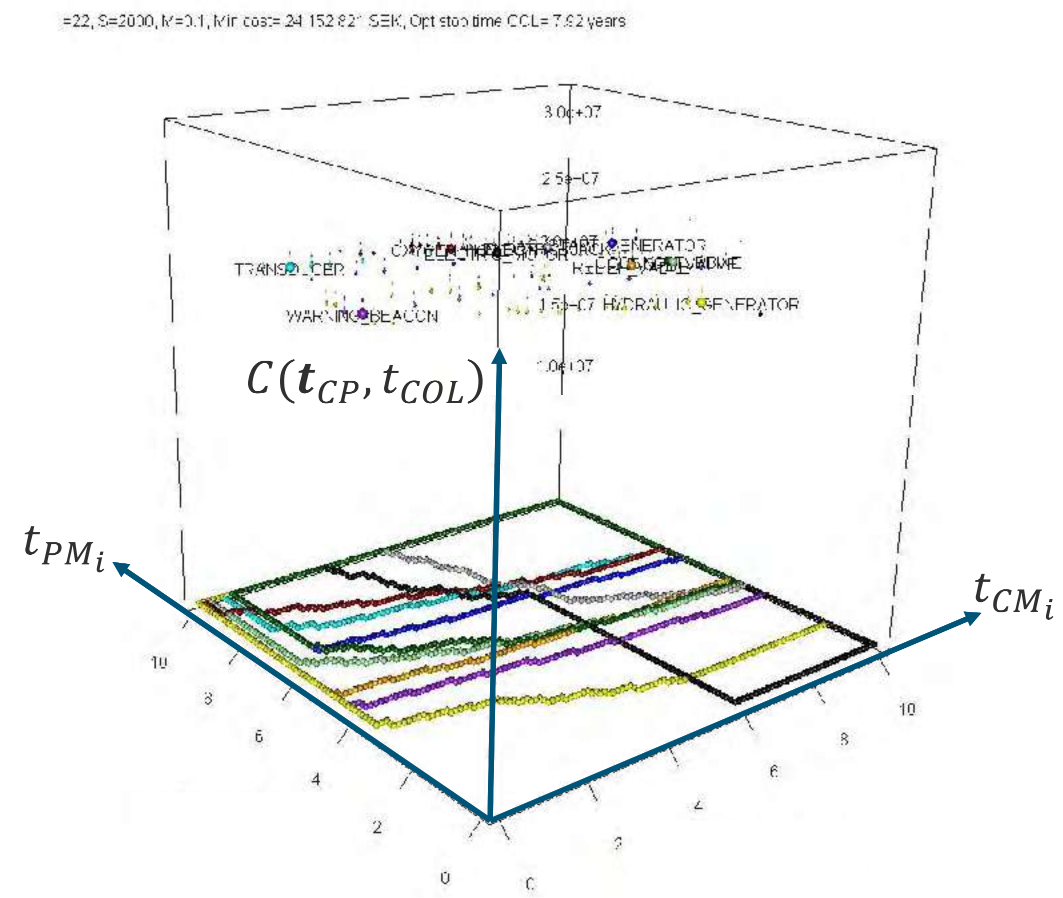
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

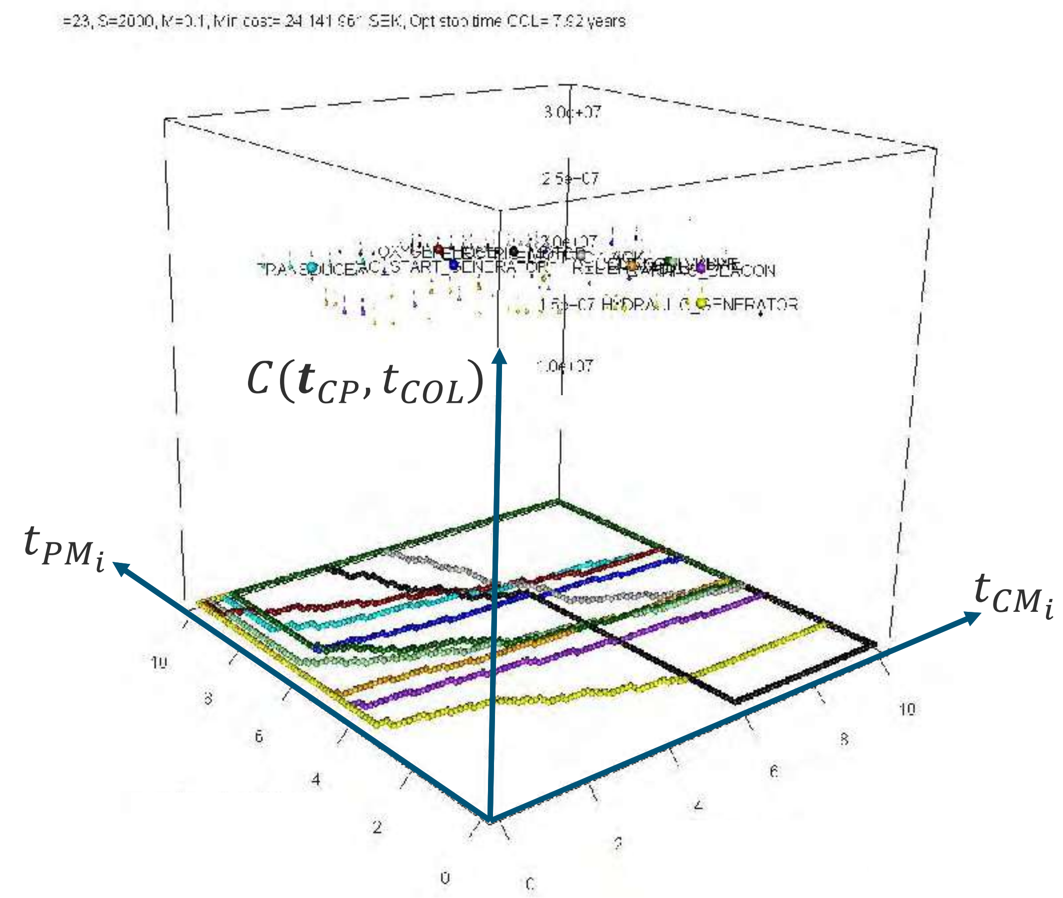
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

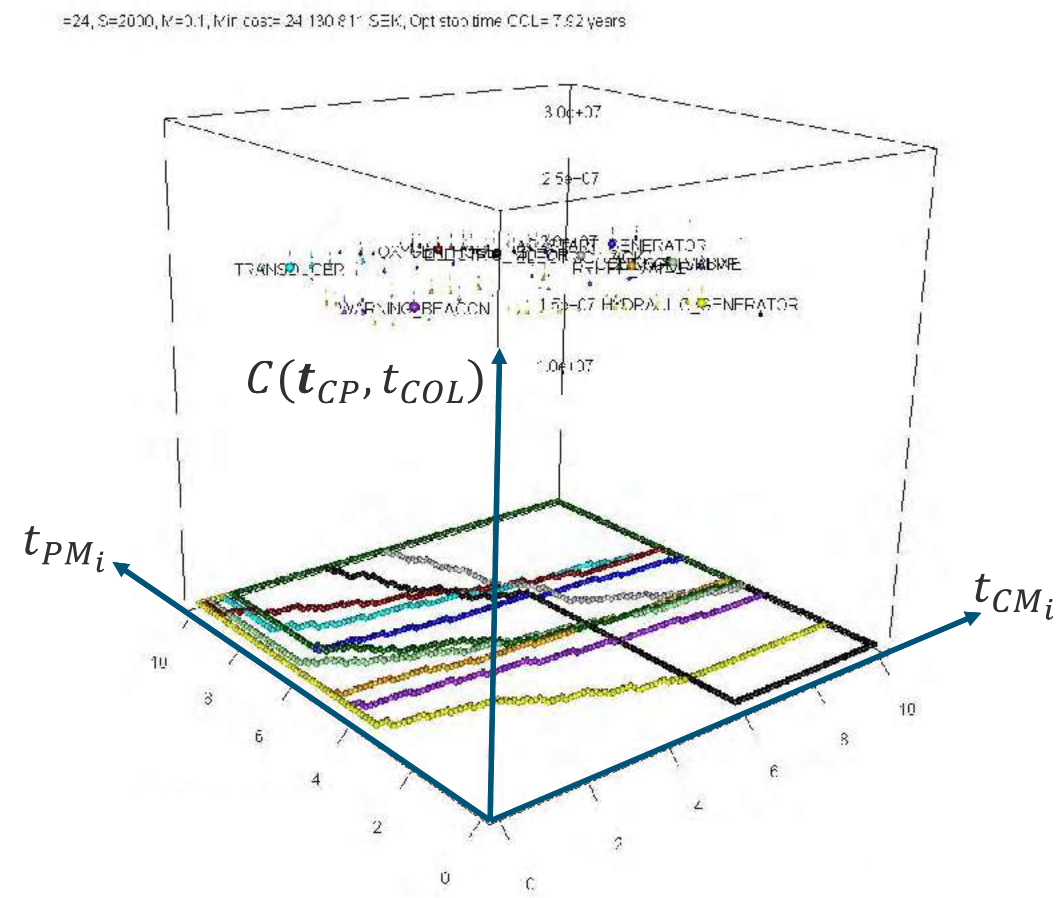
ΔT=1000 h



Systecon

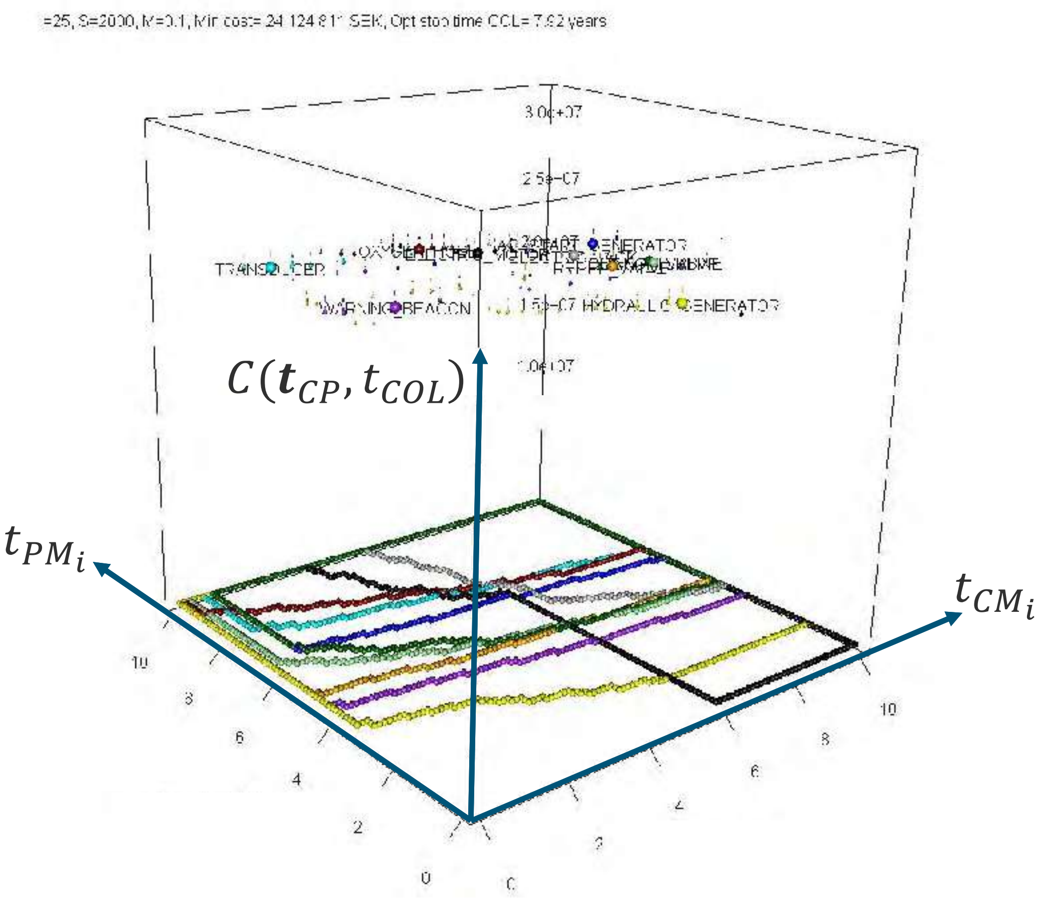
Genetic Algorithm (2000 samples)

ΔT=1000 h



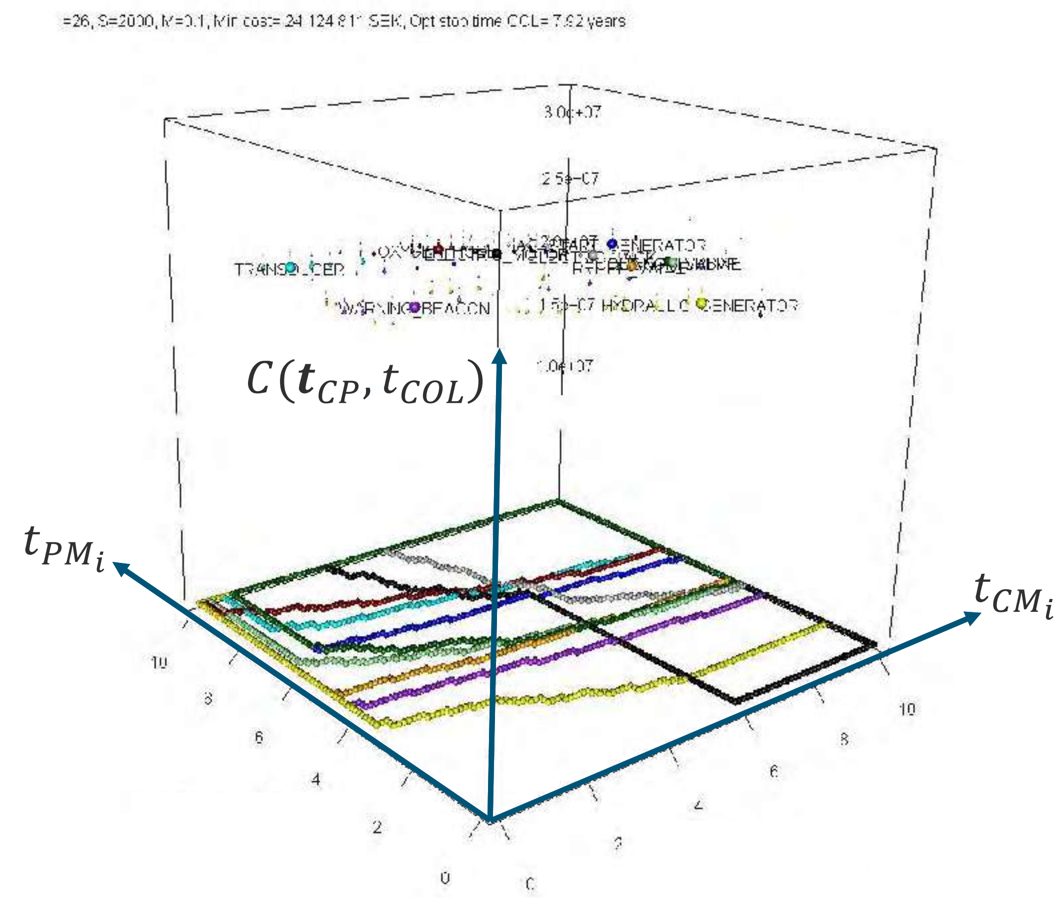
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

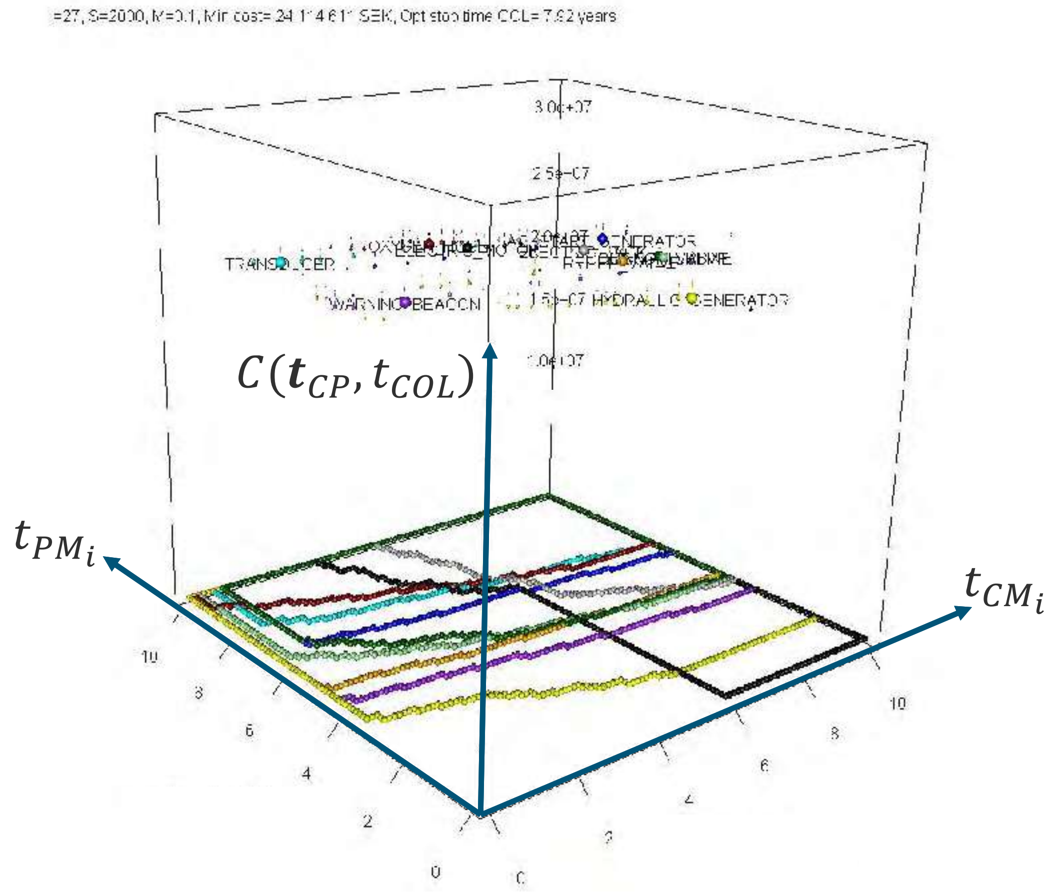
ΔT=1000 h



Systecon

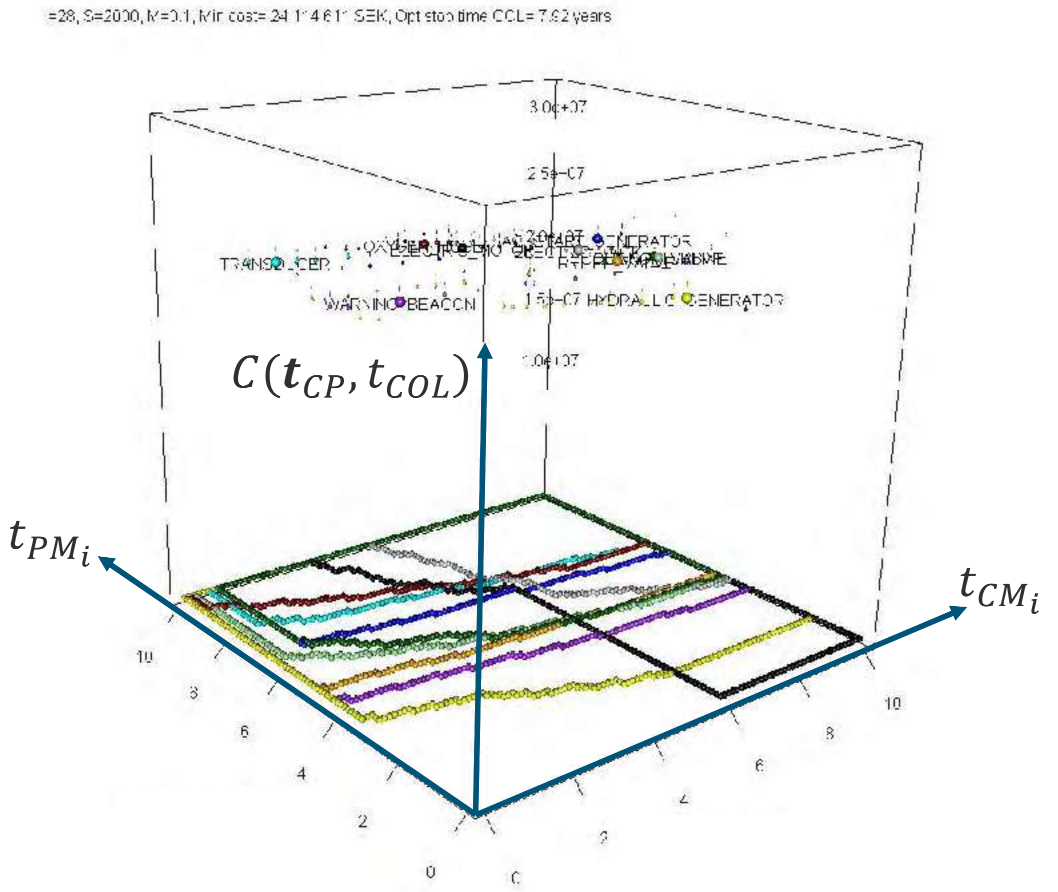
Genetic Algorithm (2000 samples)

ΔT=1000 h



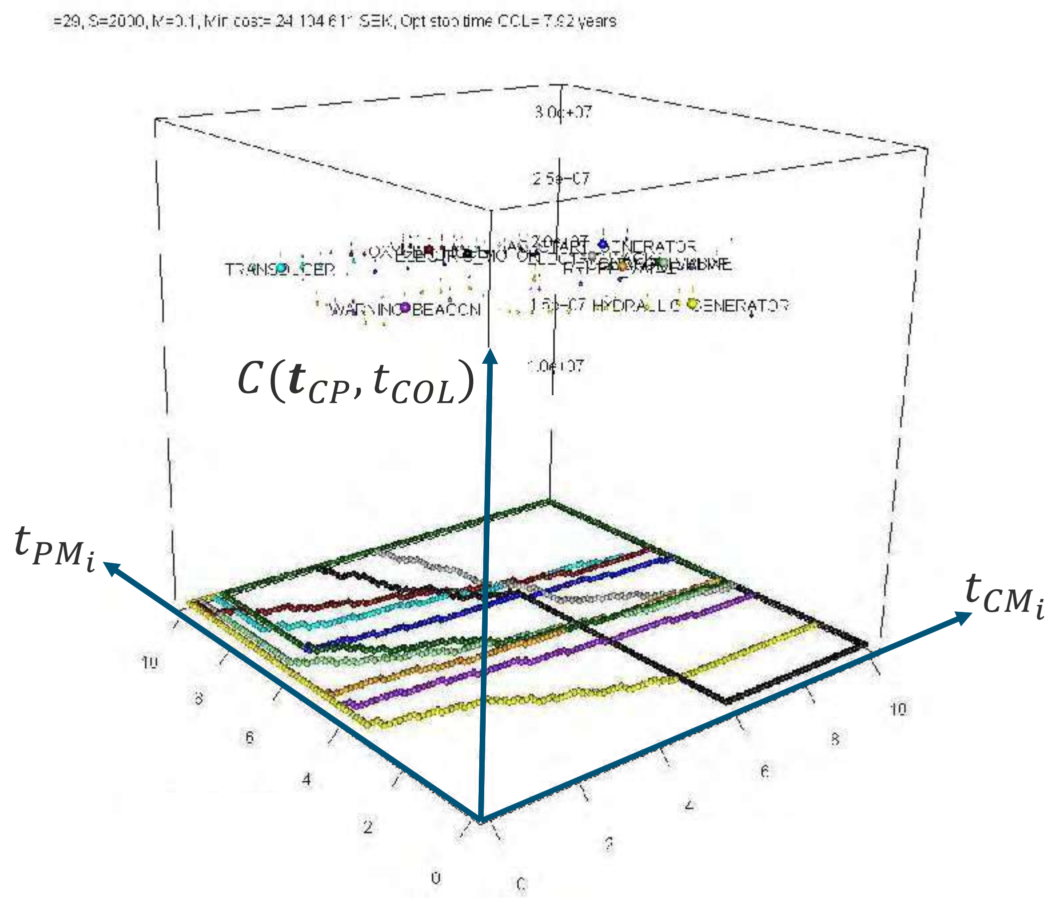
Genetic Algorithm (2000 samples)

ΔT=1000 h



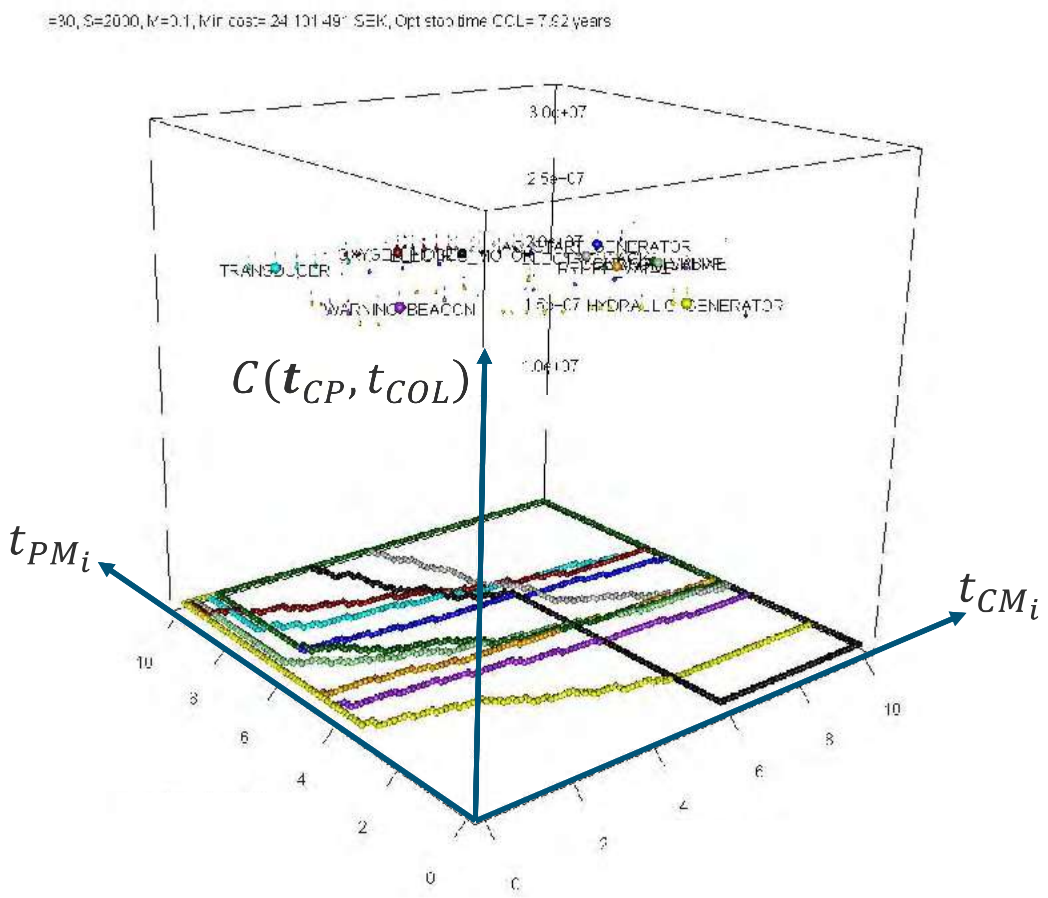
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

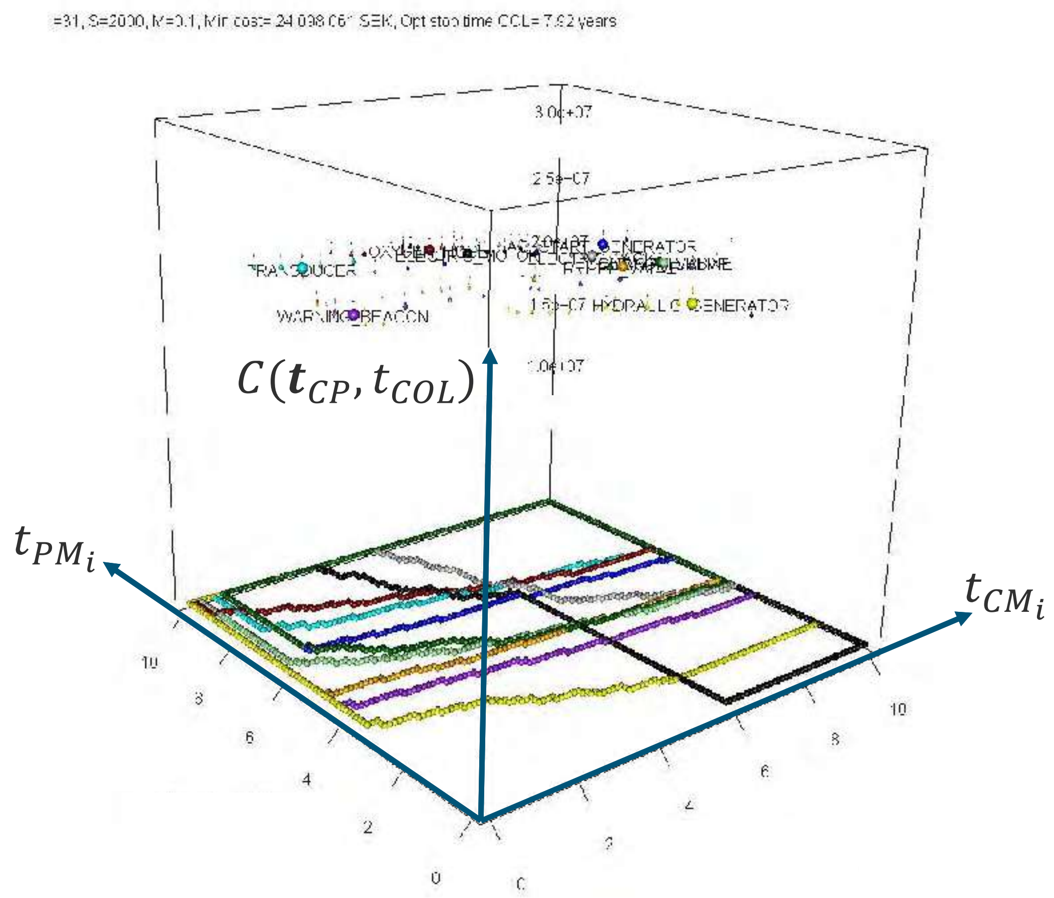
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

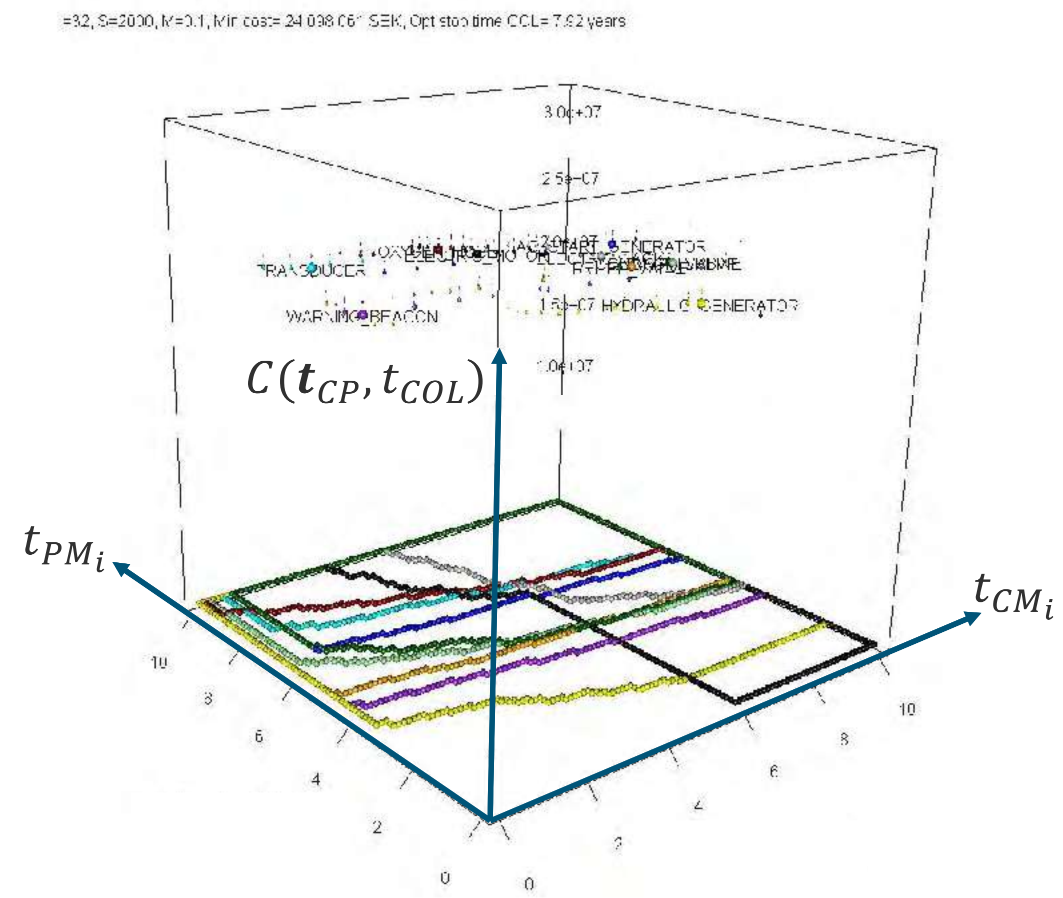
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

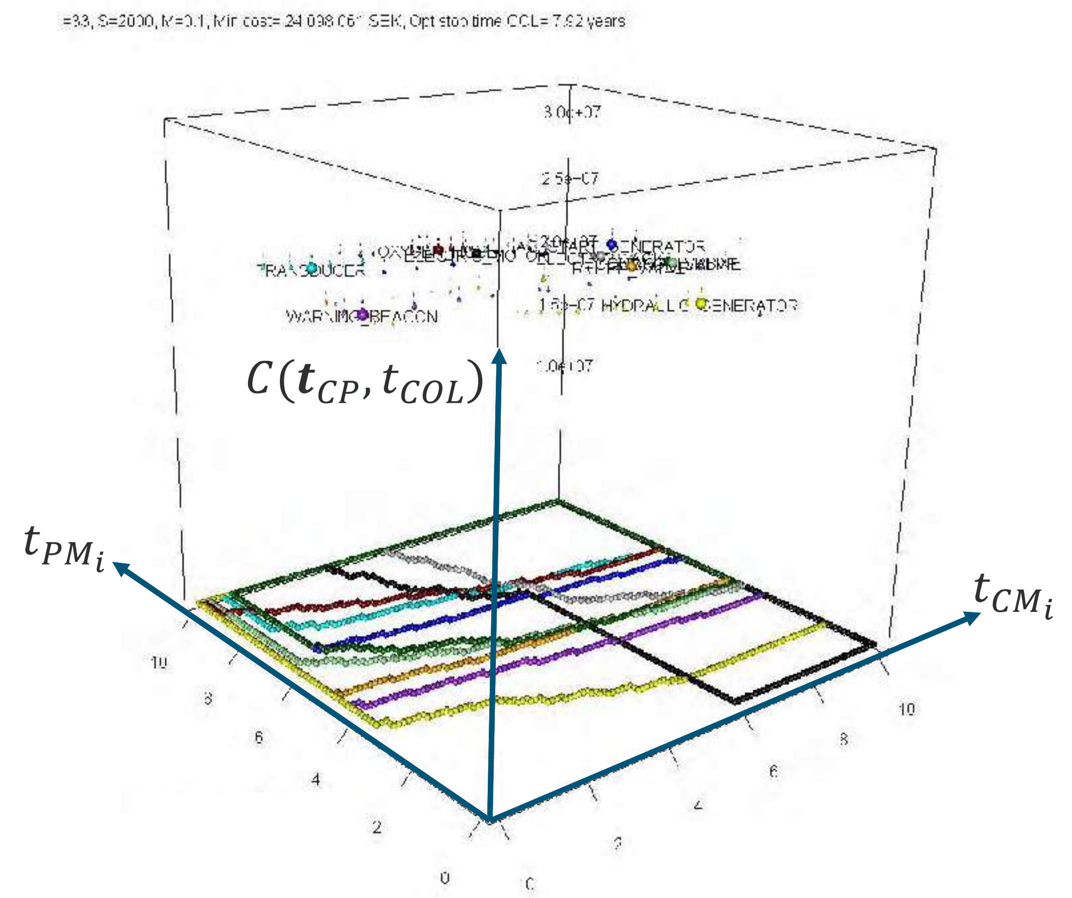
ΔT=1000 h



Systecon

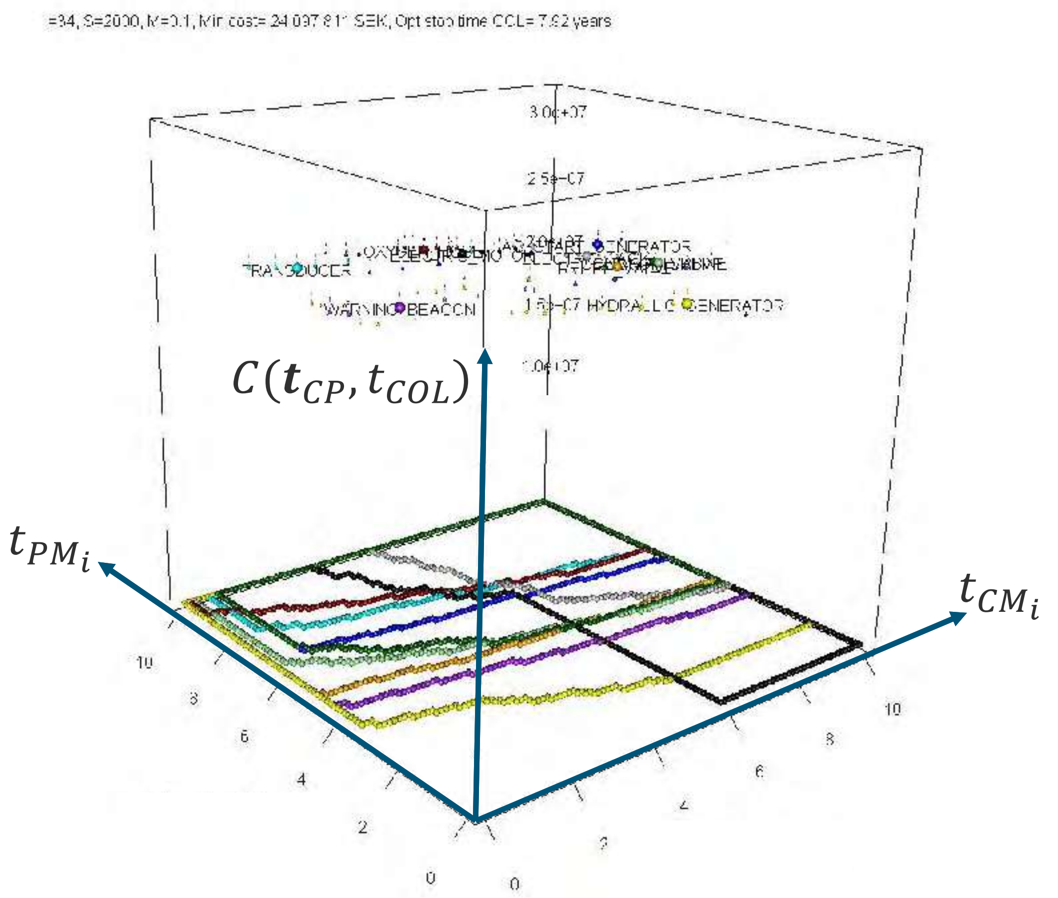
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

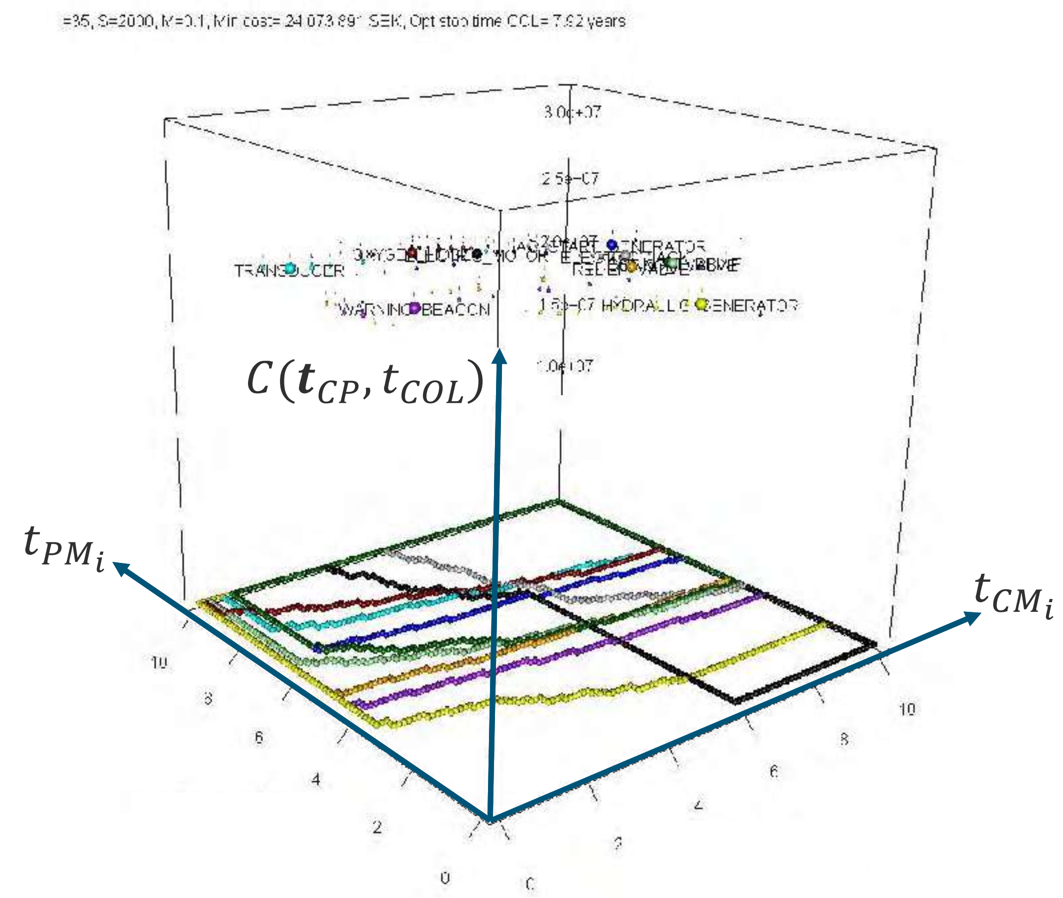
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

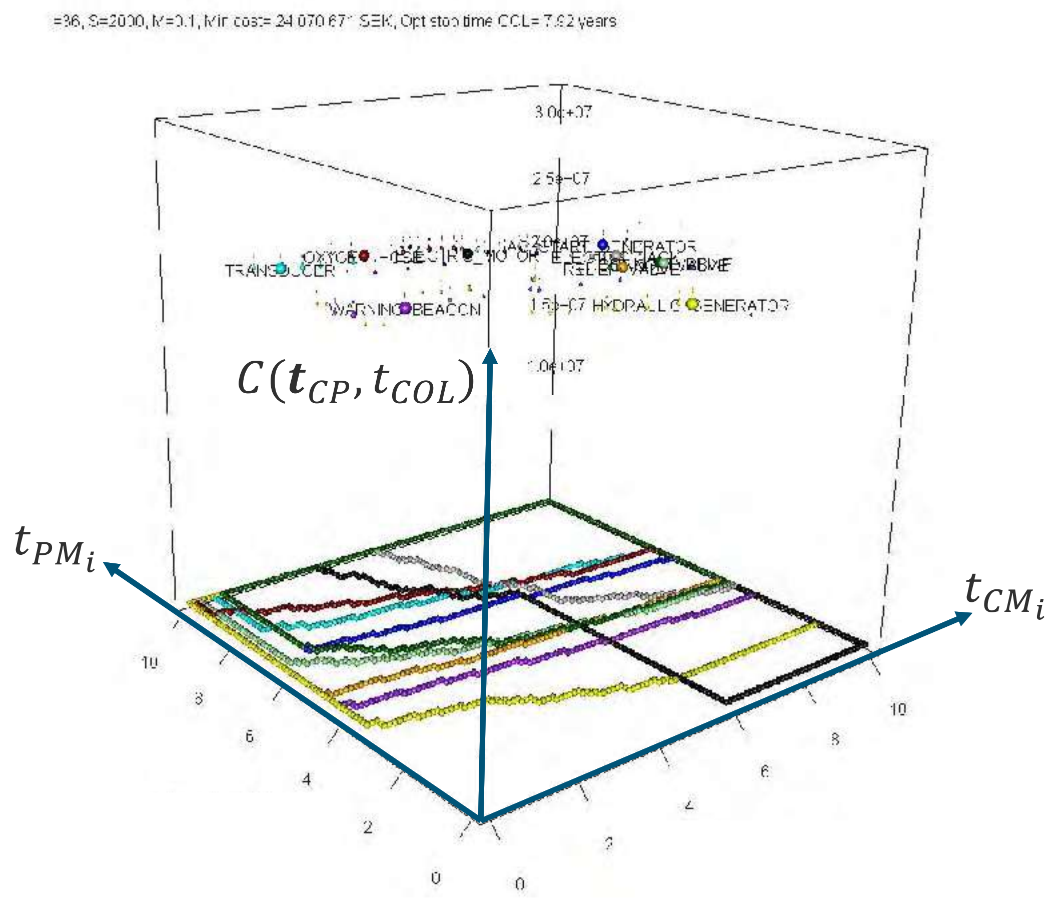
ΔT=1000 h



Systecon

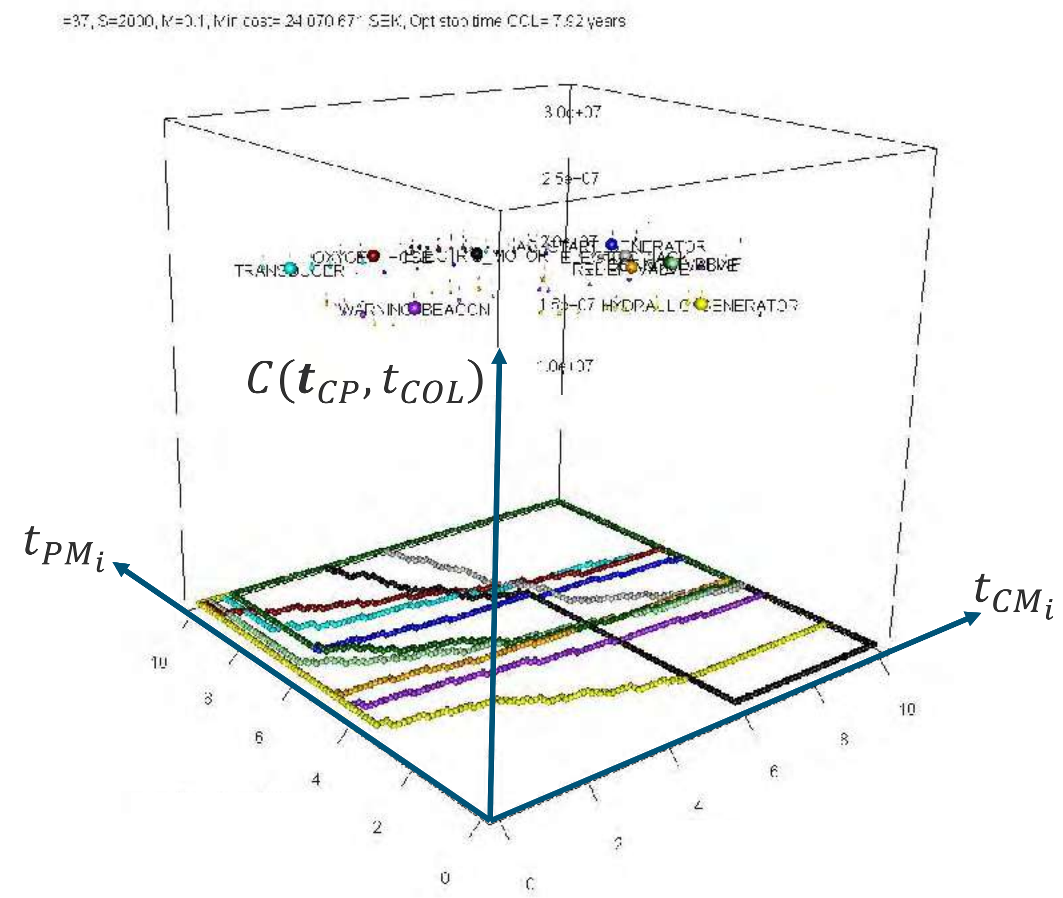
Genetic Algorithm (2000 samples)

ΔT=1000 h



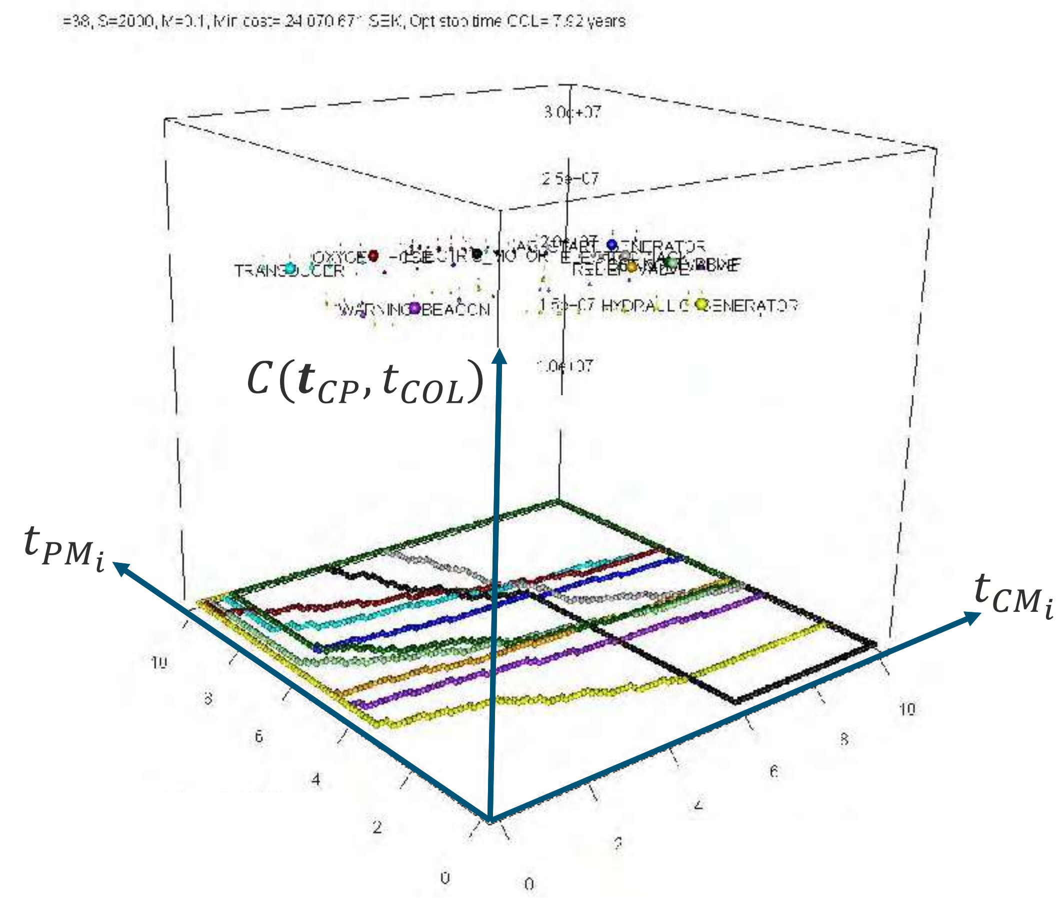
Genetic Algorithm (2000 samples)

ΔT=1000 h



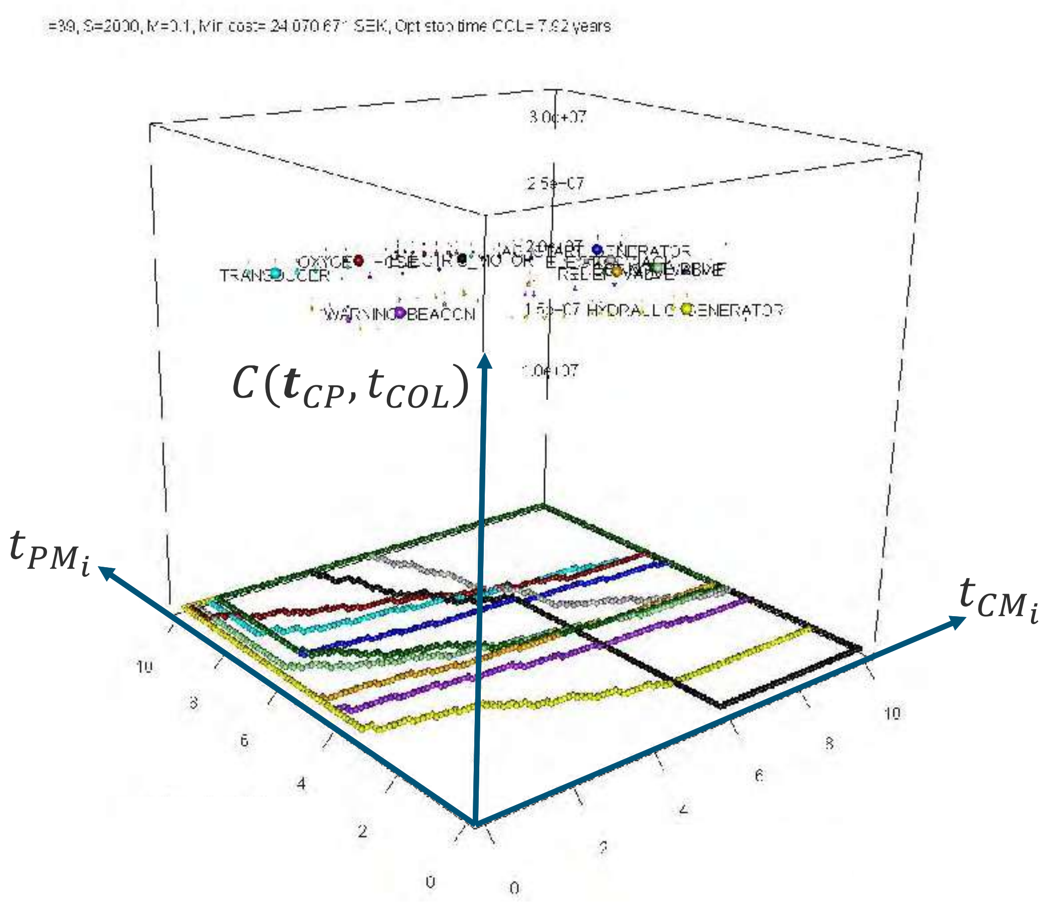
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

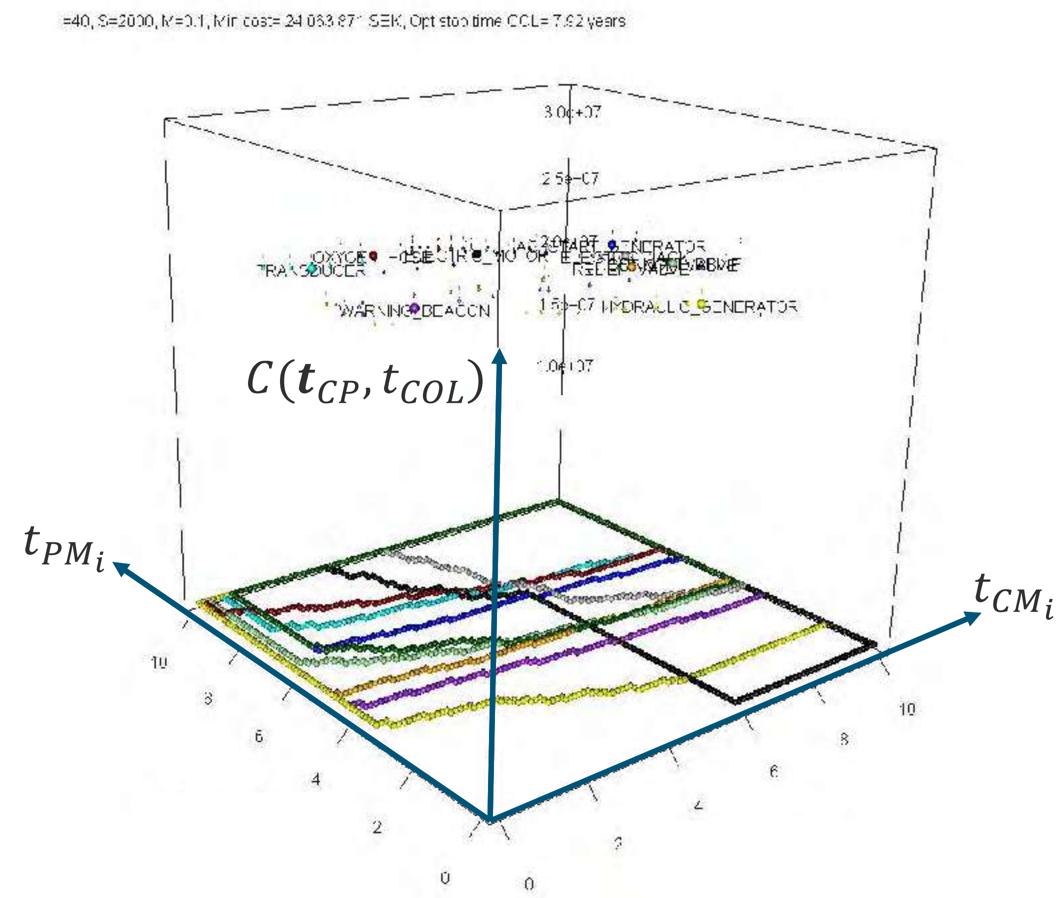
ΔT=1000 h



Systecon

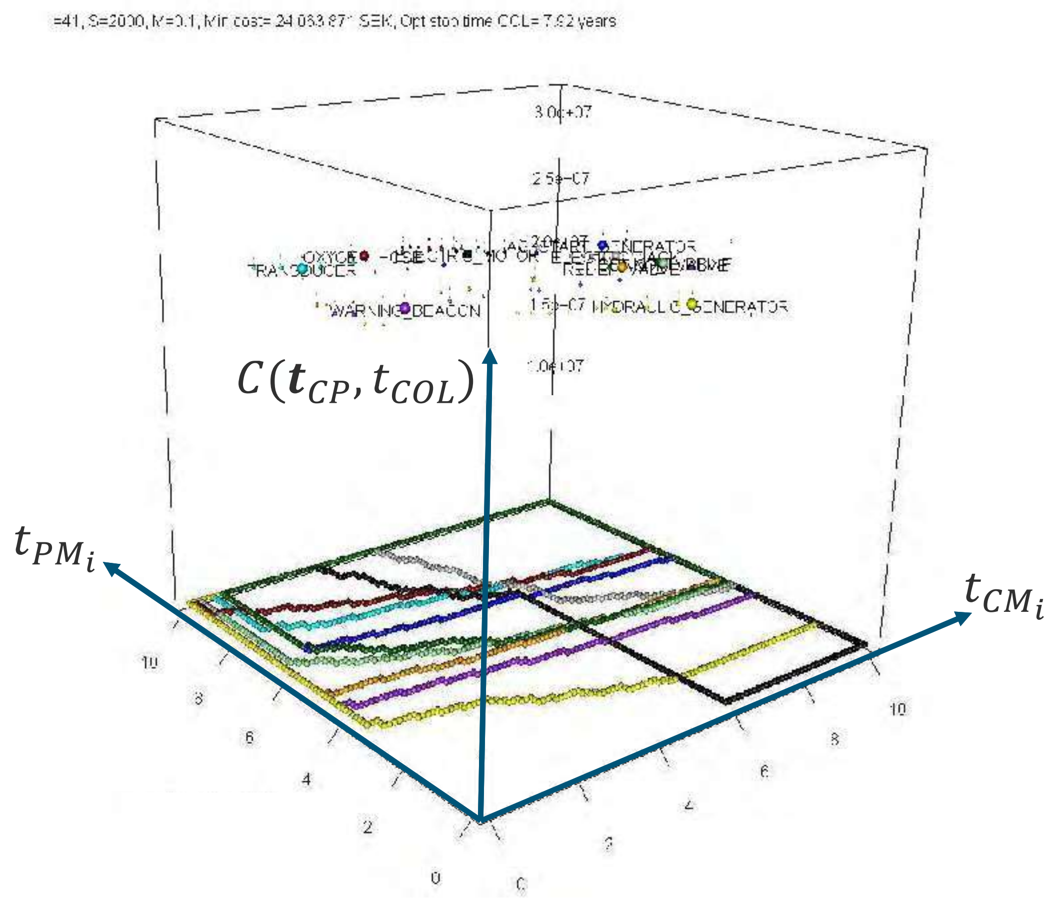
Genetic Algorithm (2000 samples)

ΔT=1000 h



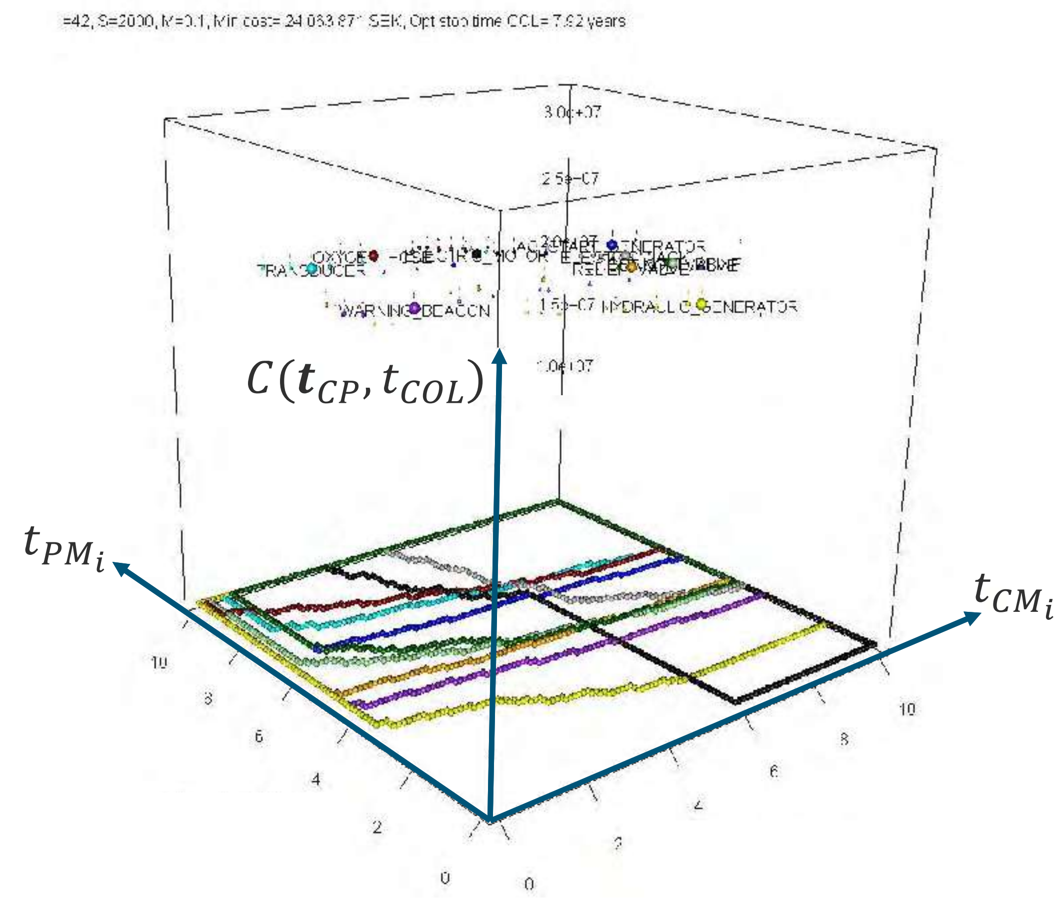
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

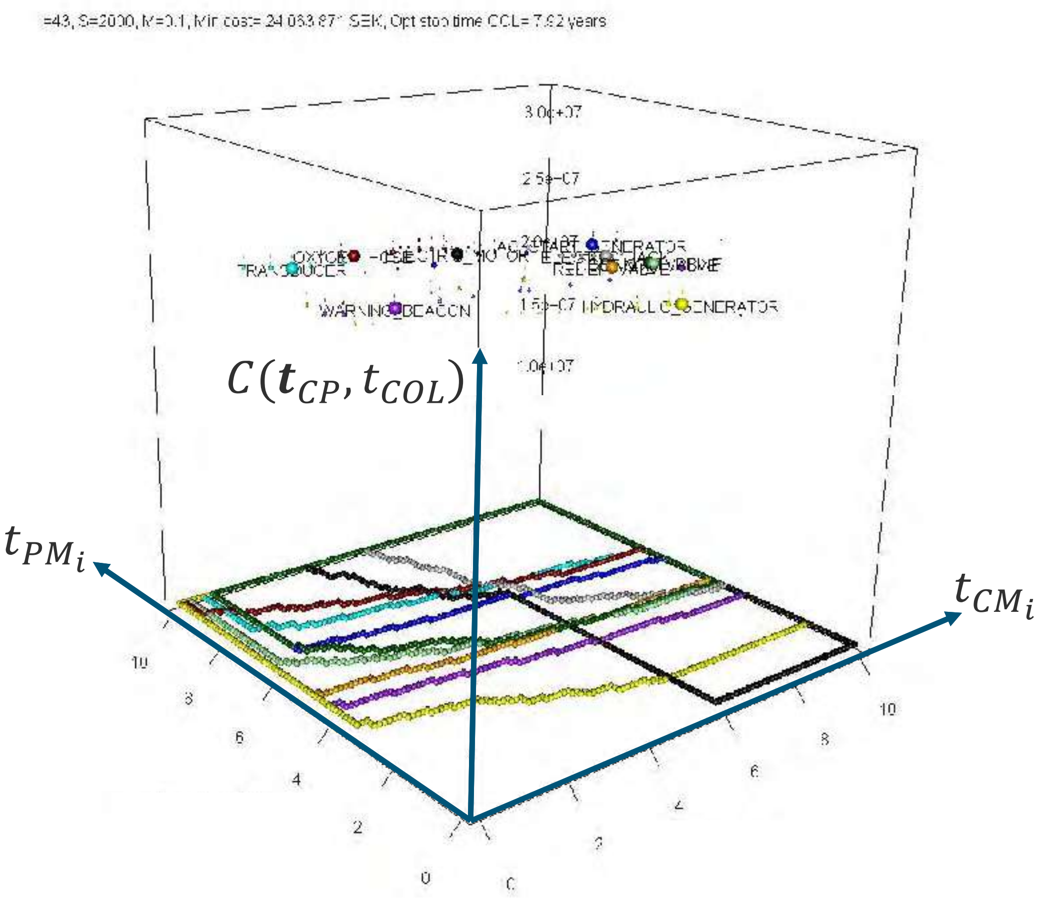
ΔT=1000 h



Systecon

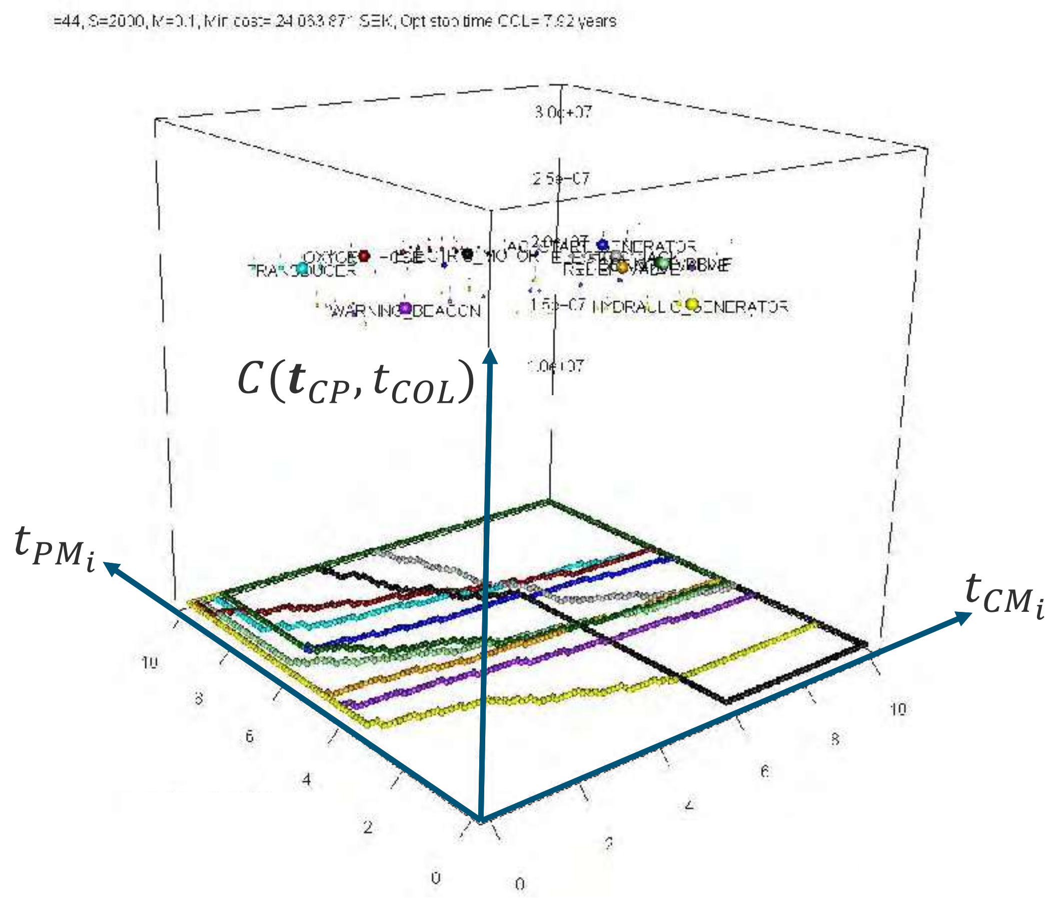
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

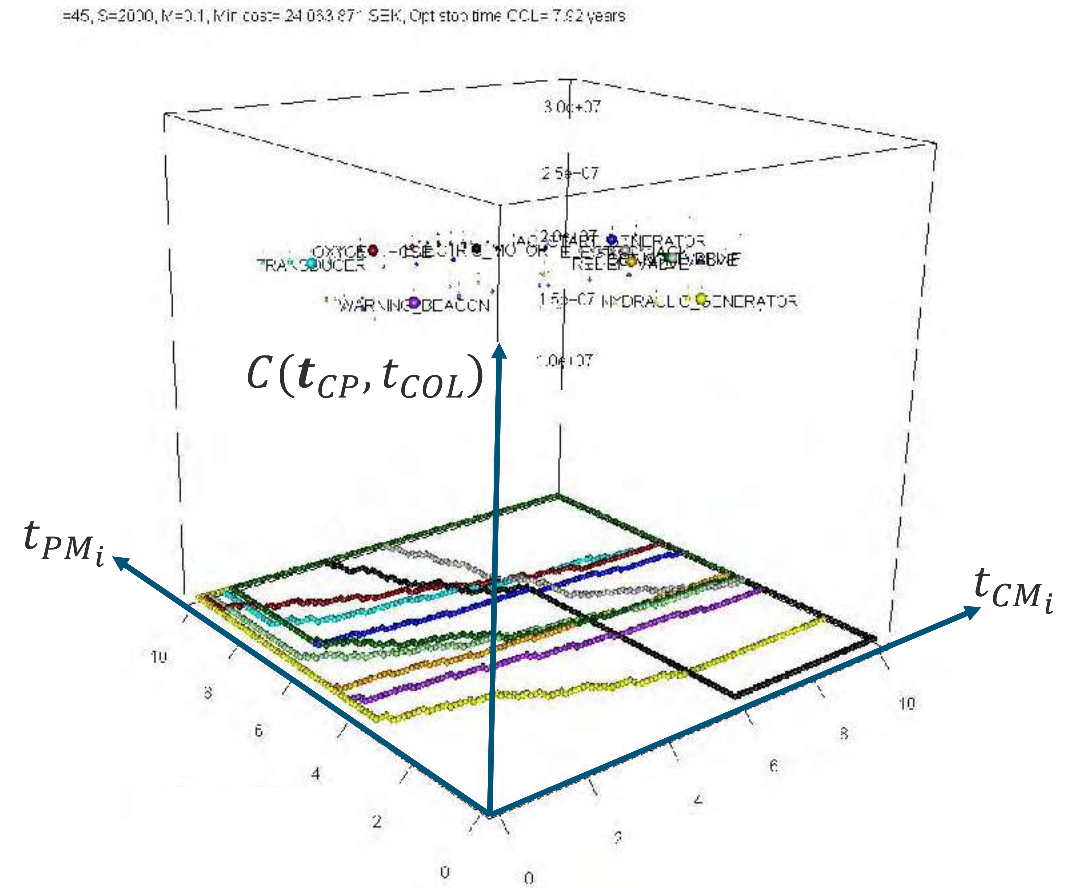
ΔT=1000 h



Systecon

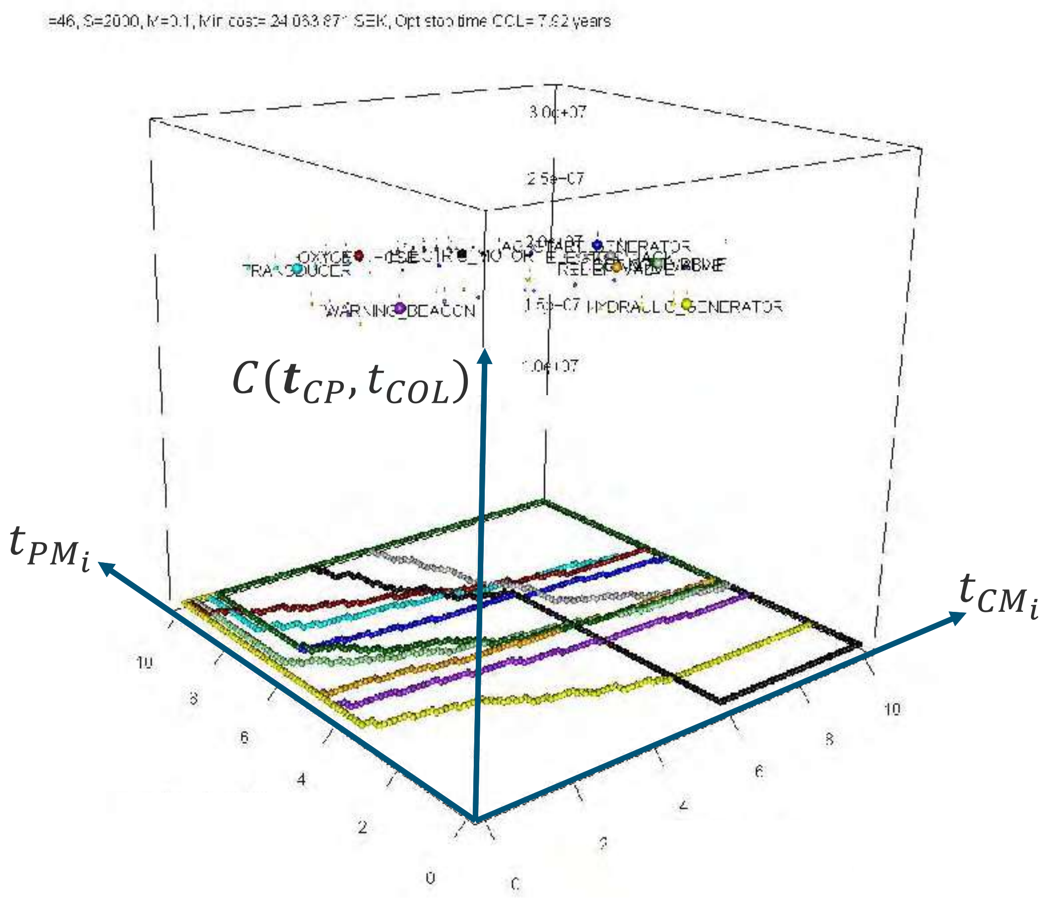
Genetic Algorithm (2000 samples)

ΔT=1000 h



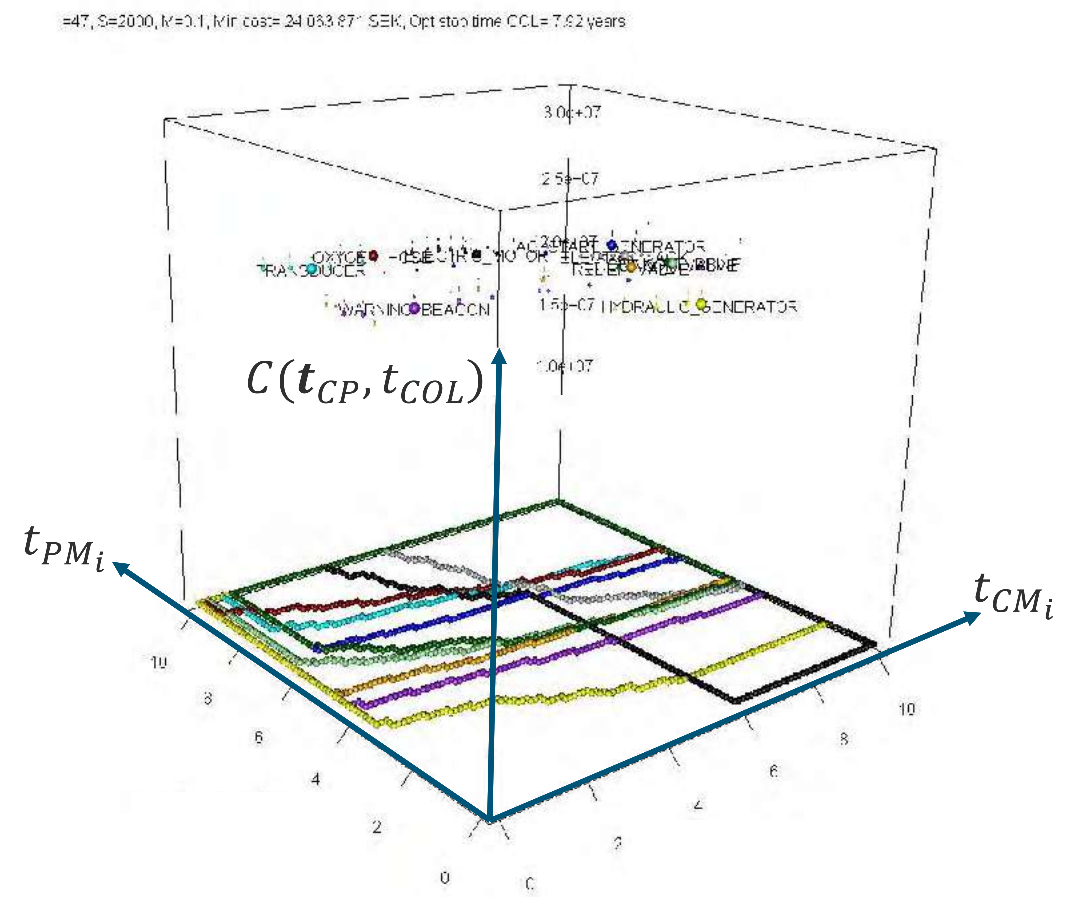
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

ΔT=1000 h



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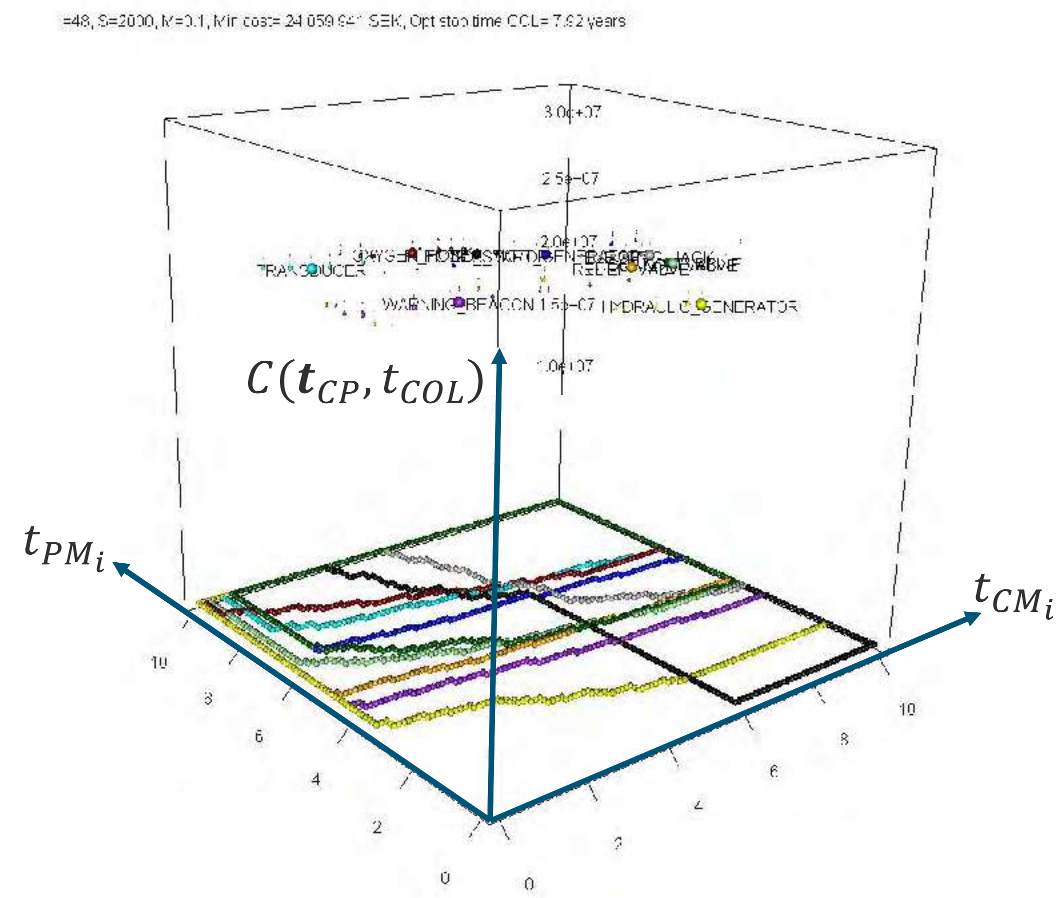
Genetic Algorithm (2000 samples)

ΔT=1000 h



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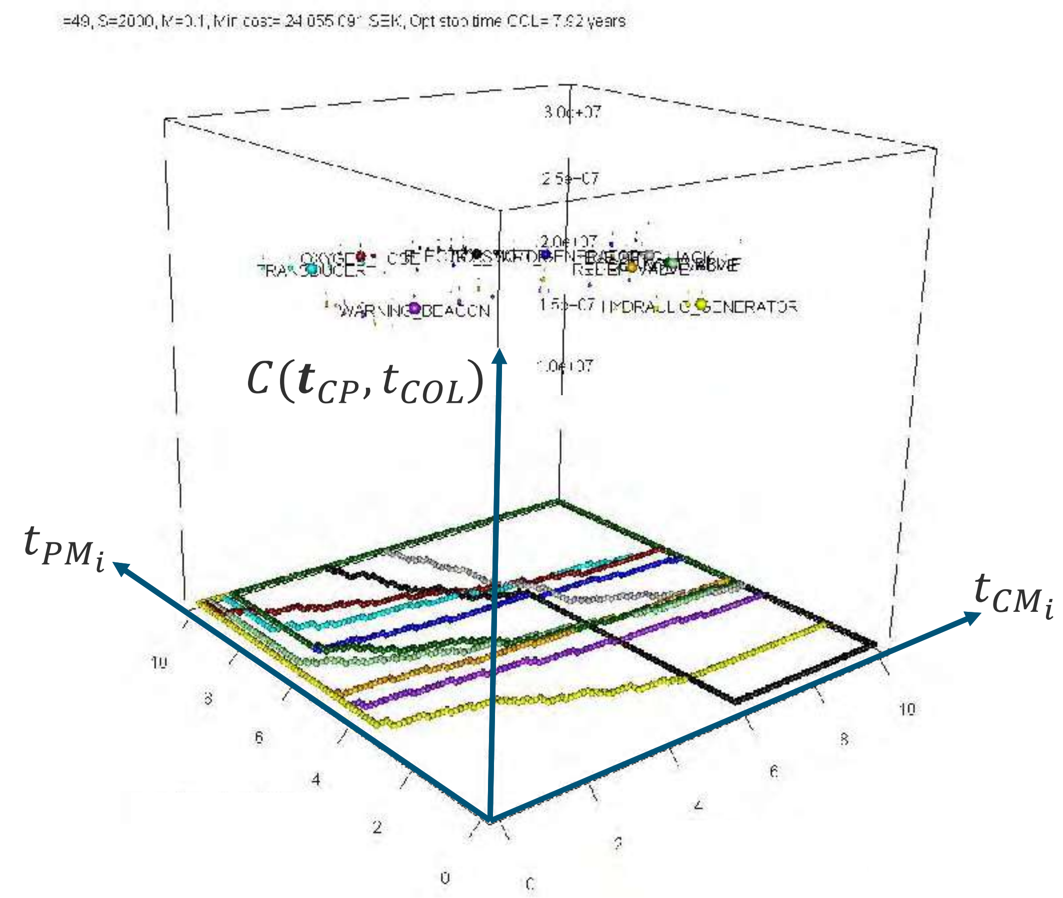
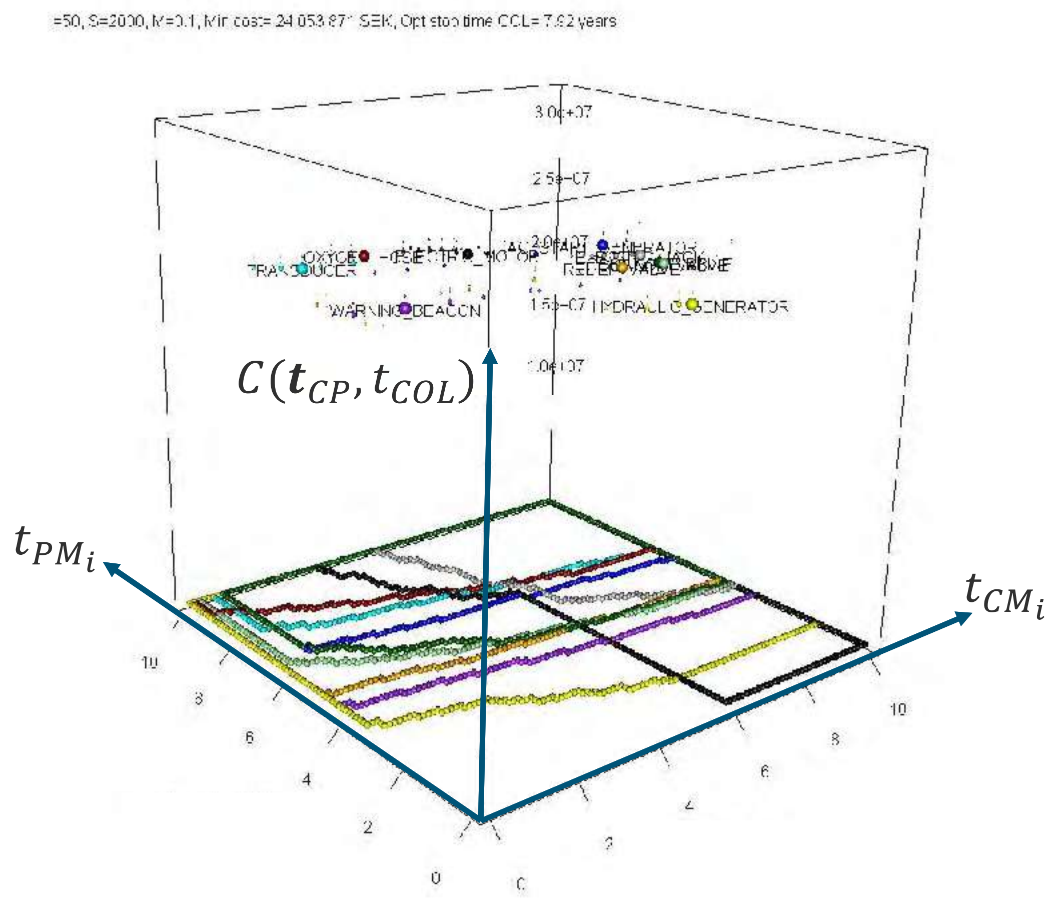
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

ΔT=1000 h



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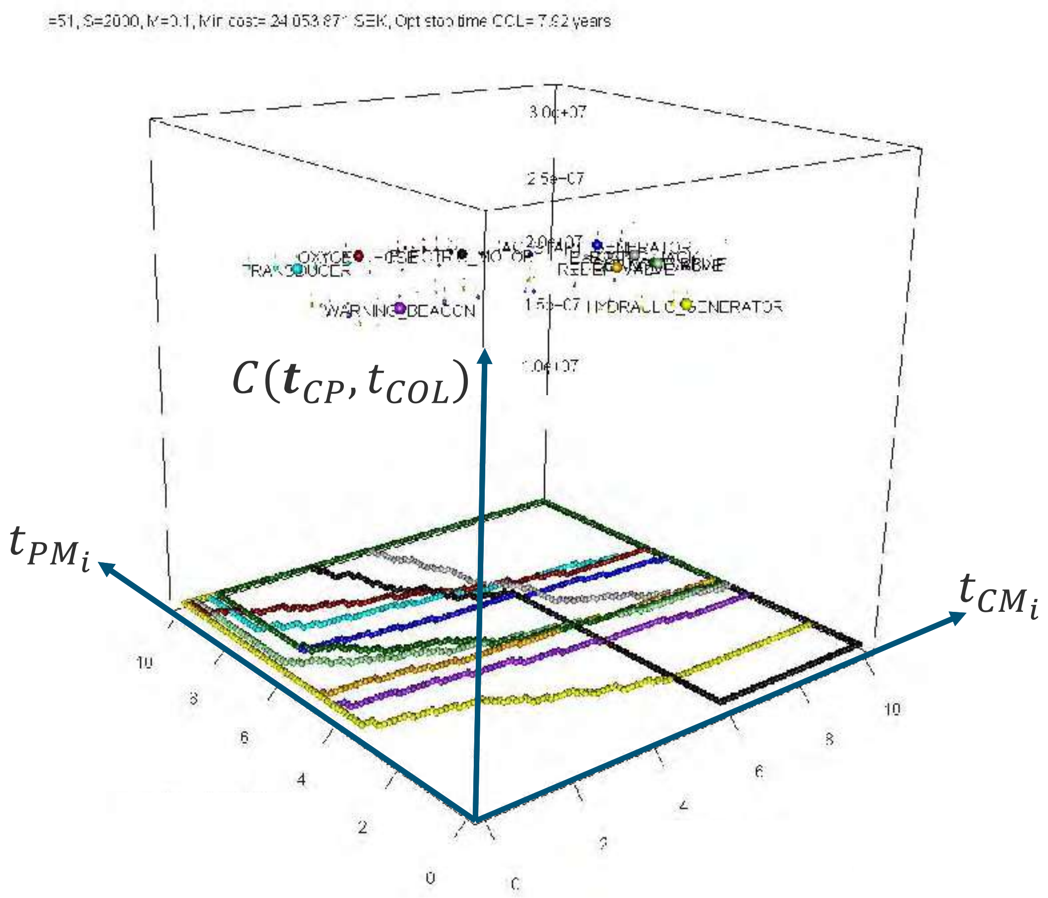
Genetic Algorithm (2000 samples)

ΔT=1000 h



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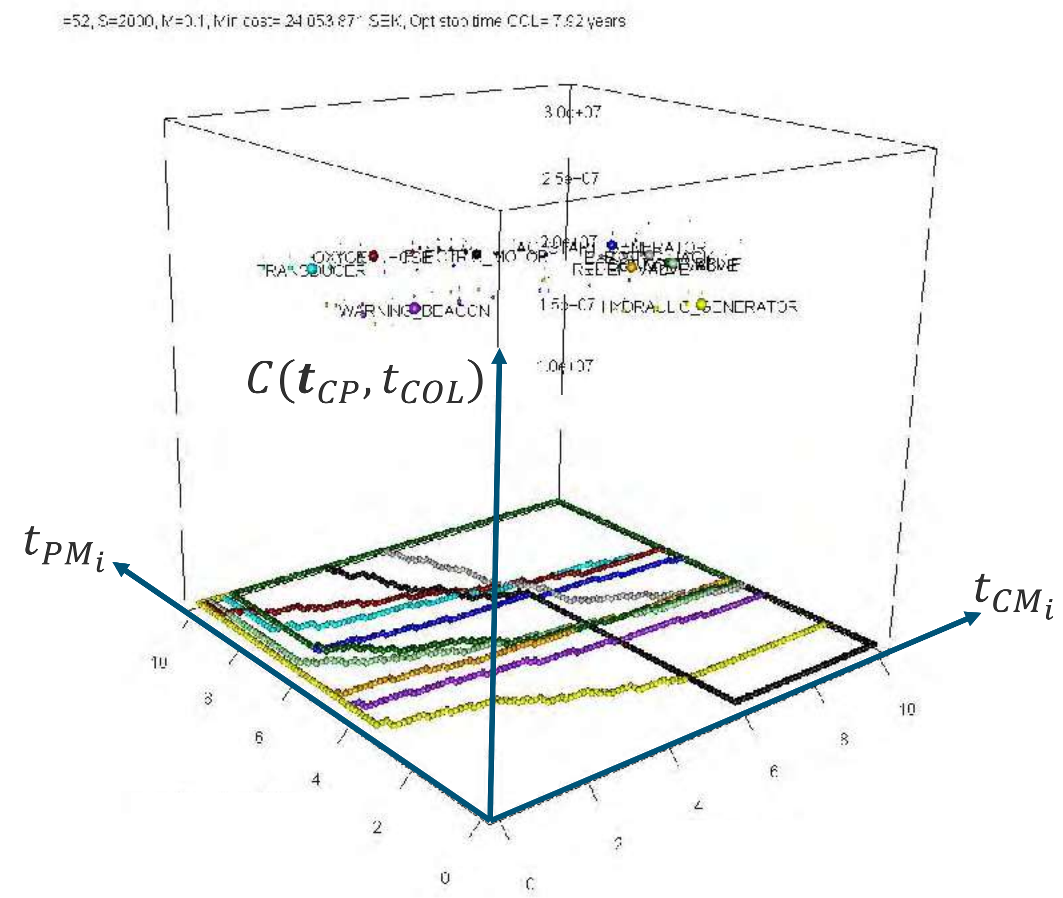
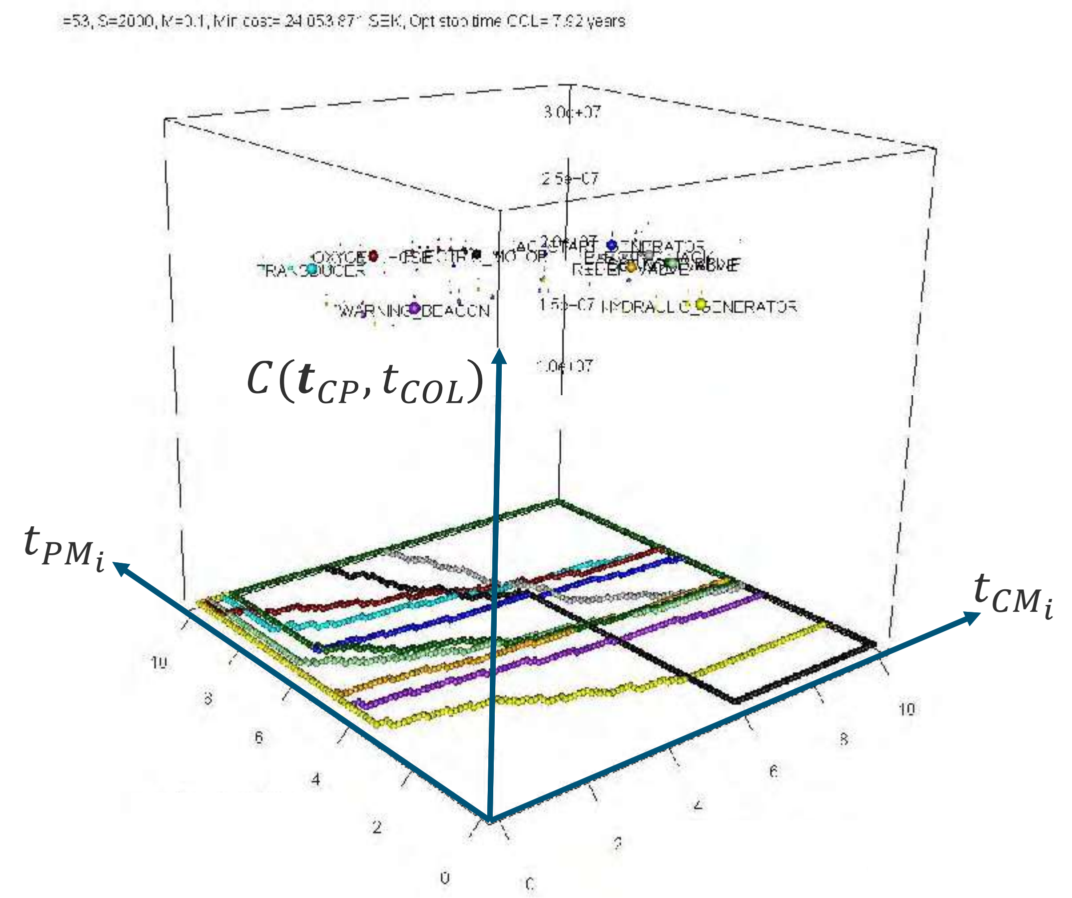
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

ΔT=1000 h



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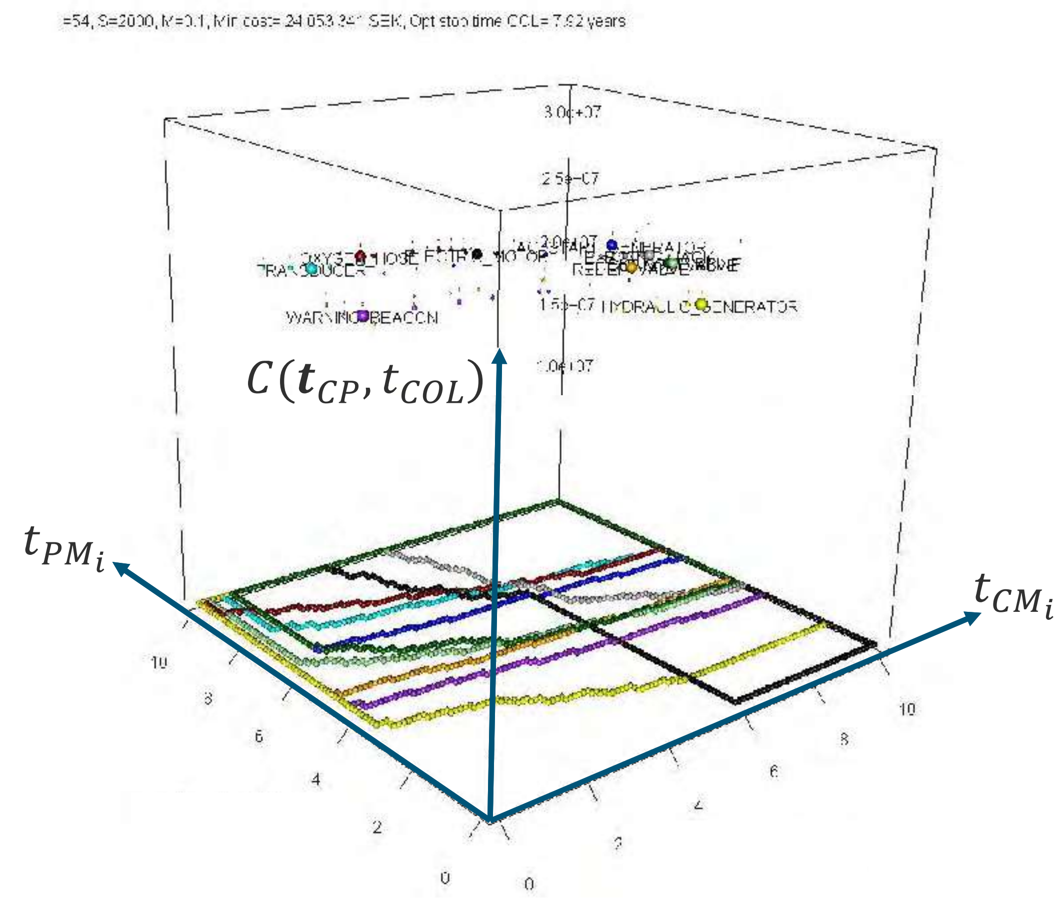
Genetic Algorithm (2000 samples)

ΔT=1000 h



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Genetic Algorithm (2000 samples)

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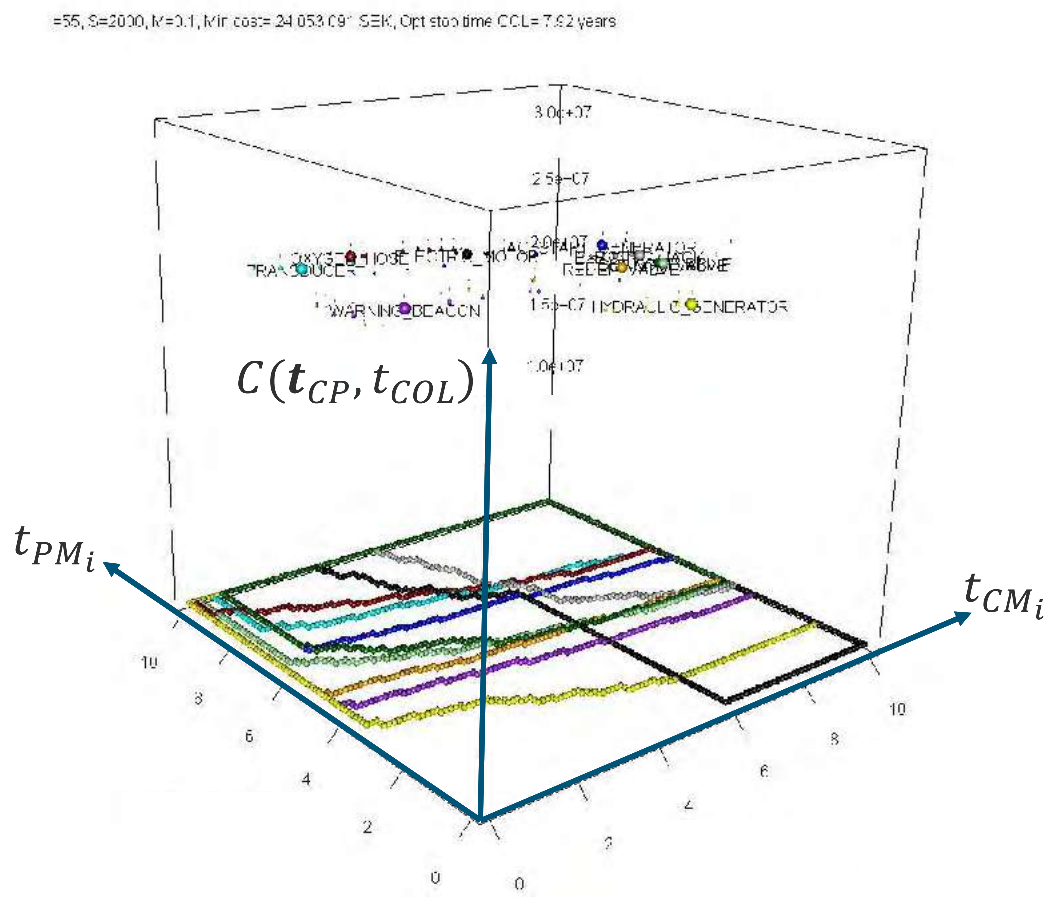

Genetic Algorithm (2000 samples)

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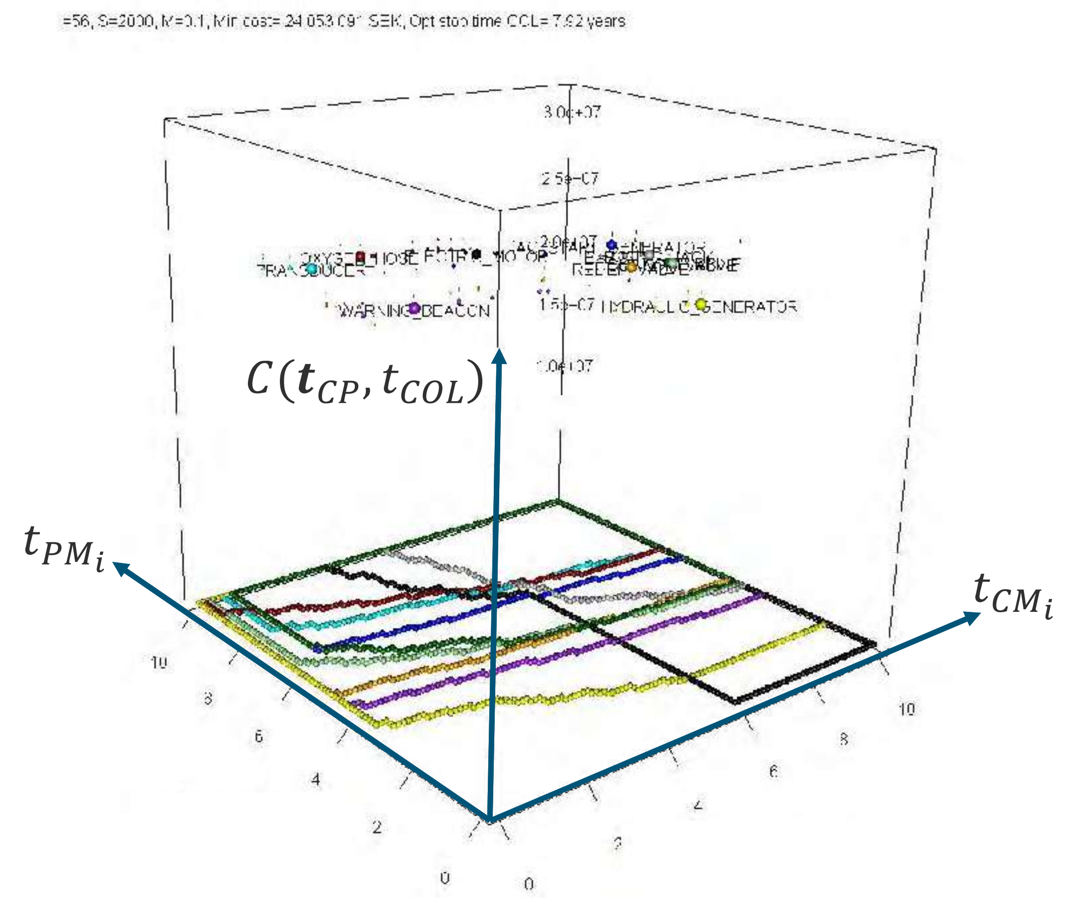

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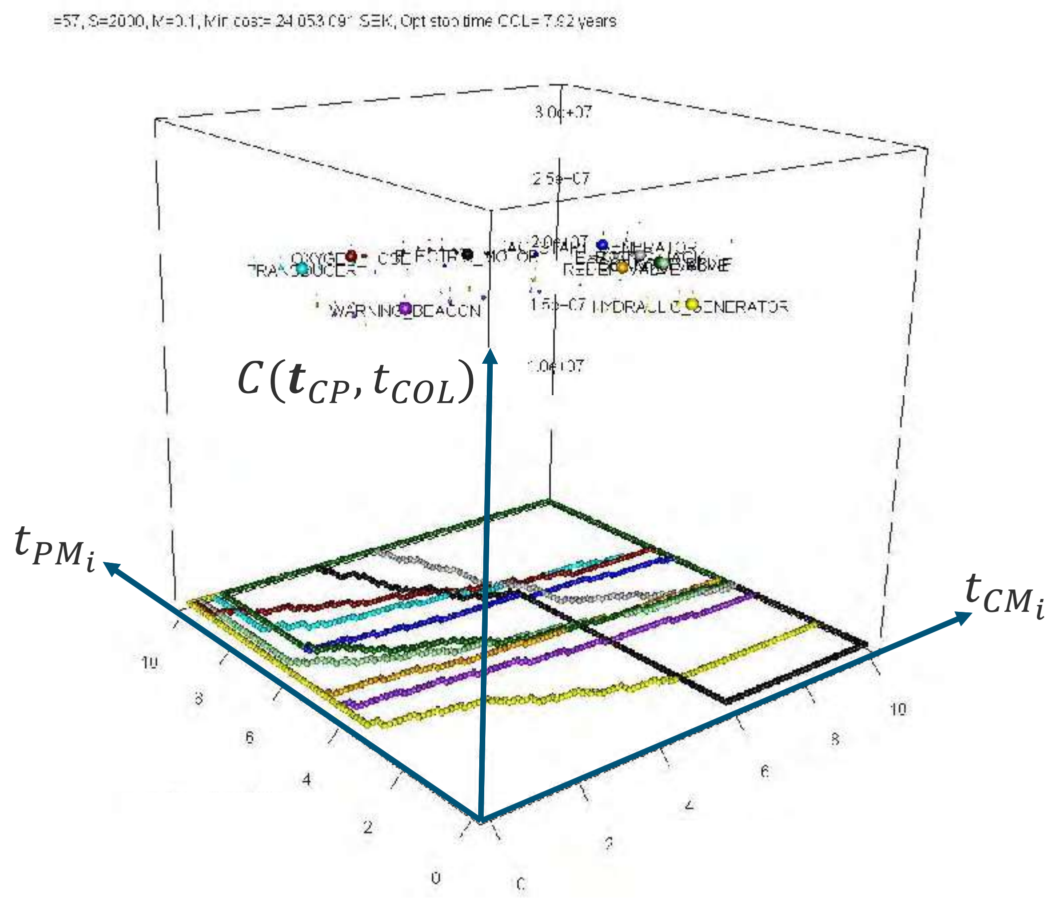
ΔT=1000 h



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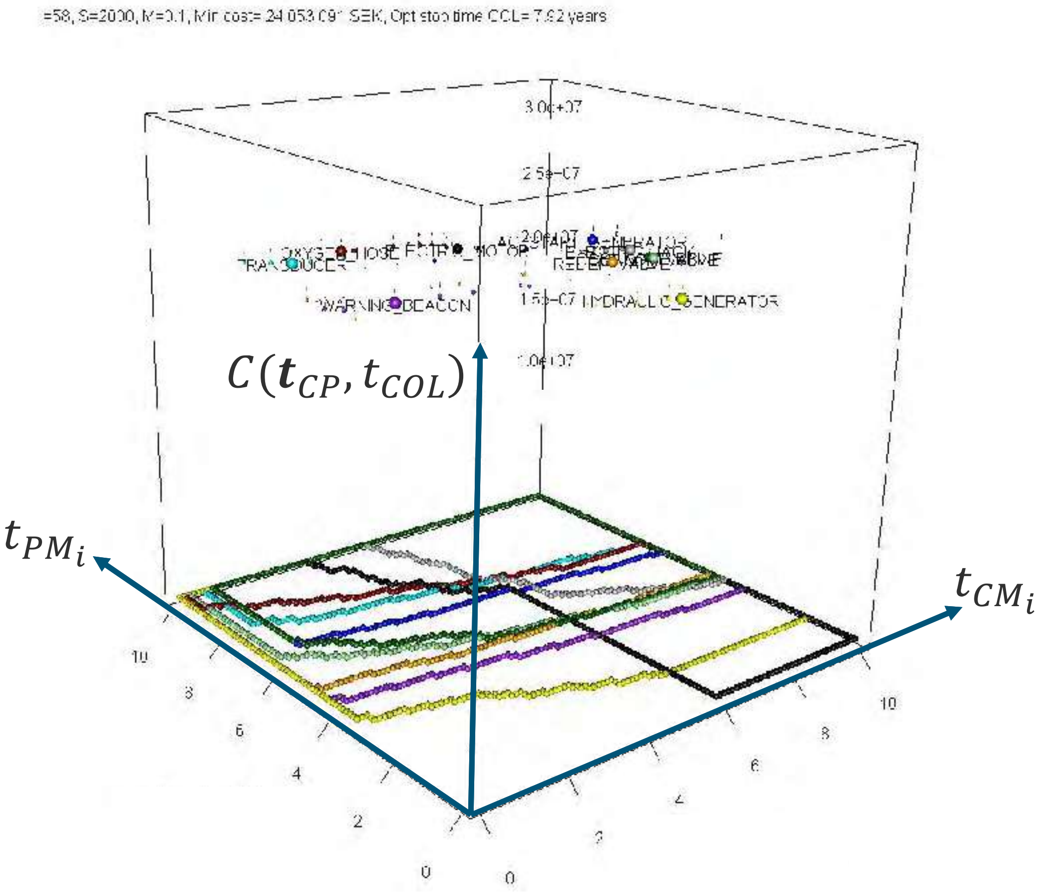
Genetic Algorithm (2000 samples)

ΔT=1000 h



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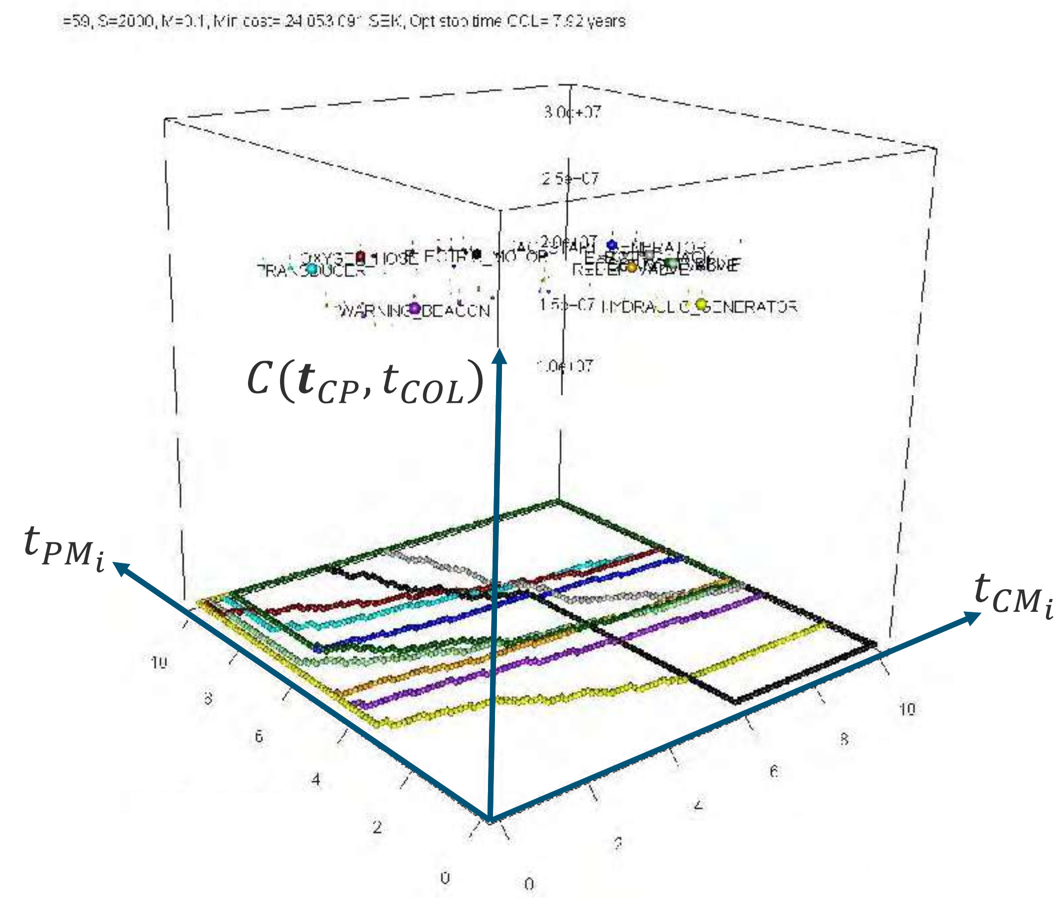
Genetic Algorithm (2000 samples)

ΔT=1000 h



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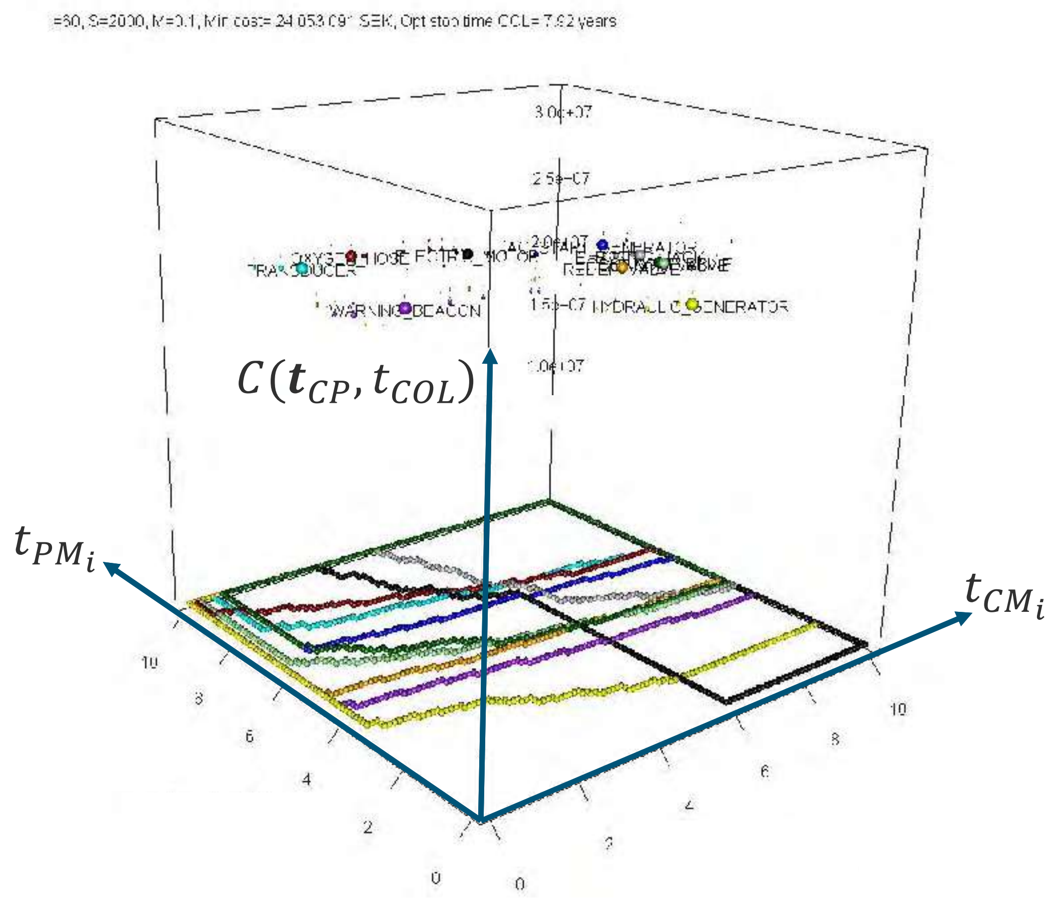
Genetic Algorithm (2000 samples)

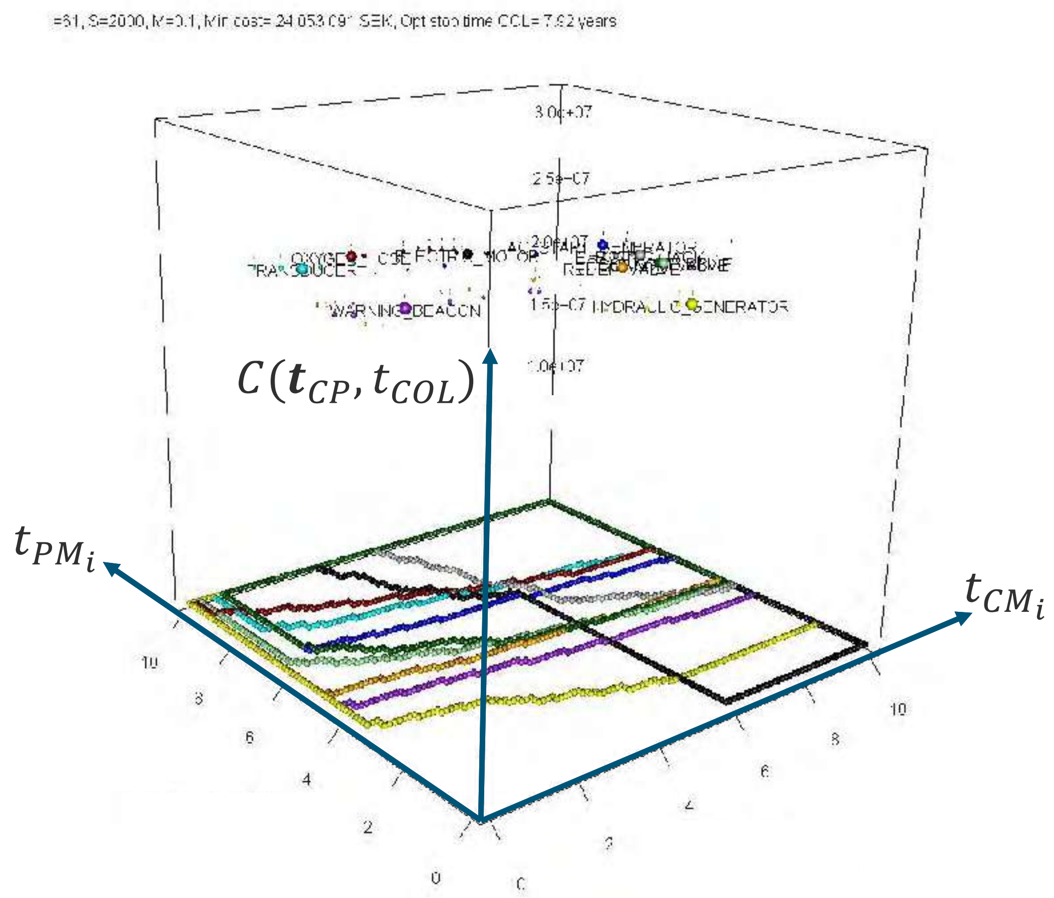
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

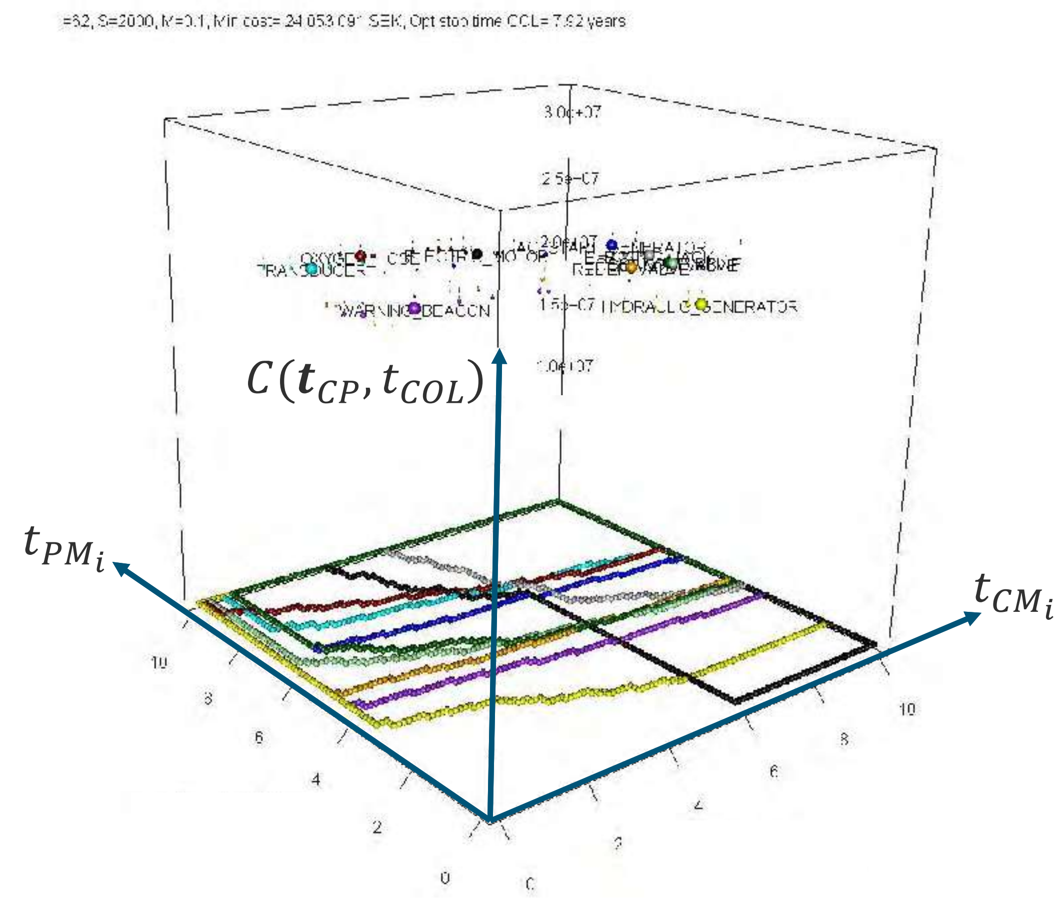
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

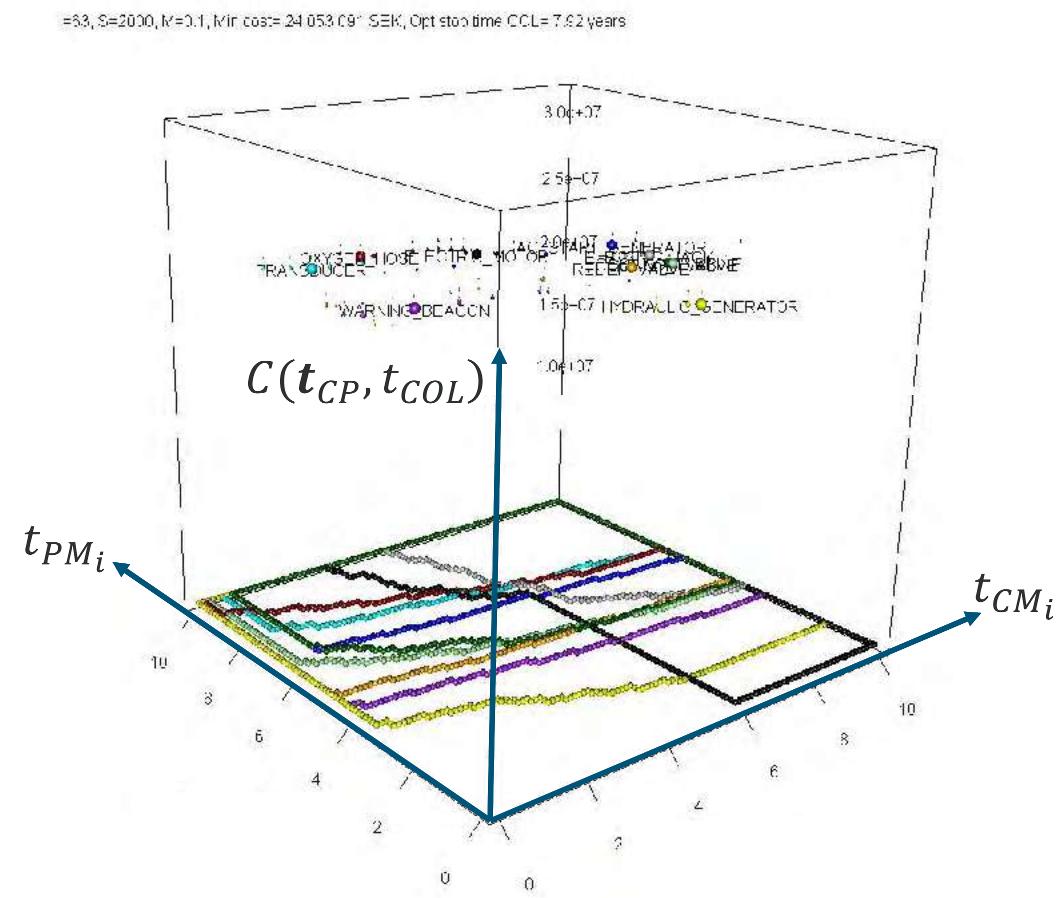
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

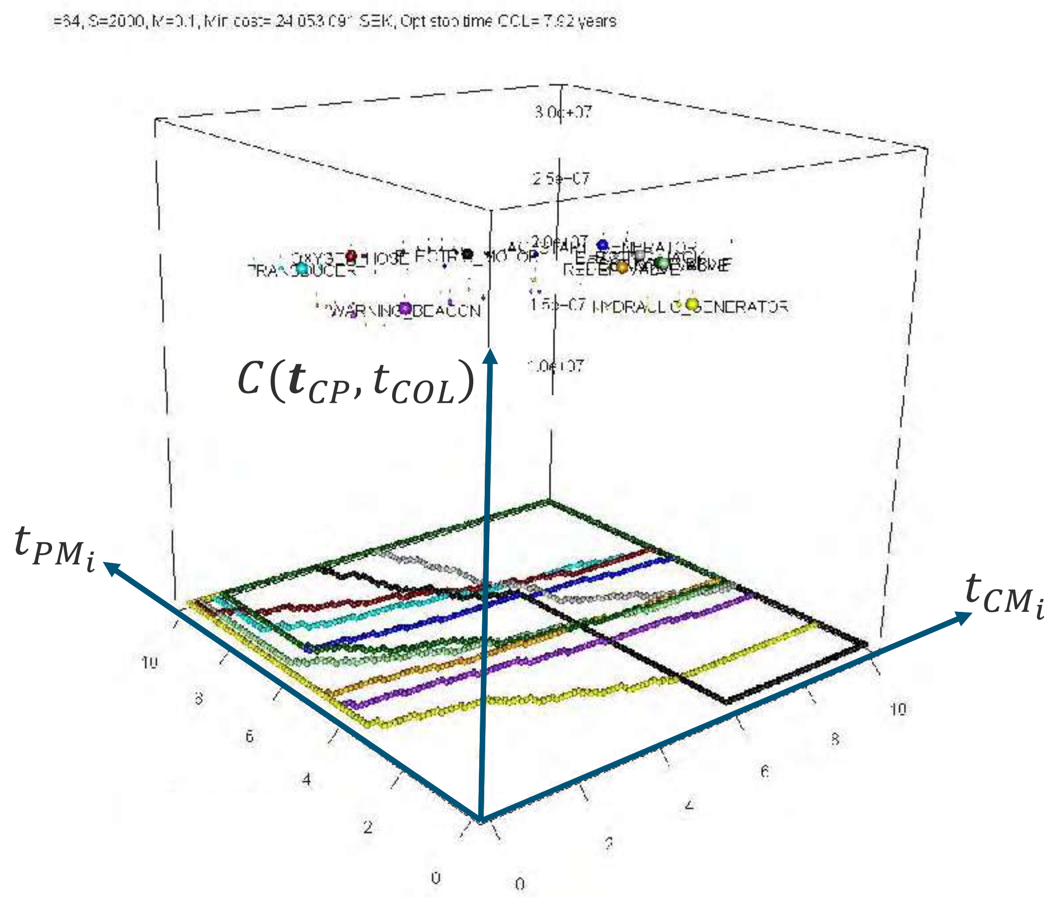
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

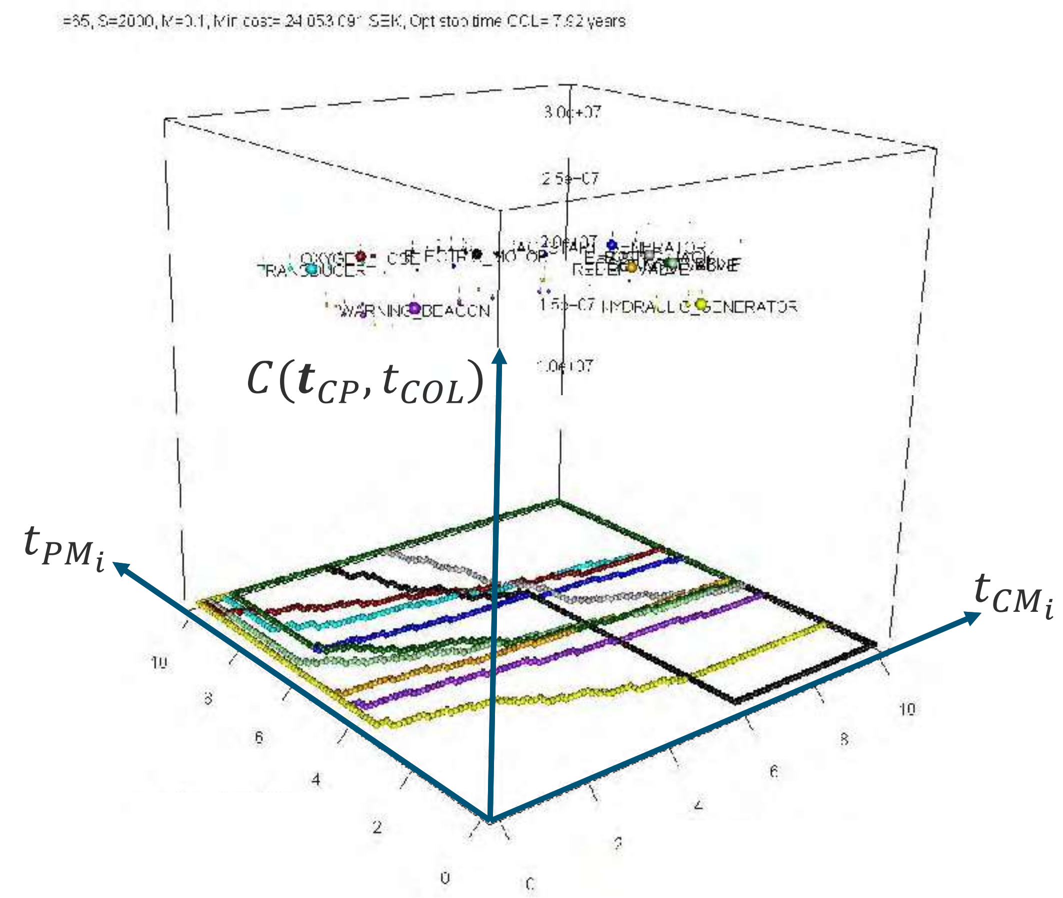
ΔT=1000 h



Systecon

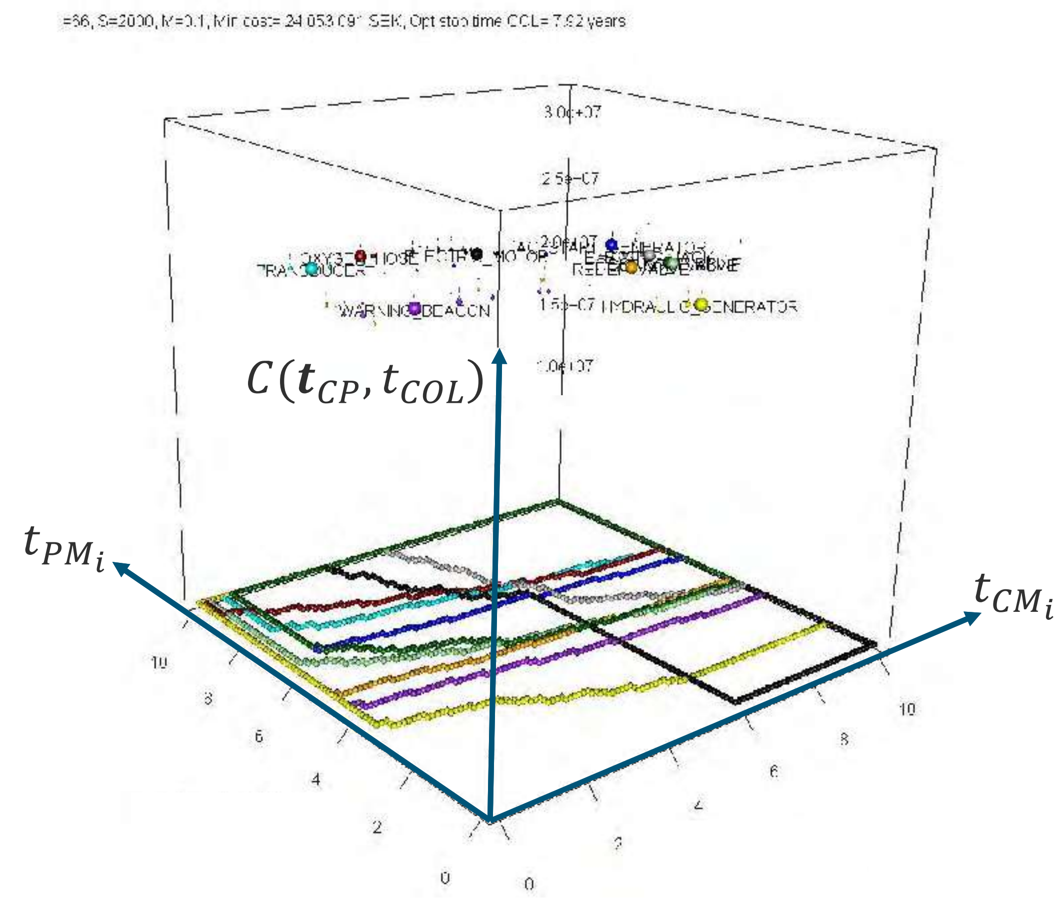
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

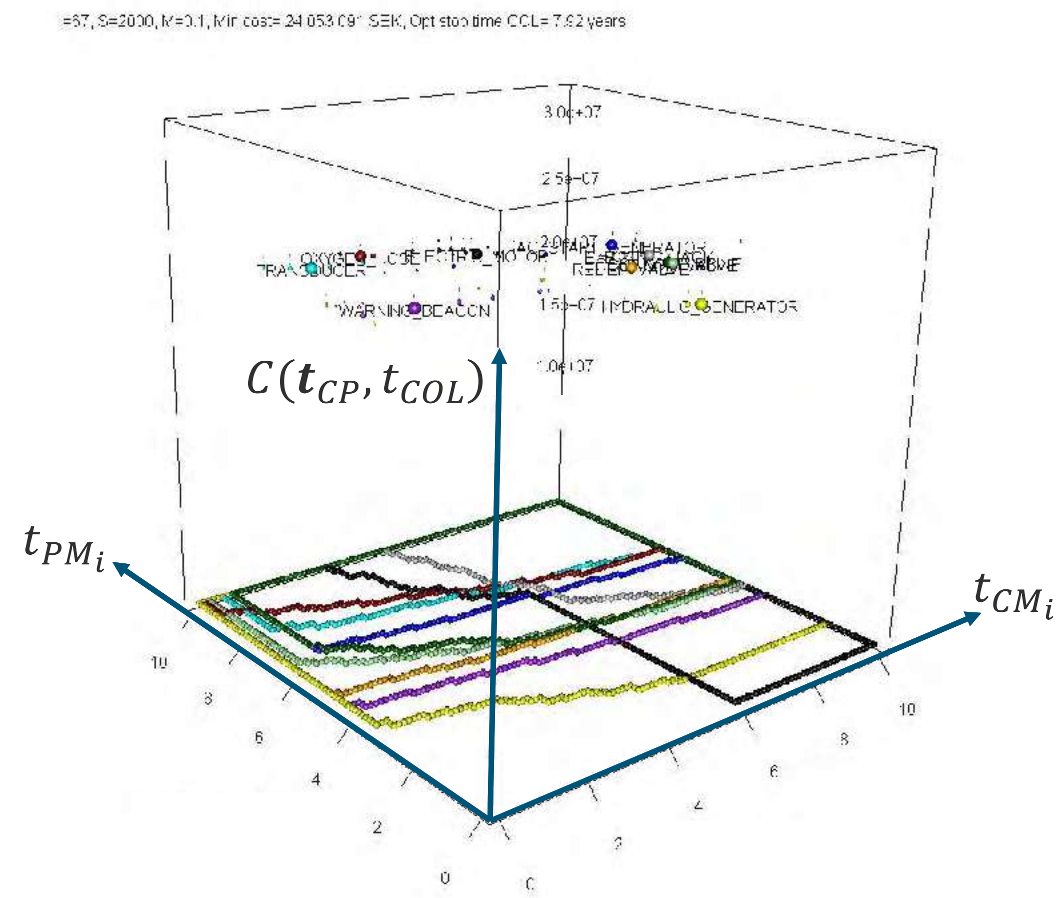
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

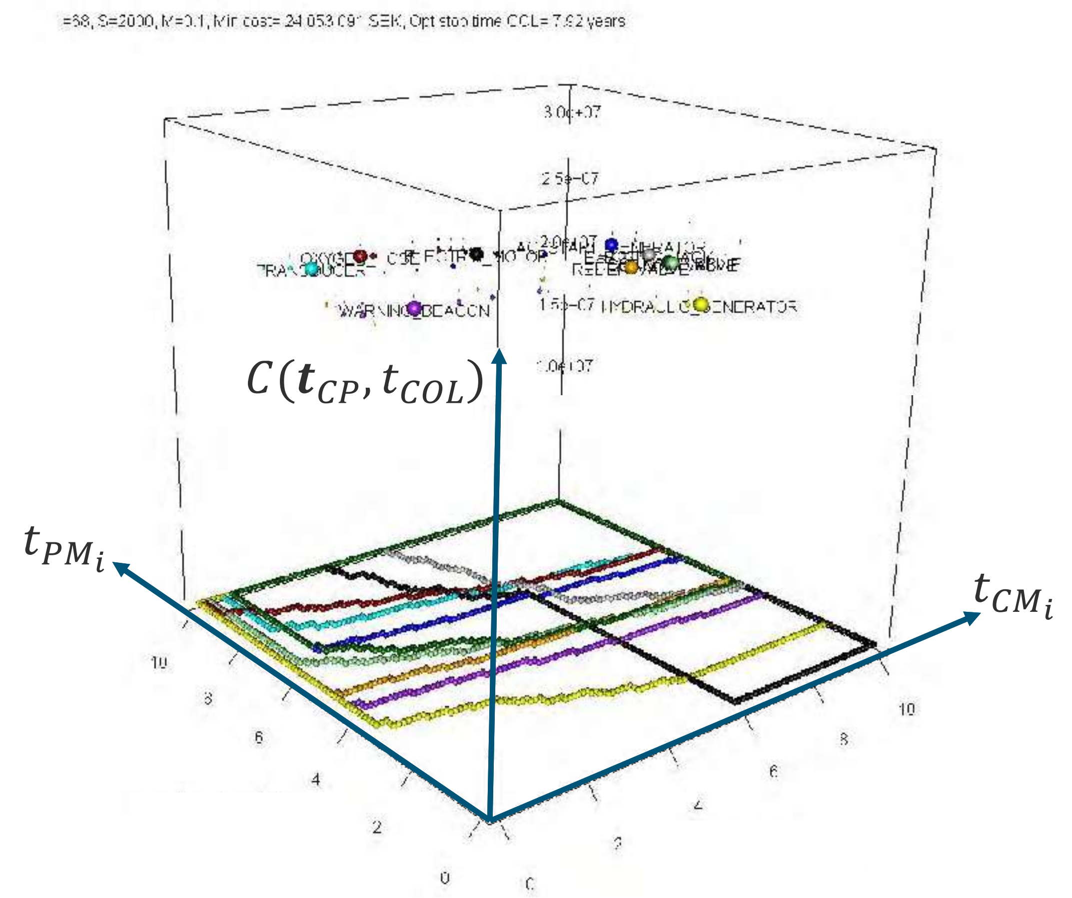
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

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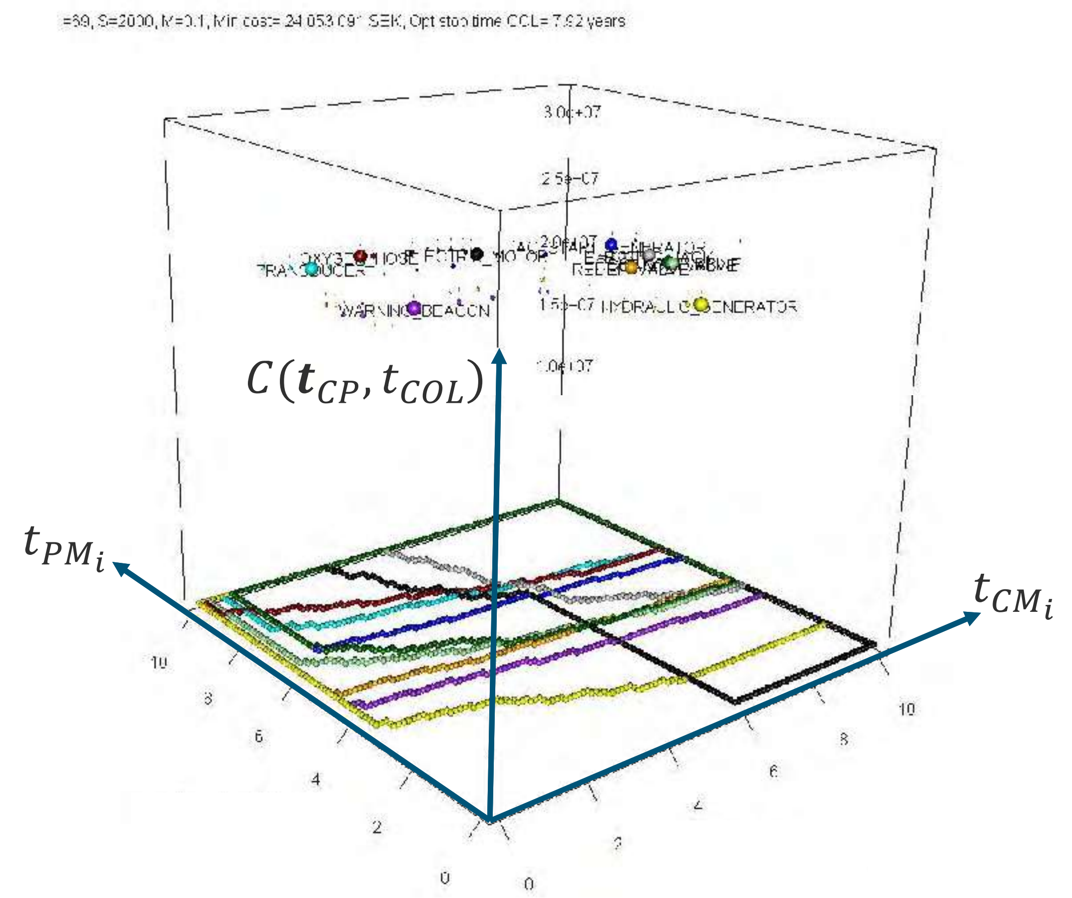
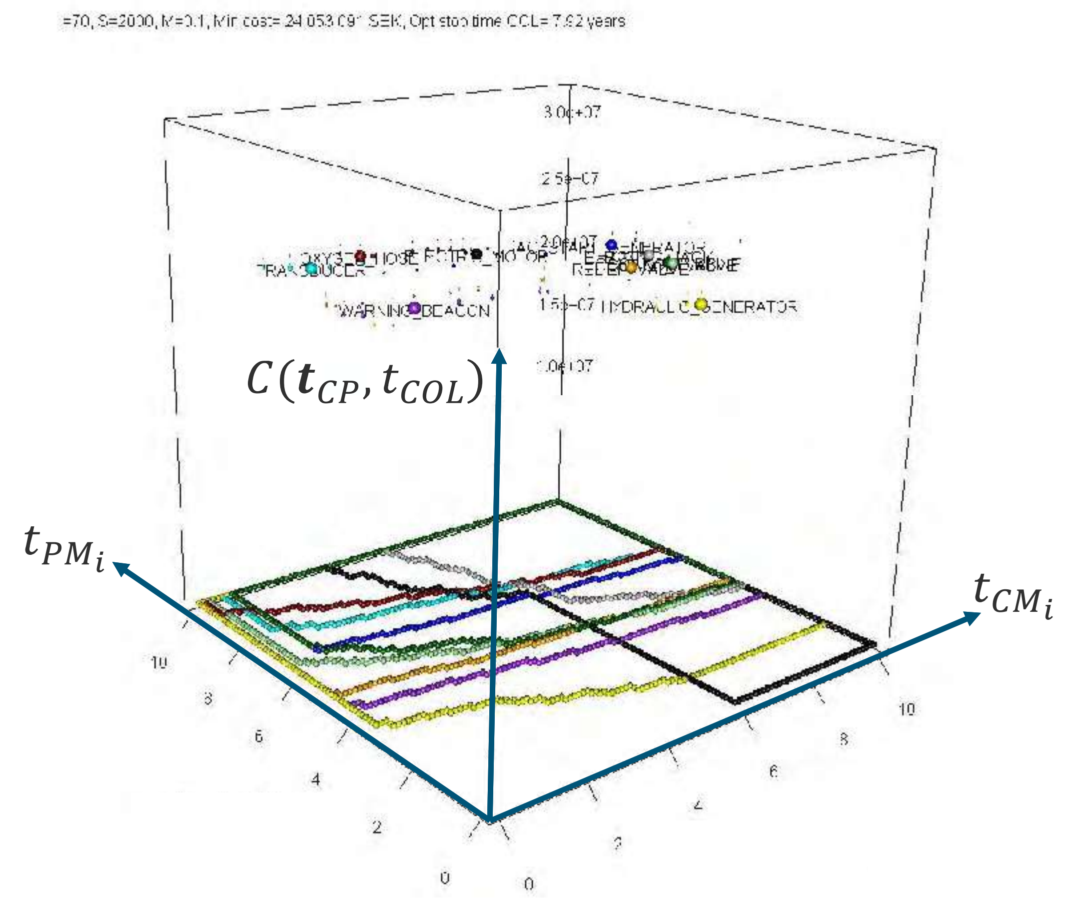


Systecon

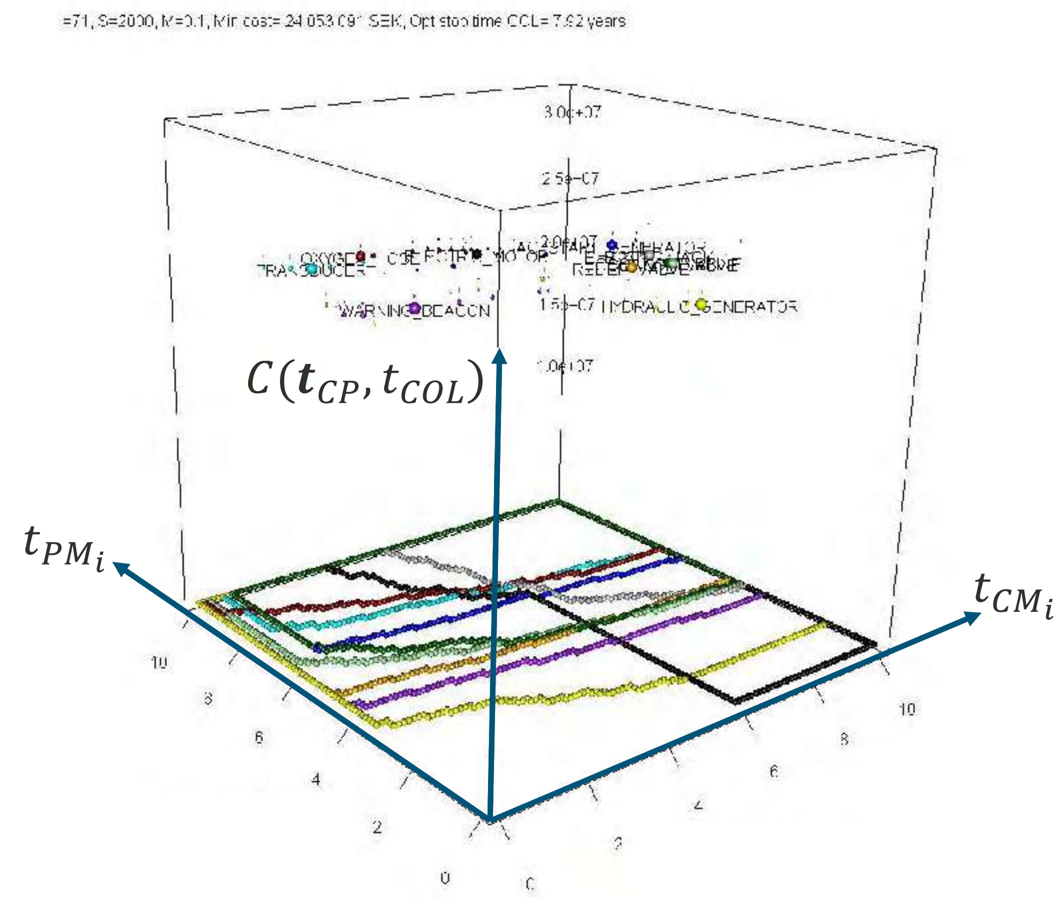
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

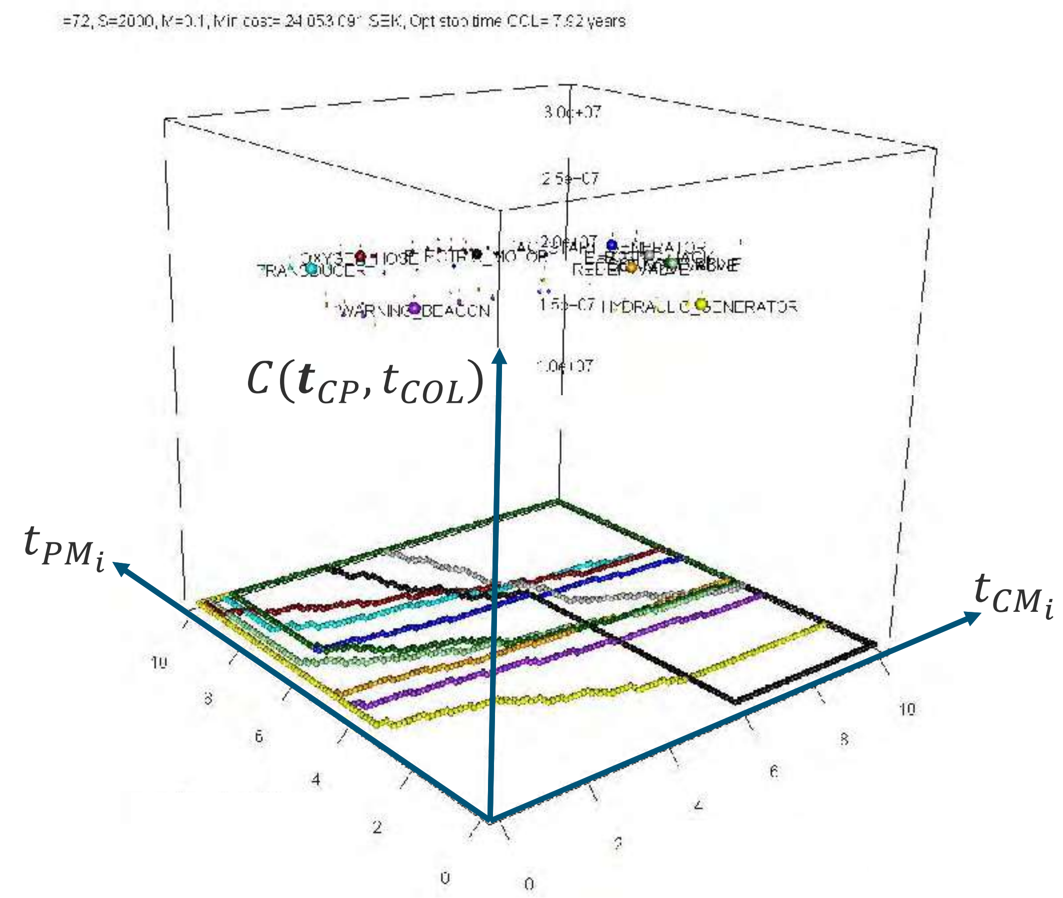
ΔT=1000 h



Systecon

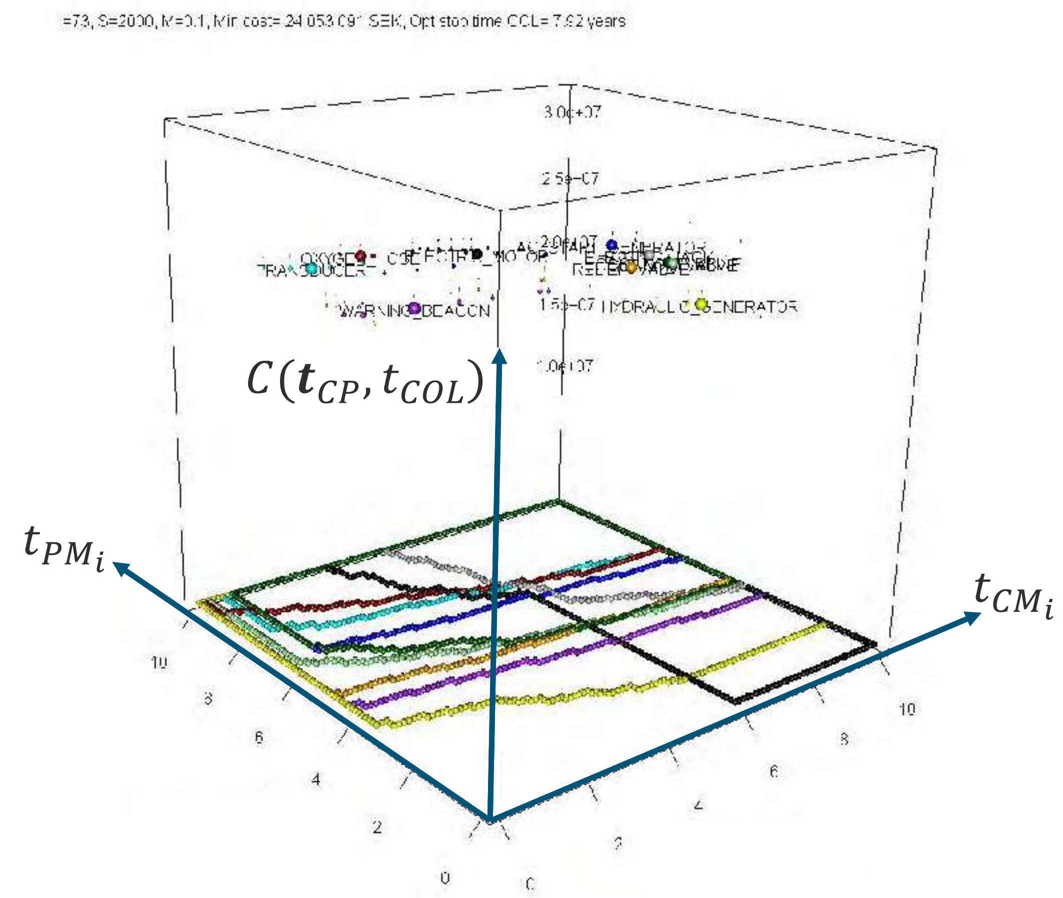
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

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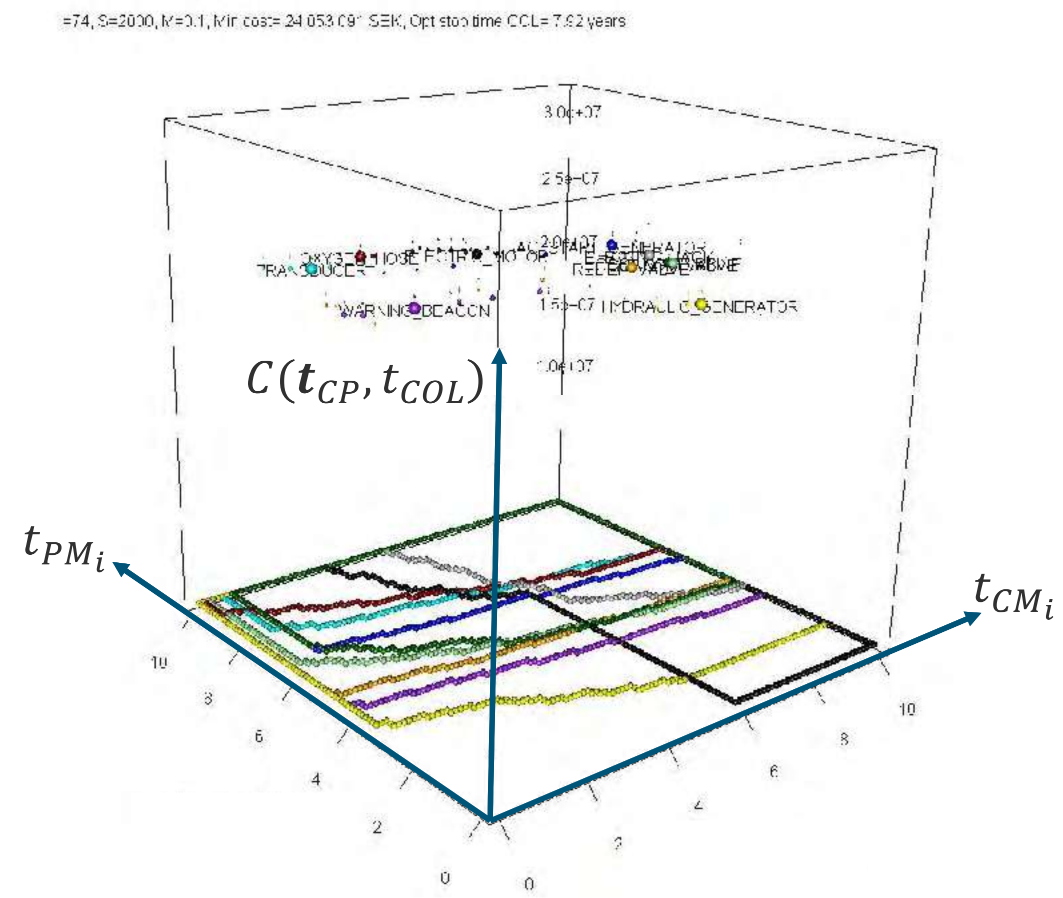
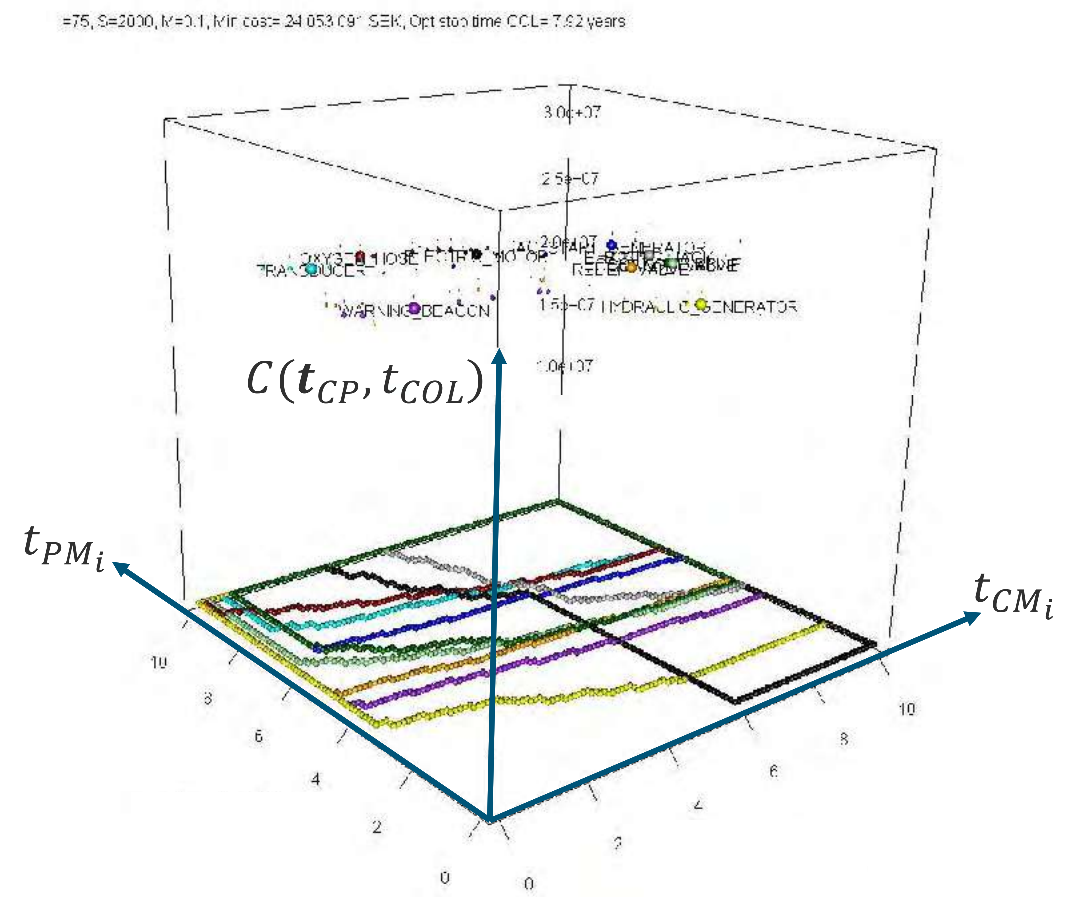


Systecon

Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

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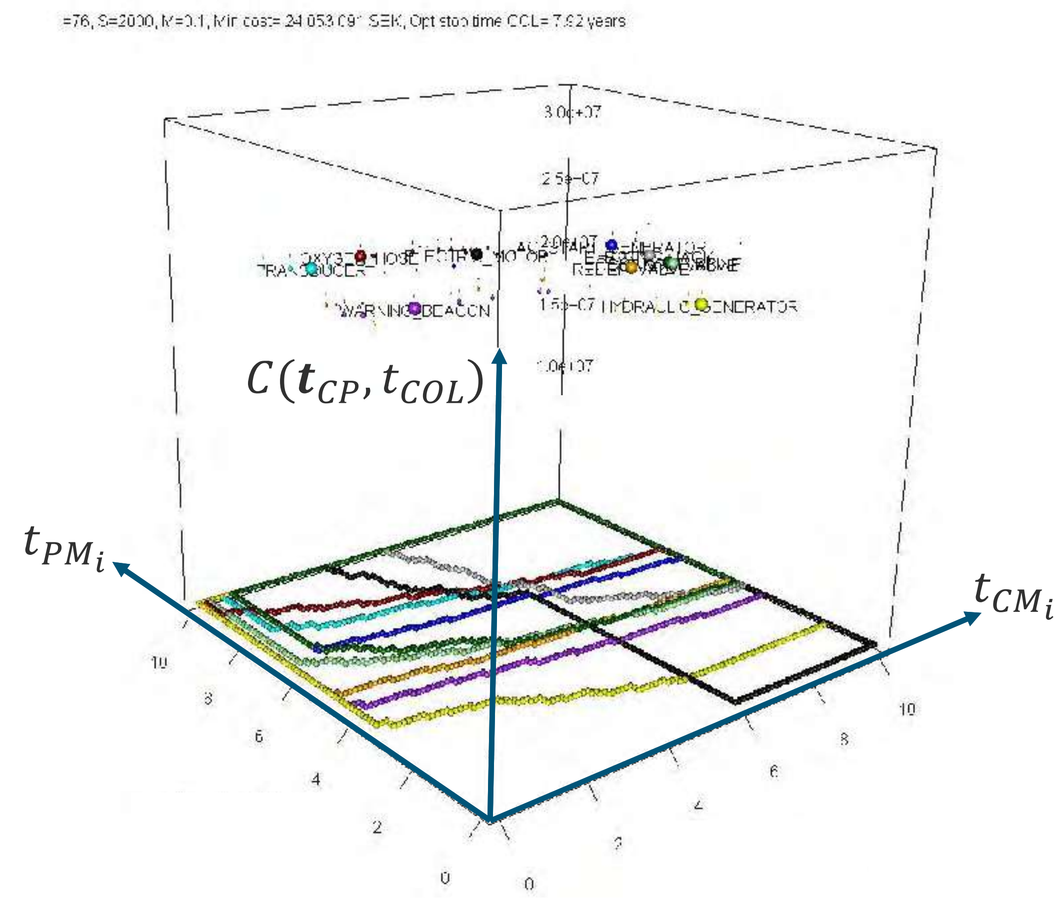
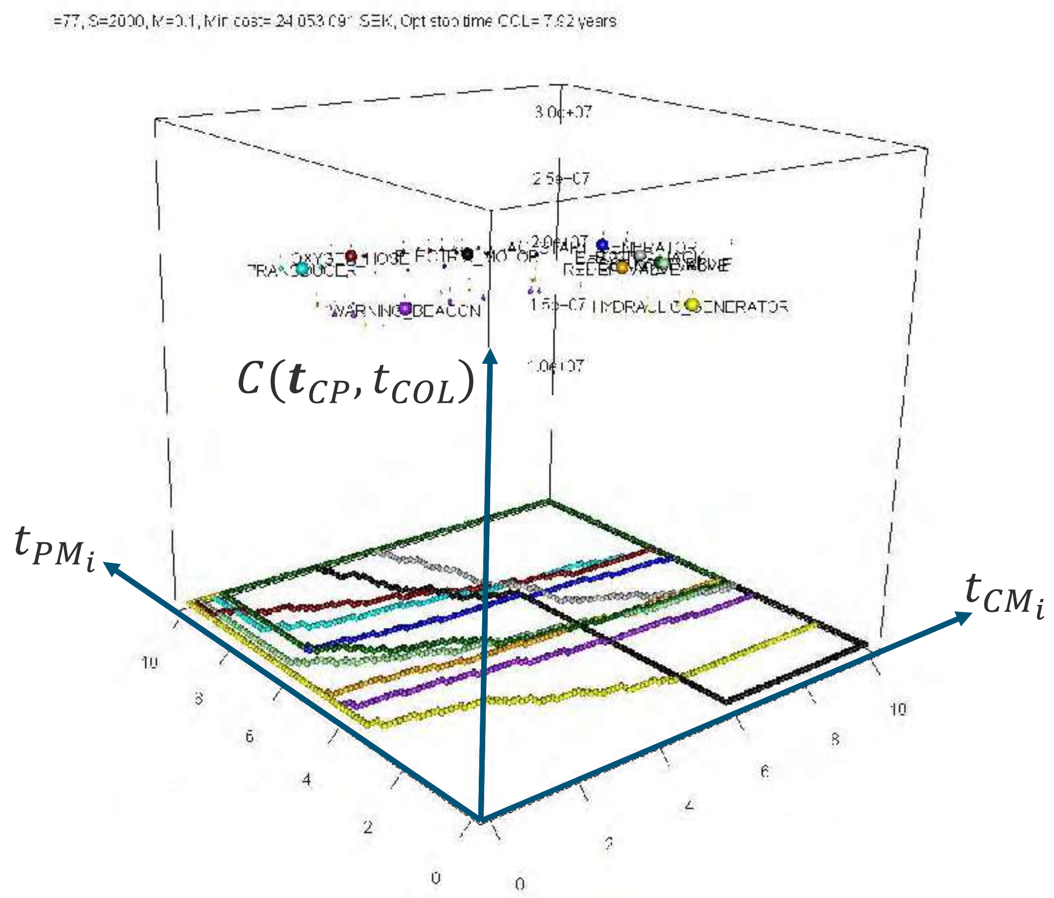


Genetic Algorithm (2000 samples)

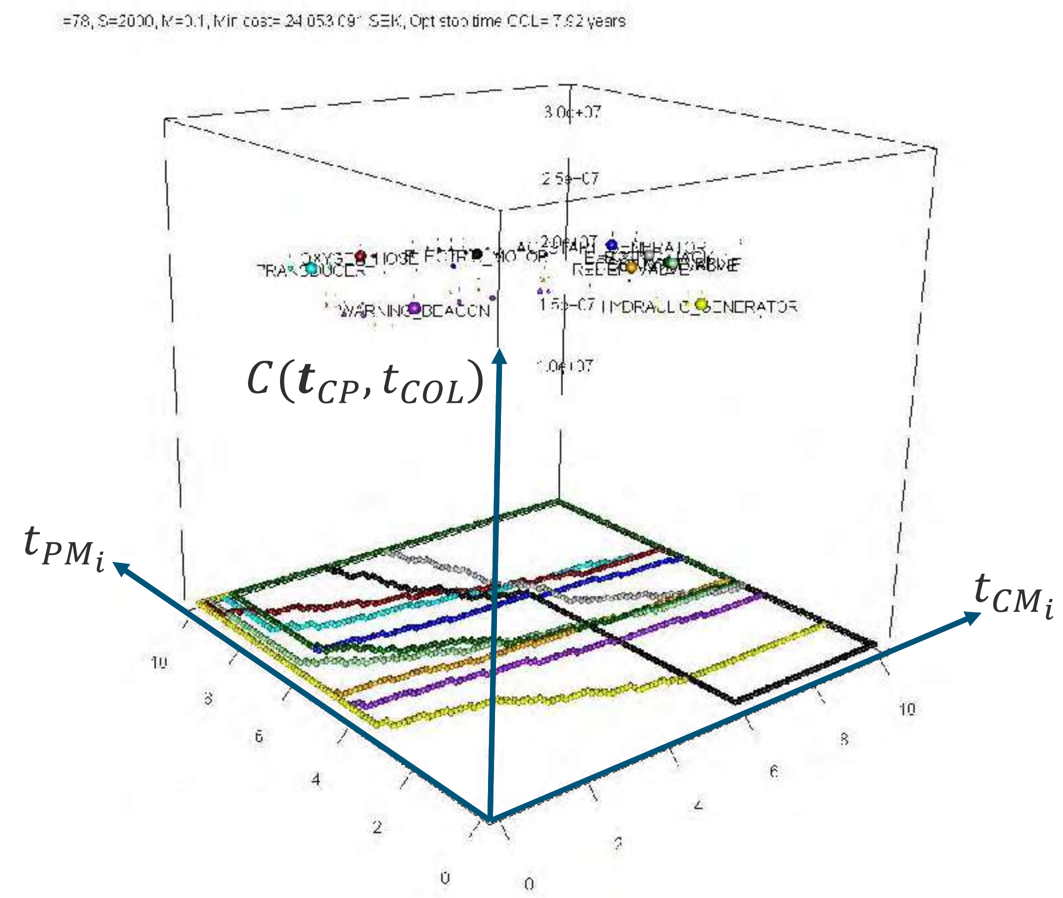
ΔT=1000 h



Systecon

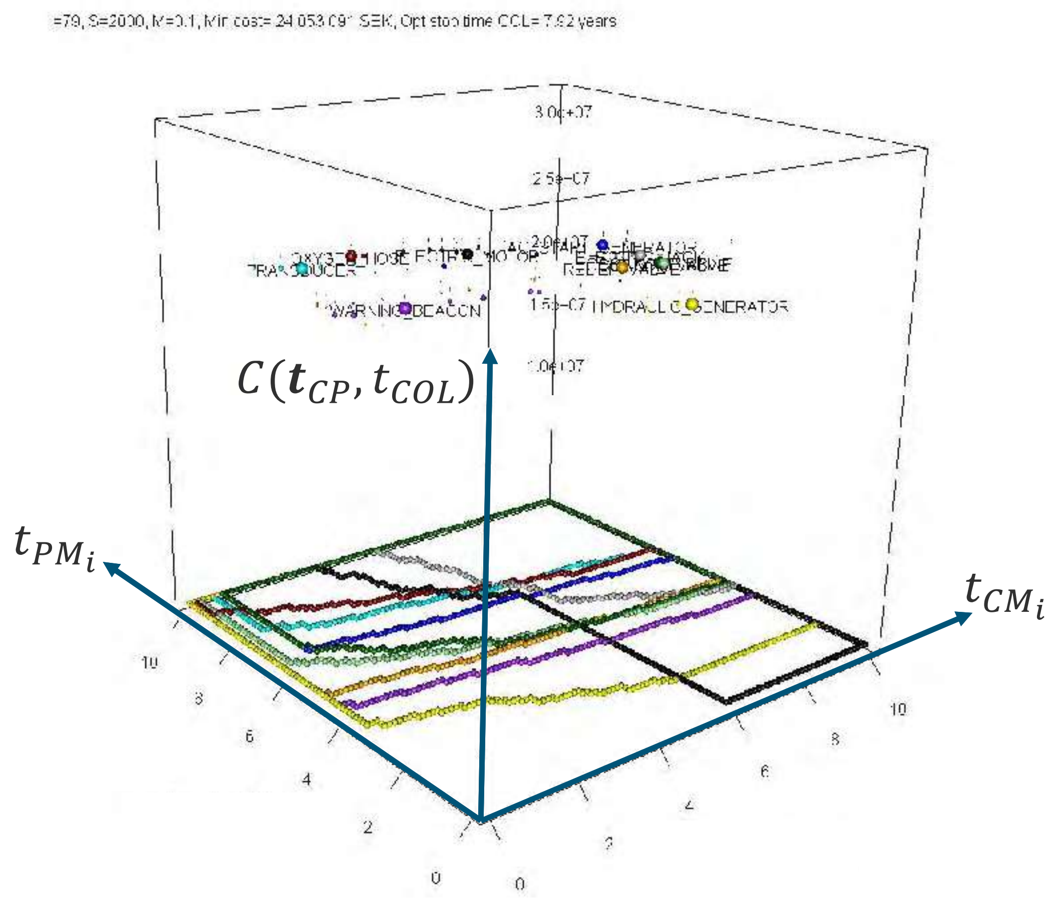
Genetic Algorithm (2000 samples)

ΔT=1000 h



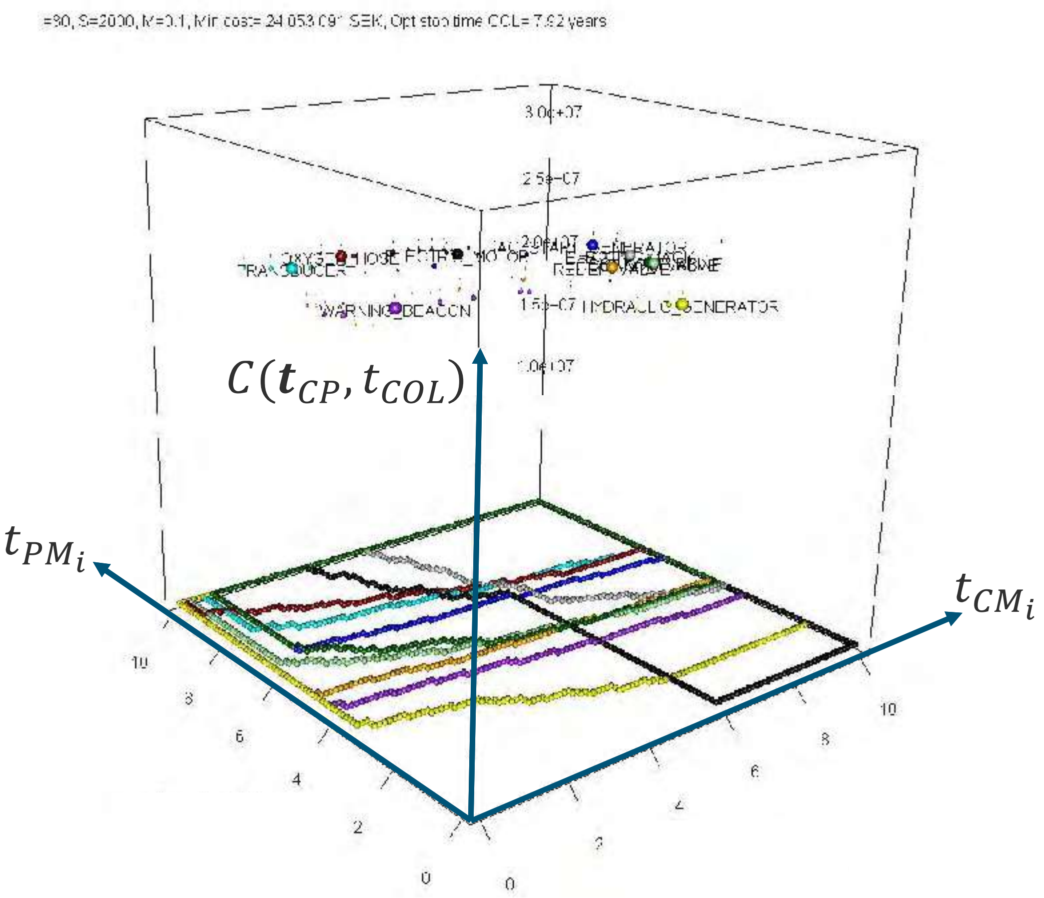
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

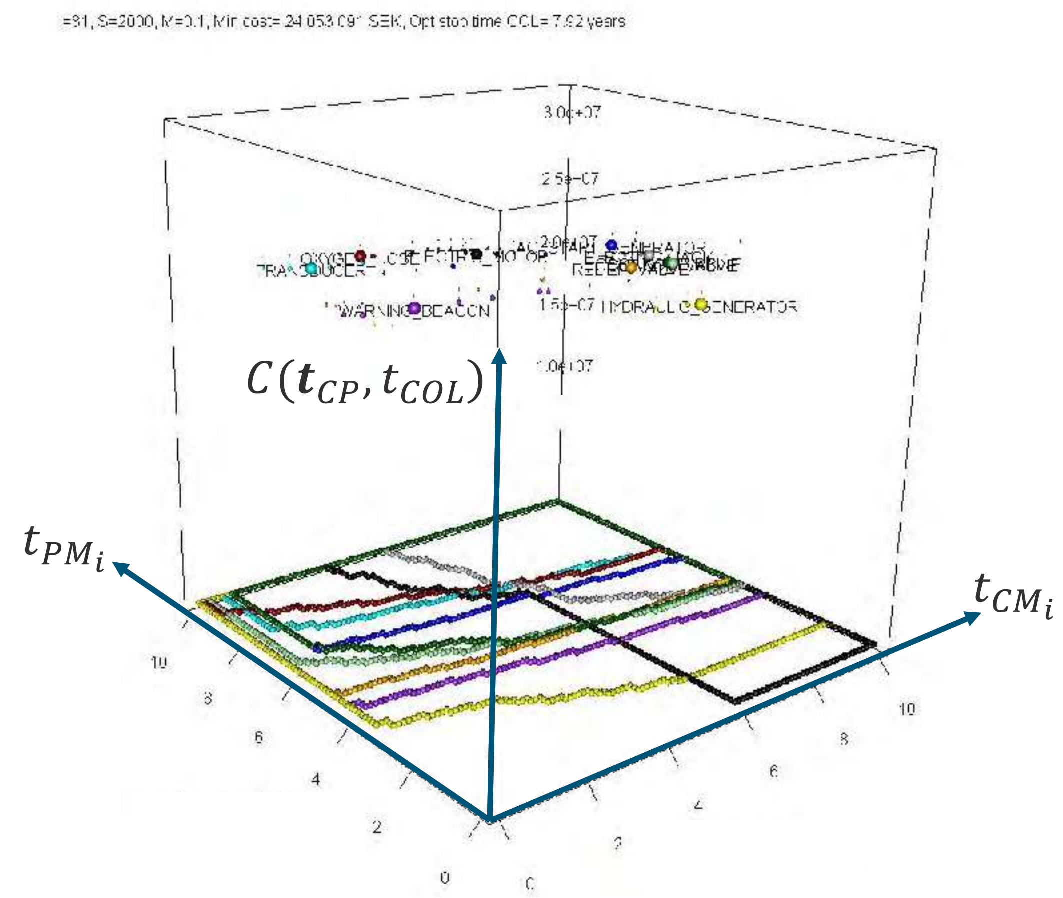
ΔT=1000 h



Systecon

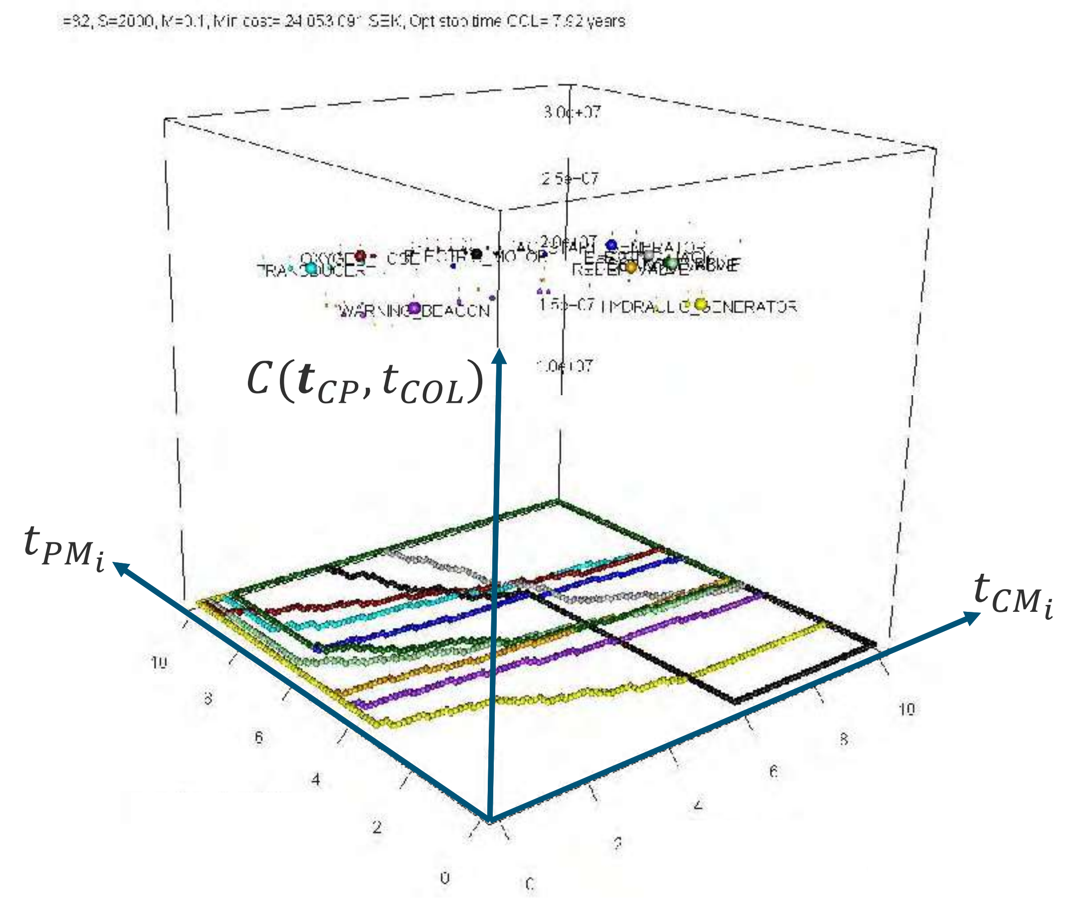
Genetic Algorithm (2000 samples)

ΔT=1000 h



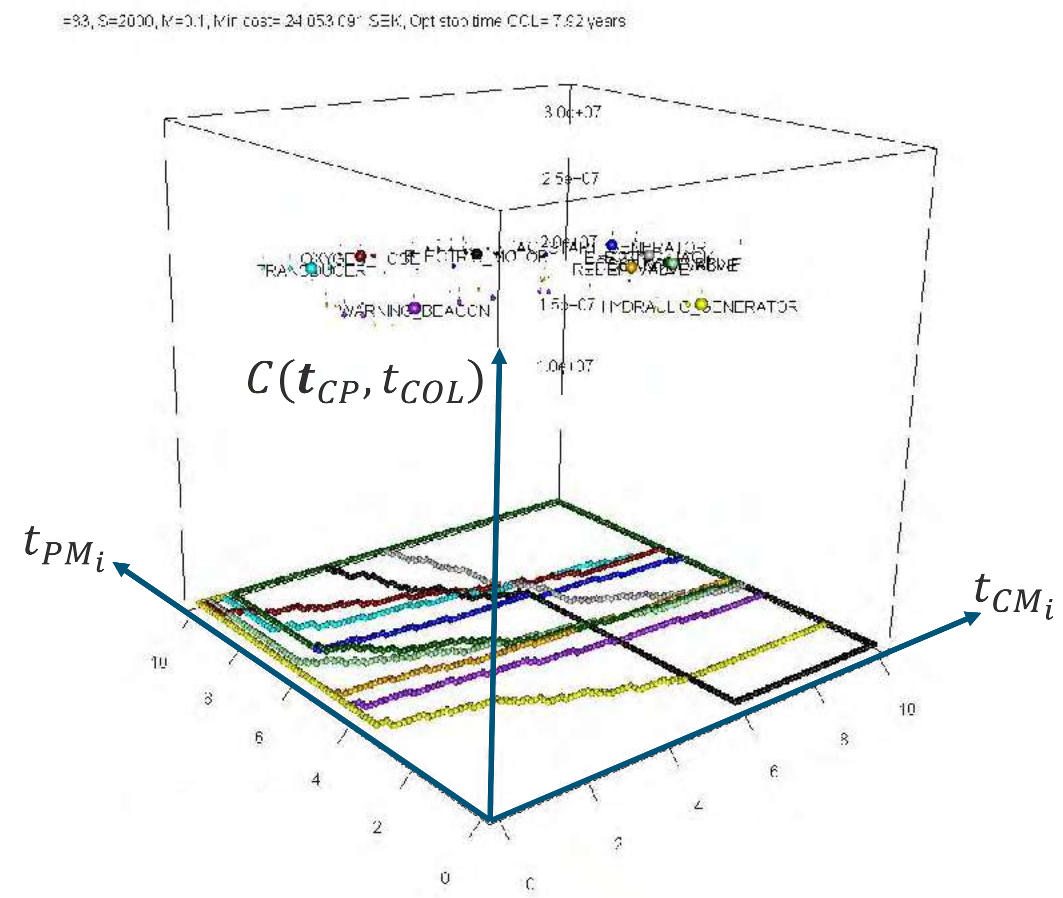
Genetic Algorithm (2000 samples)

ΔT=1000 h



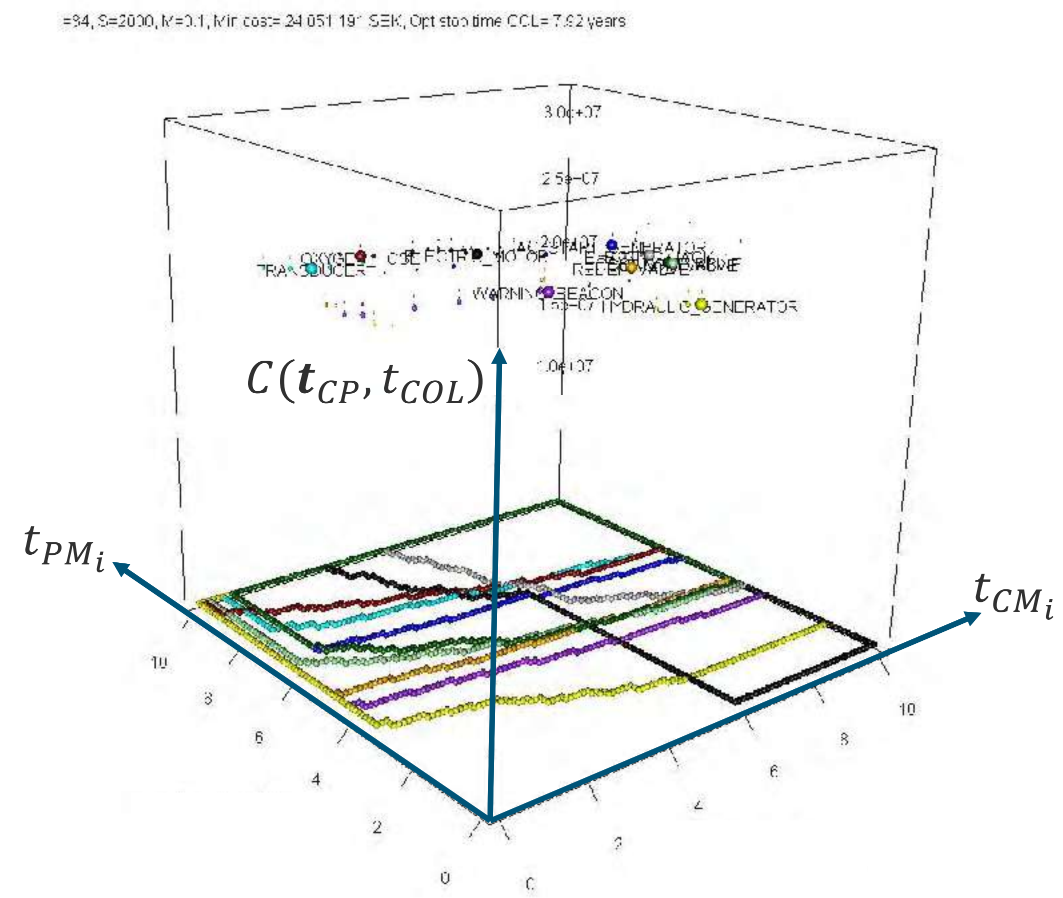
Genetic Algorithm (2000 samples)

ΔT=1000 h



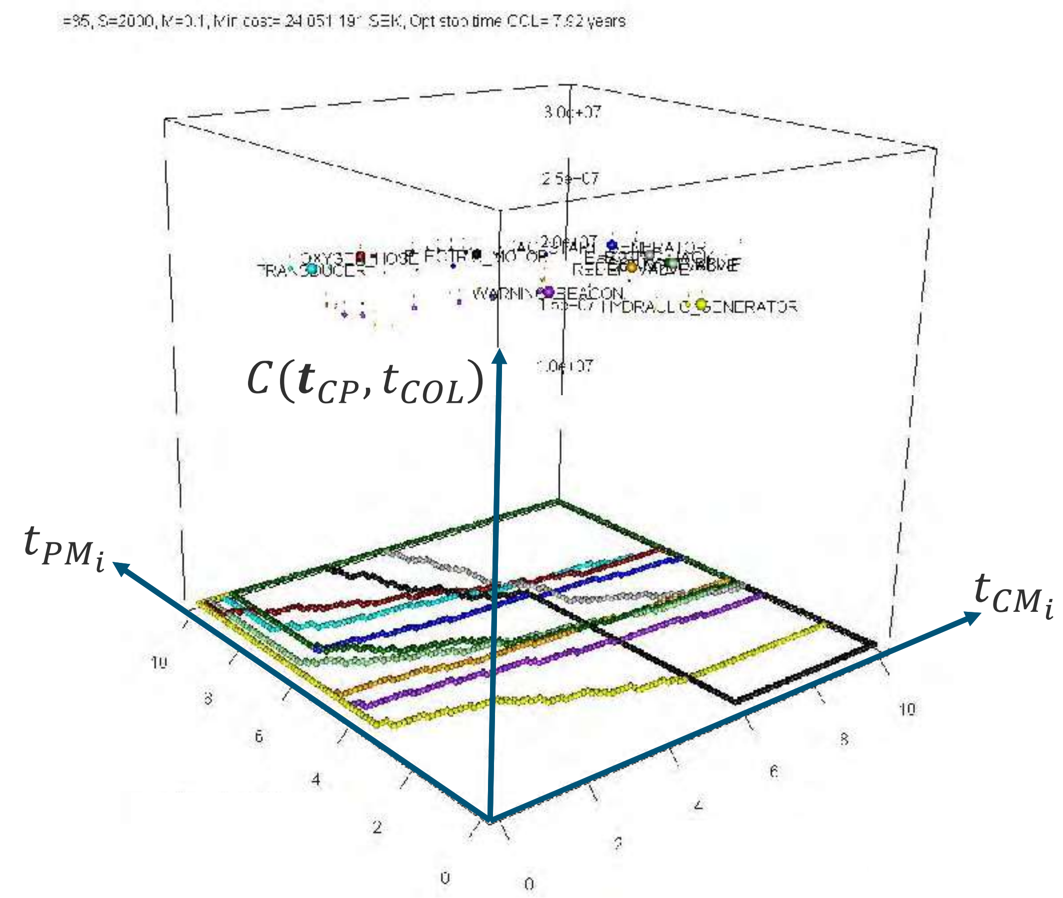
Genetic Algorithm (2000 samples)

ΔT=1000 h



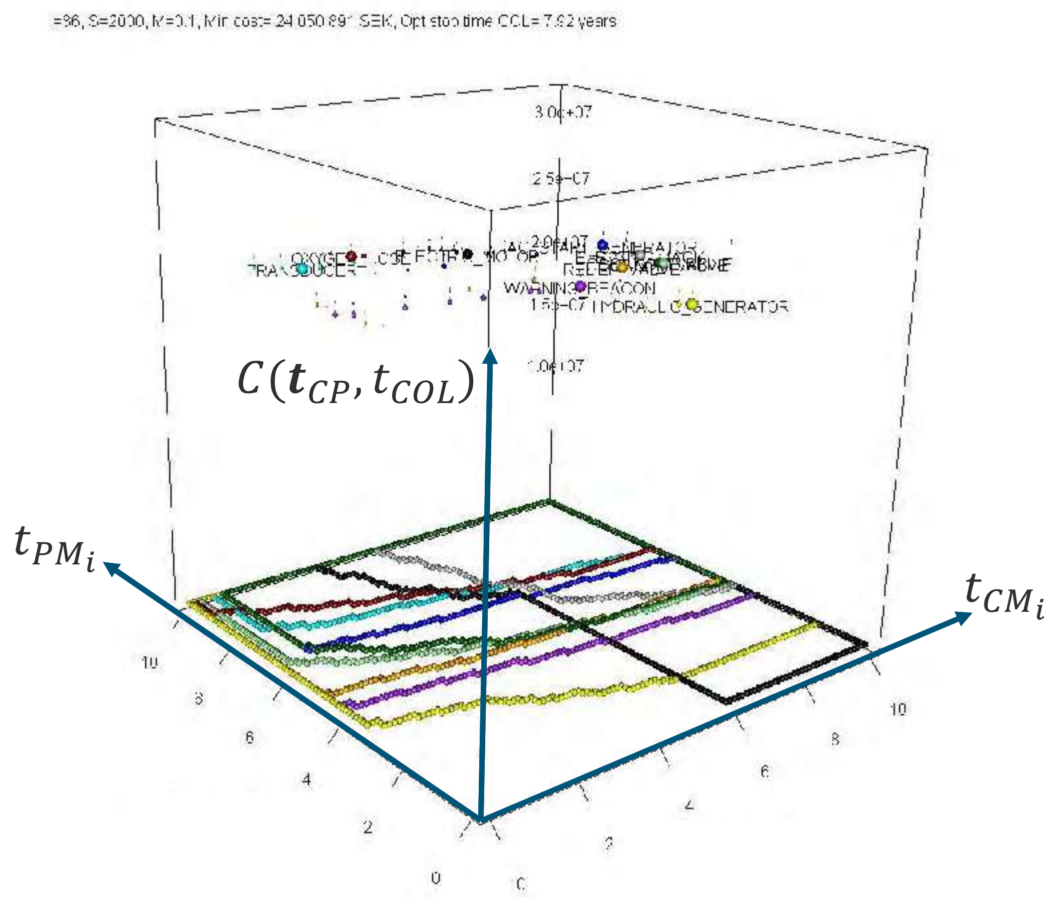
Genetic Algorithm (2000 samples)

ΔT=1000 h



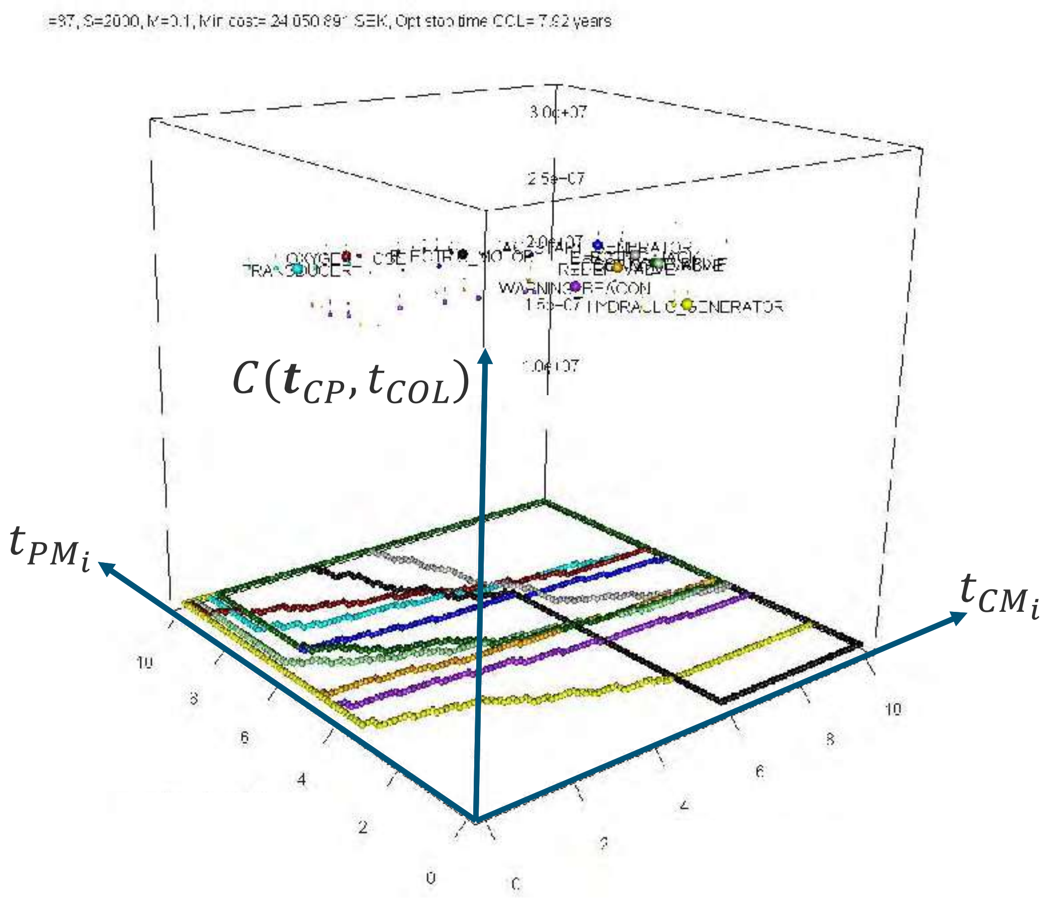
Genetic Algorithm (2000 samples)

ΔT=1000 h



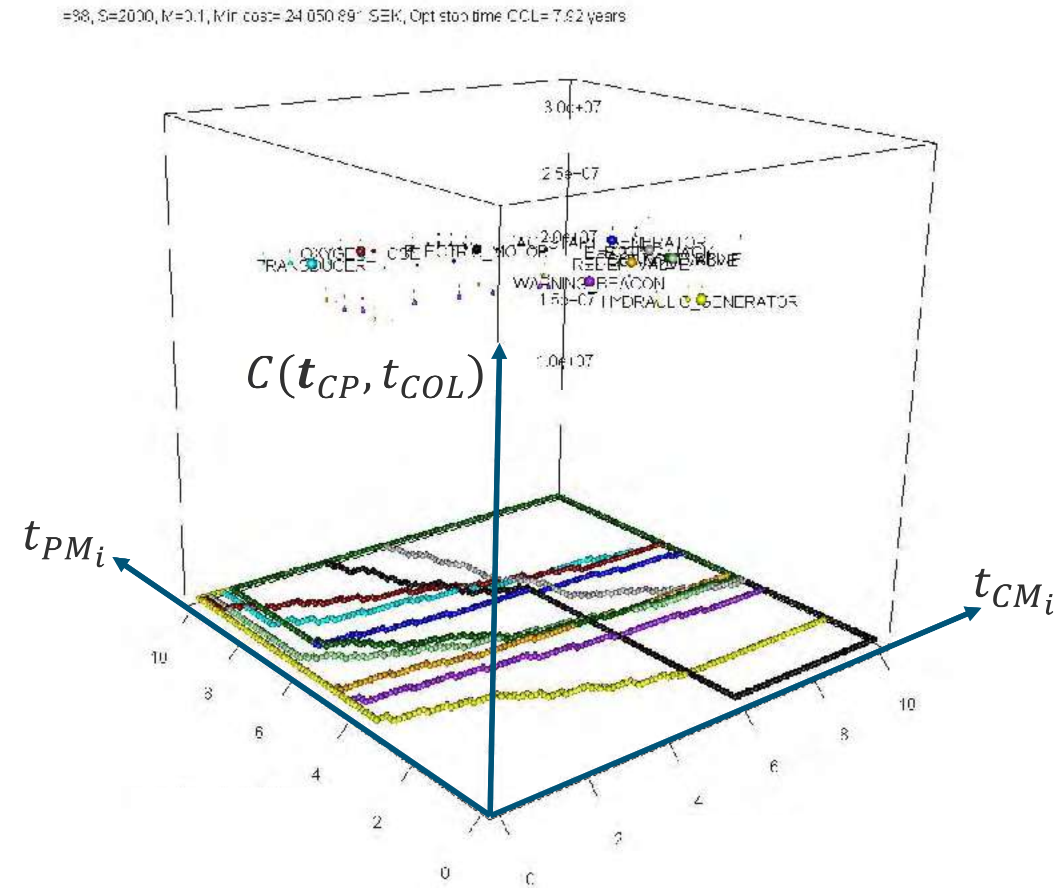
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

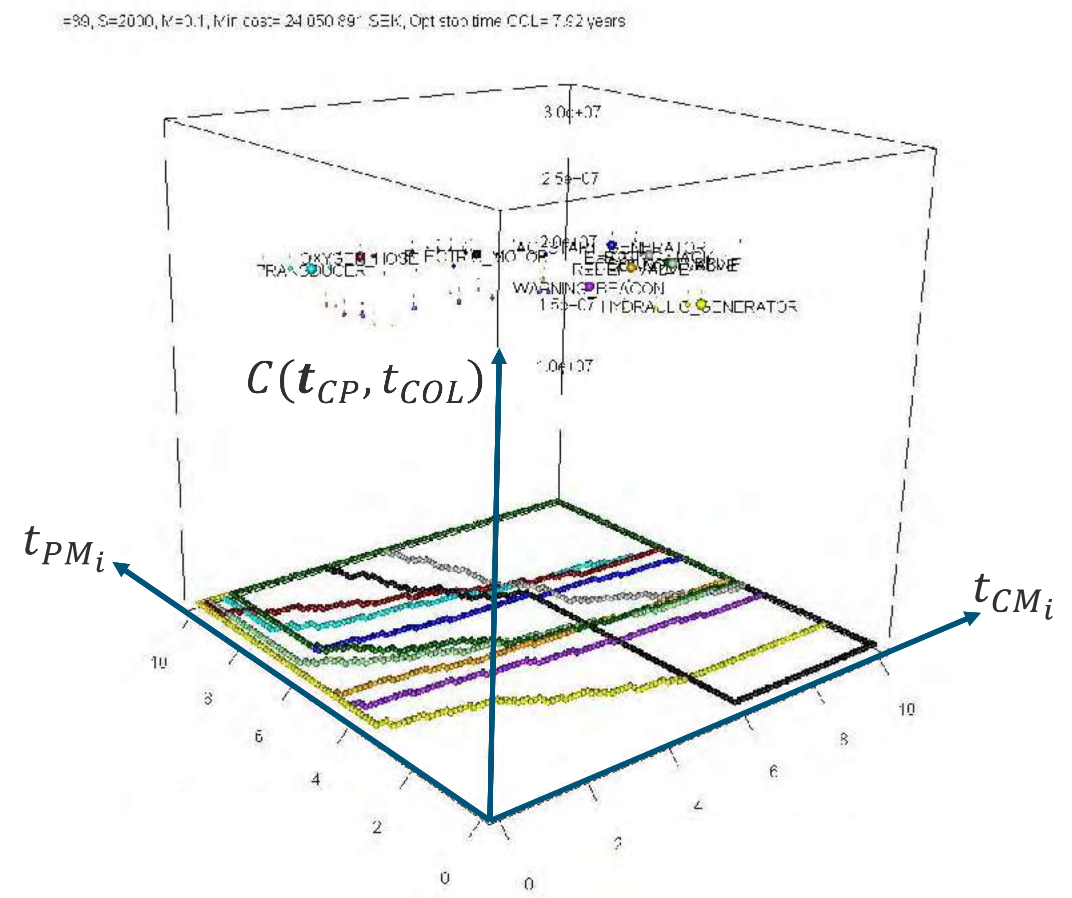
ΔT=1000 h



Slide 246

Genetic Algorithm (2000 samples)

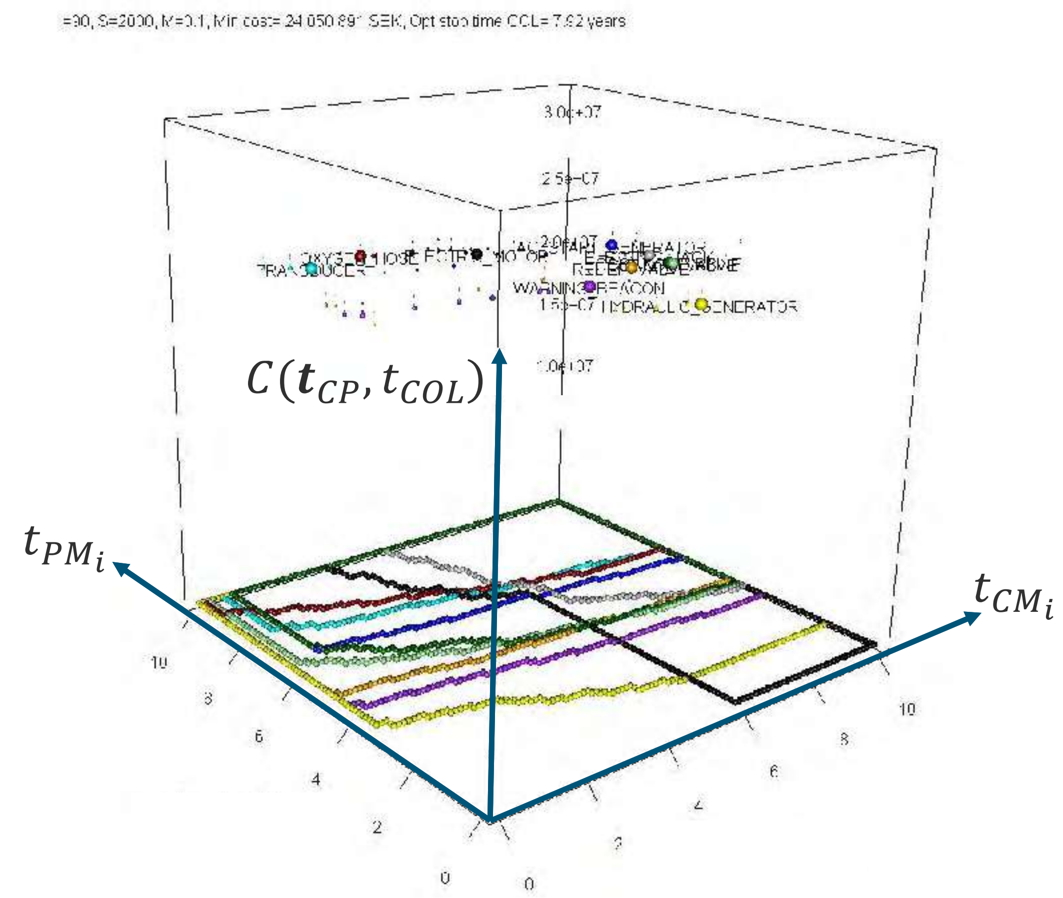
ΔT=1000 h



Systecon

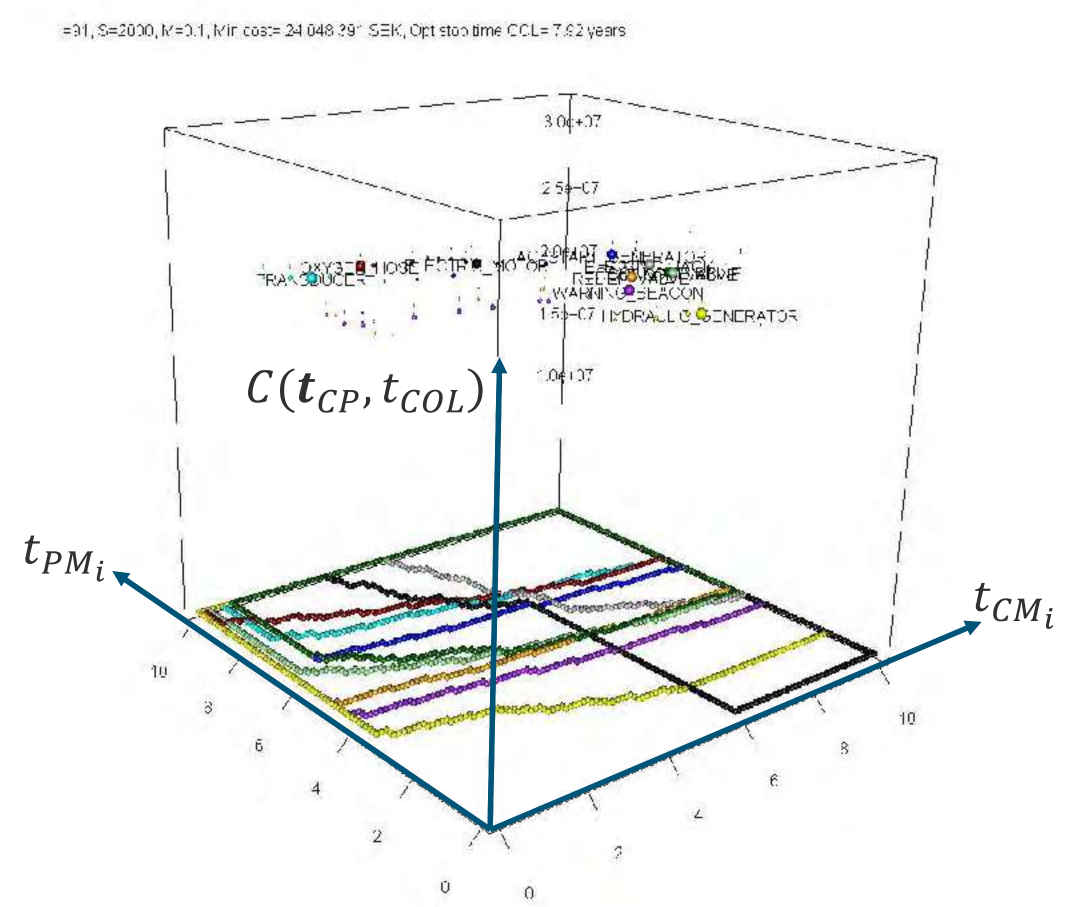
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

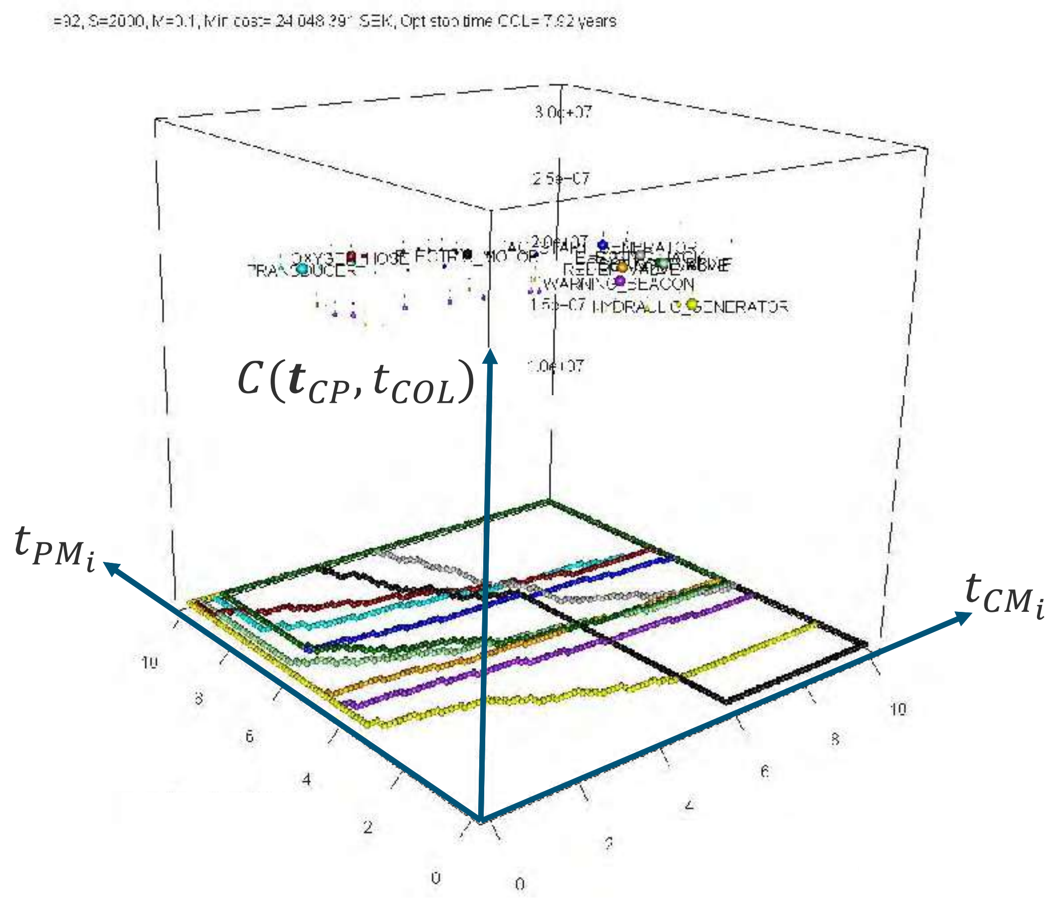
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

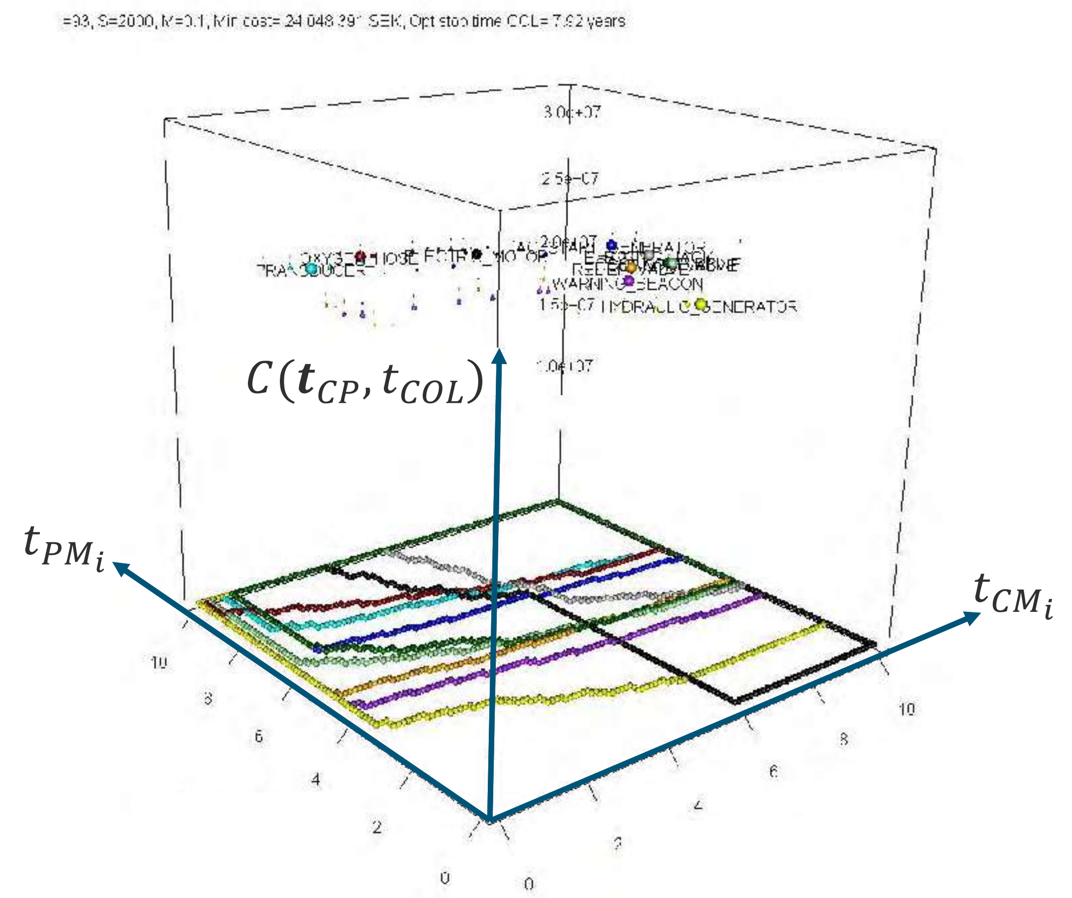
ΔT=1000 h



Slide 250

Genetic Algorithm (2000 samples)

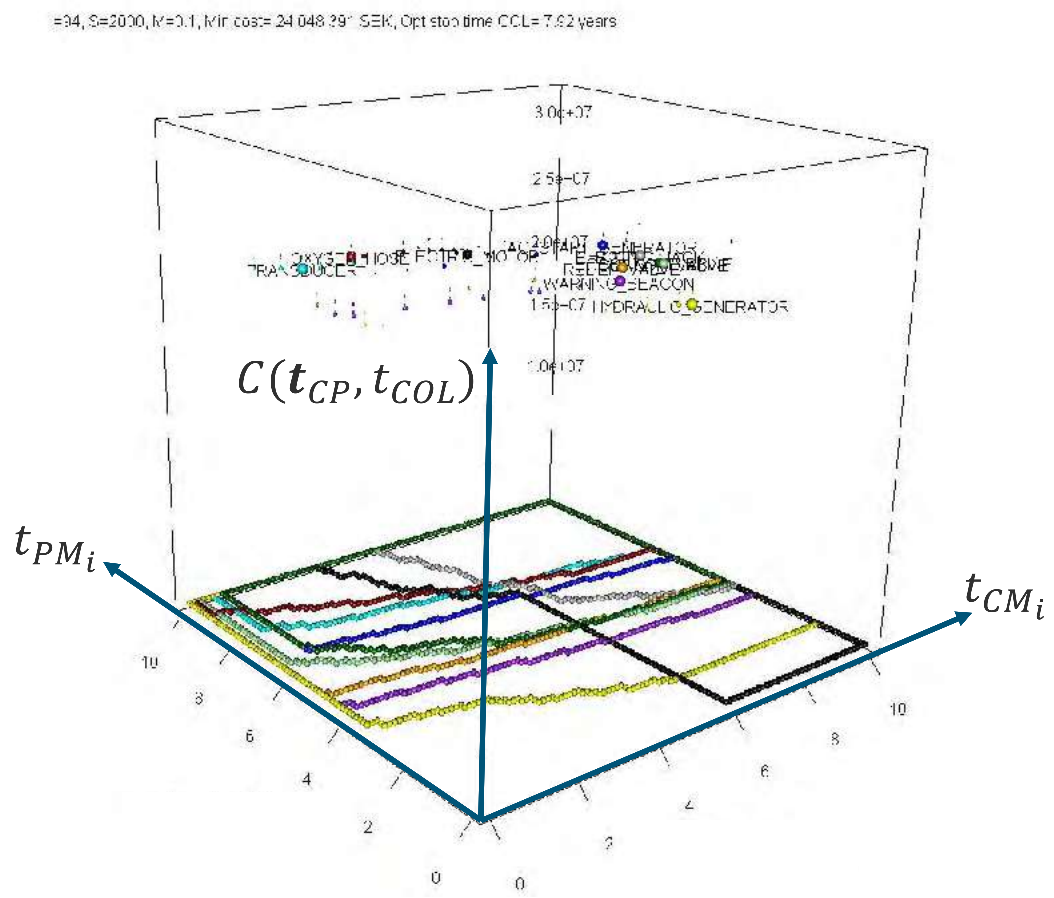
ΔT=1000 h



Systecon

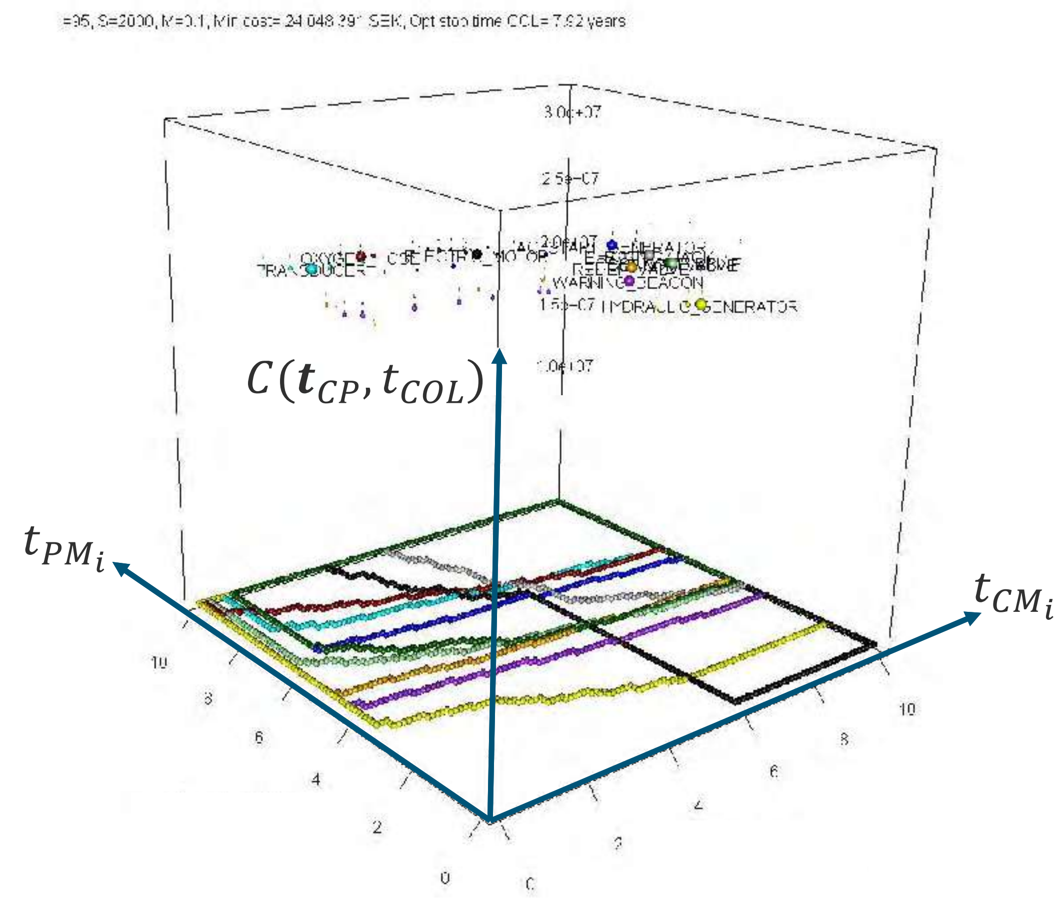
Genetic Algorithm (2000 samples)

ΔT=1000 h



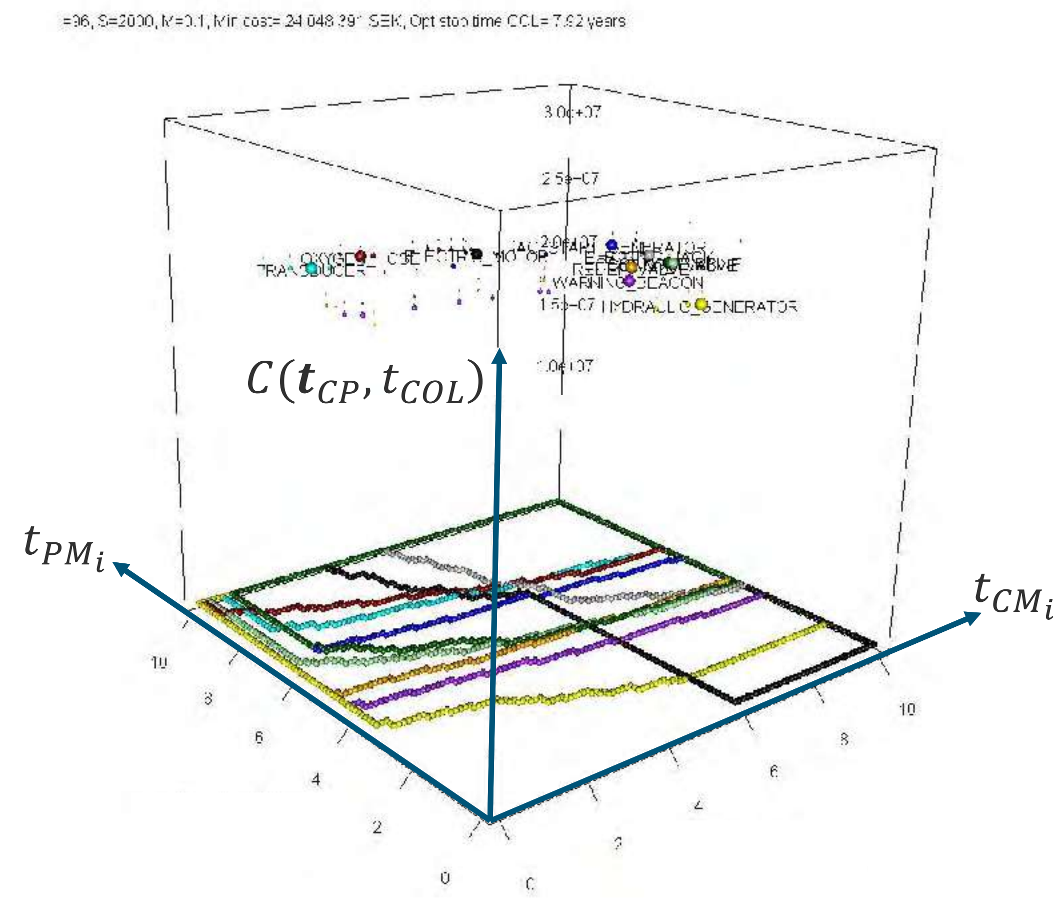
Genetic Algorithm (2000 samples)

ΔT=1000 h



Genetic Algorithm (2000 samples)

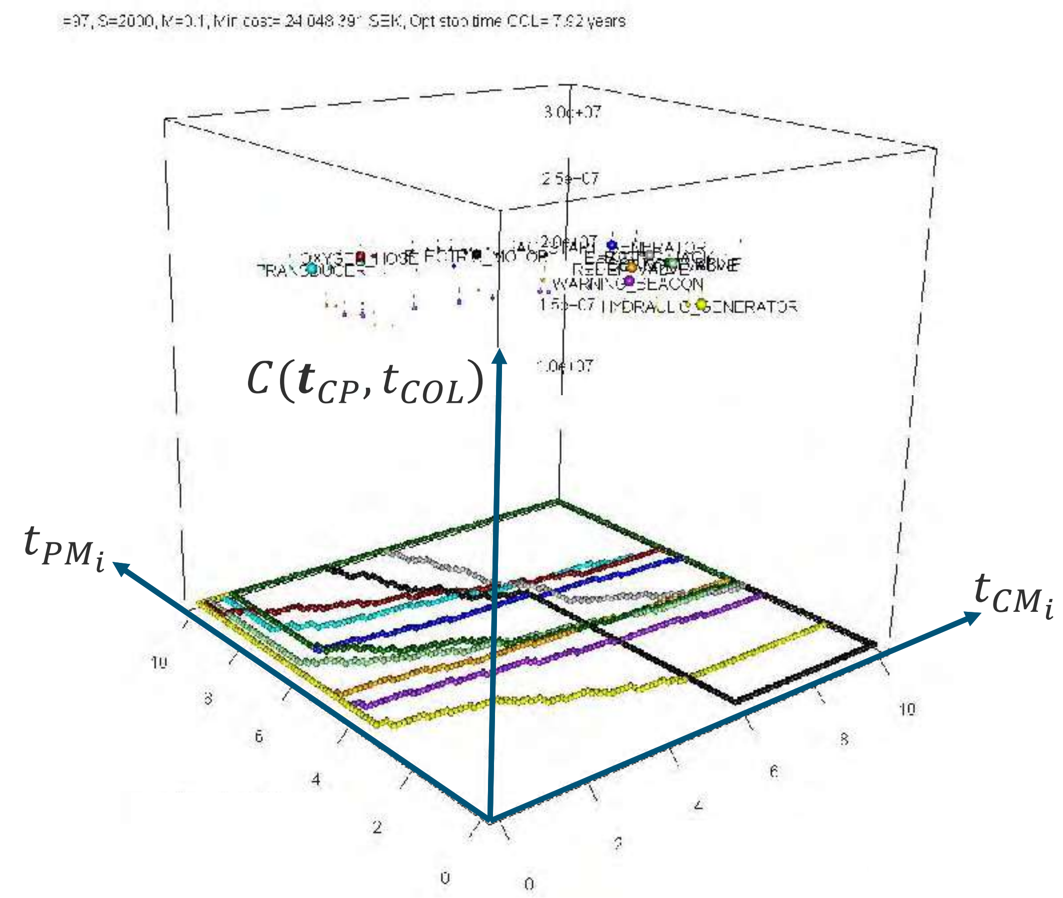
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

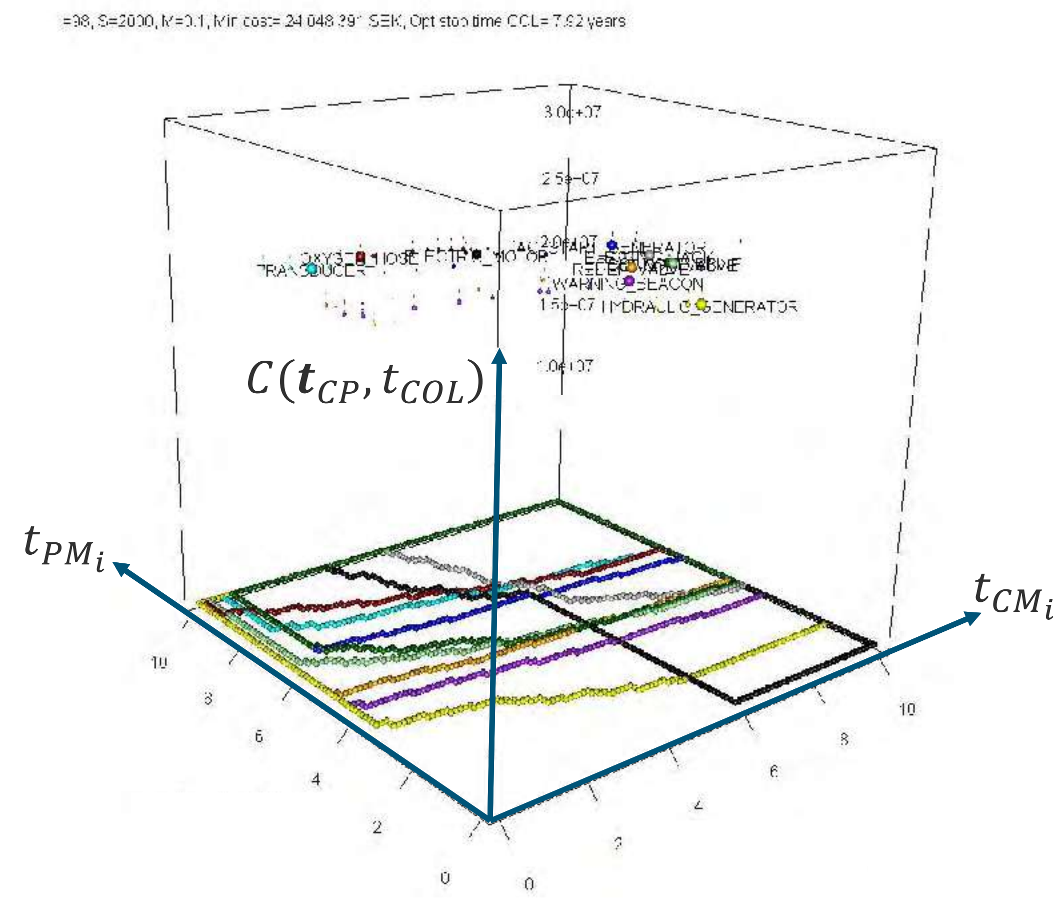
ΔT=1000 h



Systecon

Genetic Algorithm (2000 samples)

ΔT=1000 h



Systecon

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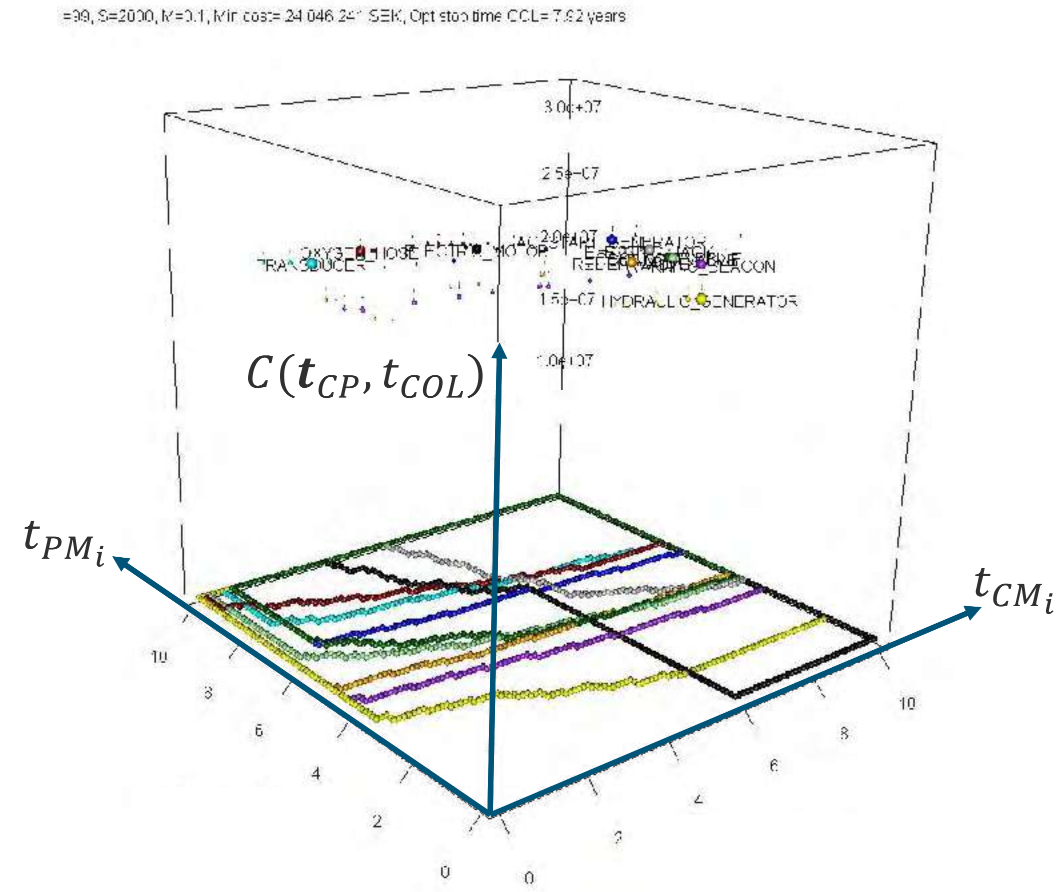
ΔT=1000 h



Genetic Algorithm (2000 samples)

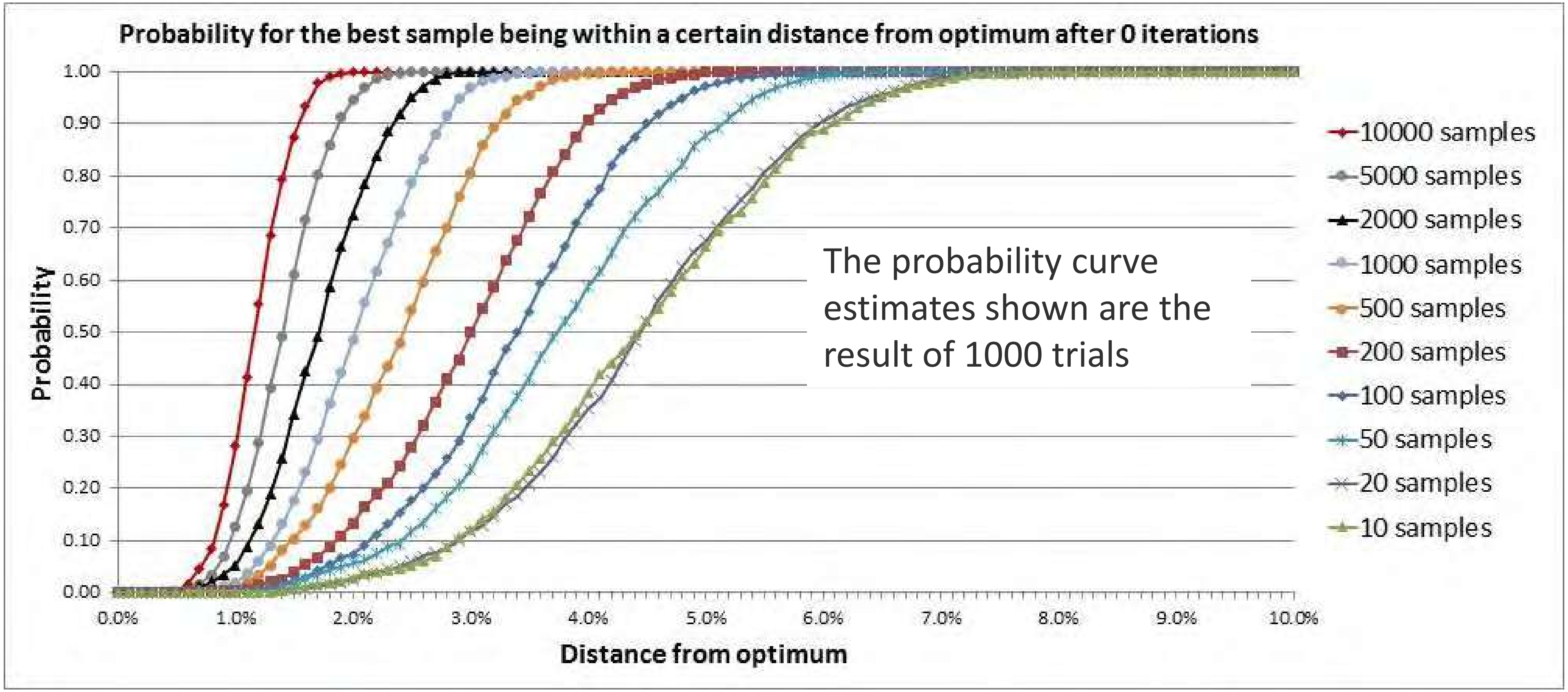
ΔT=1000 h

- Found true optimum
  - $C_{min} = \mathbf{24.05}$ **MSEK**
  - $t_{COL}^{opt} = 7.92$ years

Item ID	t_{CM}^{opt}	t_{PM}^{opt}
Warning Beacon	7.65 years	3.20 years
Relief Valve	6.62 years	4.11 years
Transducer	1.37 years	7.53 years
Cut-Off Valve	7.53 years	3.88 years
A/C - Start Generator	7.65 years	5.82 years
Hydraulic Generator	5.71 years	1.26 years
Electric Motor	4.79 years	6.74 years
Electric Jack	7.65 years	4.68 years
Oxygen Hose	2.74 years	7.88 years
Cooling Turbine	7.53 years	4.00 years

- 55 seconds on a laptop with a 2.7 GHz processor
- Only 200 000 out of 44 trillion solutions investigated!
- Q: Was it just luck?

What is the probability of finding the optimum?



Systecon

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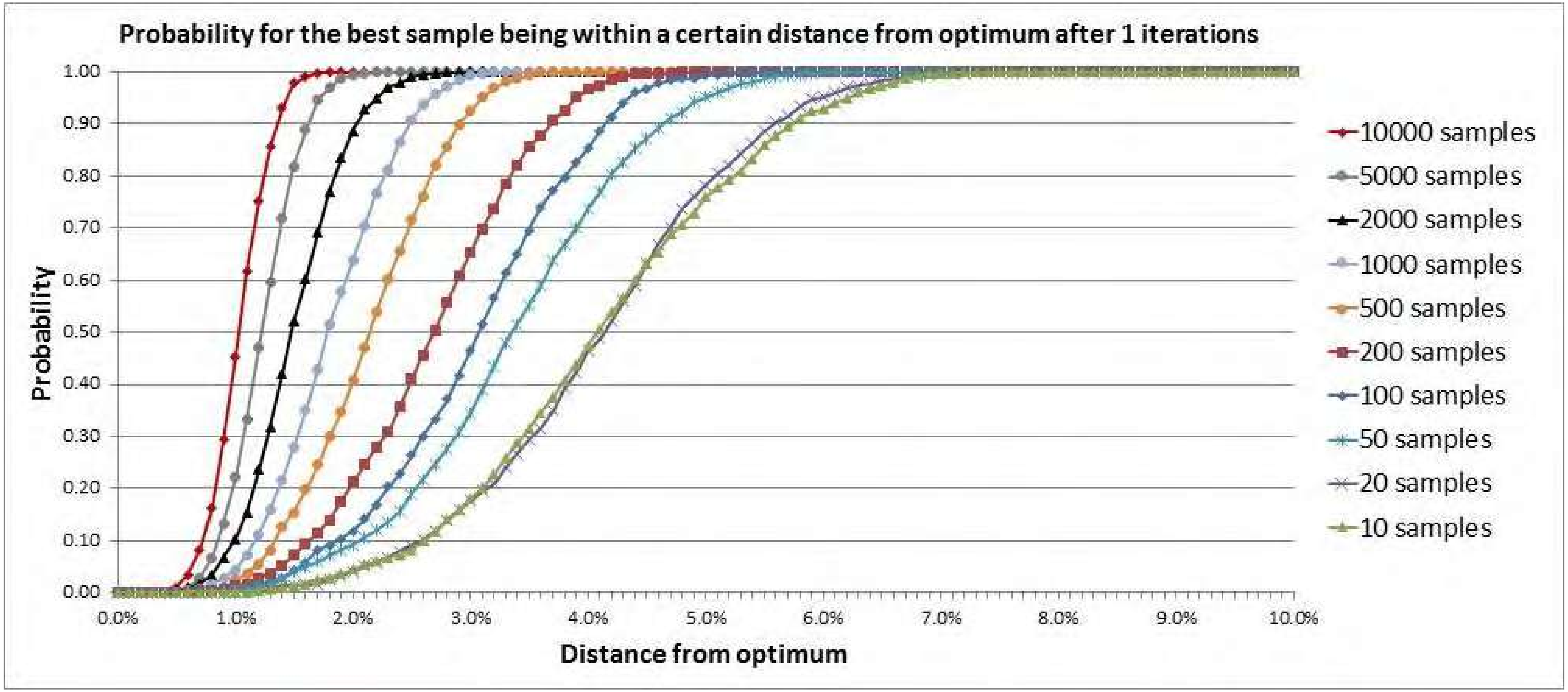

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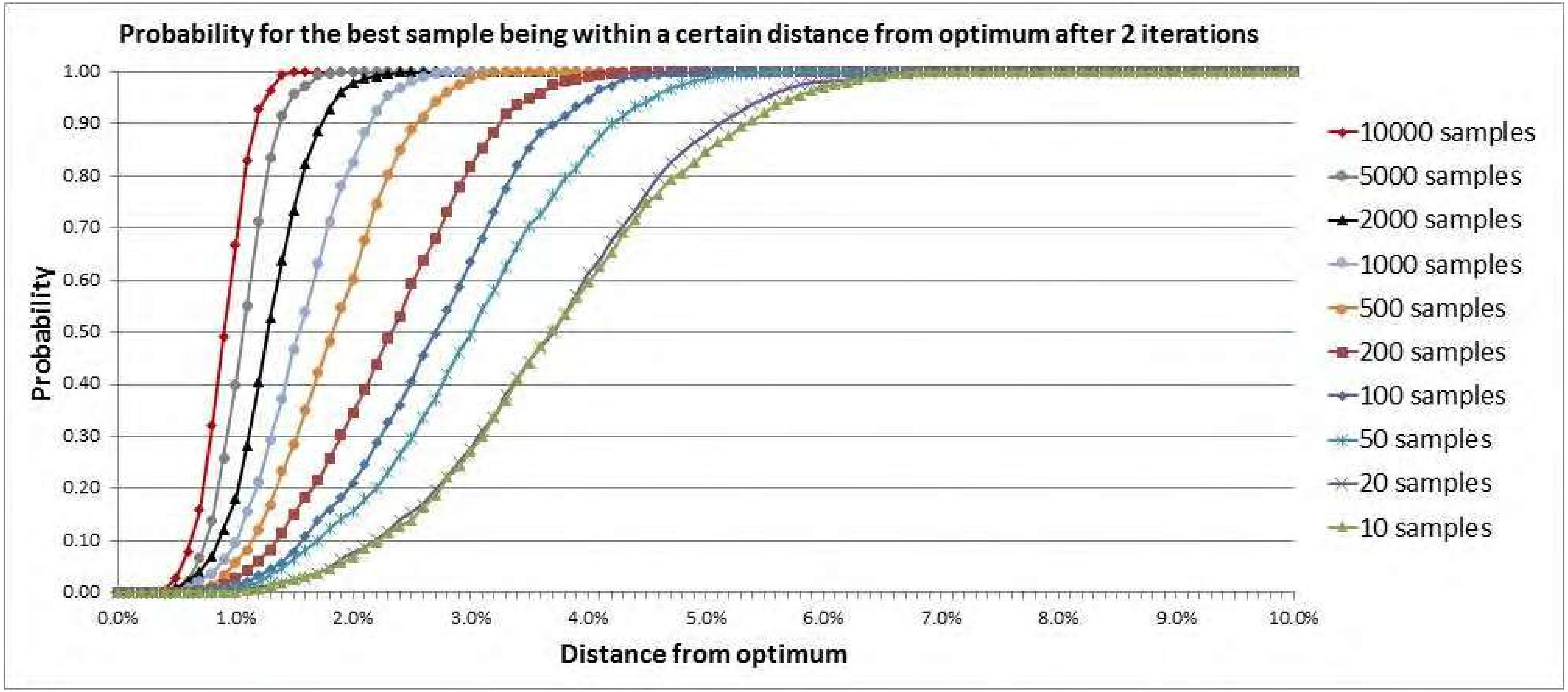

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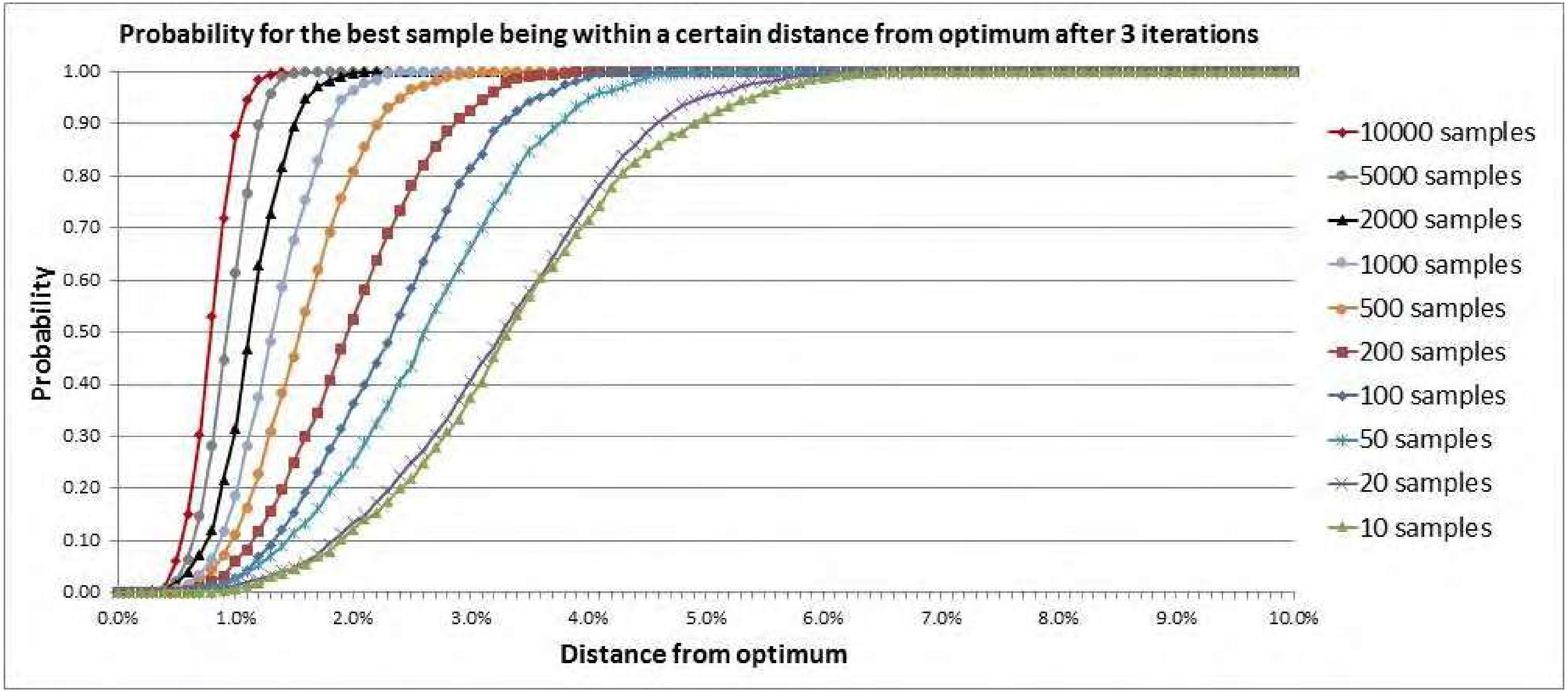

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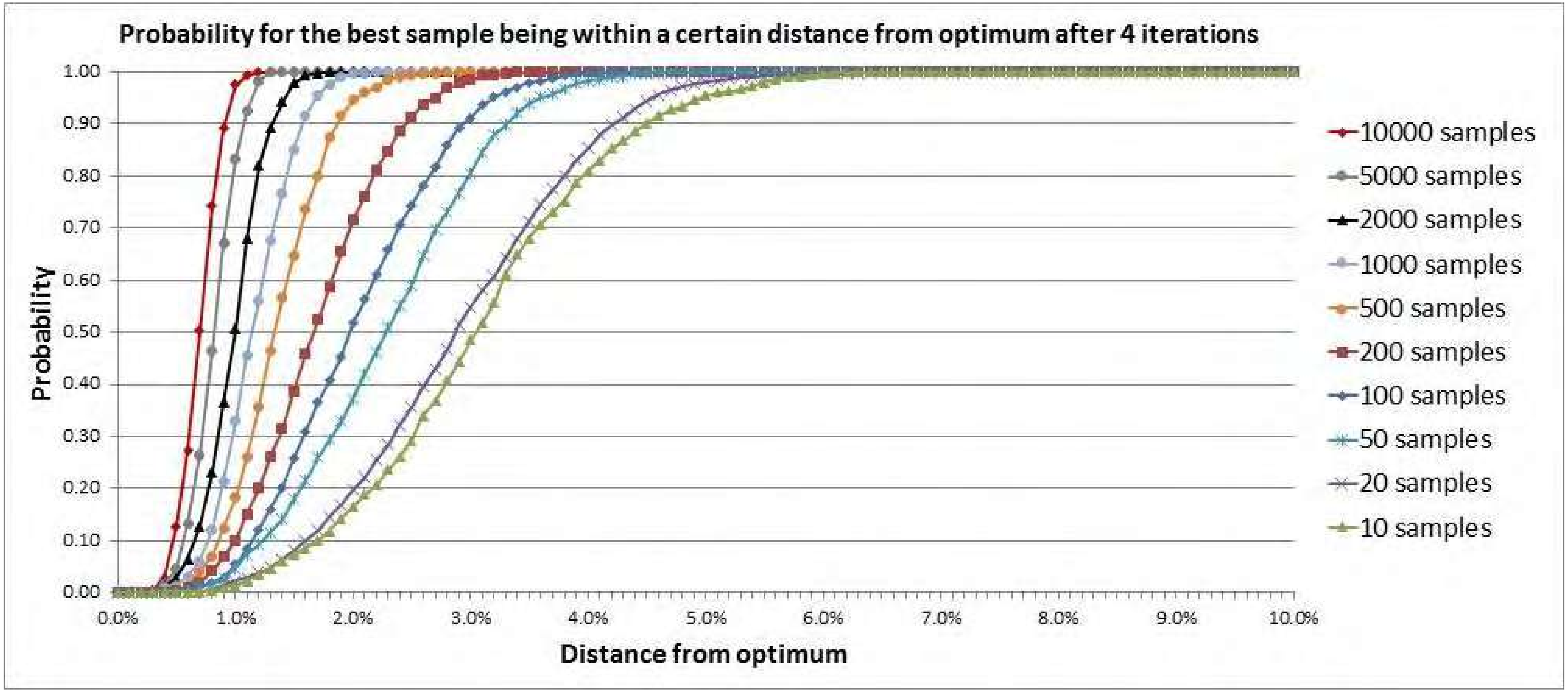

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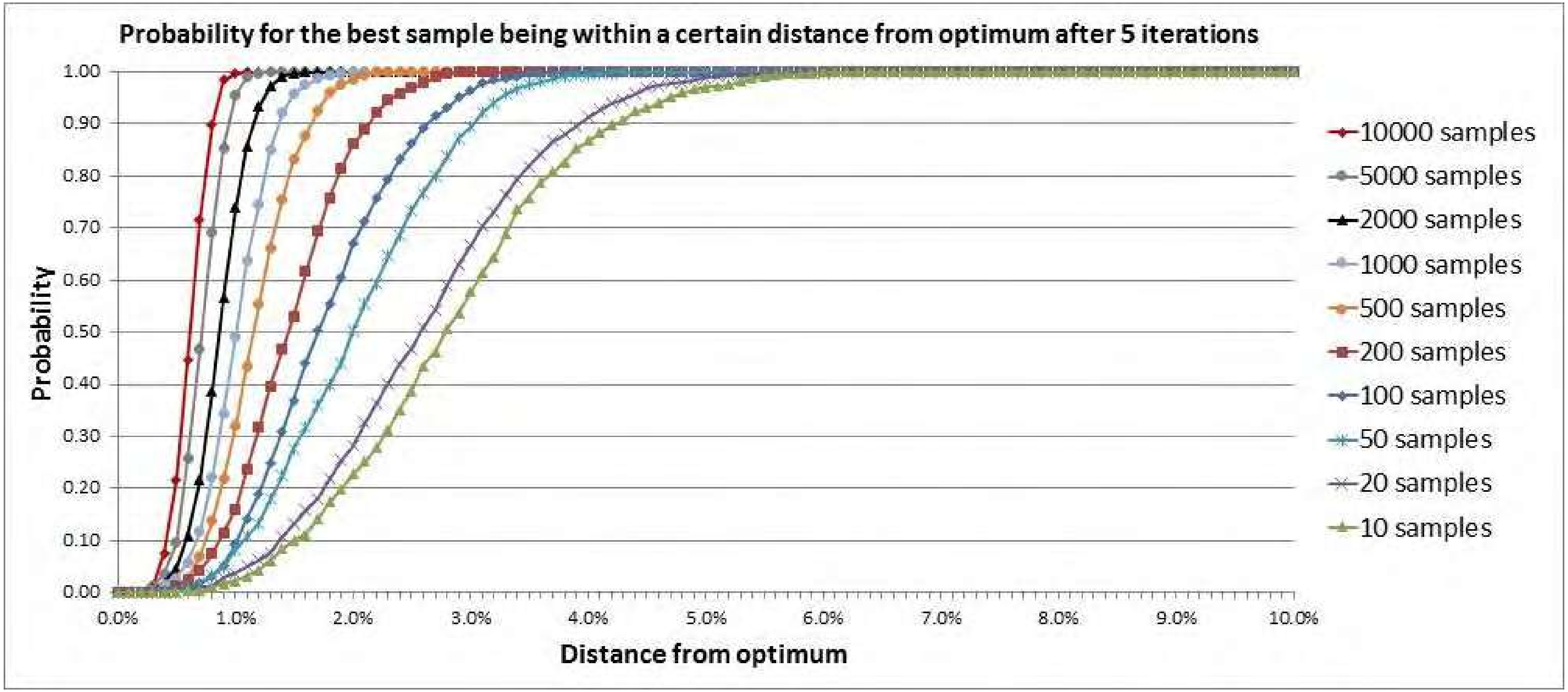

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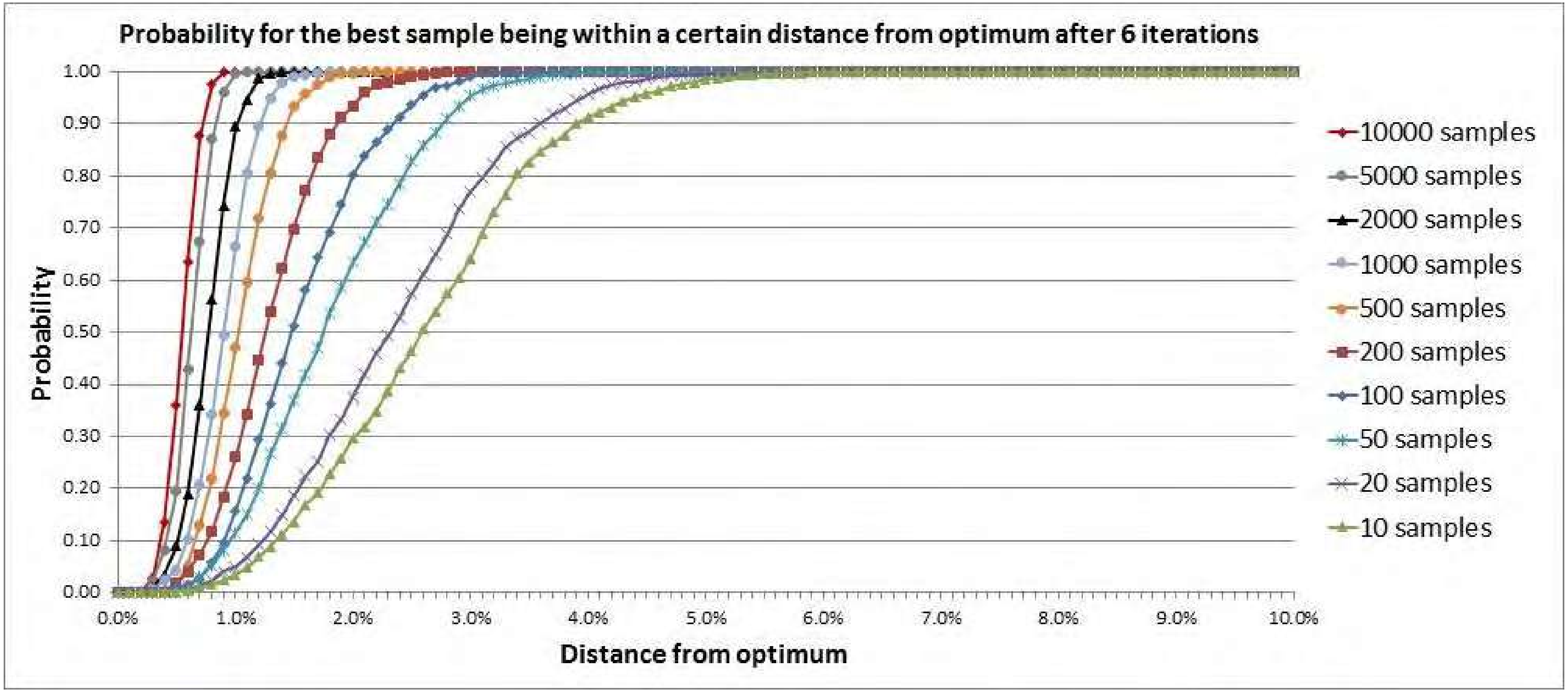

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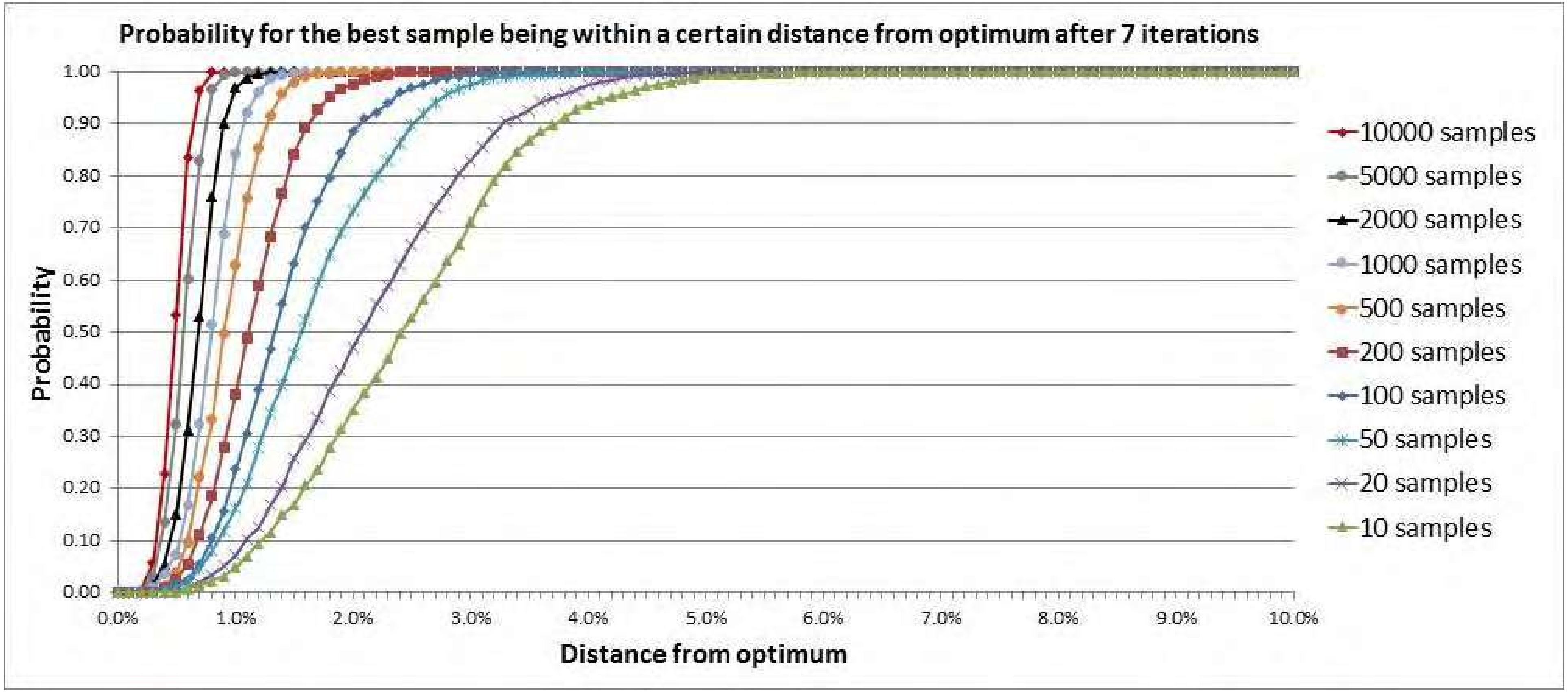

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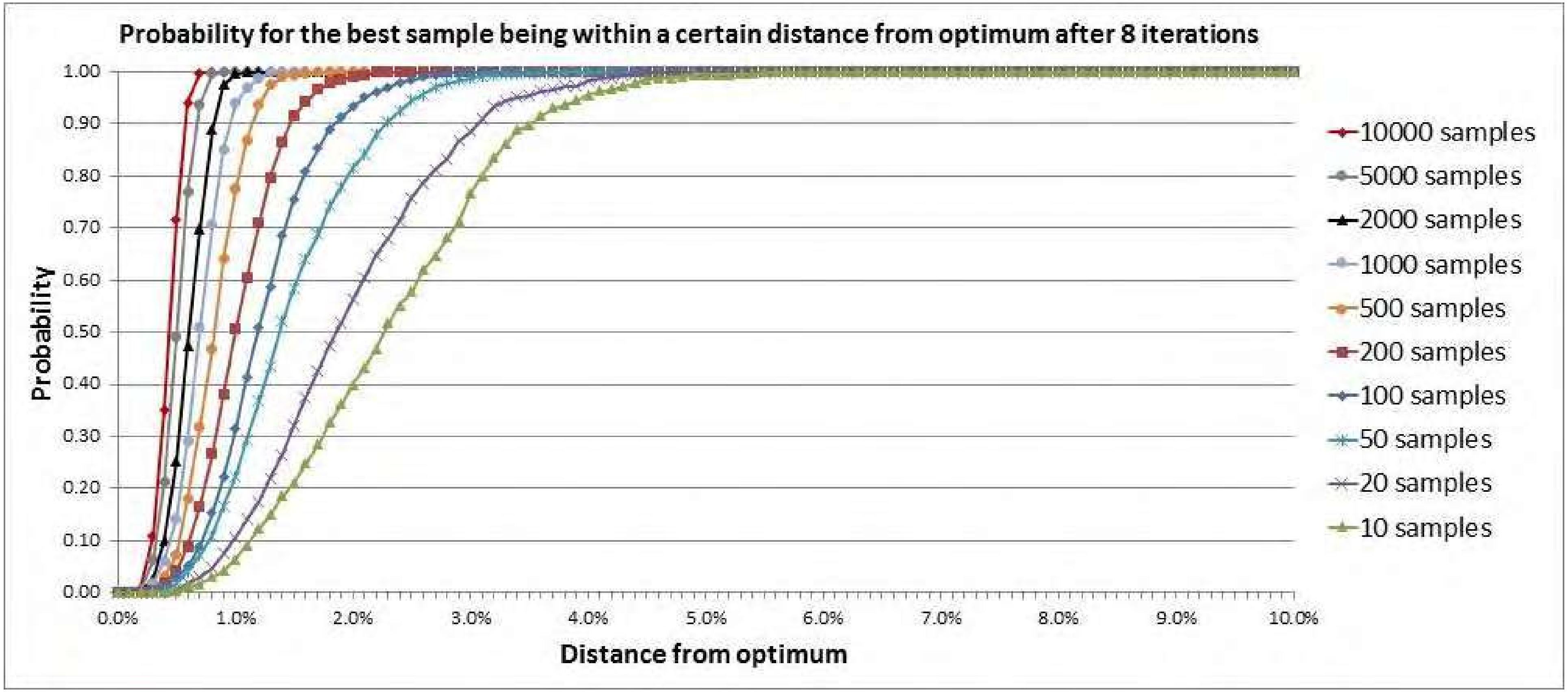

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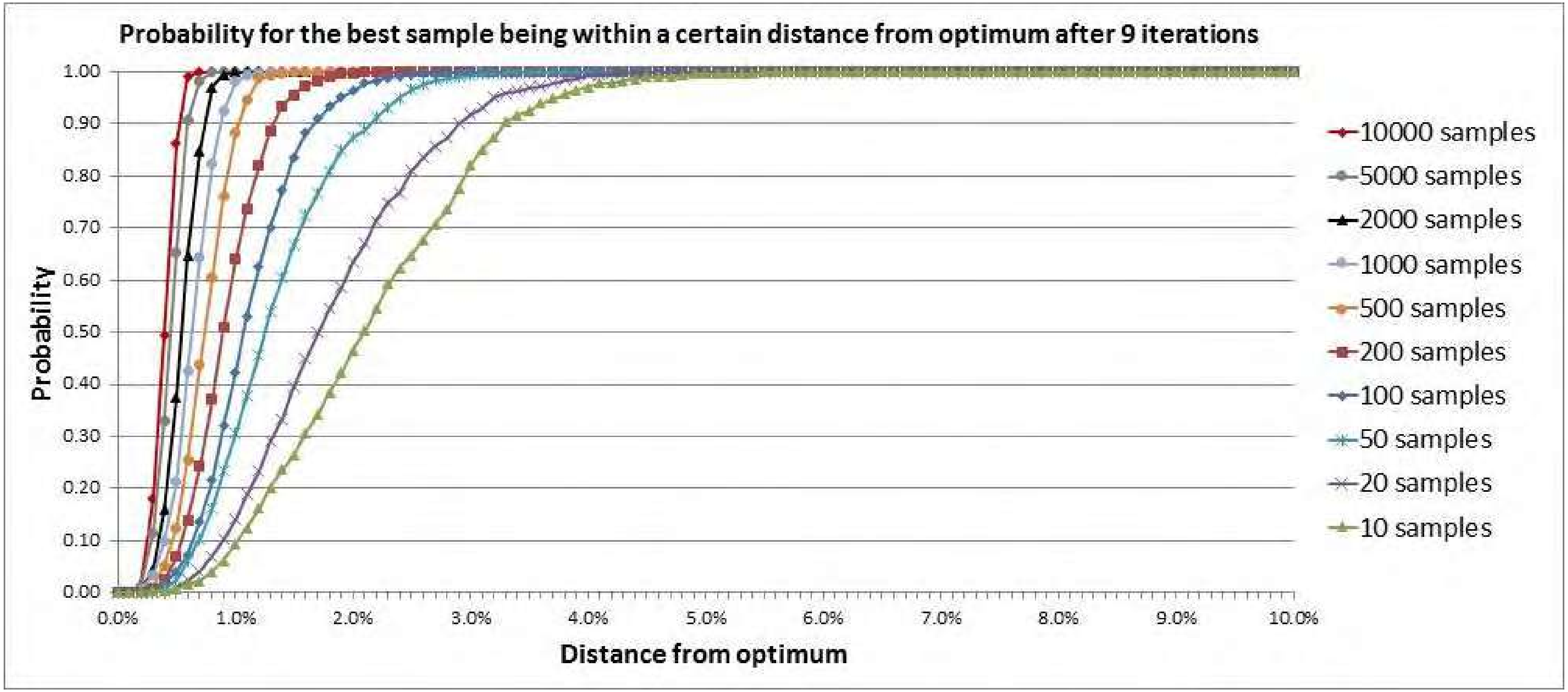

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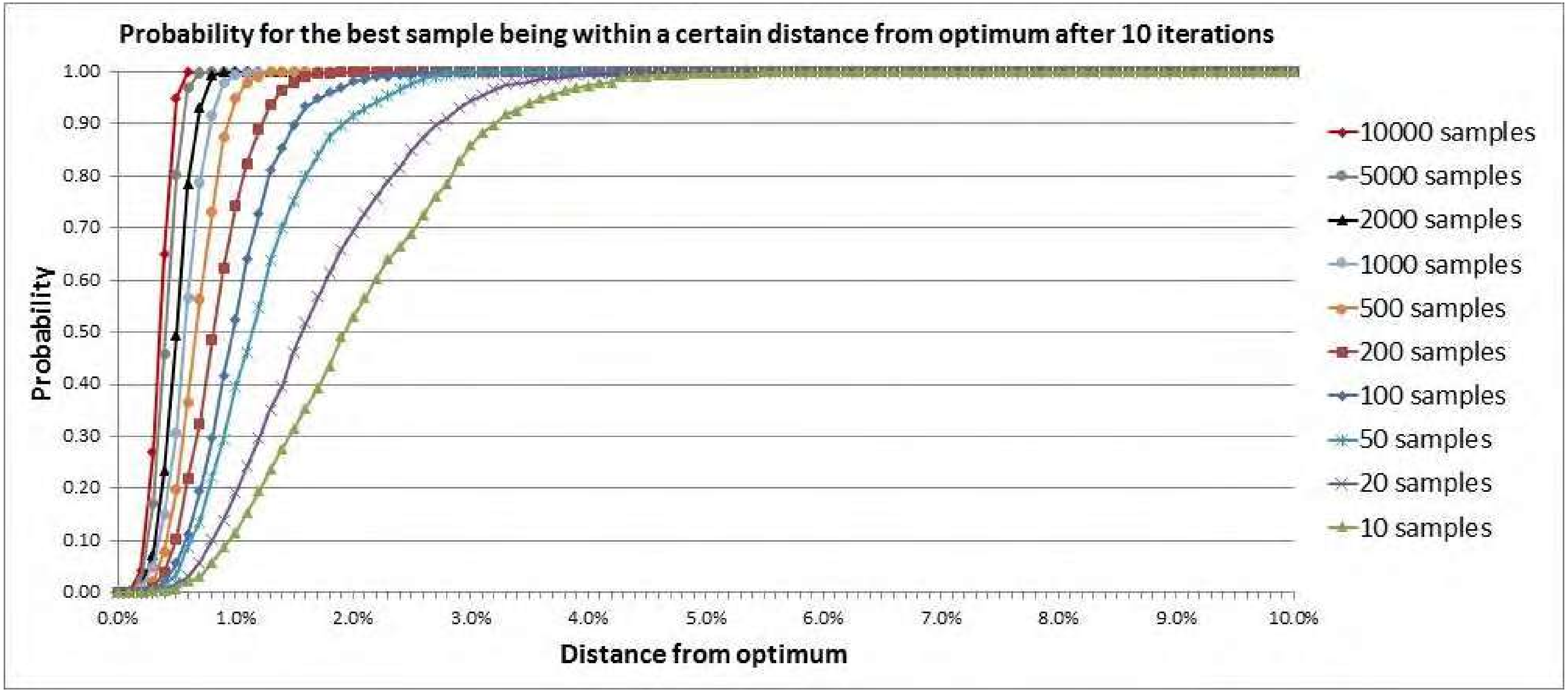

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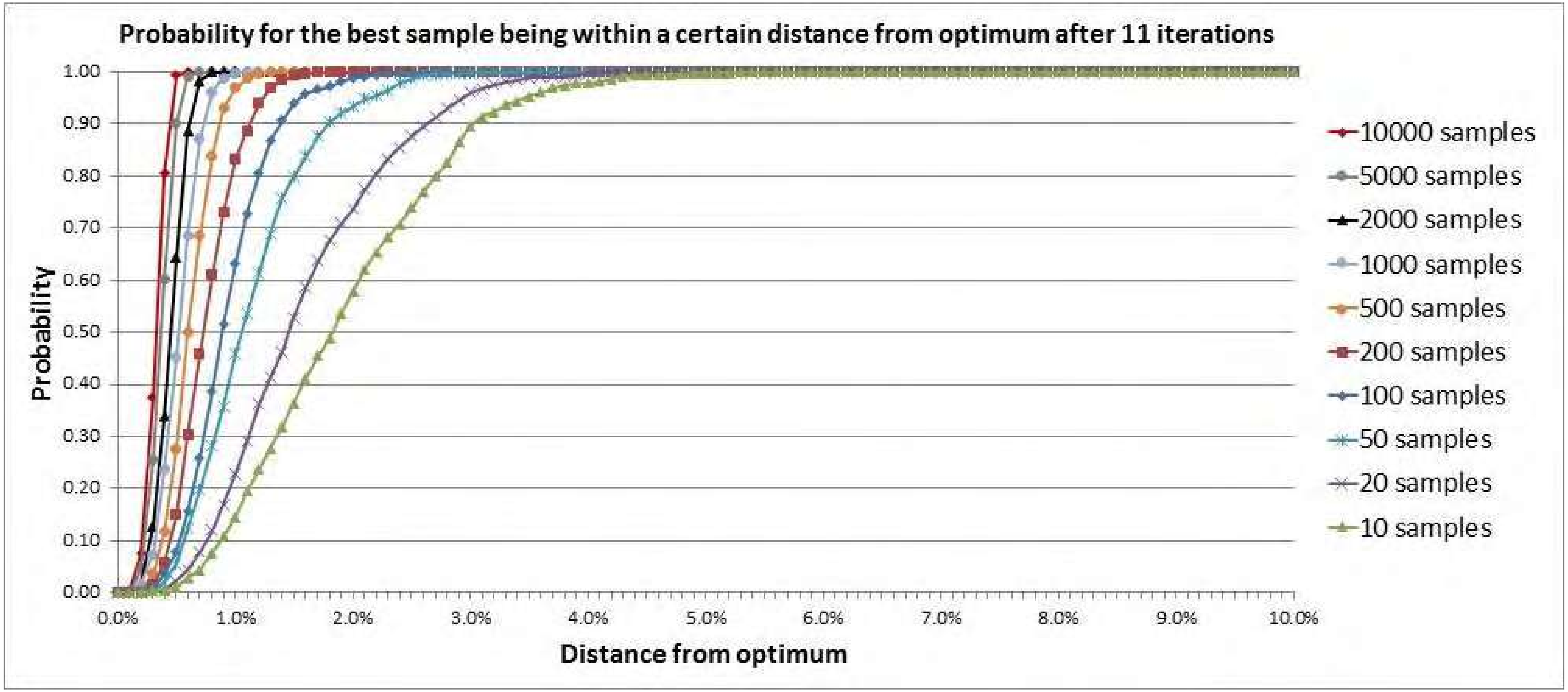

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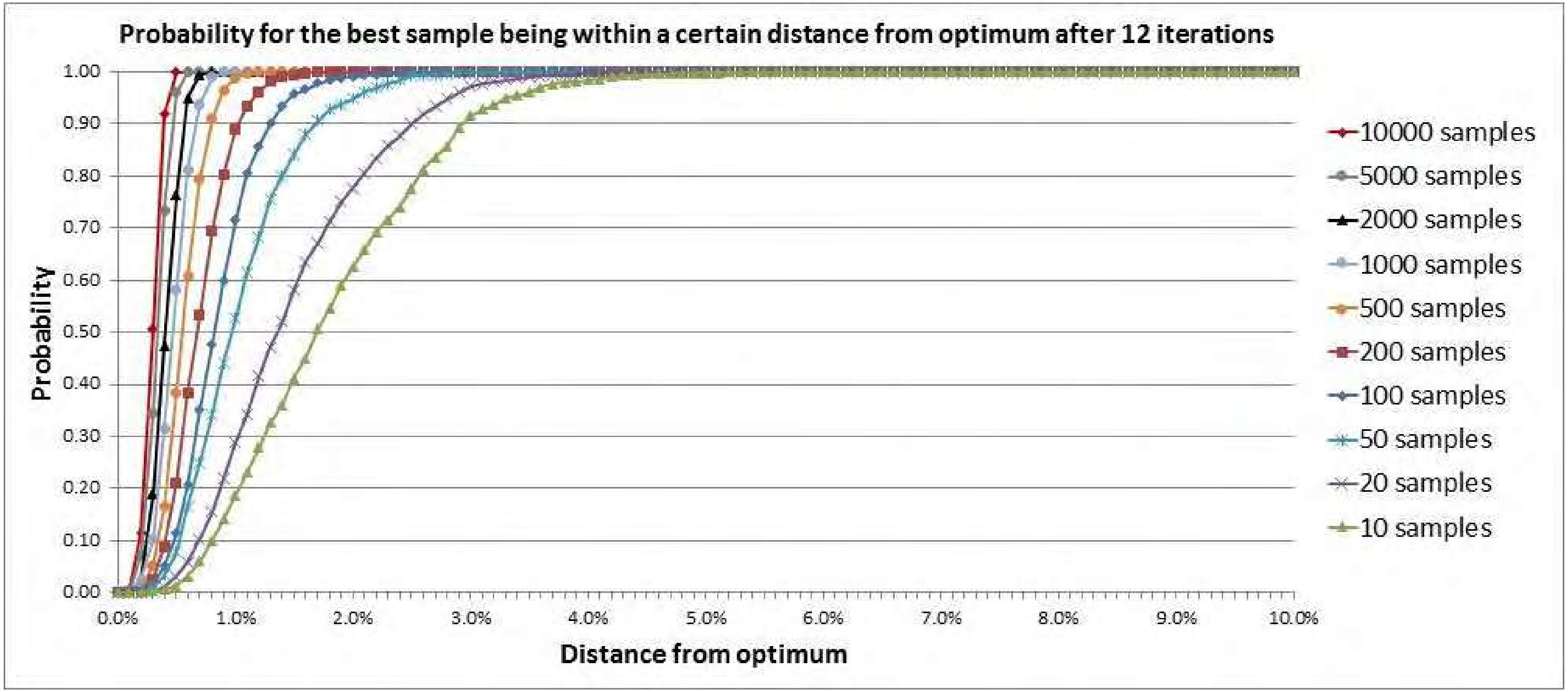

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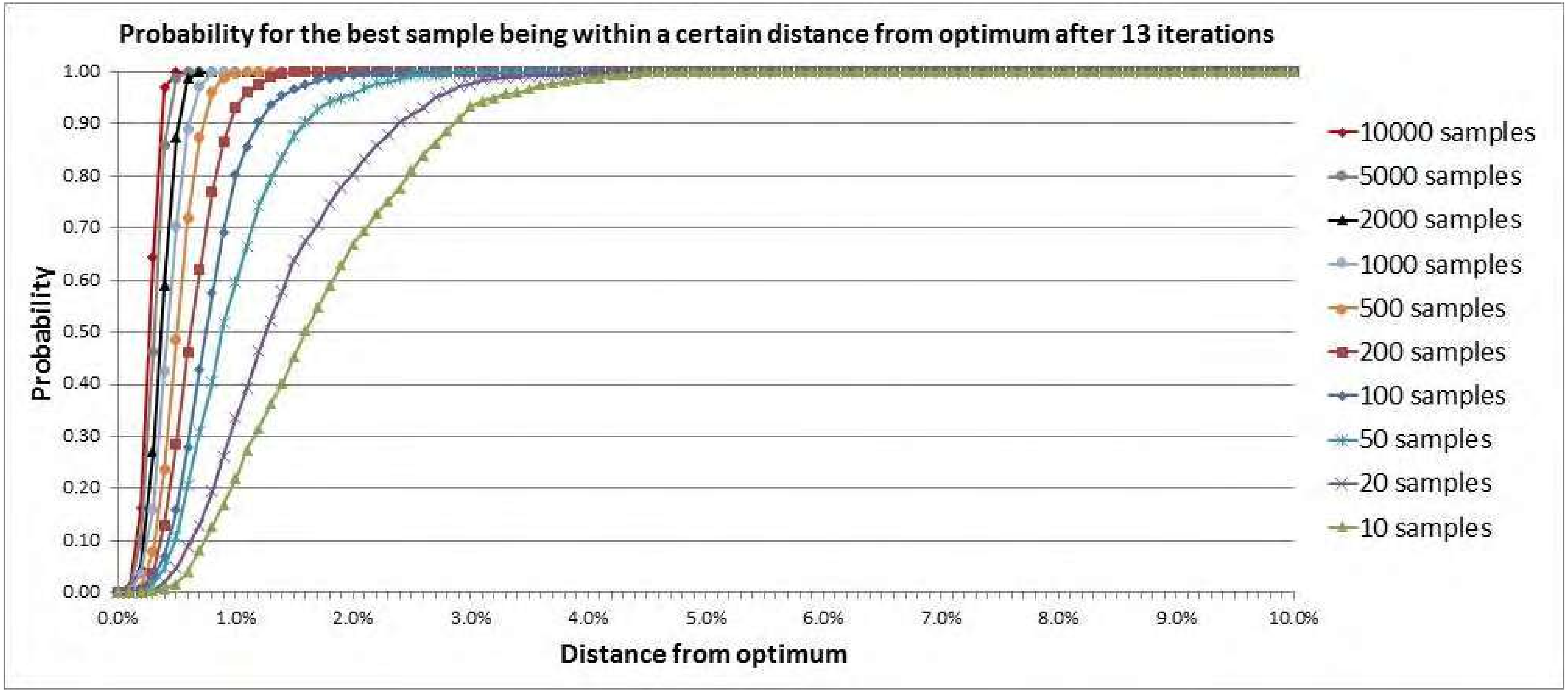

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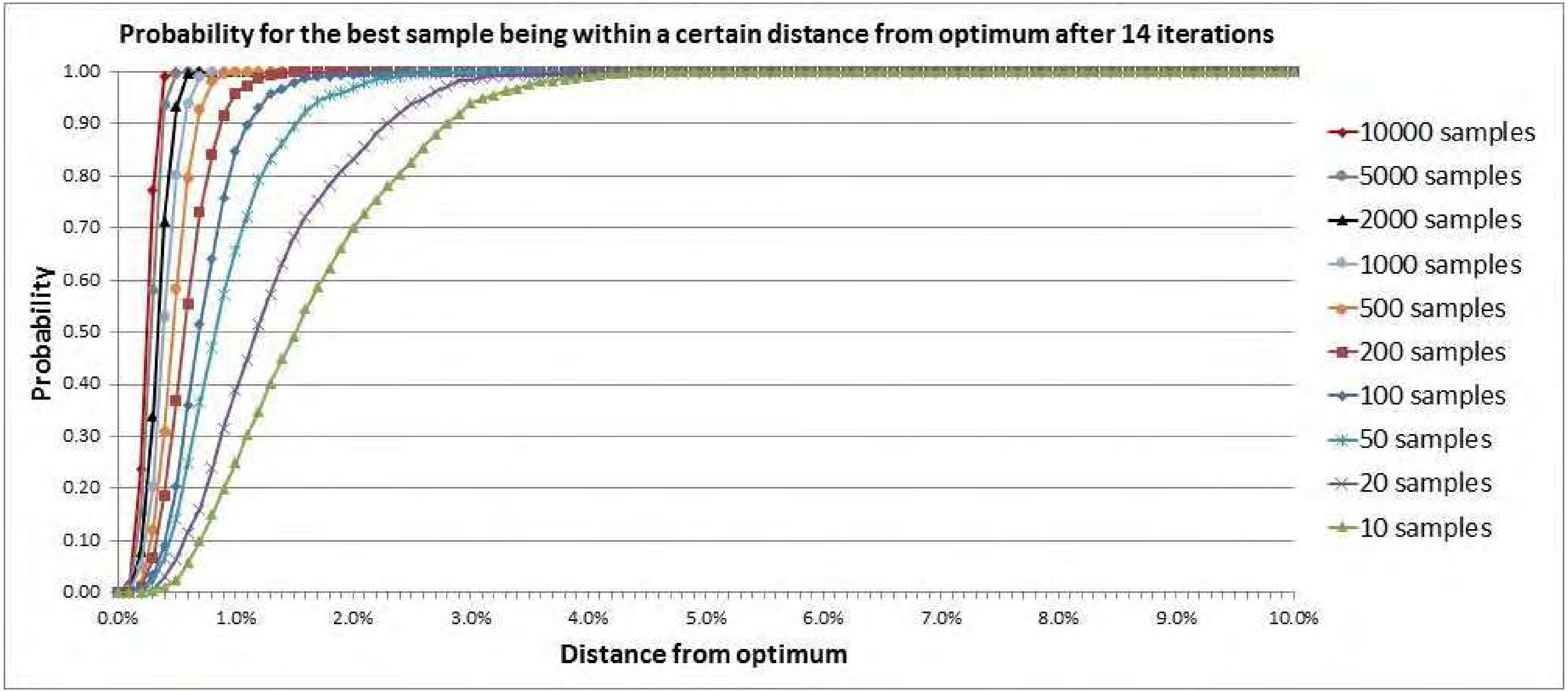

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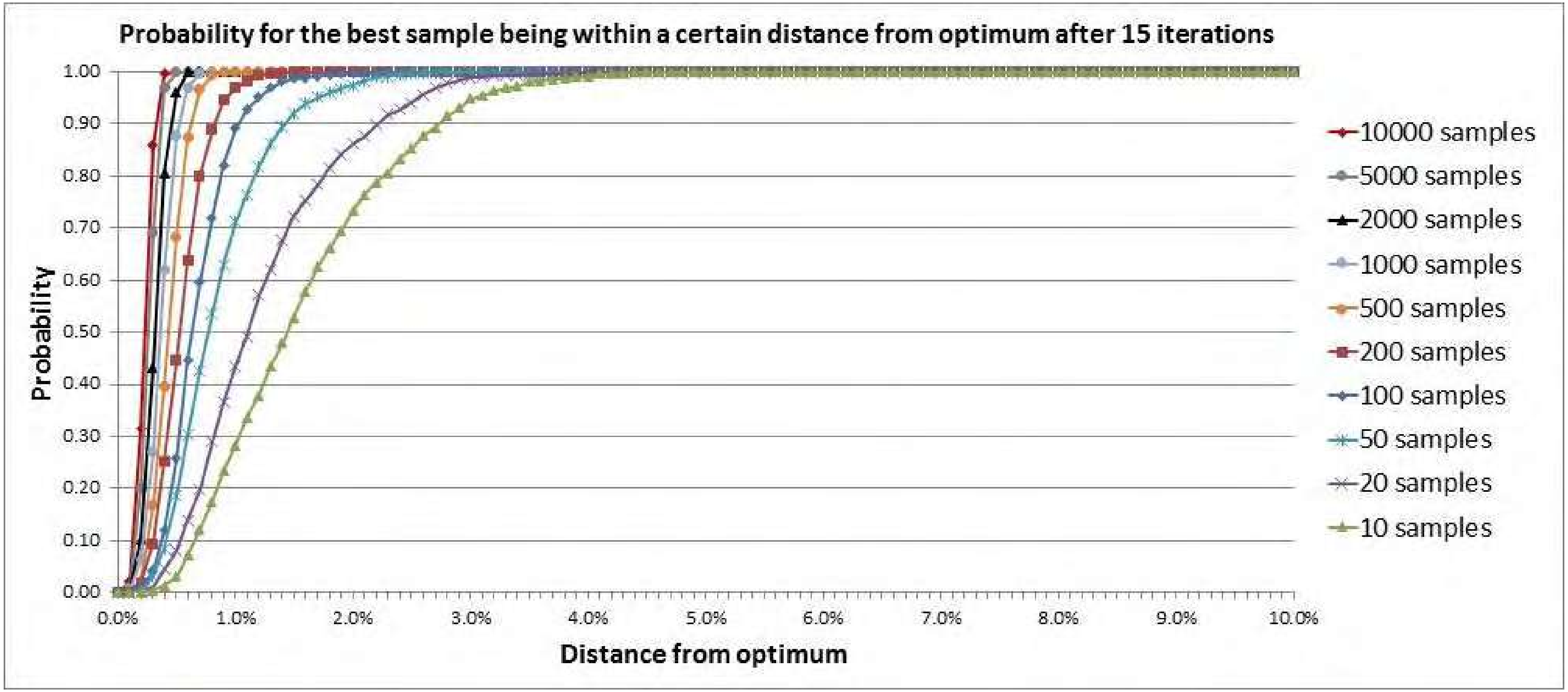

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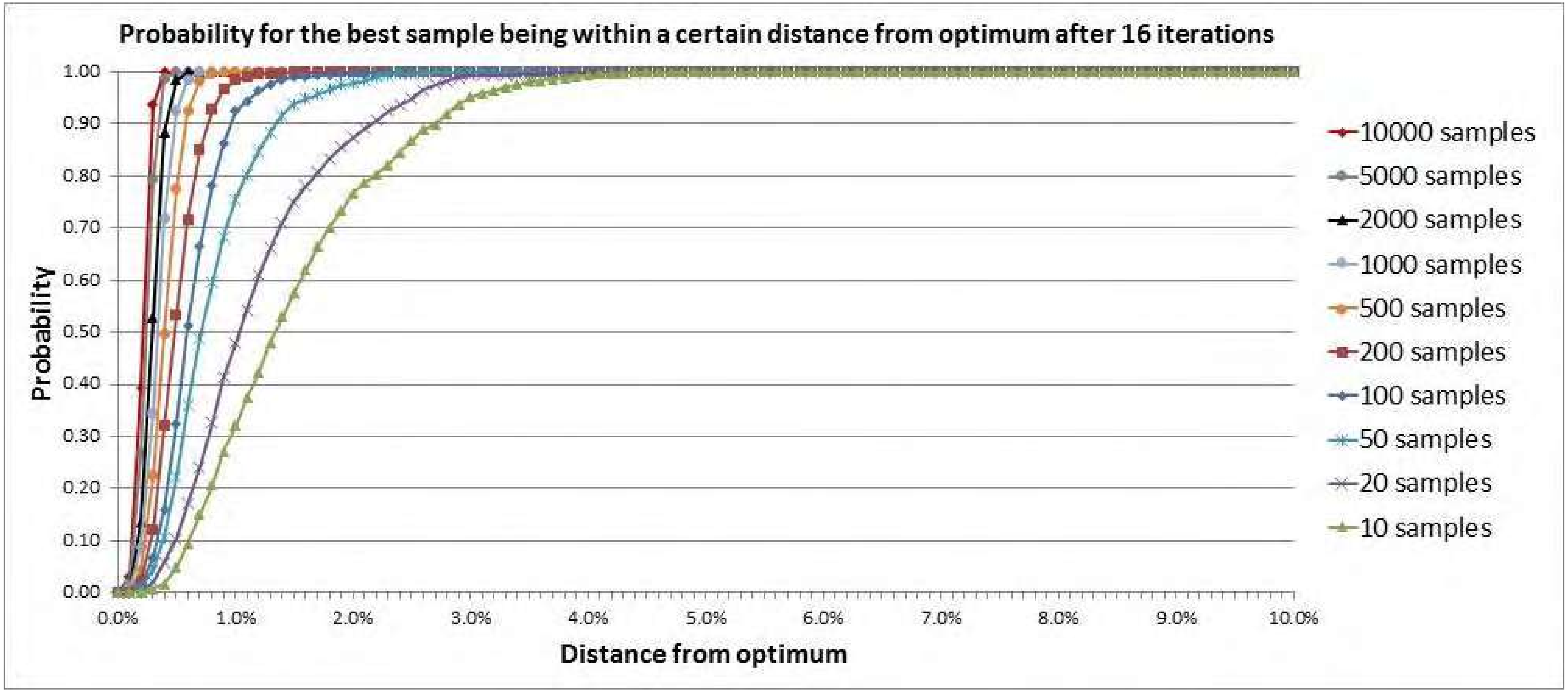

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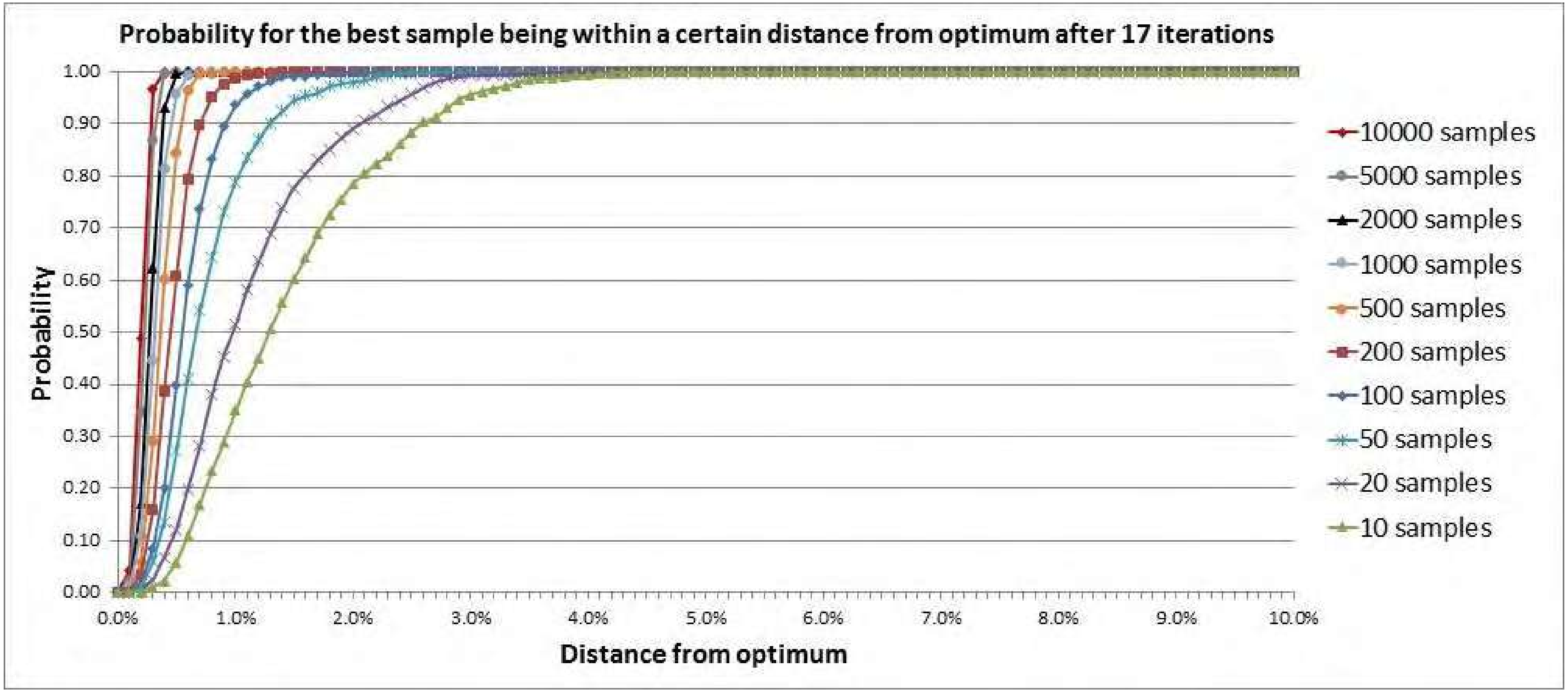

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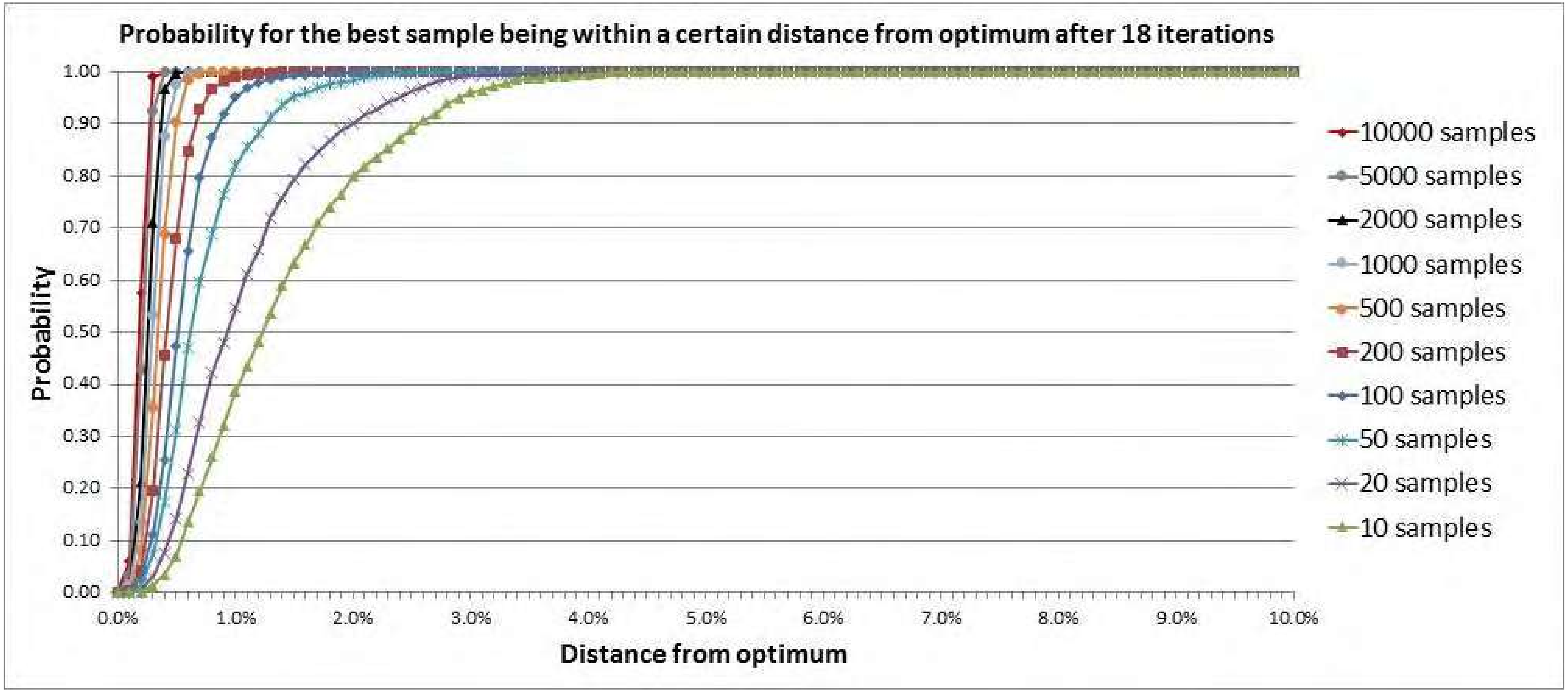

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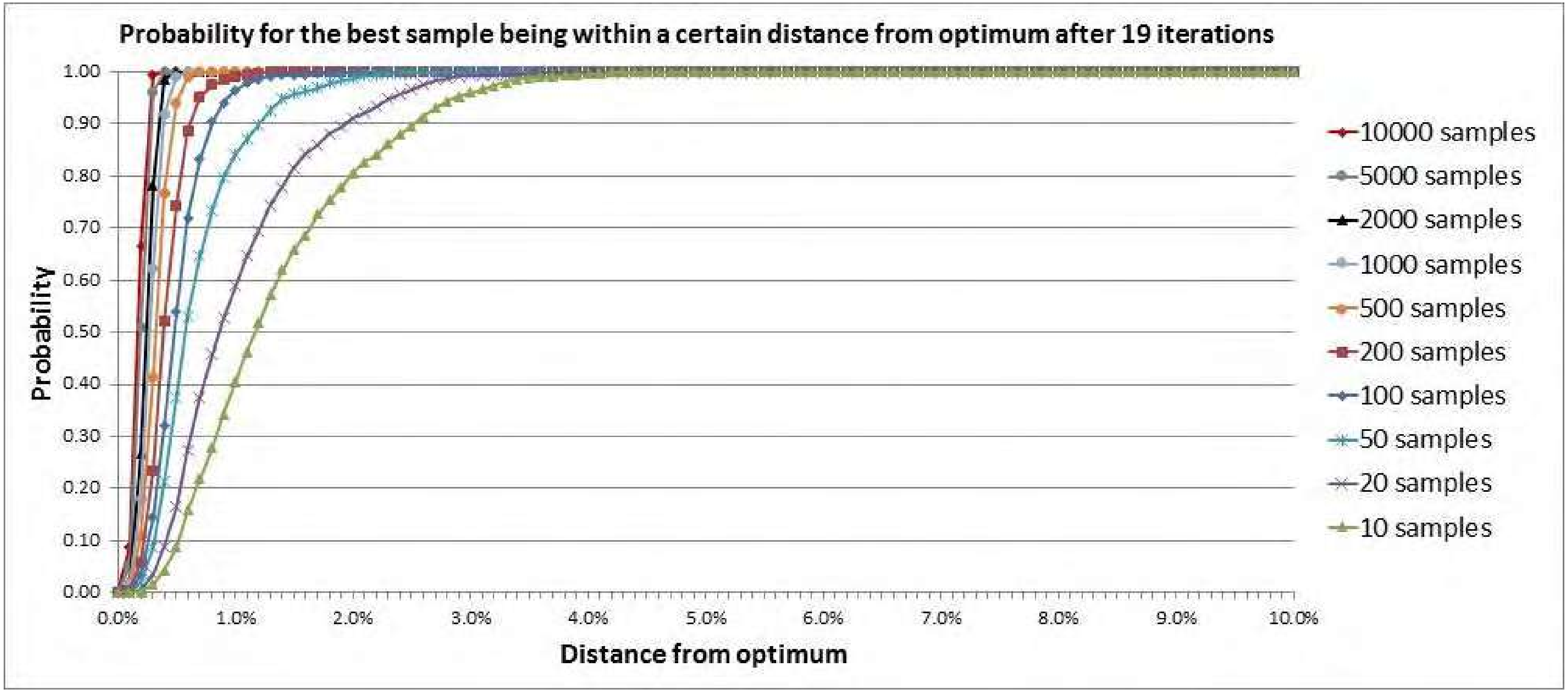

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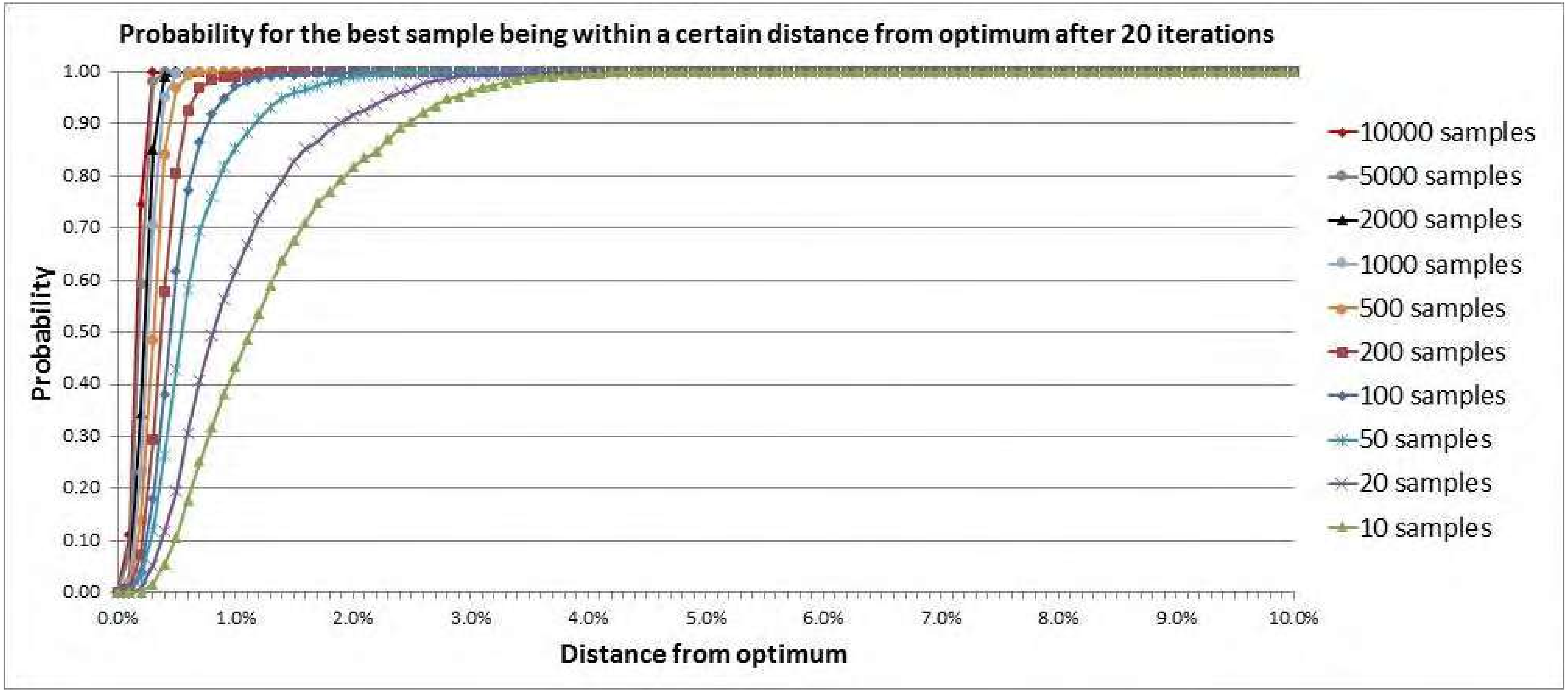

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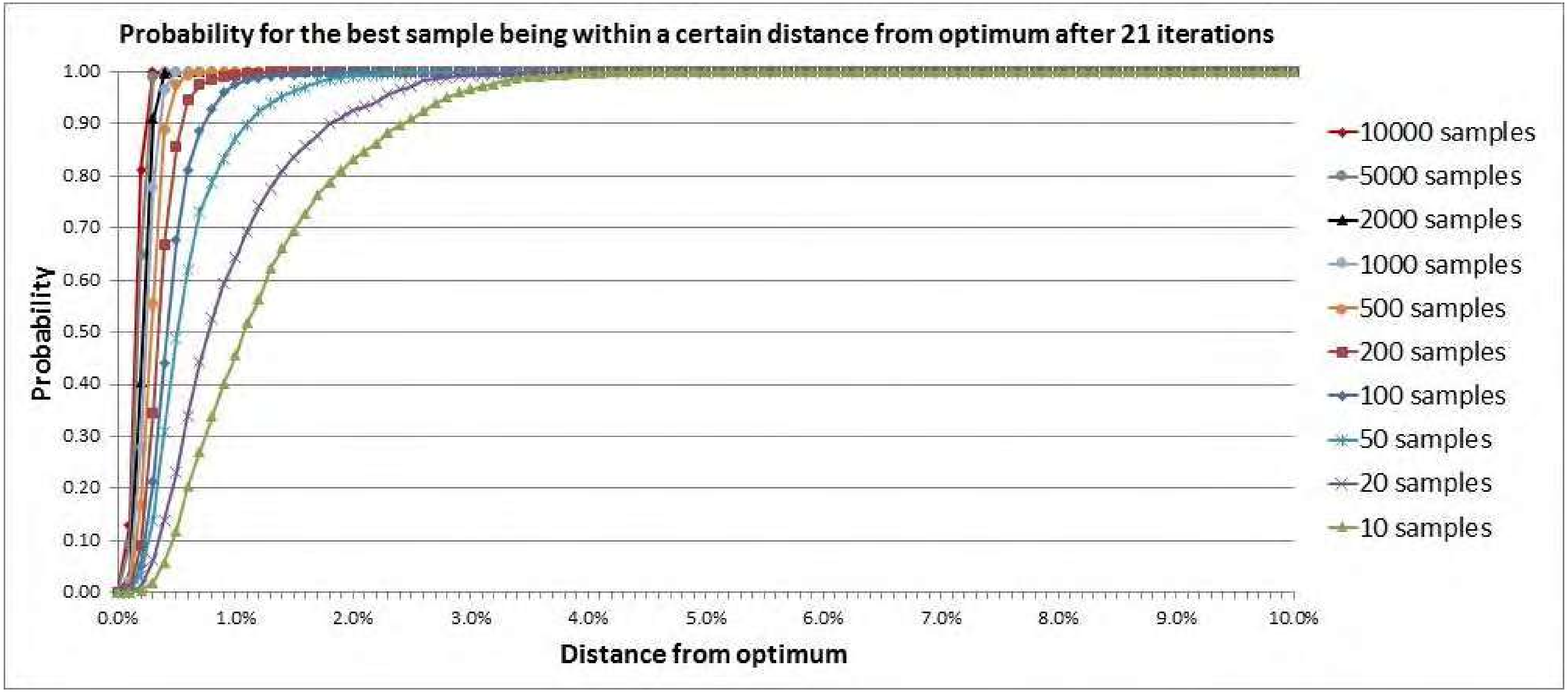

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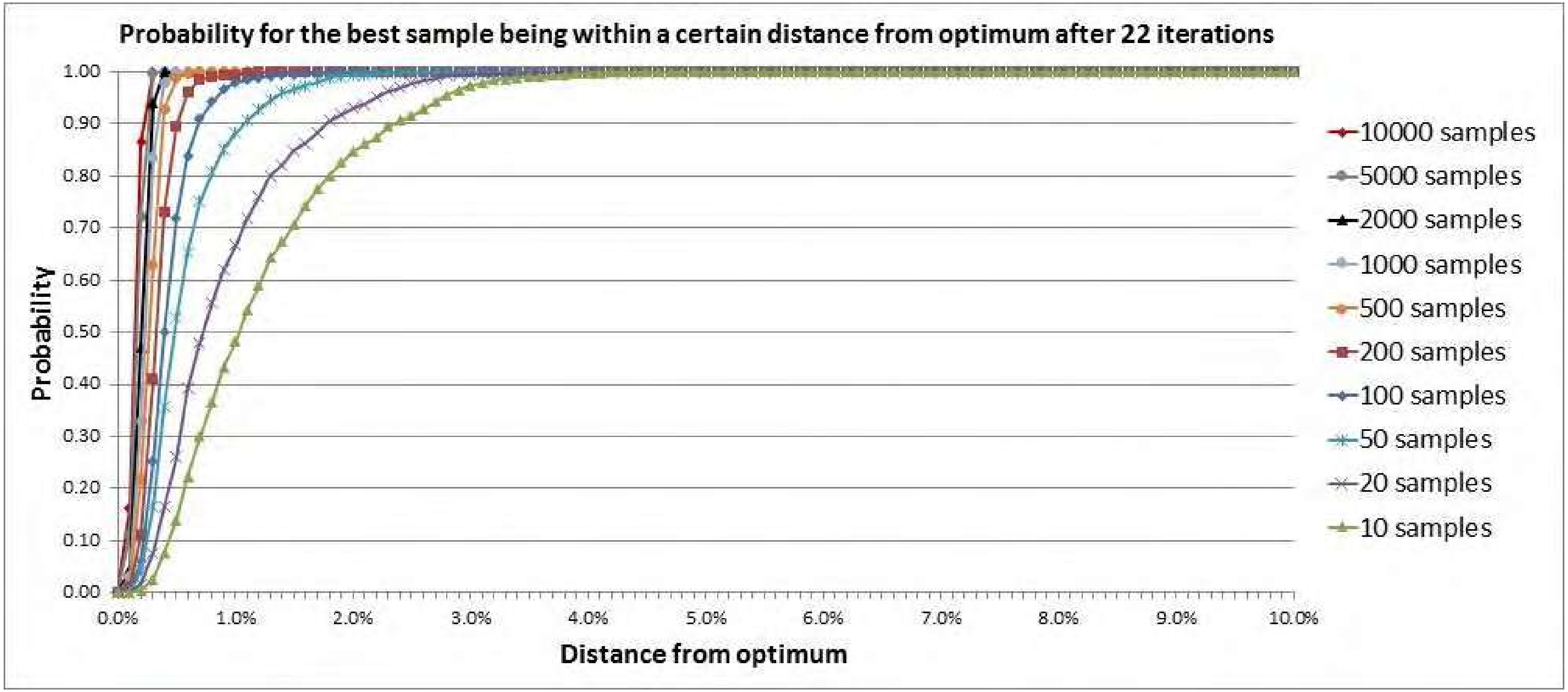

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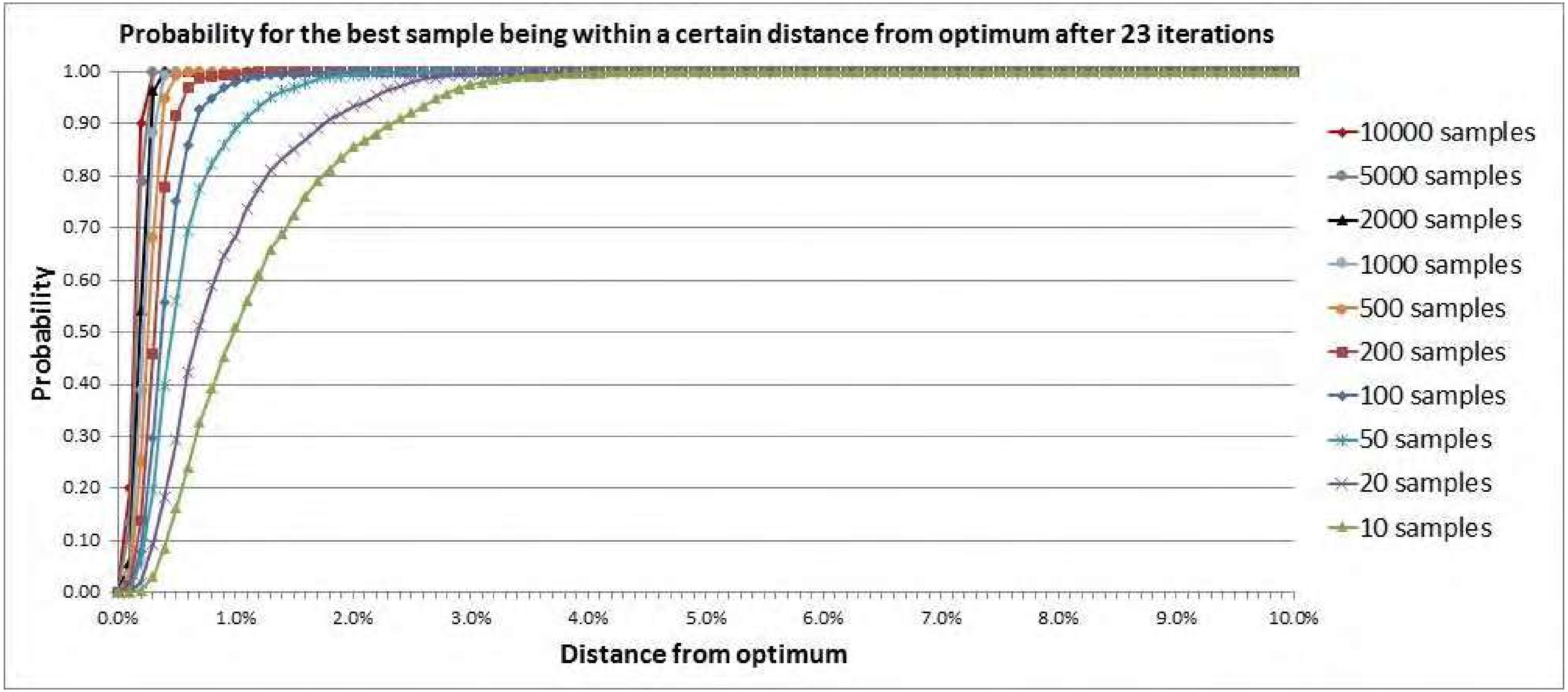

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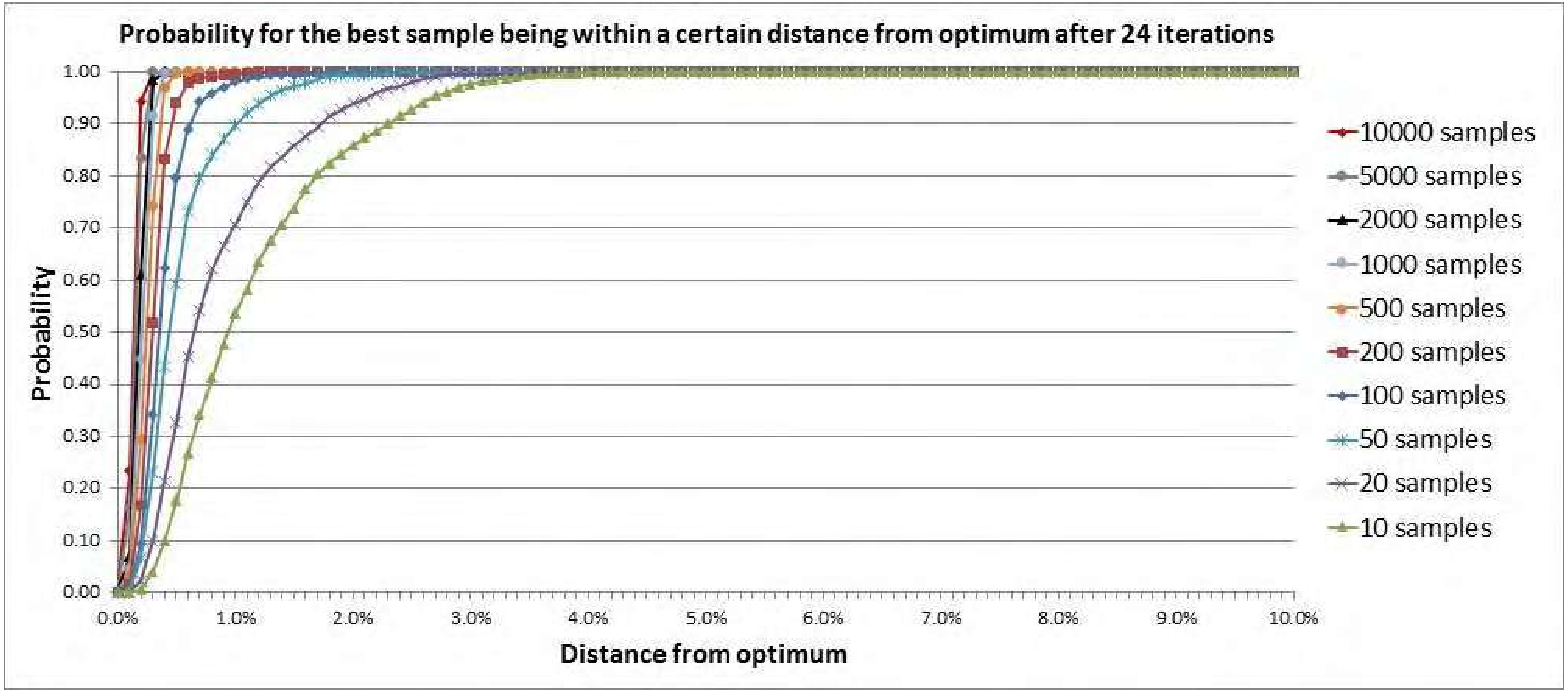

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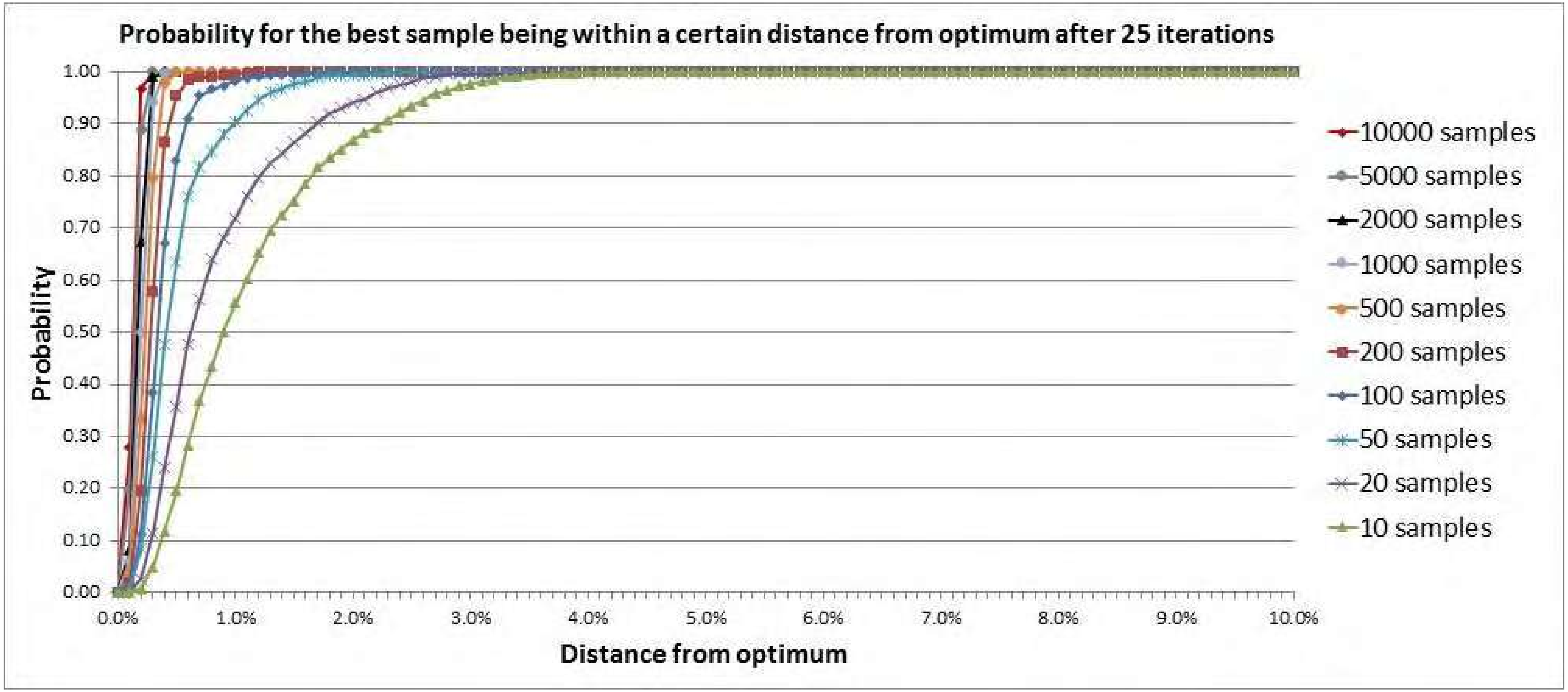

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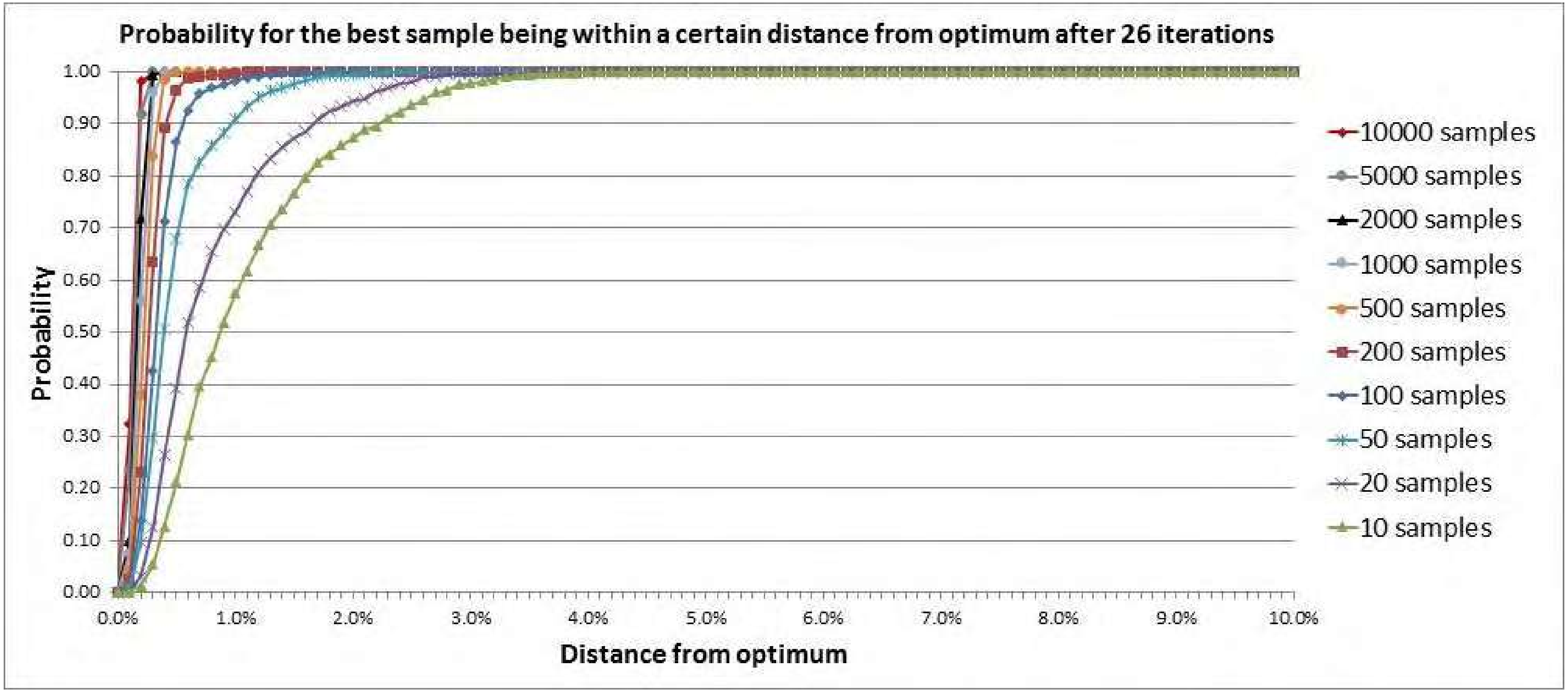

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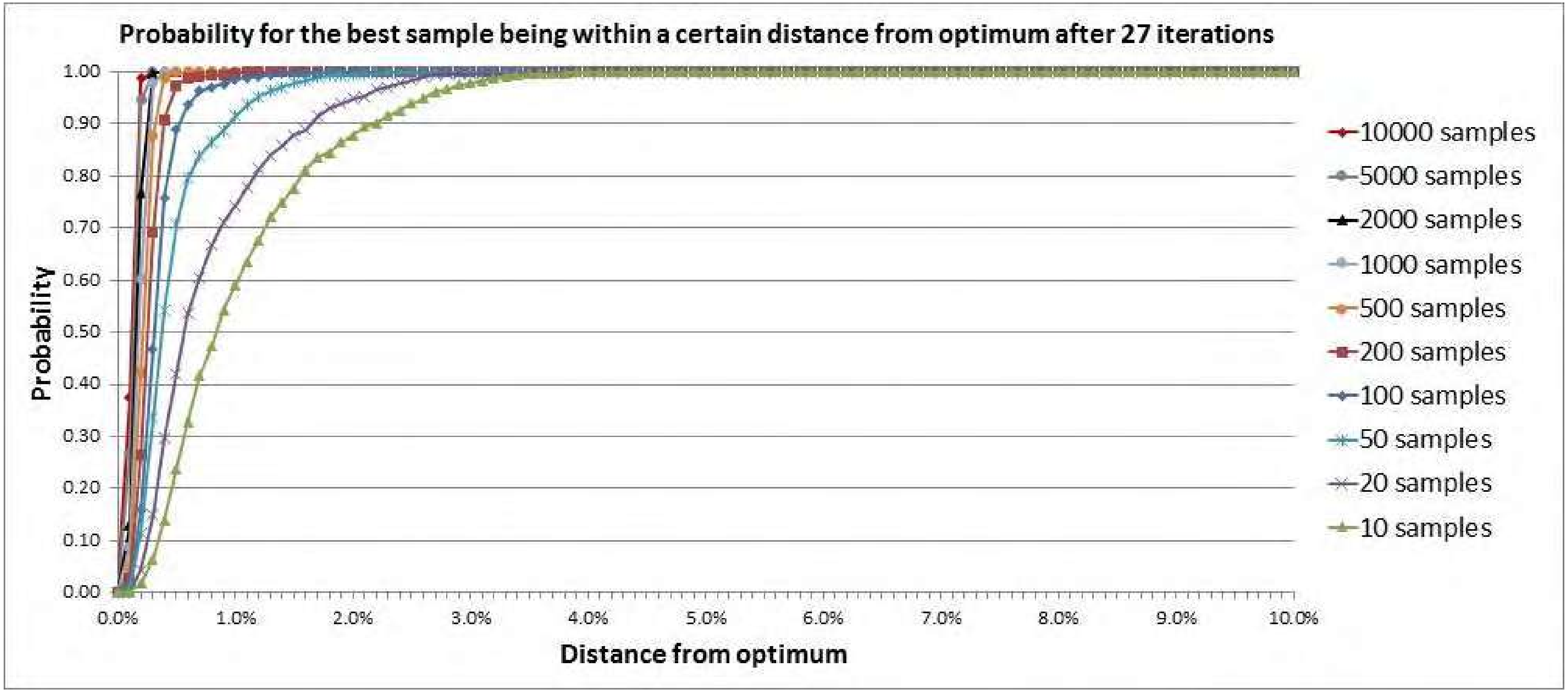

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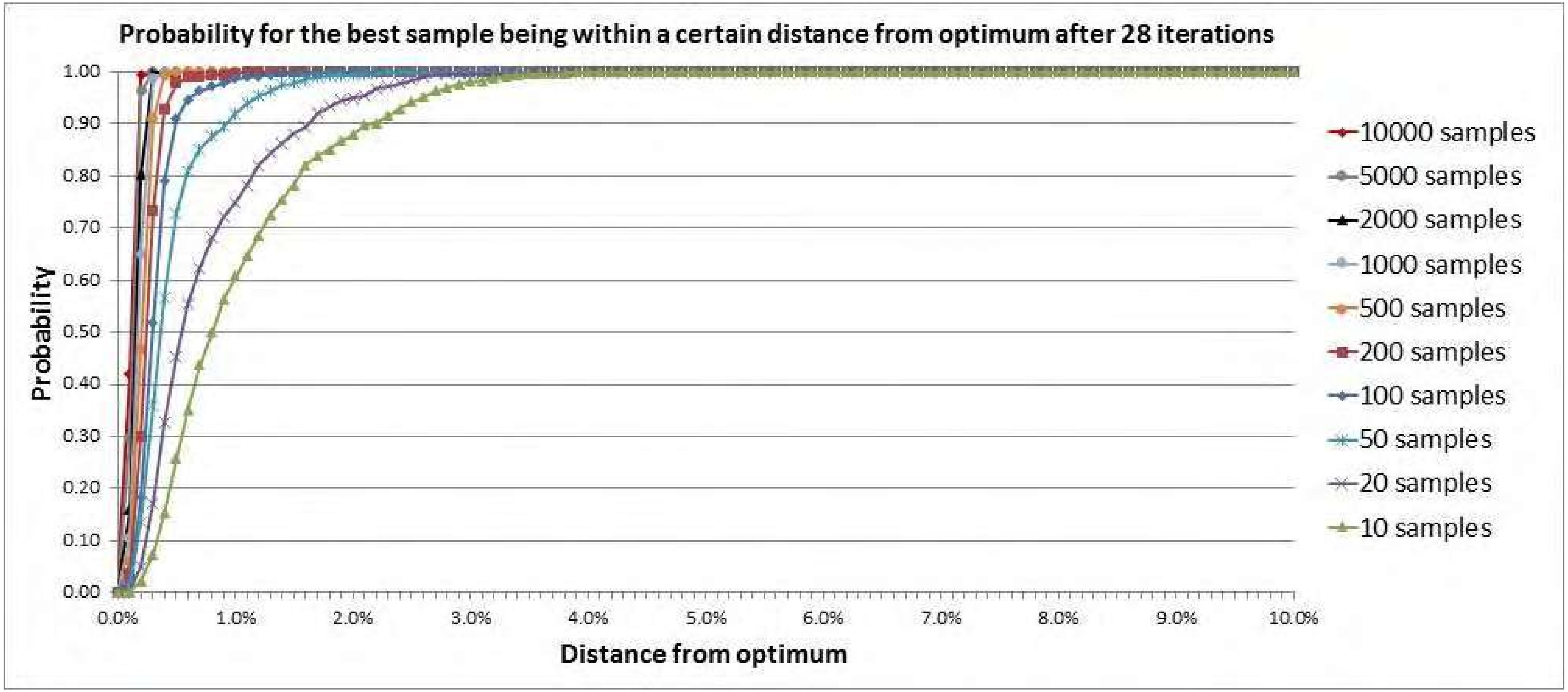

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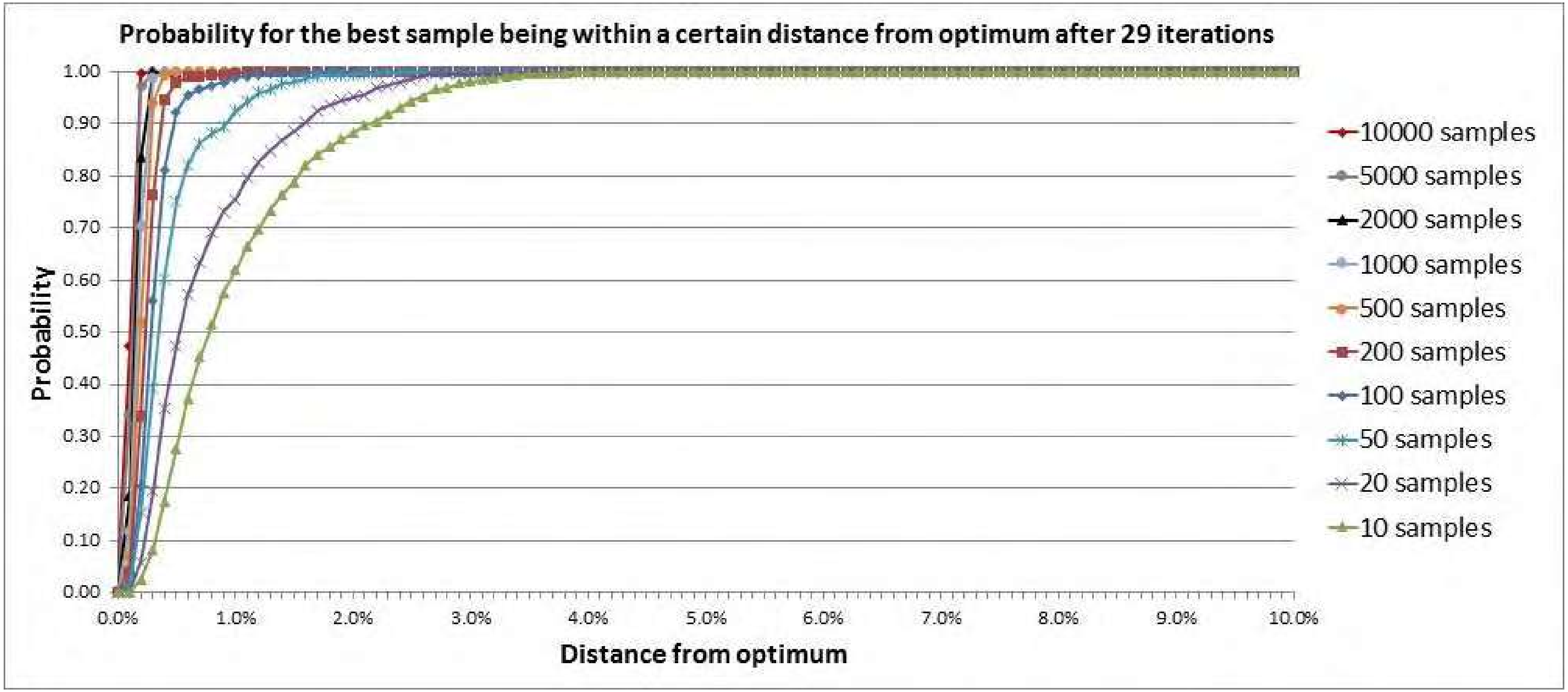

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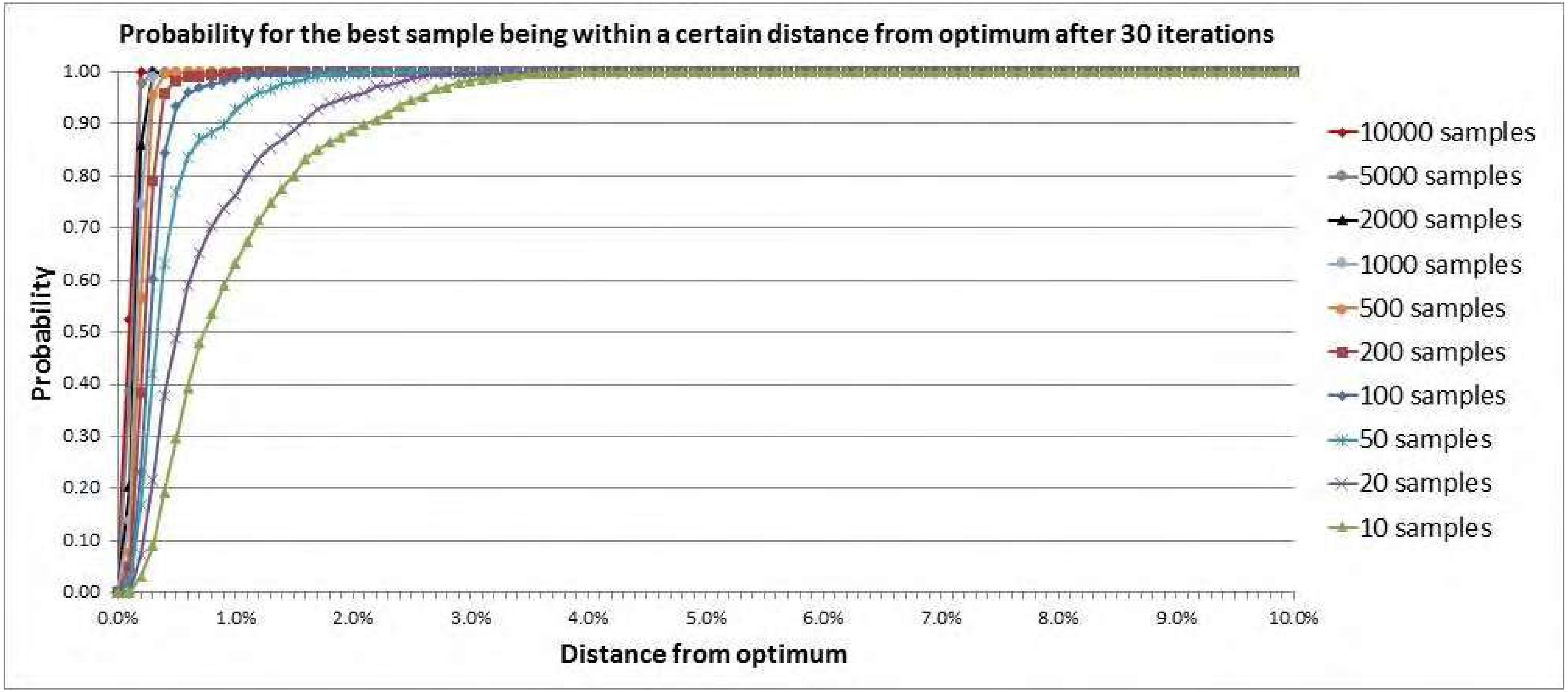

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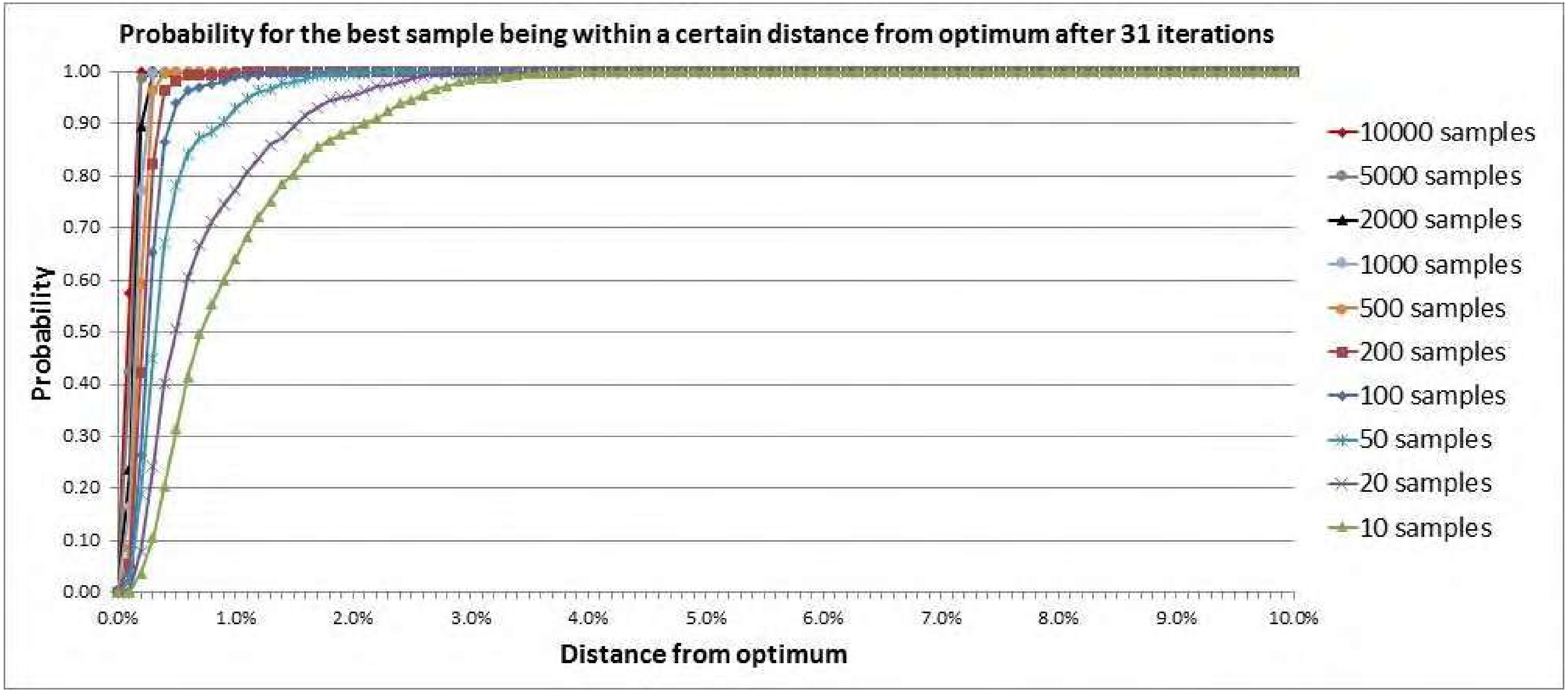

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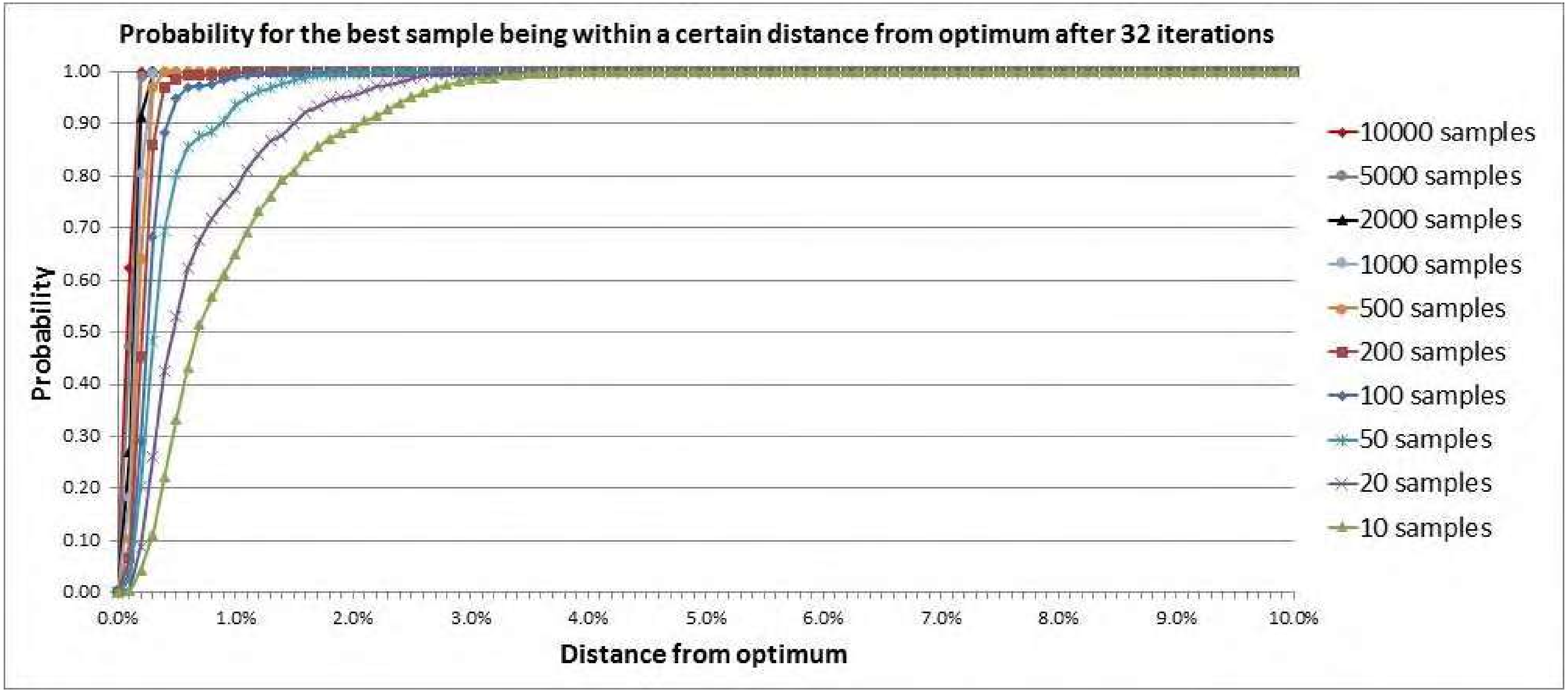

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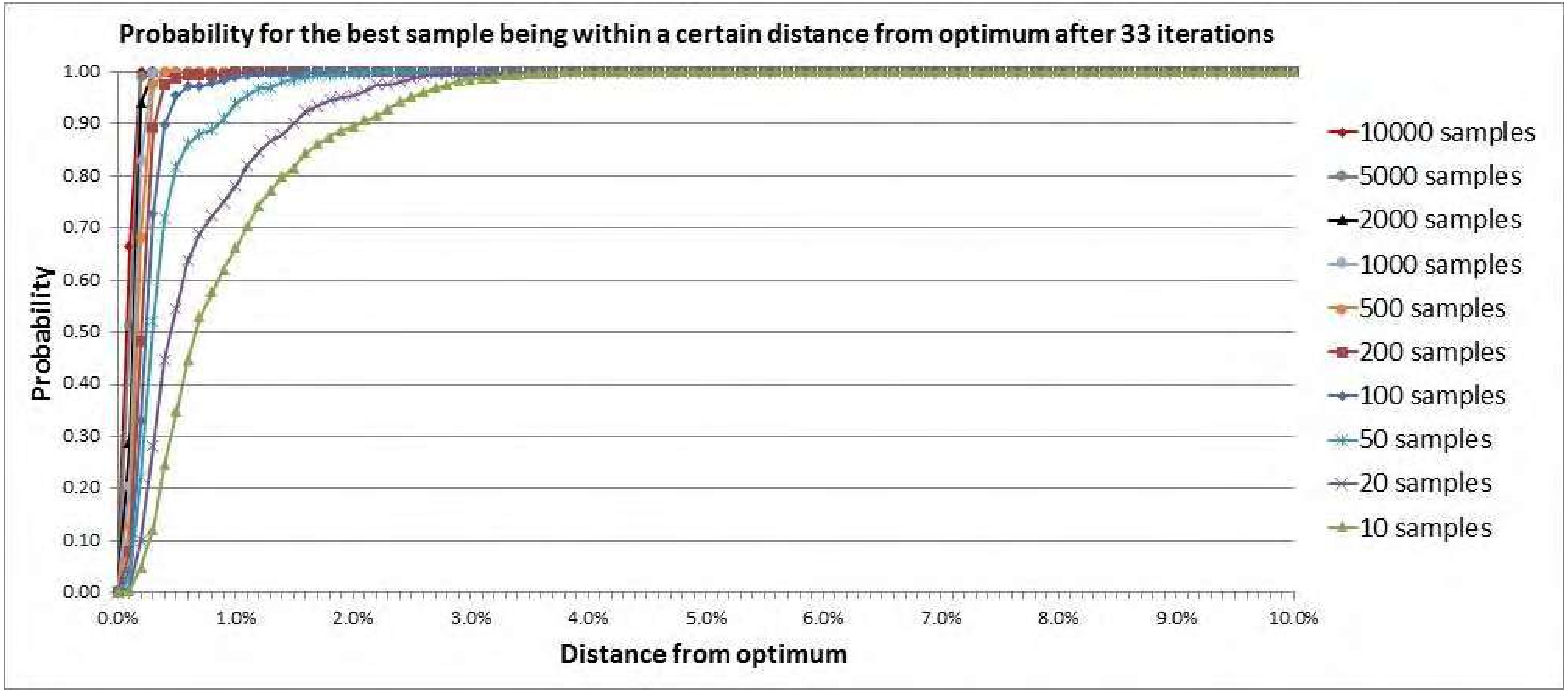

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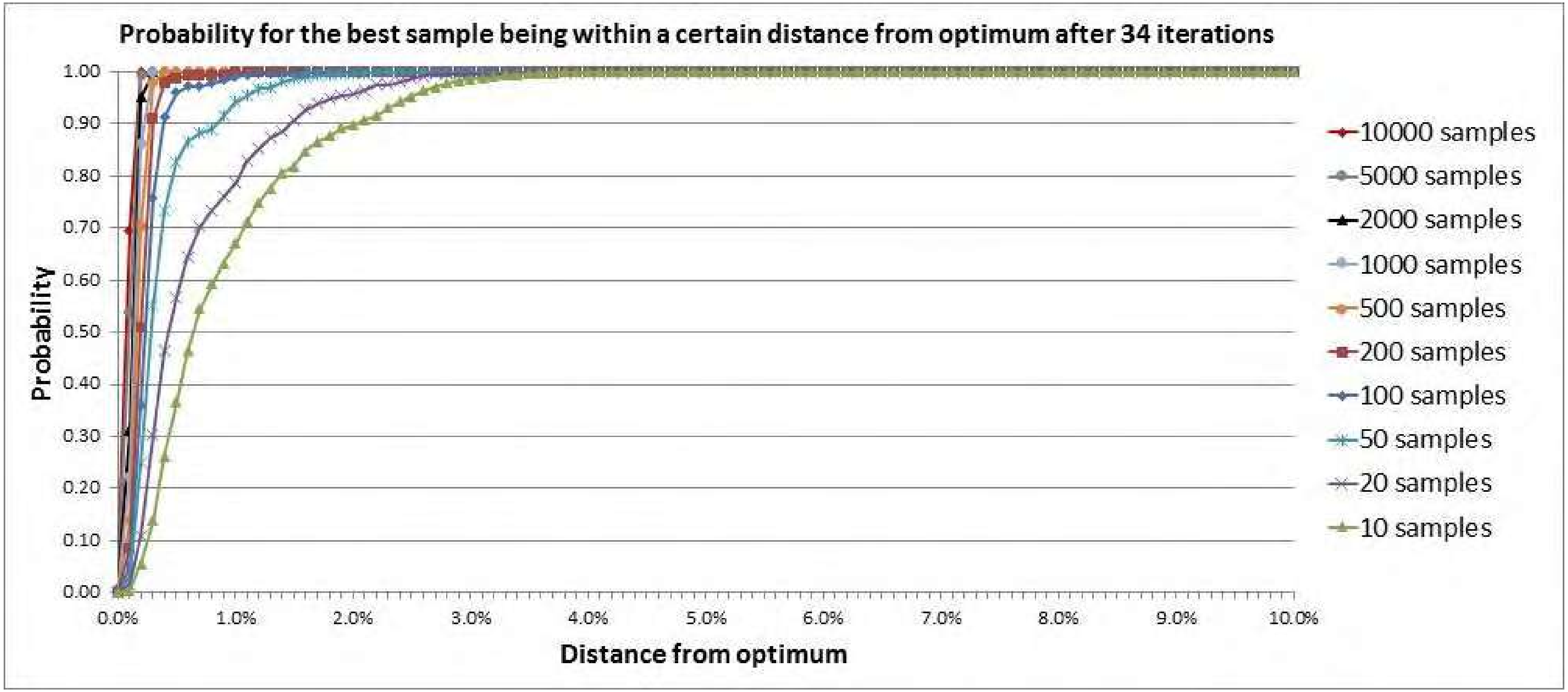

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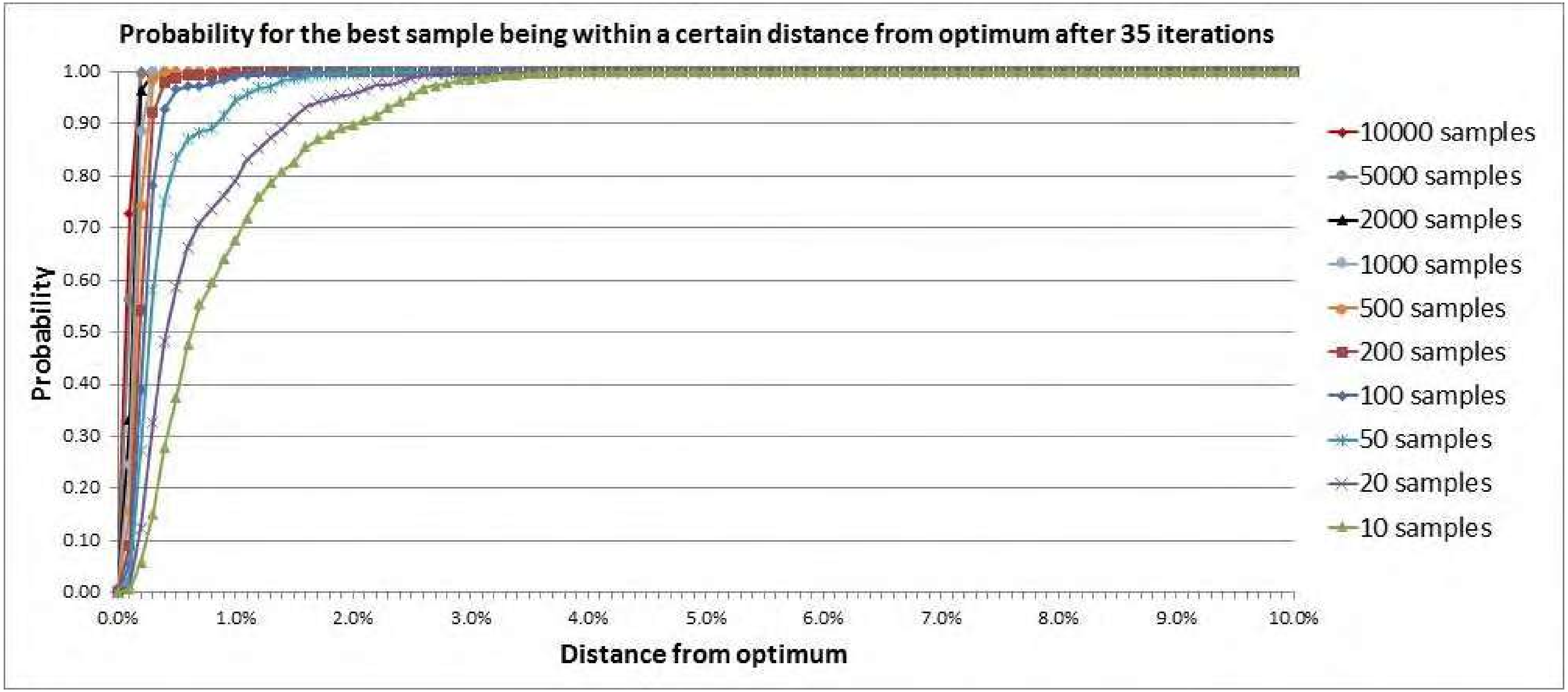

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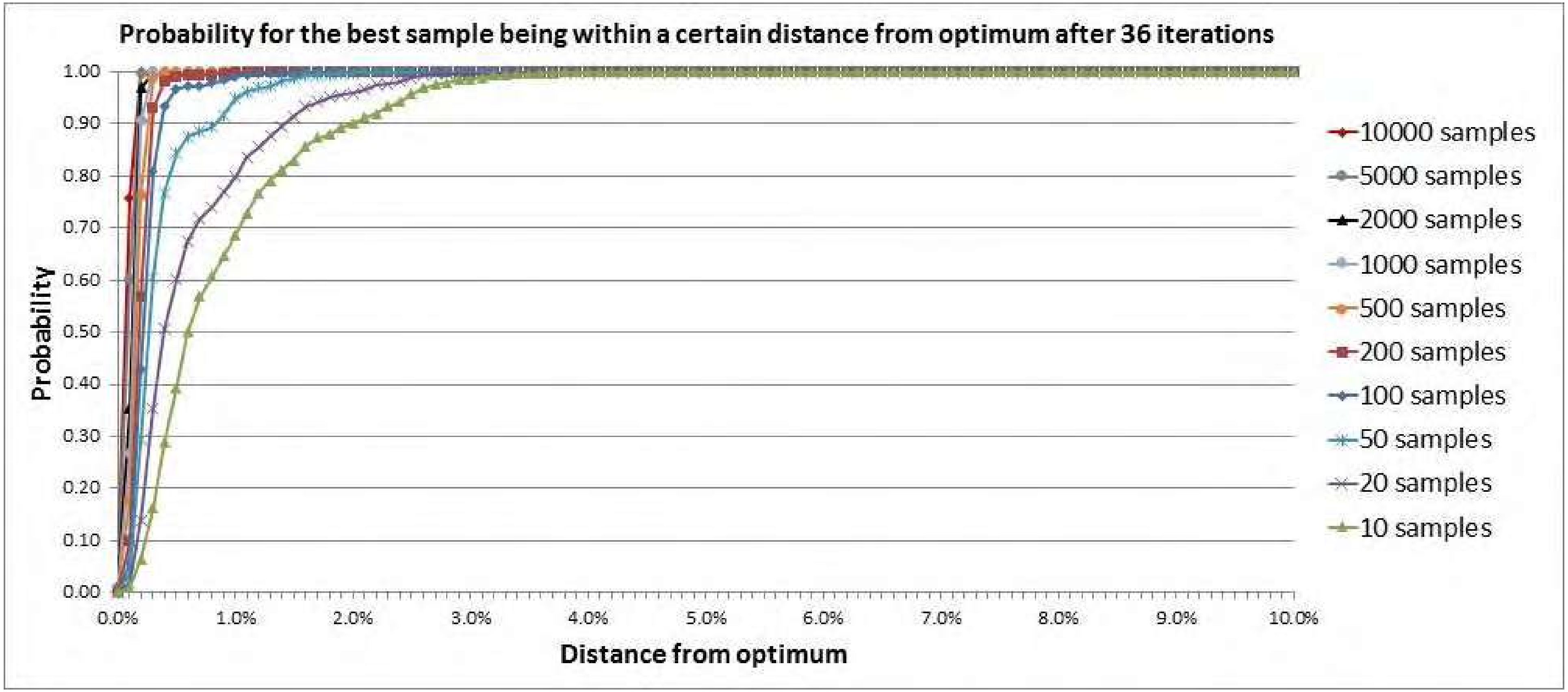

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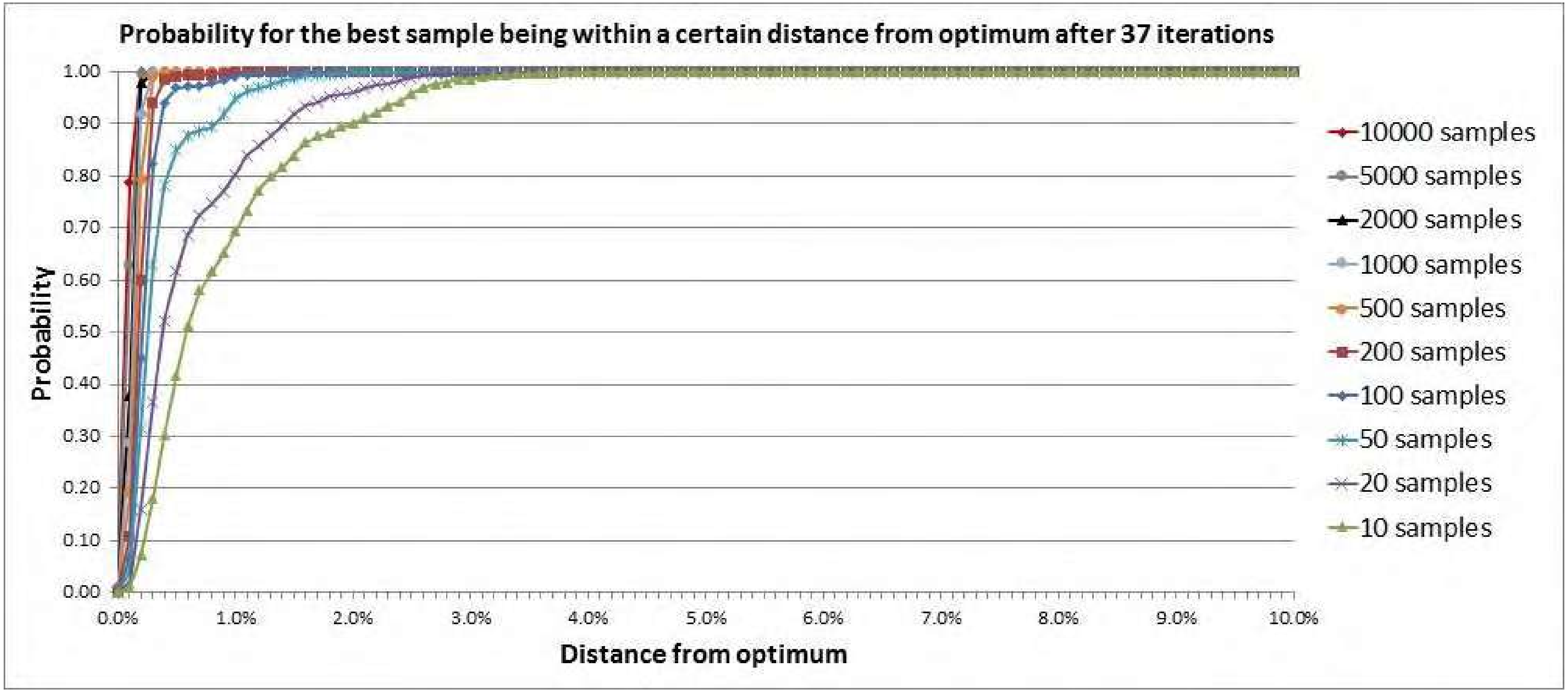

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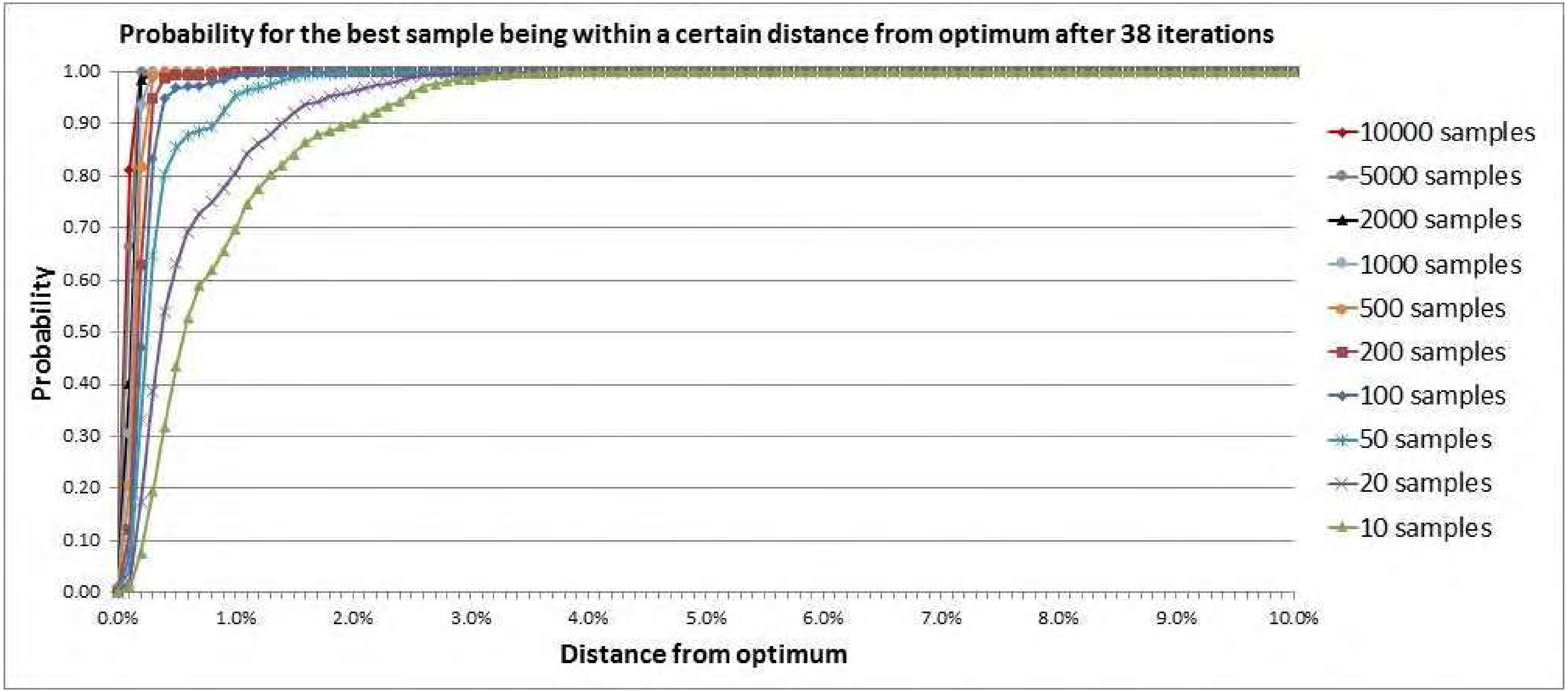

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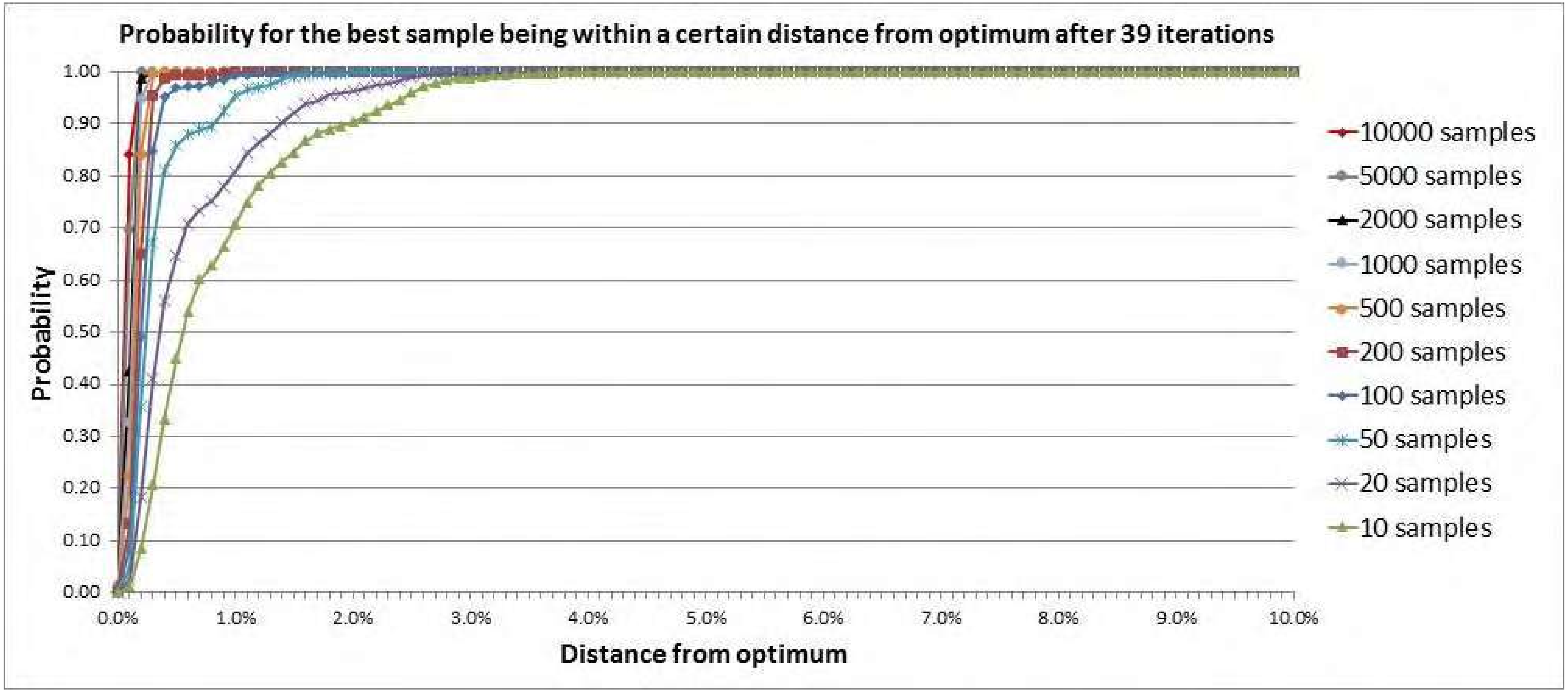

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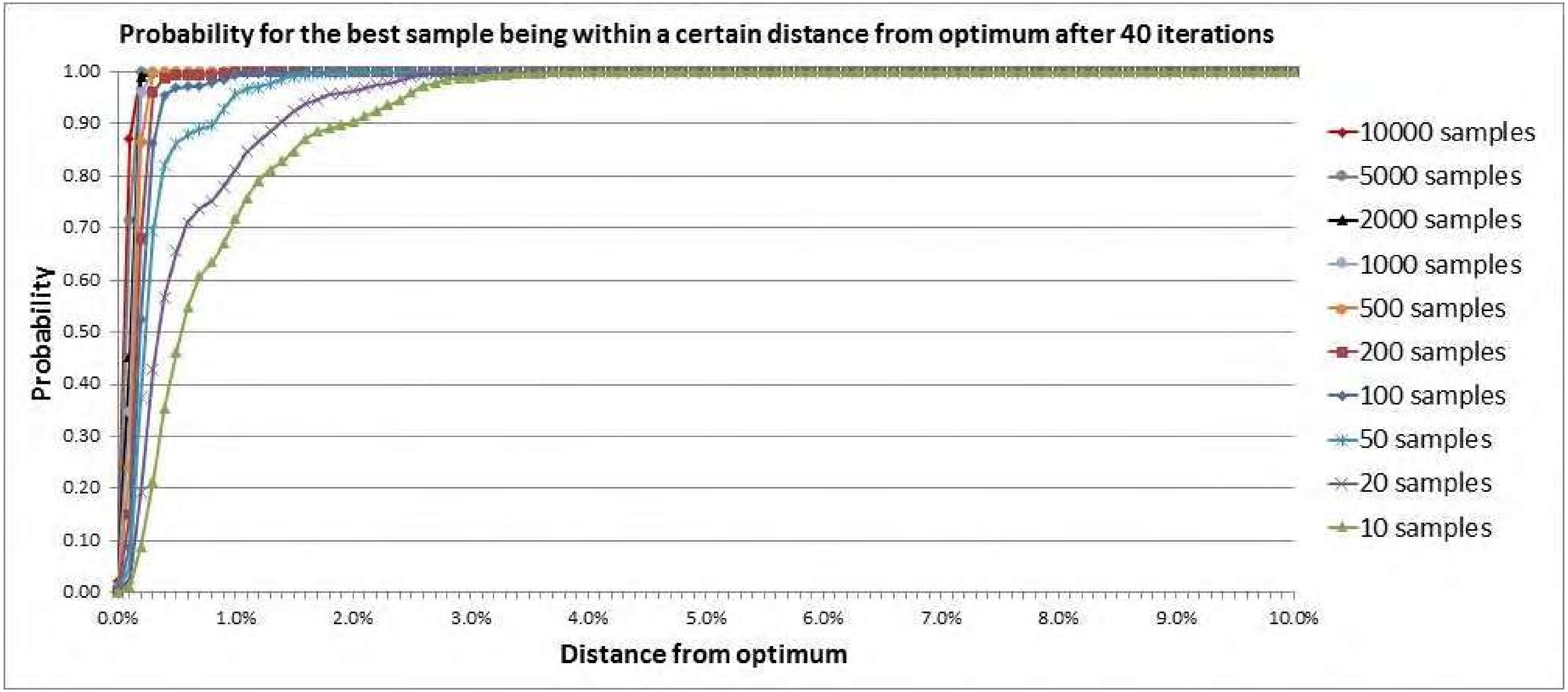

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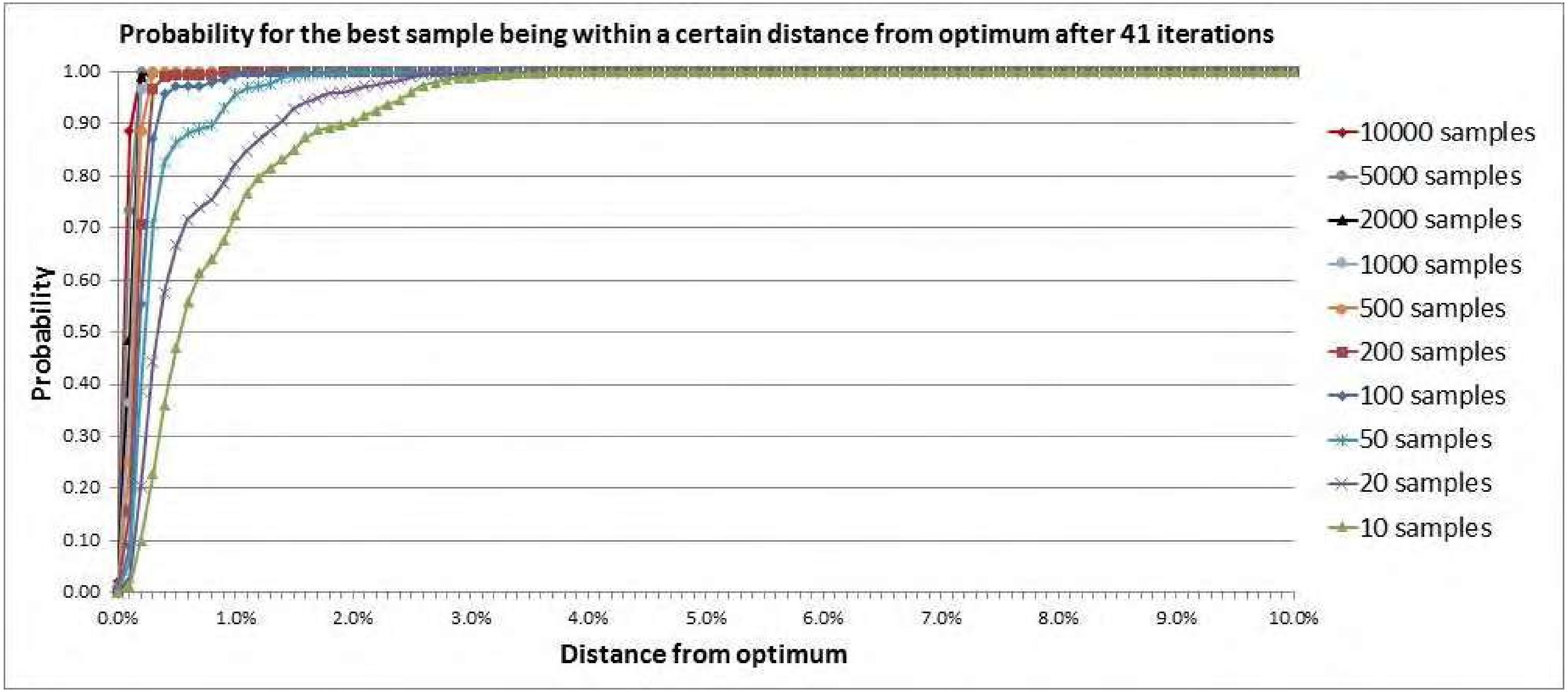

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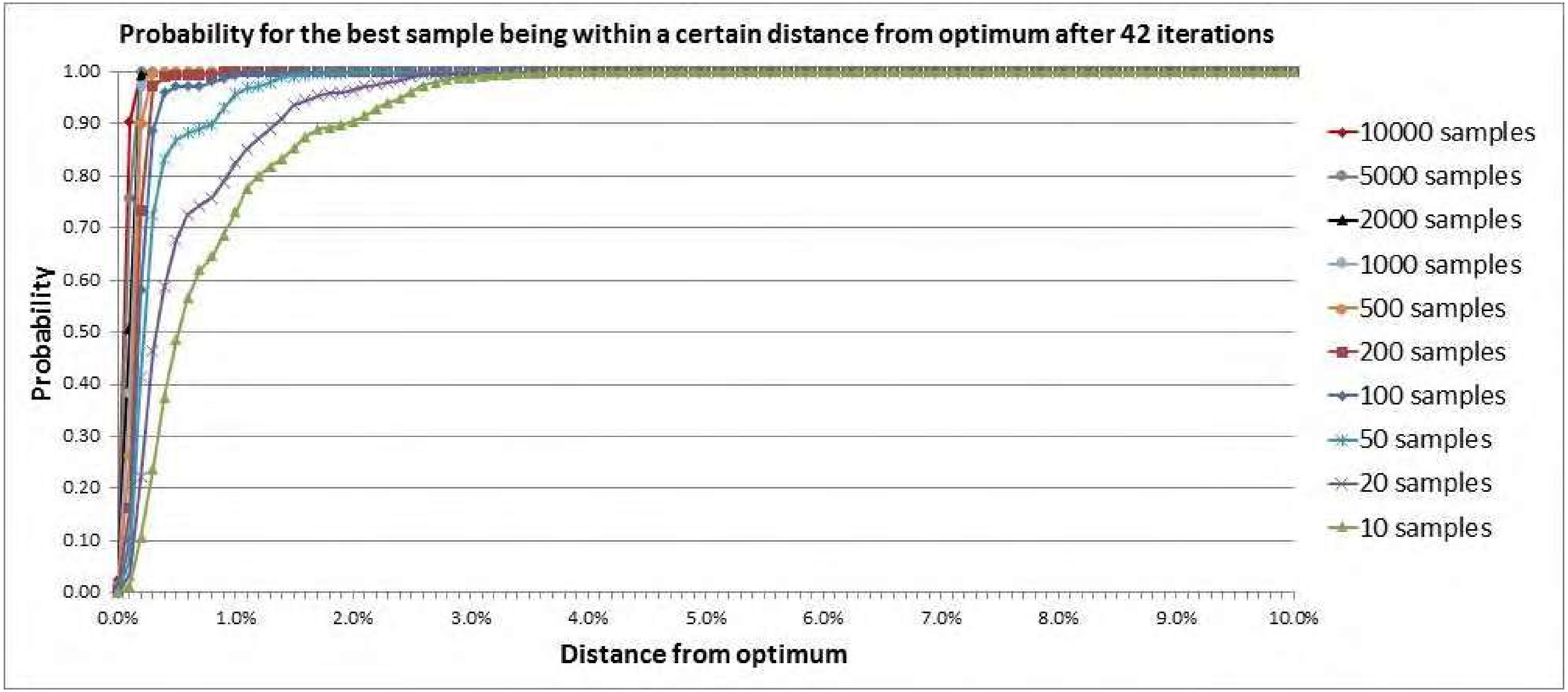

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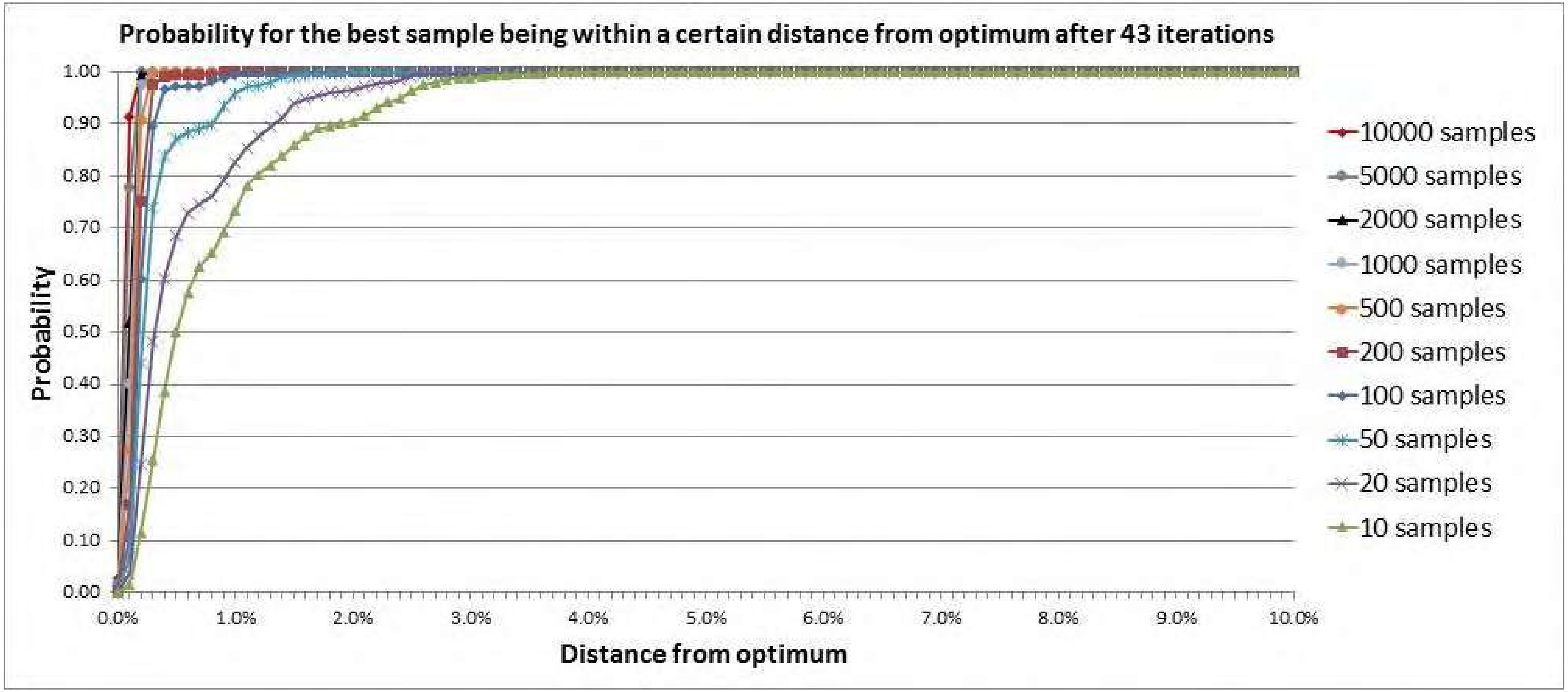

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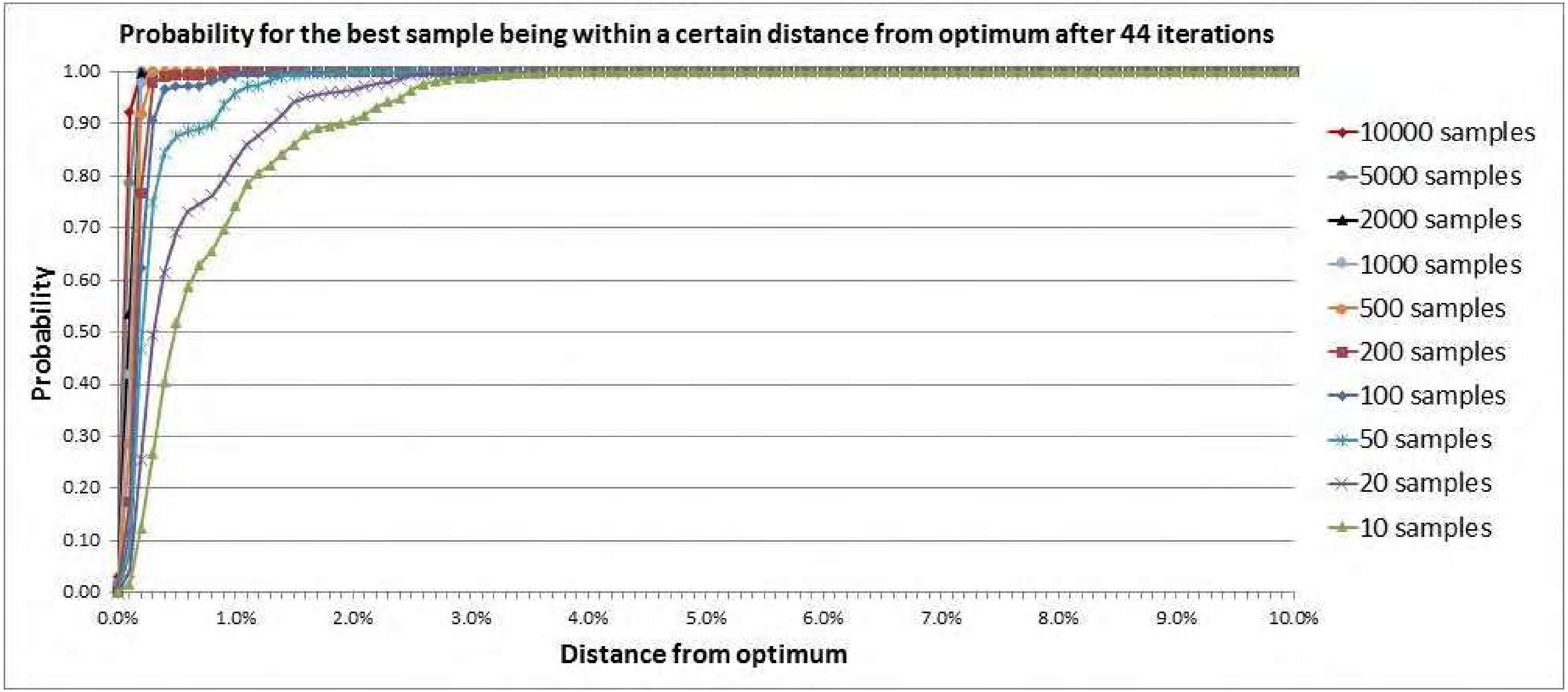

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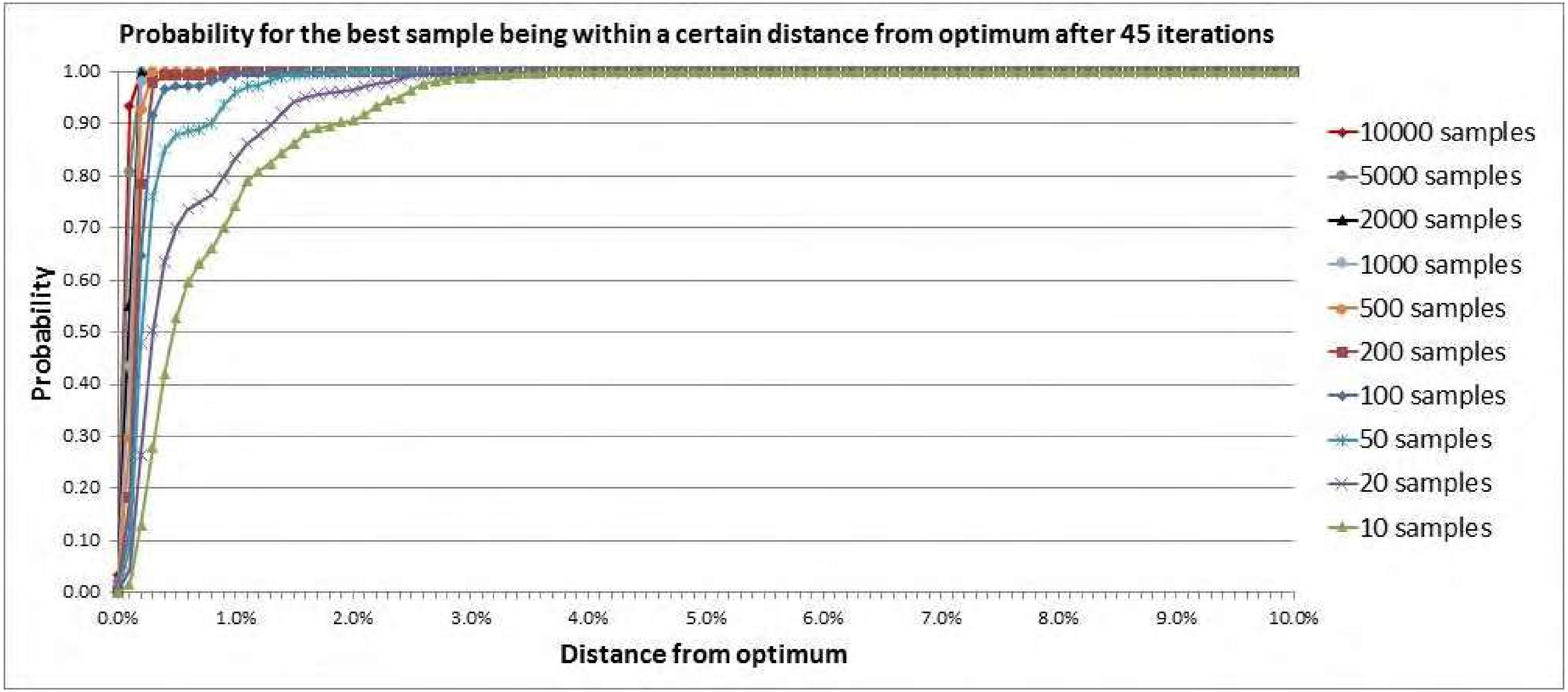

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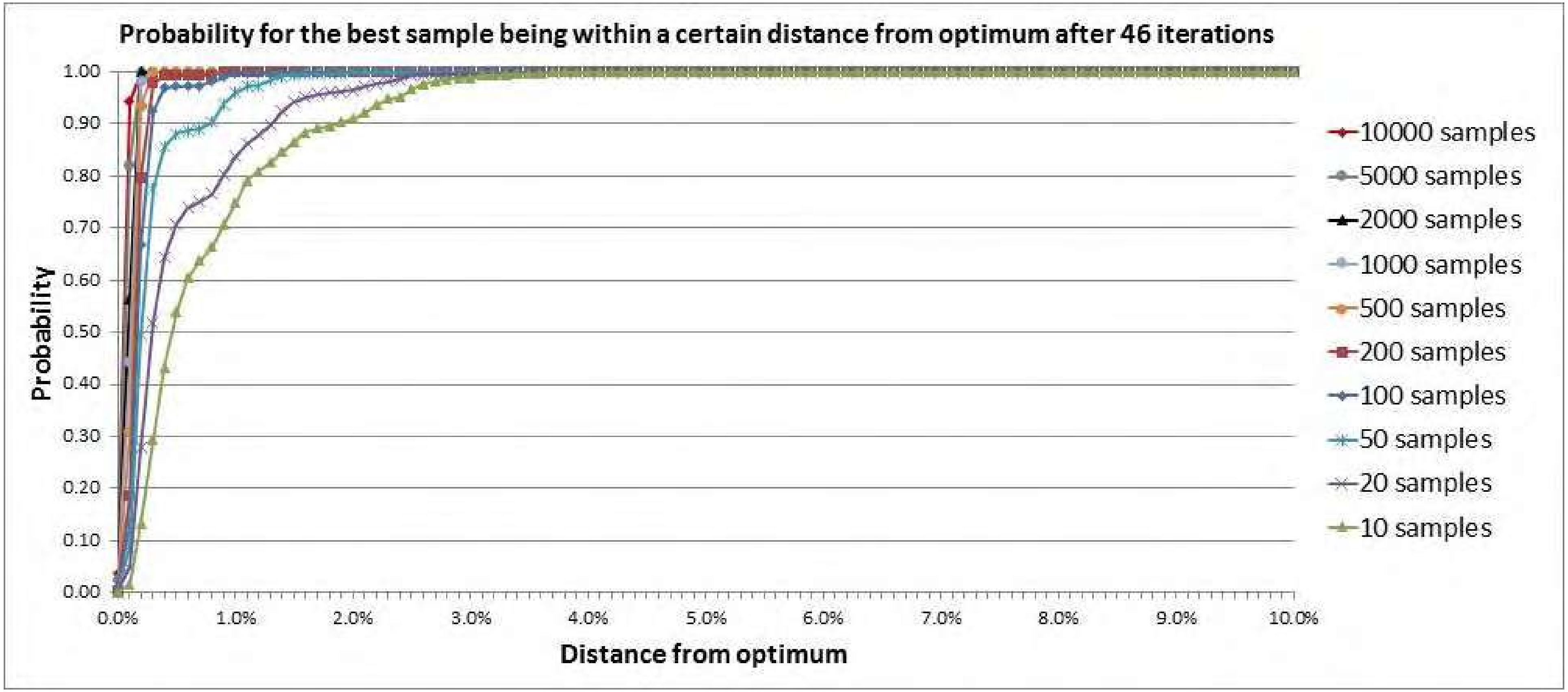

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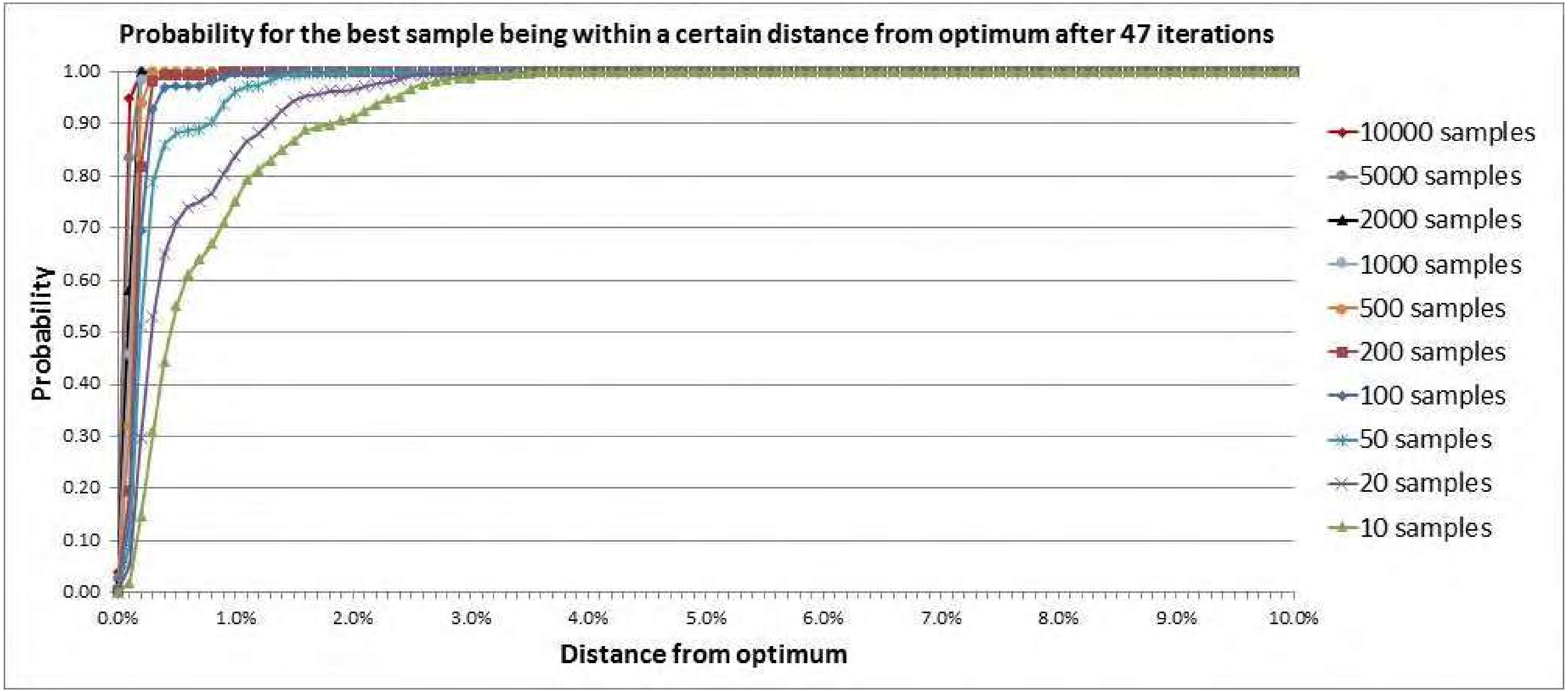

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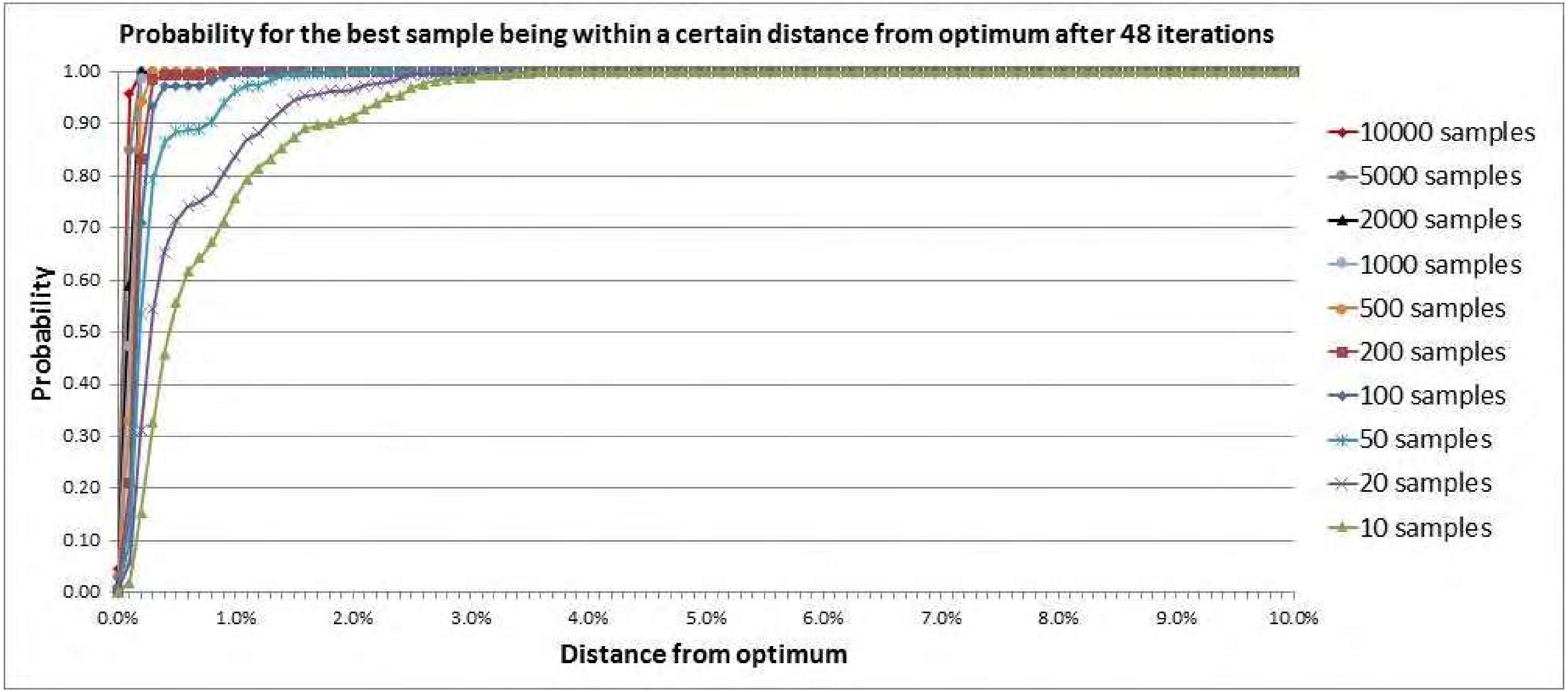

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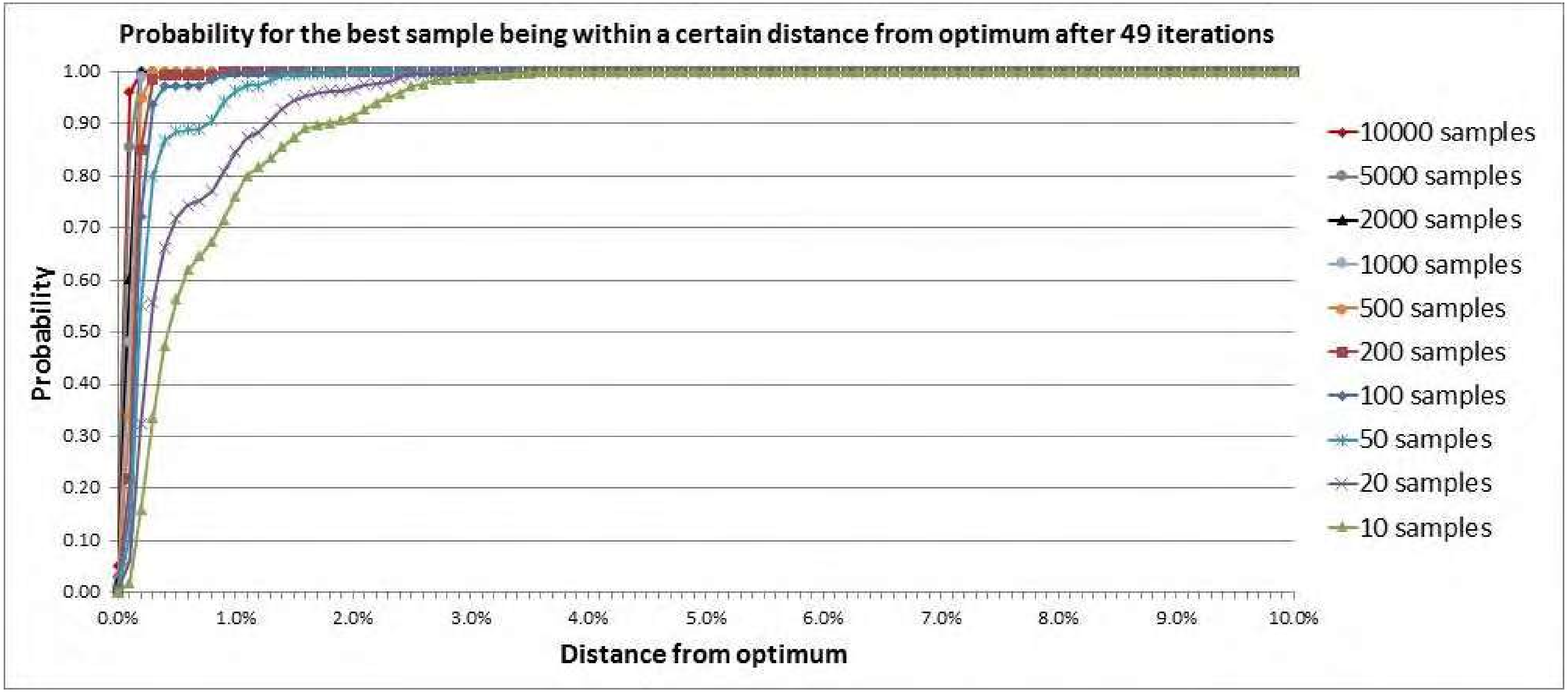

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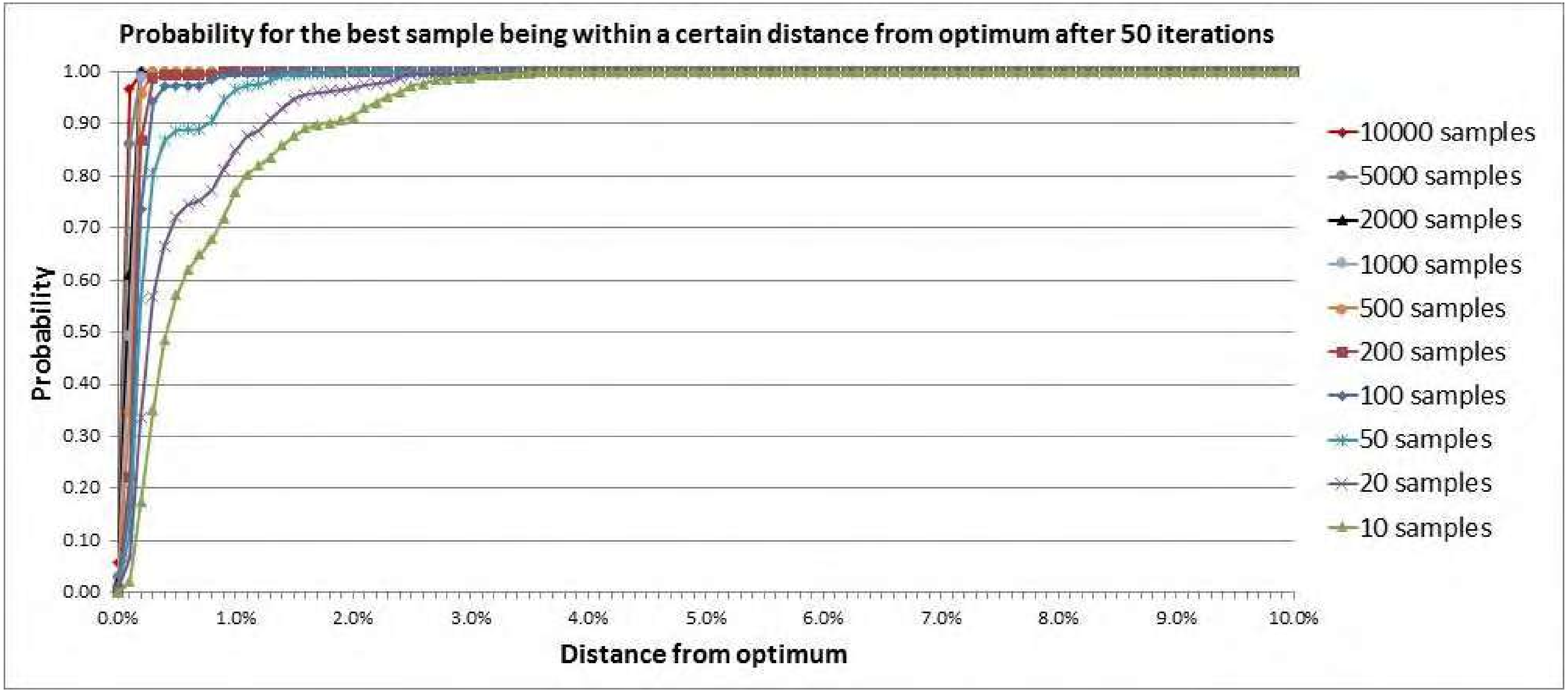

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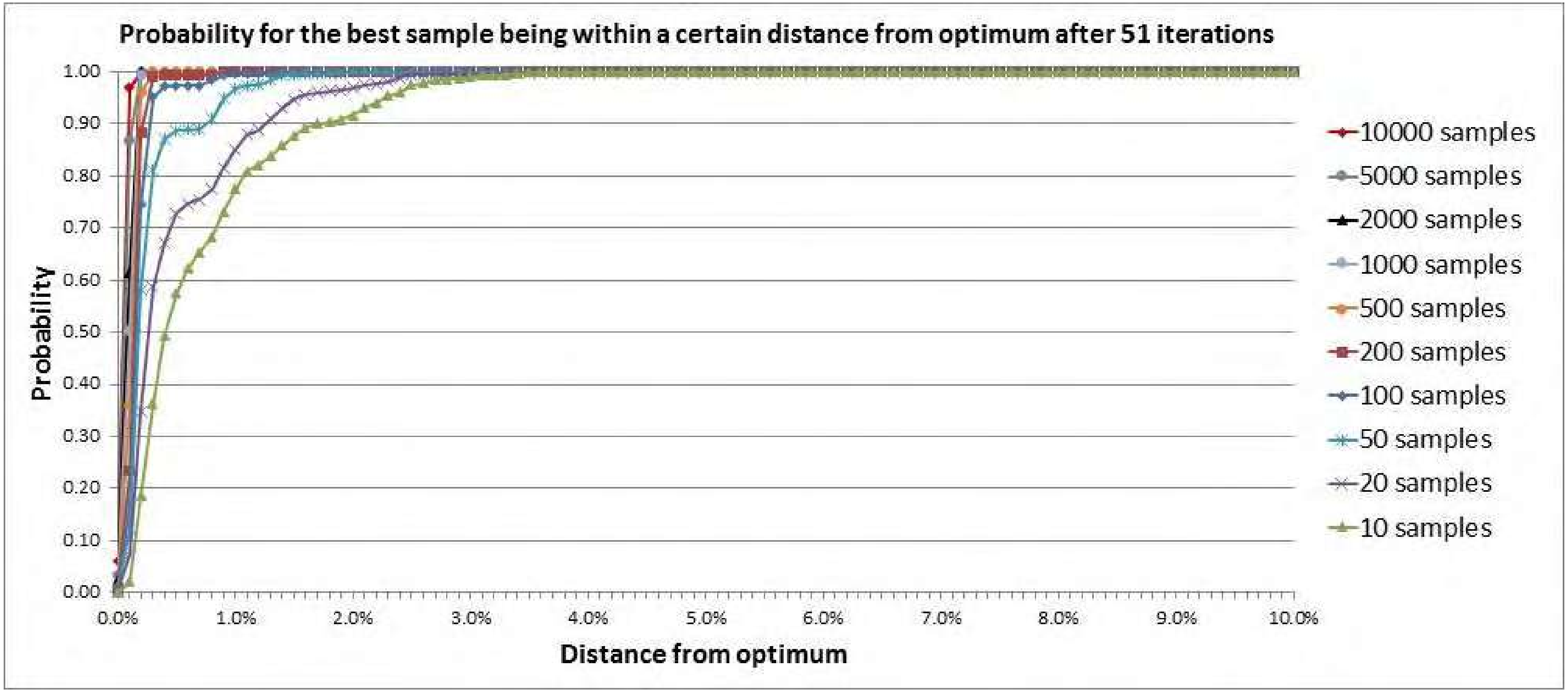

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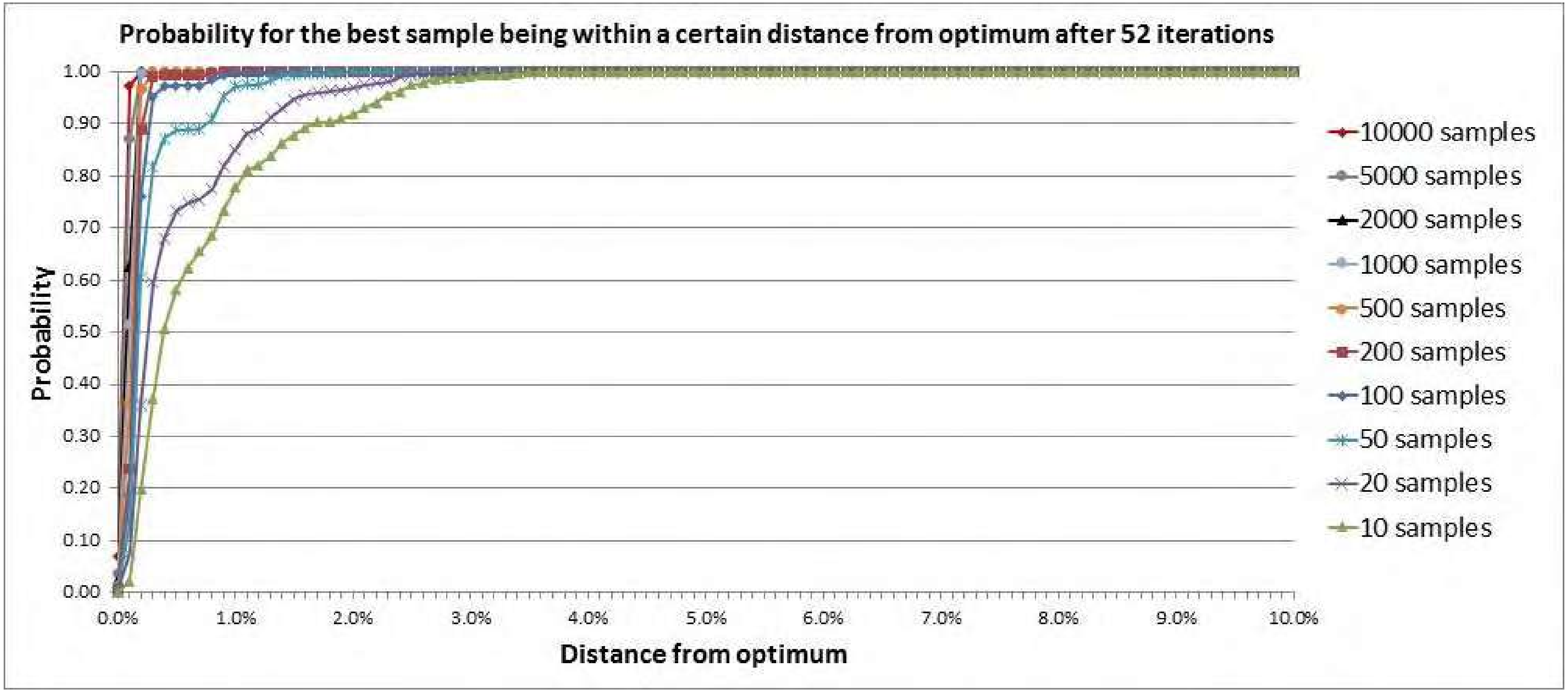

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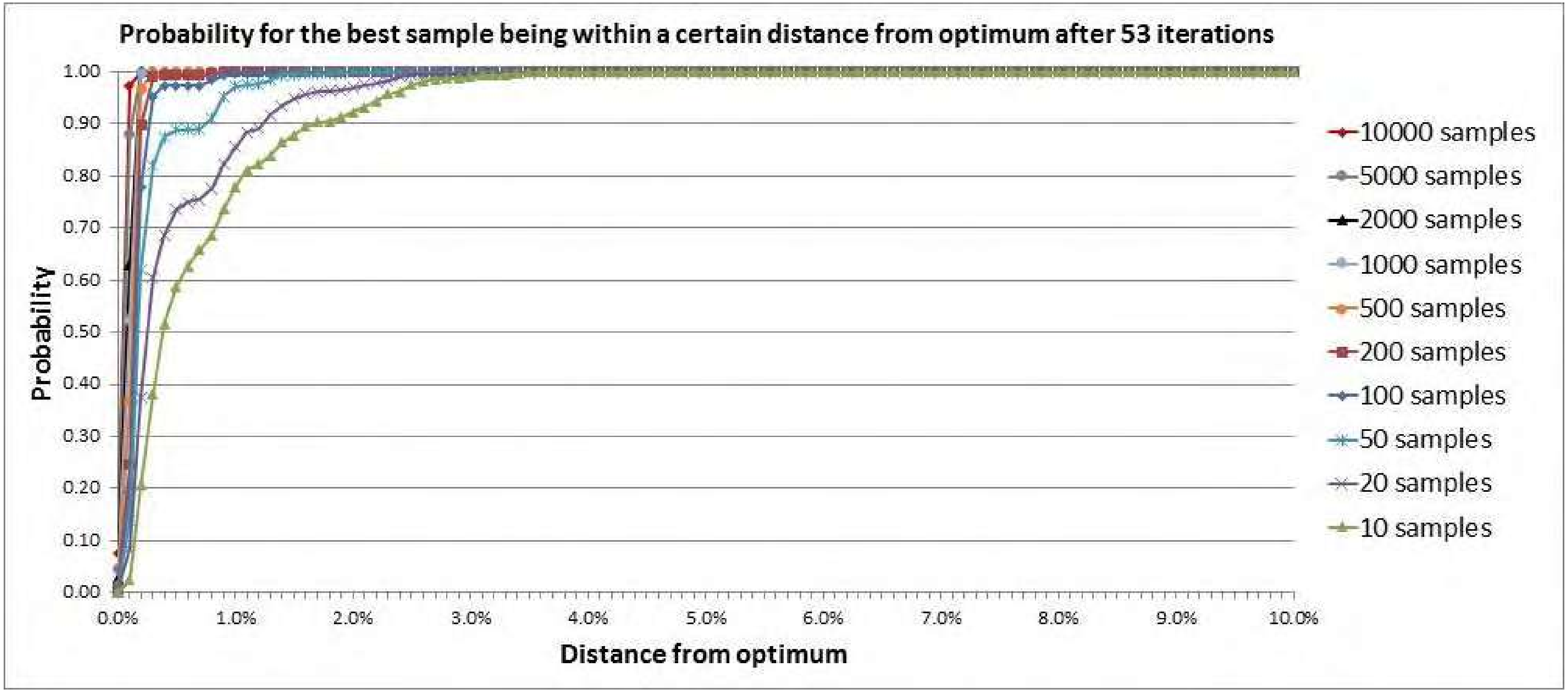

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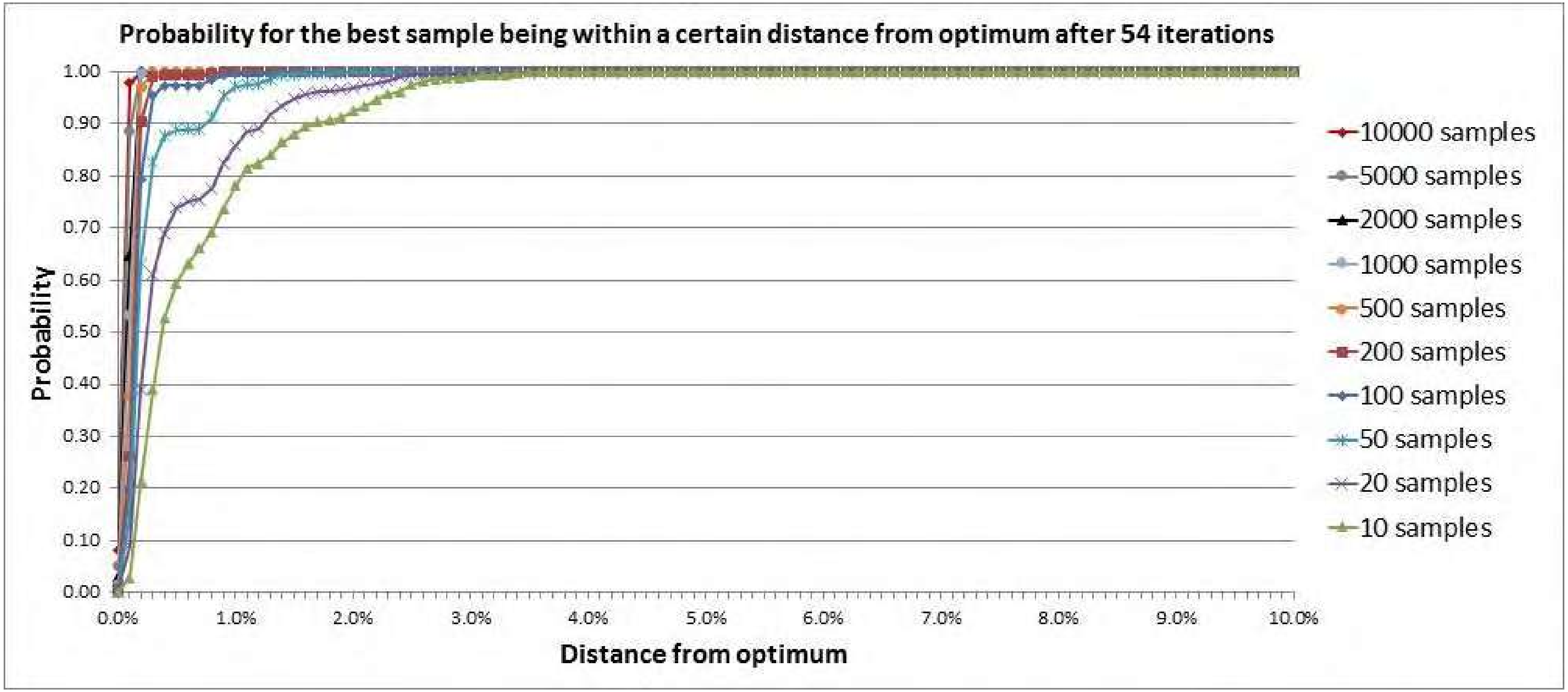

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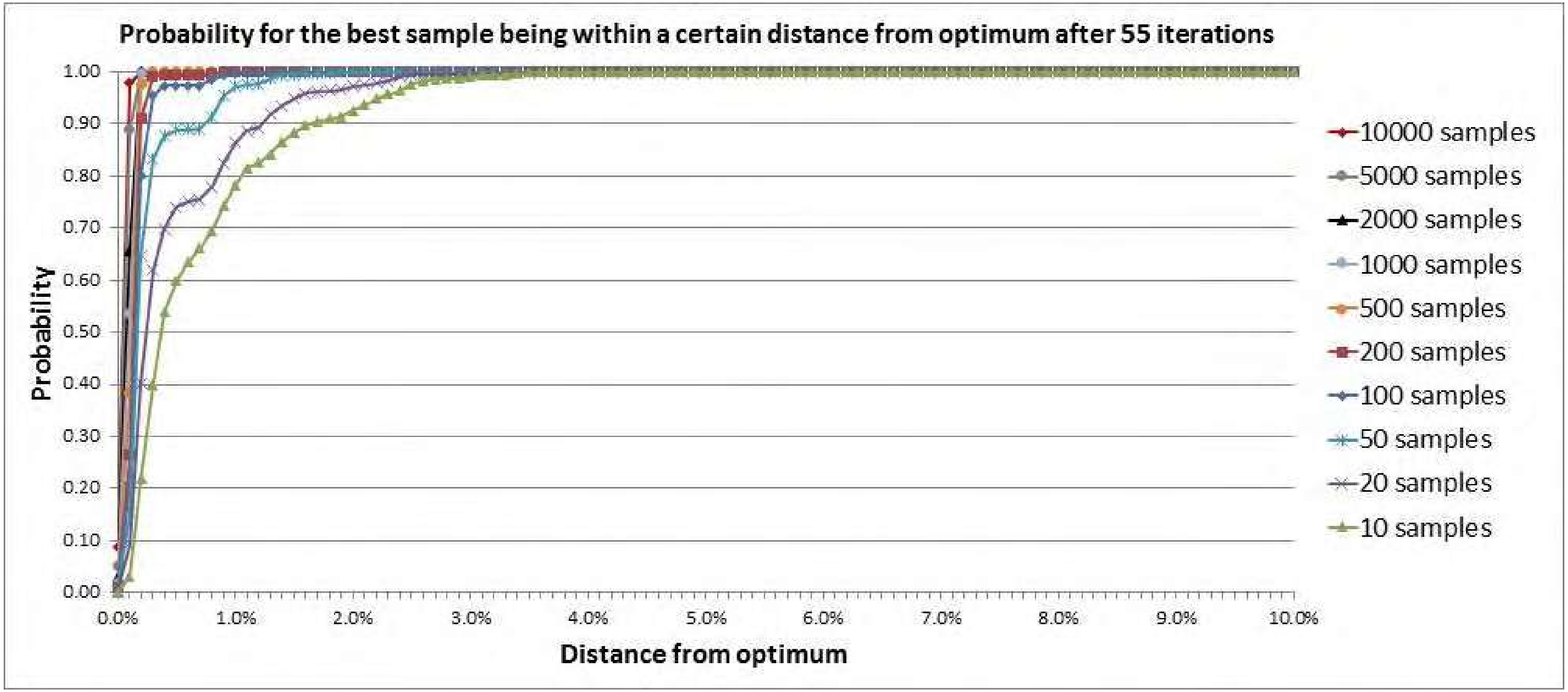

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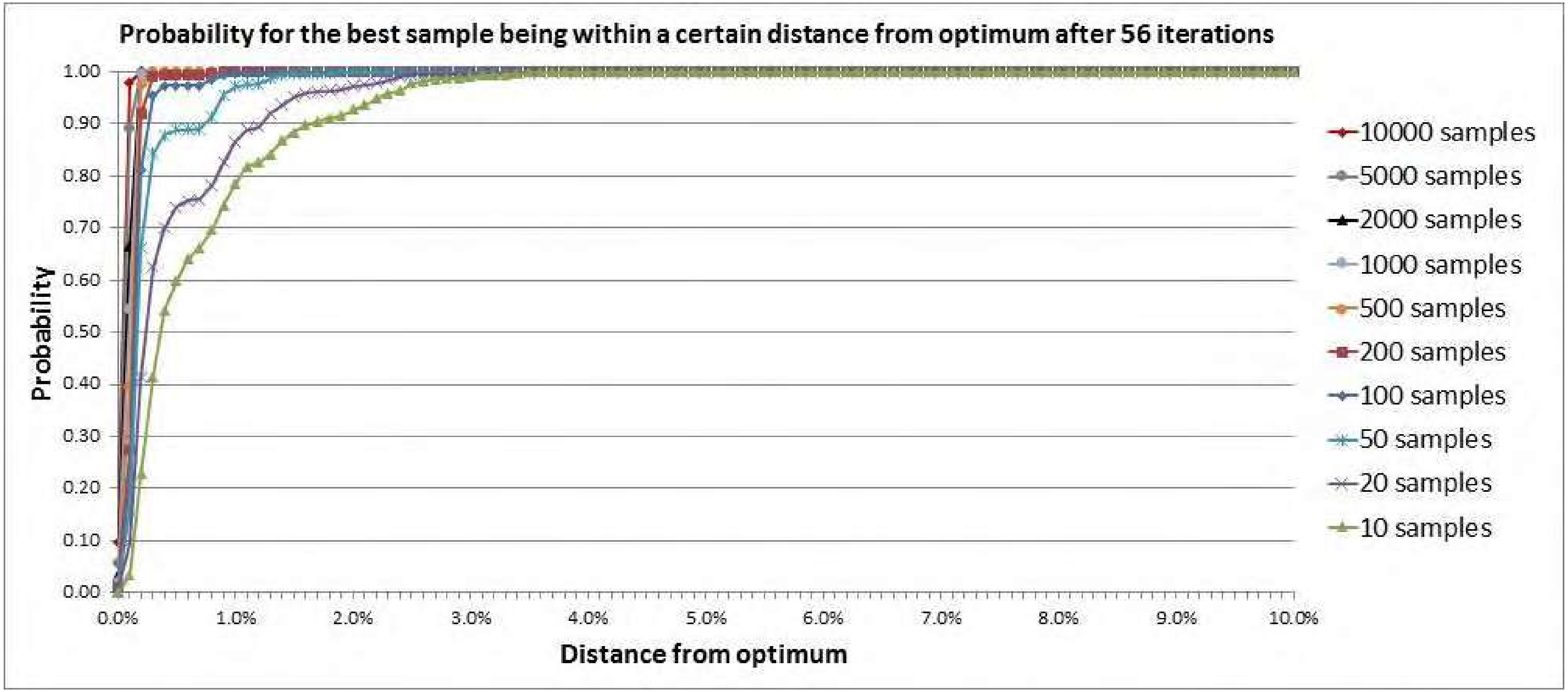

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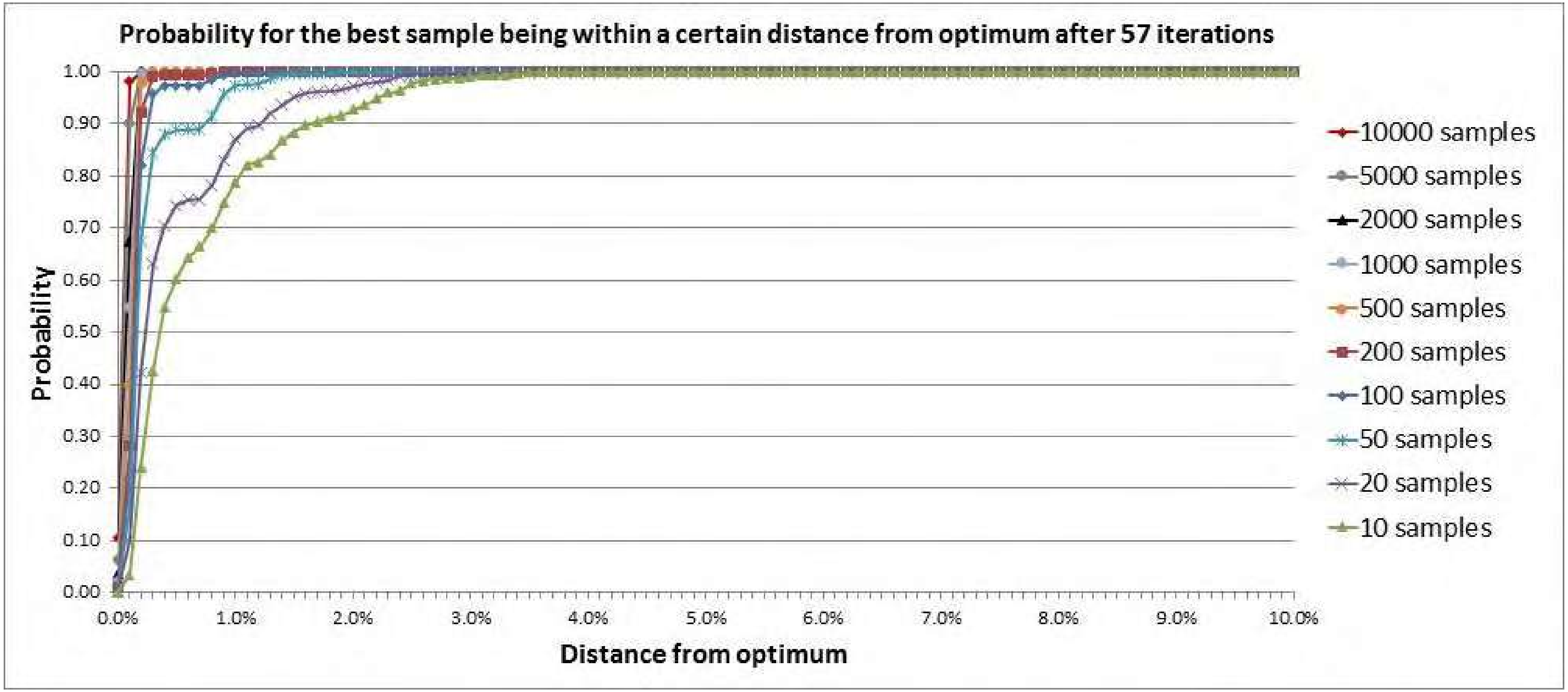

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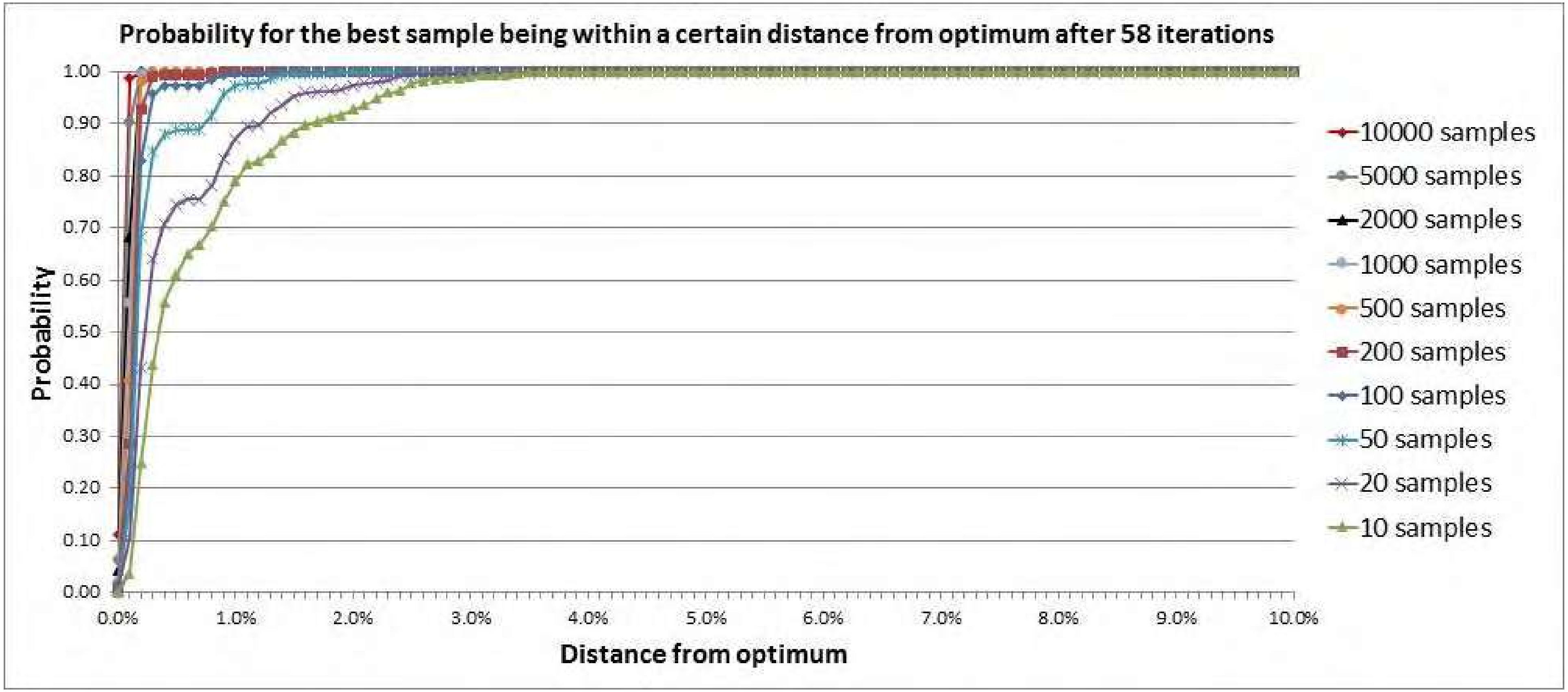

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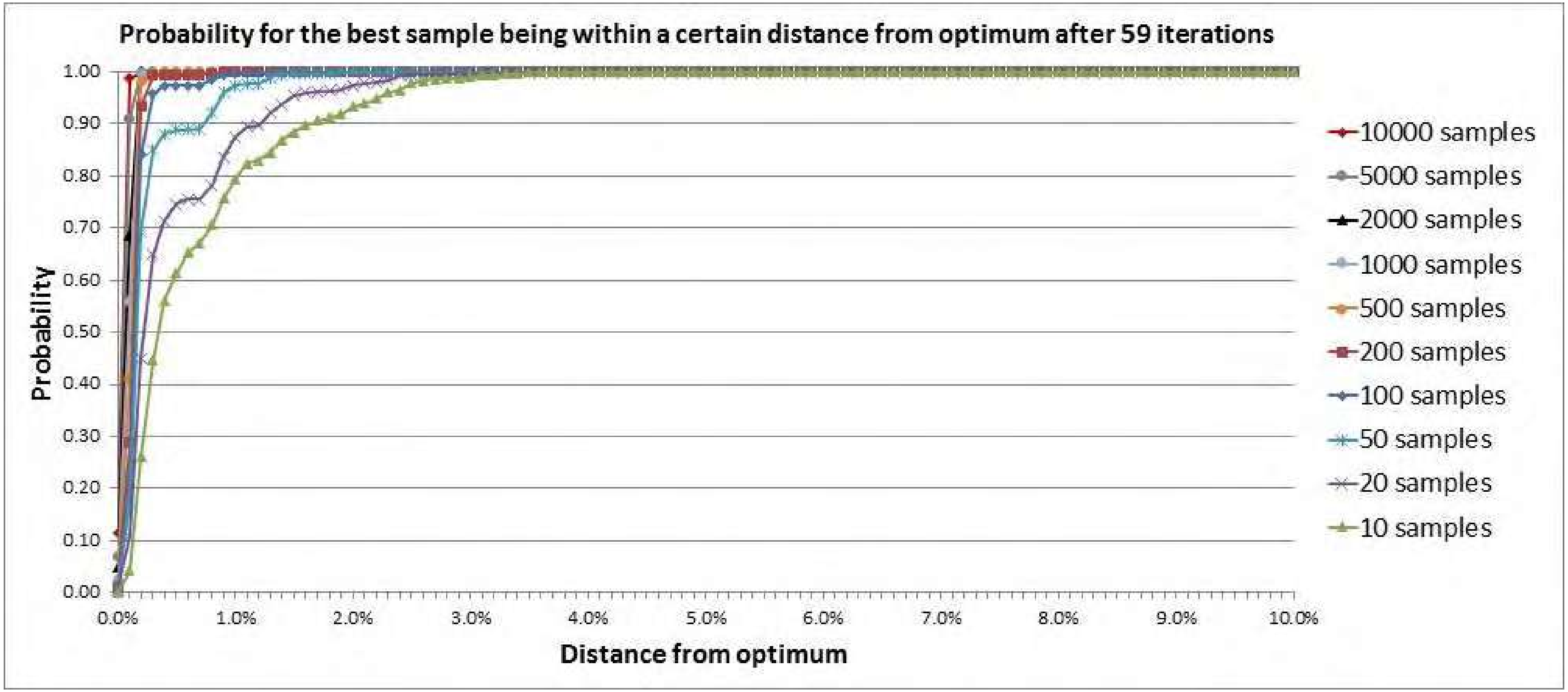

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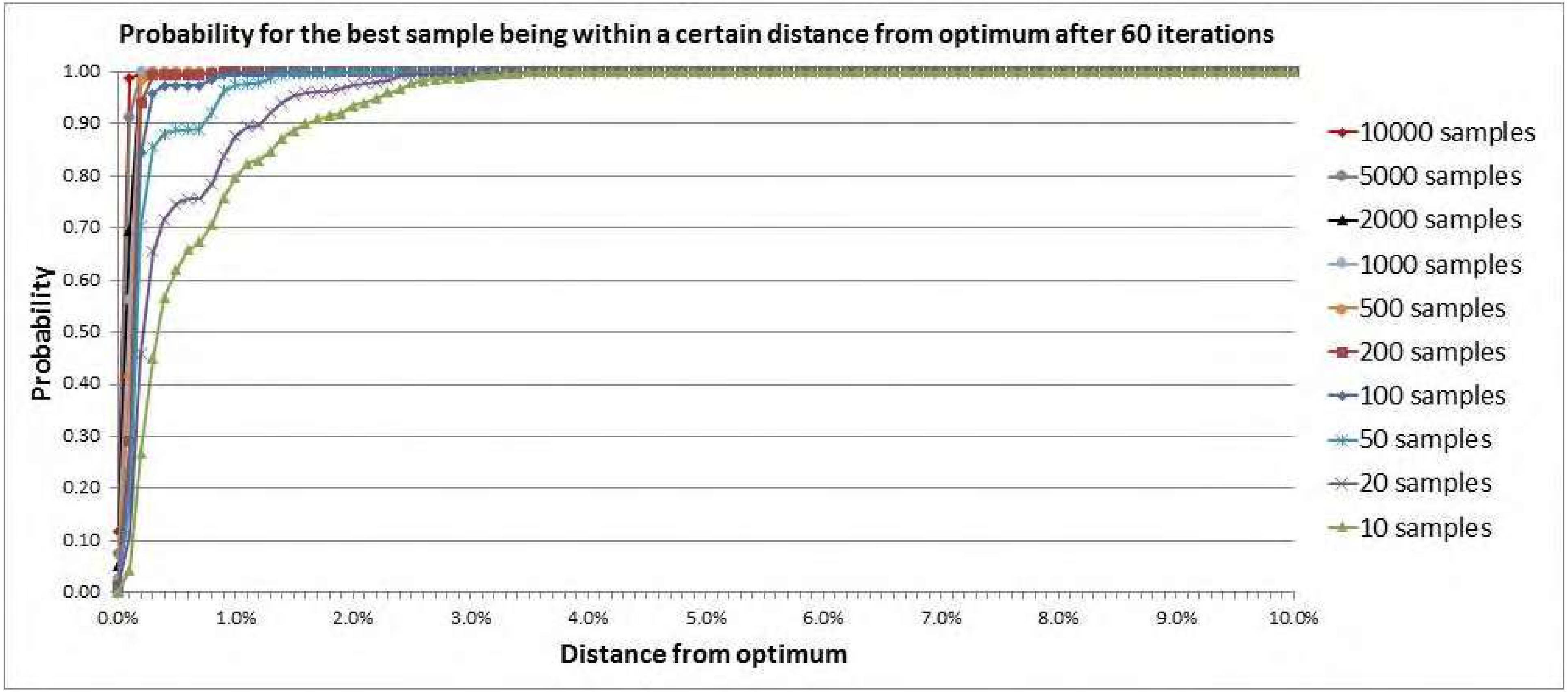

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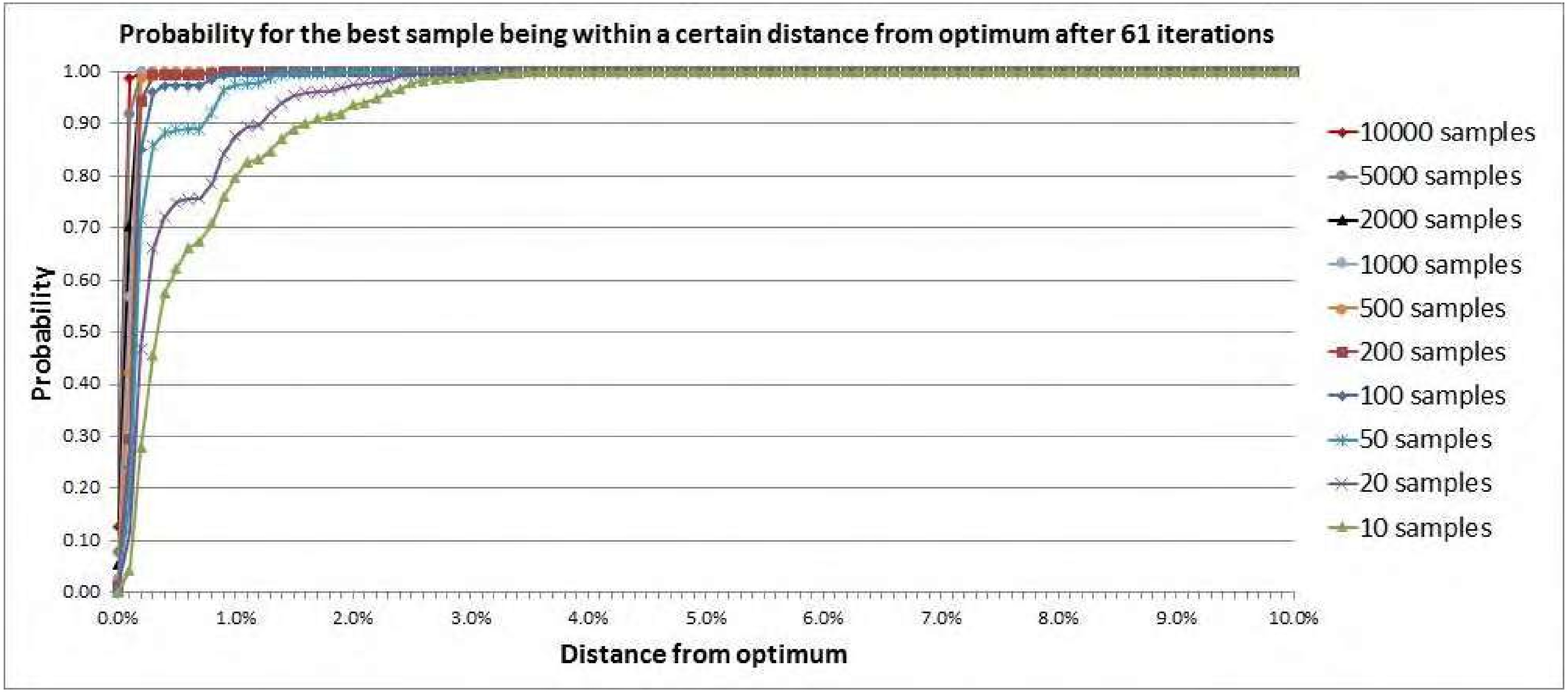

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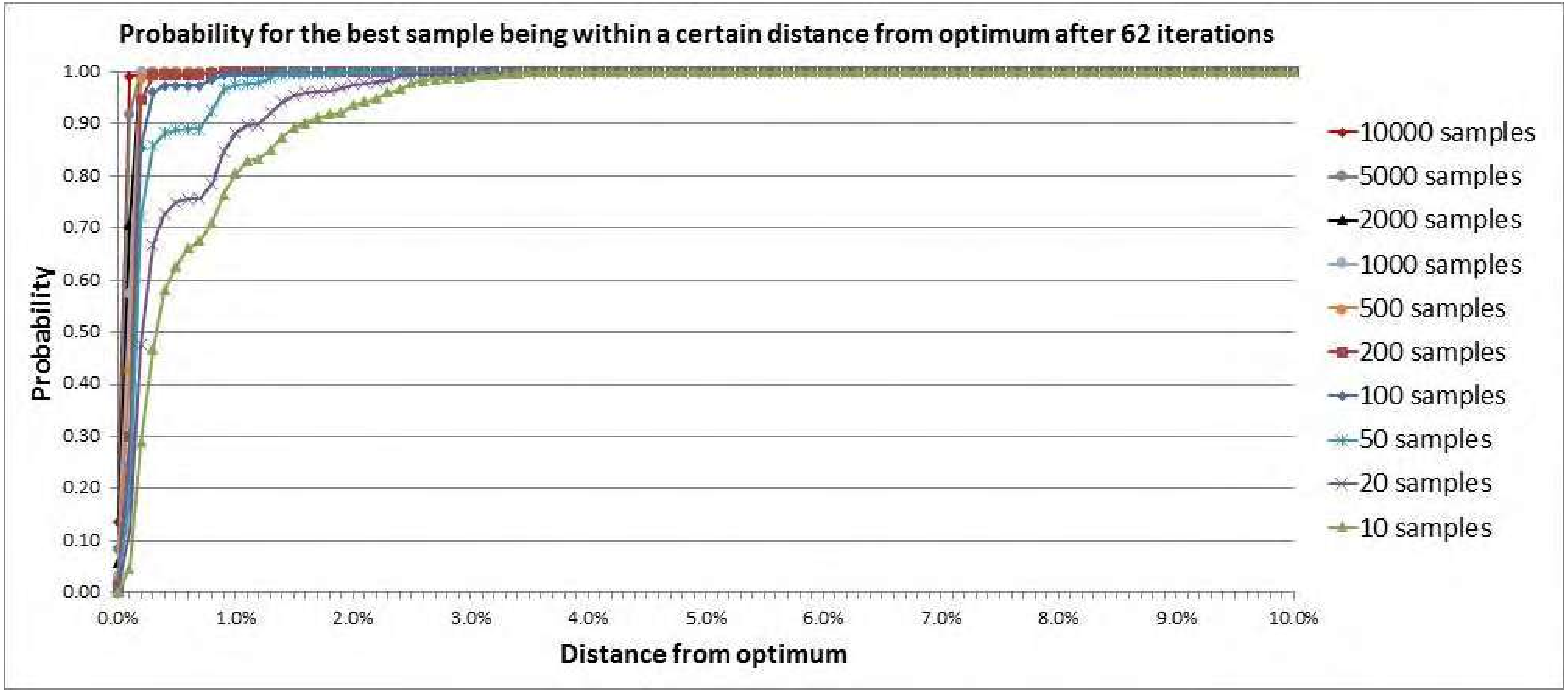

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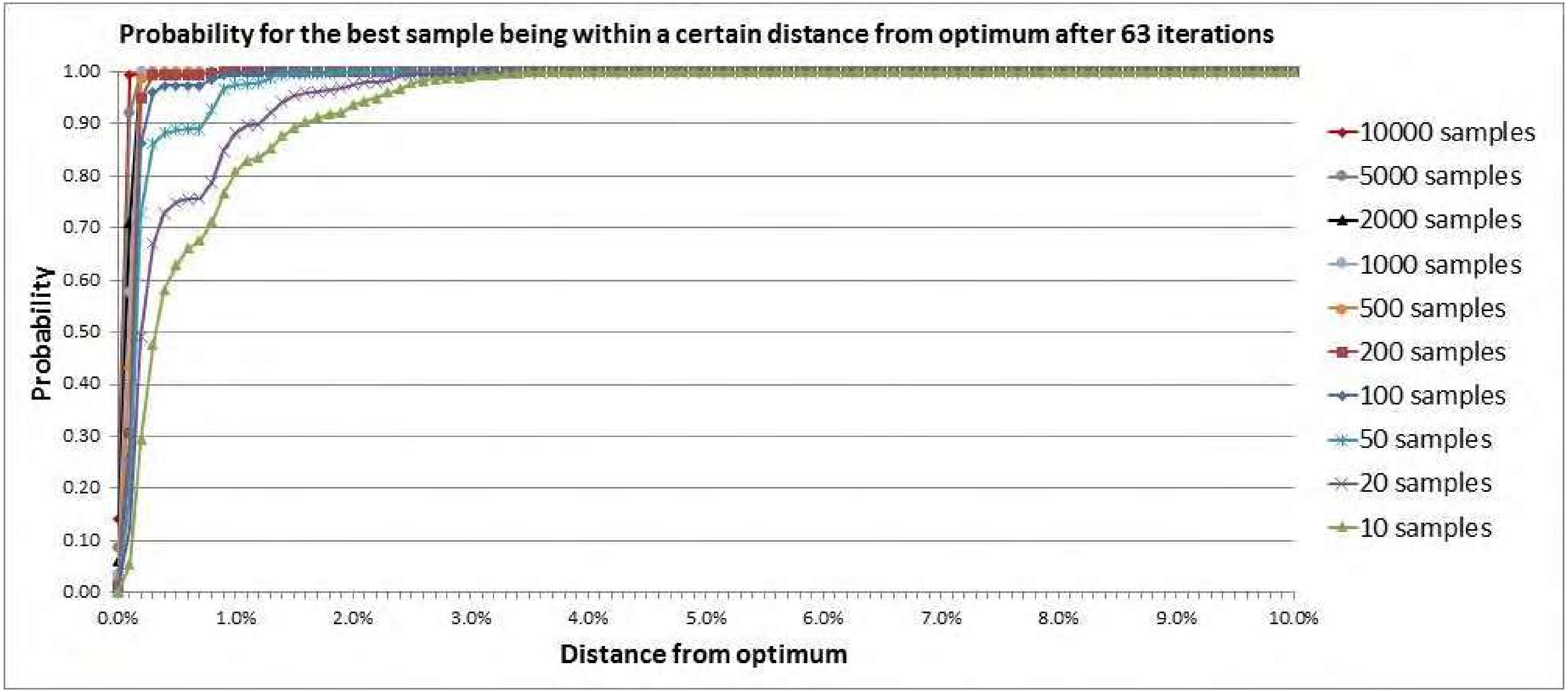

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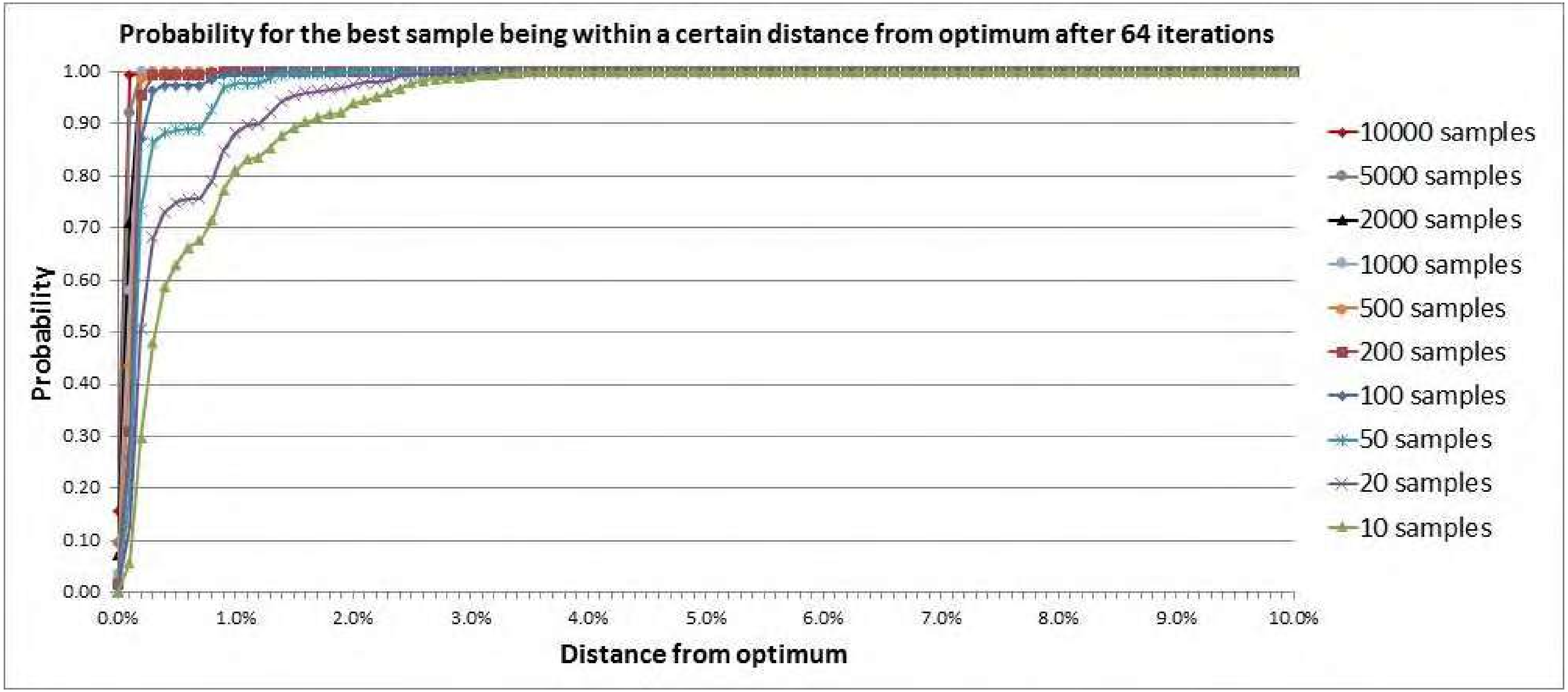

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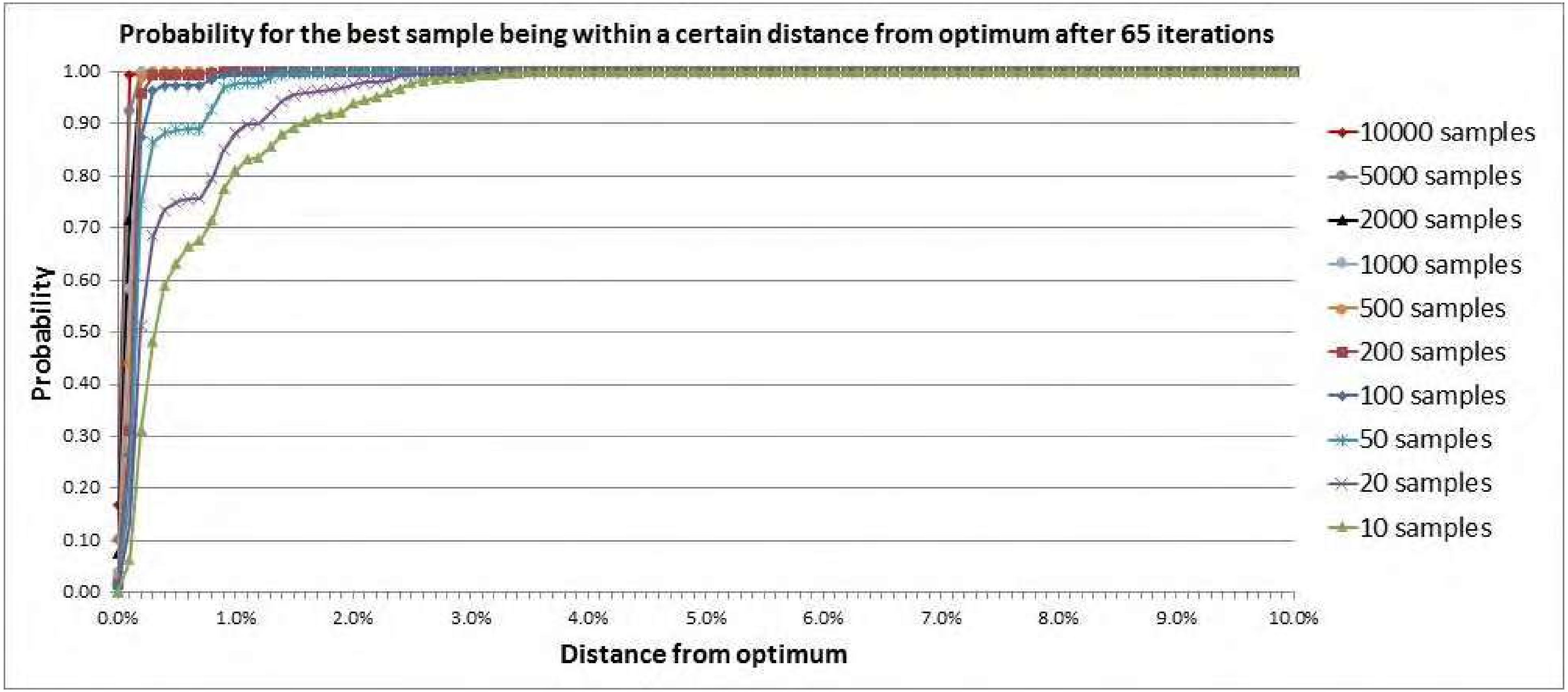

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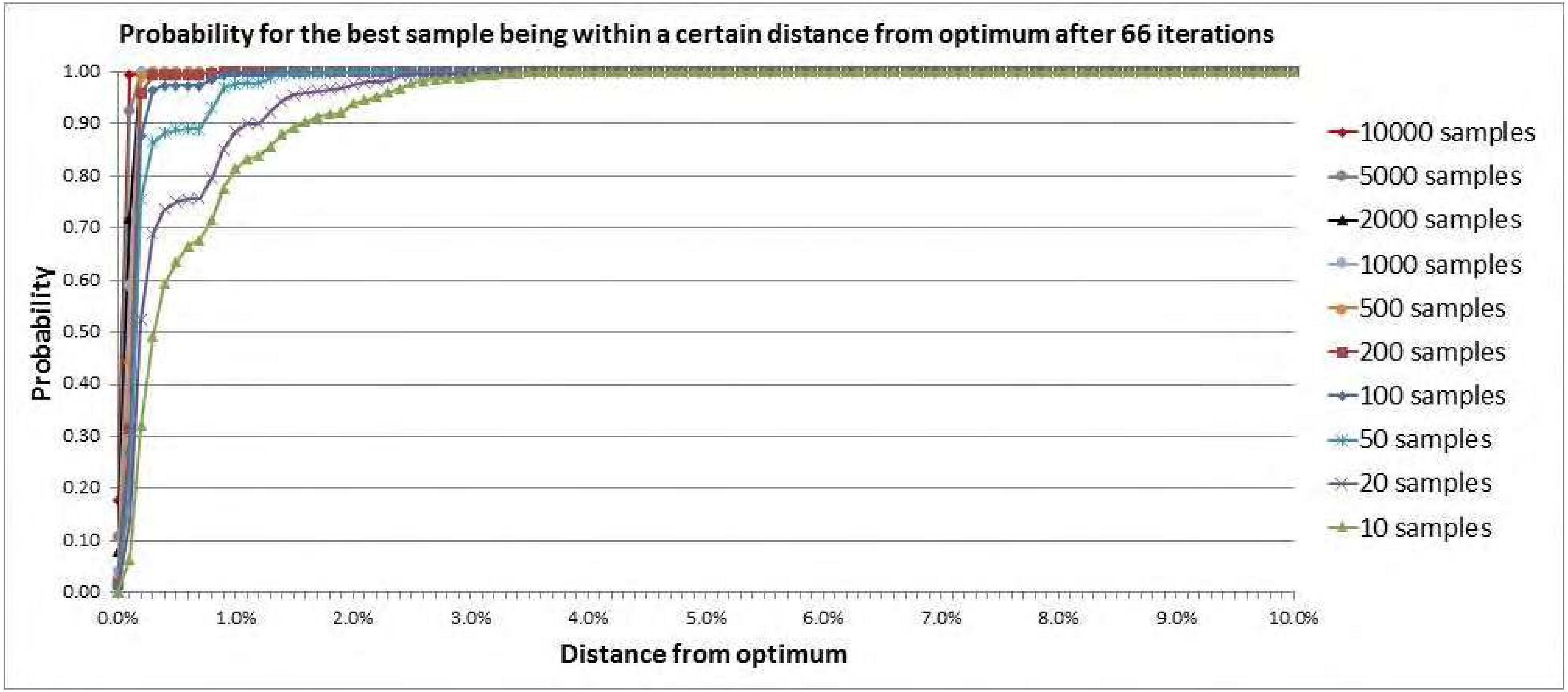

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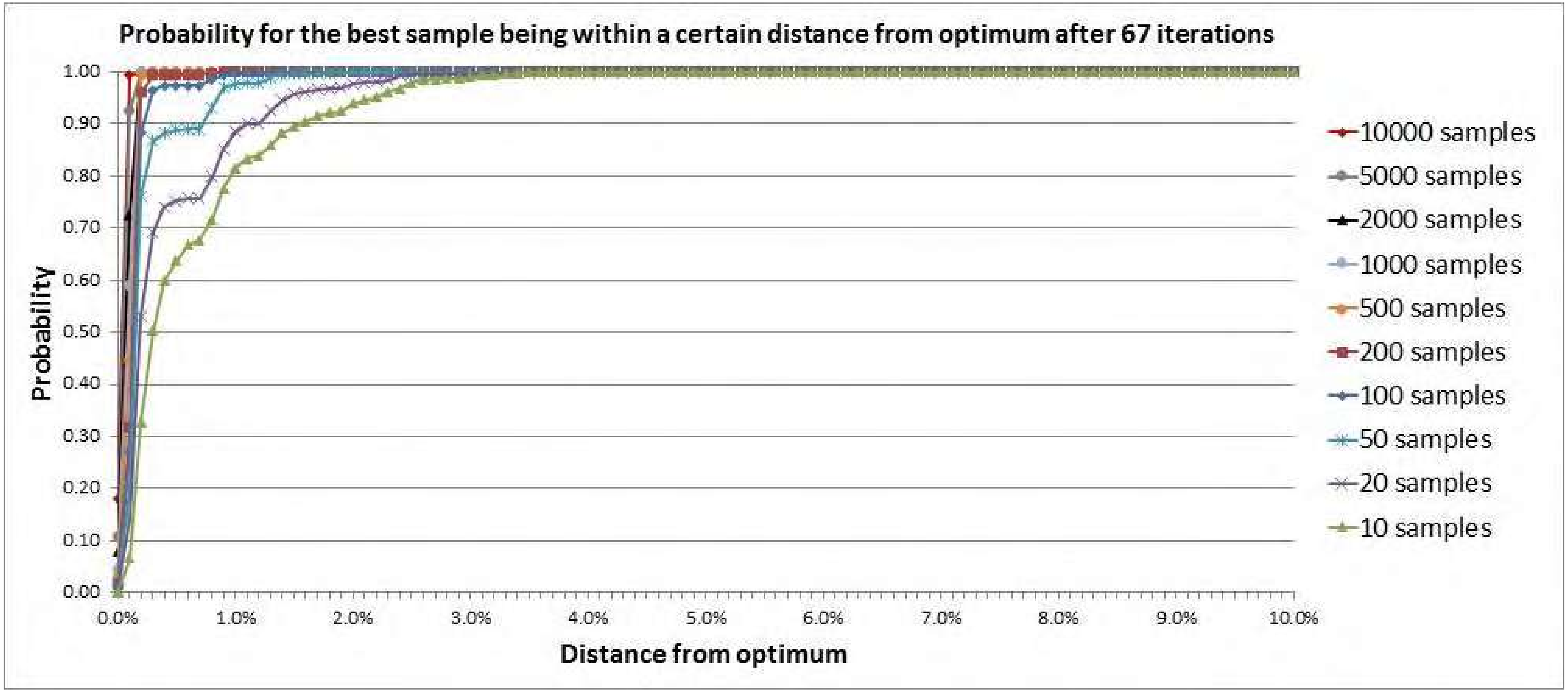

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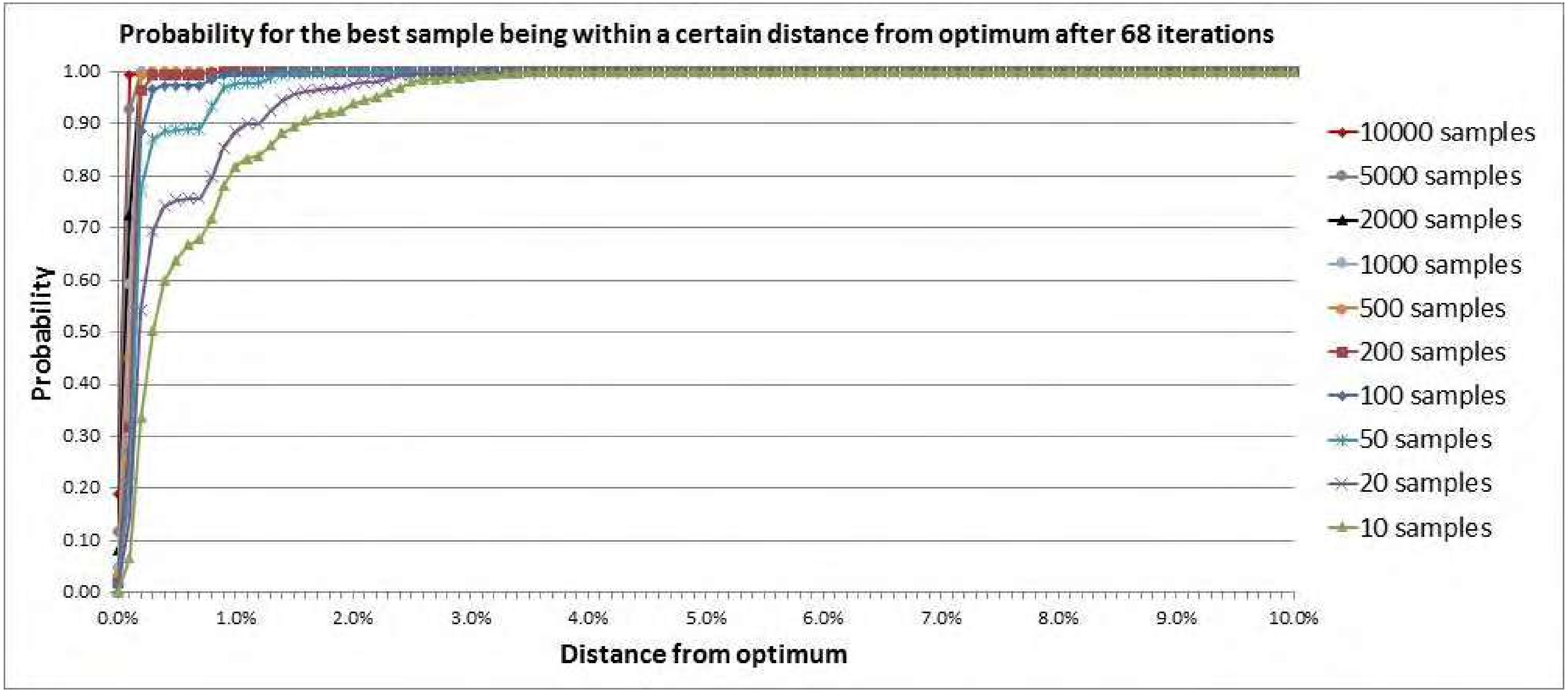

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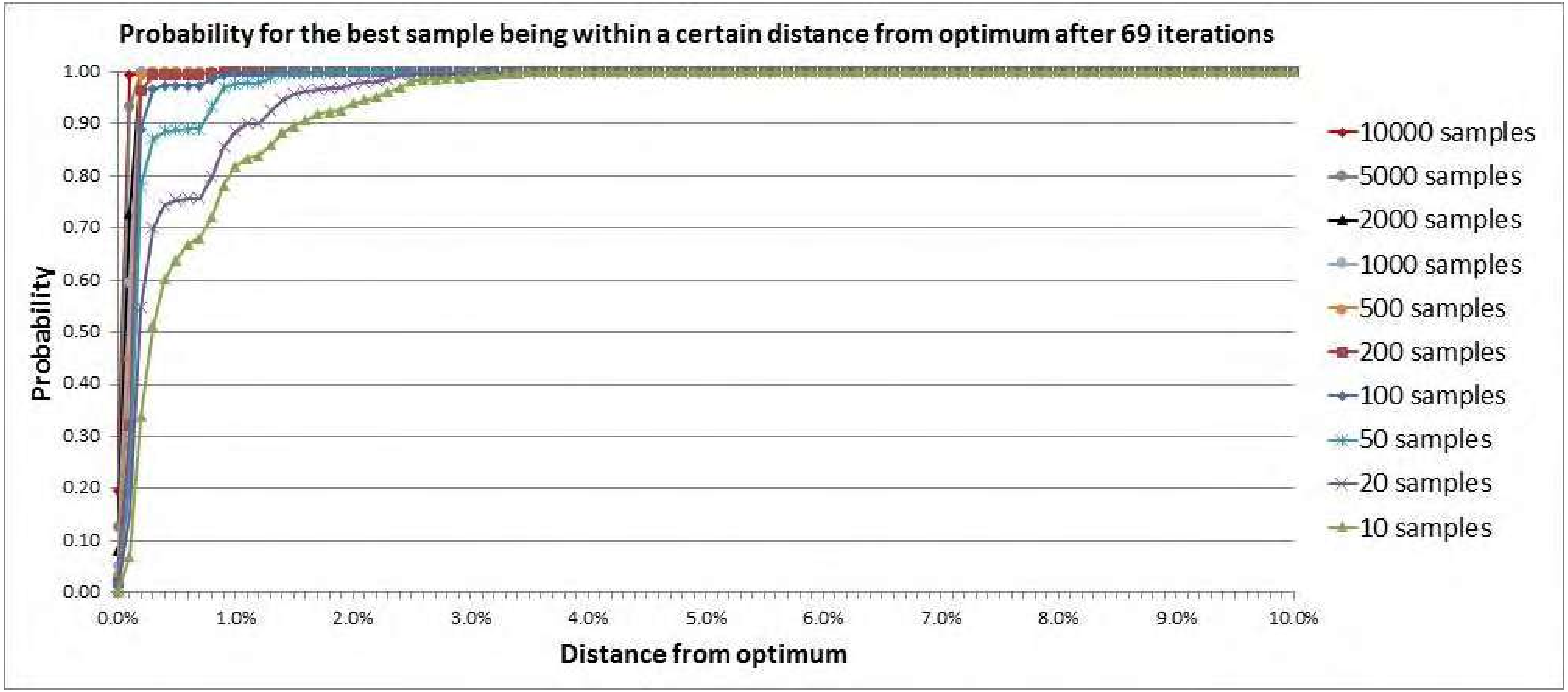

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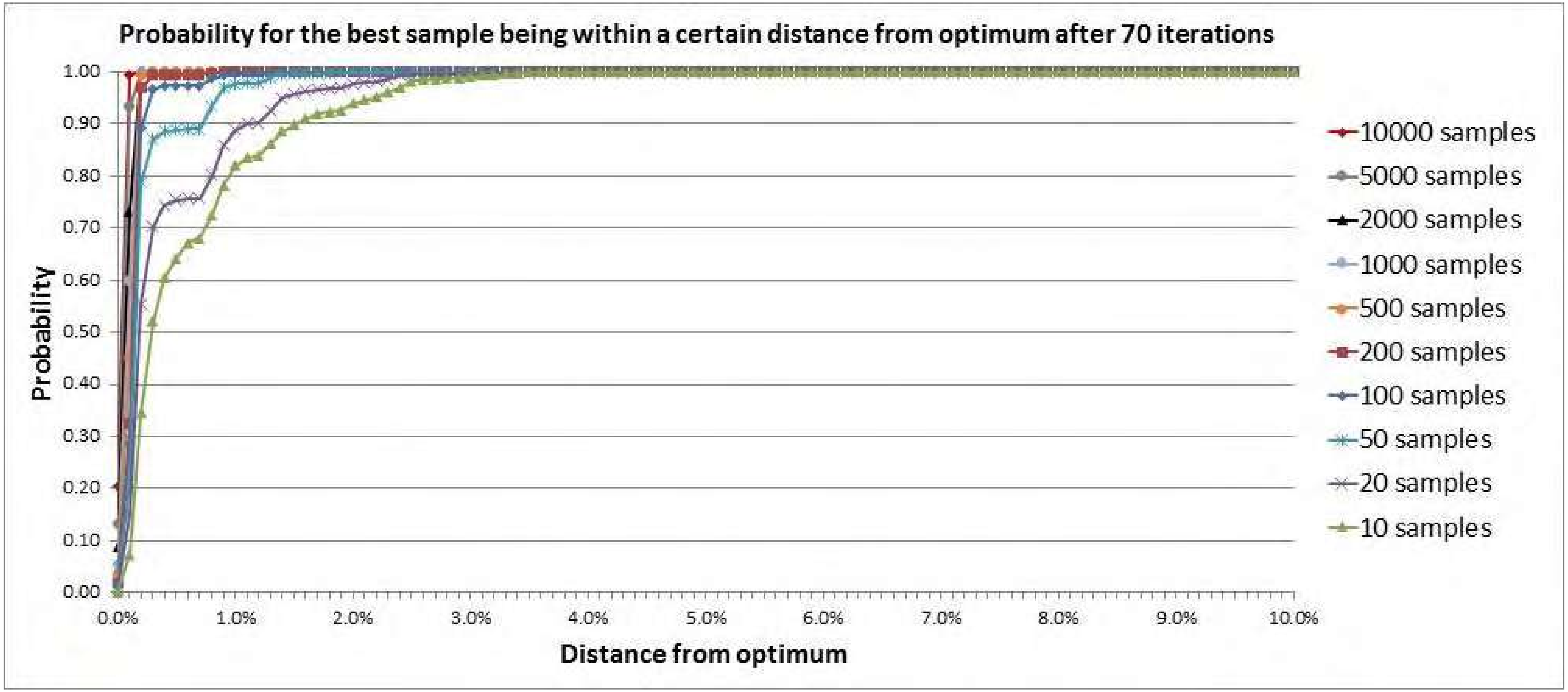

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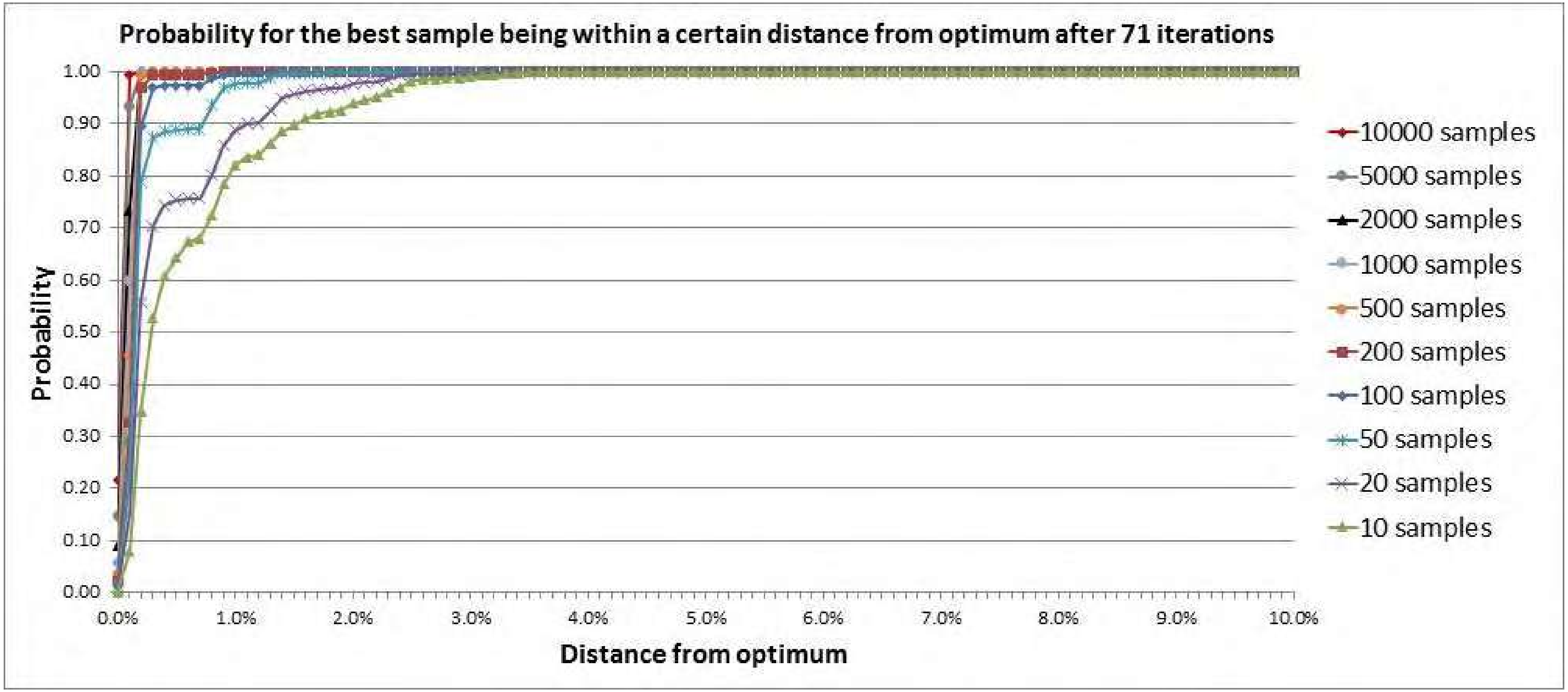

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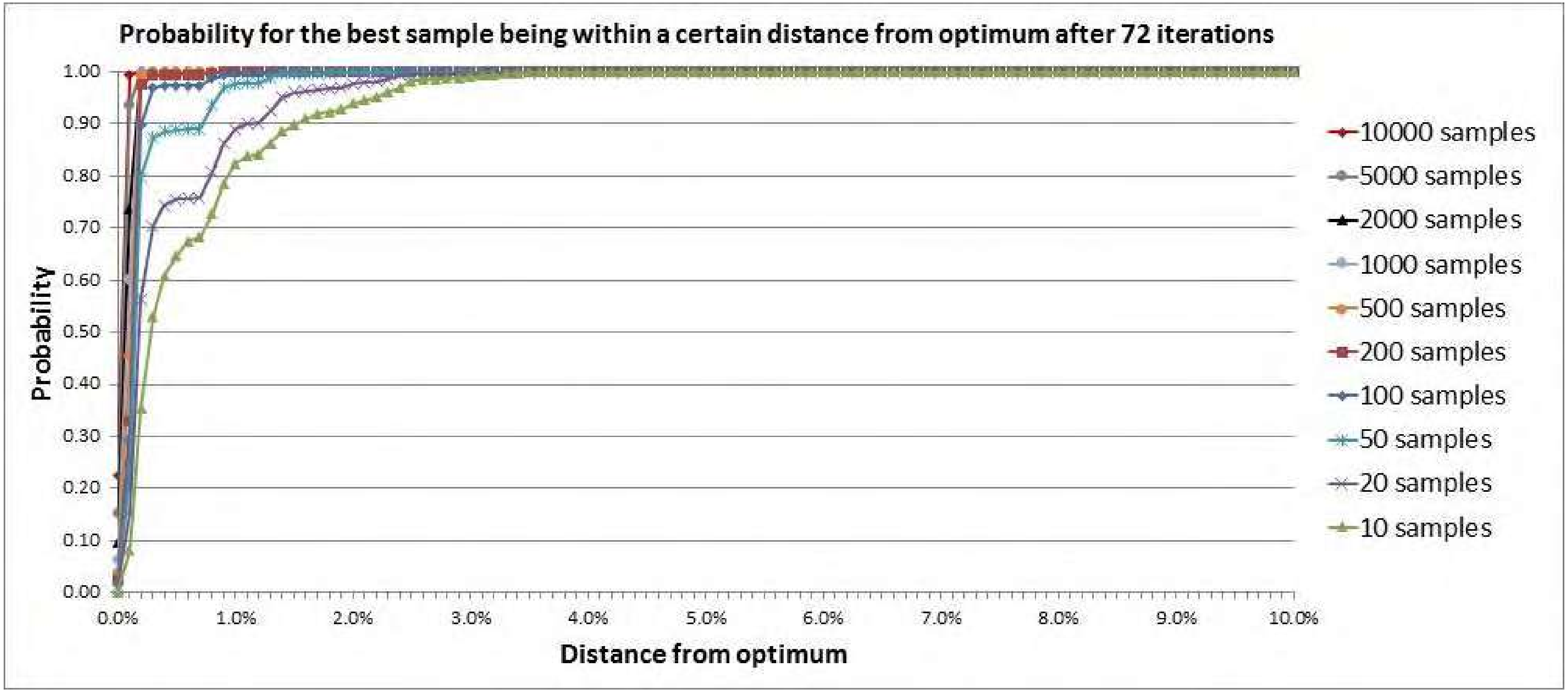

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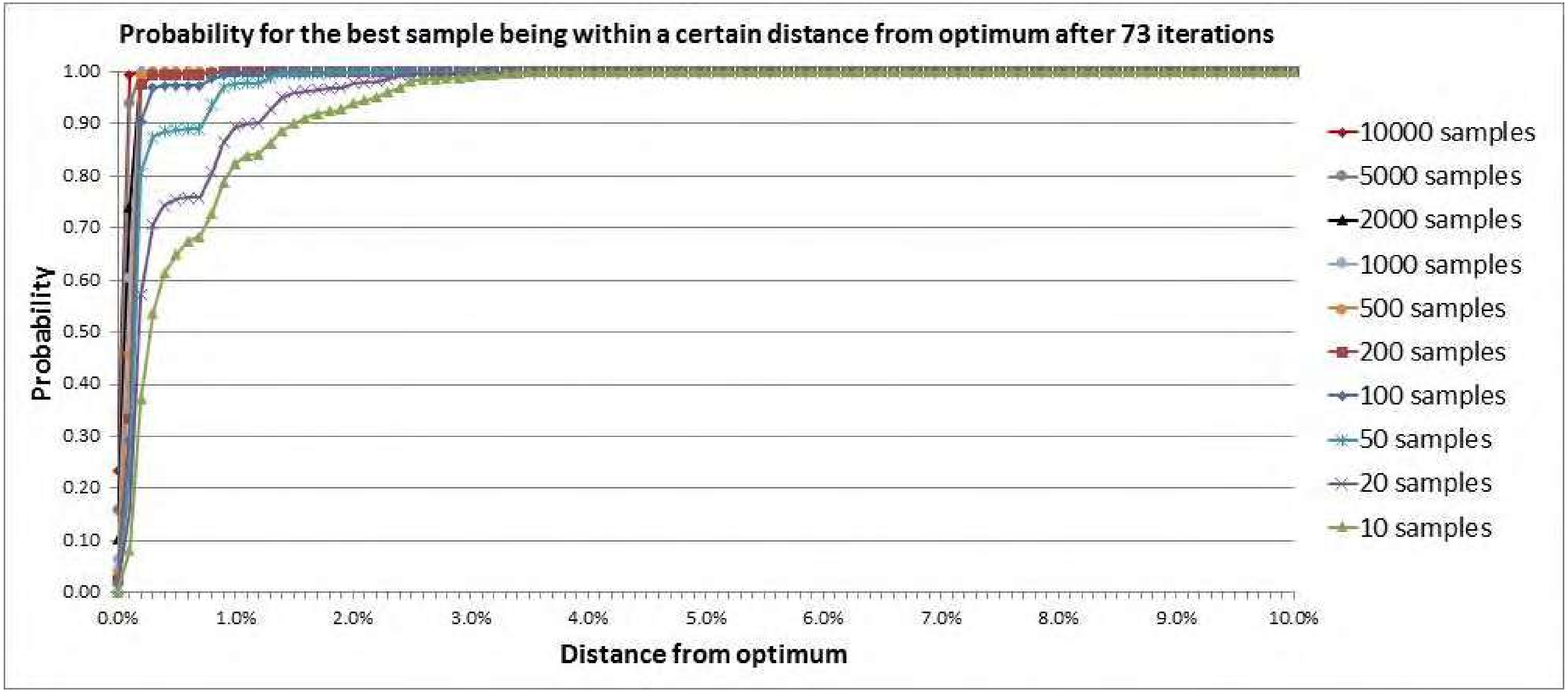

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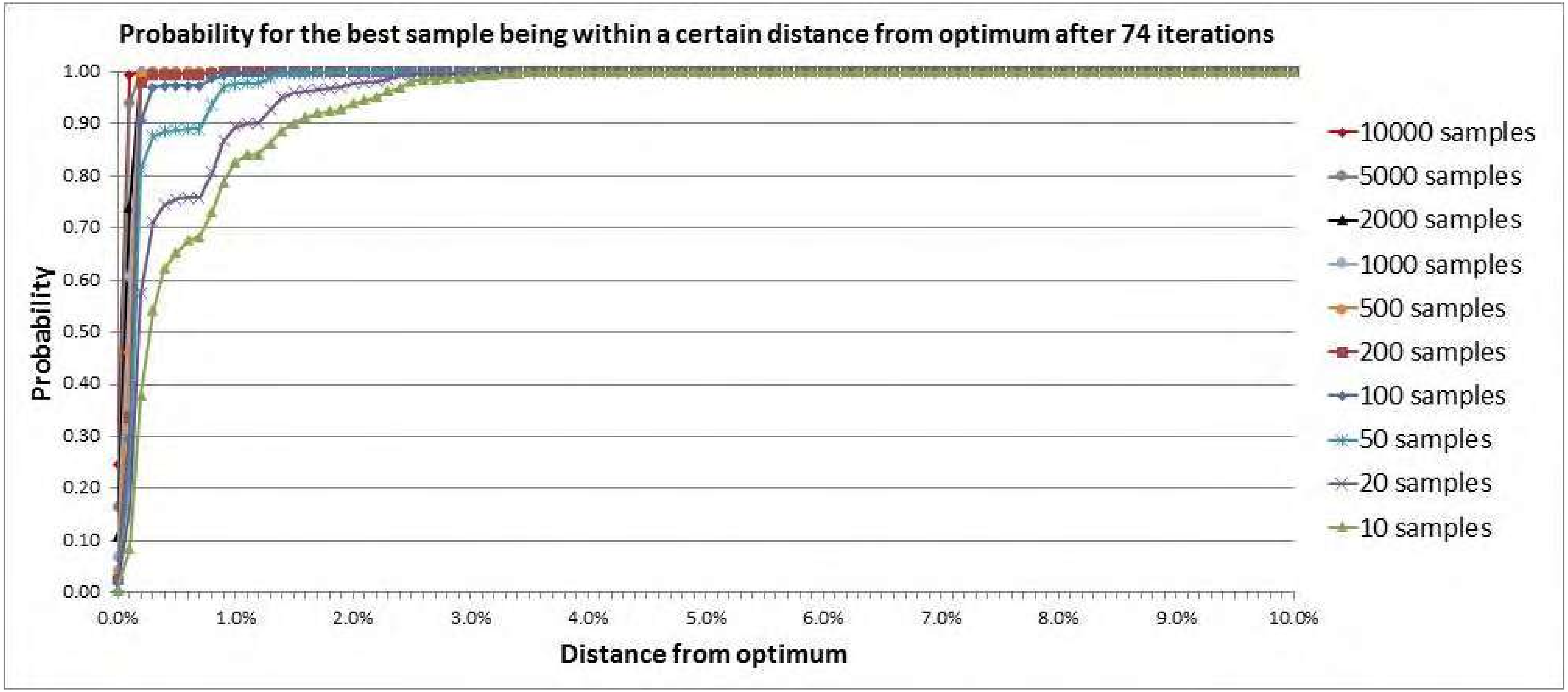

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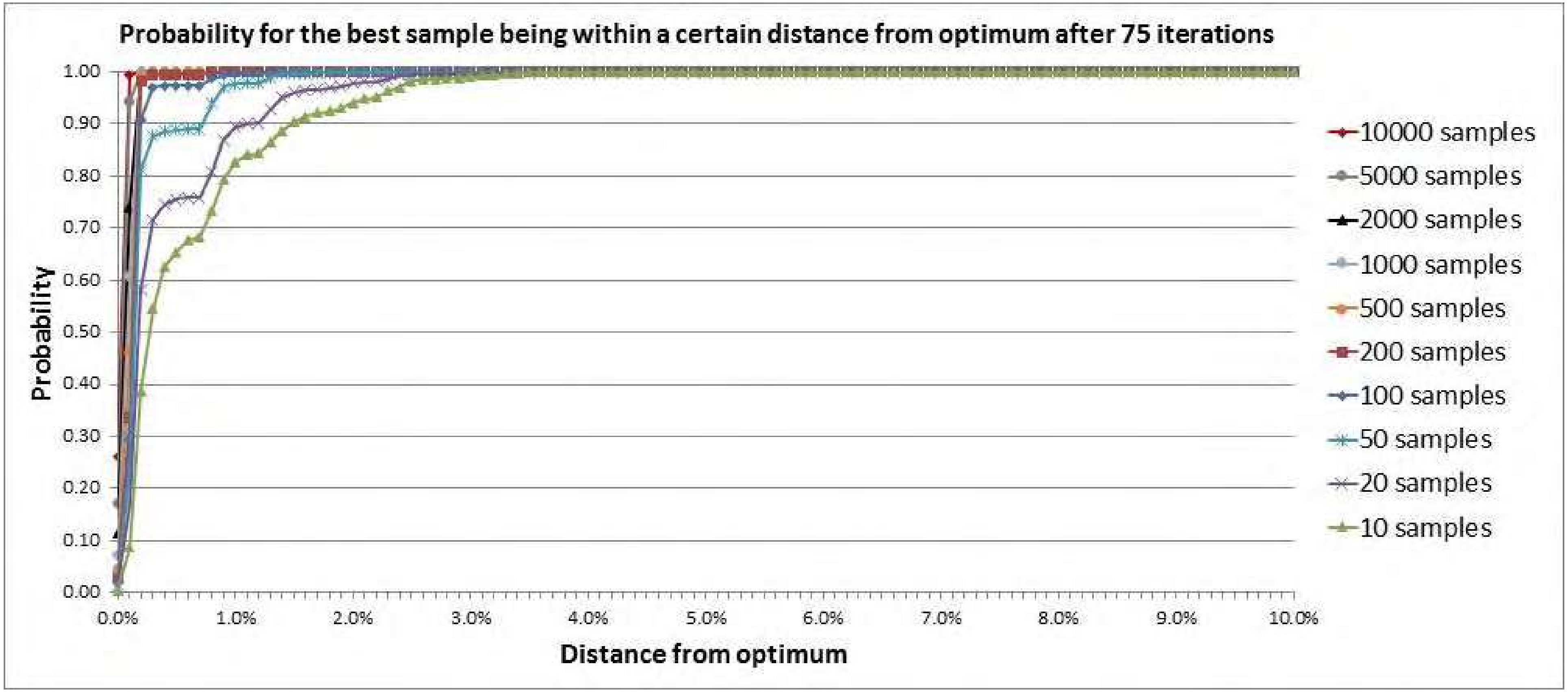

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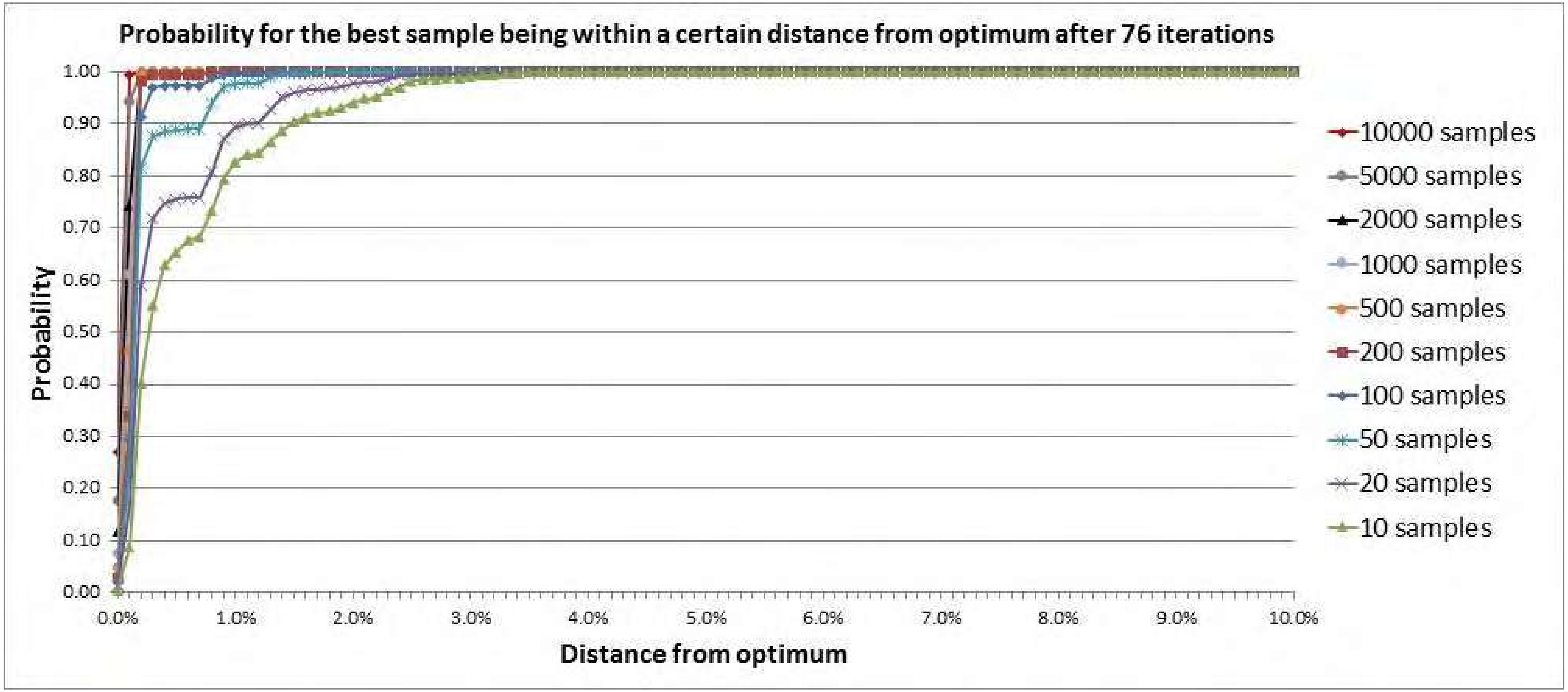

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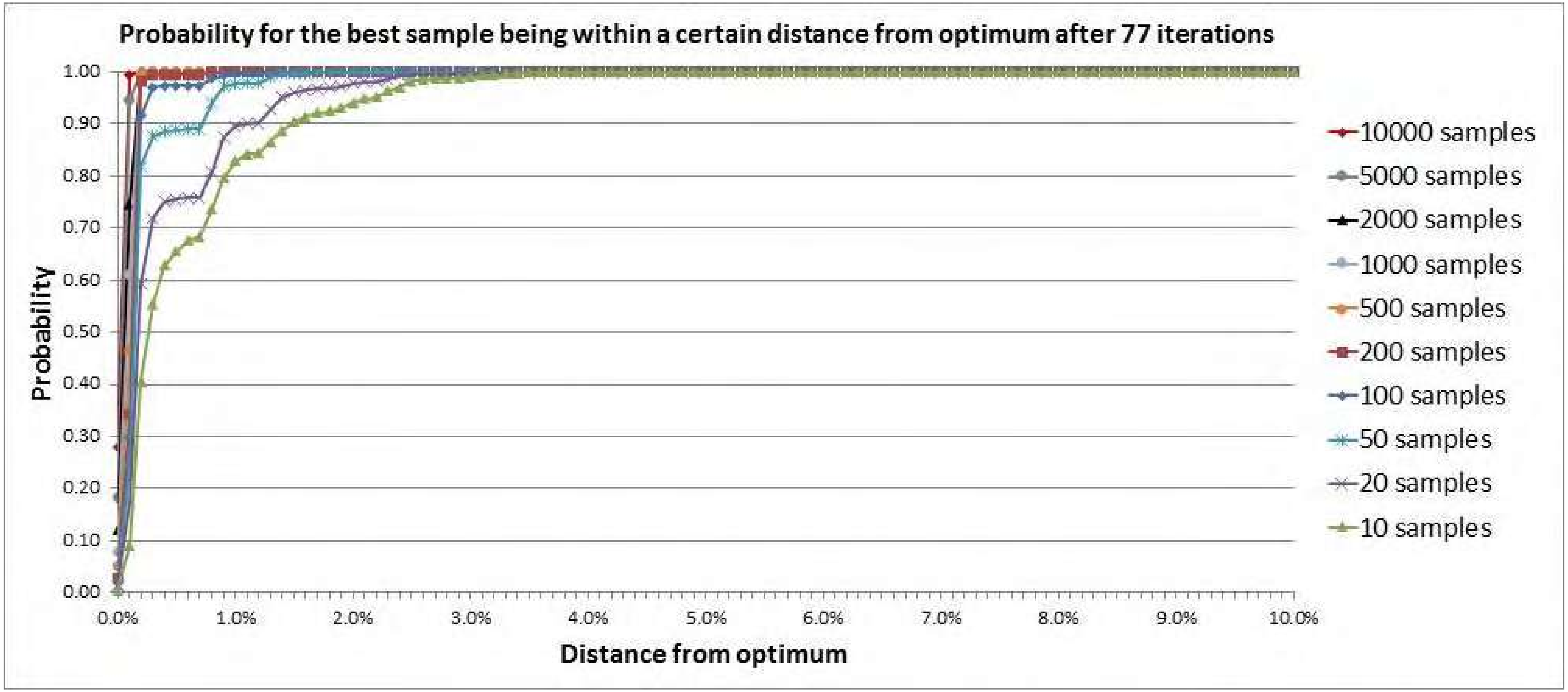

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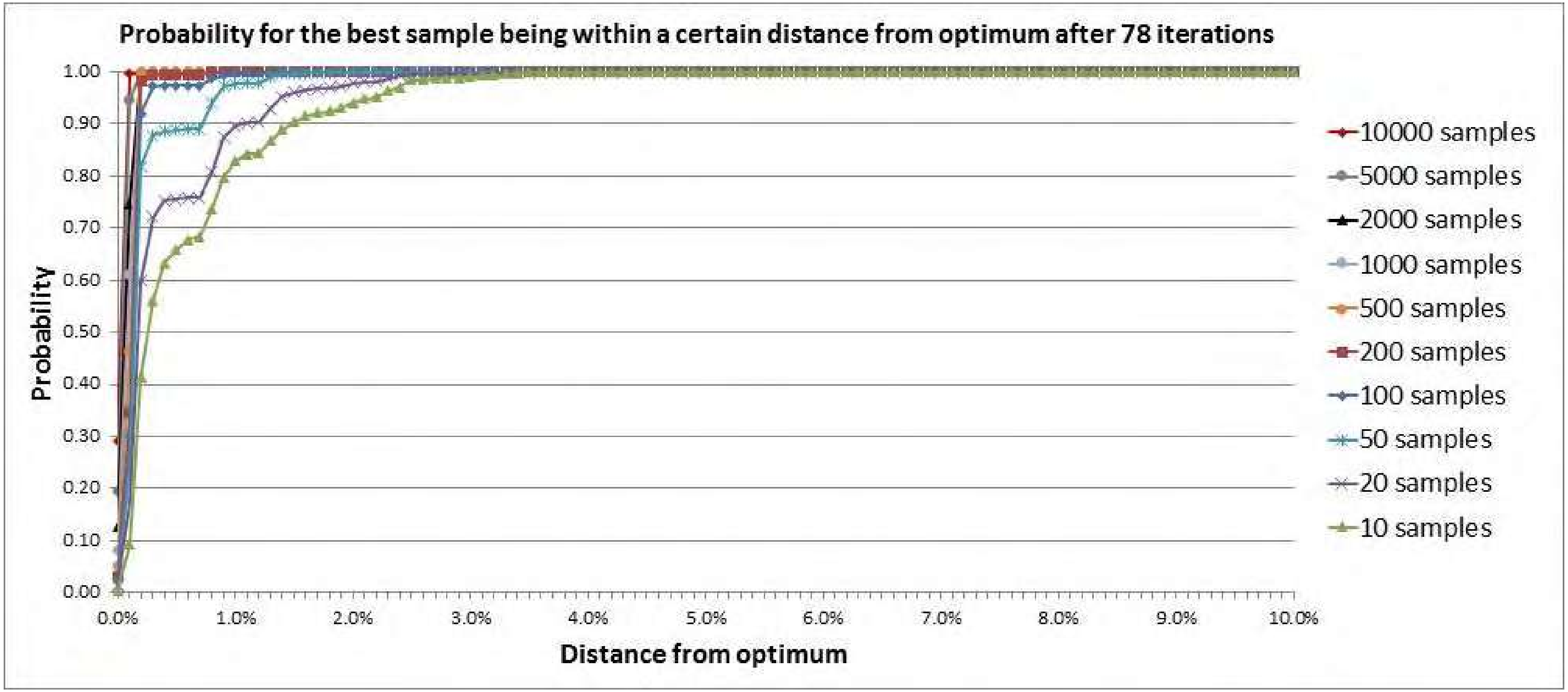

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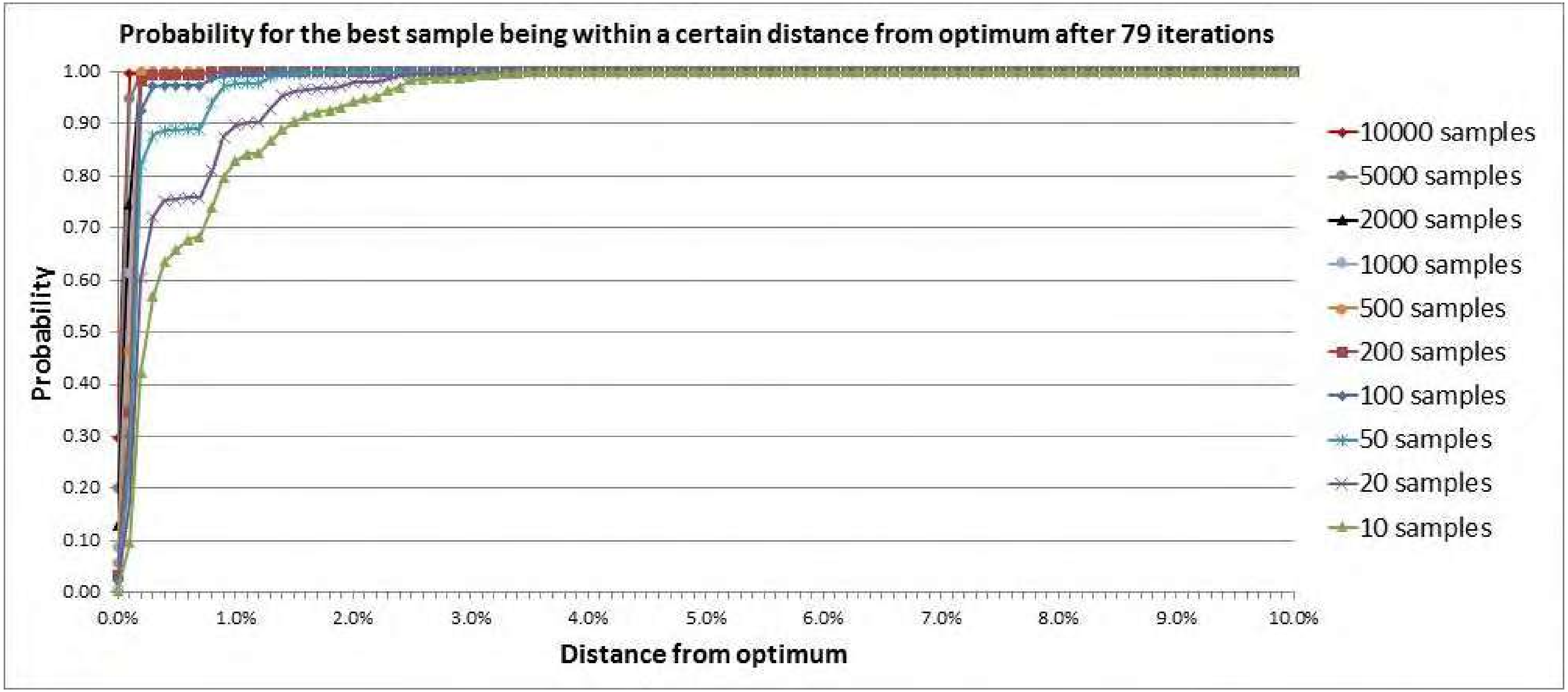

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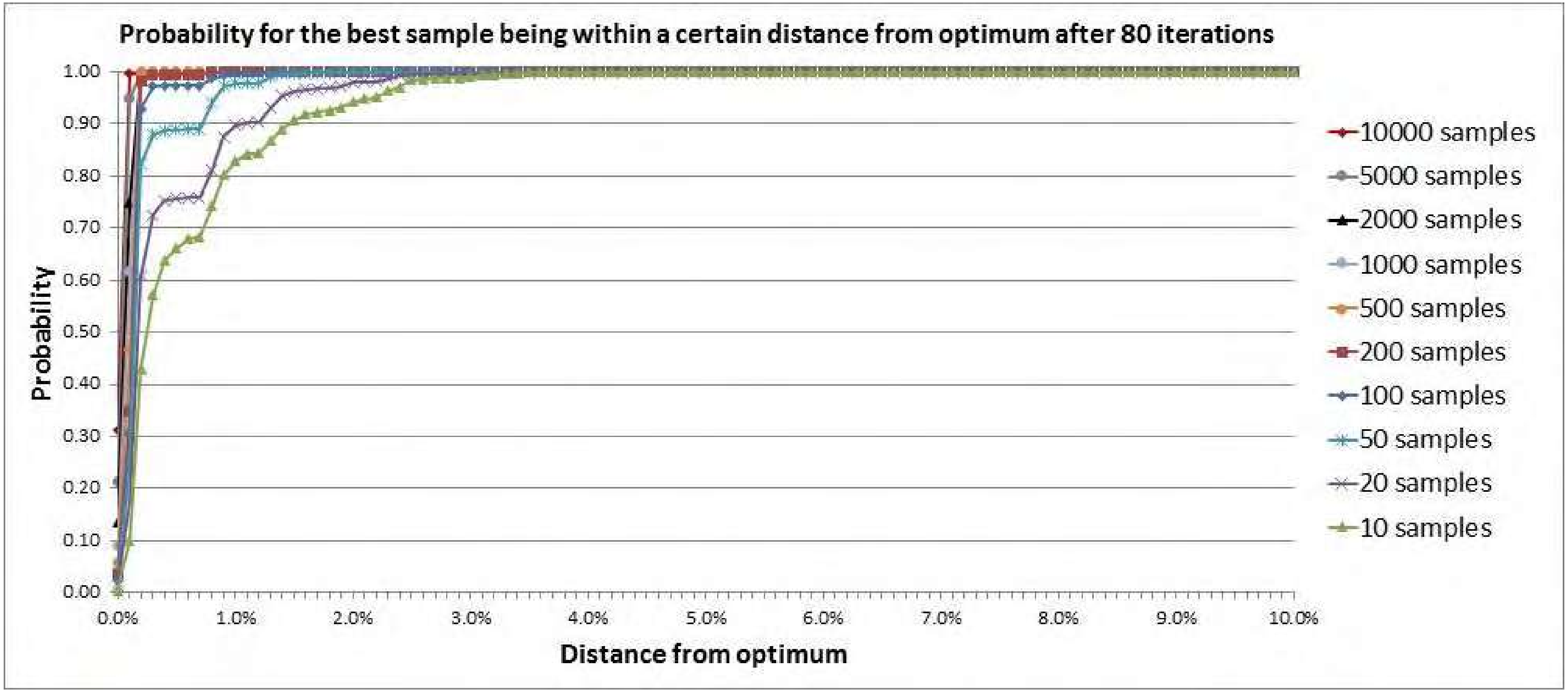

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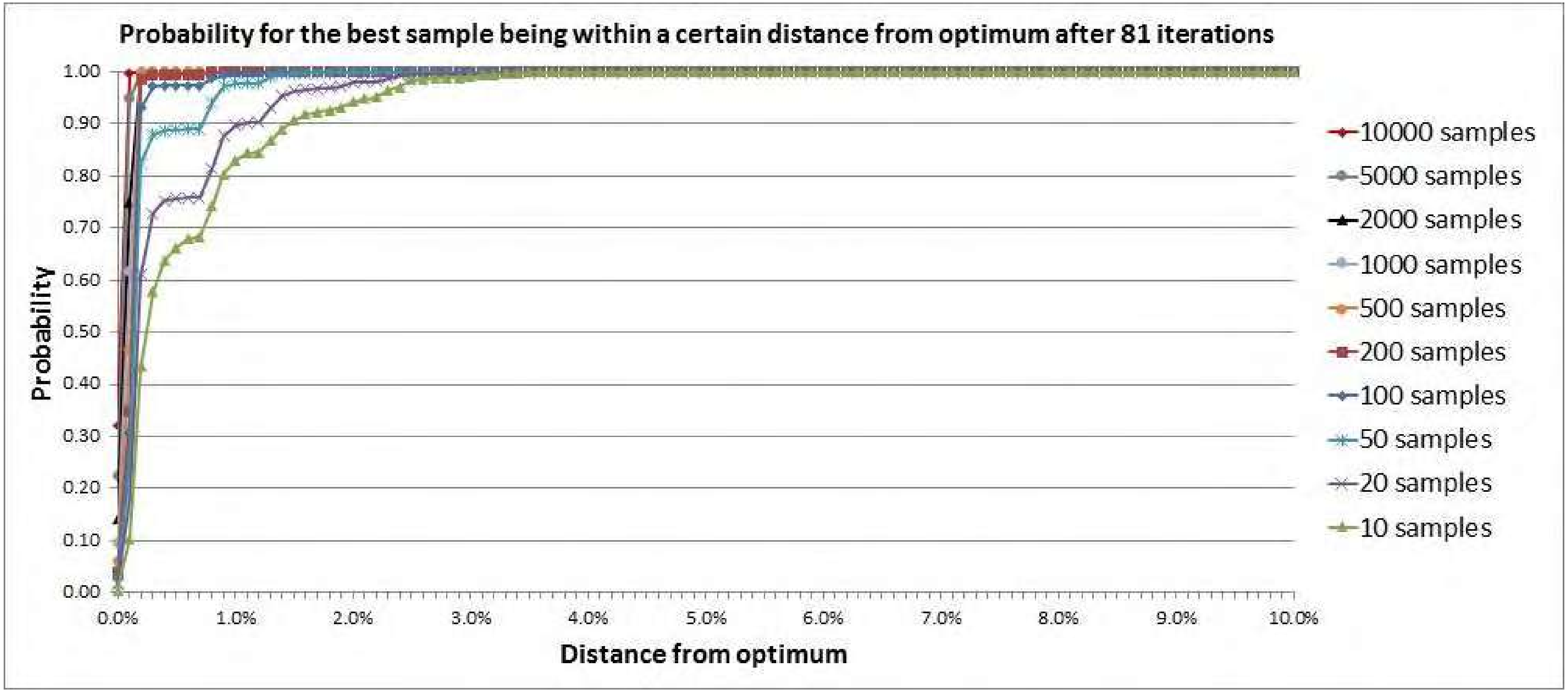

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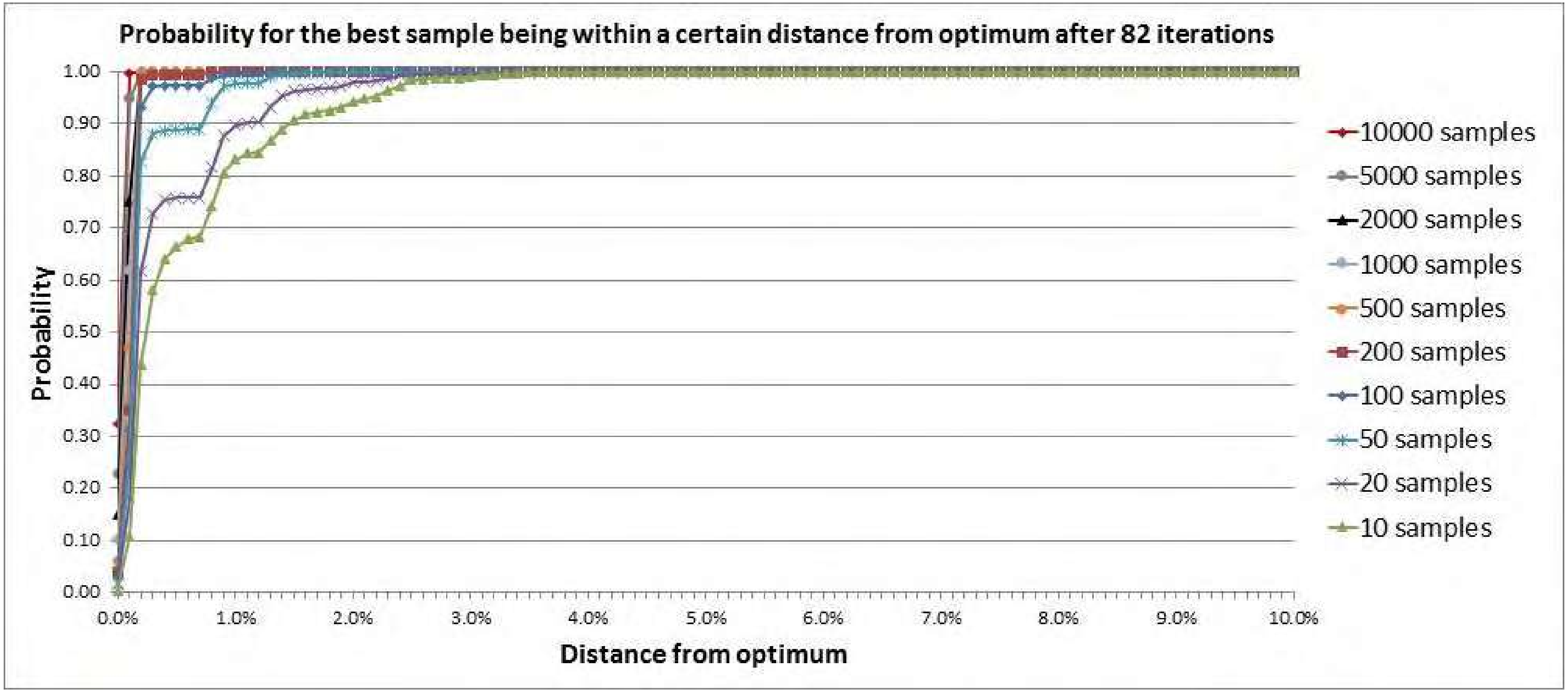

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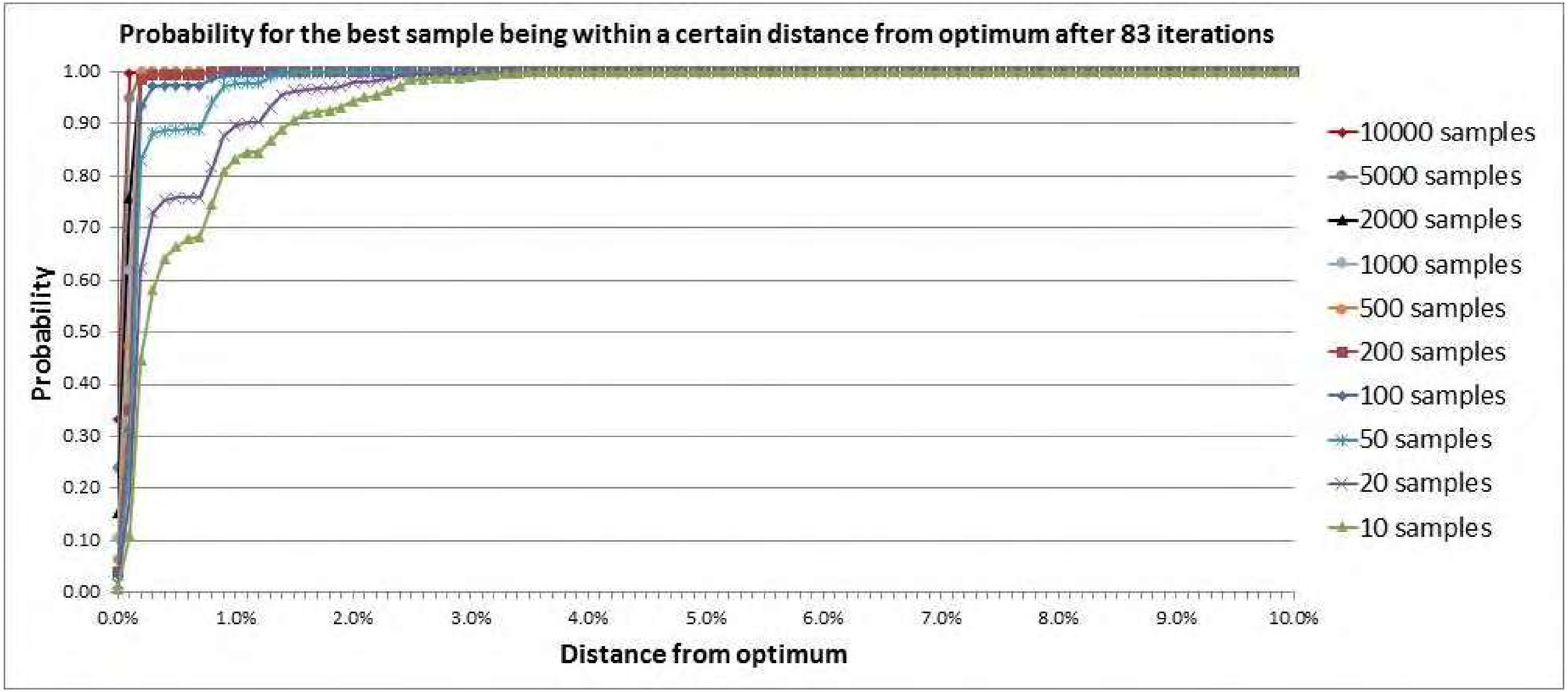

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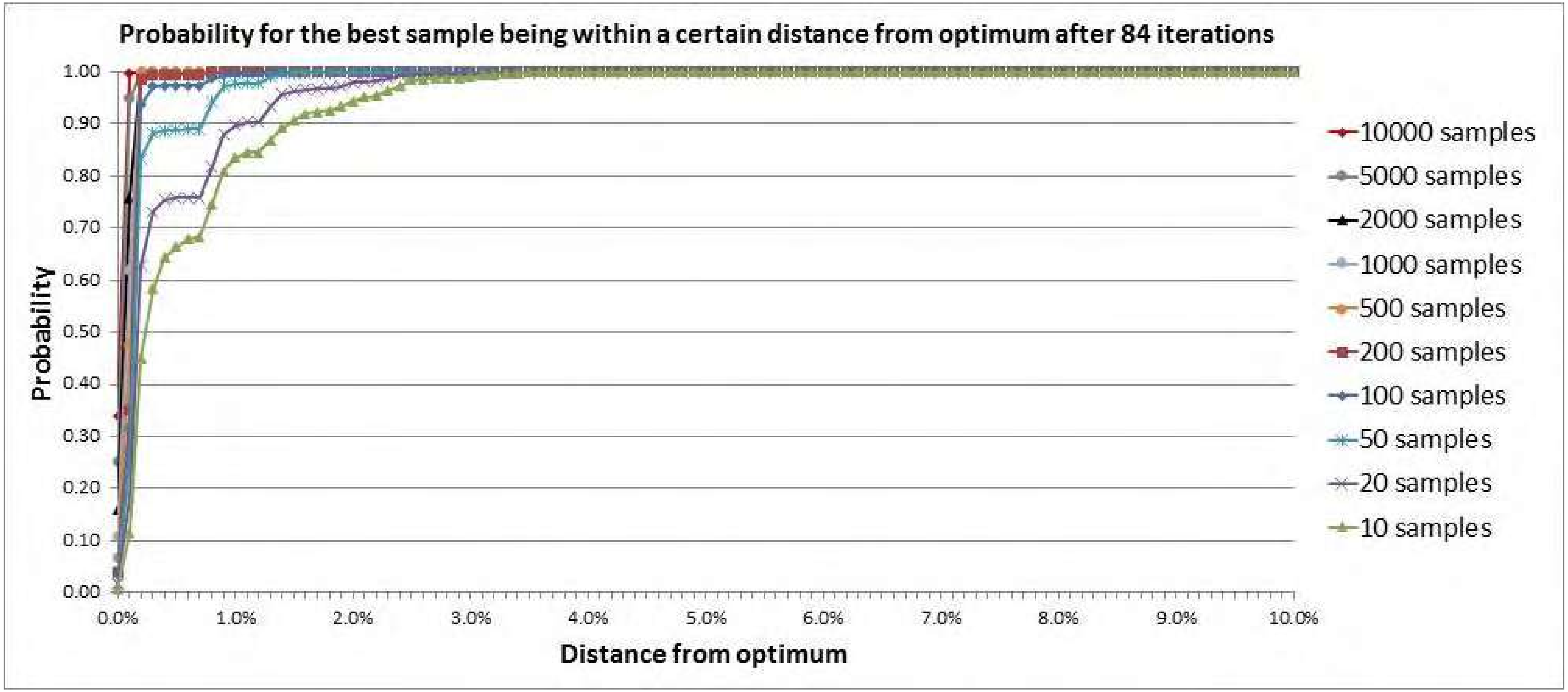

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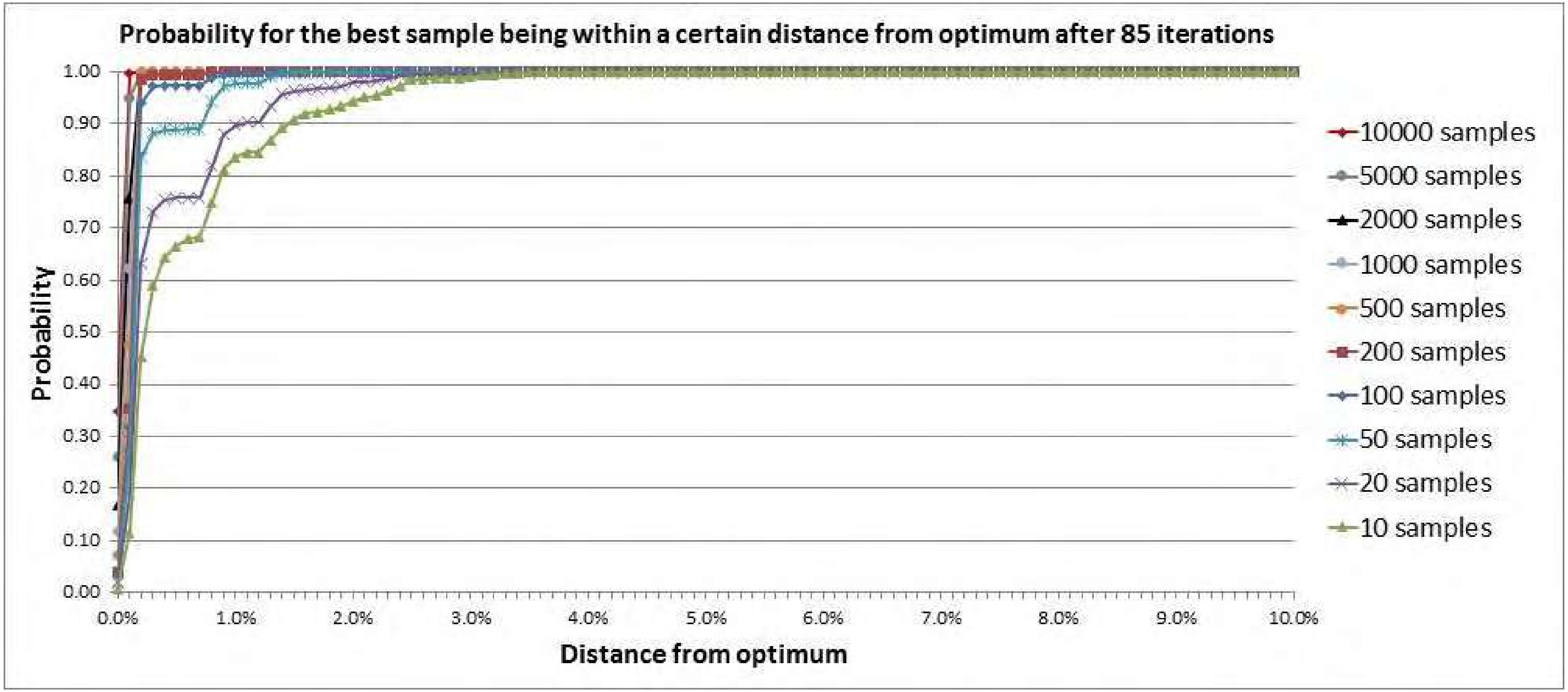

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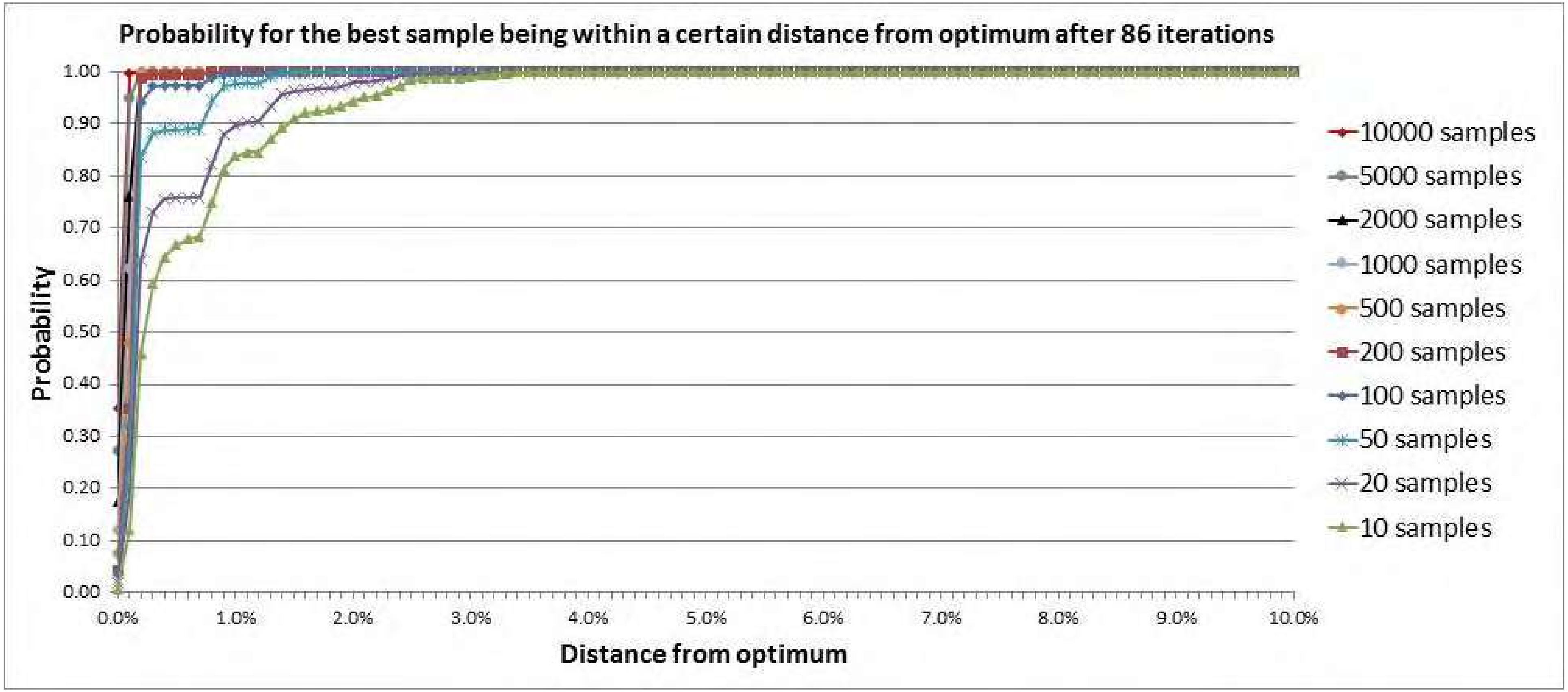

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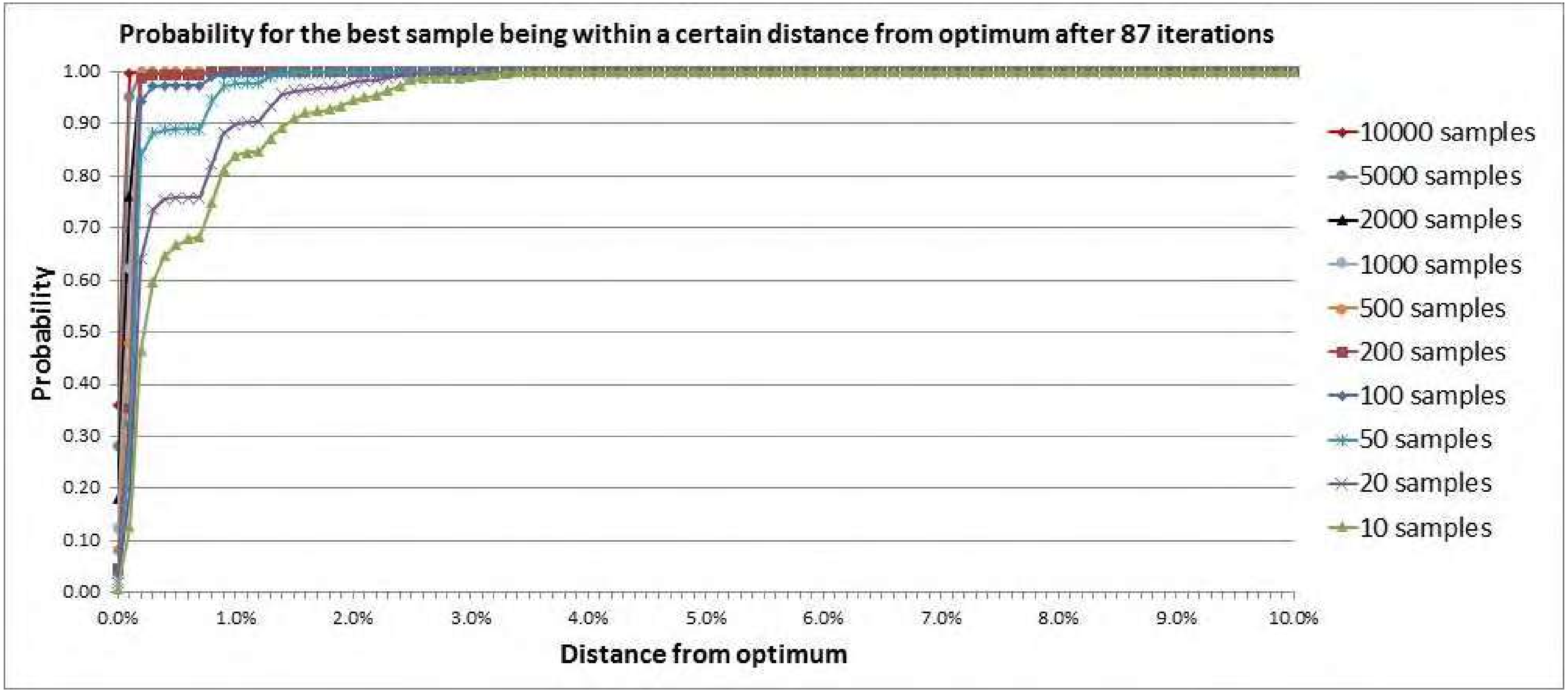

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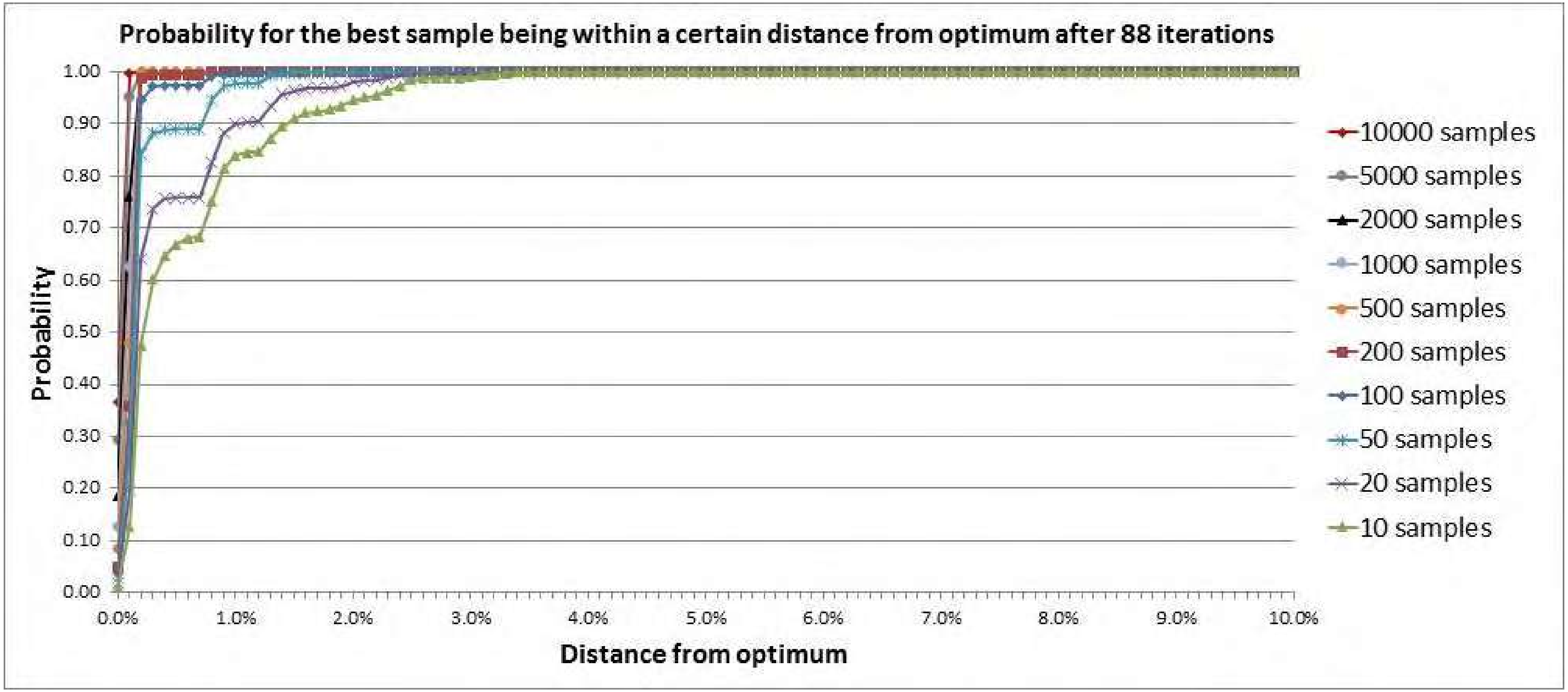

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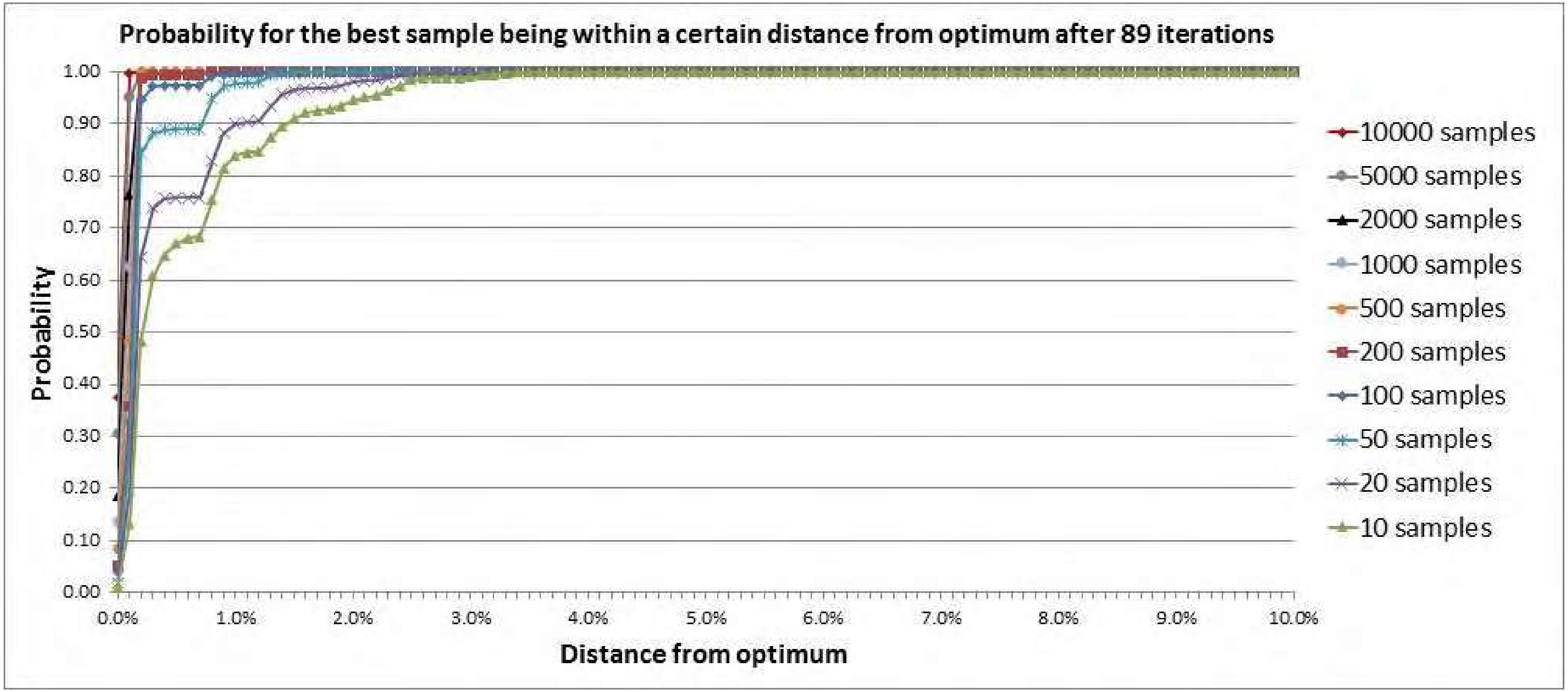

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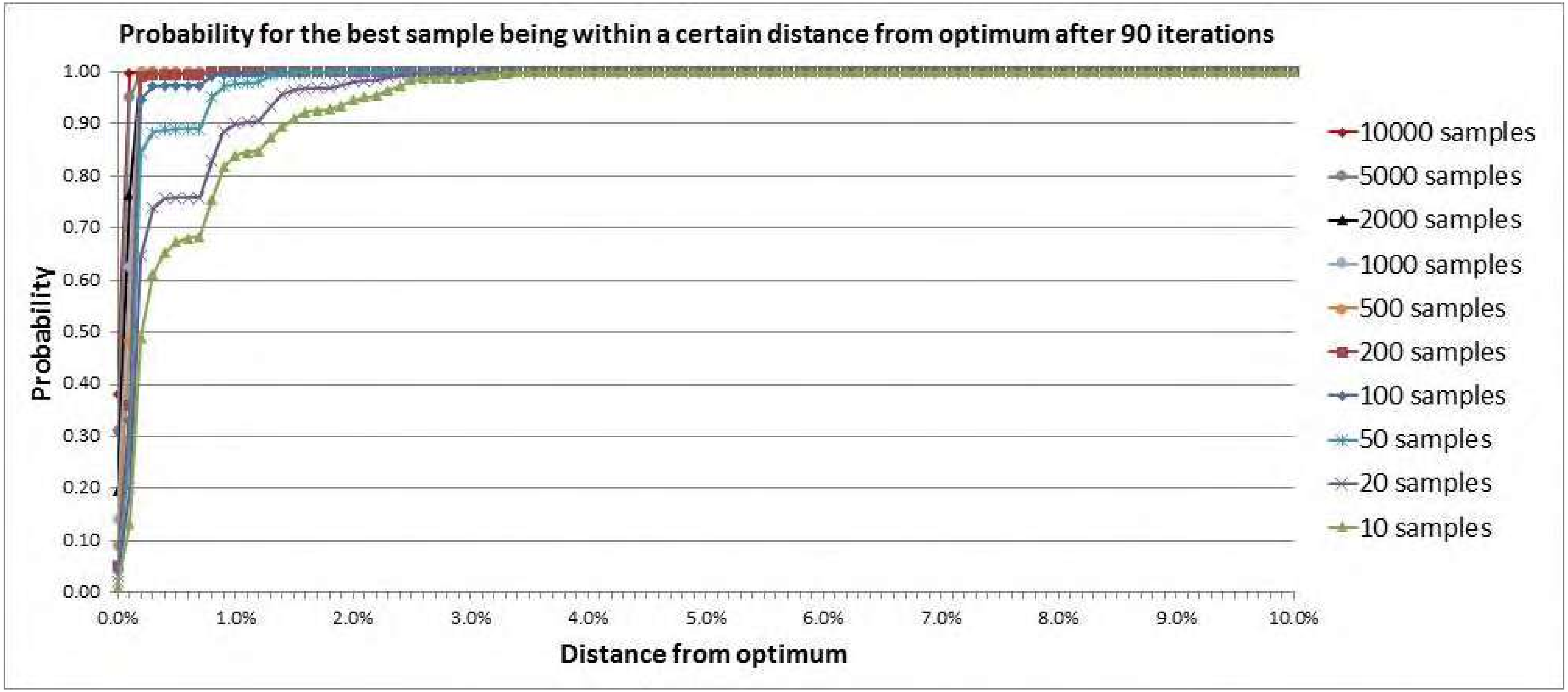

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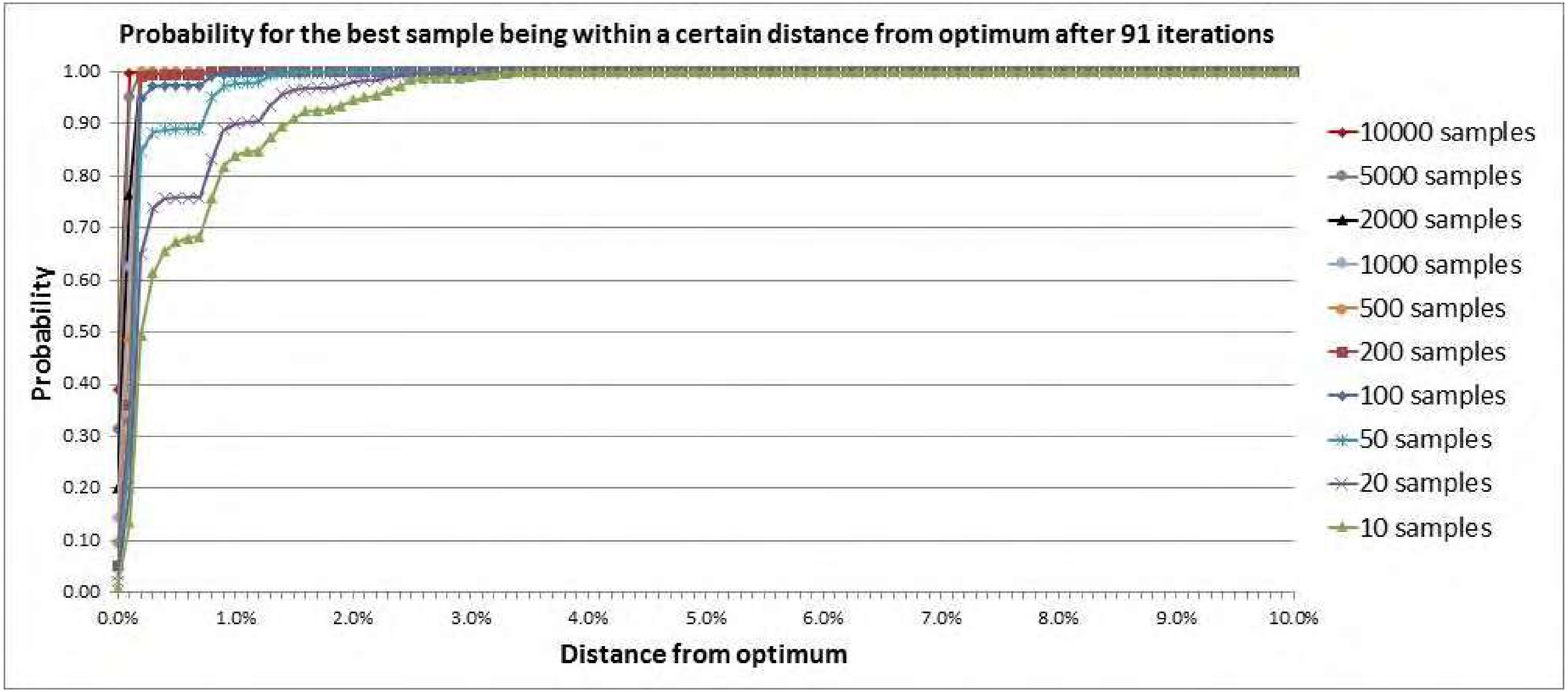

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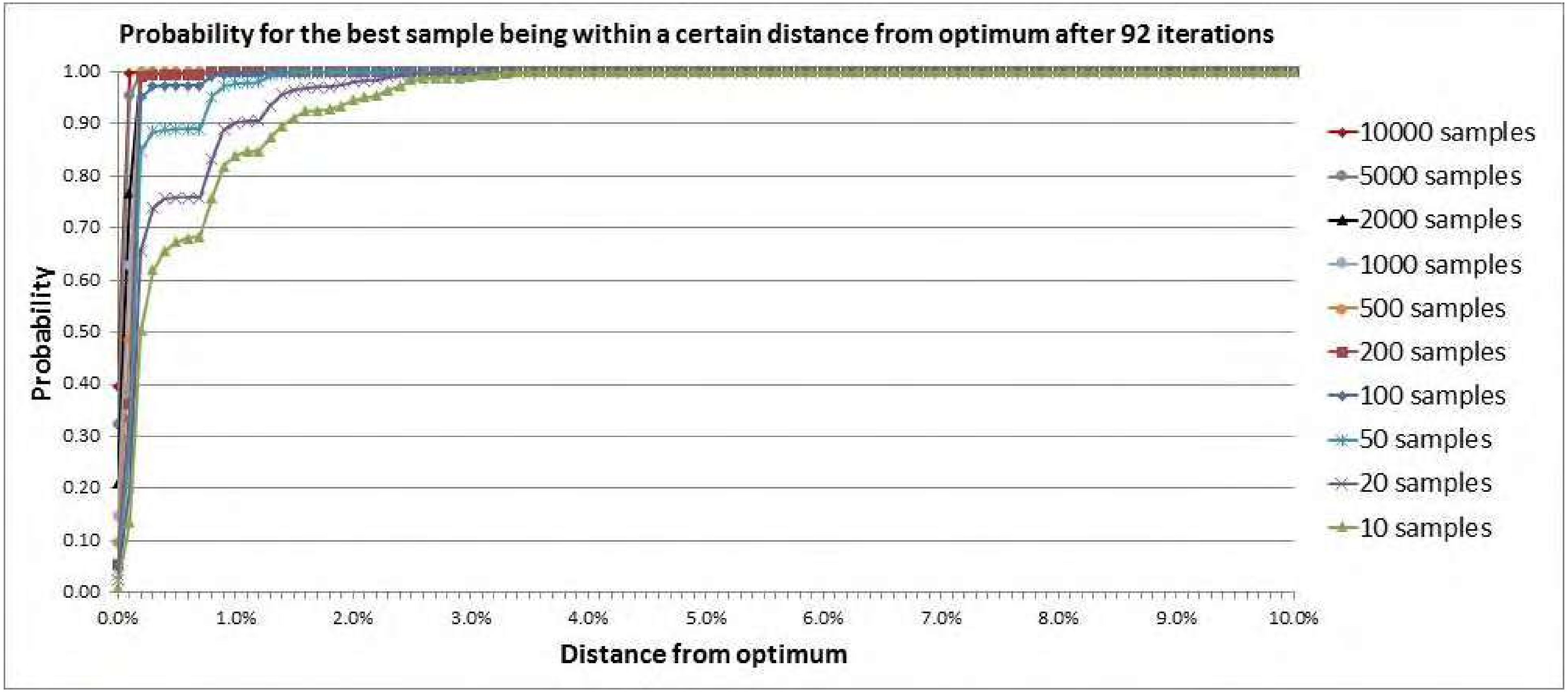

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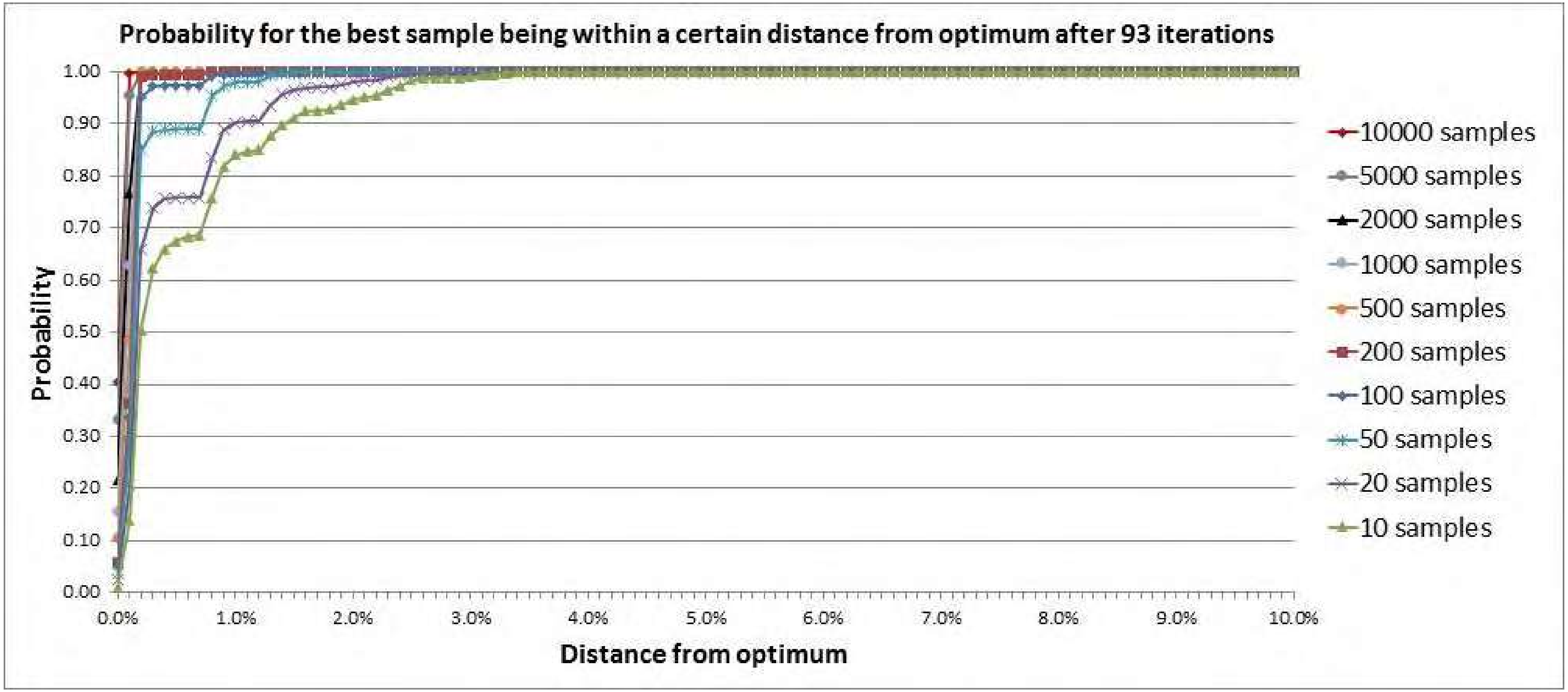

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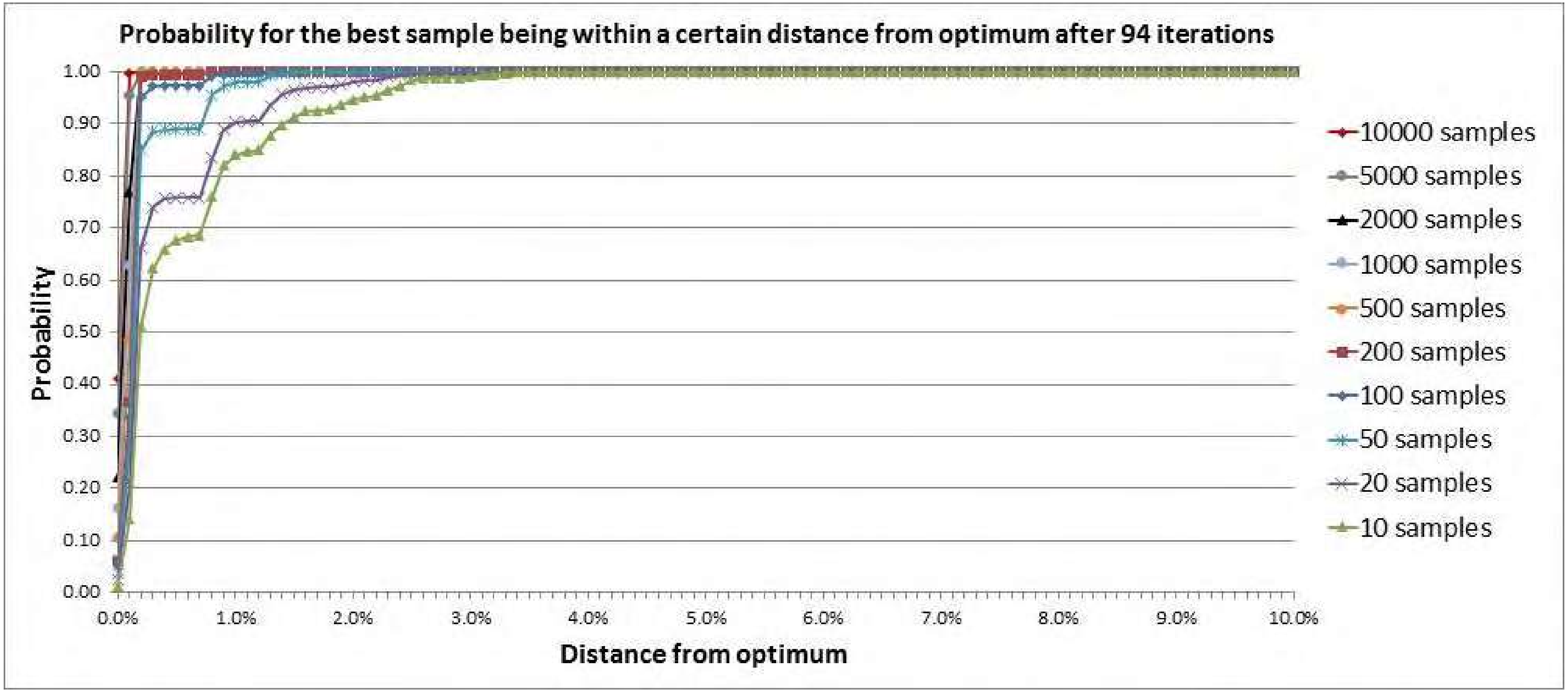

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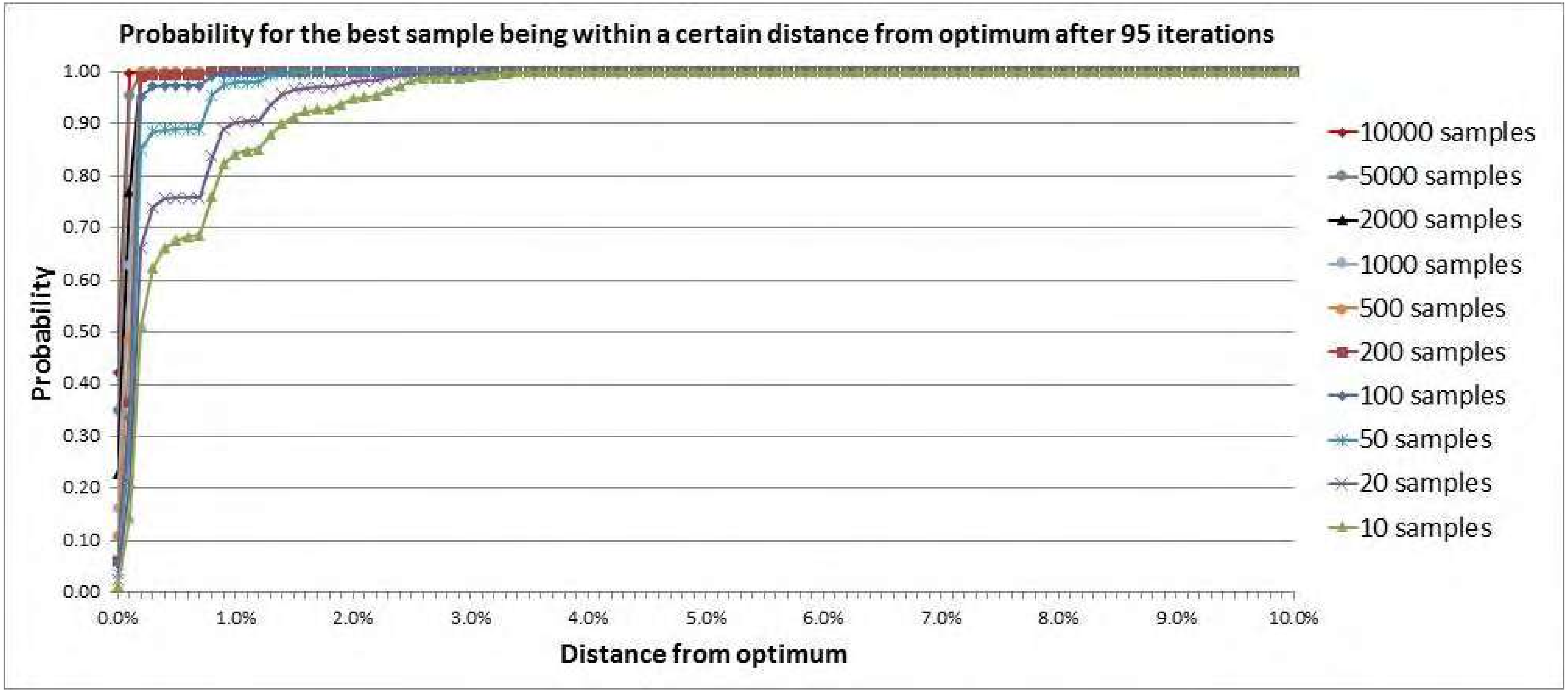

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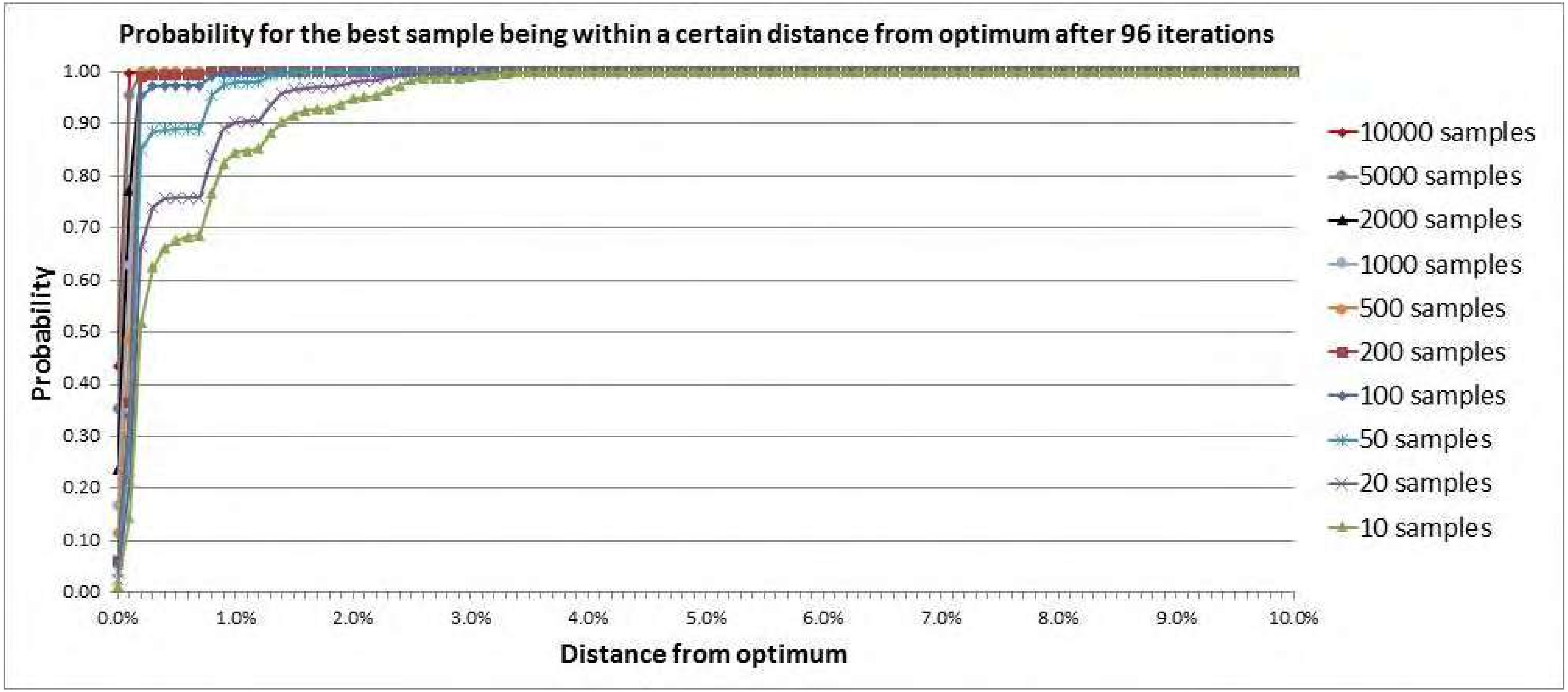

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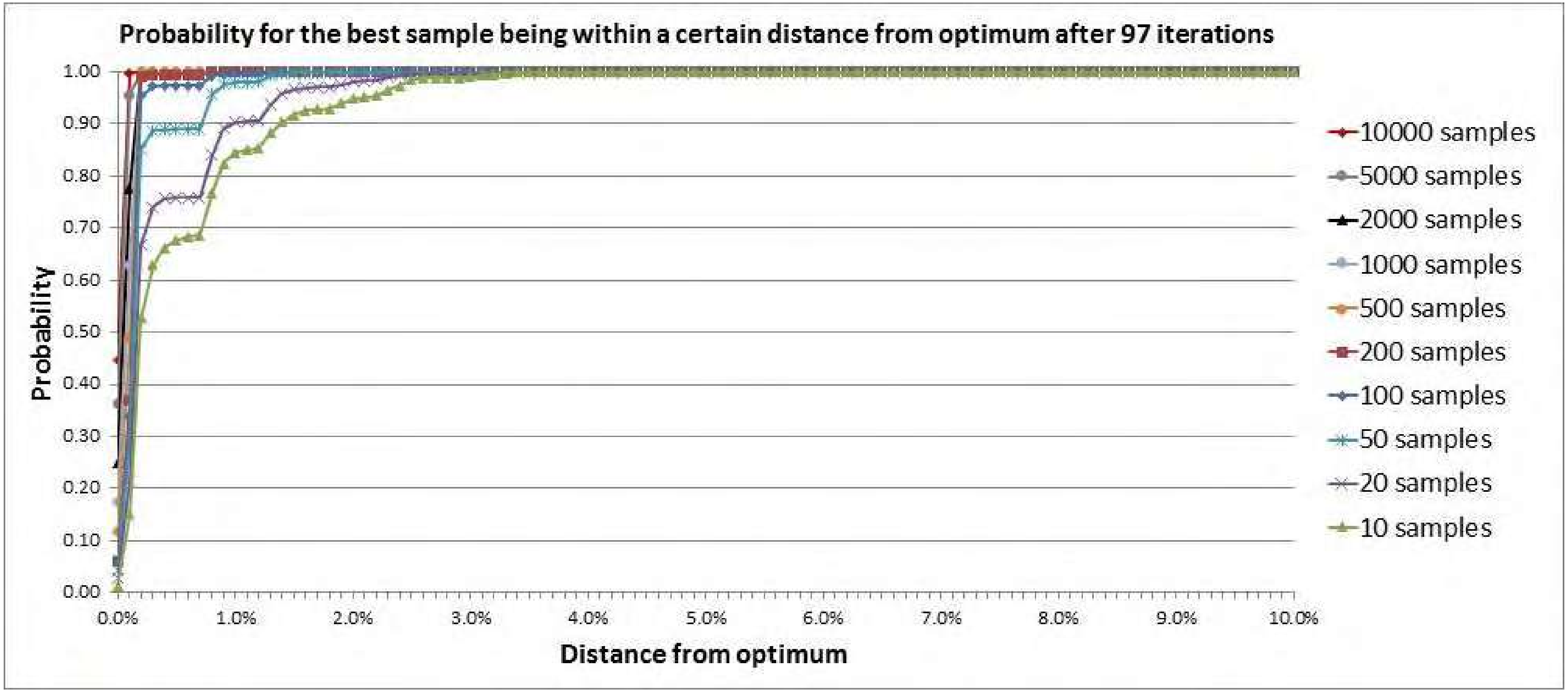

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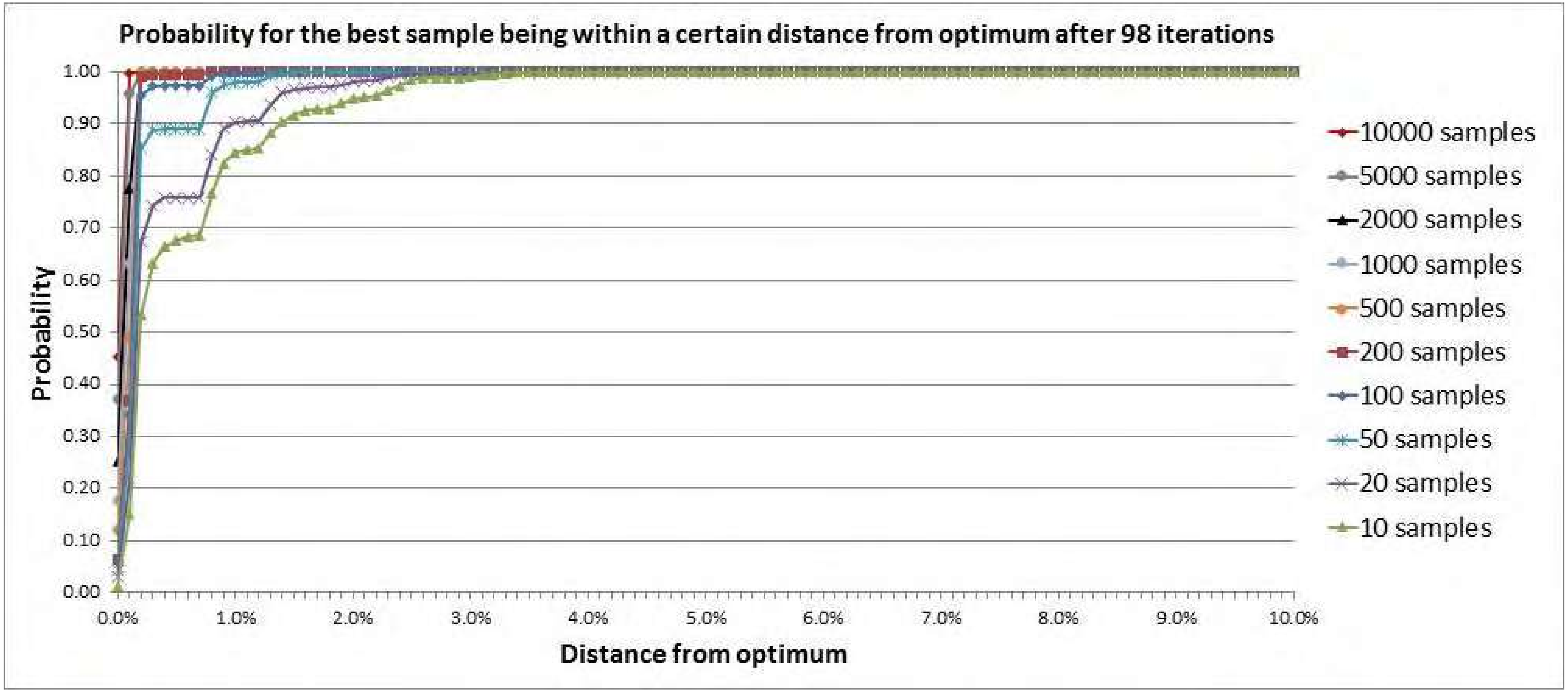

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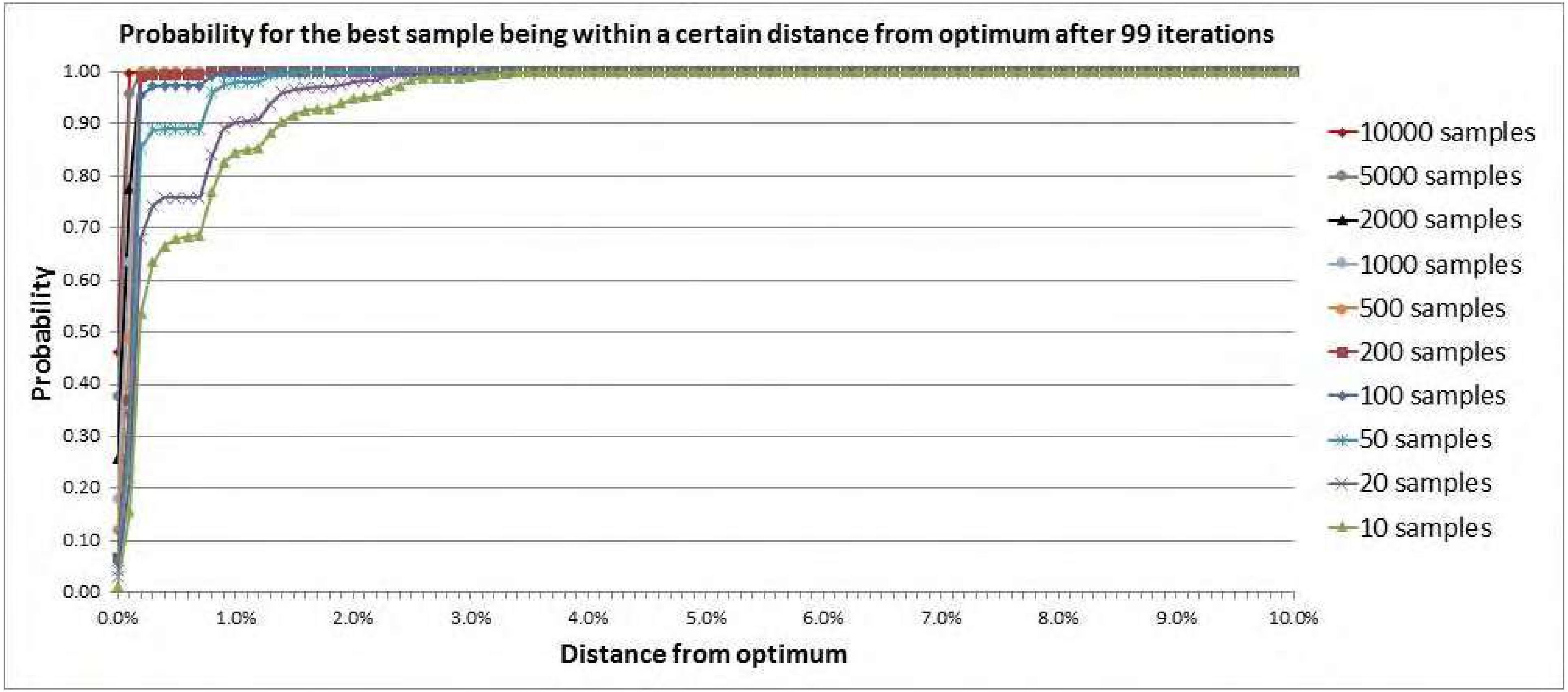

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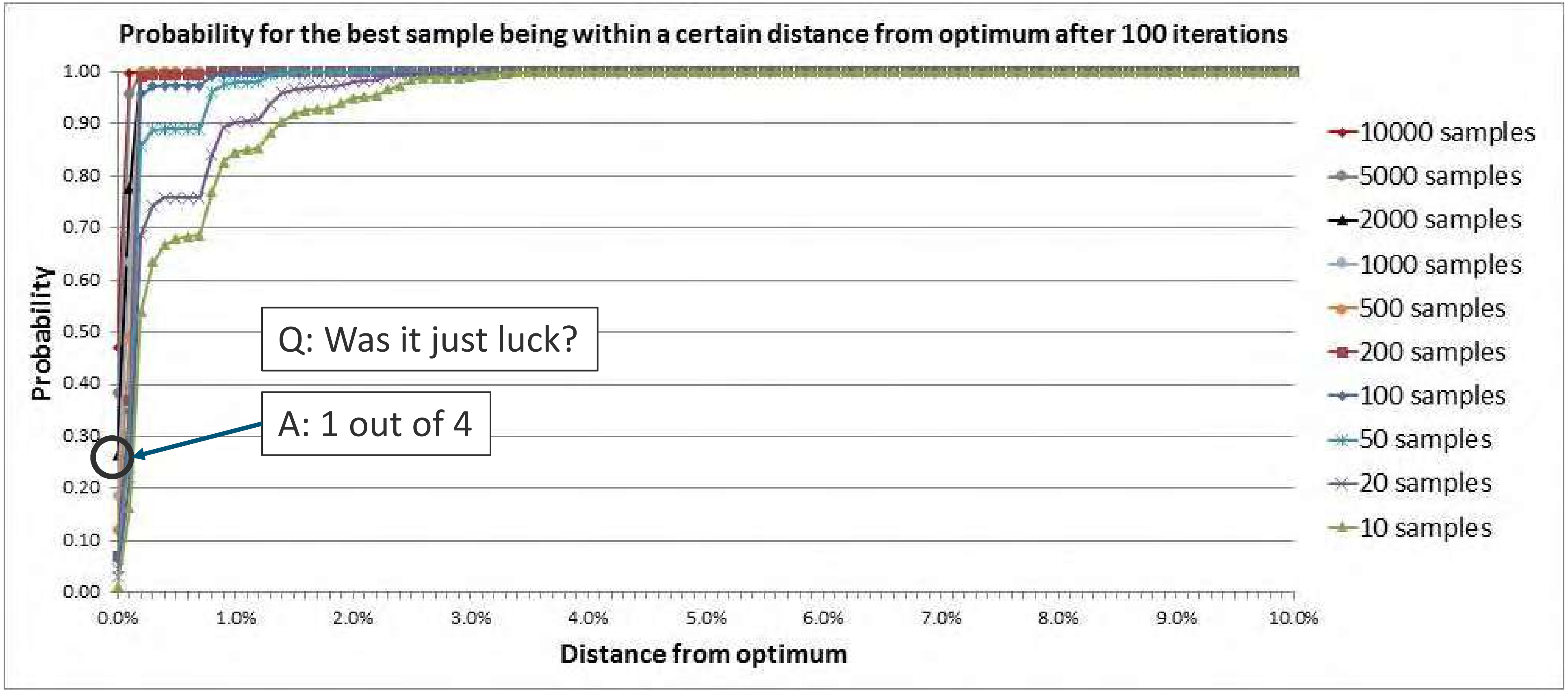

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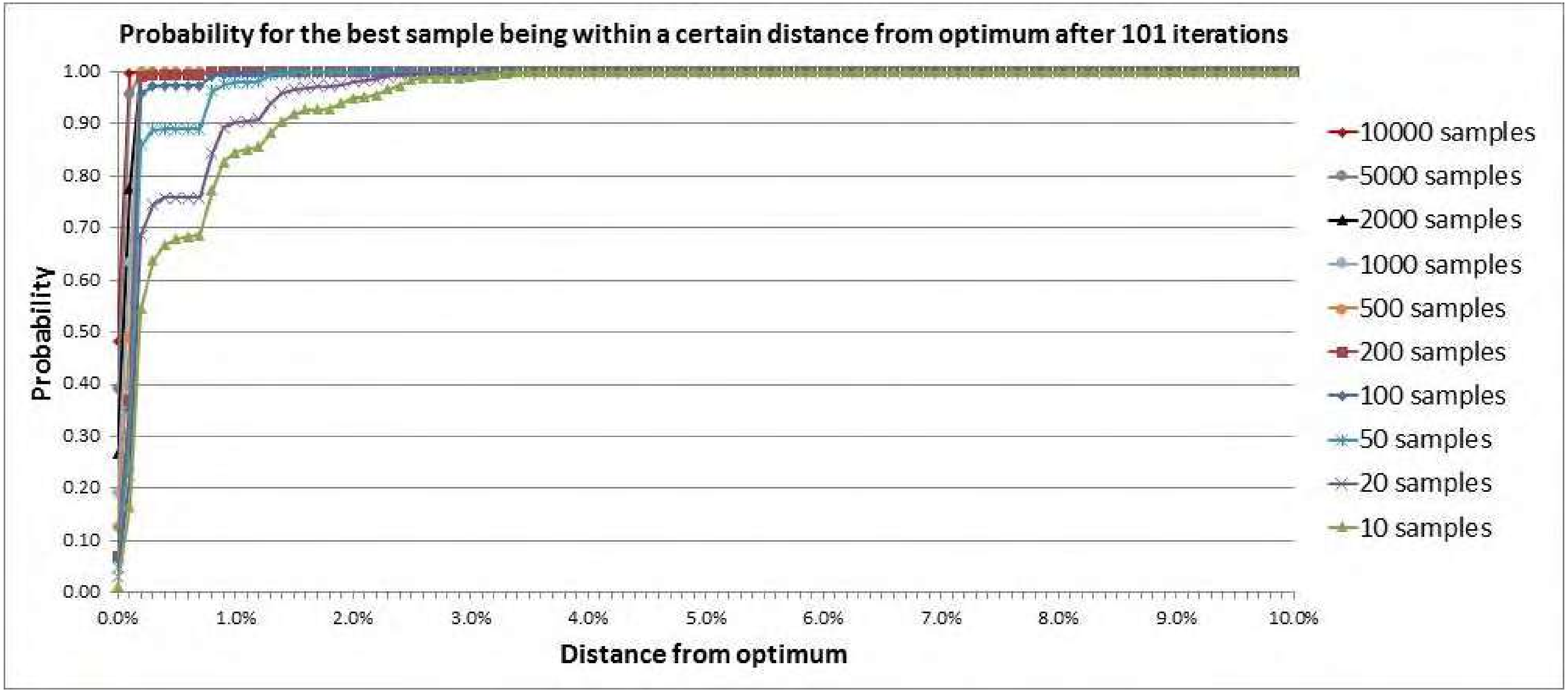

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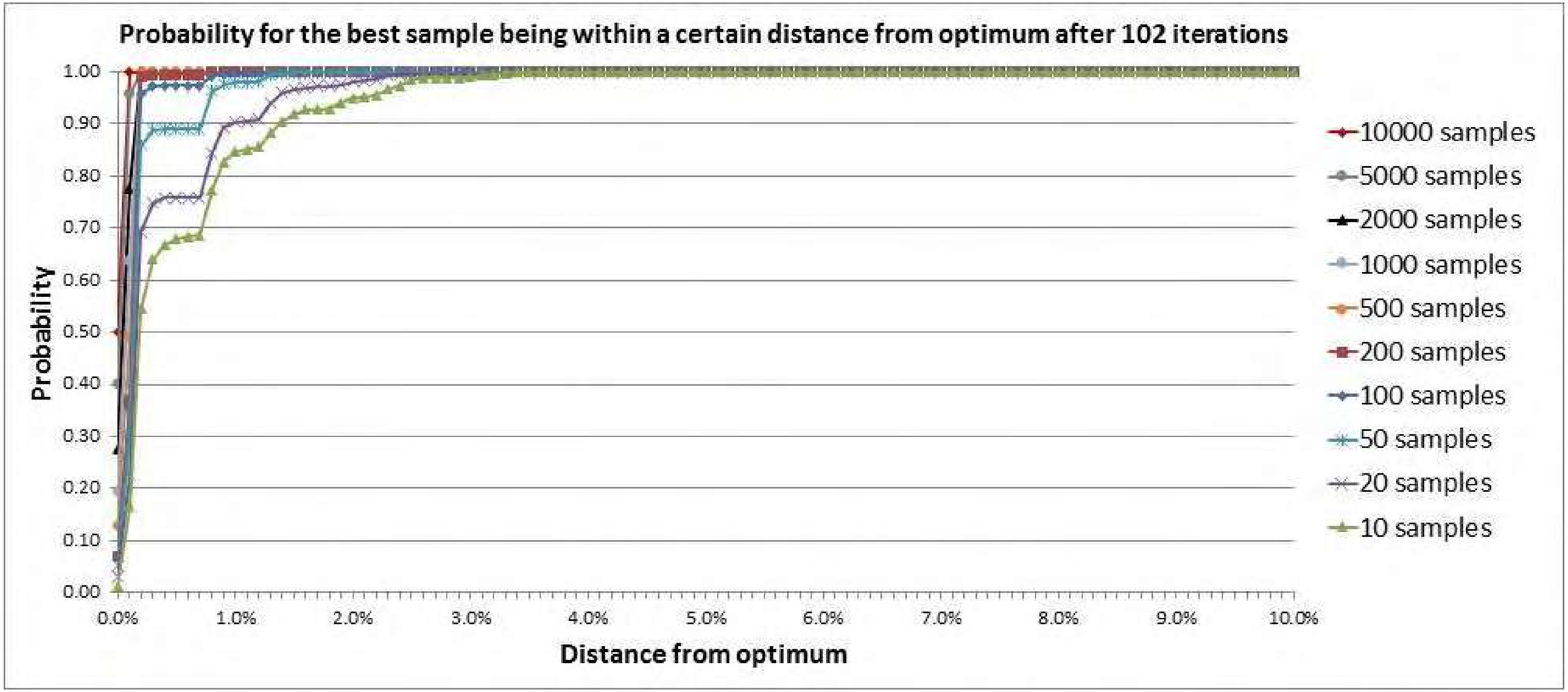

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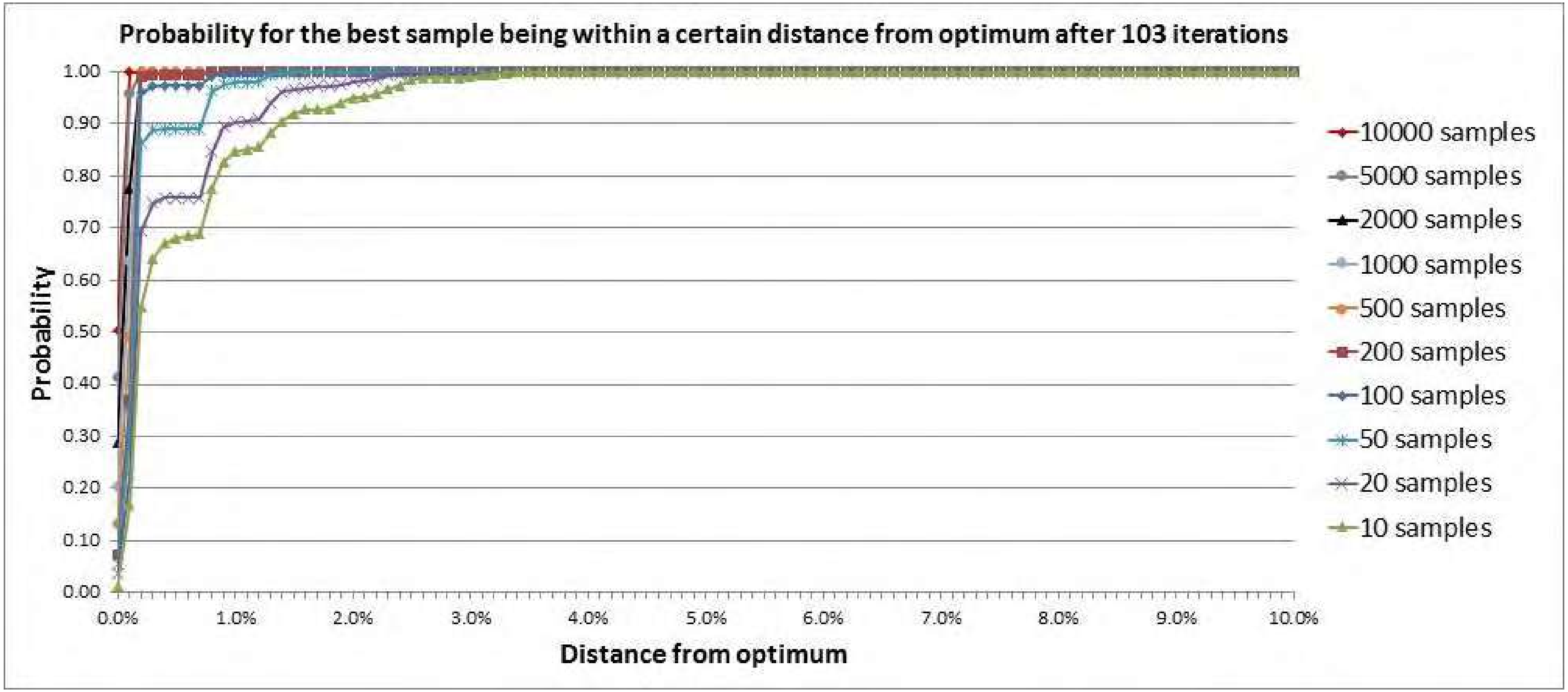

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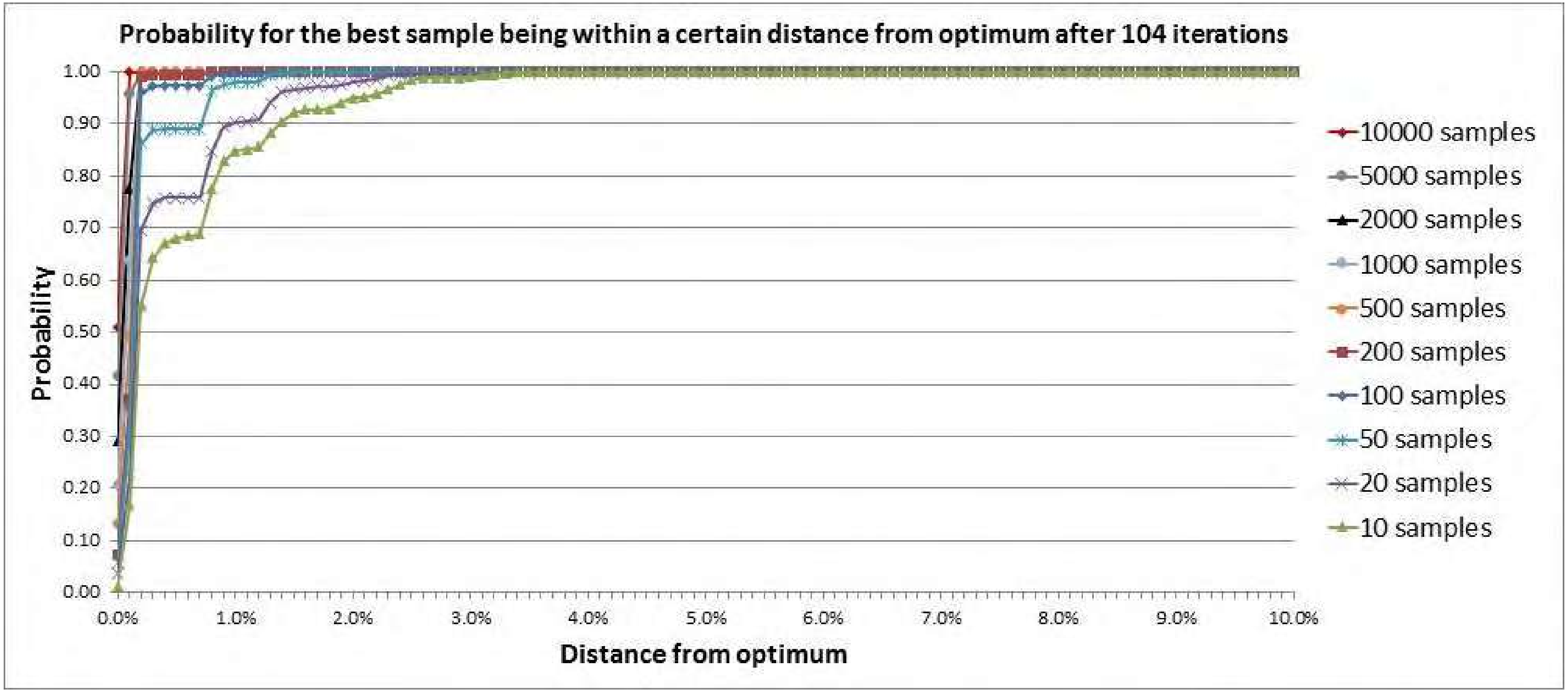

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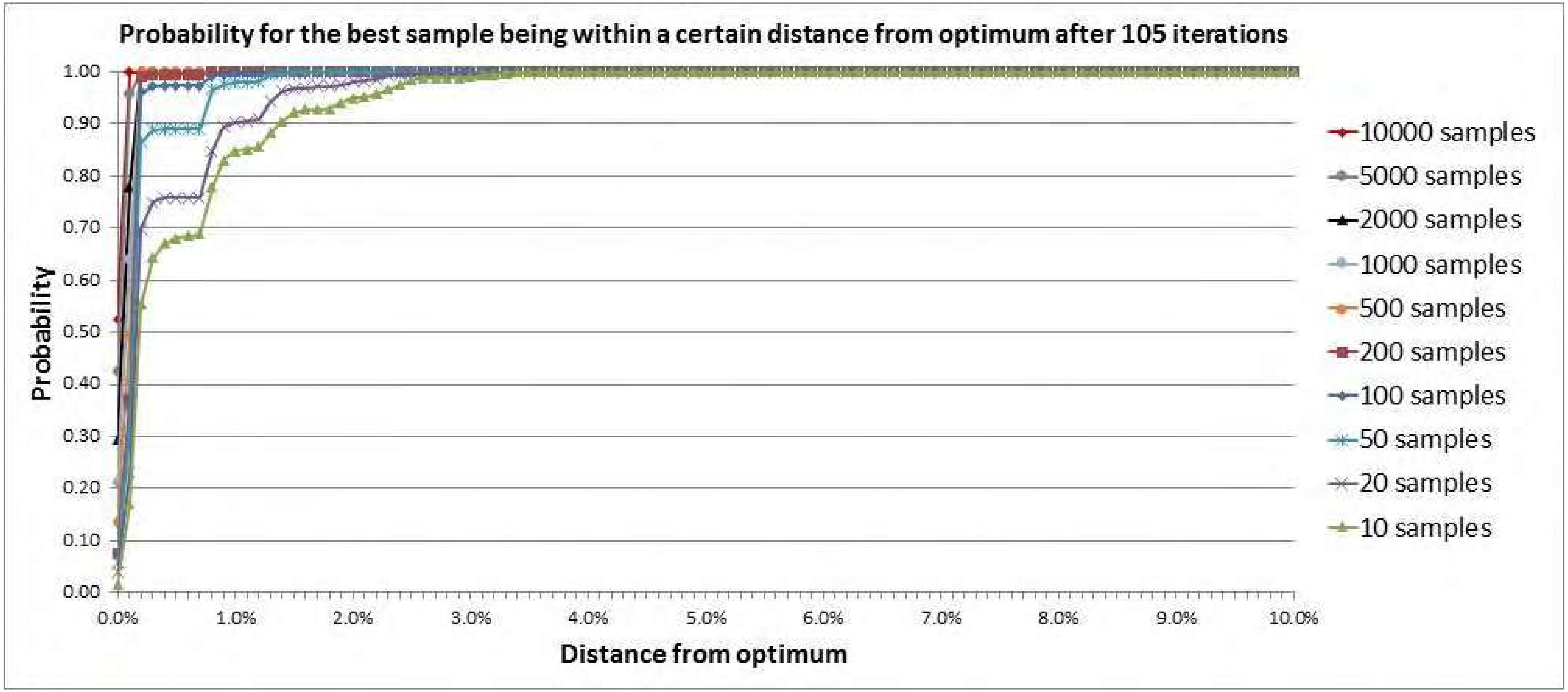

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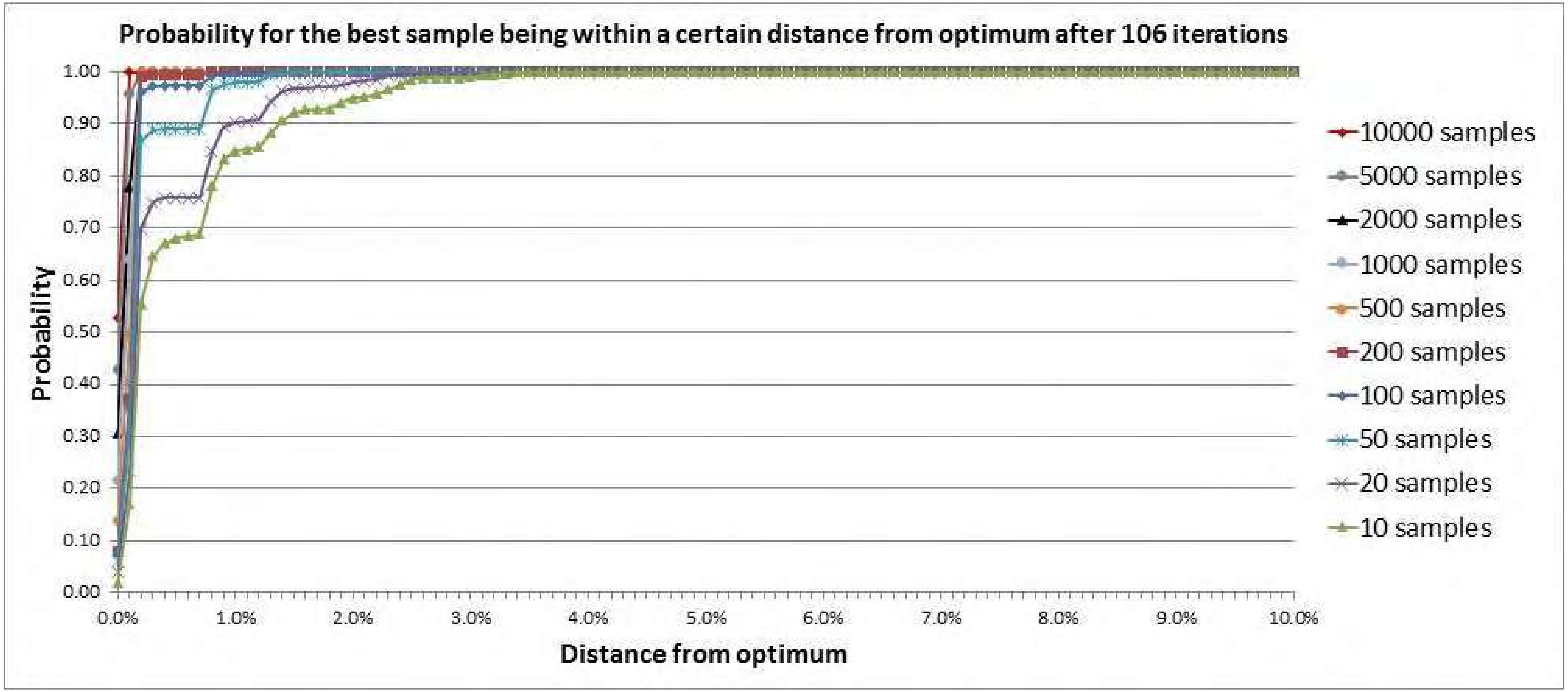

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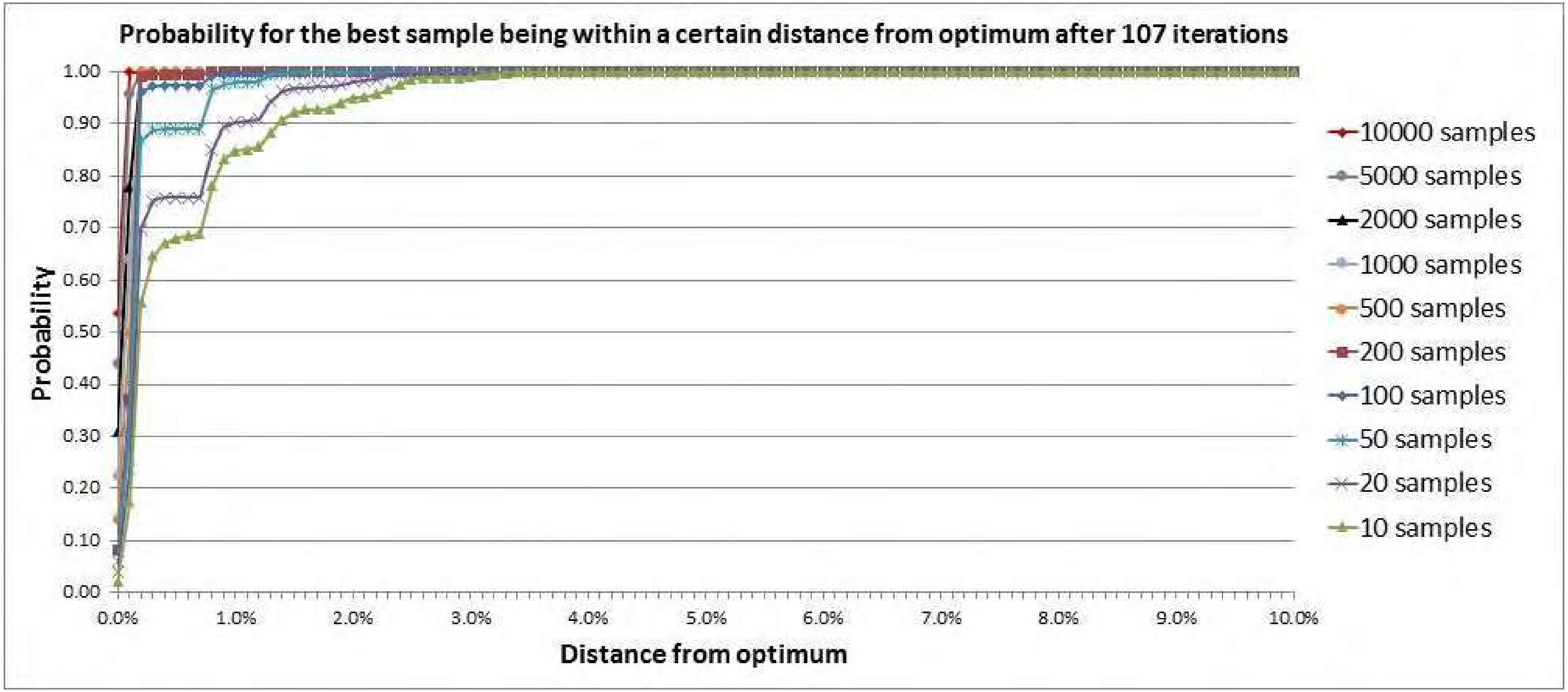

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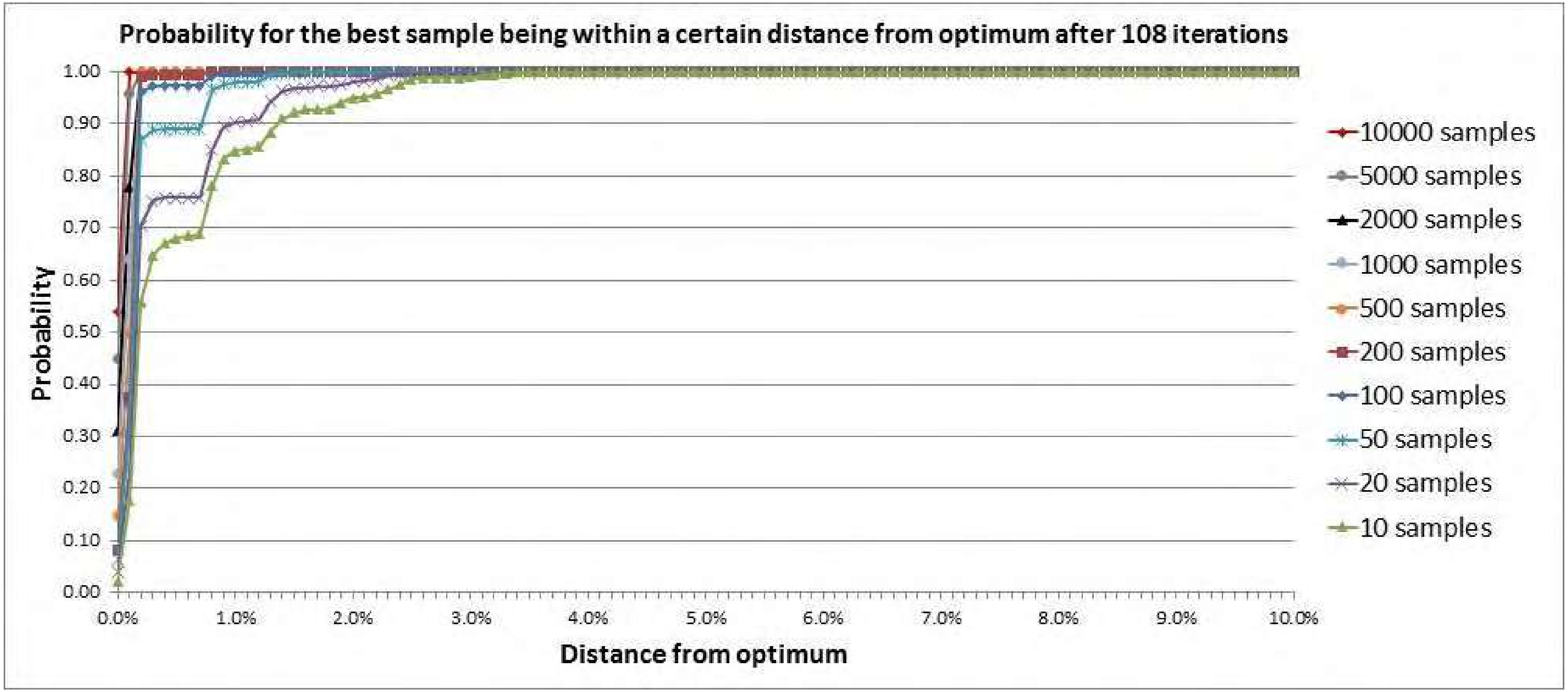

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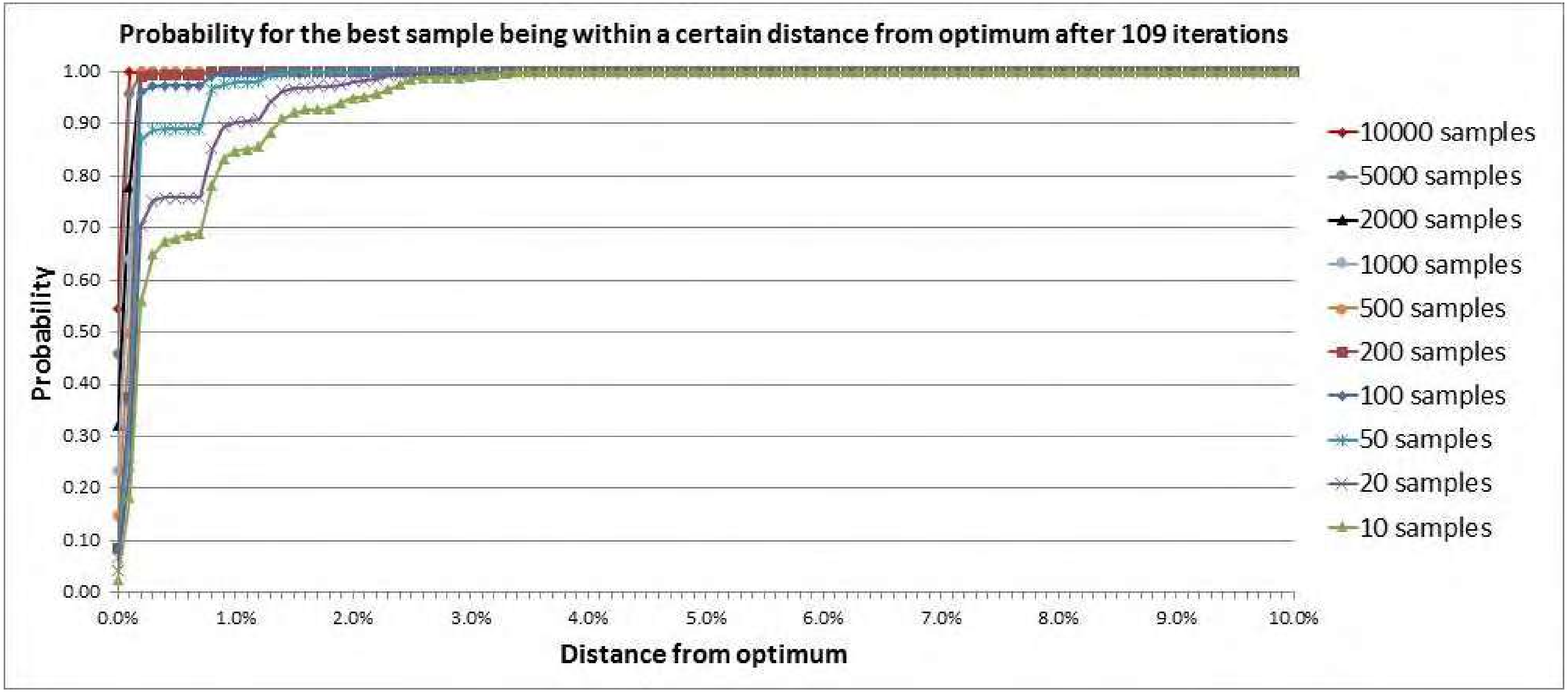

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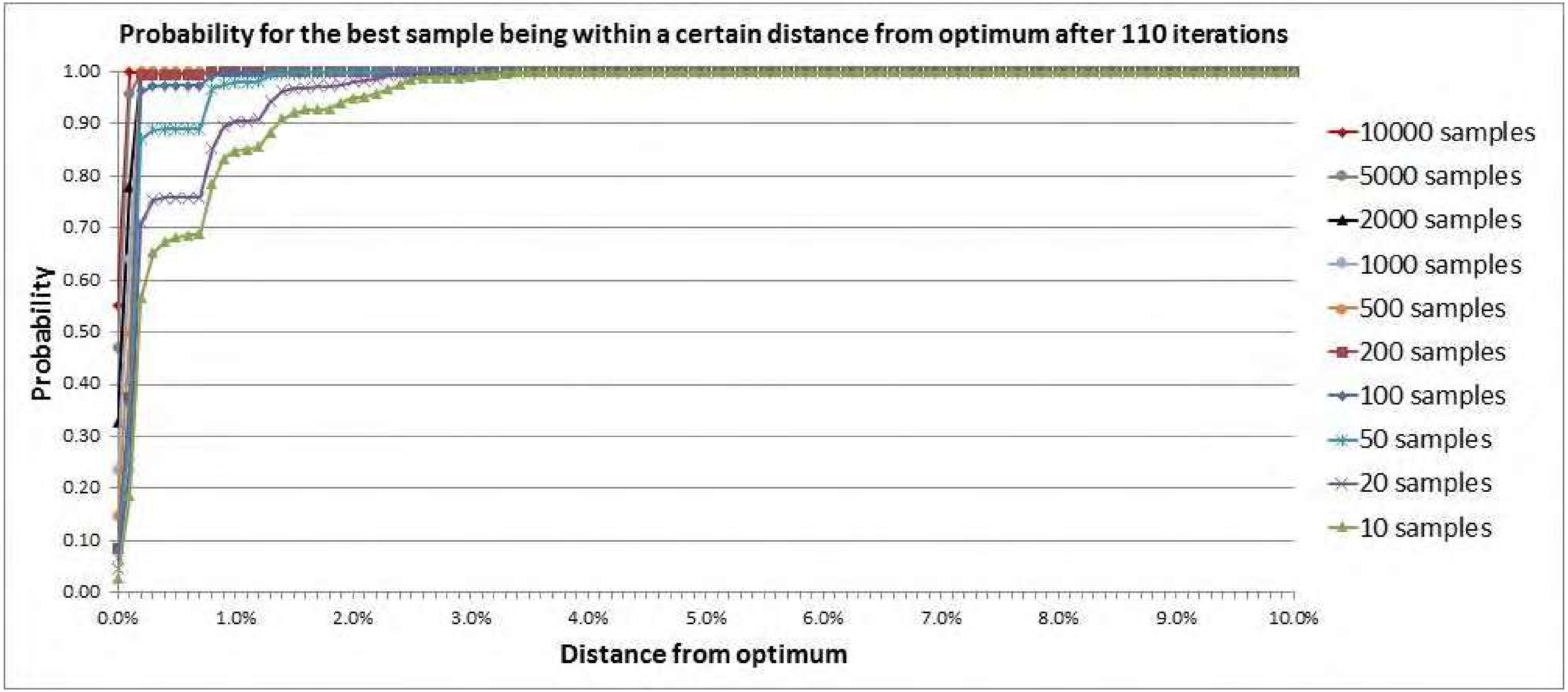

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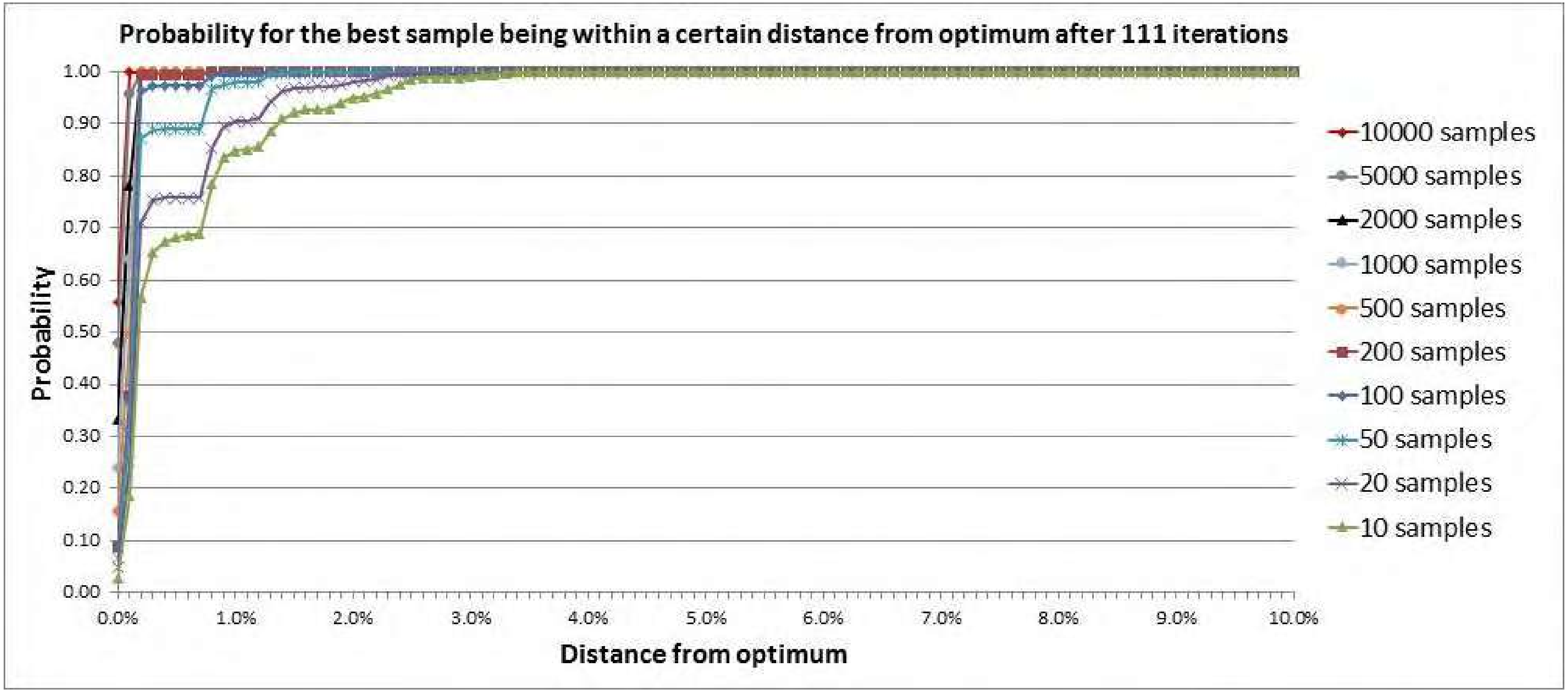

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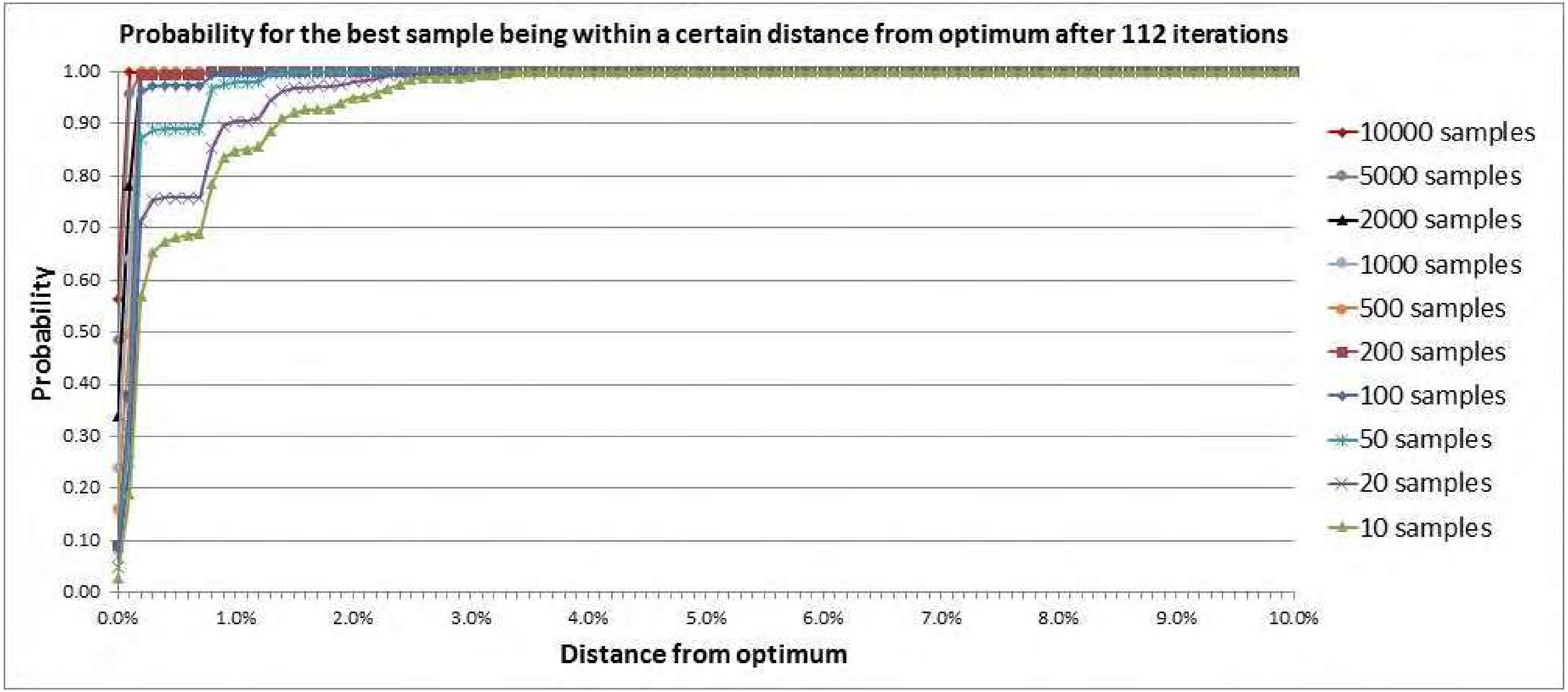

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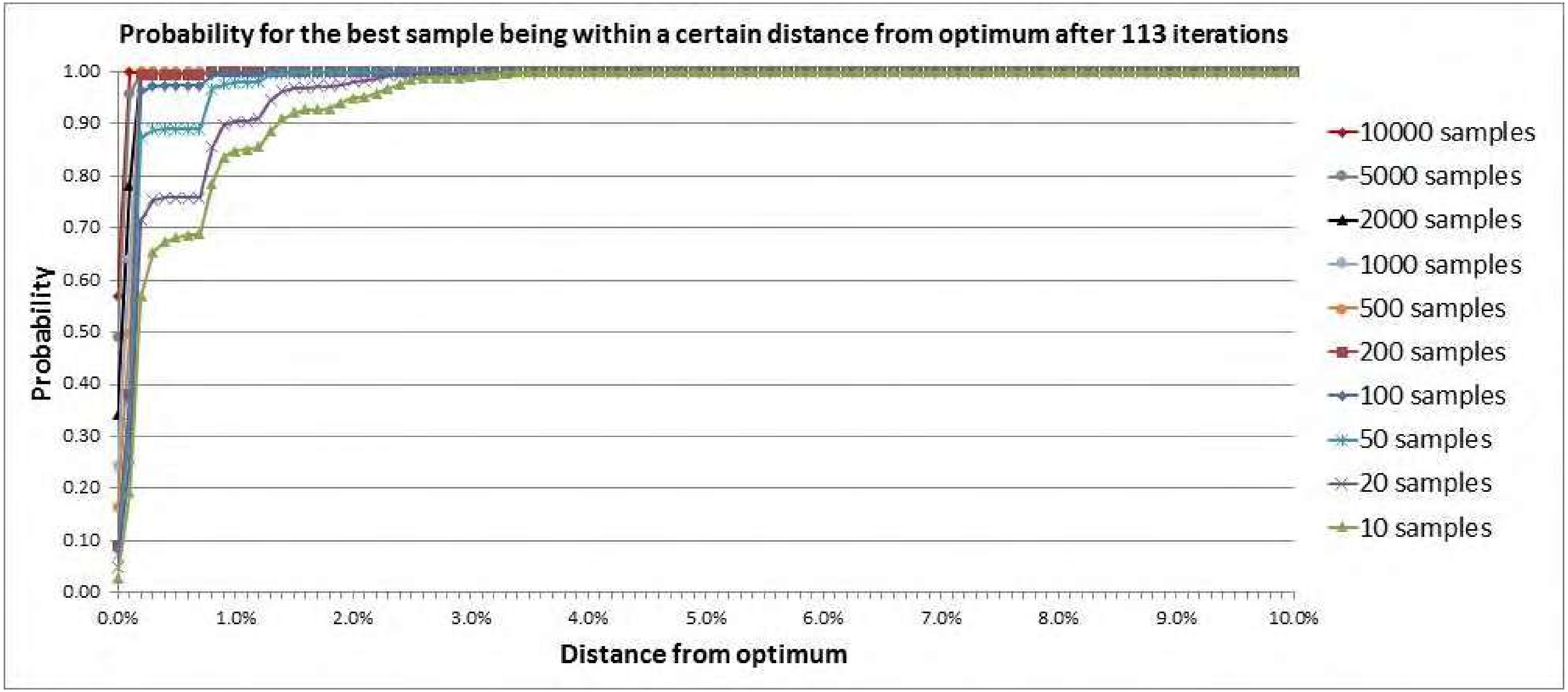

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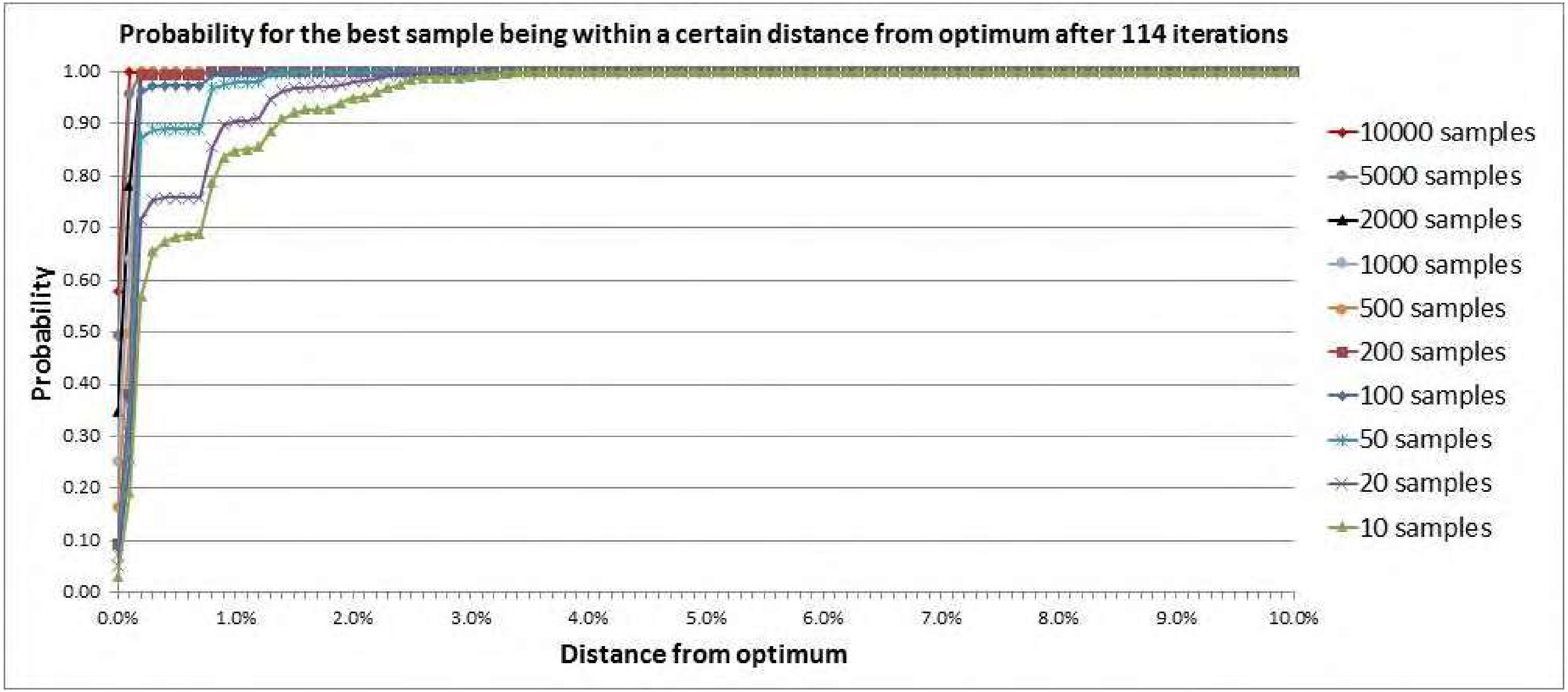

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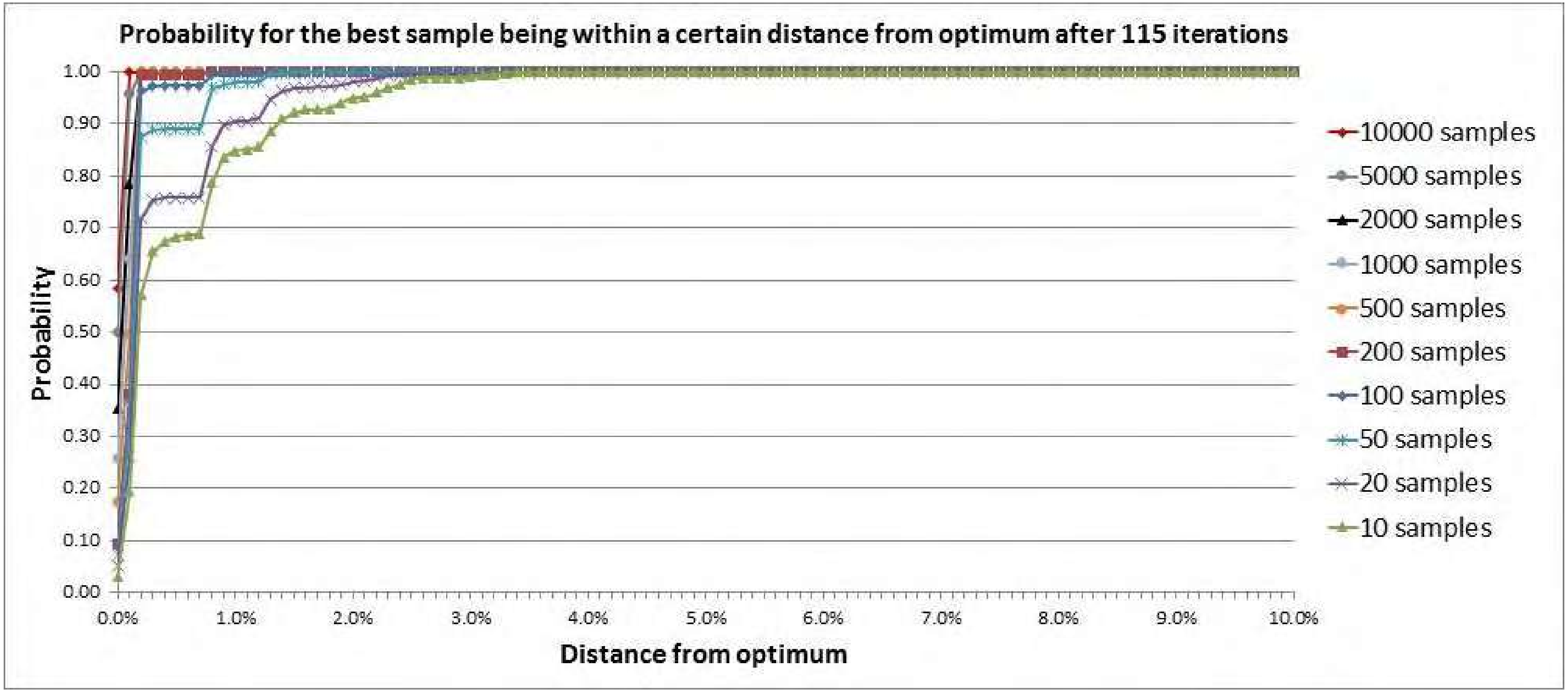

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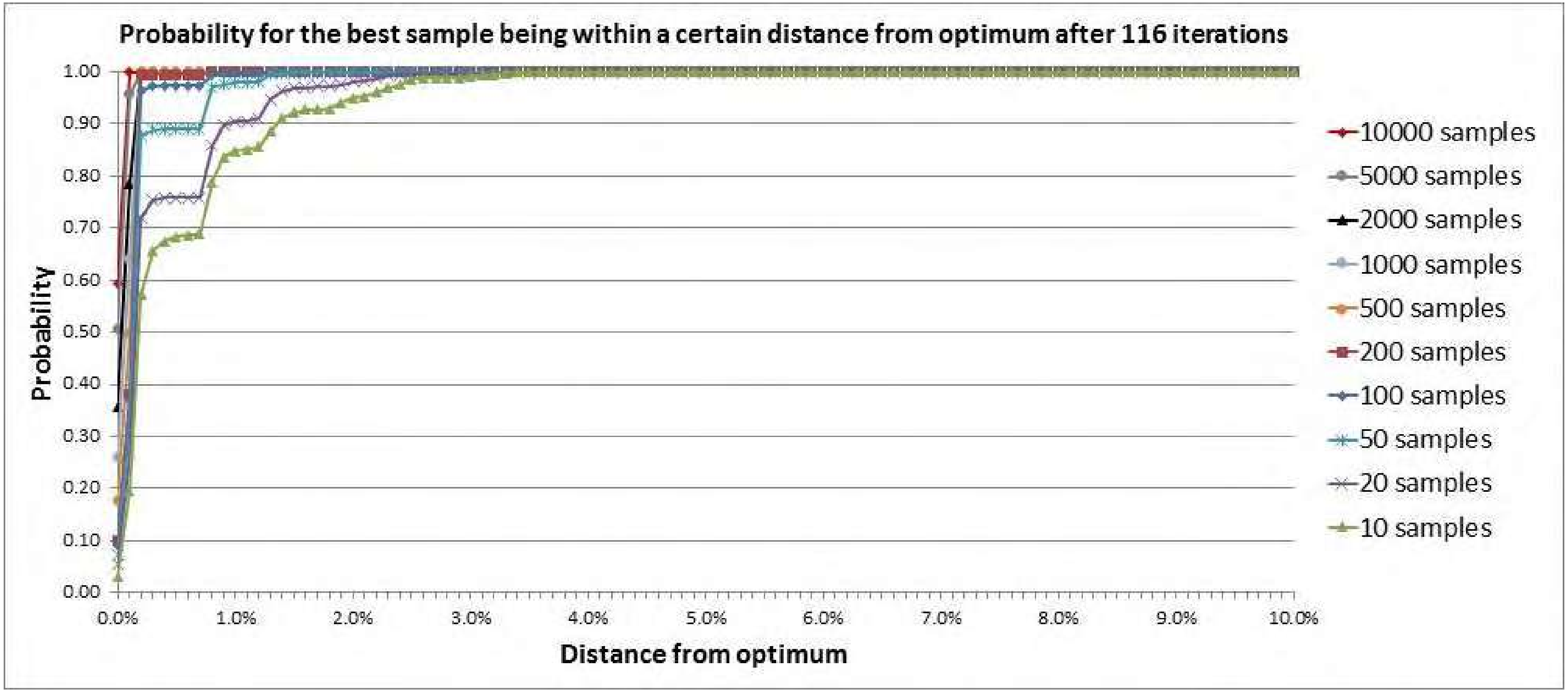

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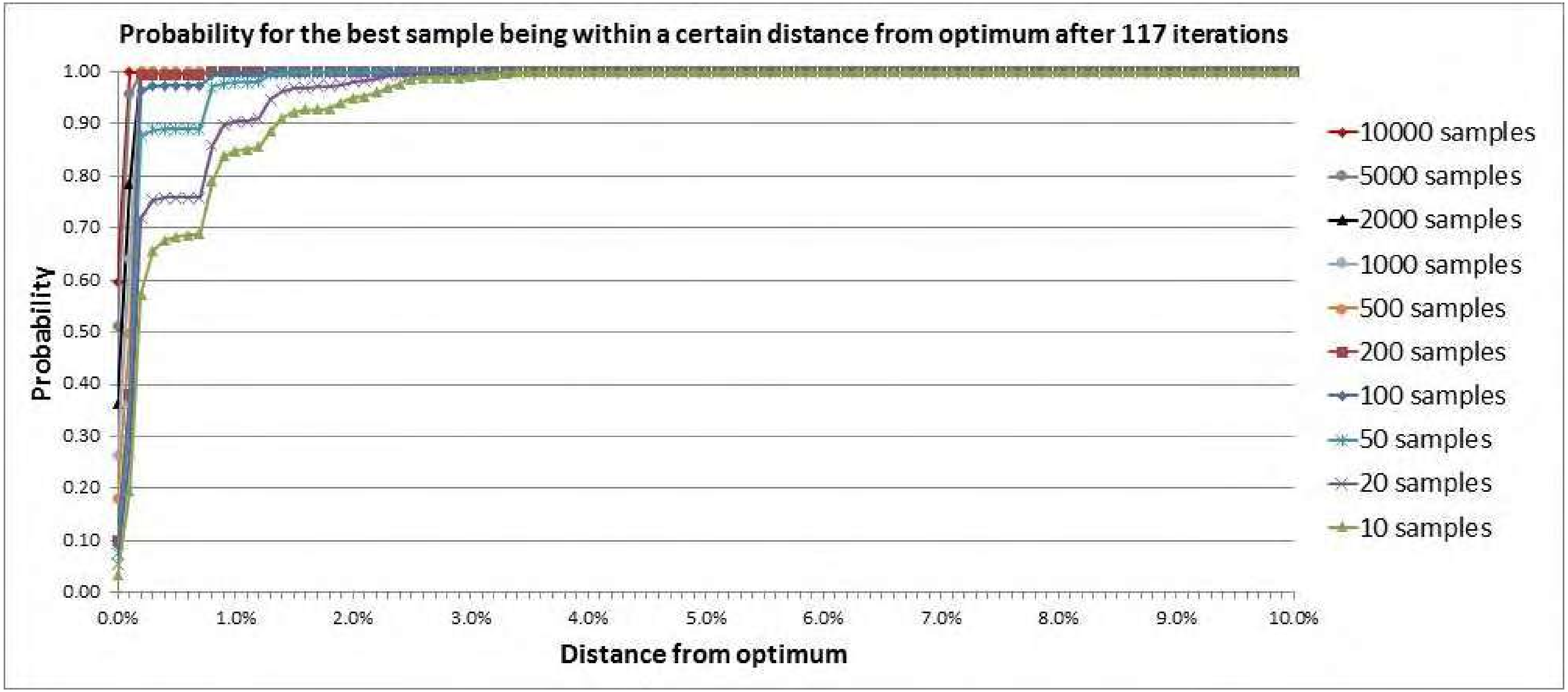

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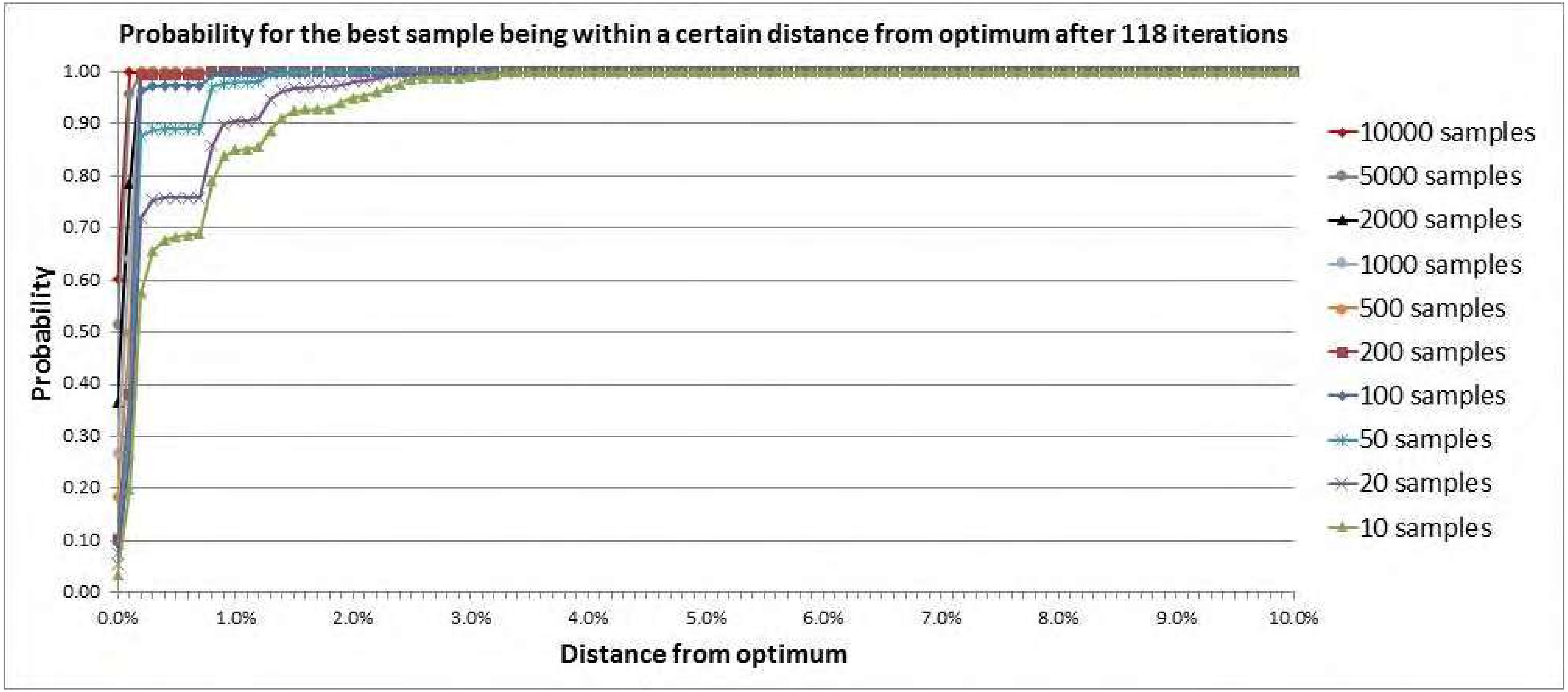

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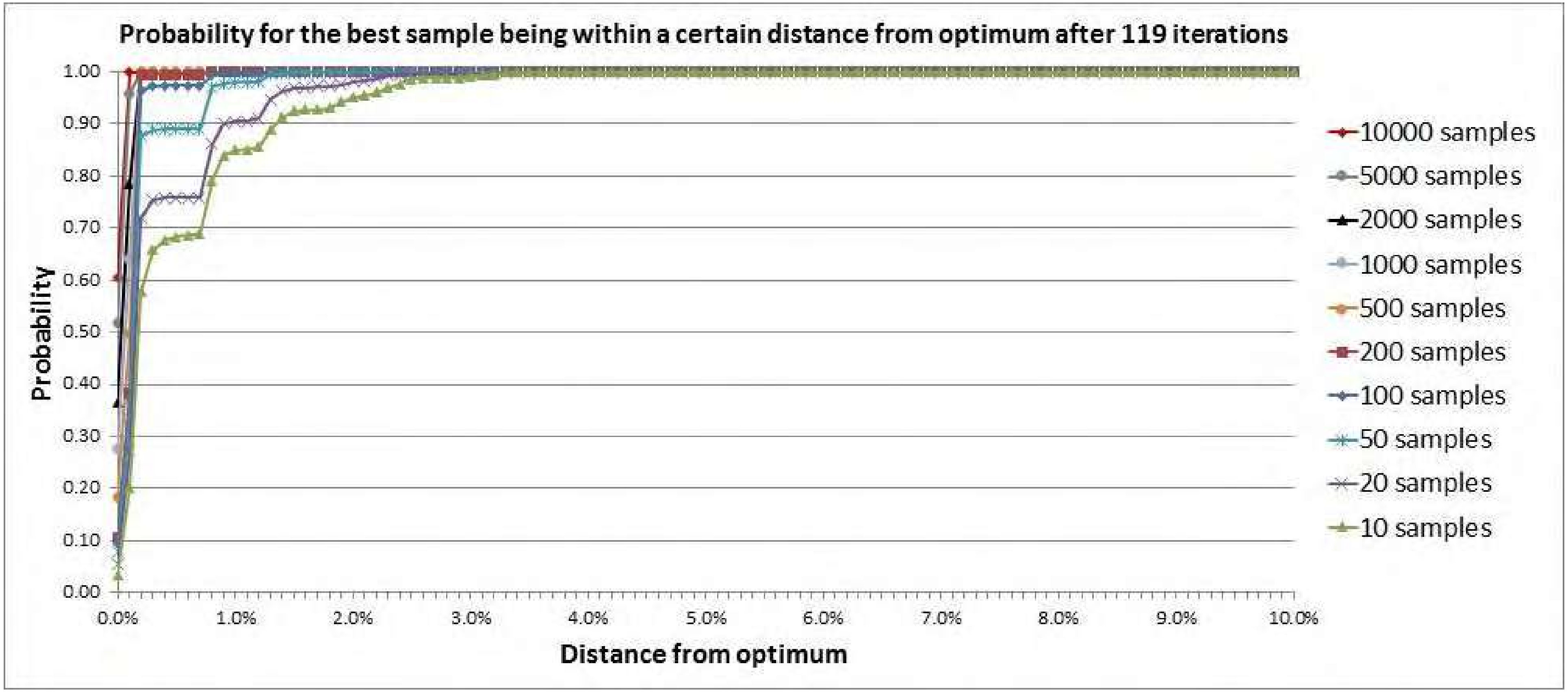

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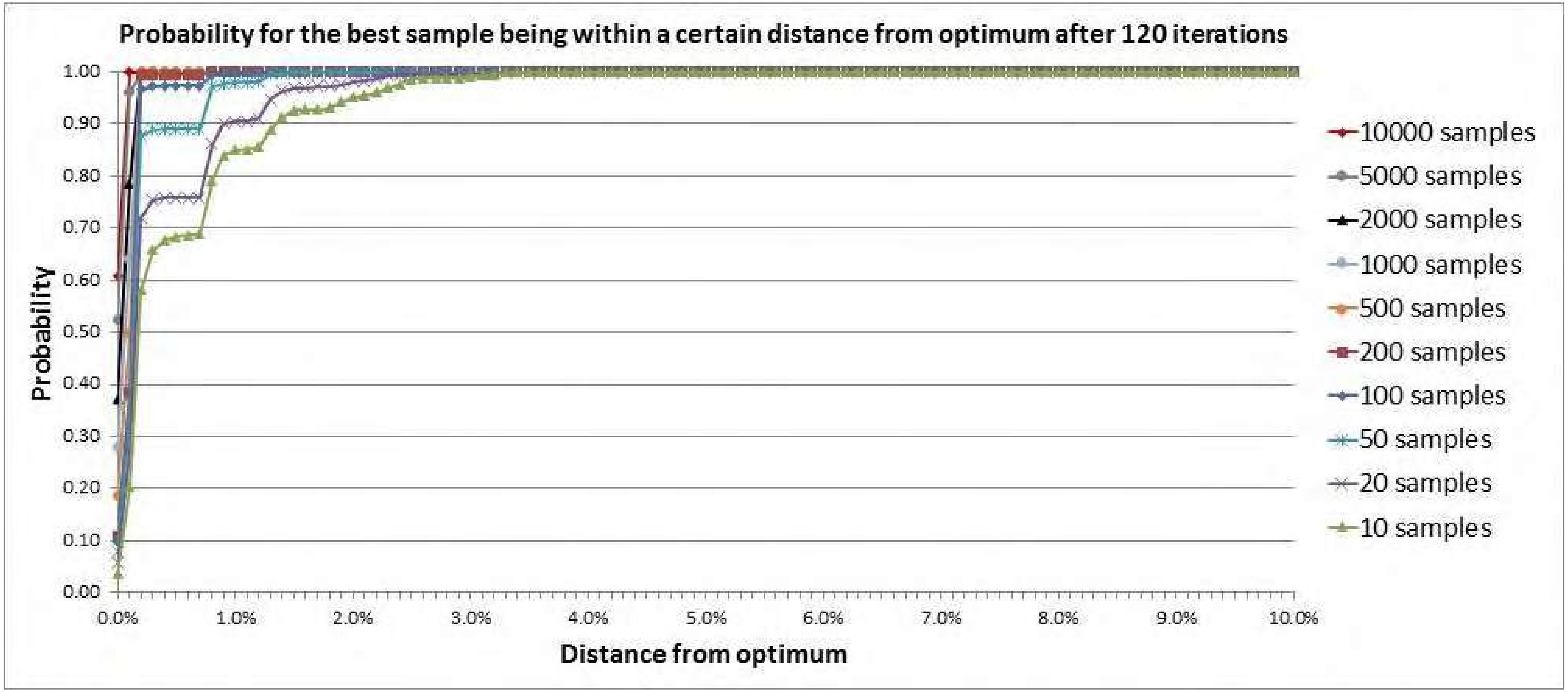

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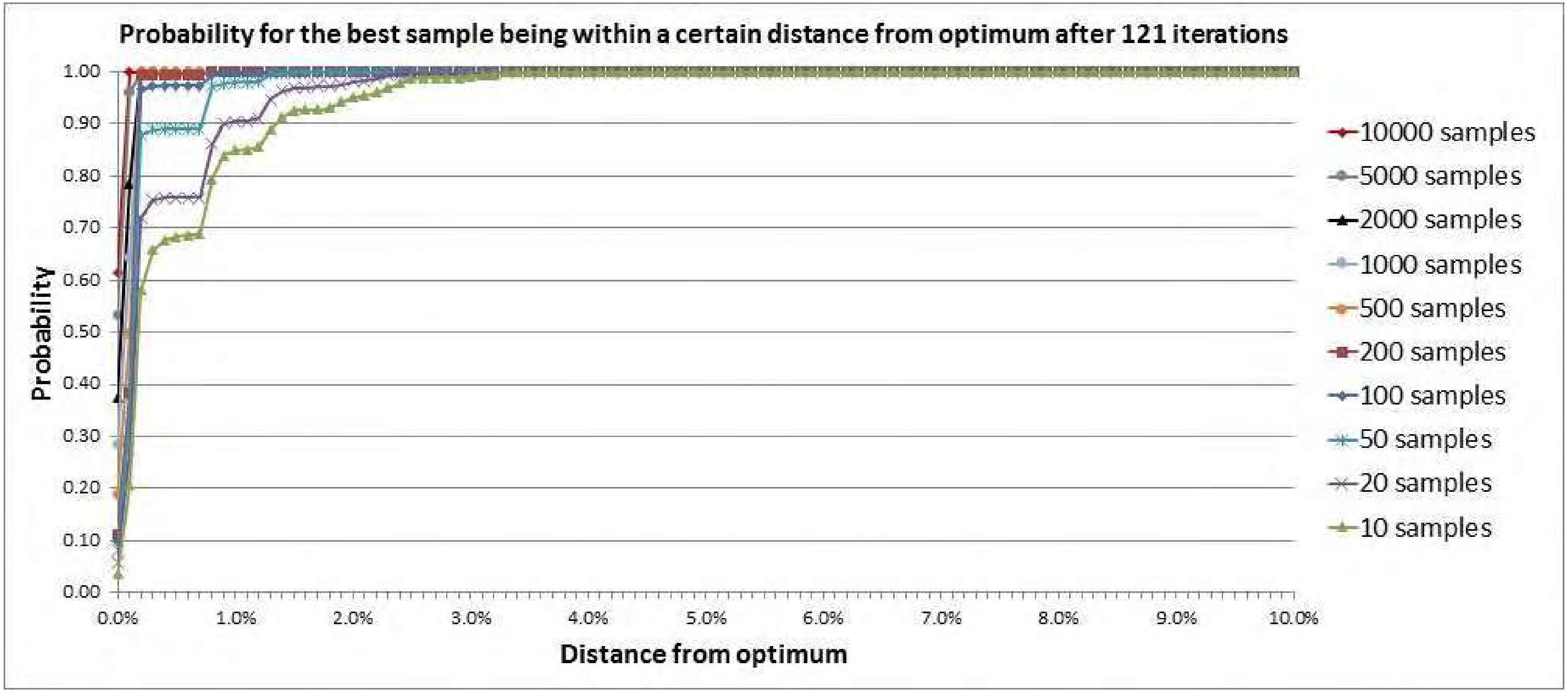

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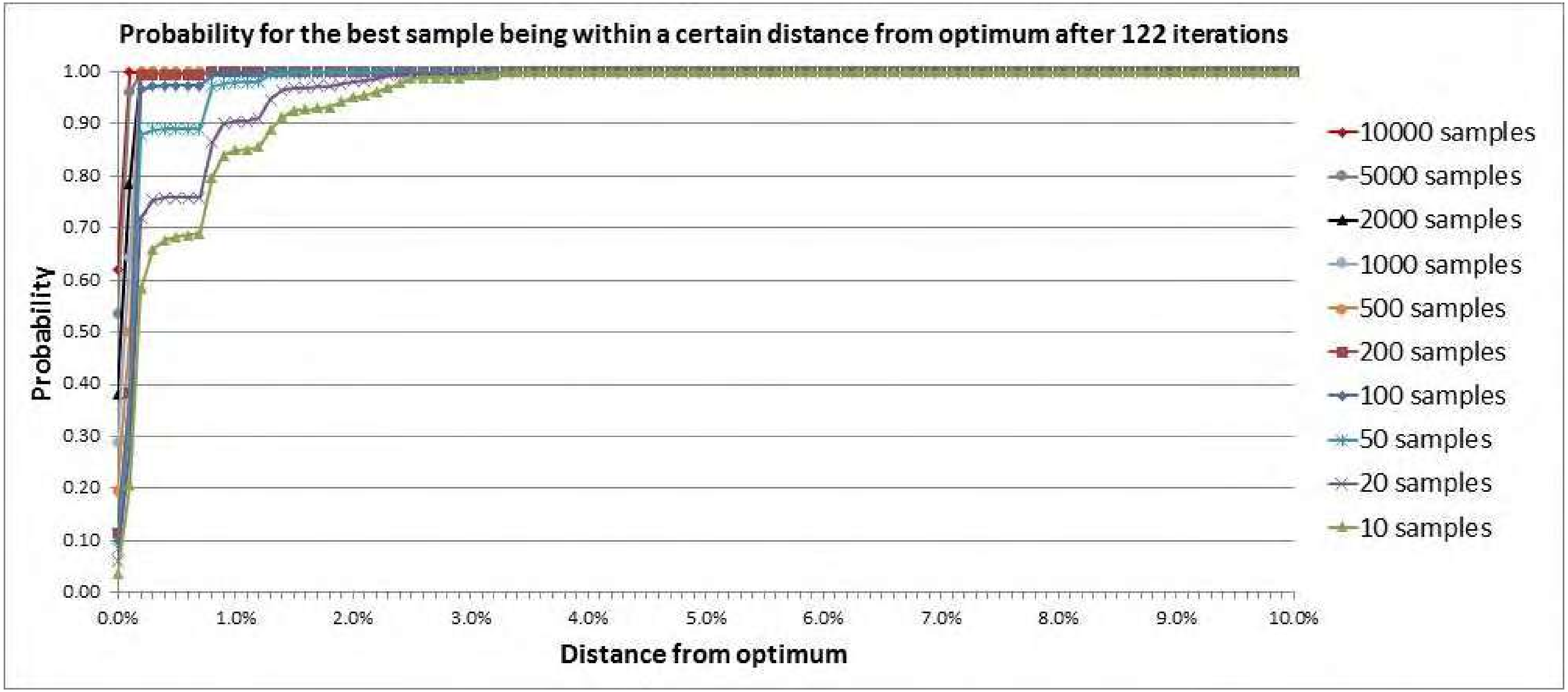

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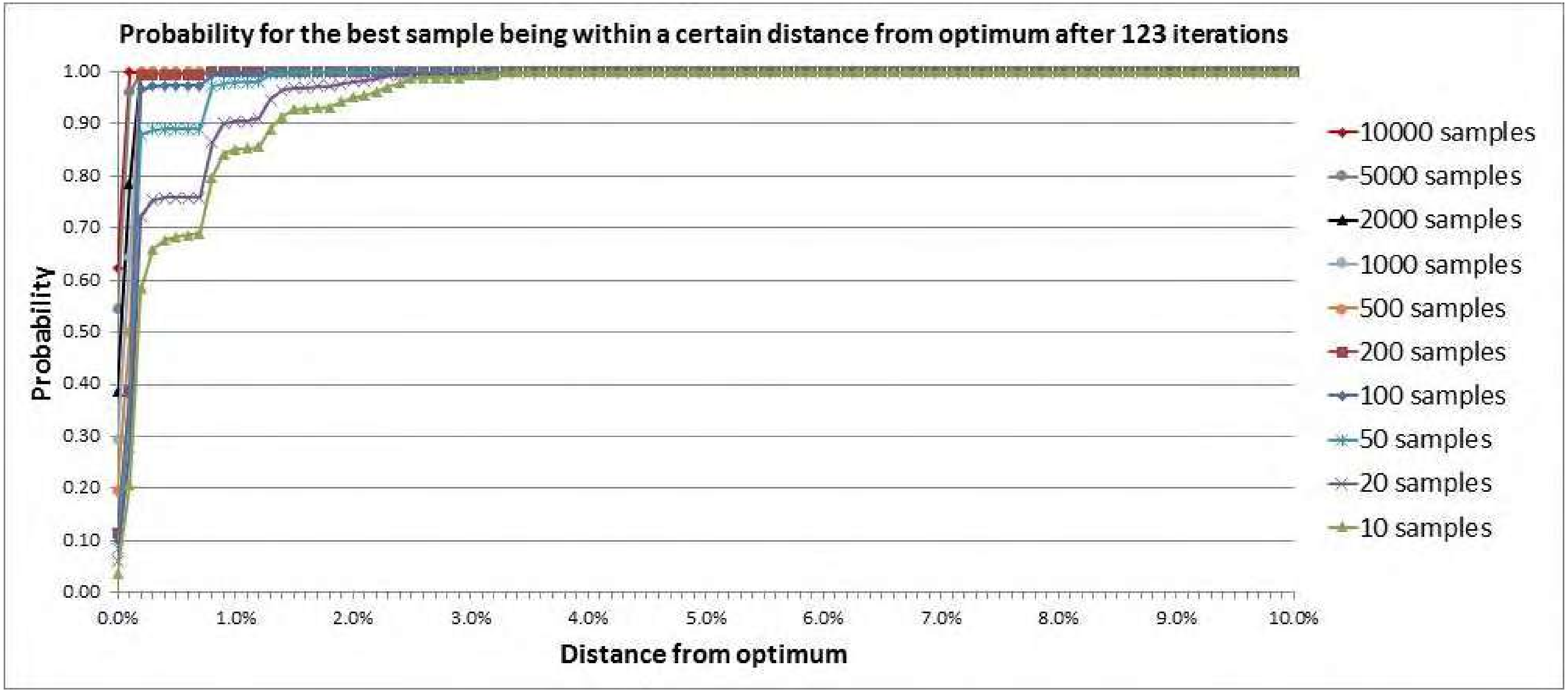

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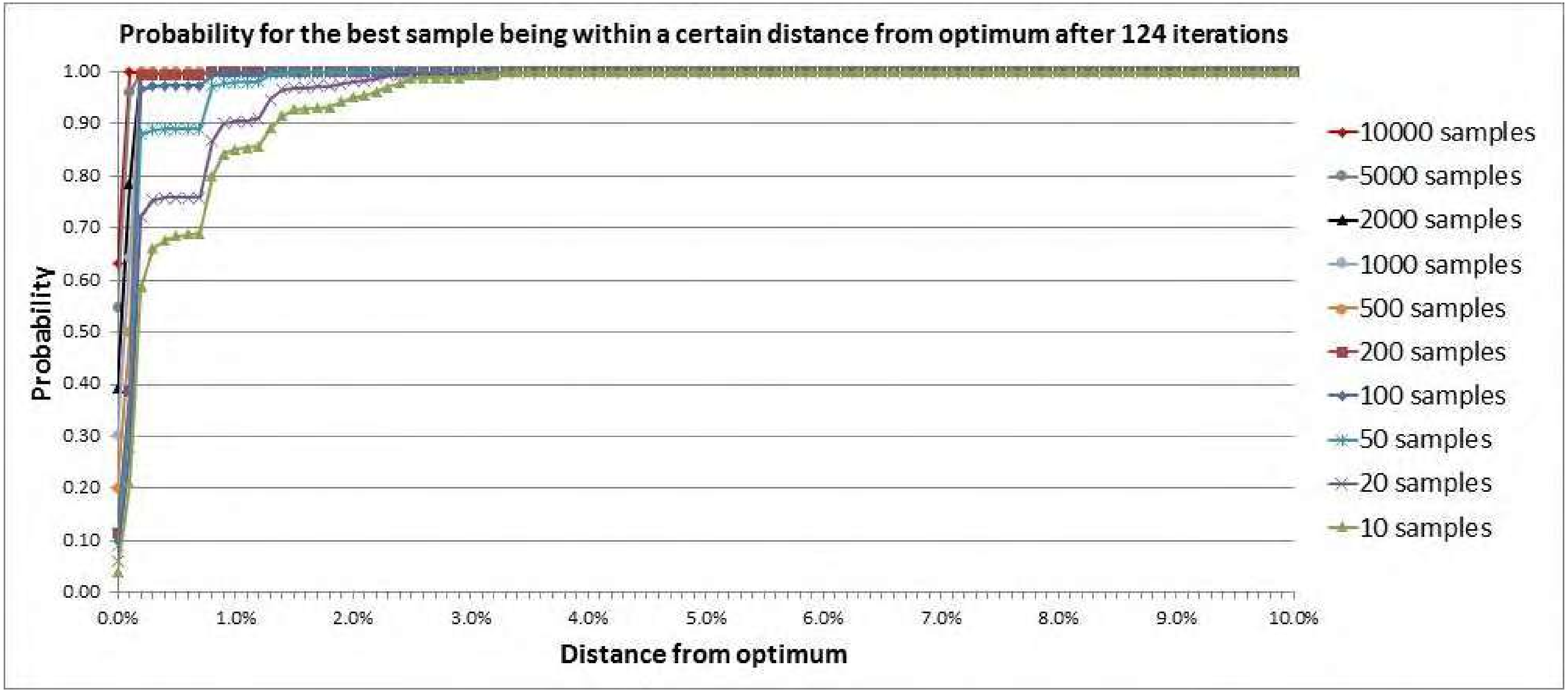

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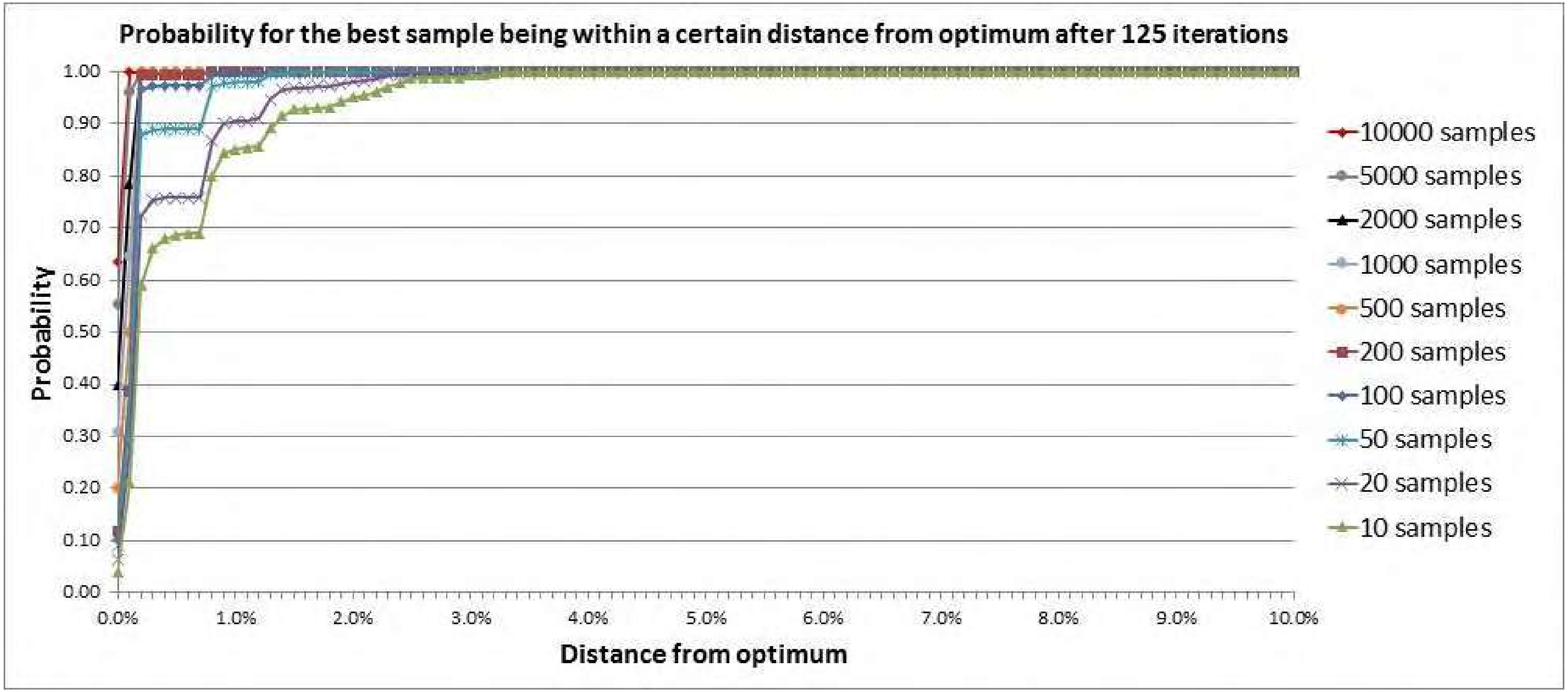

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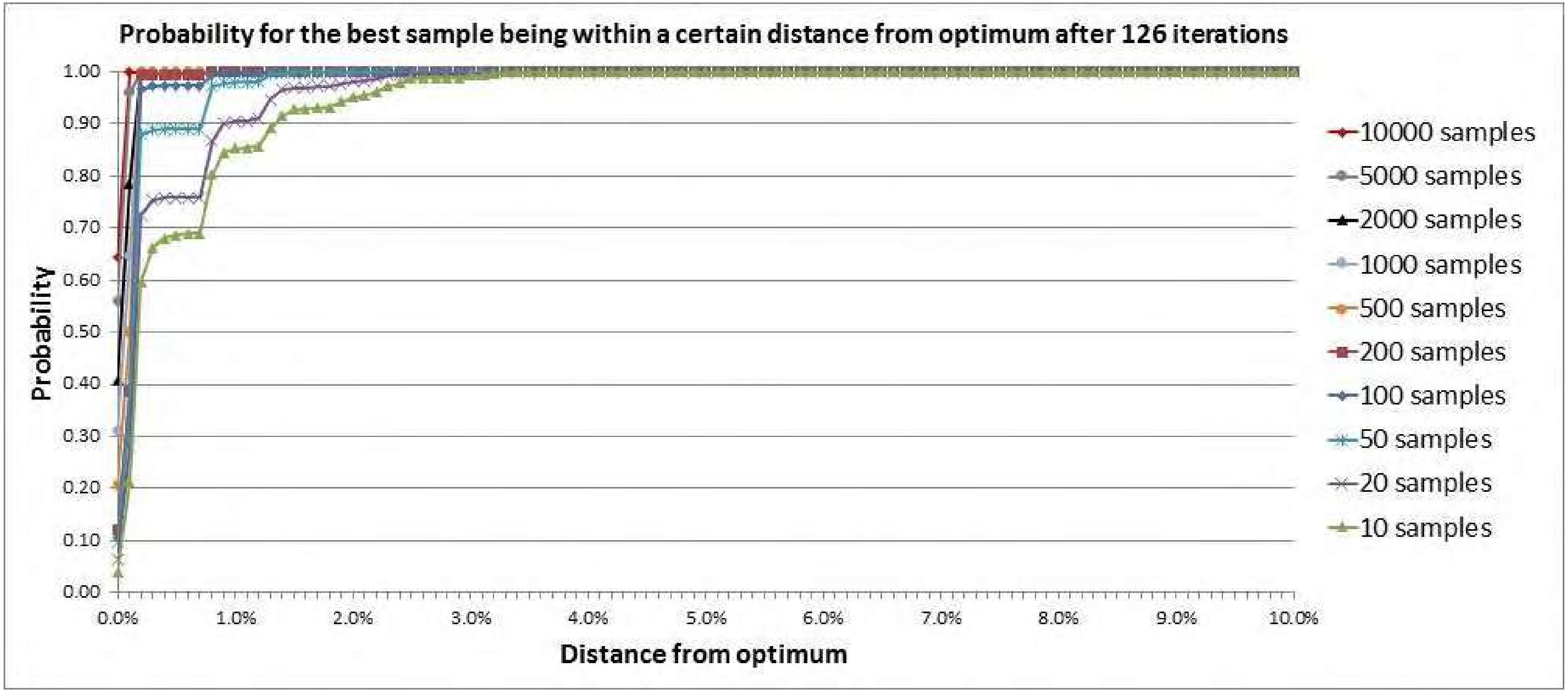

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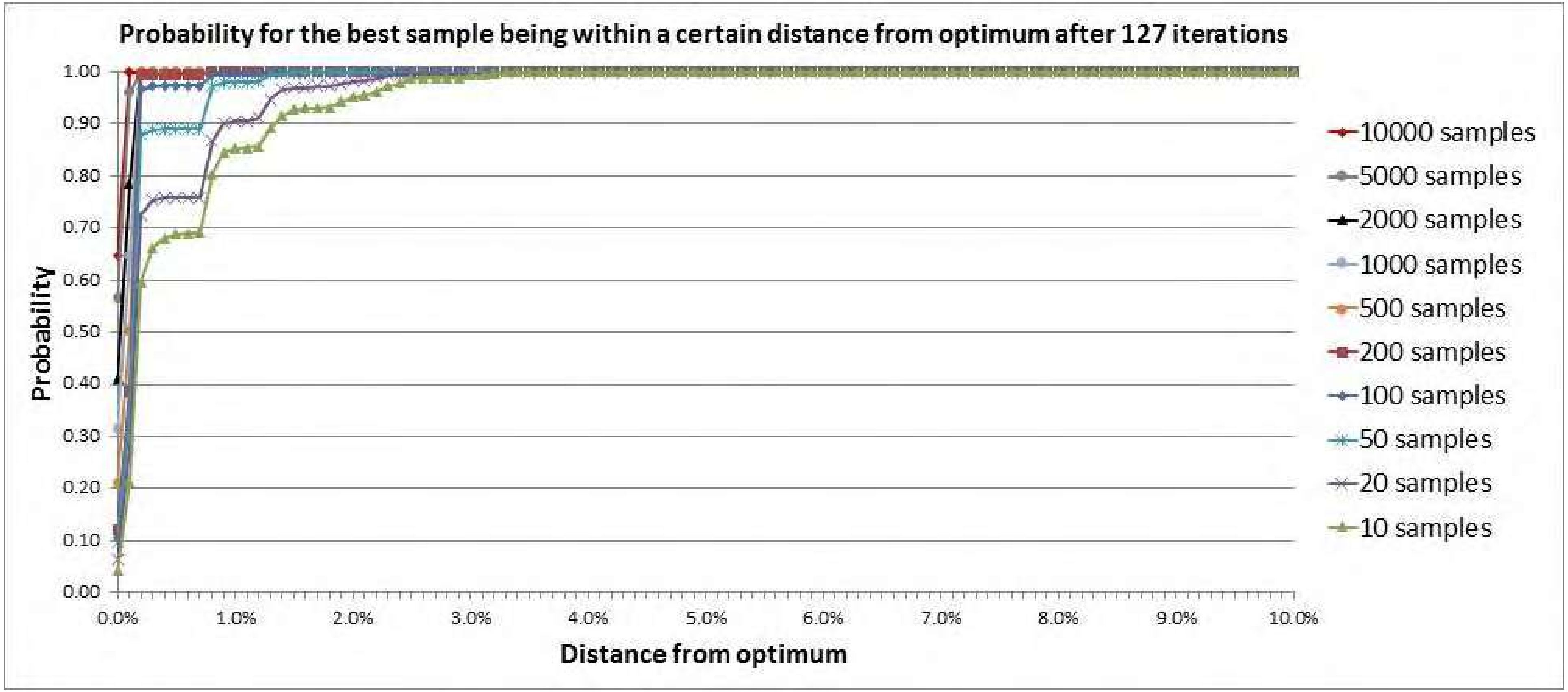

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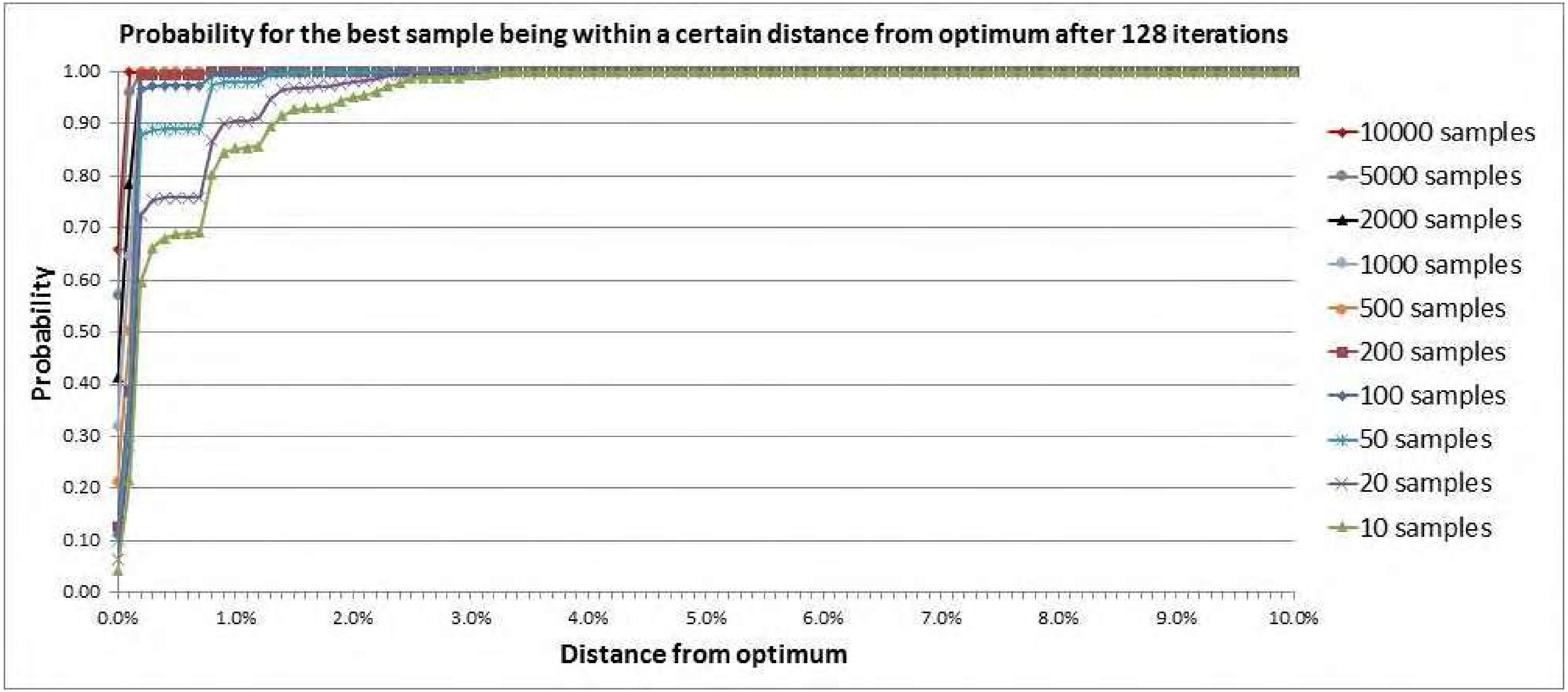

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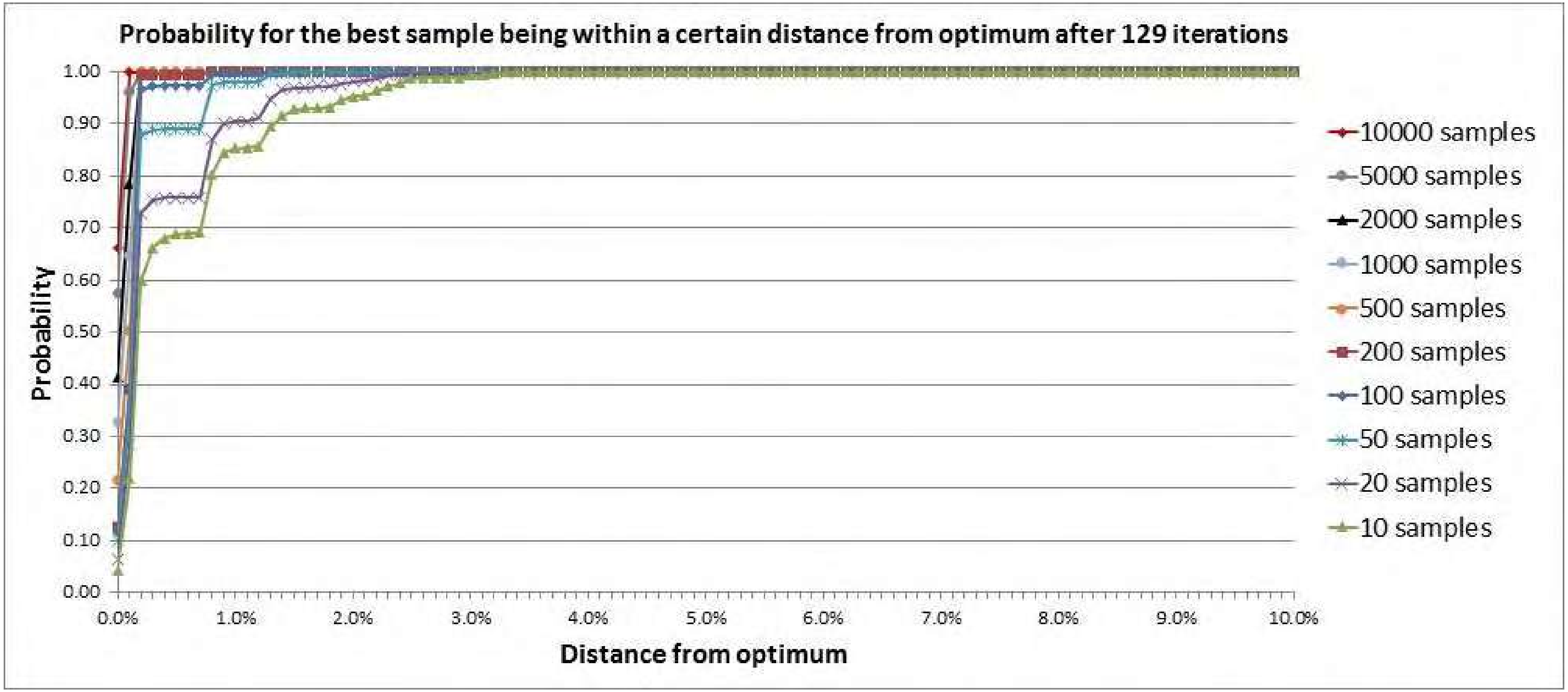

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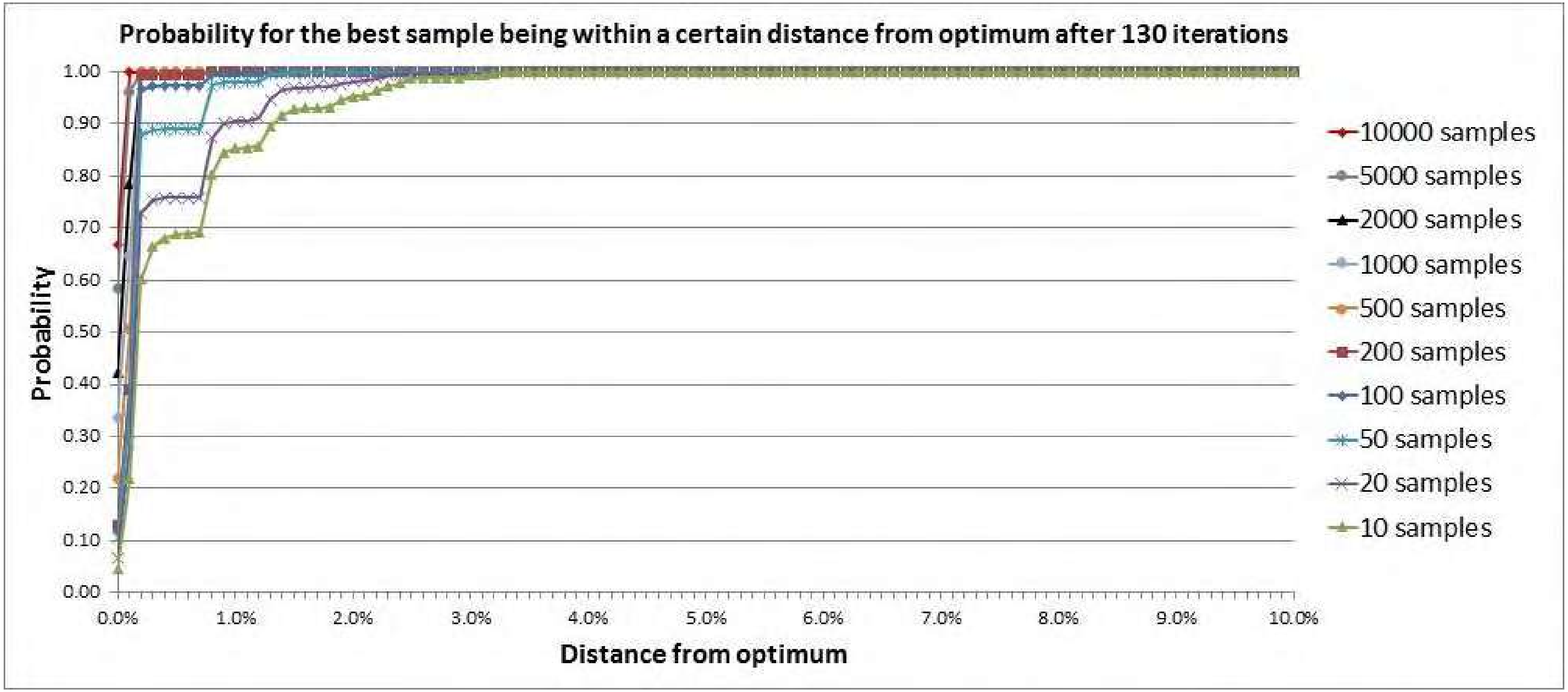

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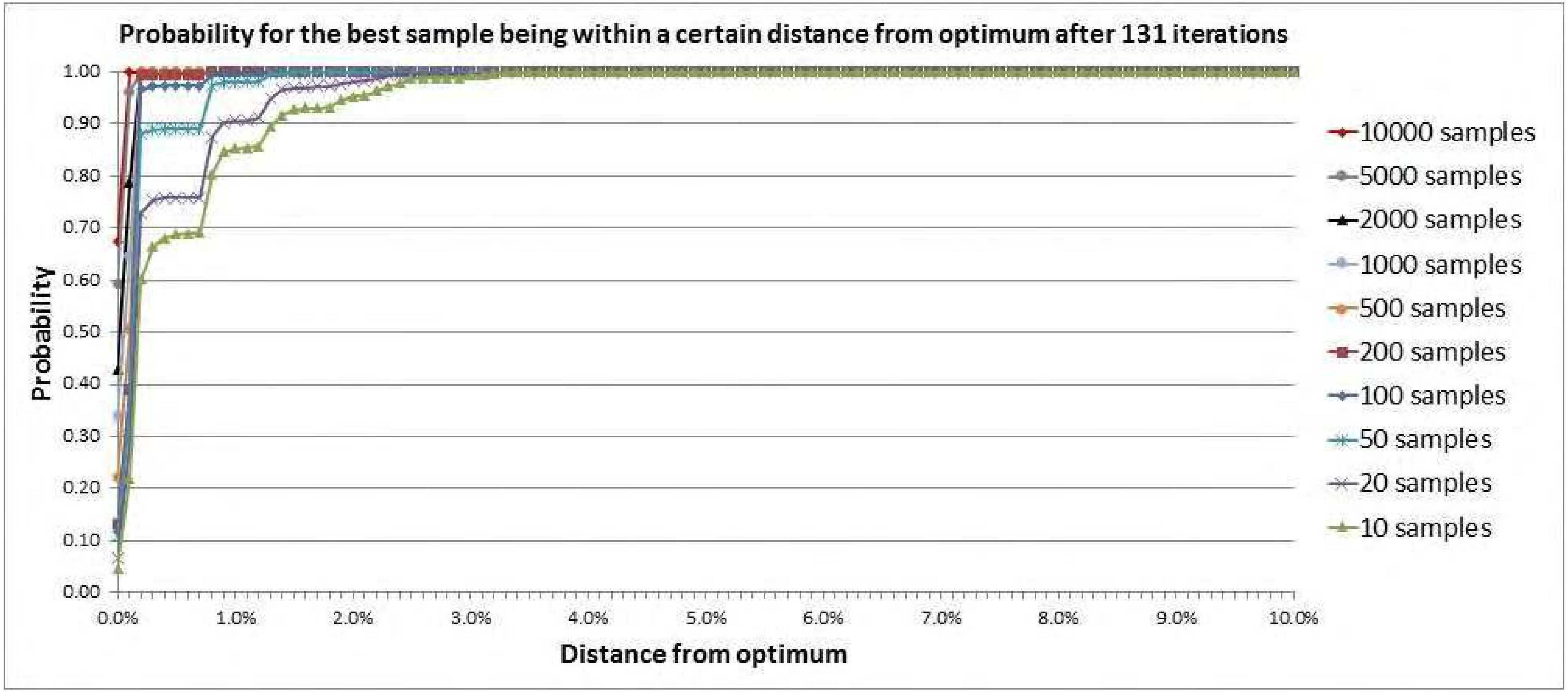

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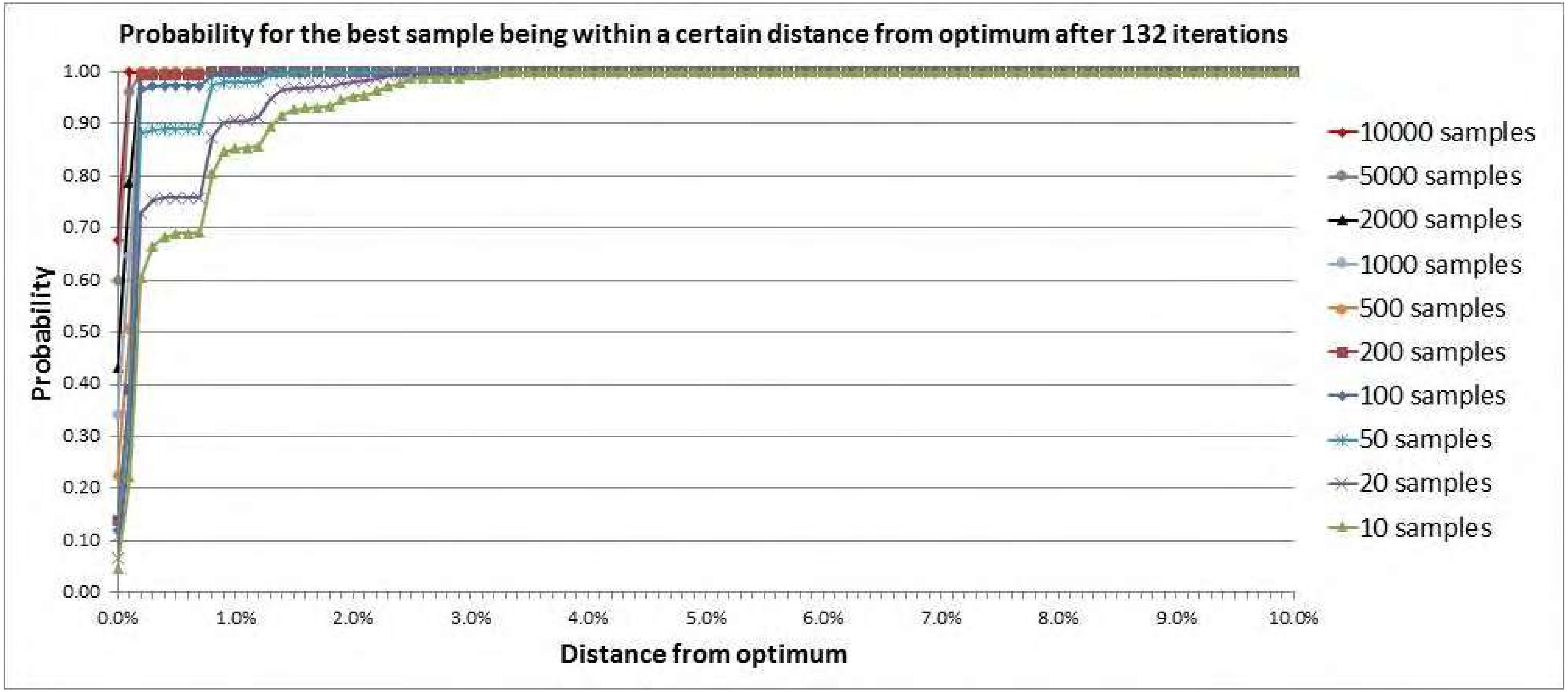

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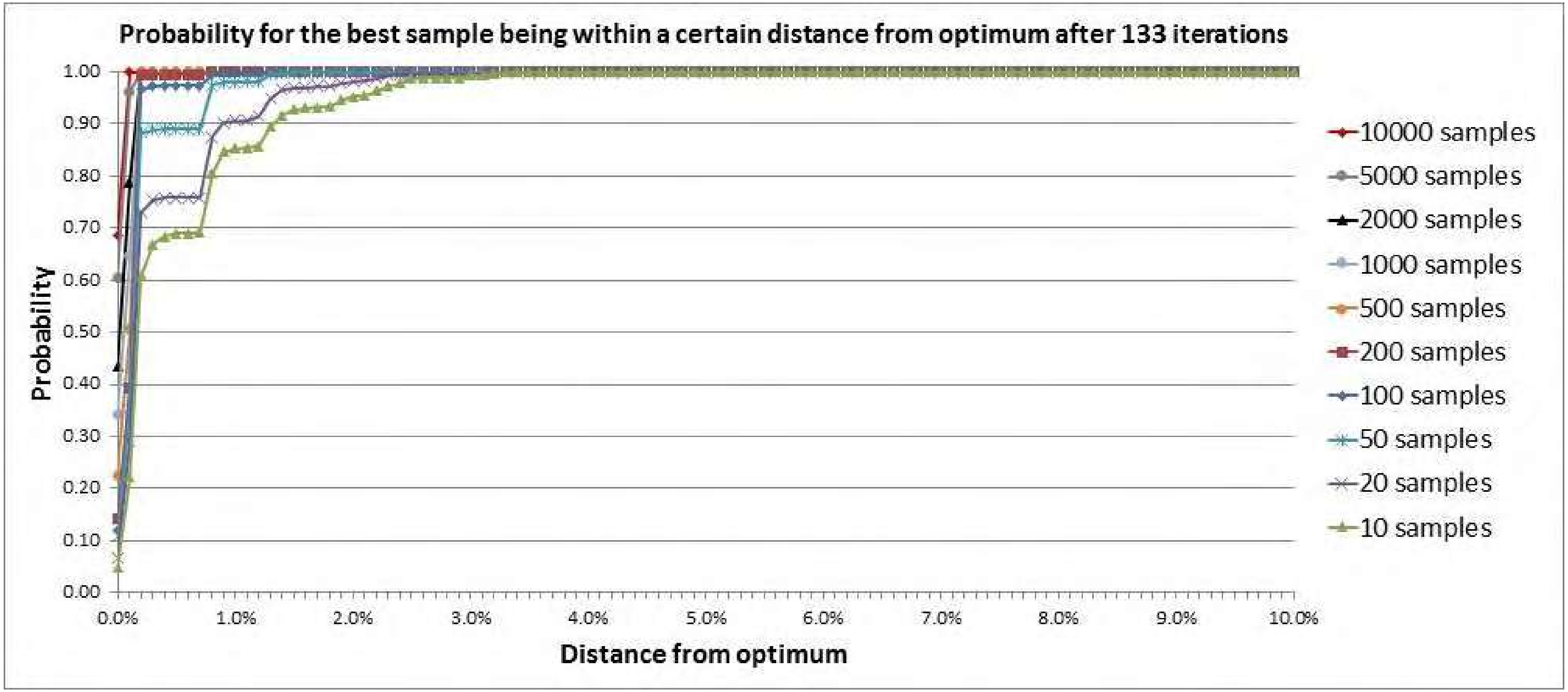

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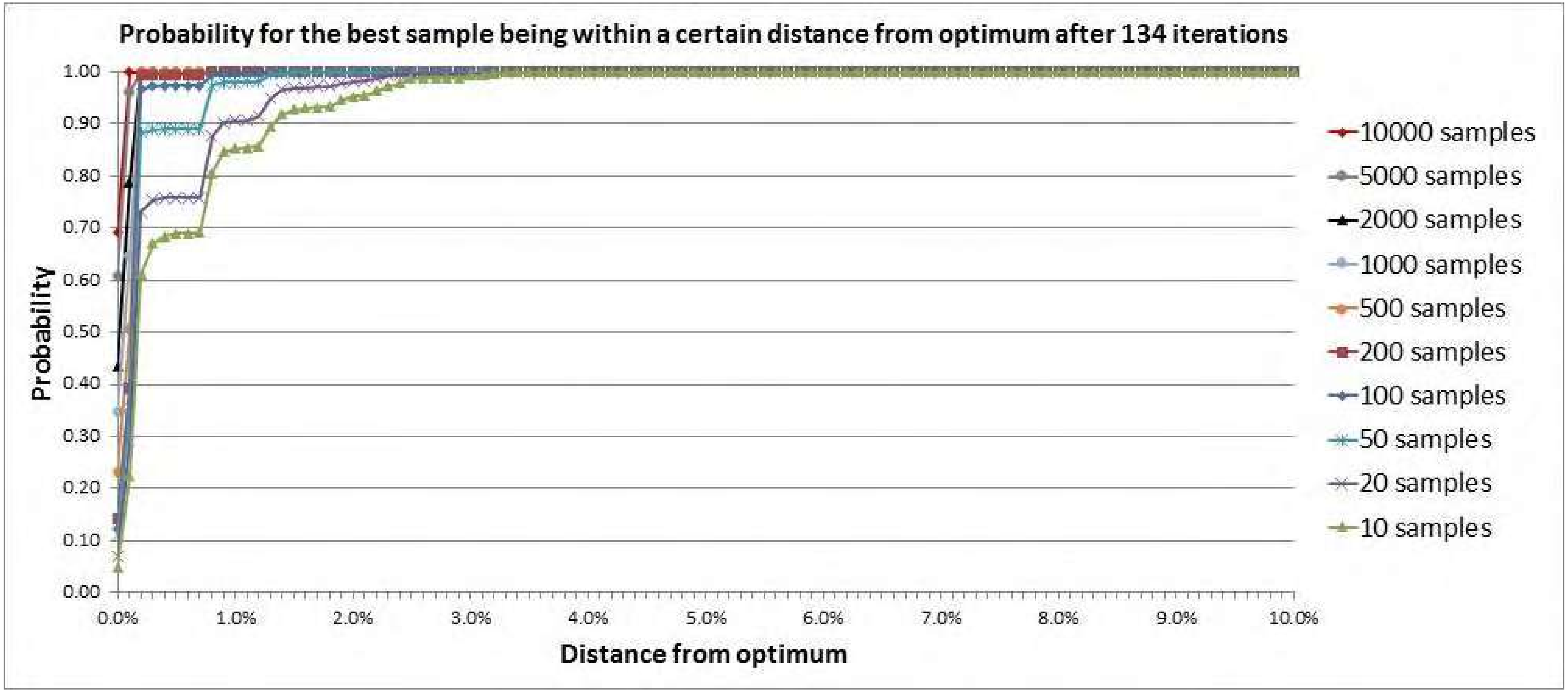

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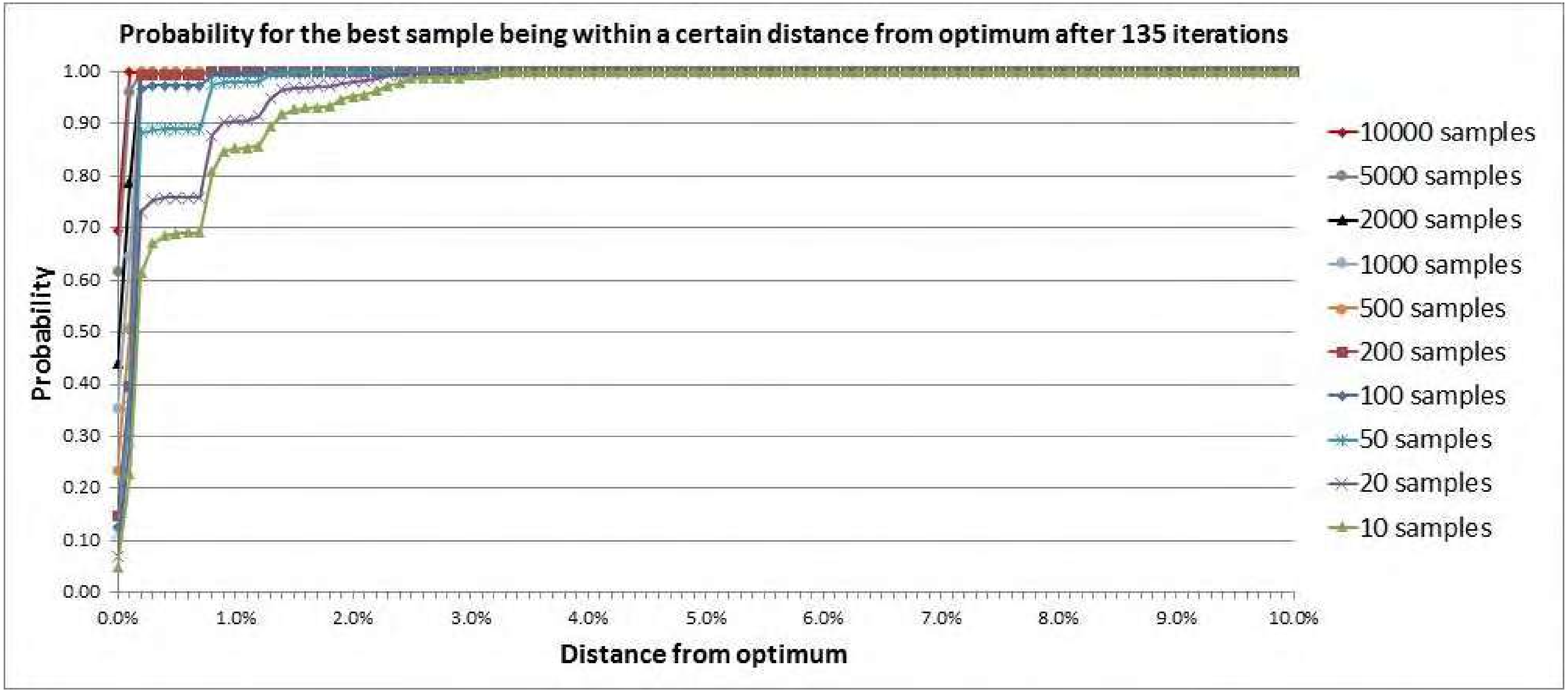

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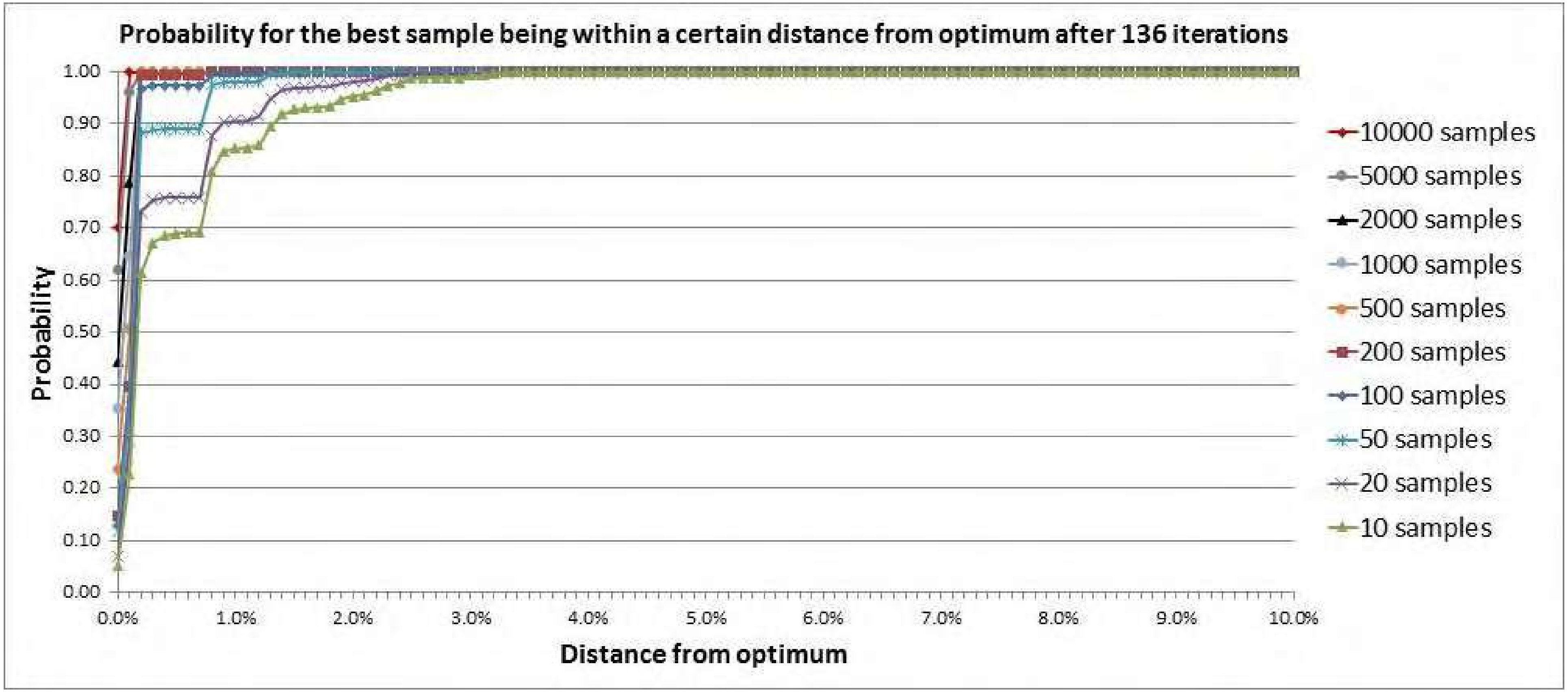

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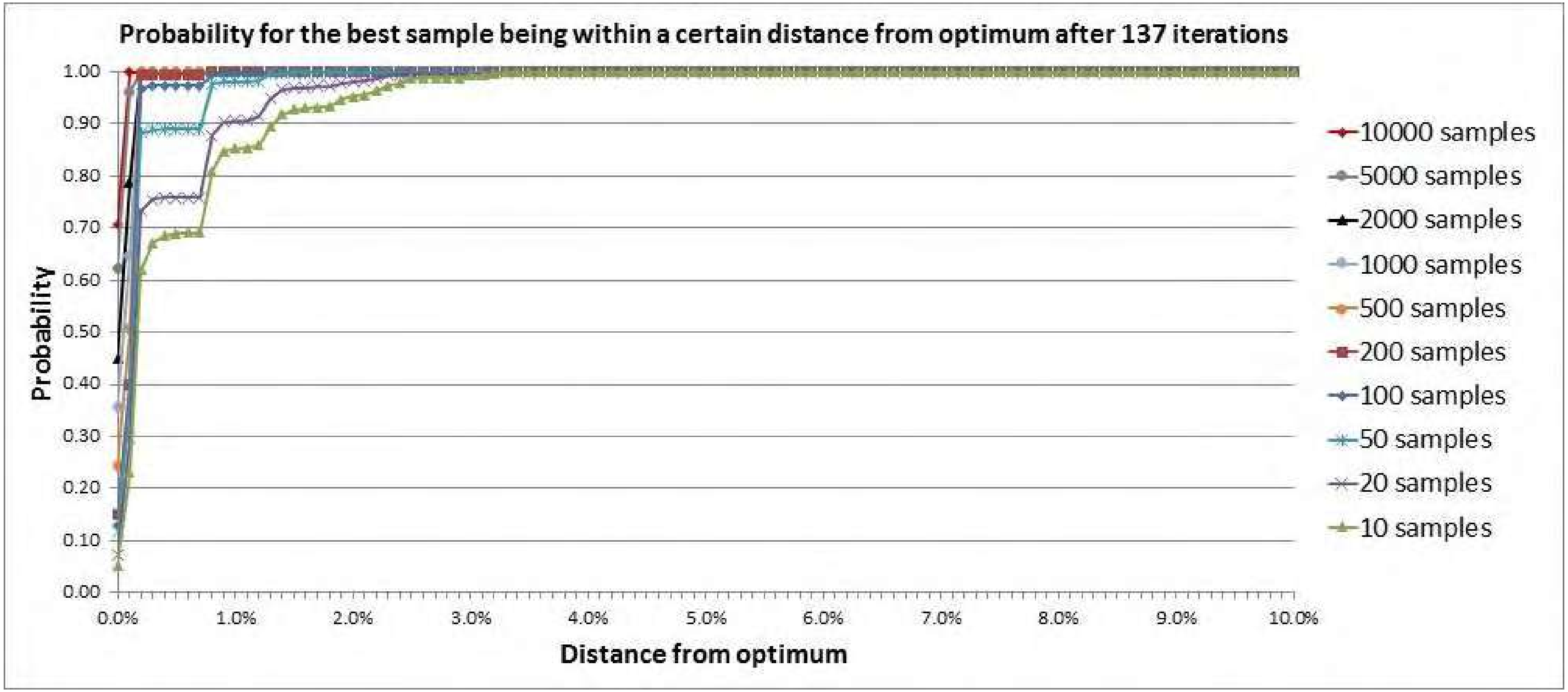

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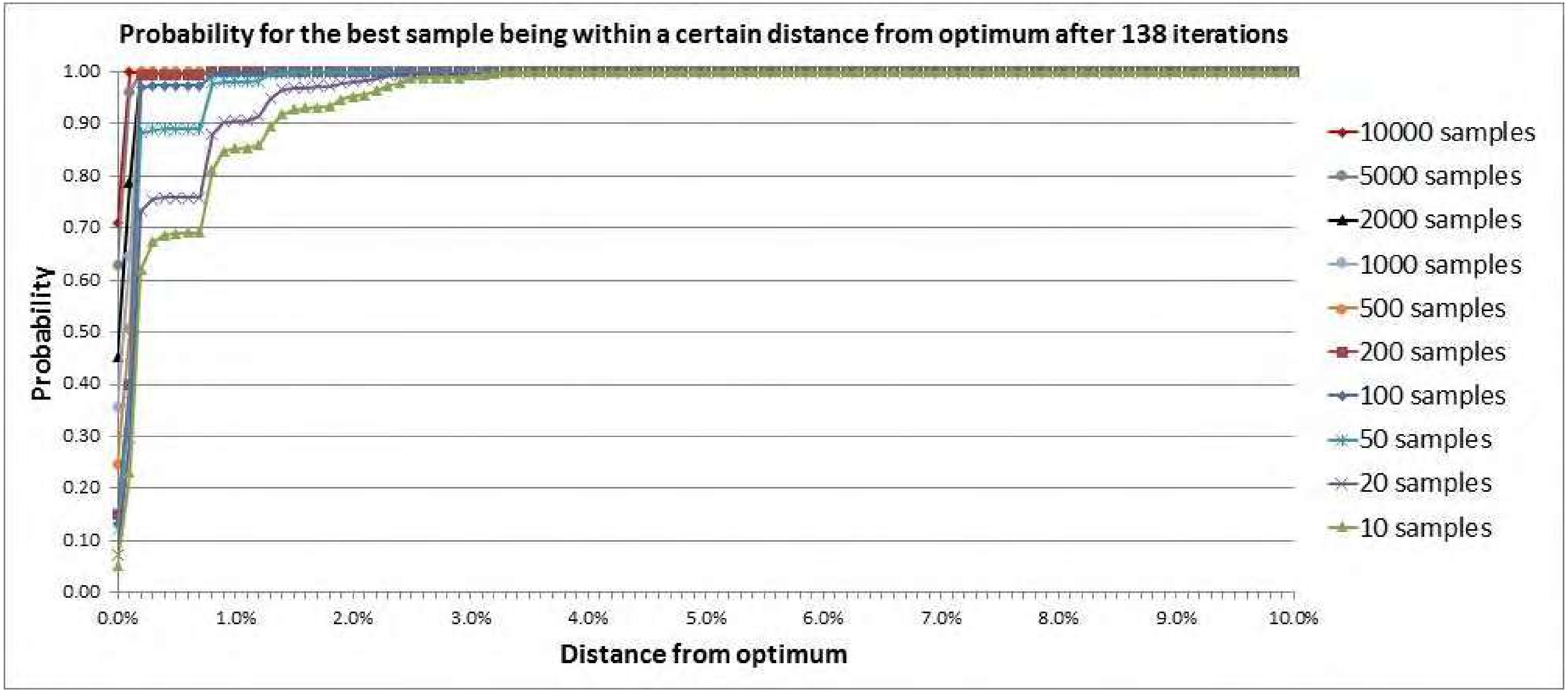

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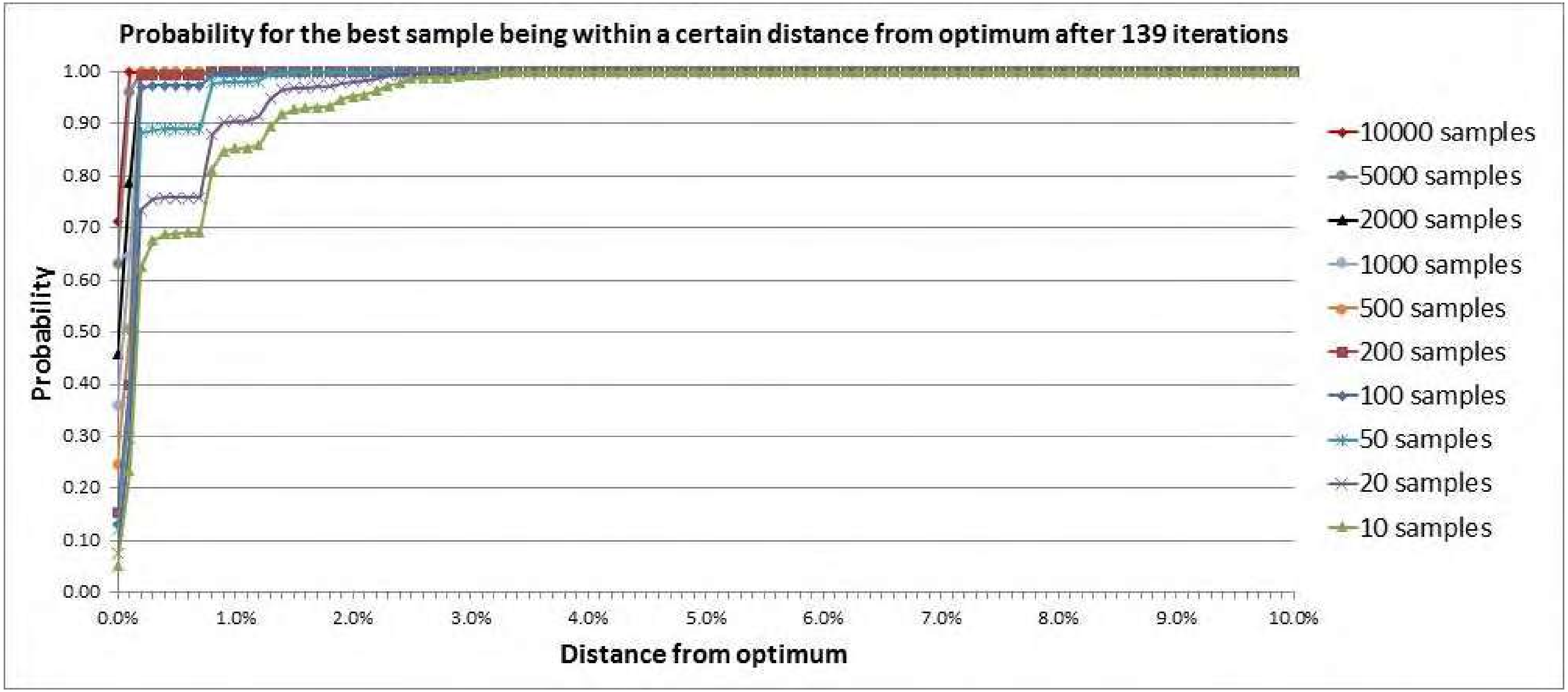

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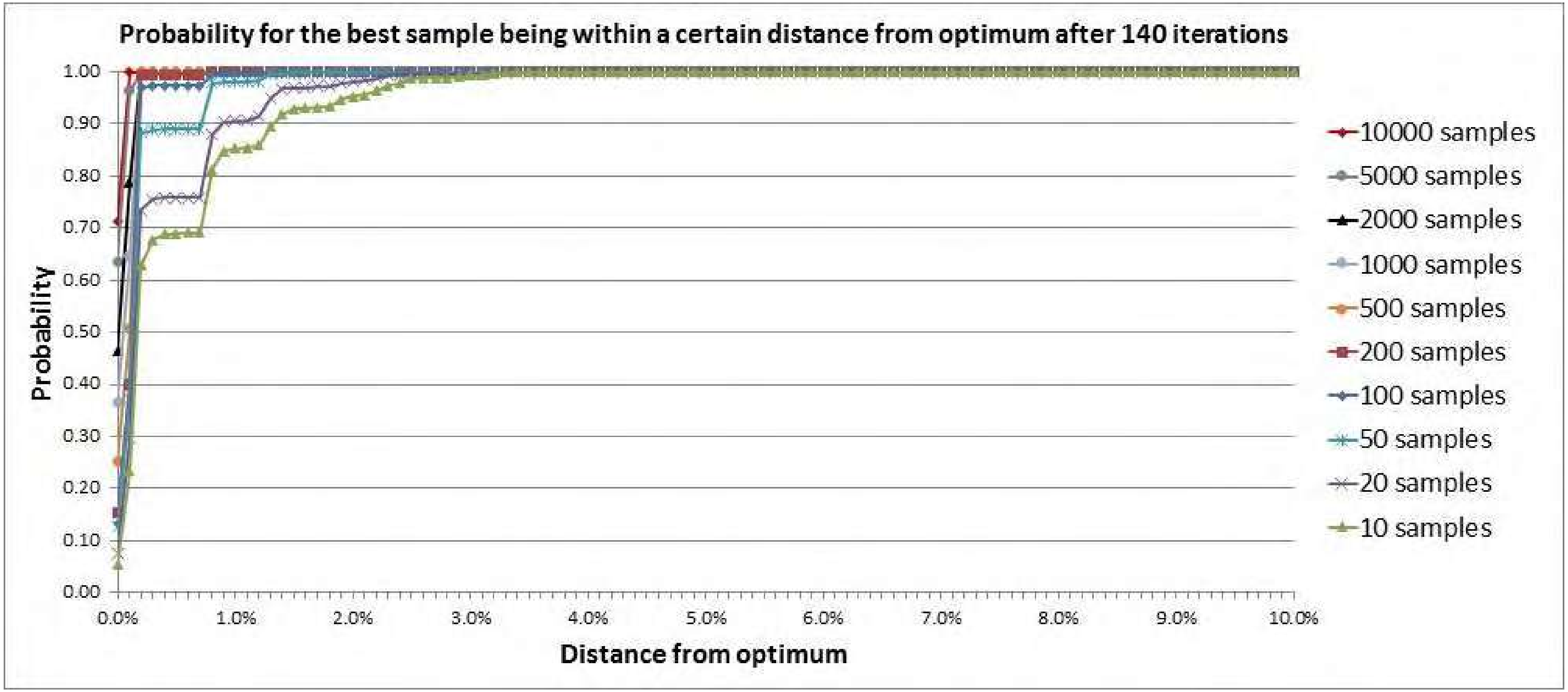

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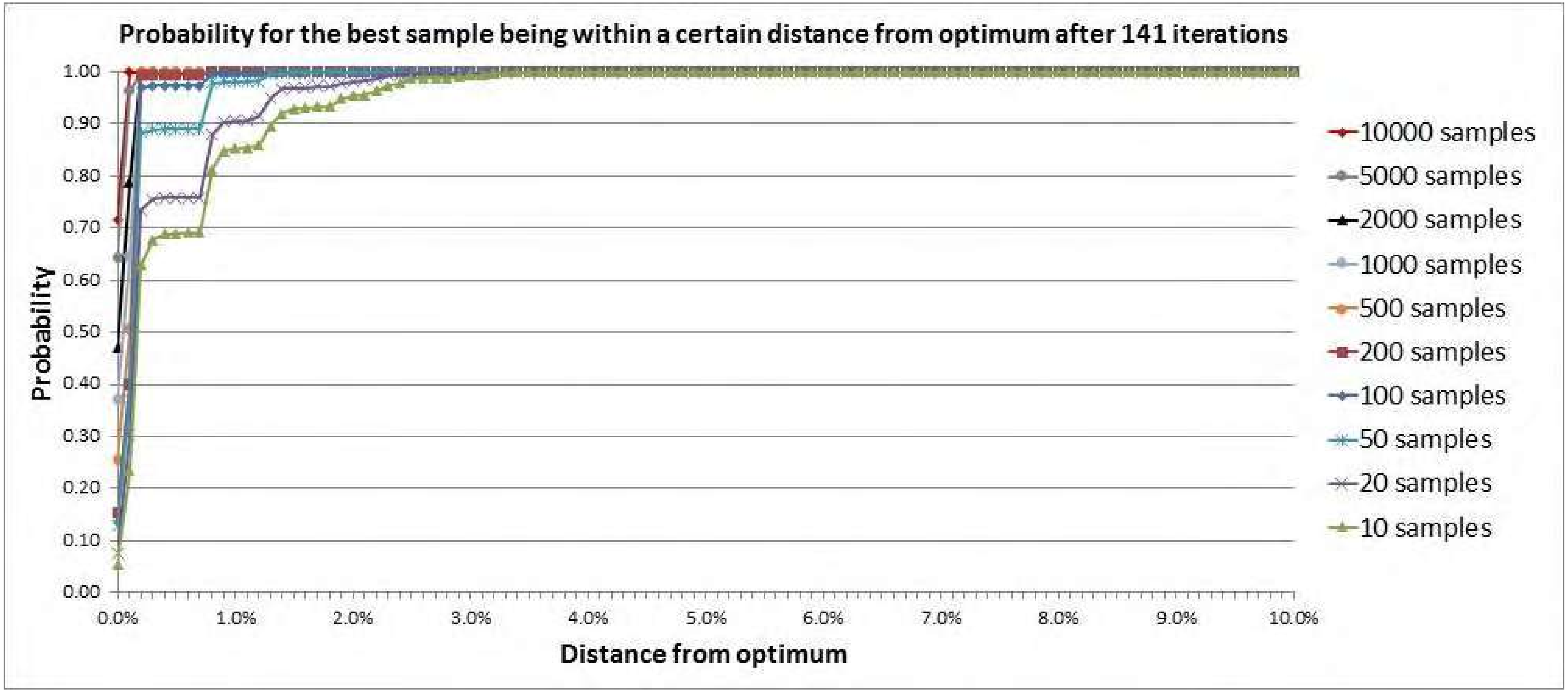

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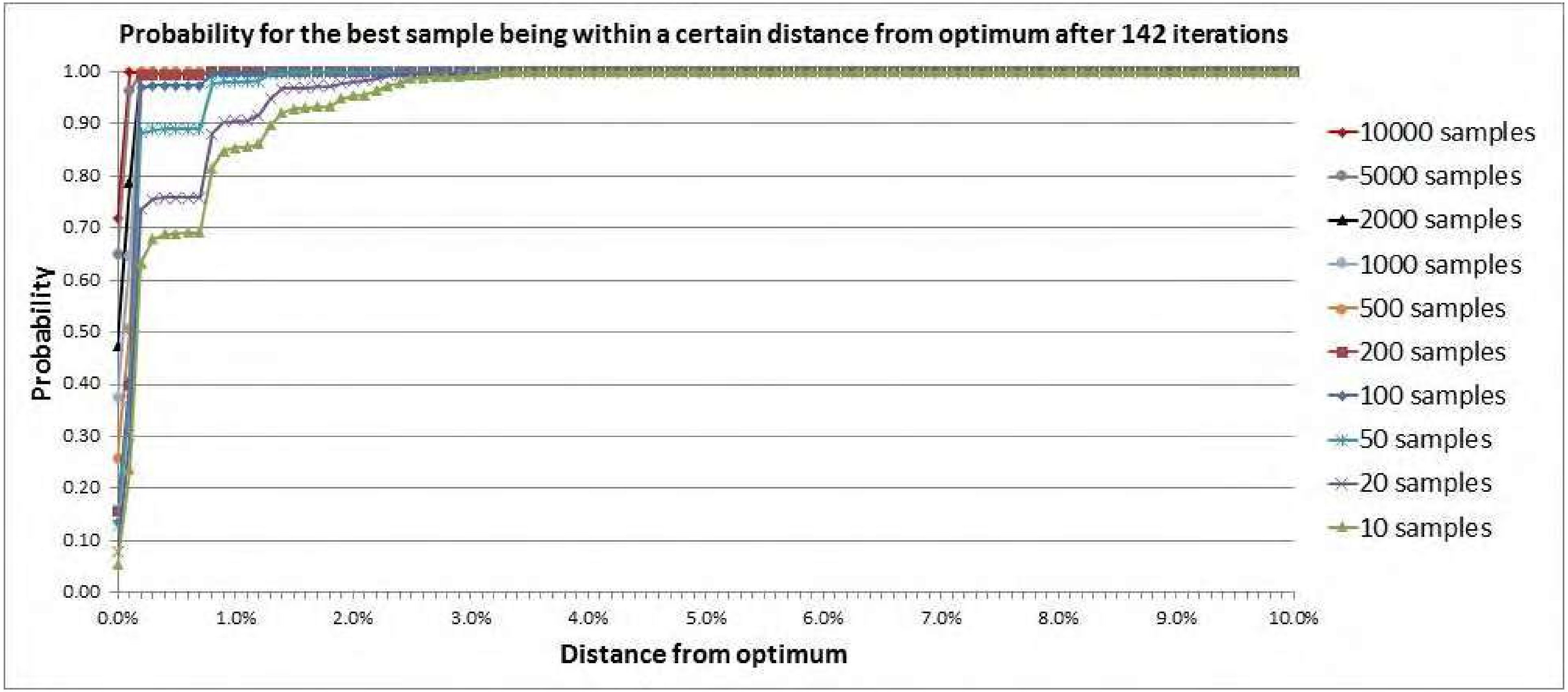

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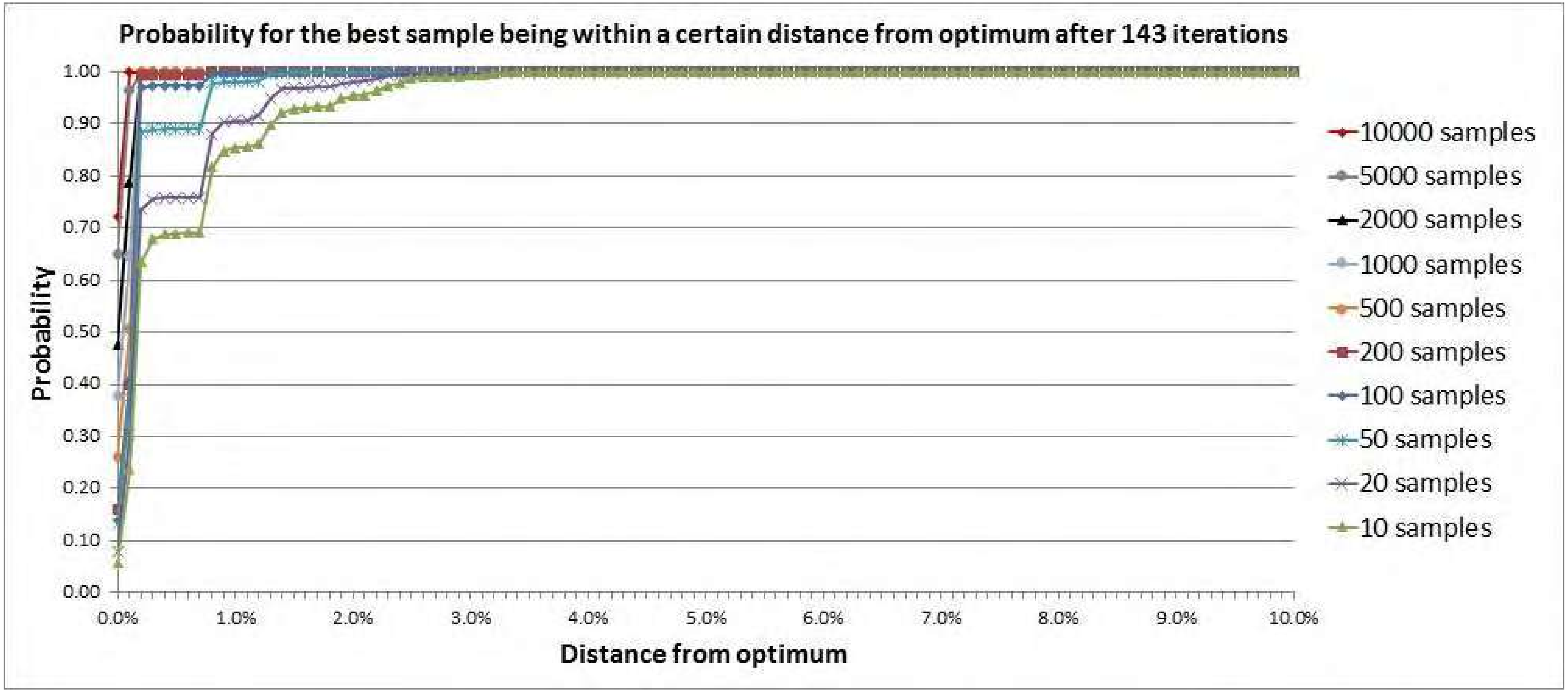

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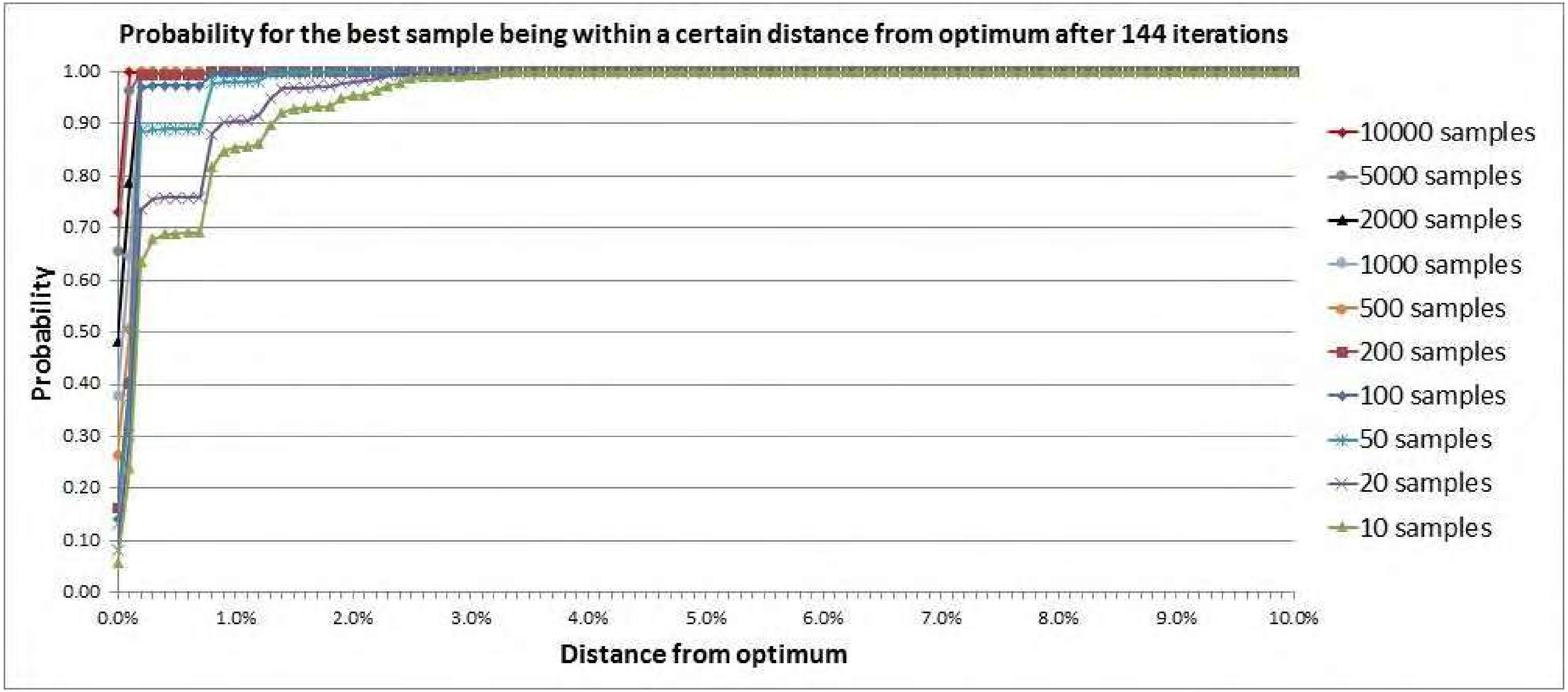

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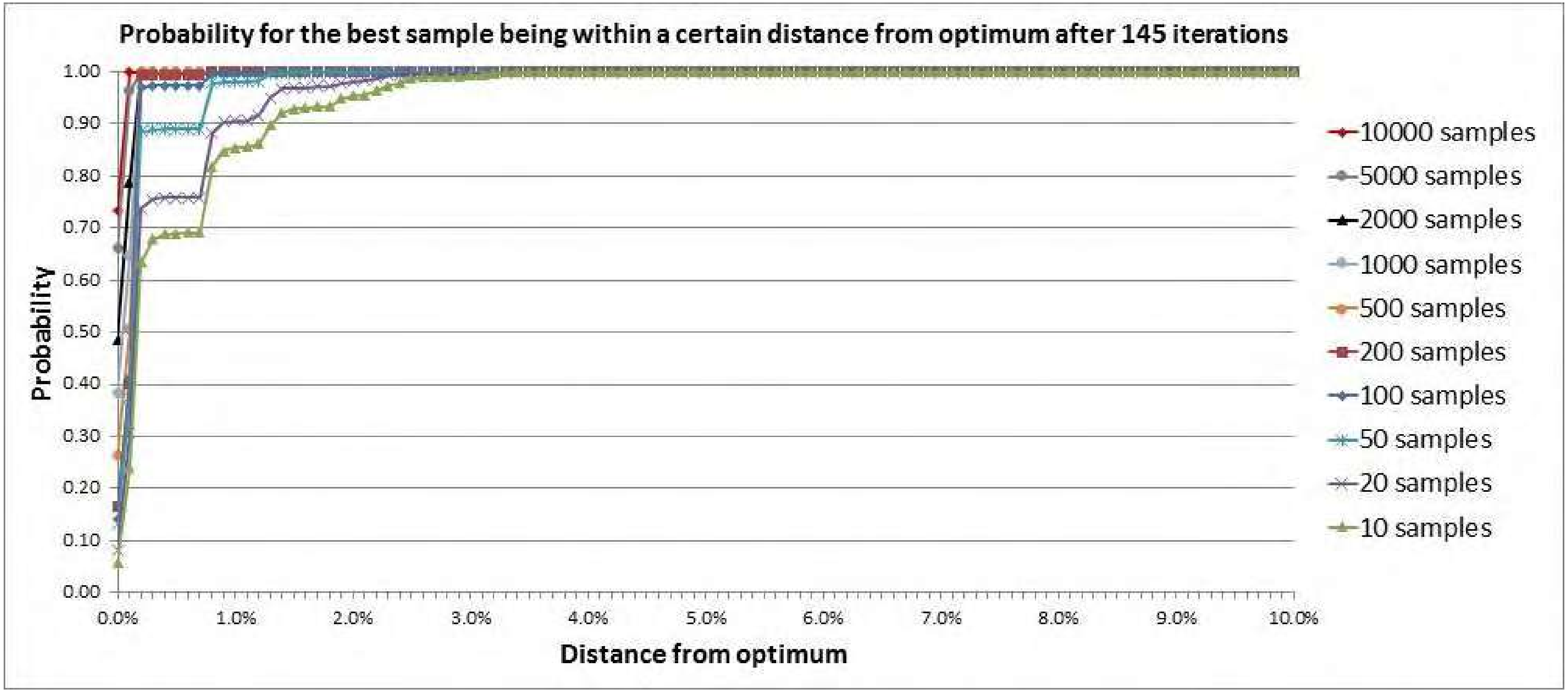

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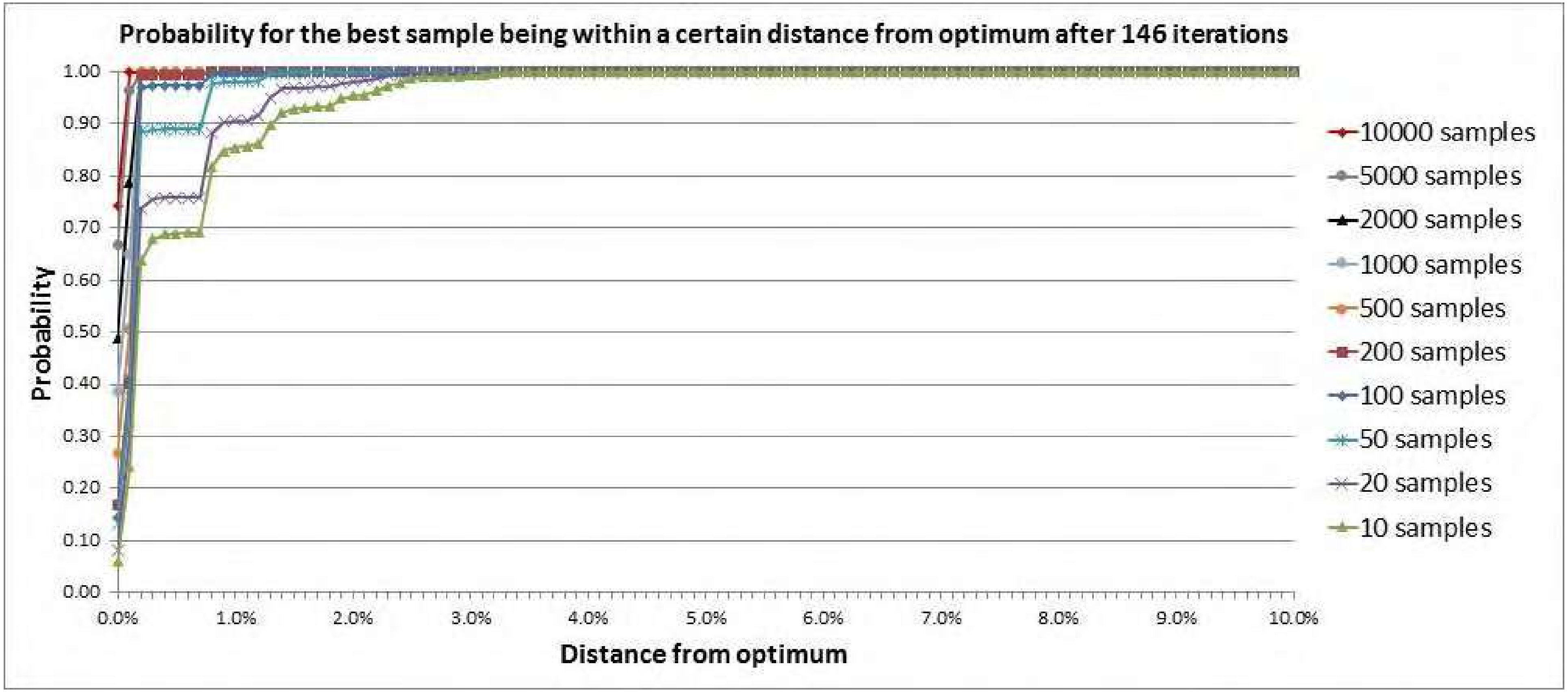

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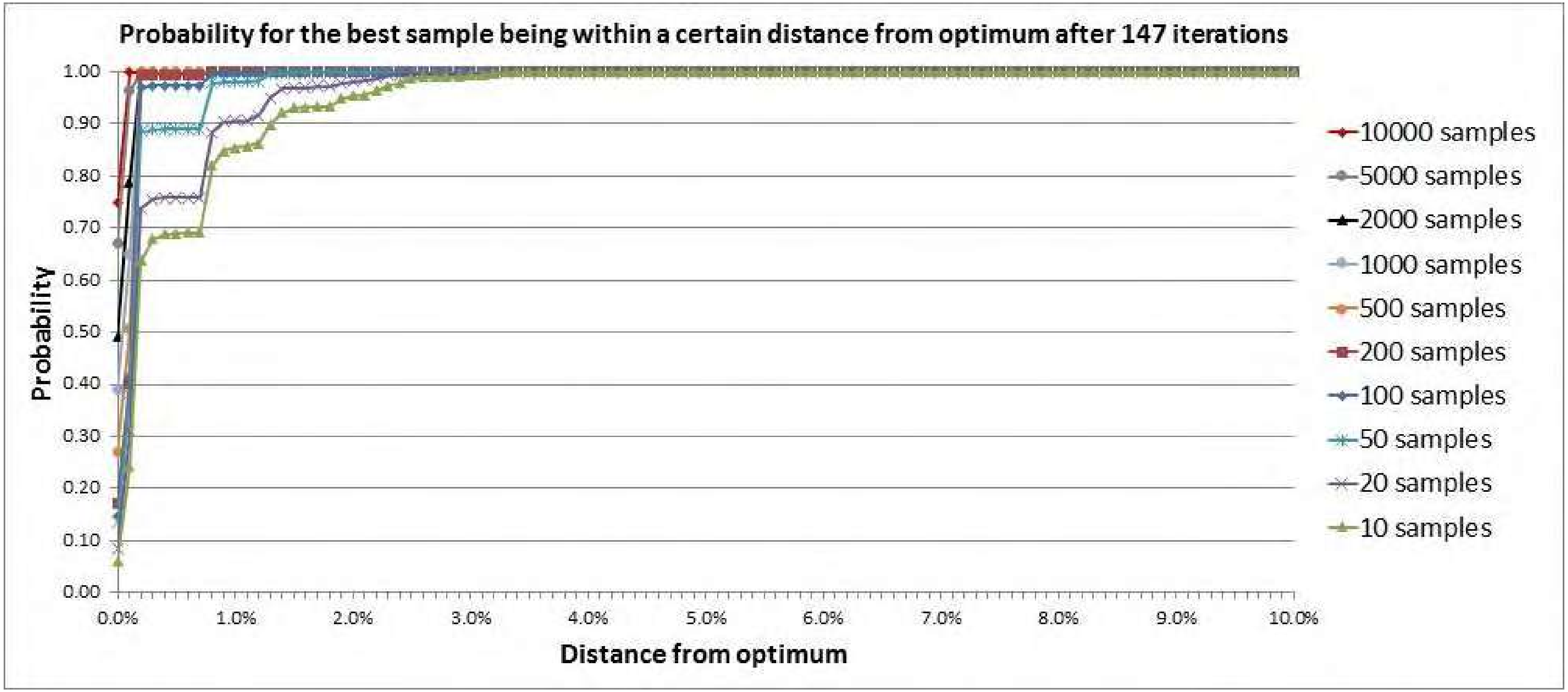

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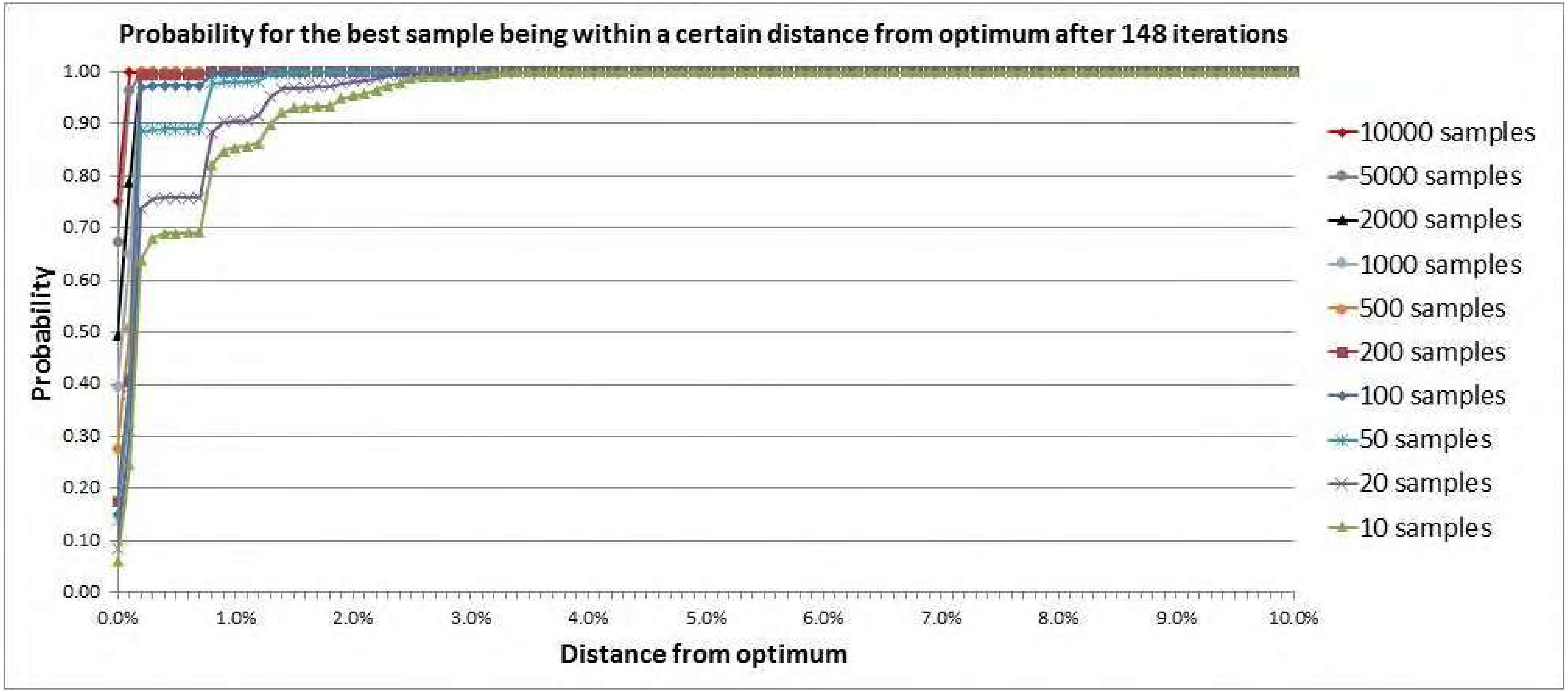

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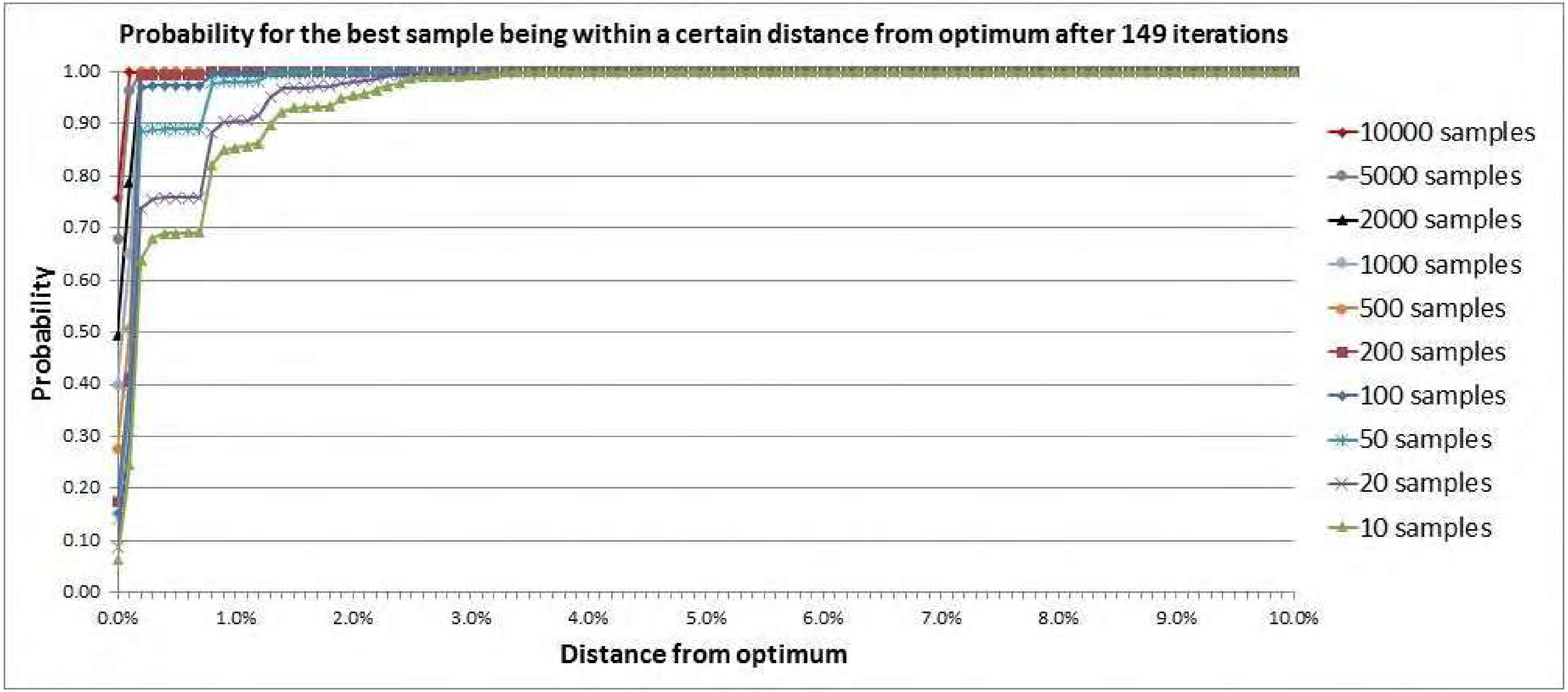

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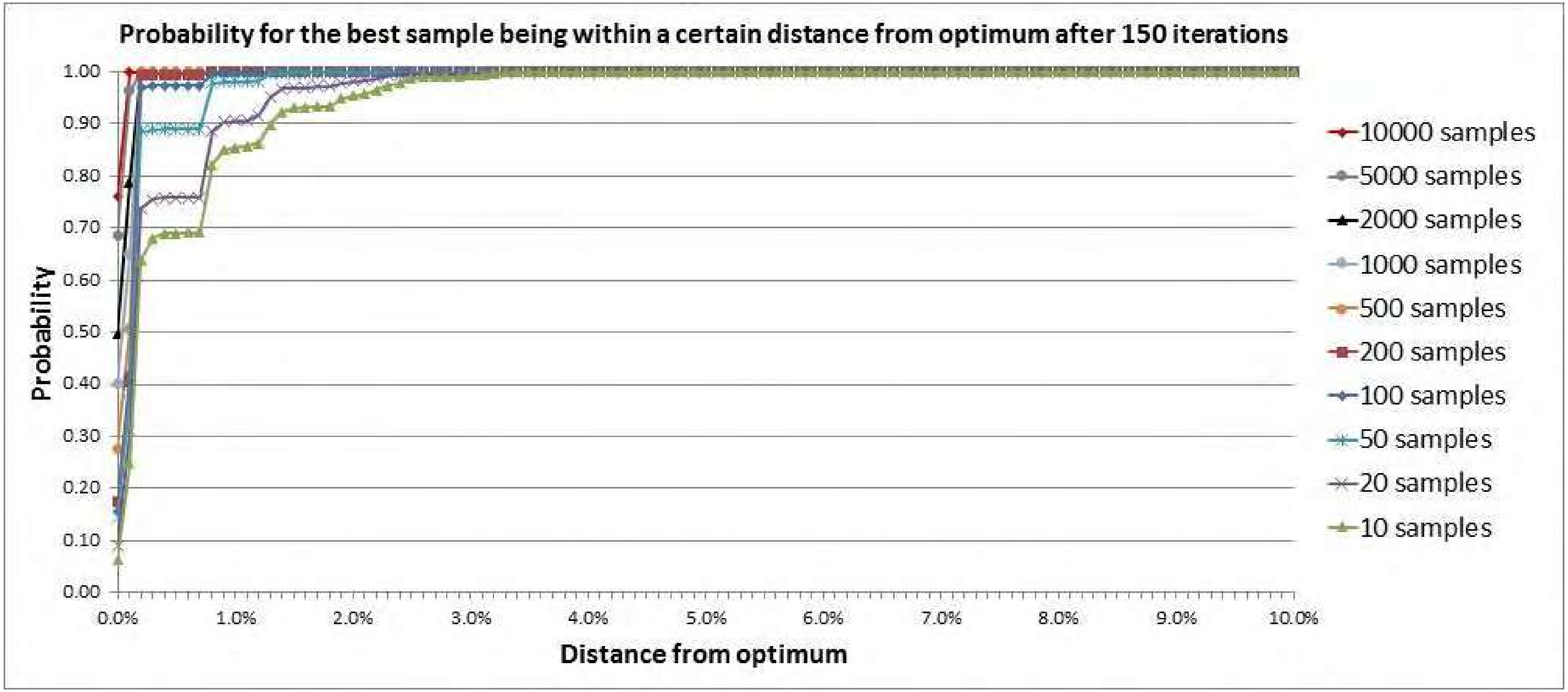

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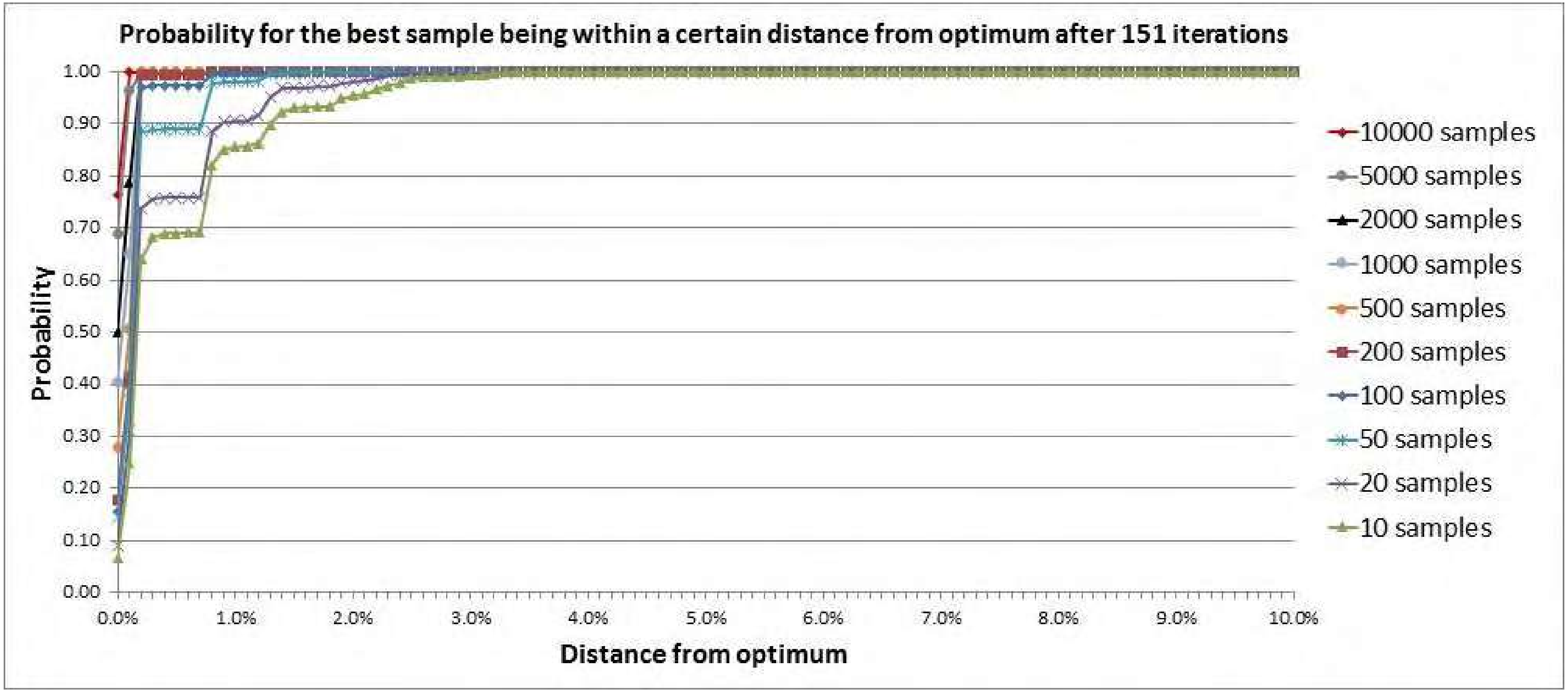

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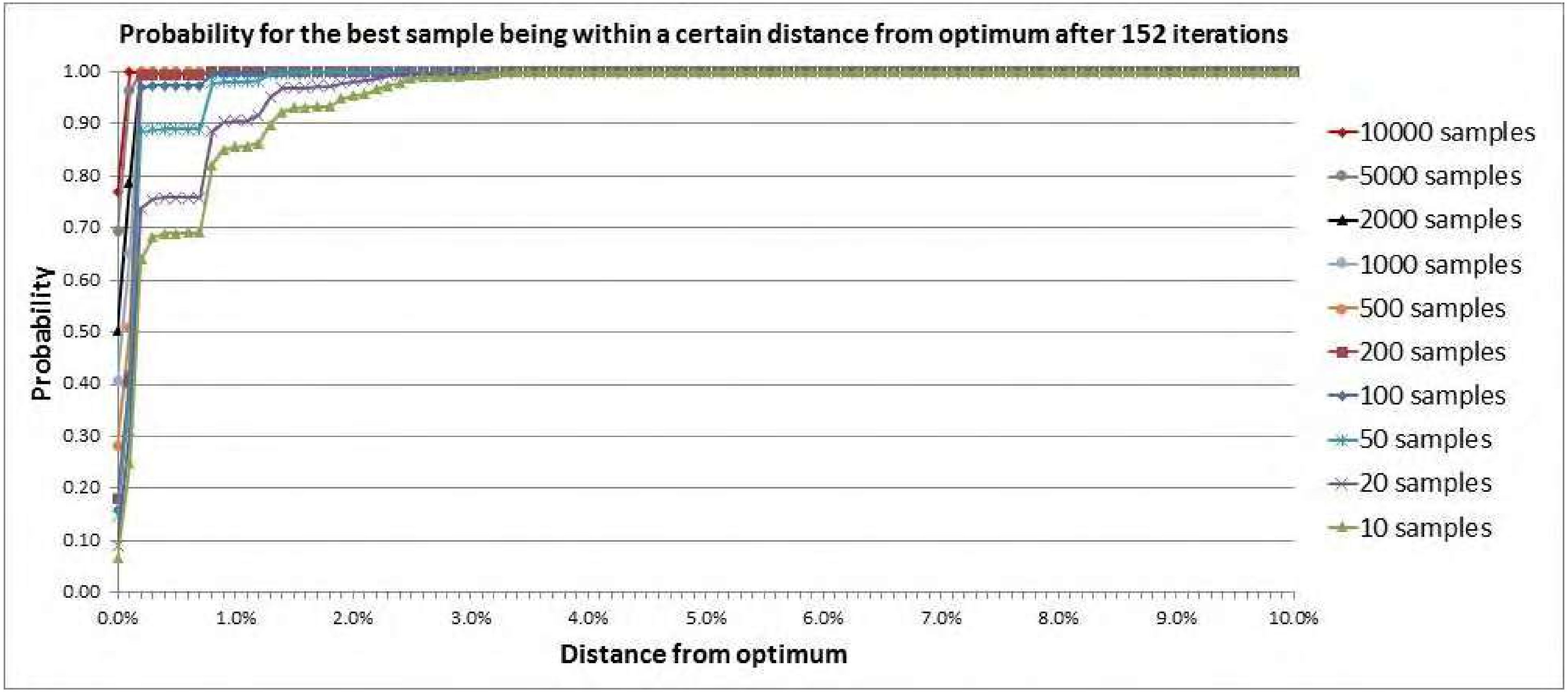

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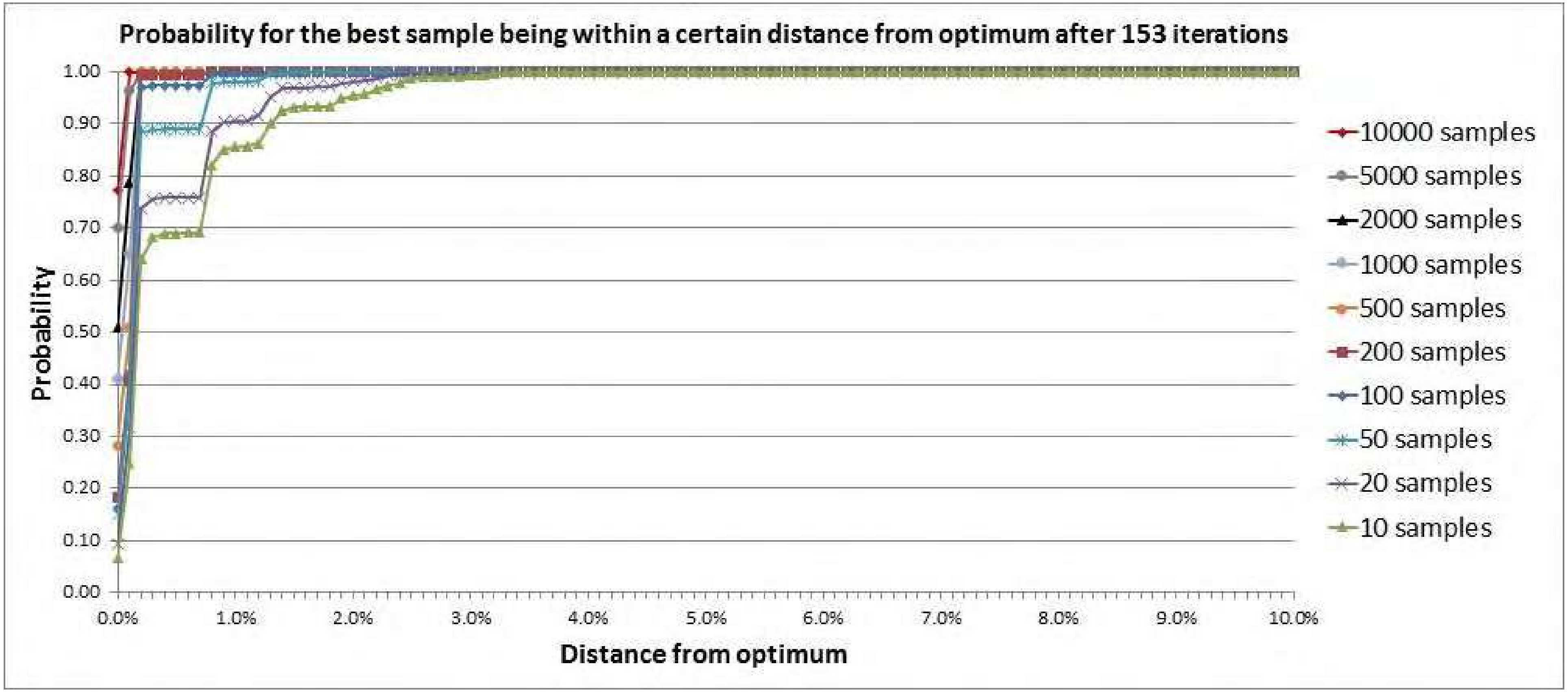

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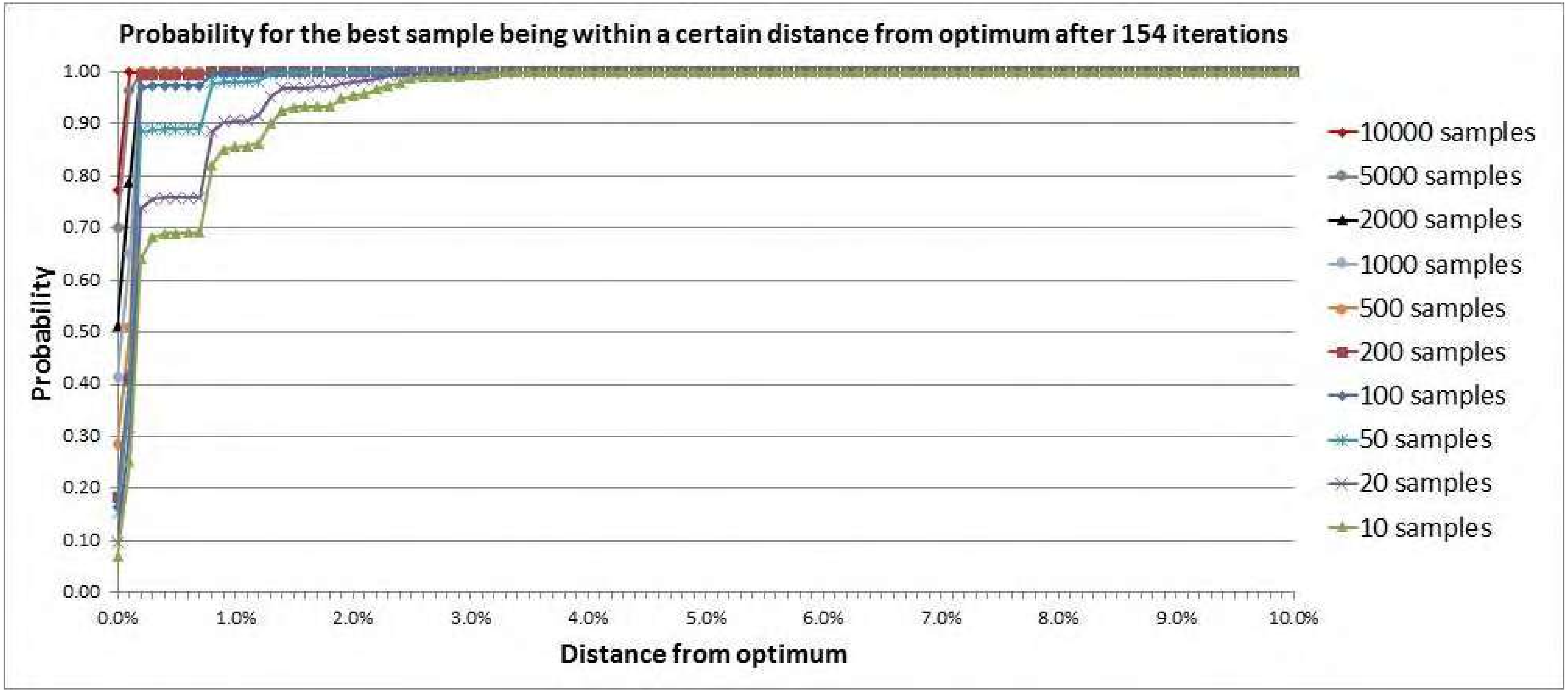

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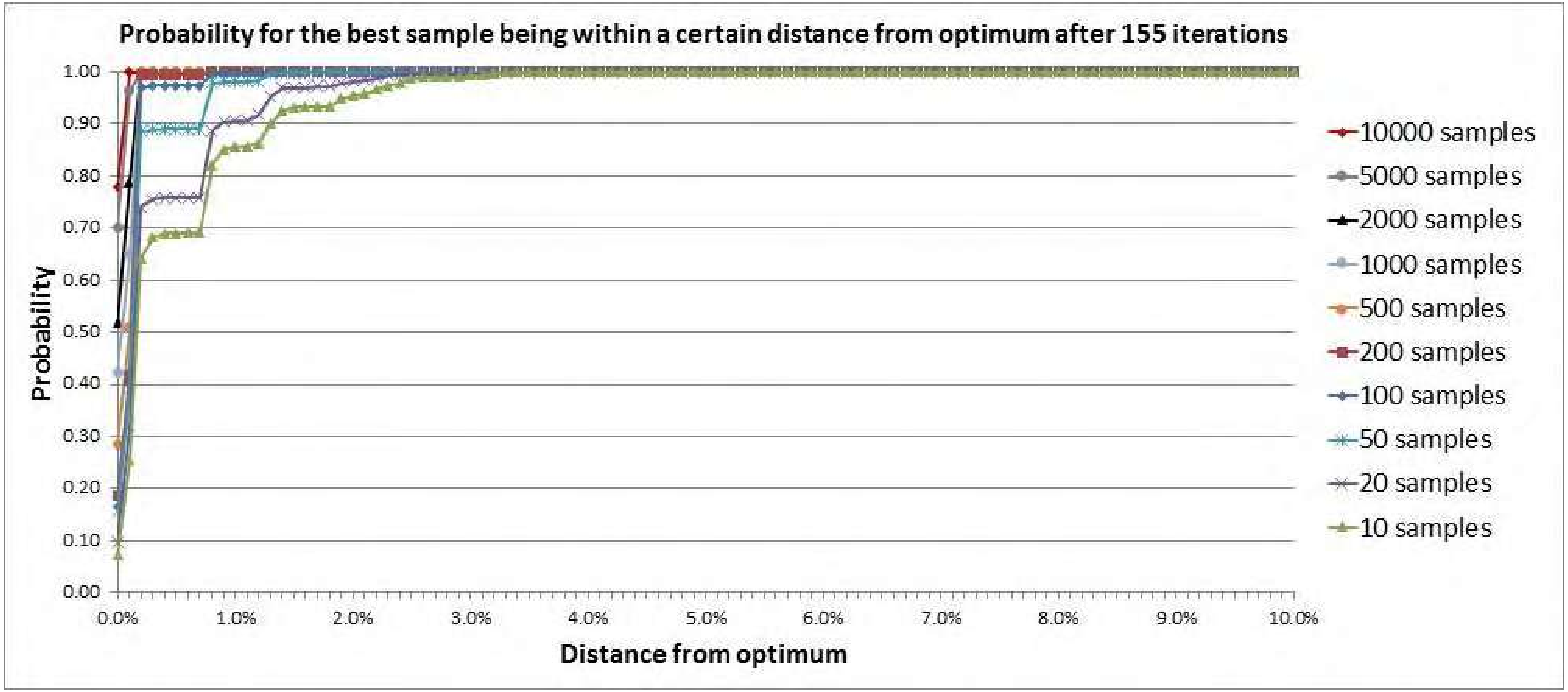

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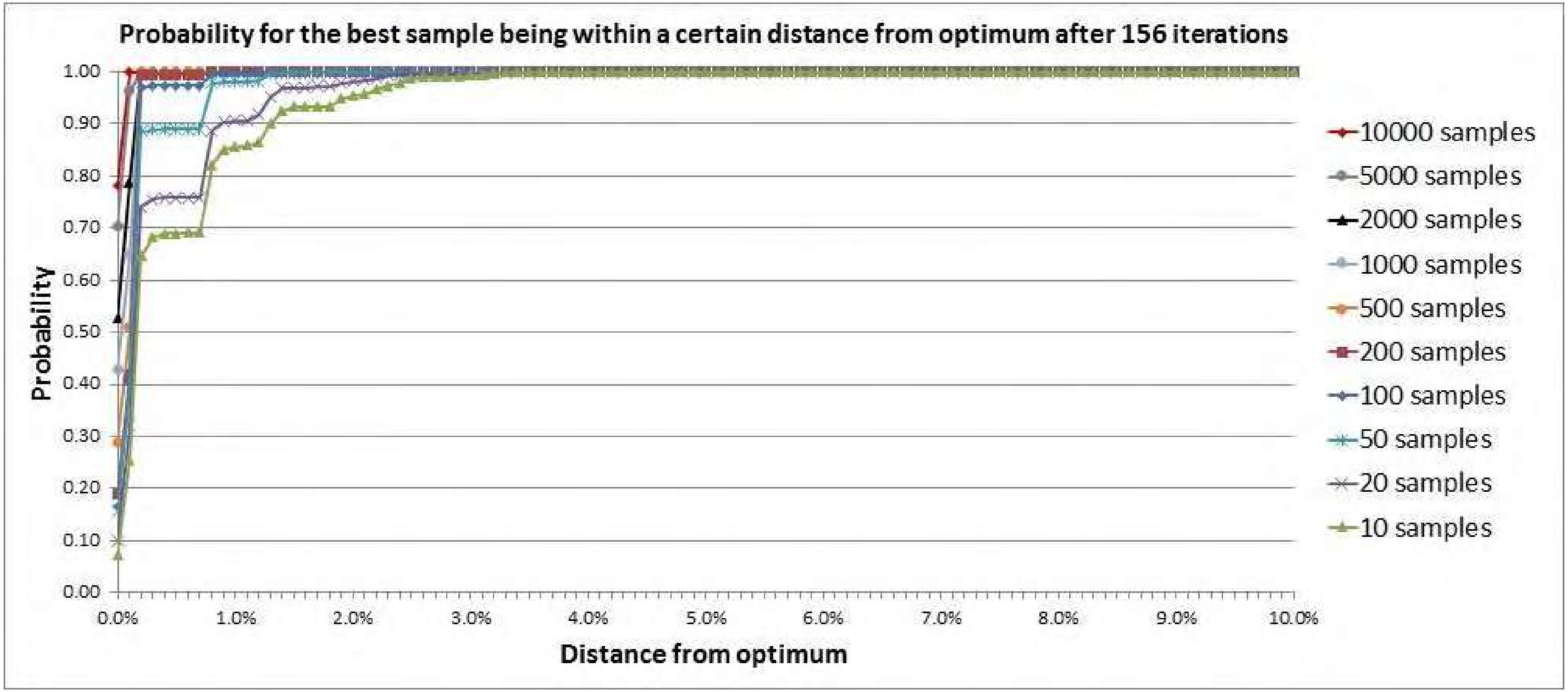

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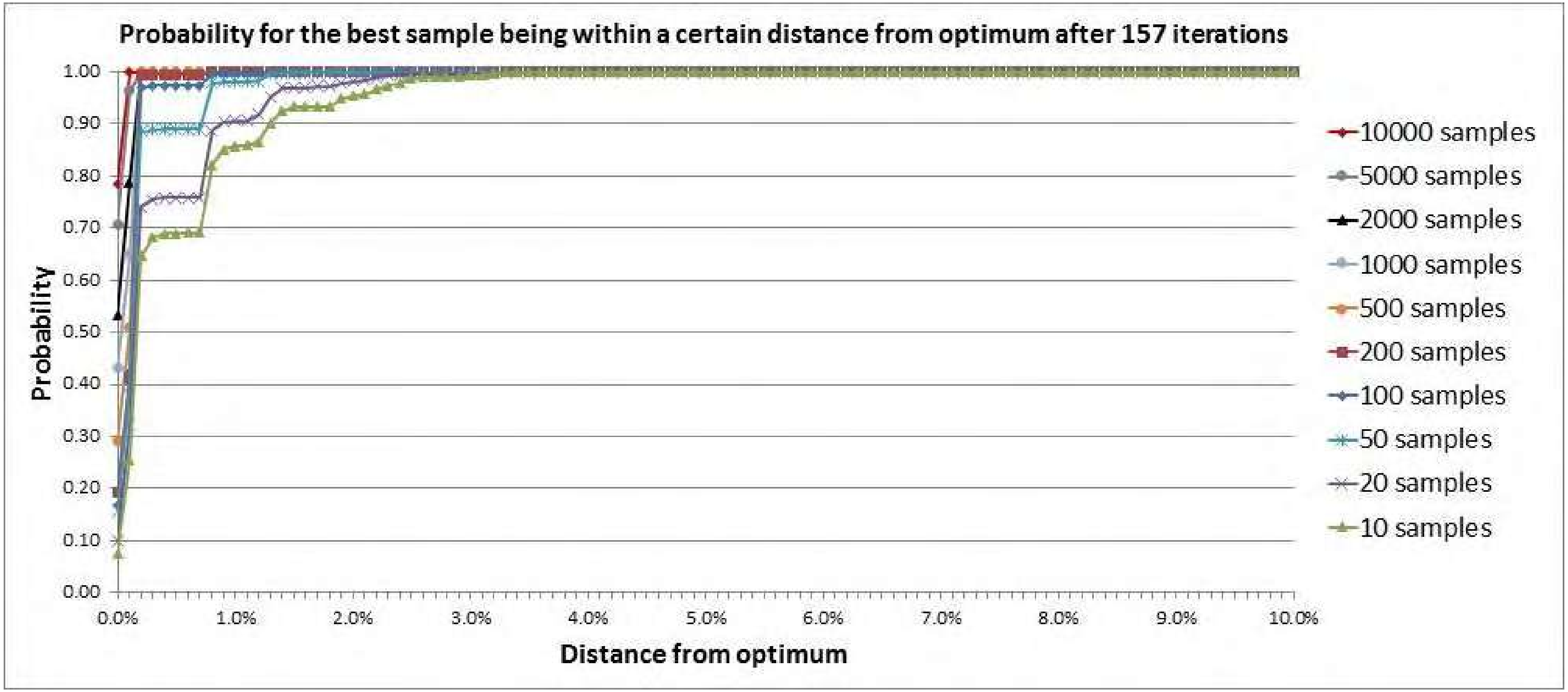

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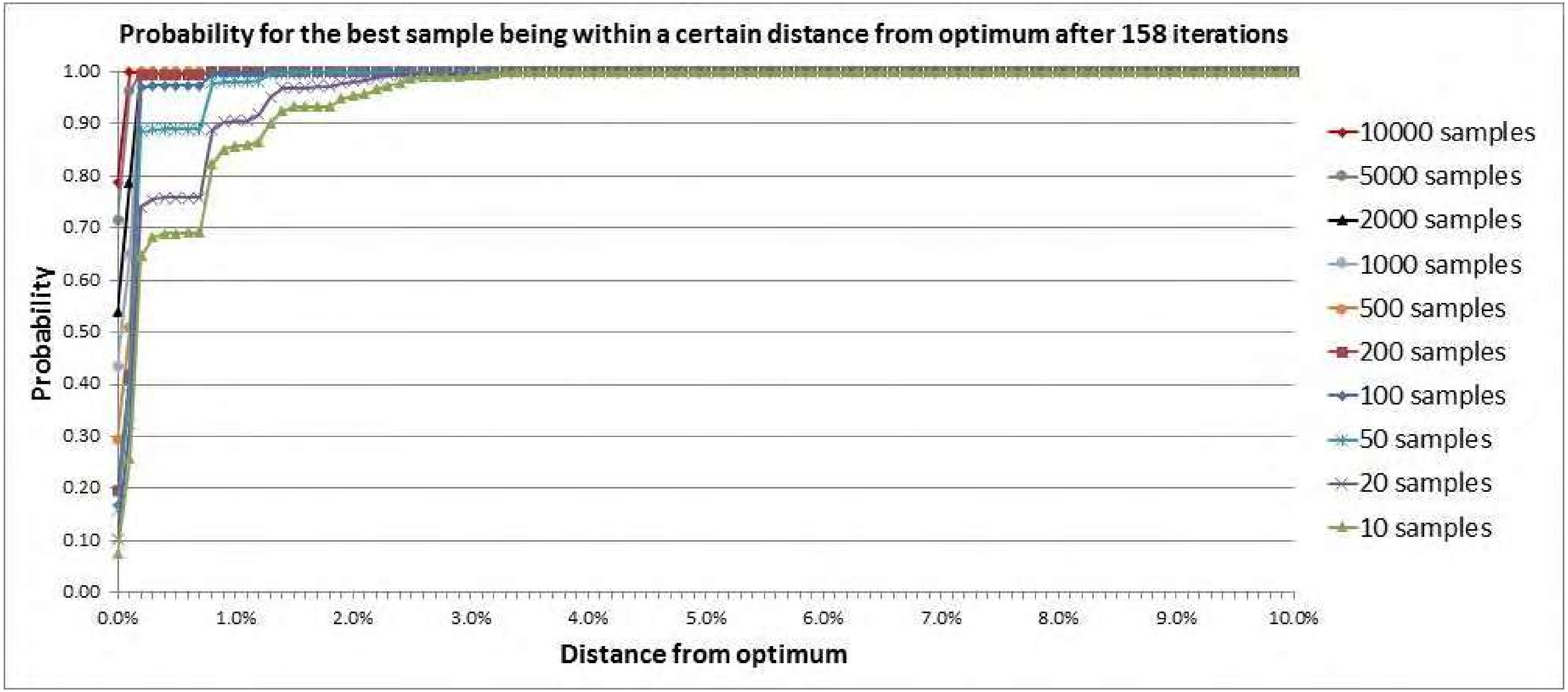

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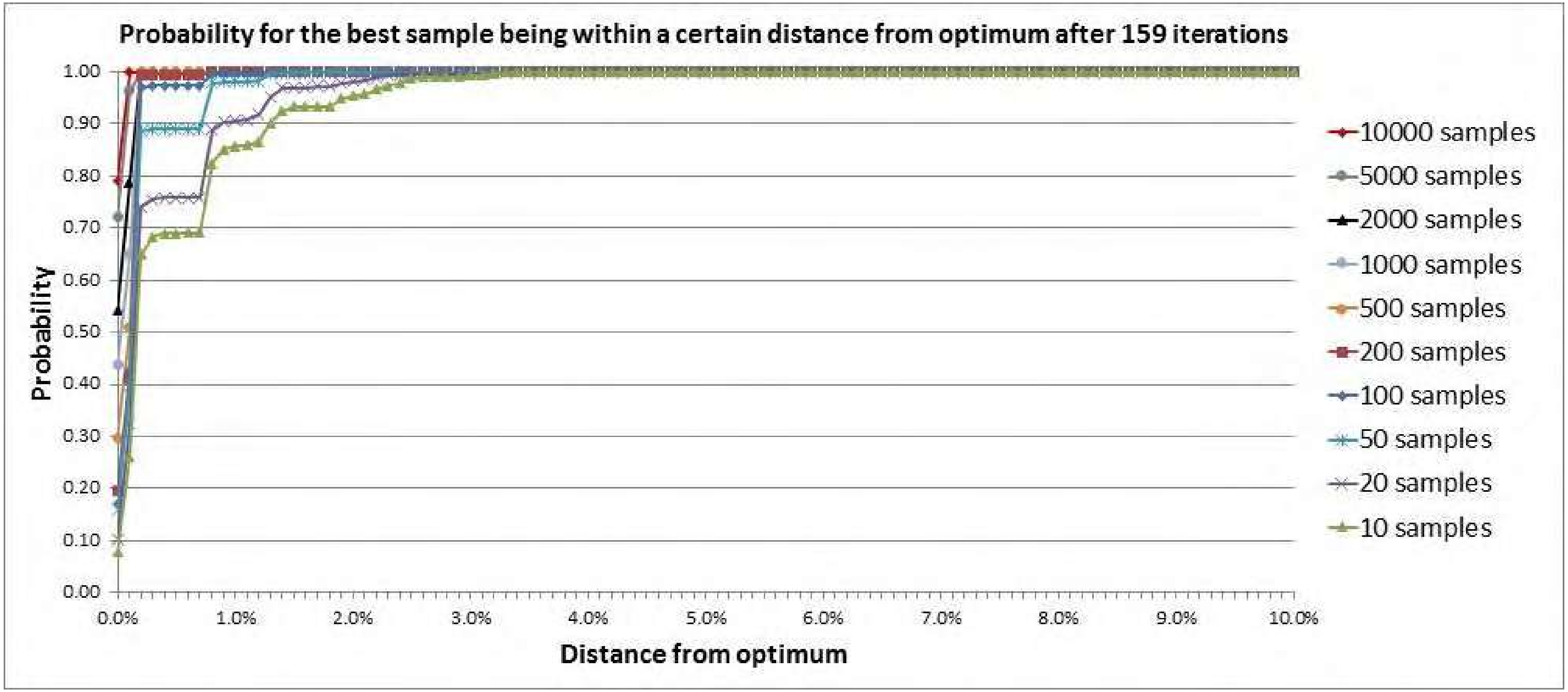

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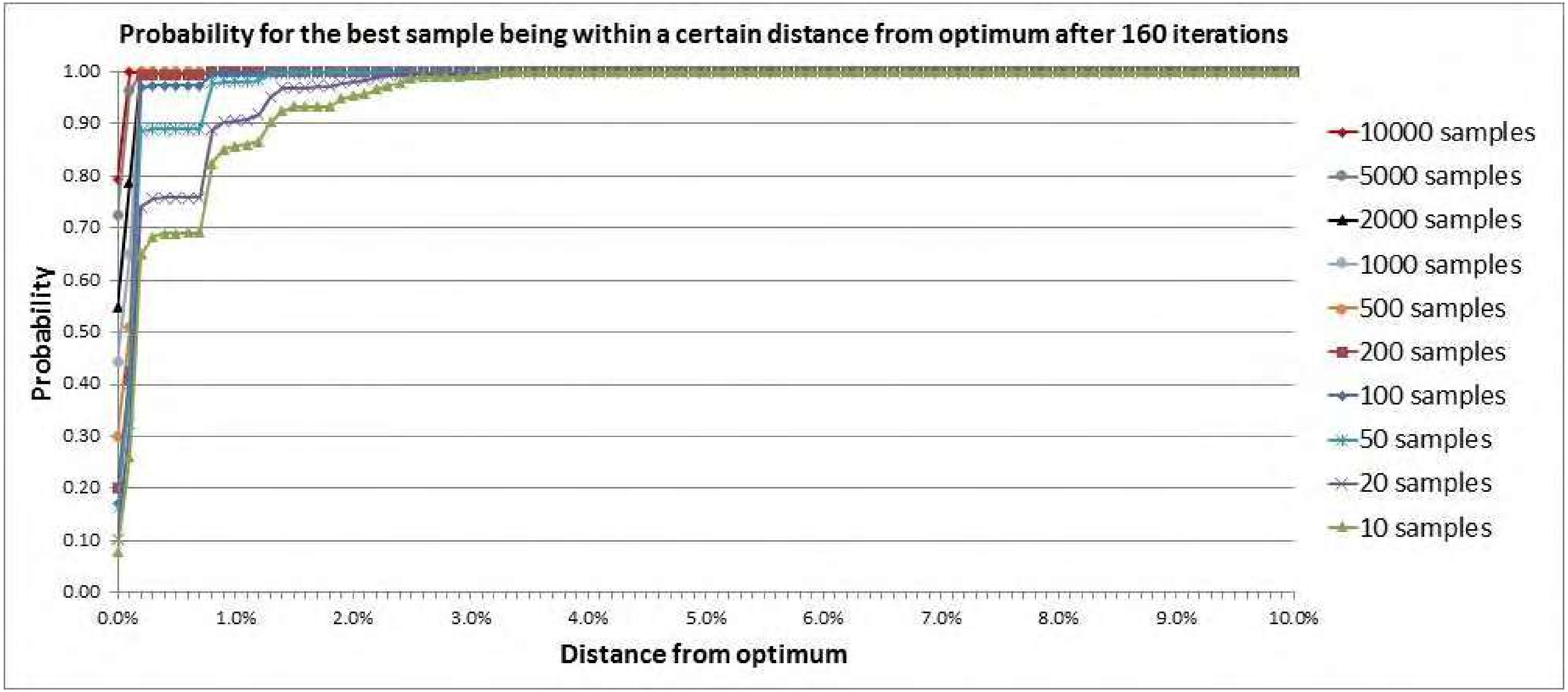

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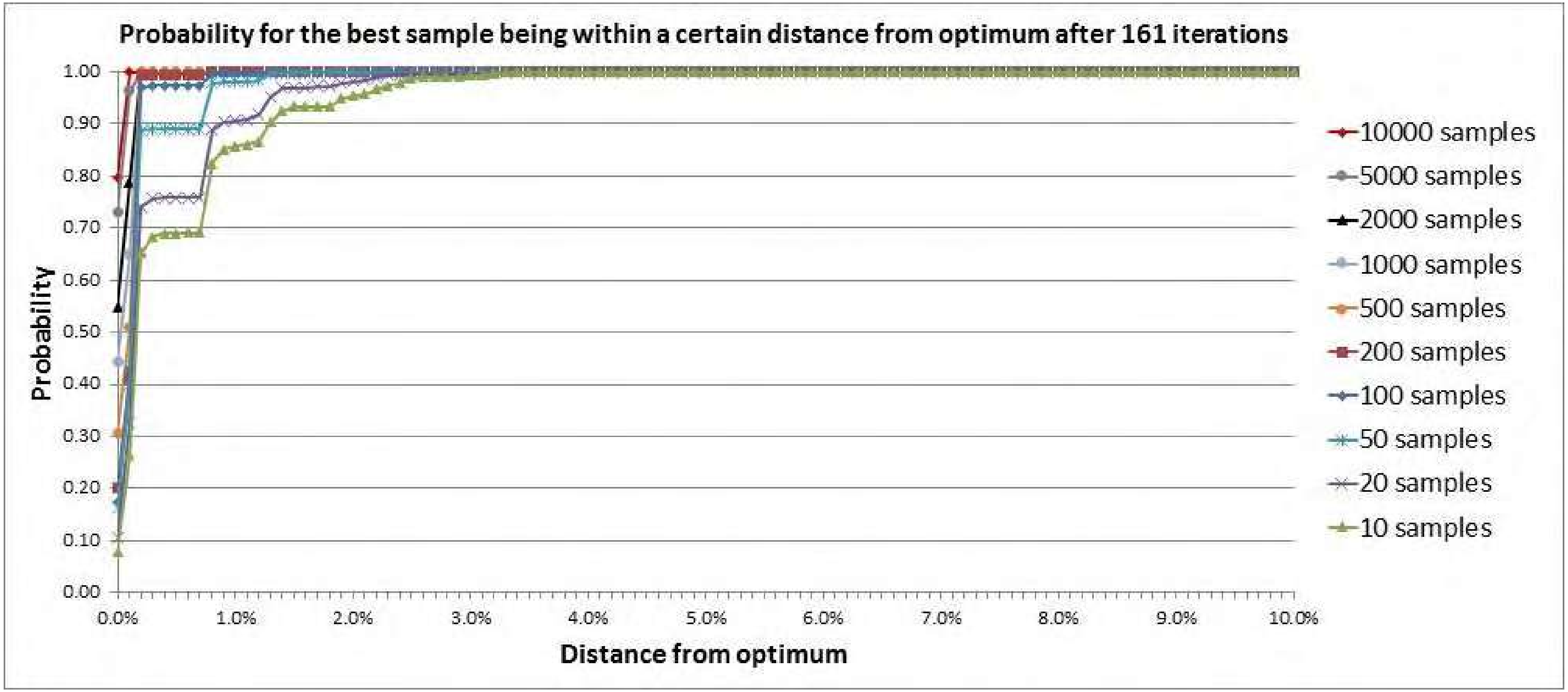

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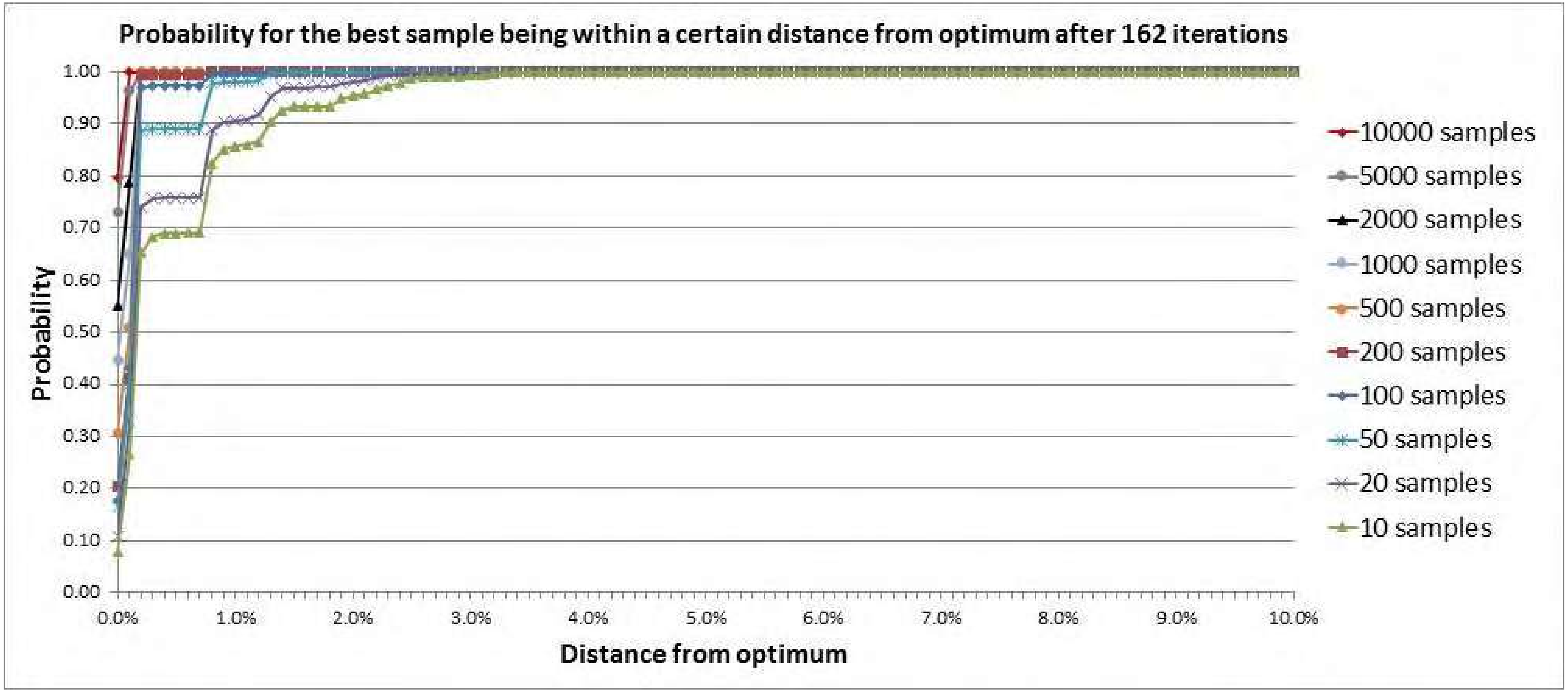

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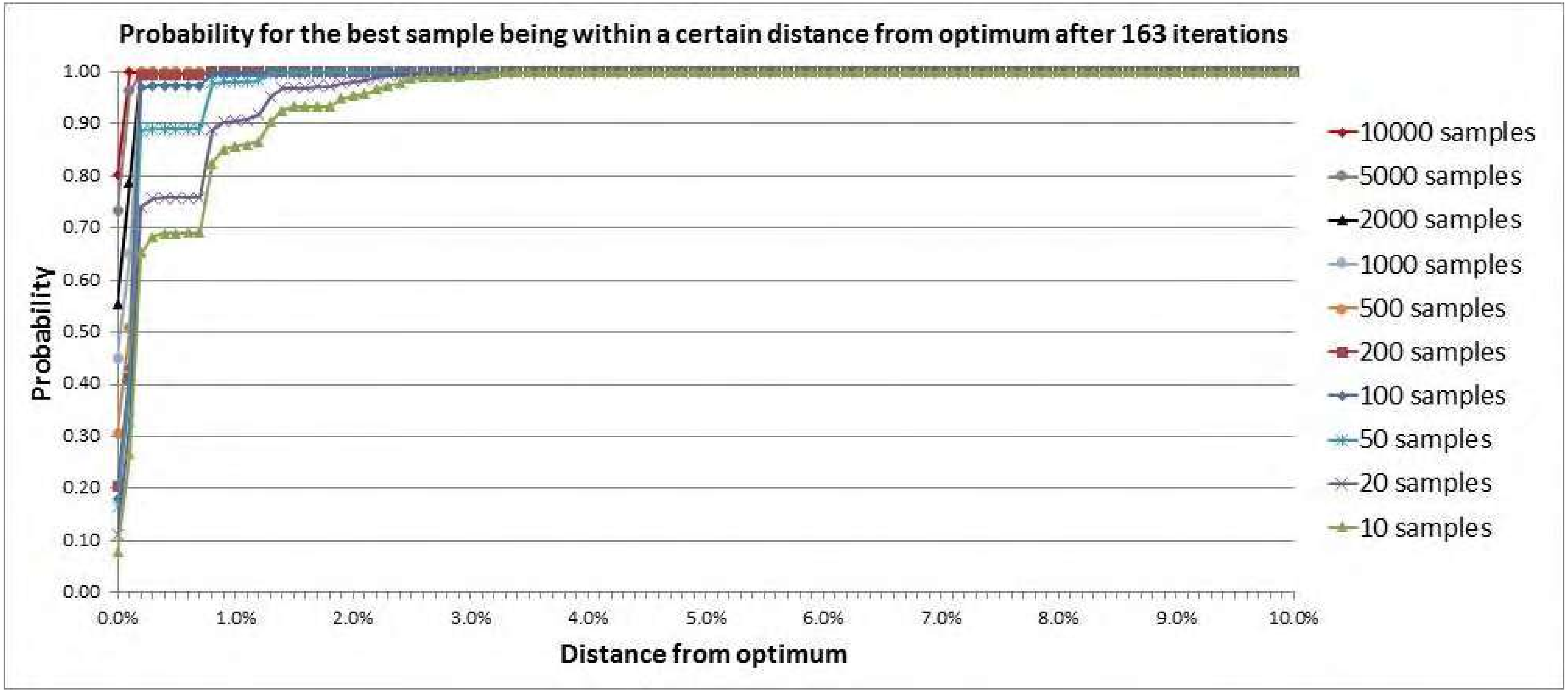

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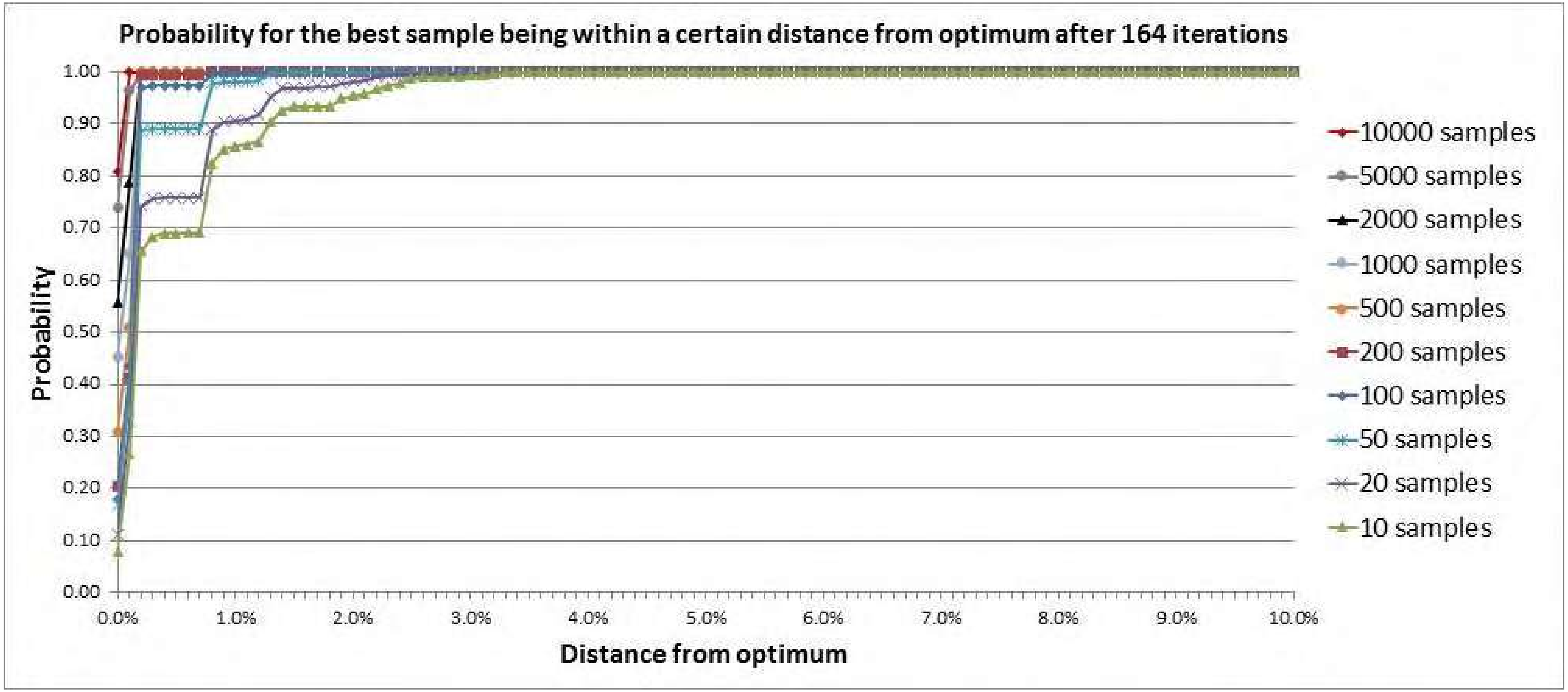

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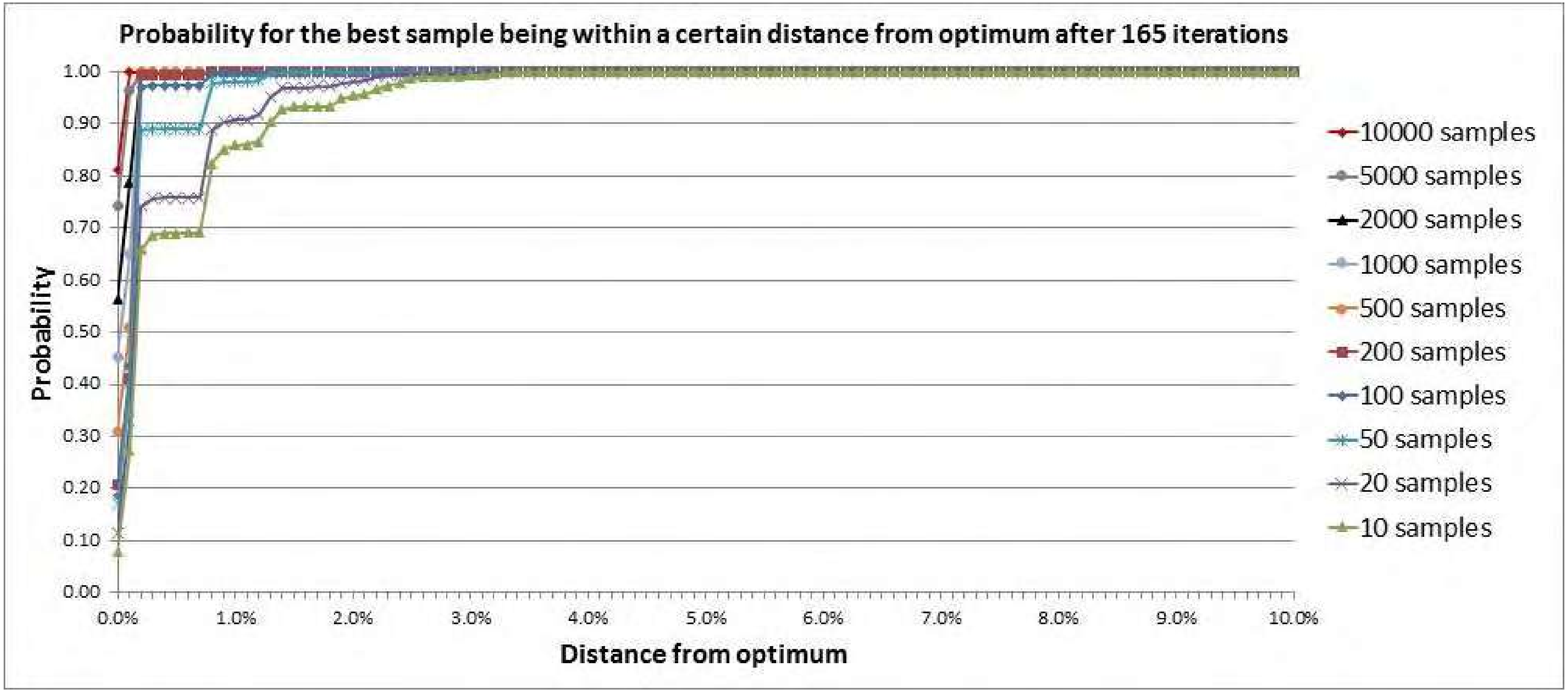

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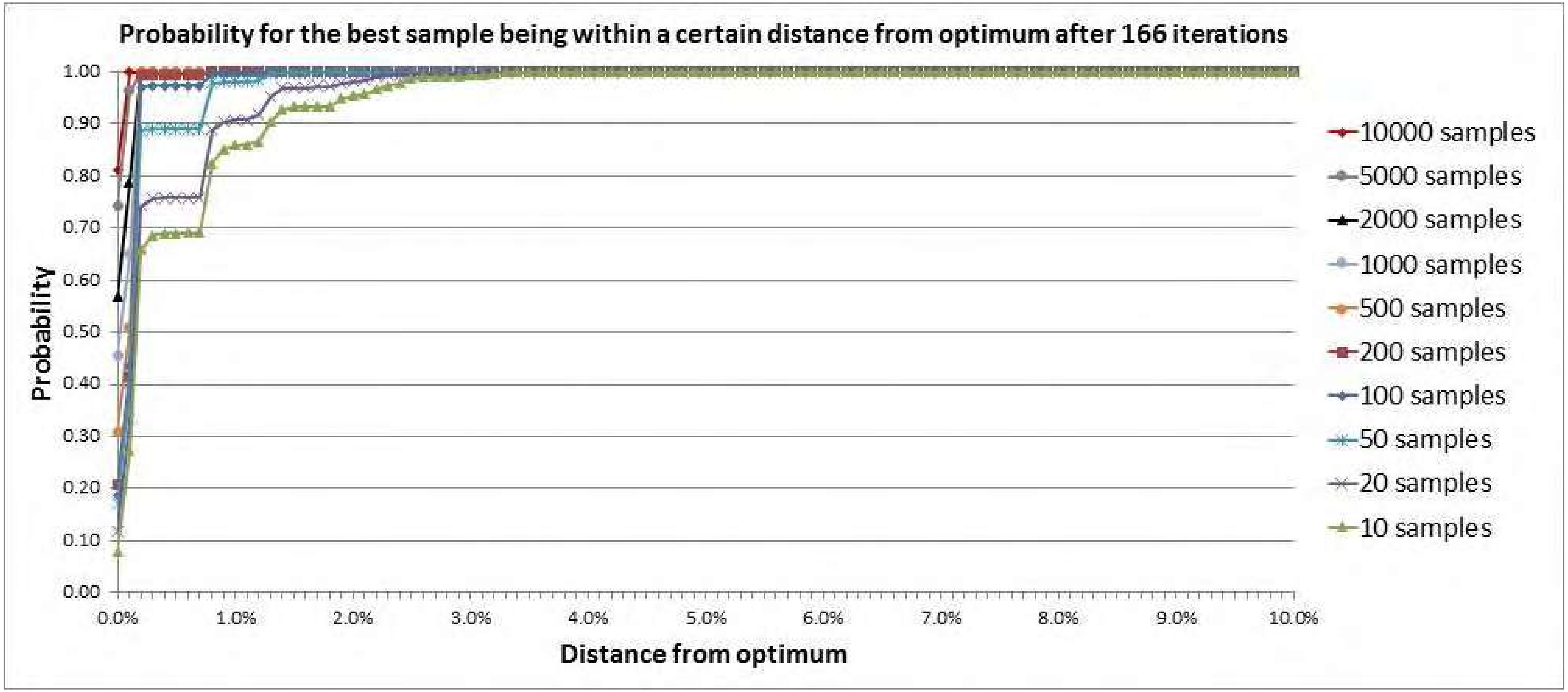

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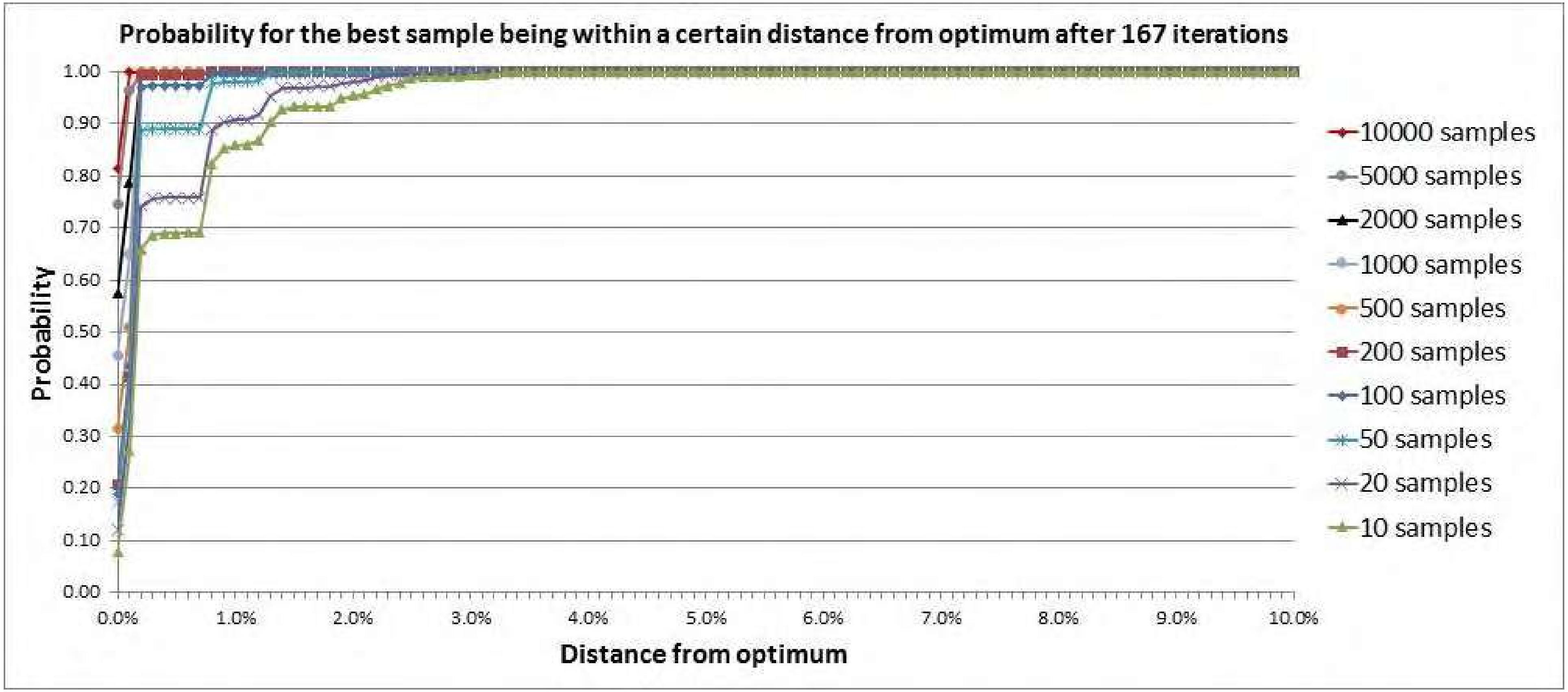

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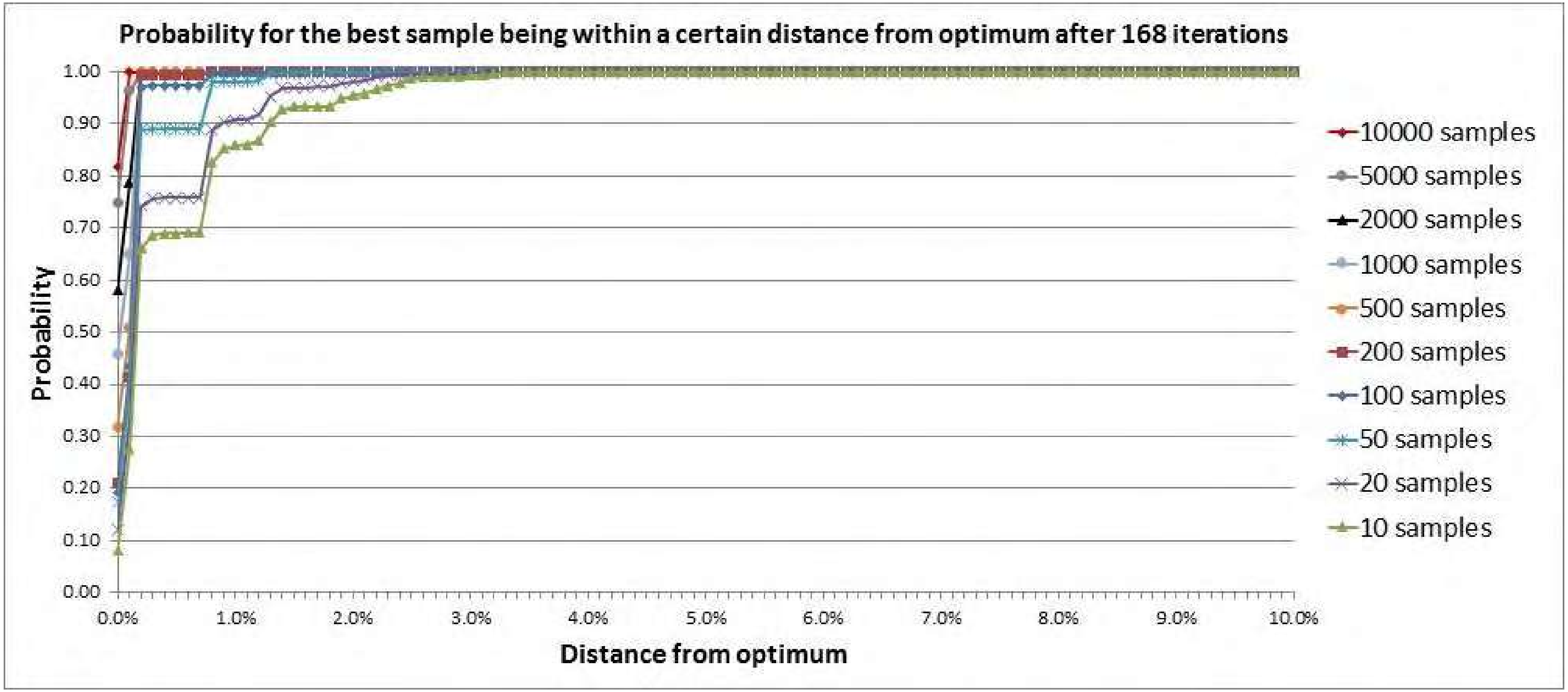

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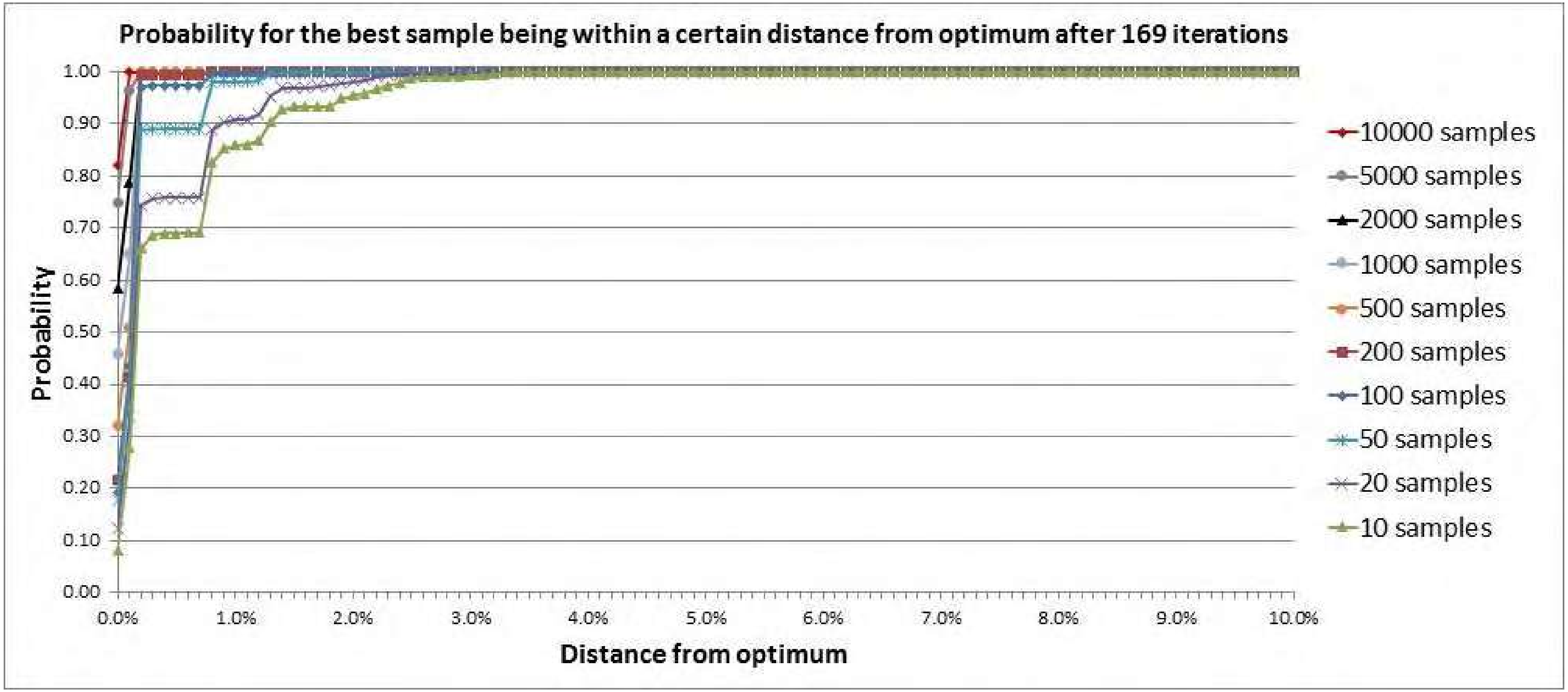

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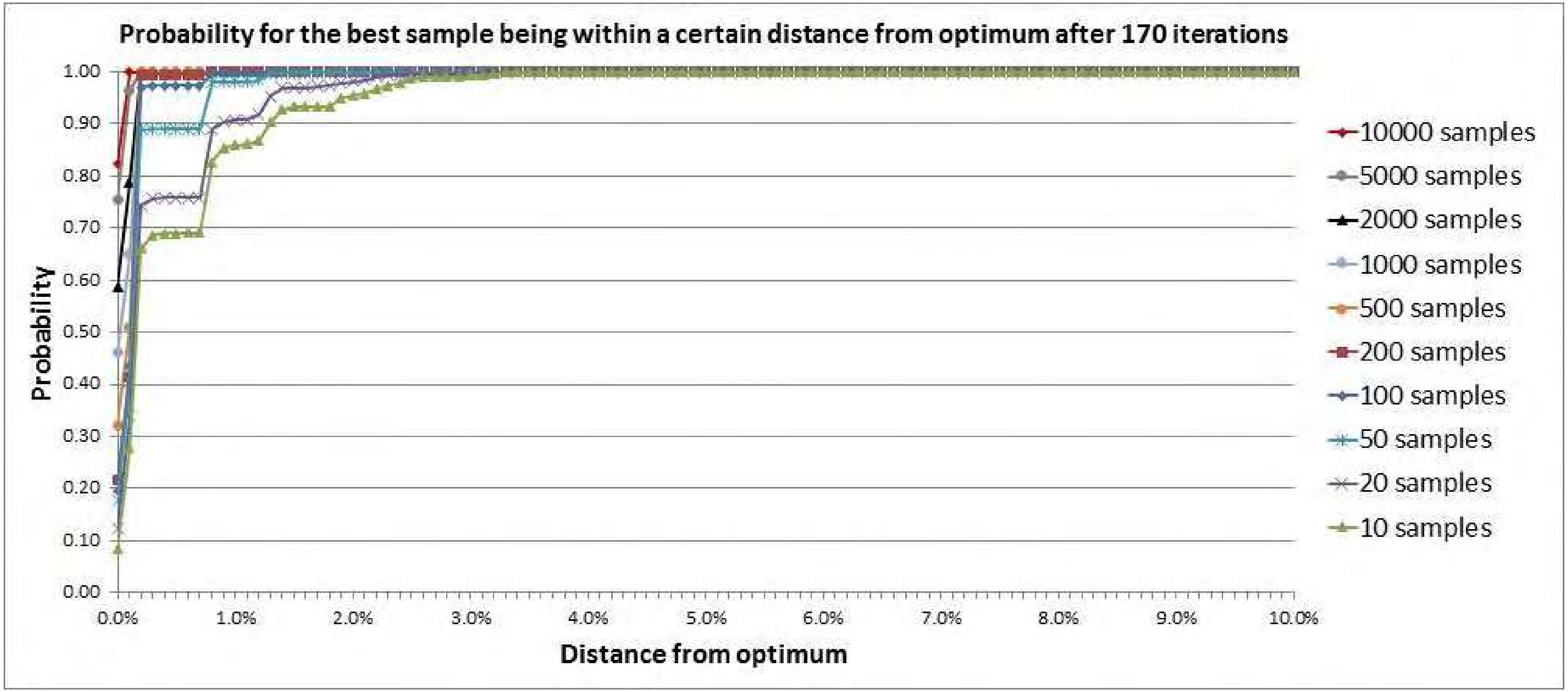

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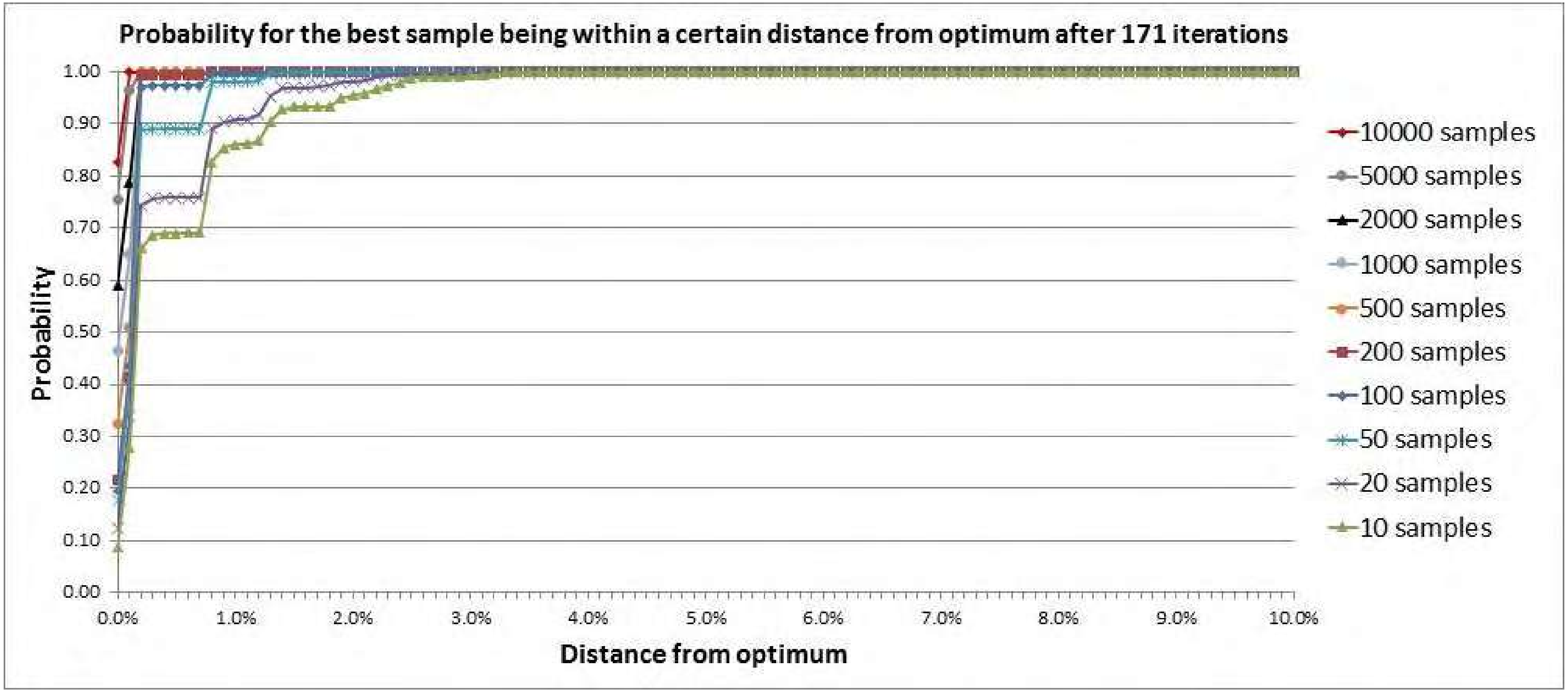

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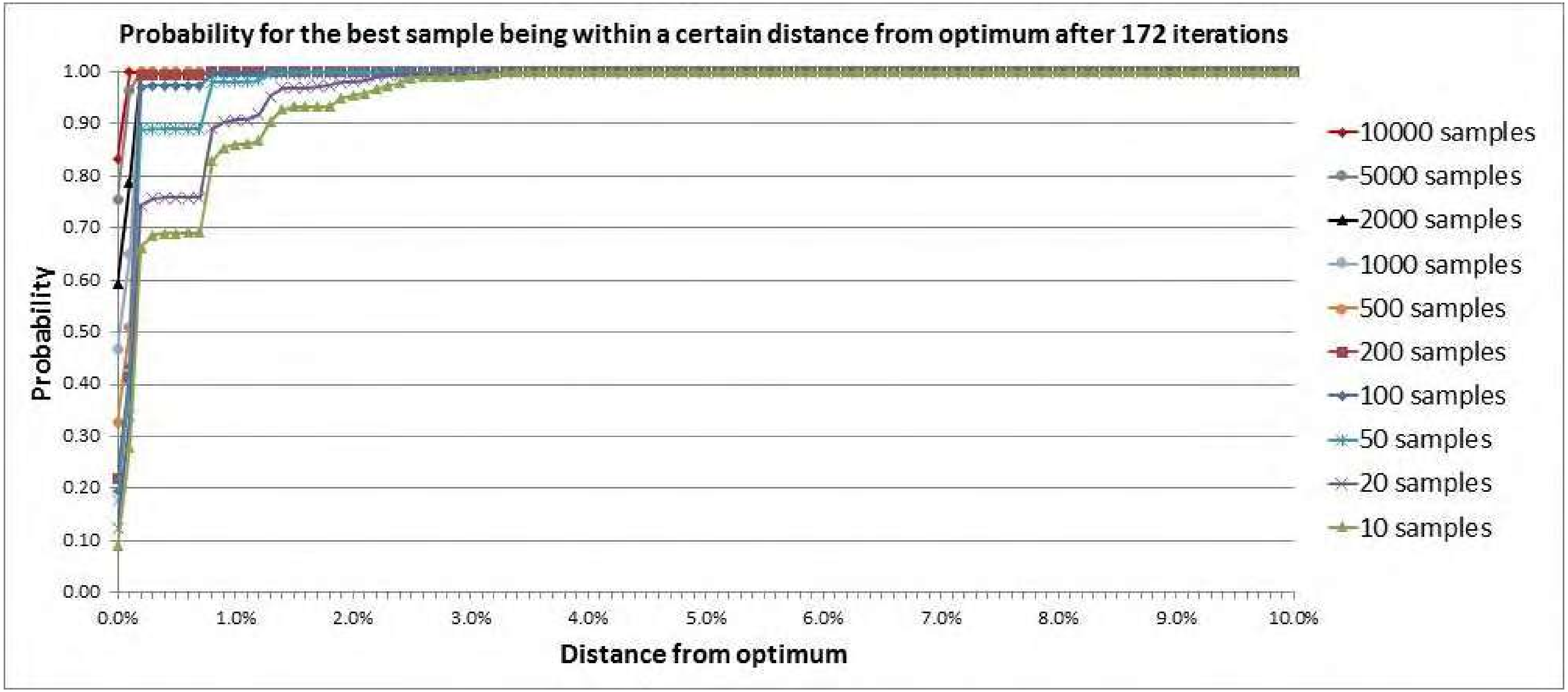

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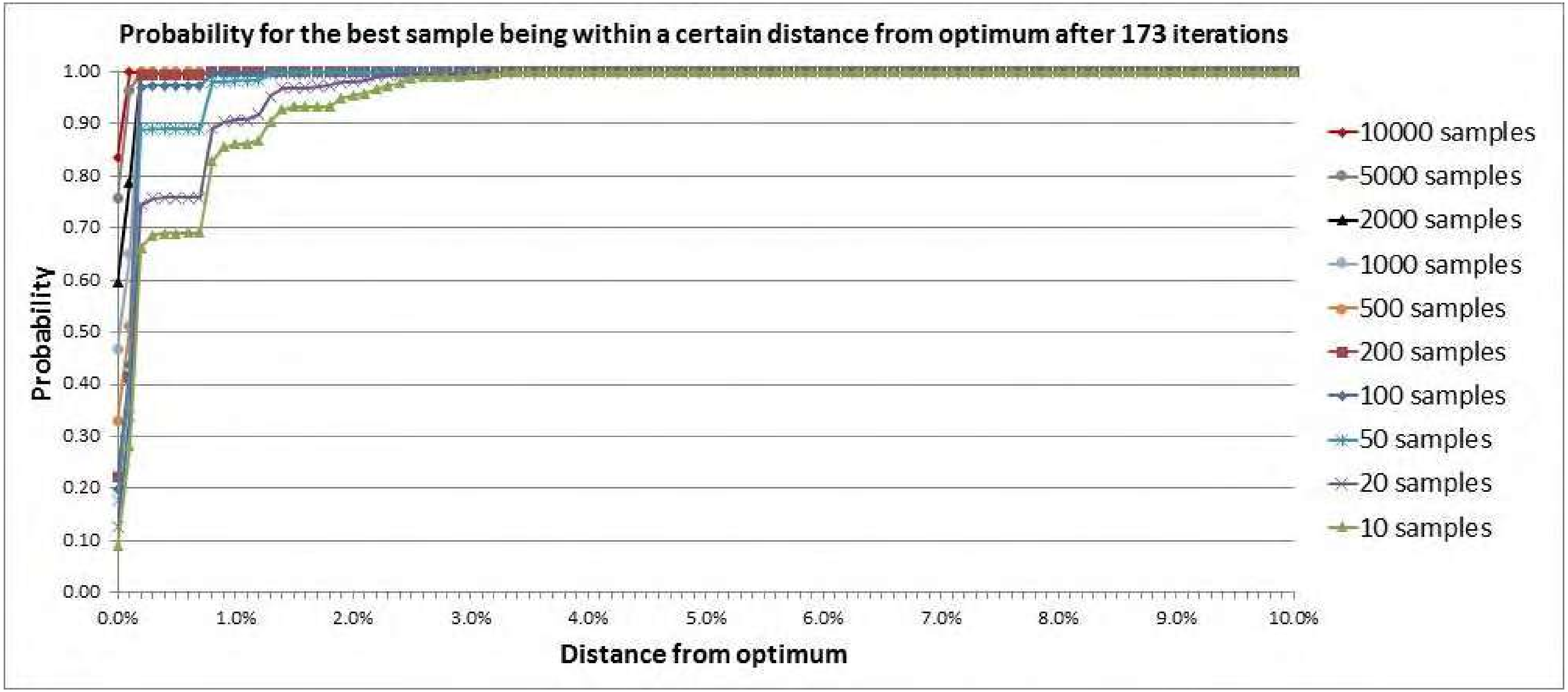

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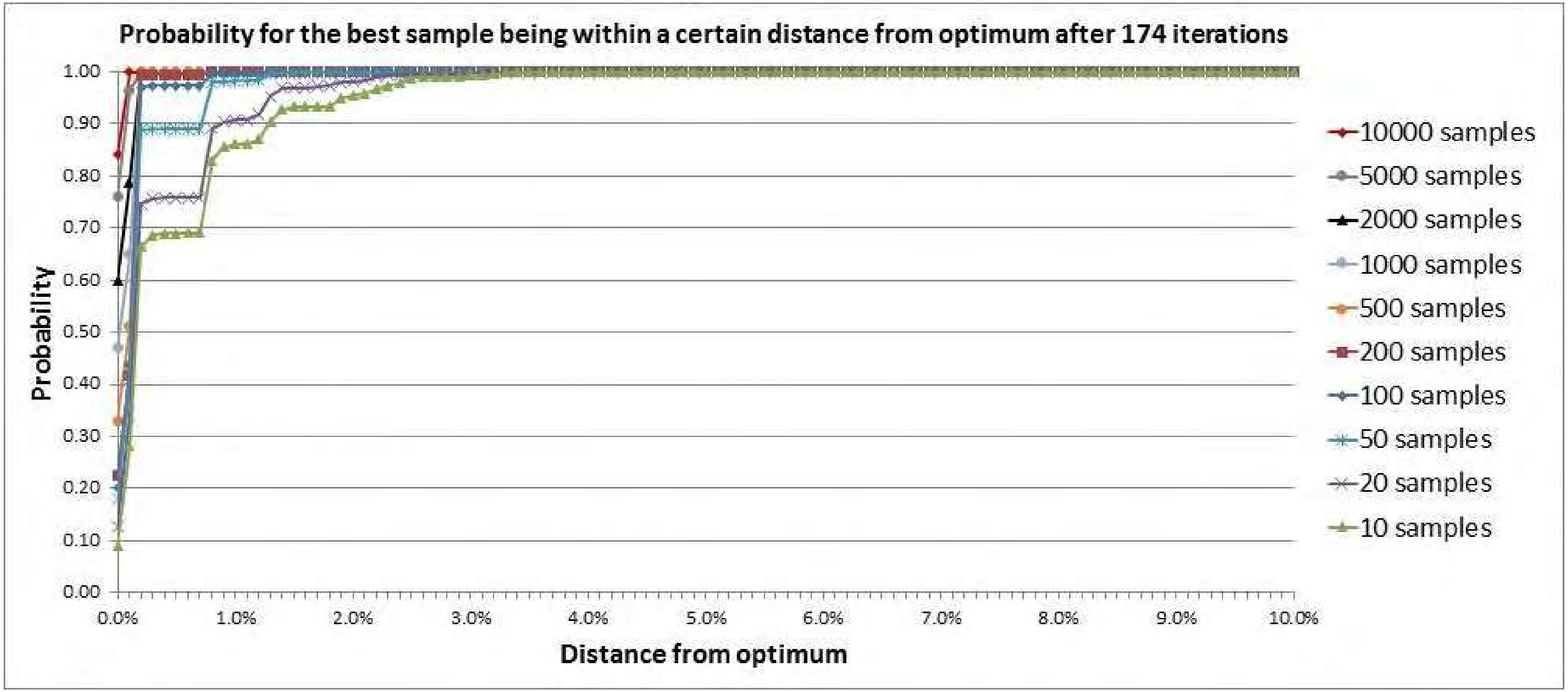

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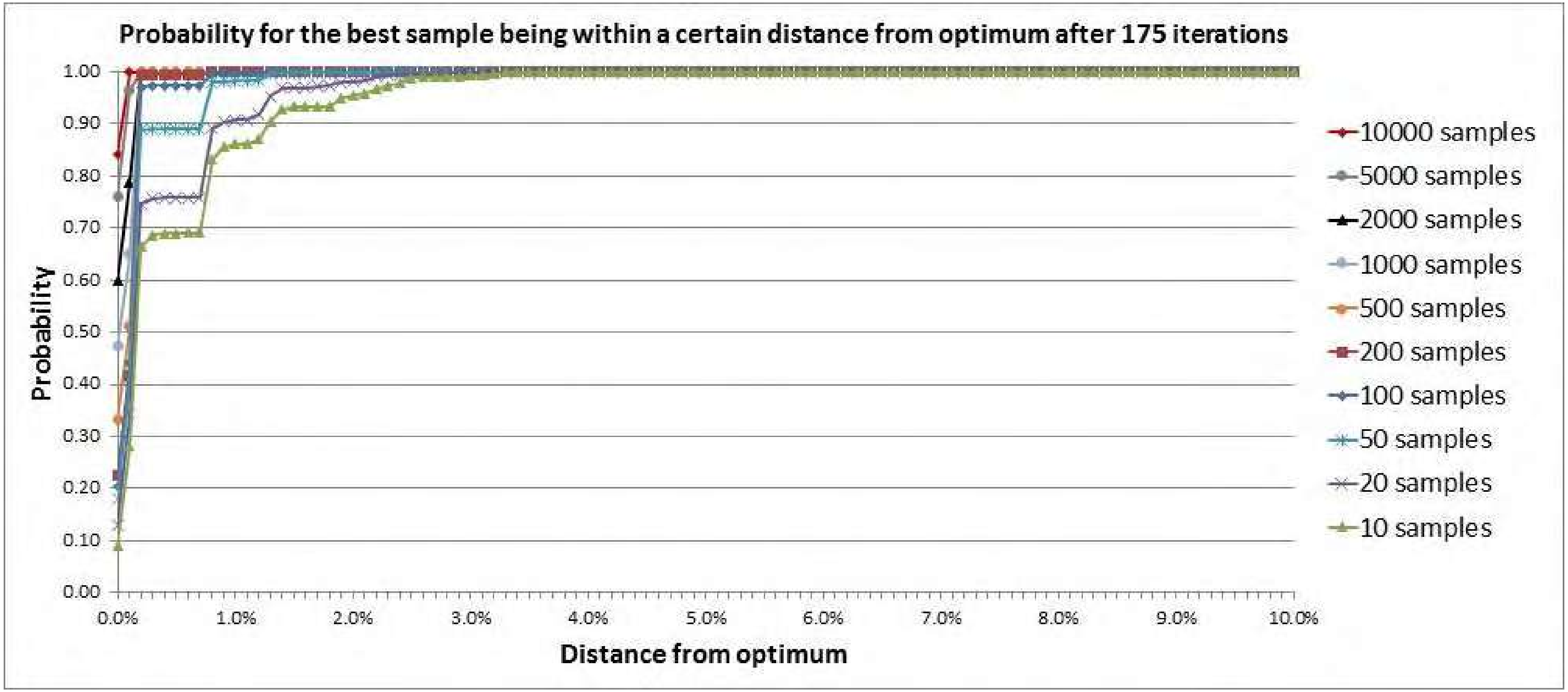

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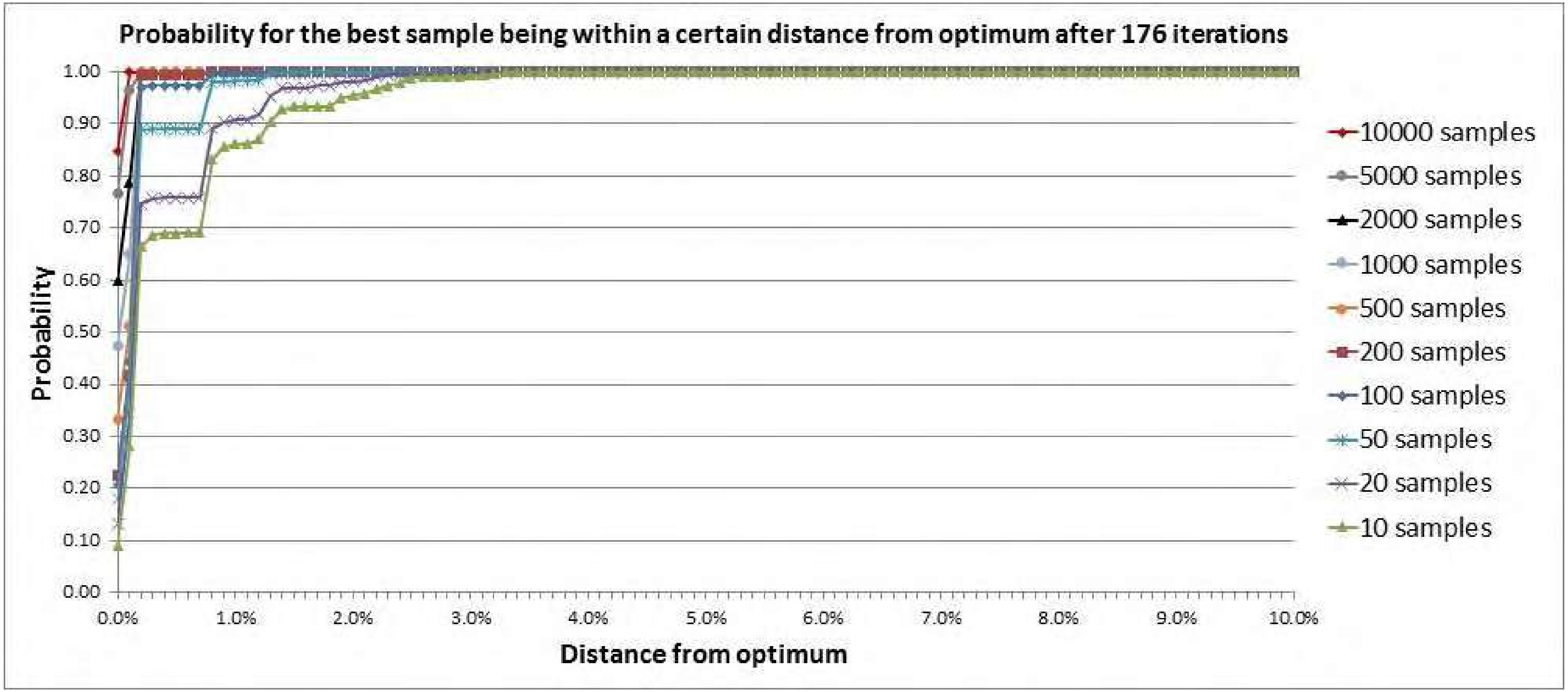

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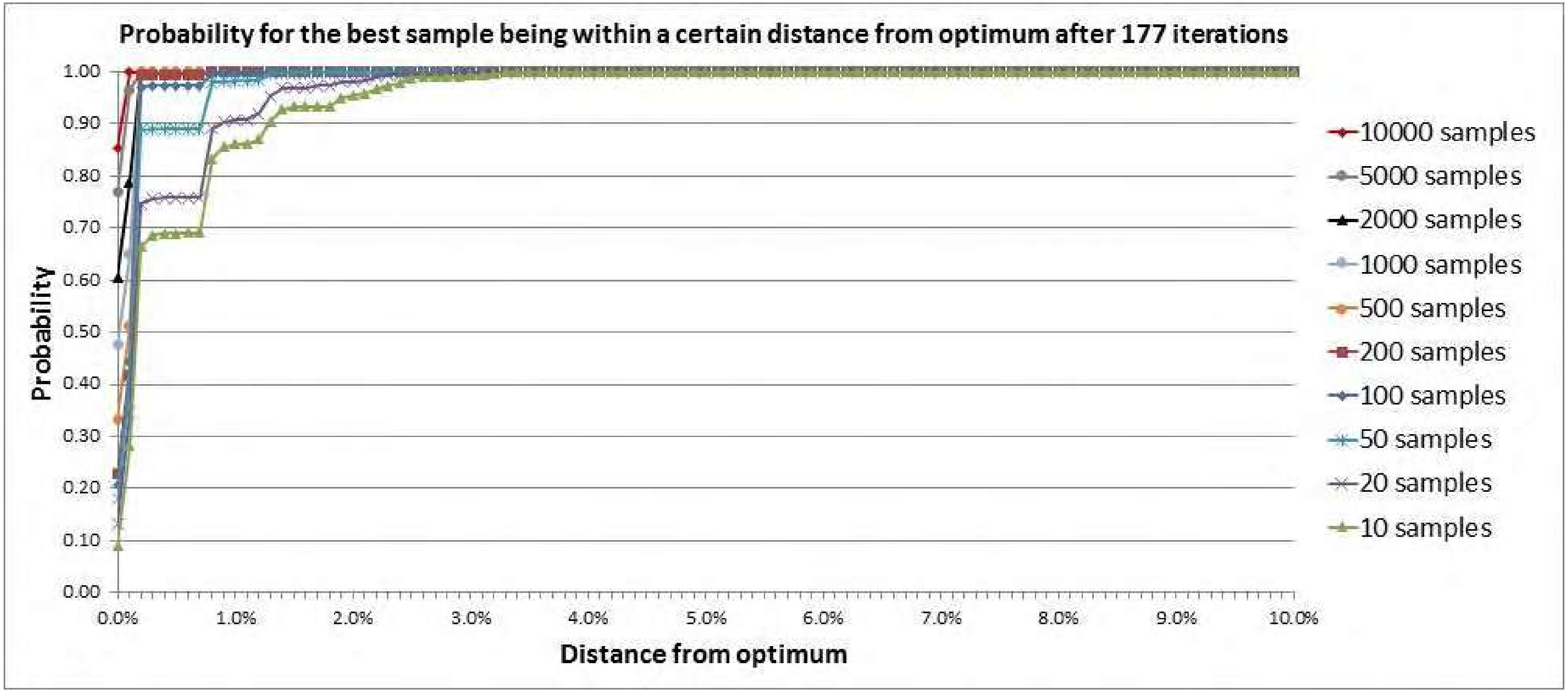

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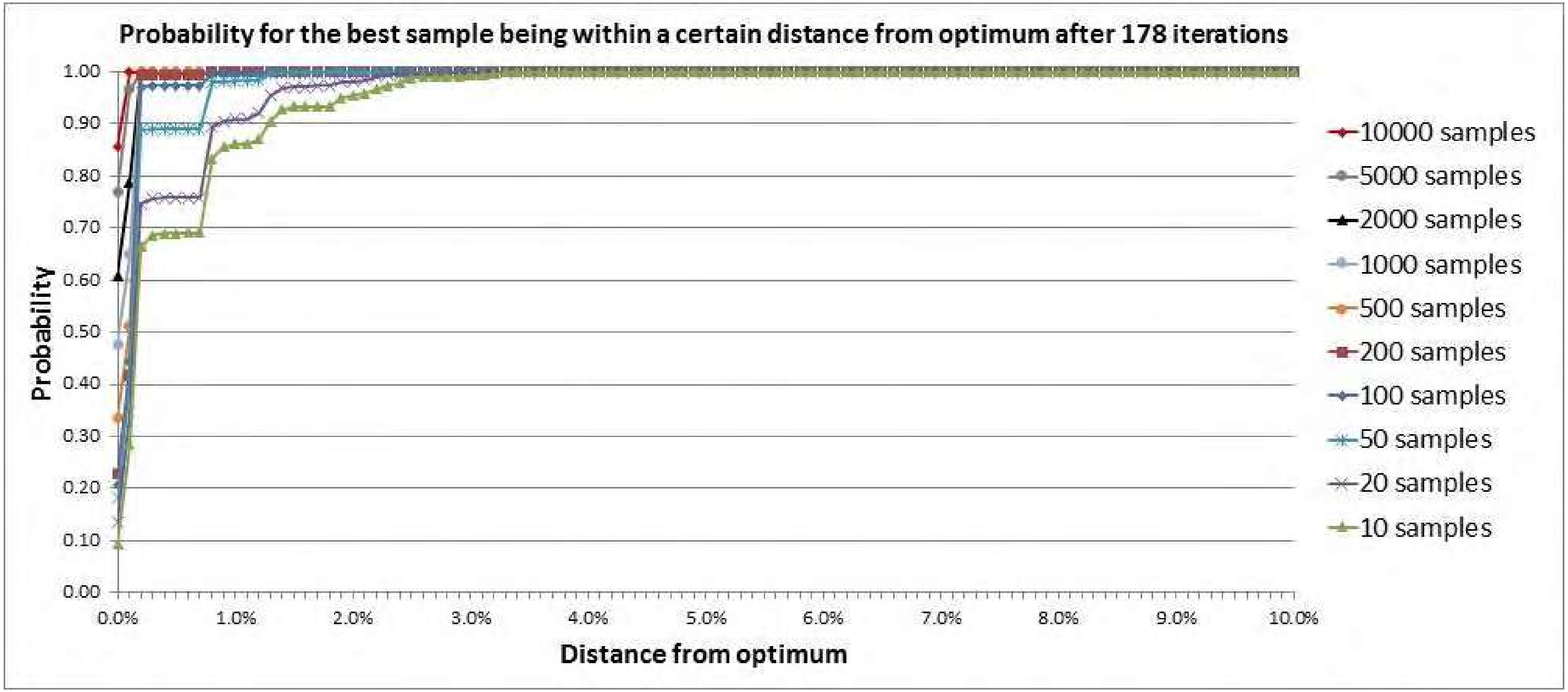

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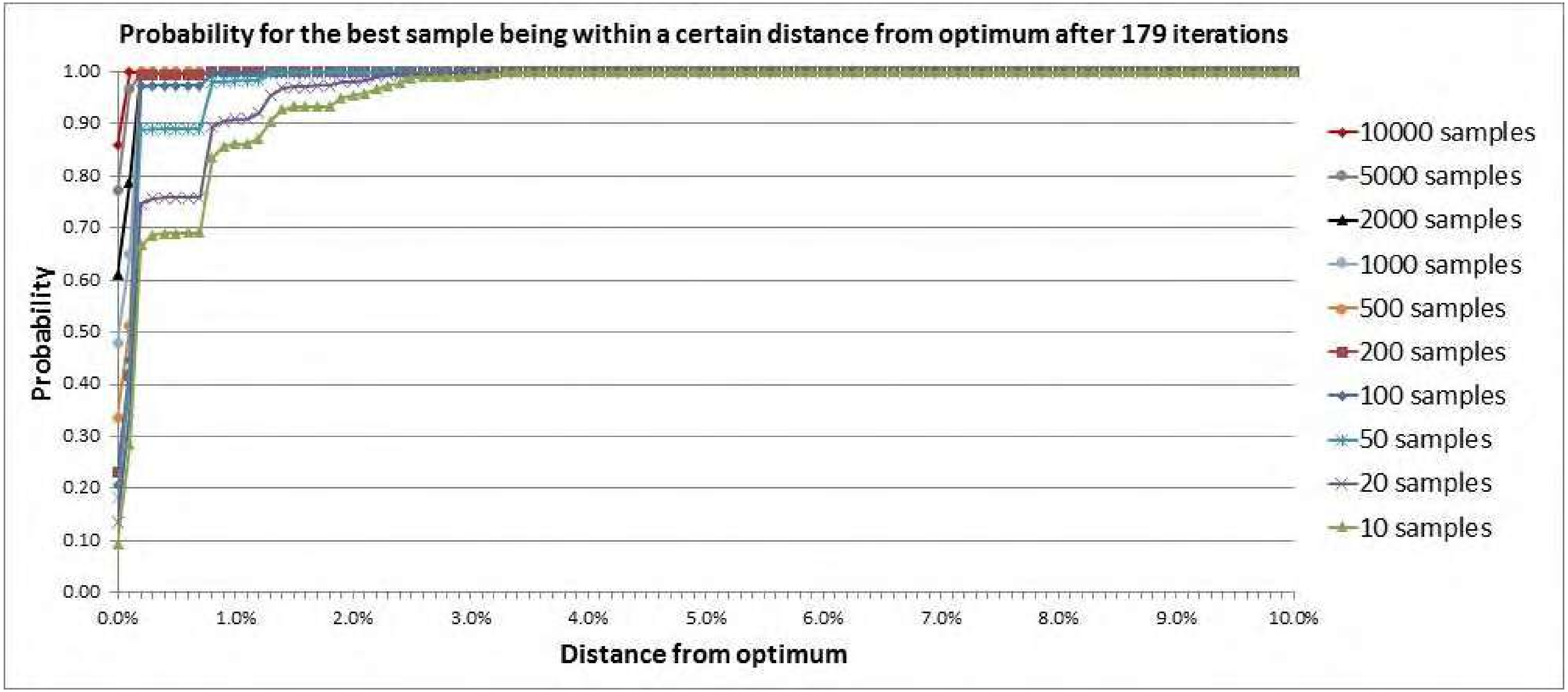

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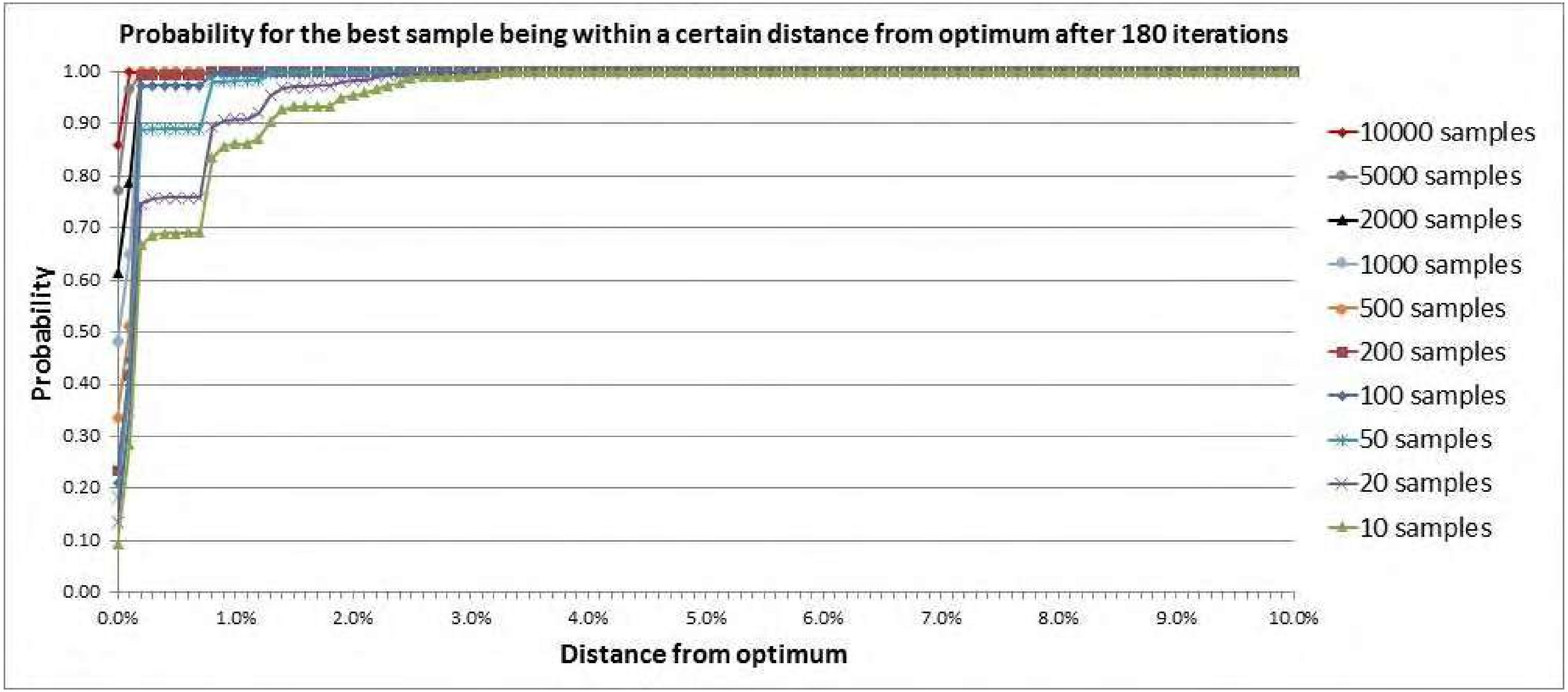

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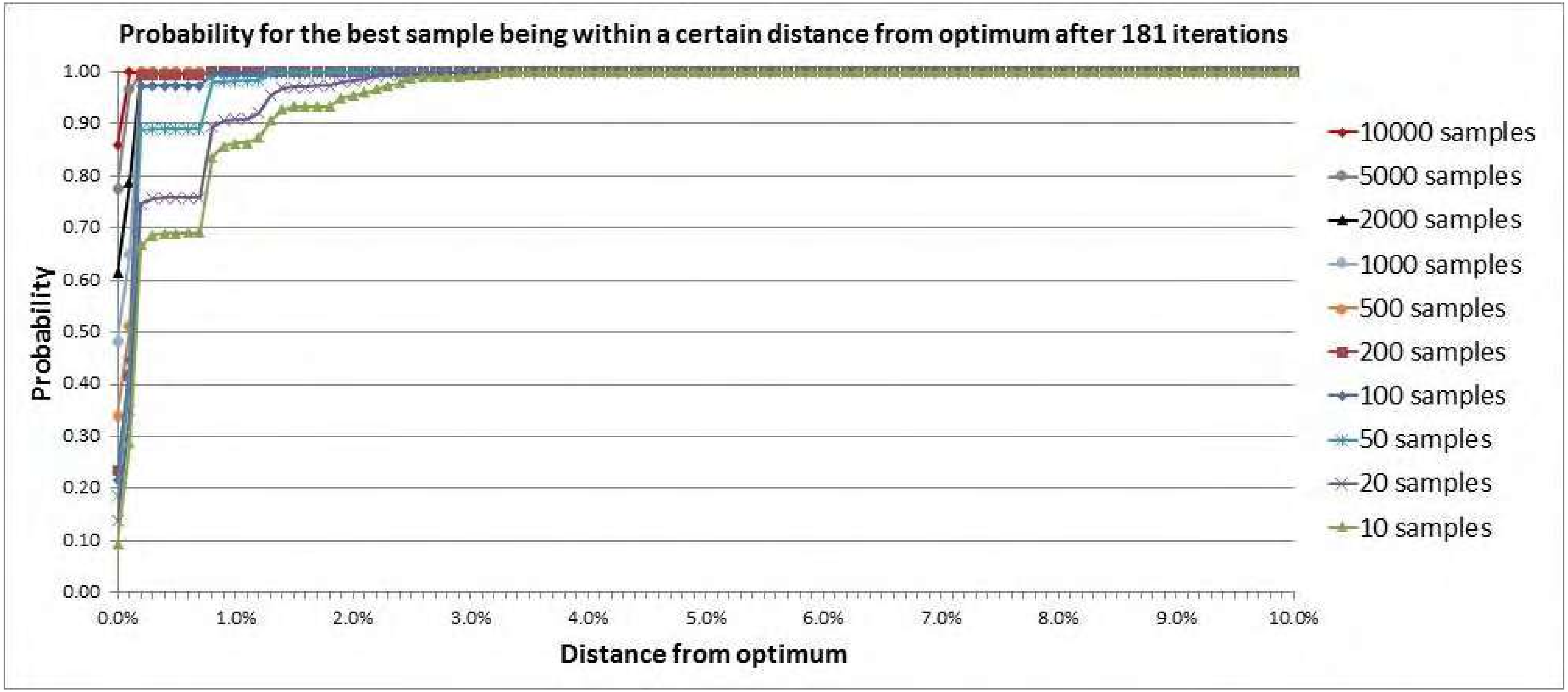

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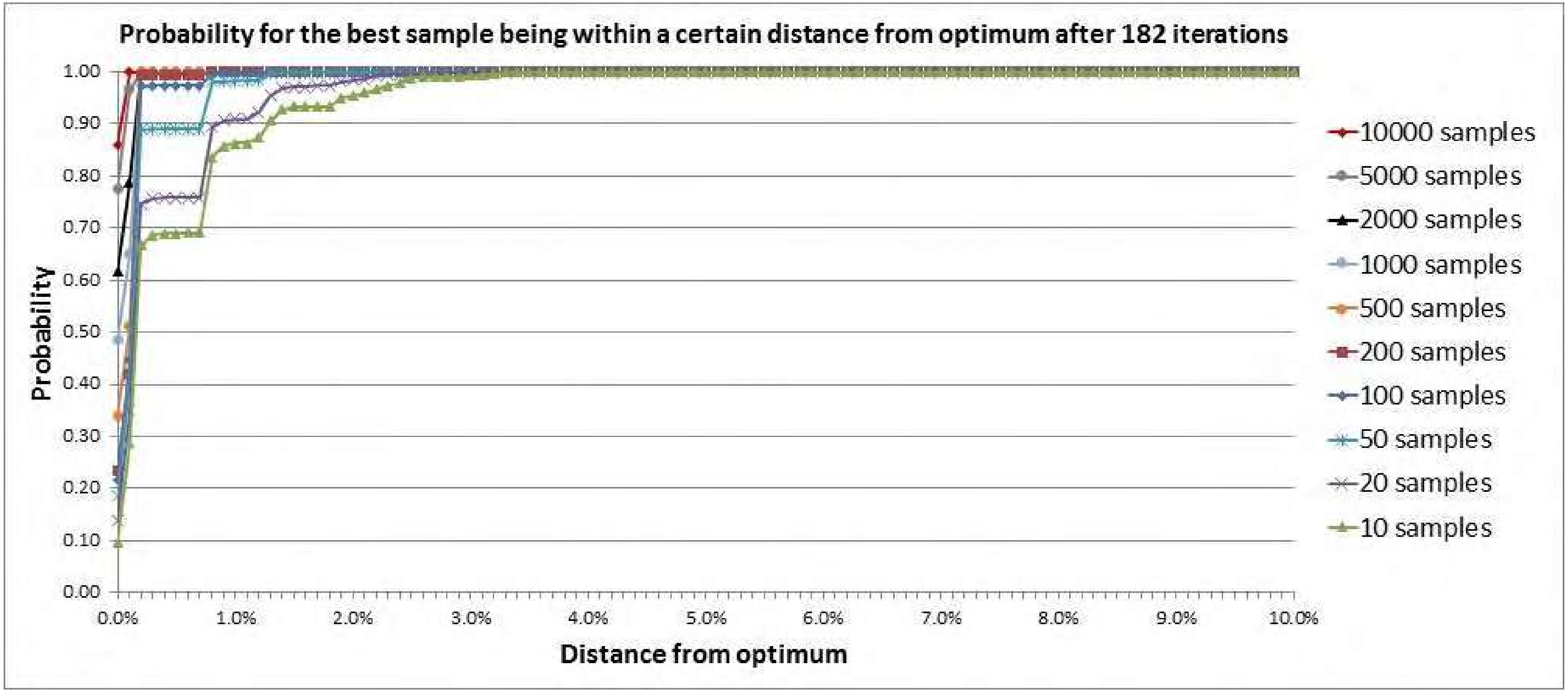

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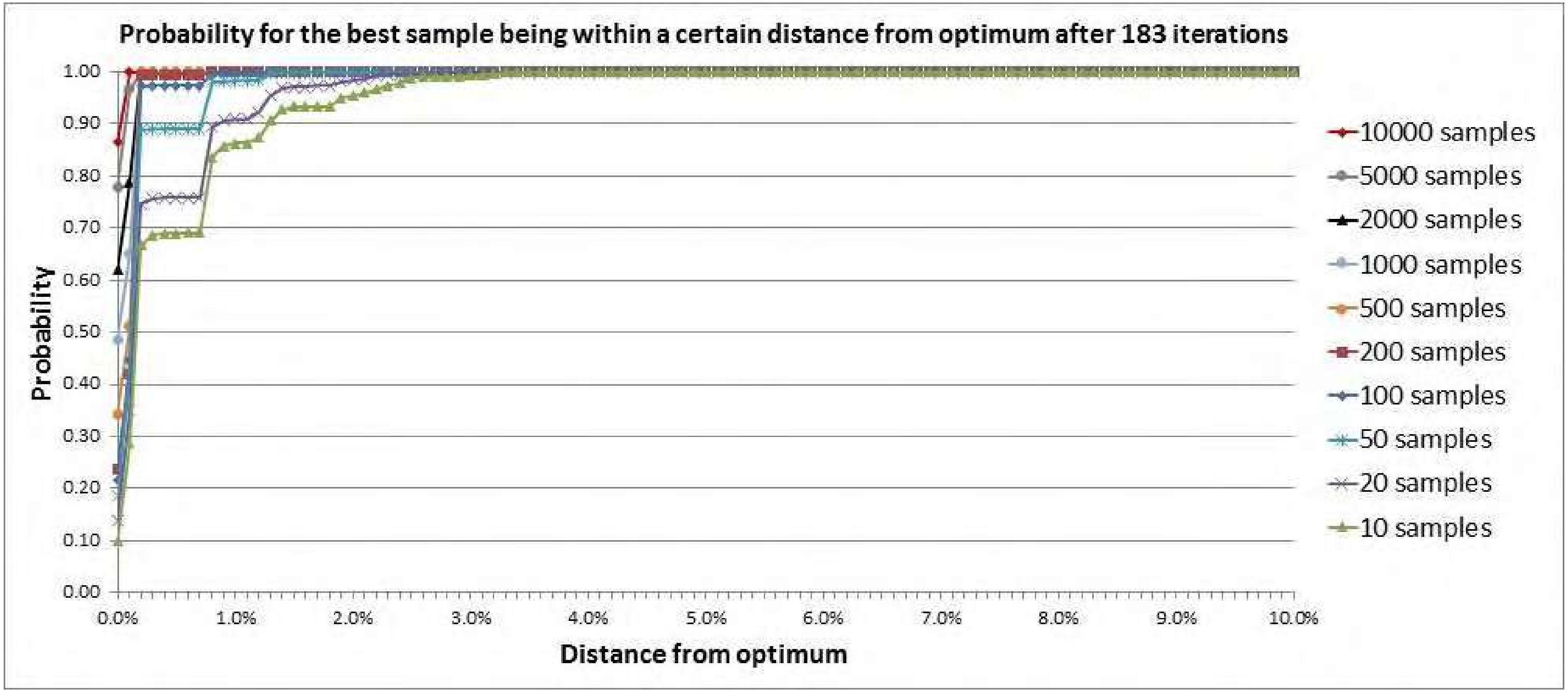

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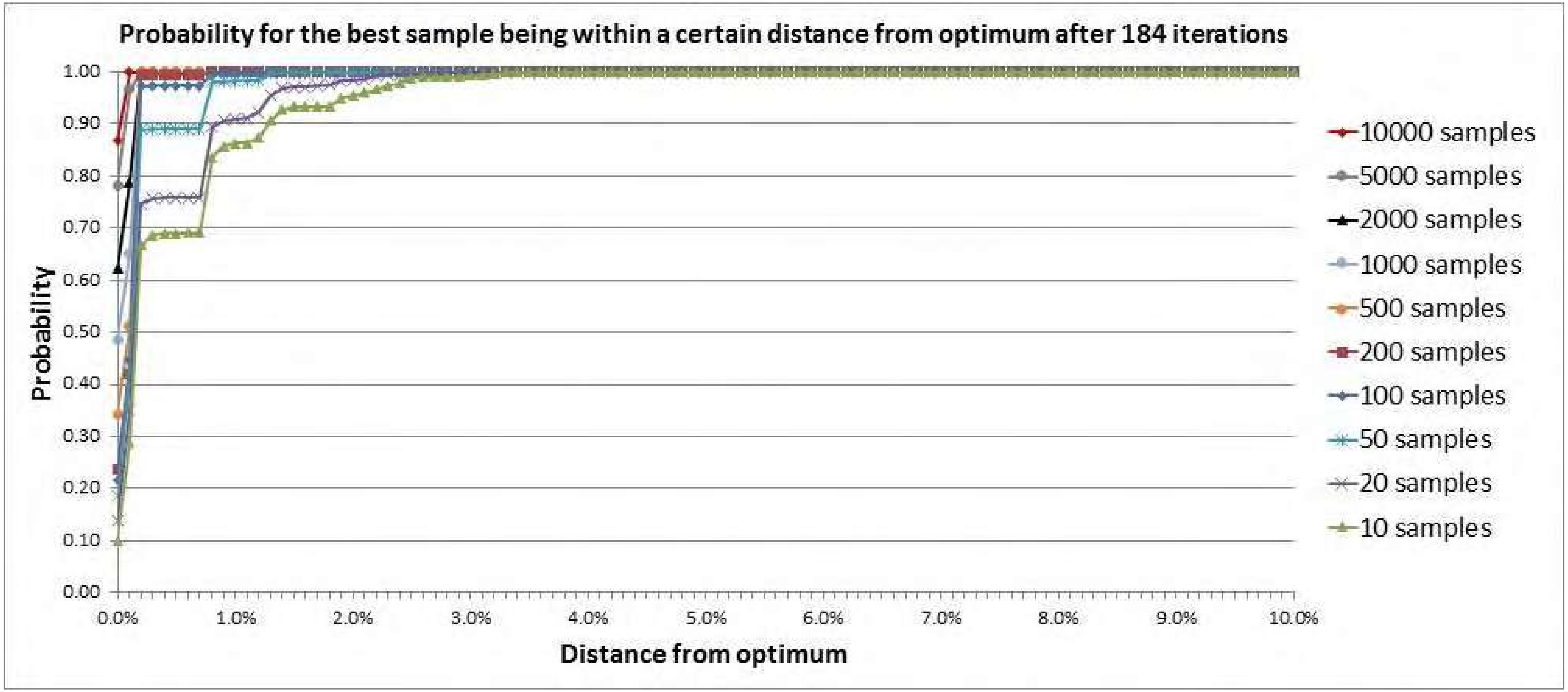

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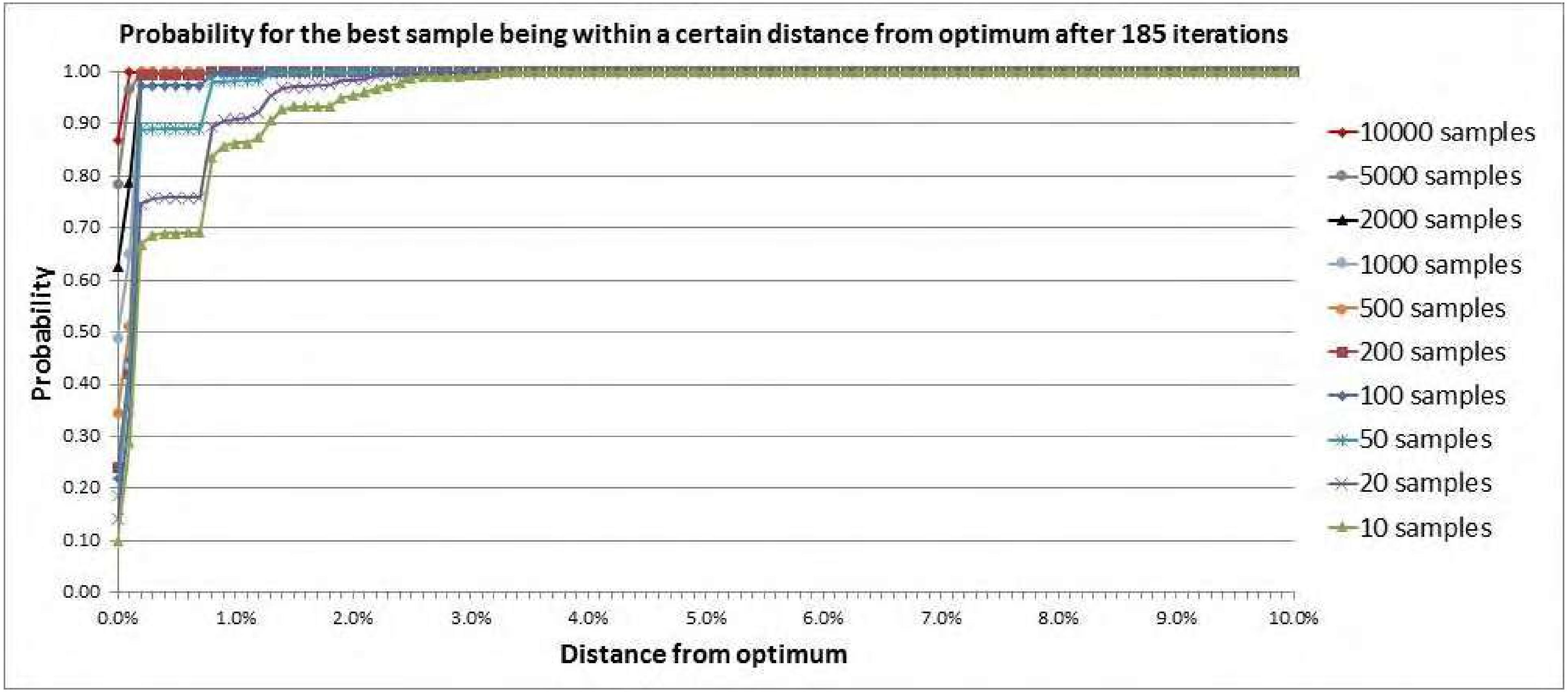

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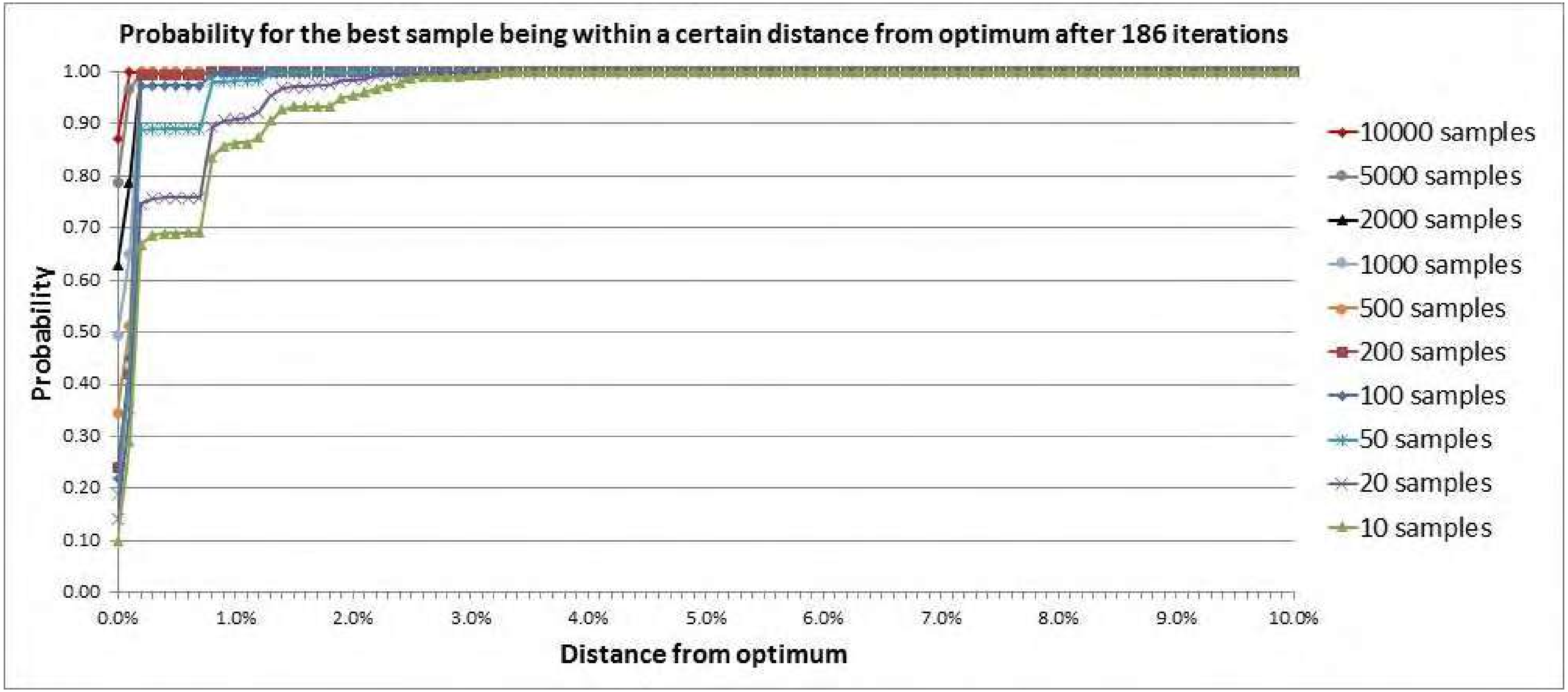

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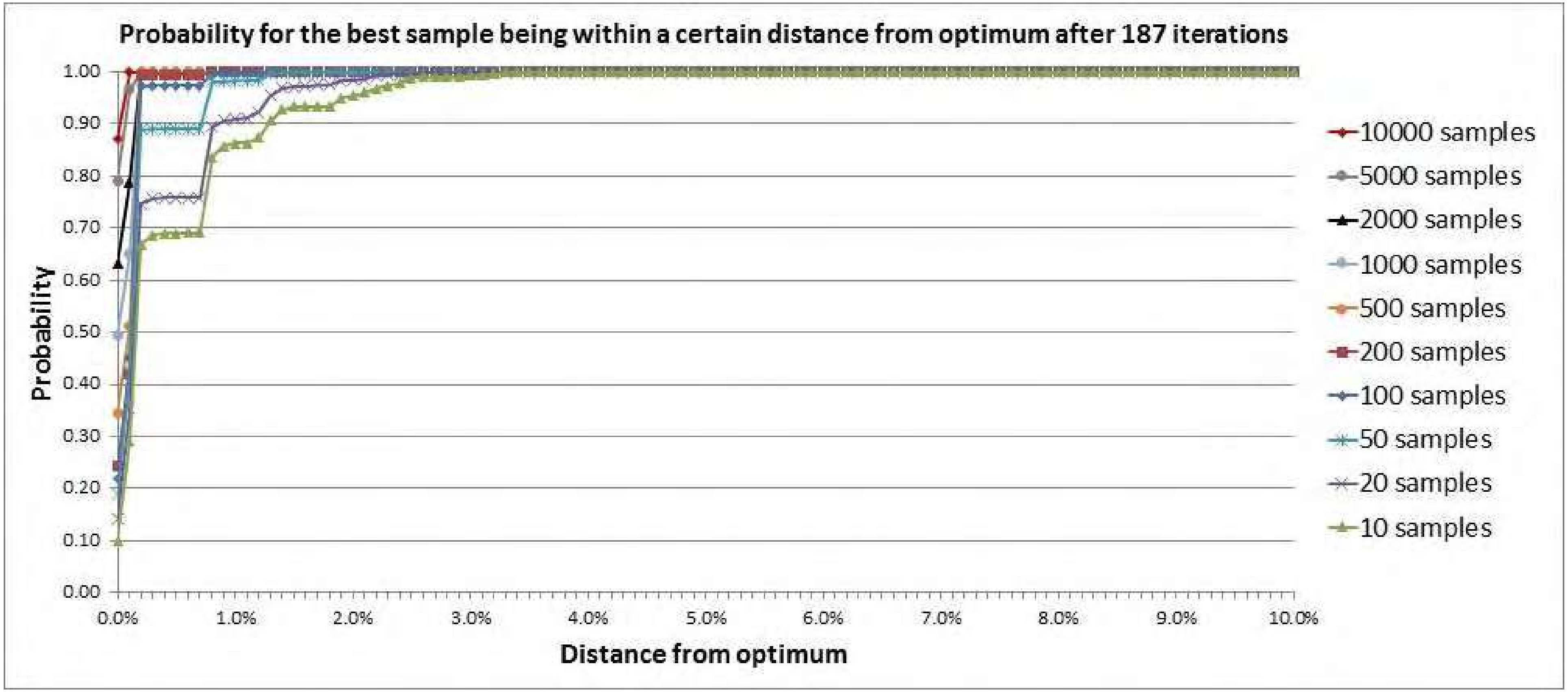

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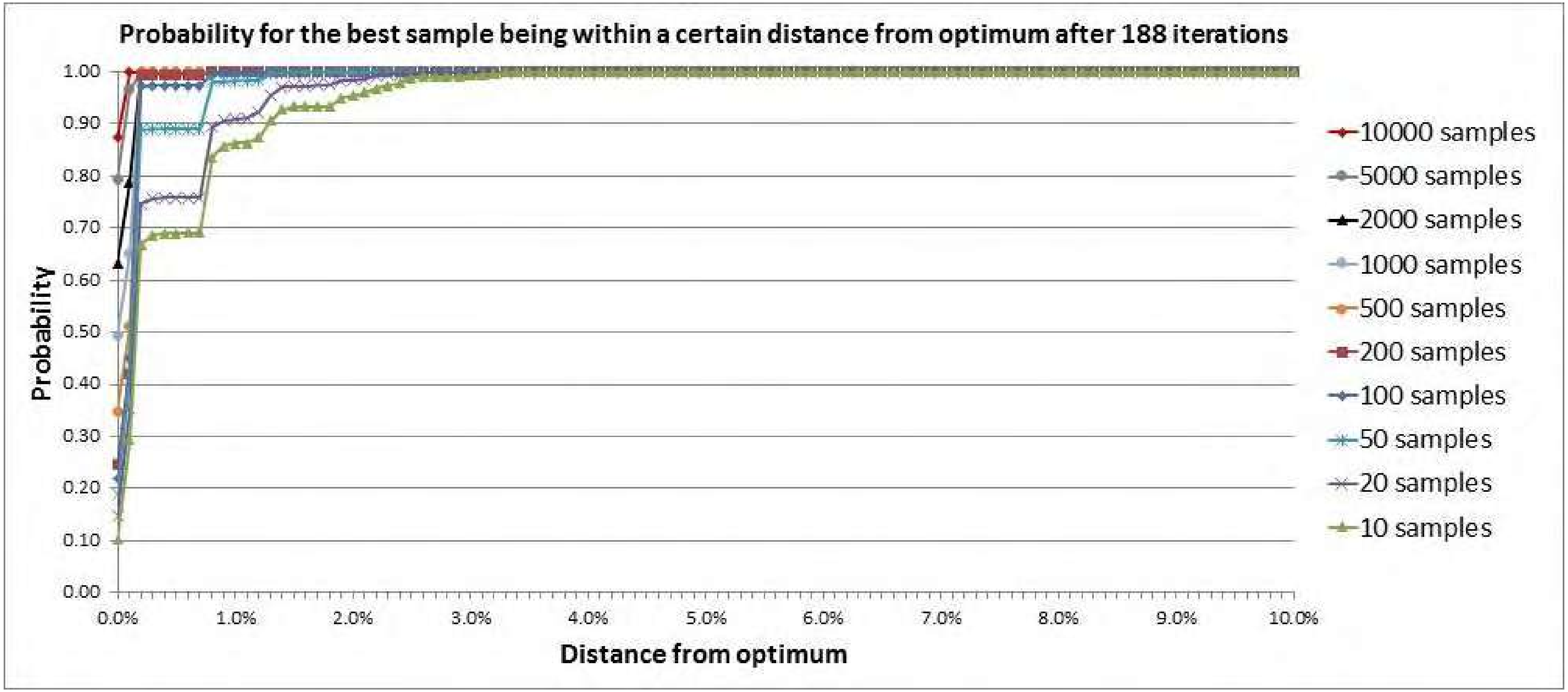

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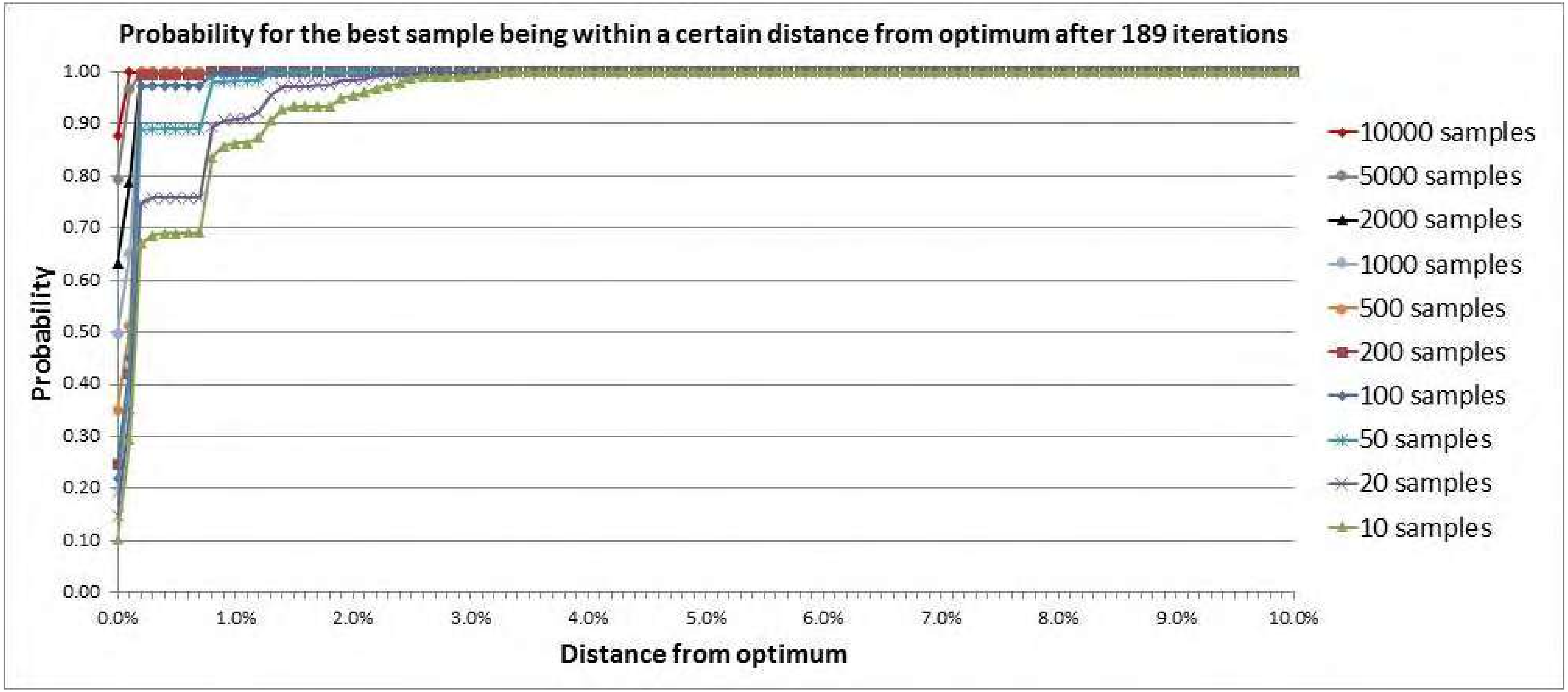
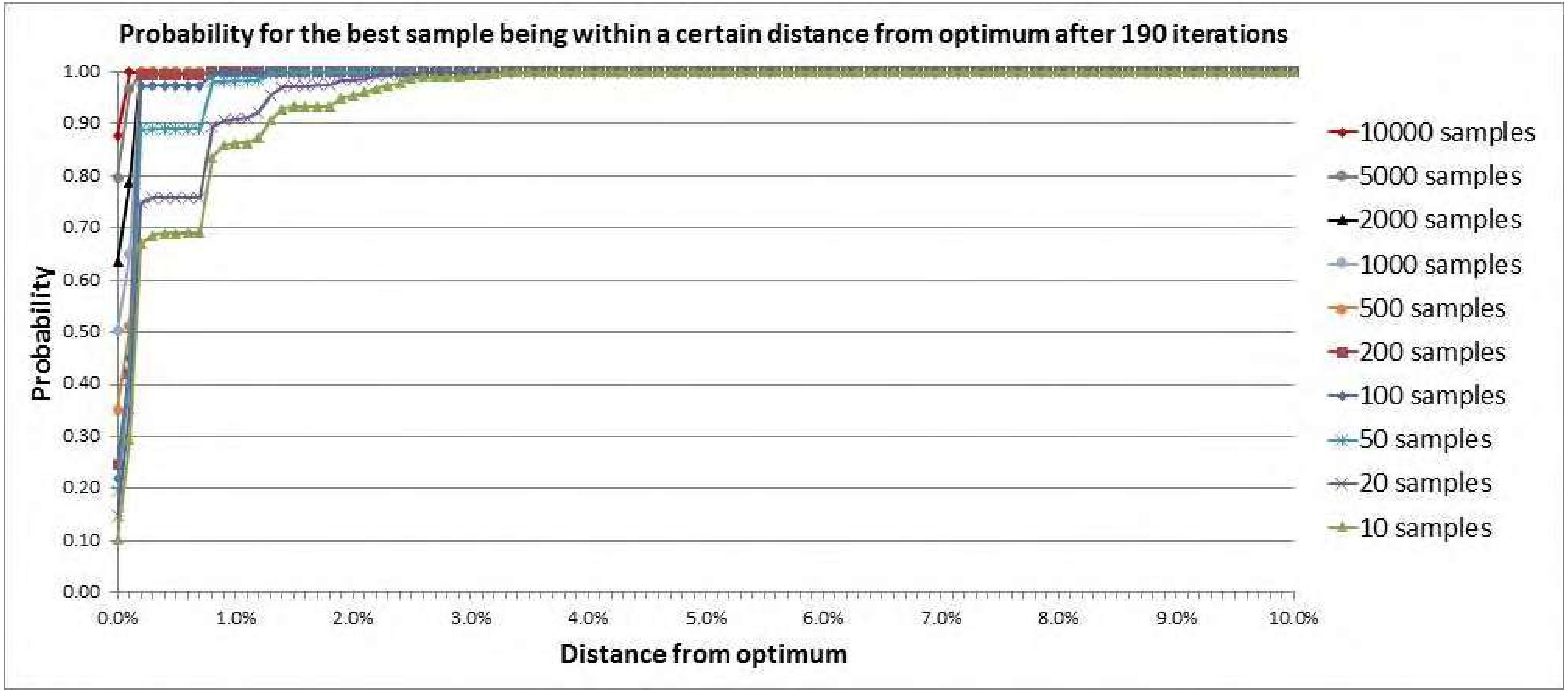


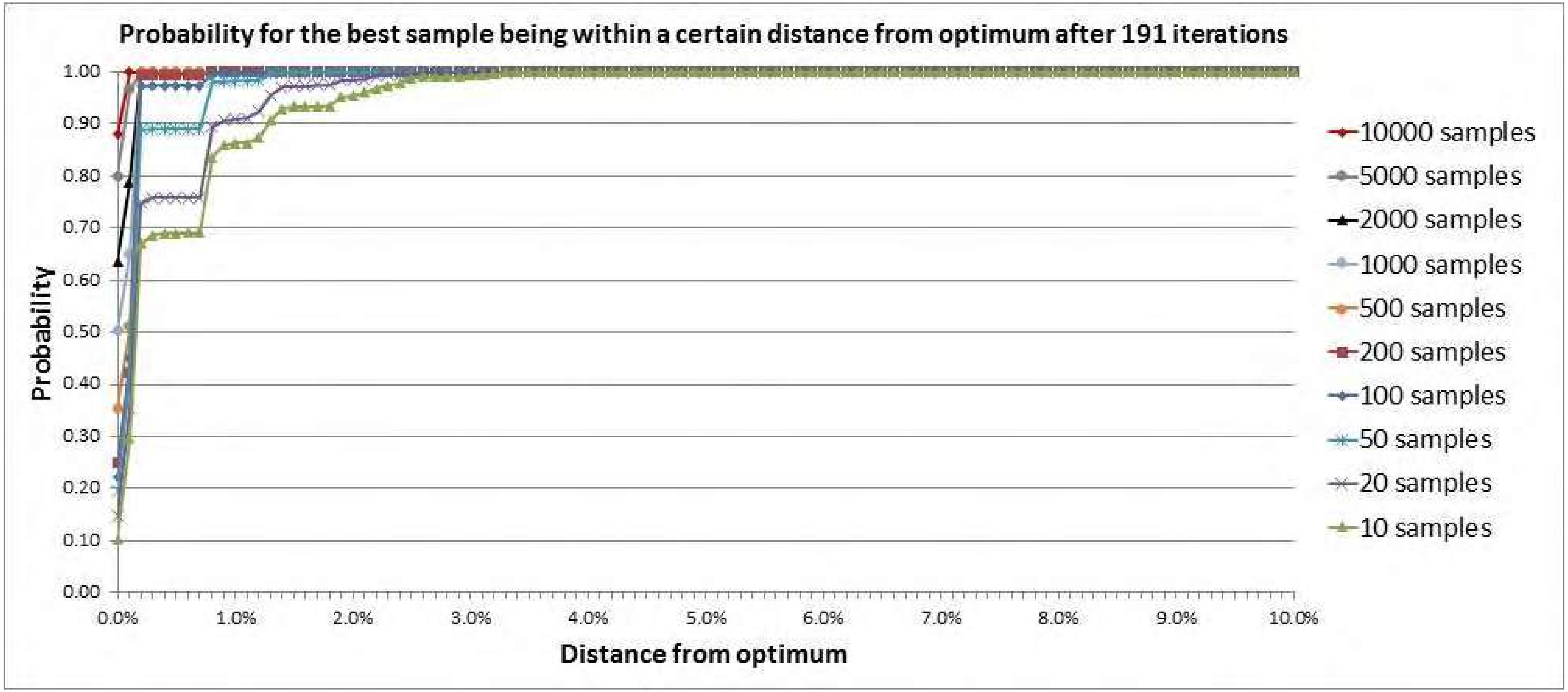
Systecon

What is the probability of finding the optimum?

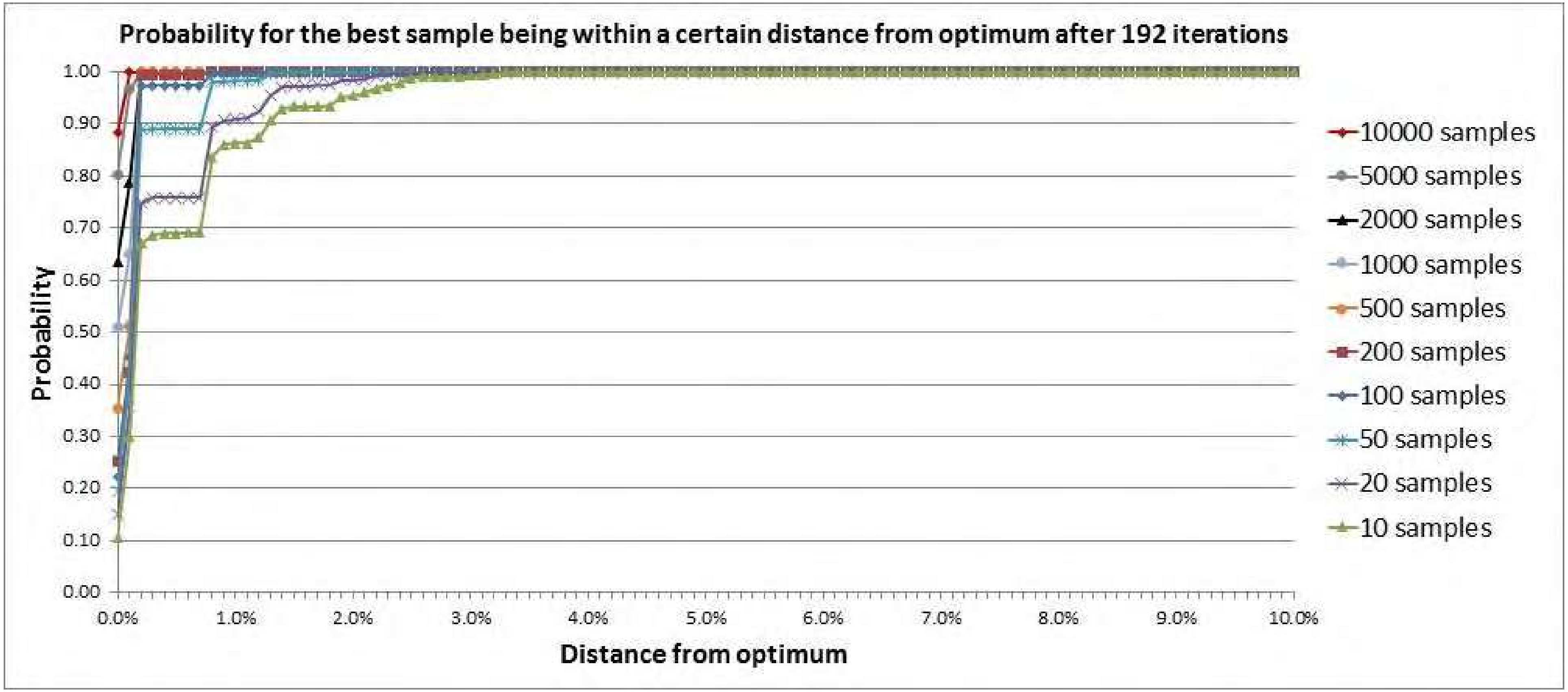


Systecon

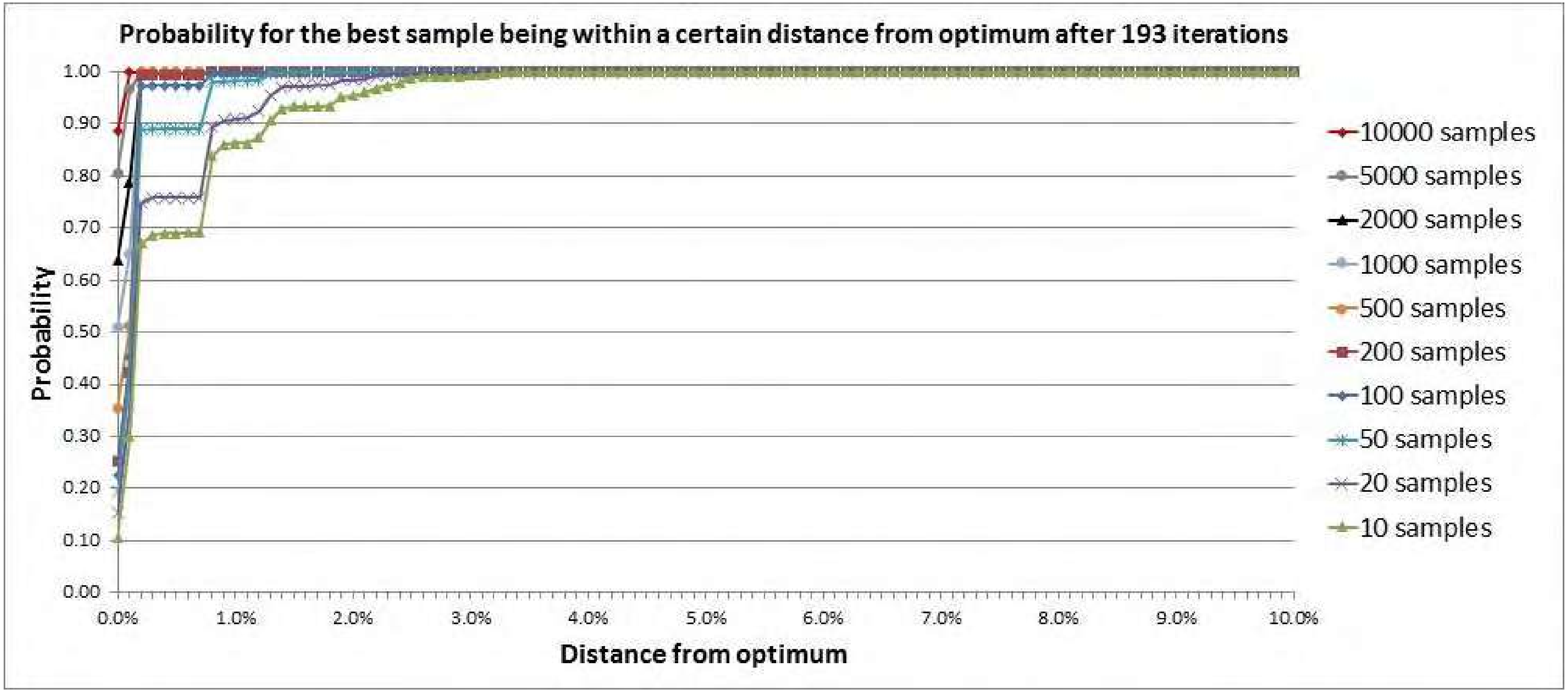
What is the probability of finding the optimum?



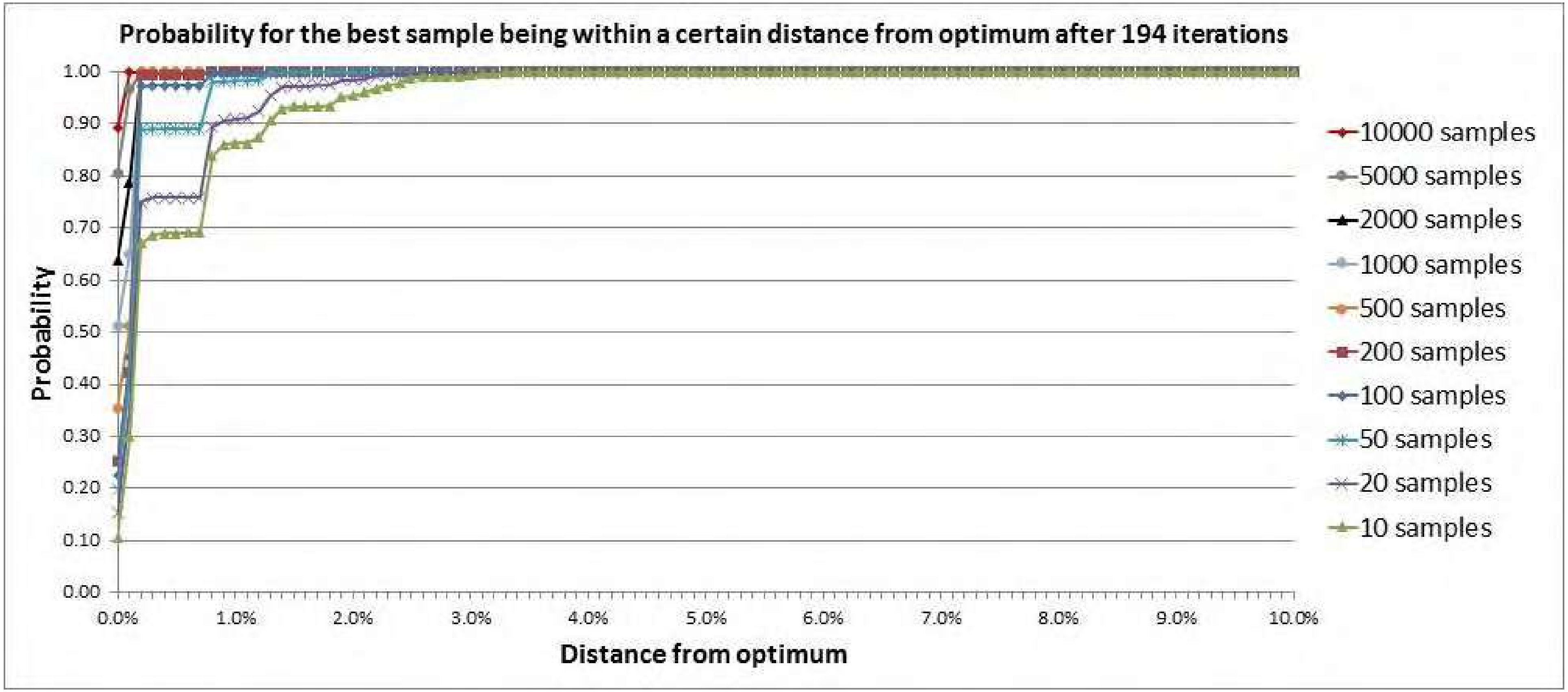
What is the probability of finding the optimum?



What is the probability of finding the optimum?

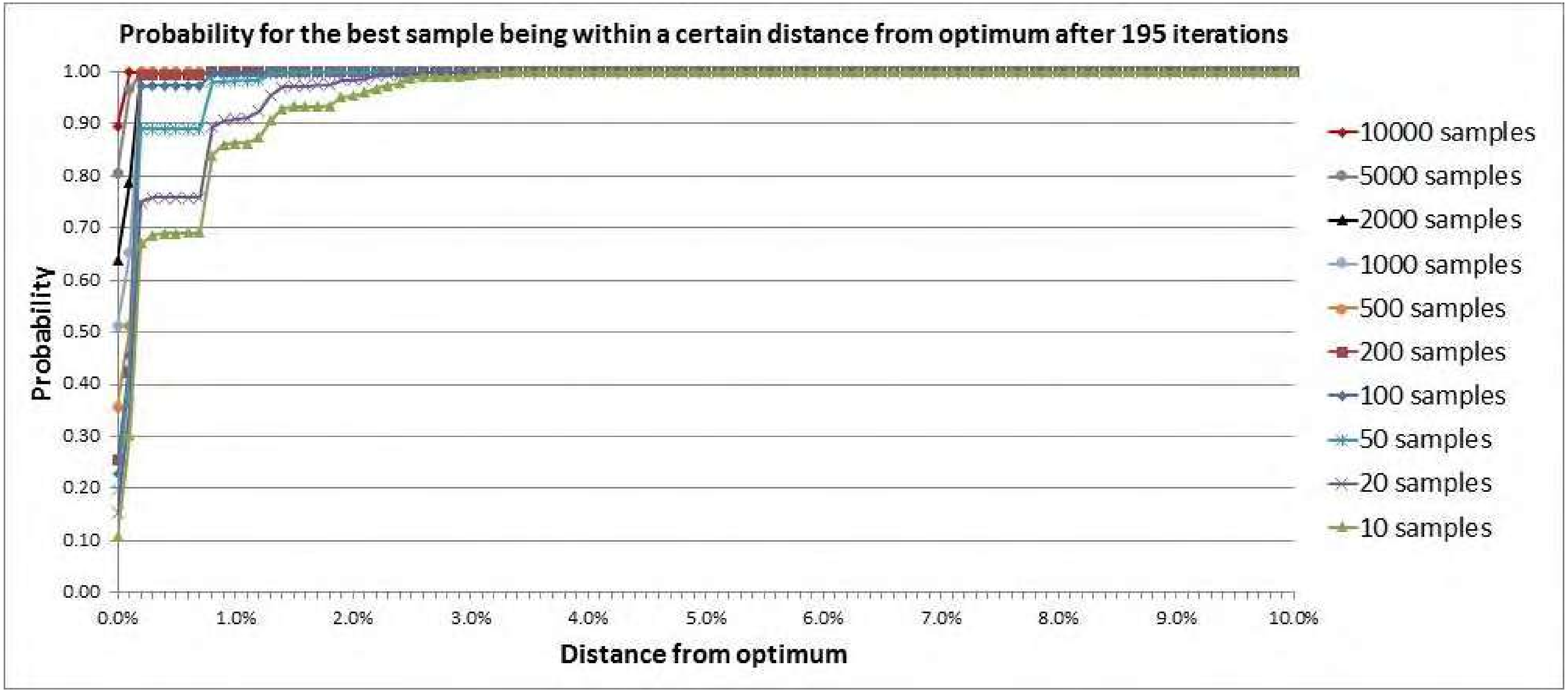


What is the probability of finding the optimum?



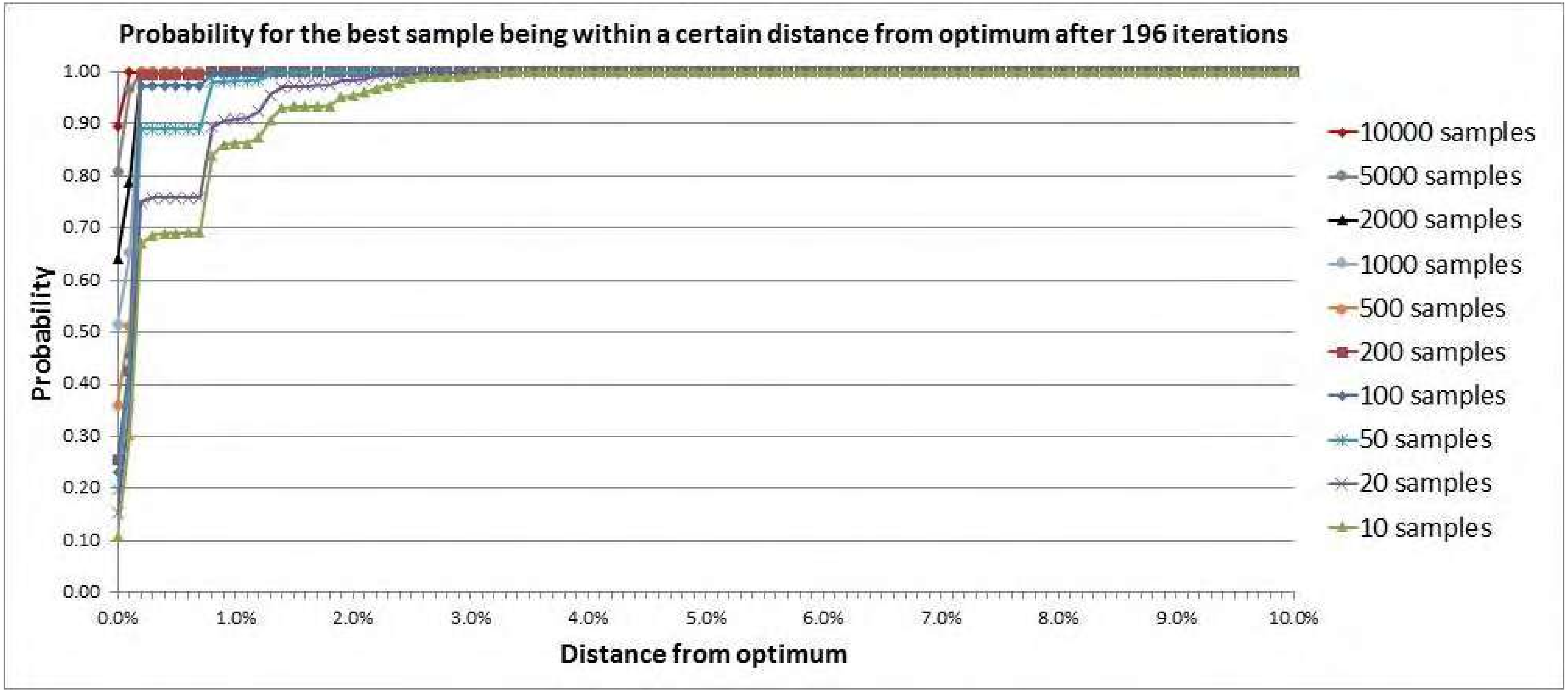
Systecon

What is the probability of finding the optimum?



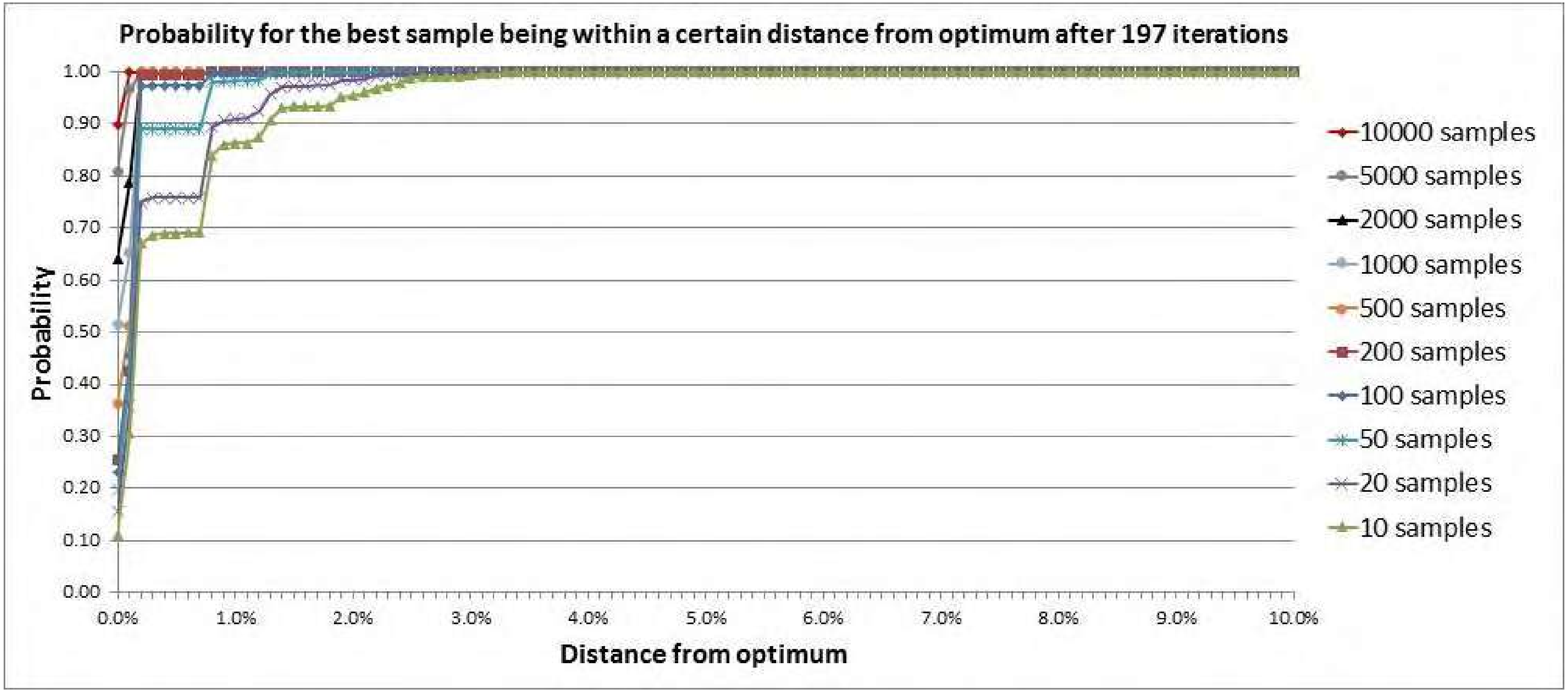
Systecon

What is the probability of finding the optimum?



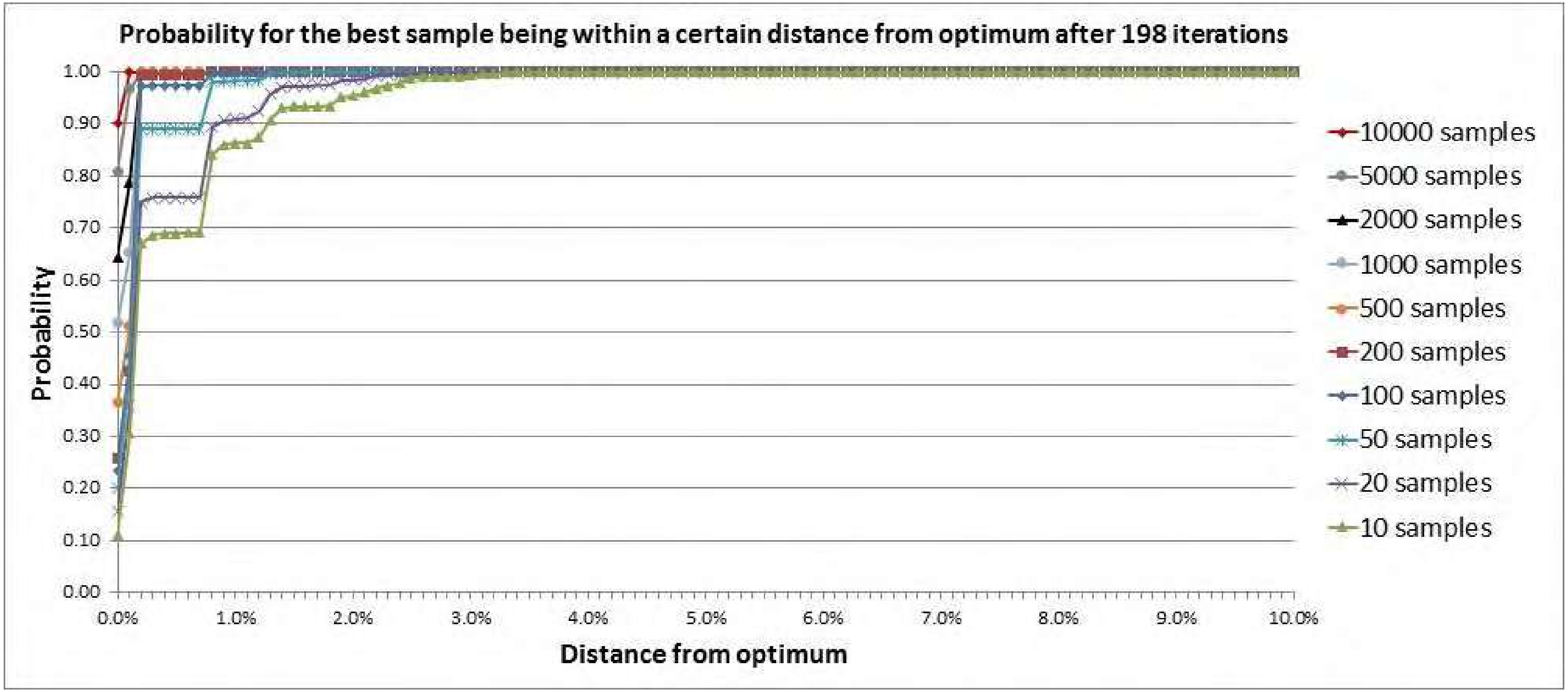
Systecon

What is the probability of finding the optimum?

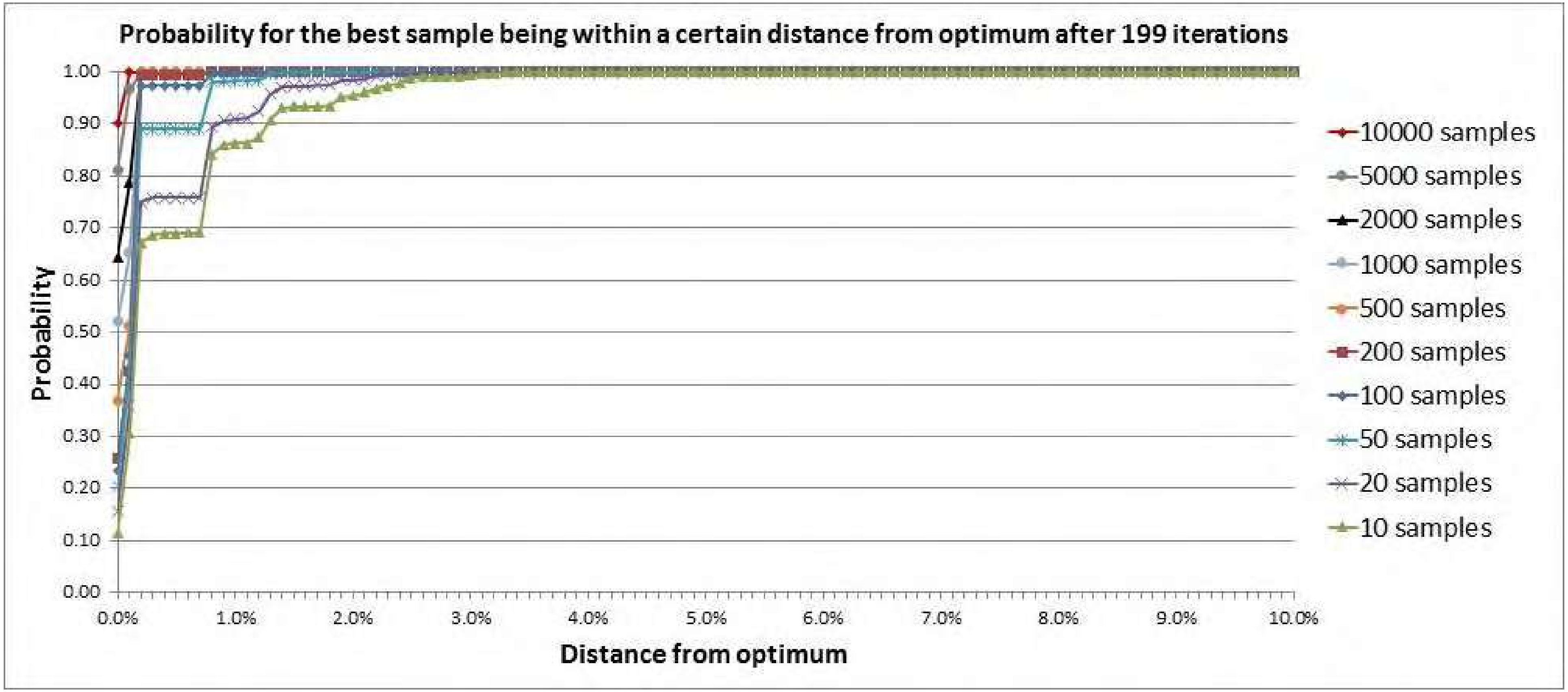


Systecon

What is the probability of finding the optimum?

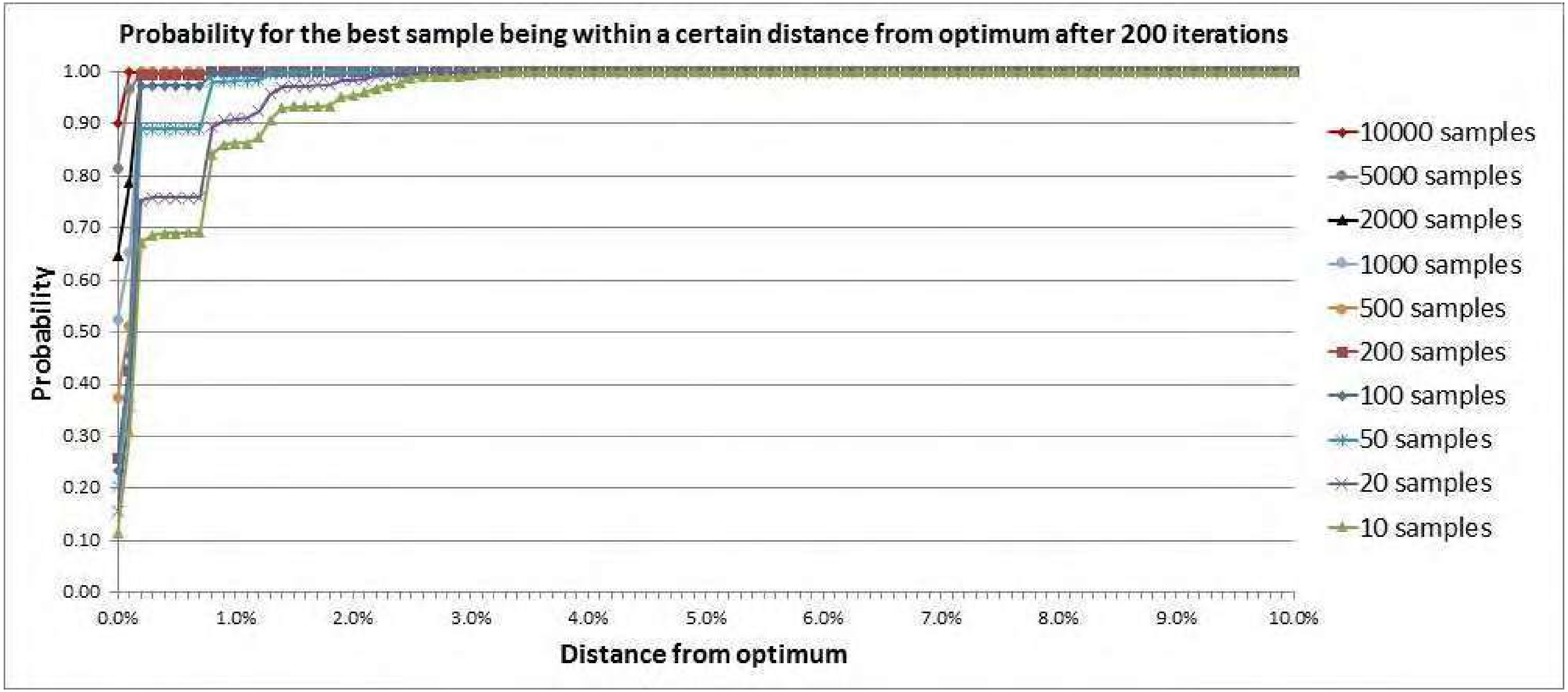


What is the probability of finding the optimum?



Systecon

What is the probability of finding the optimum?

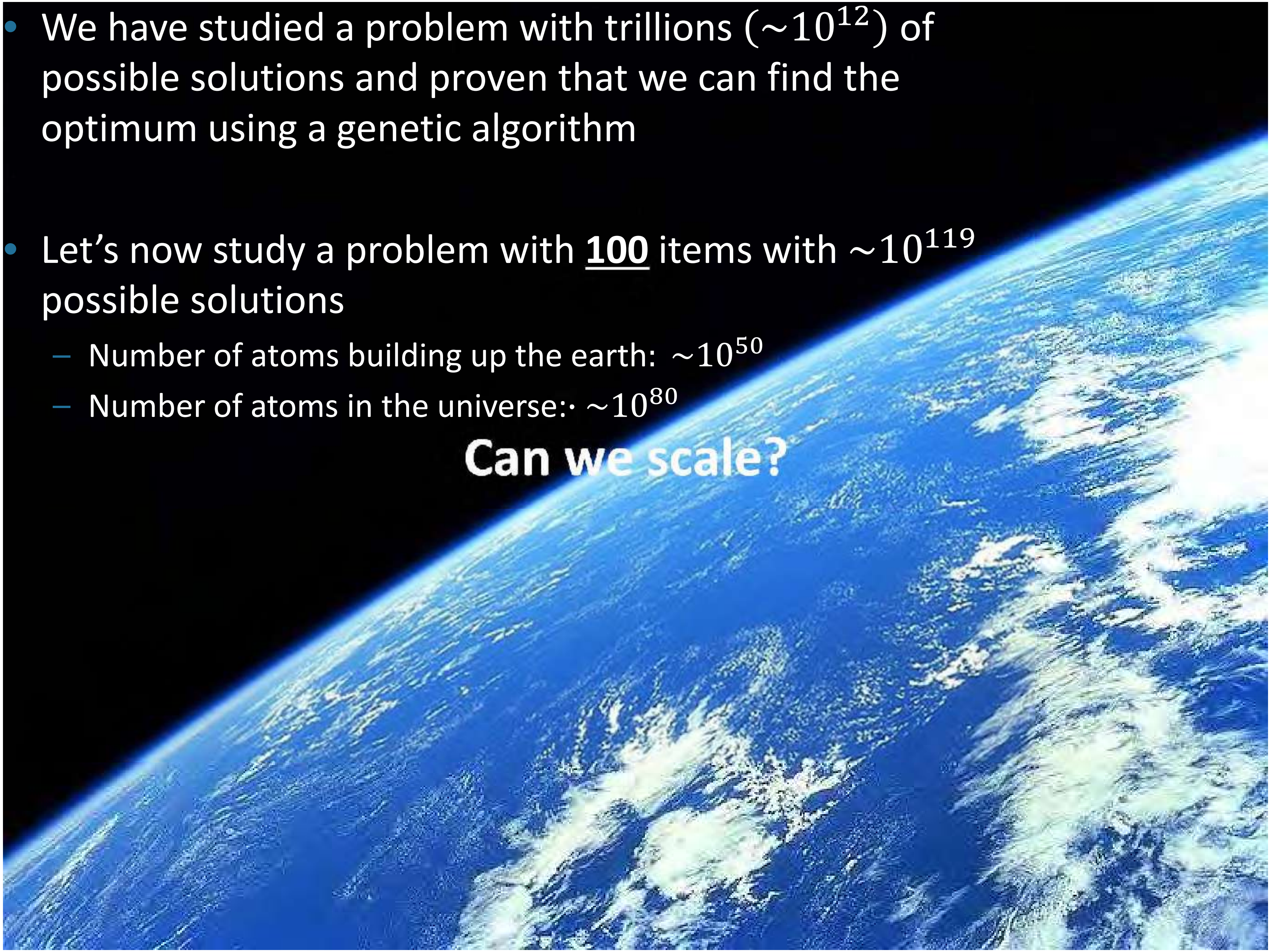


Systecon

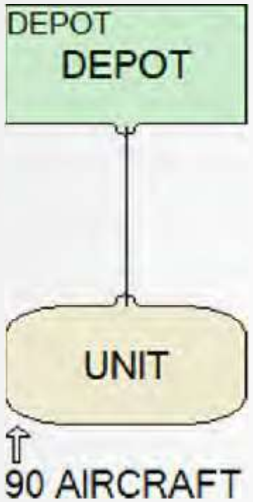
- We have studied a problem with trillions ($\sim 10^{12}$) of possible solutions and proven that we can find the optimum using a genetic algorithm

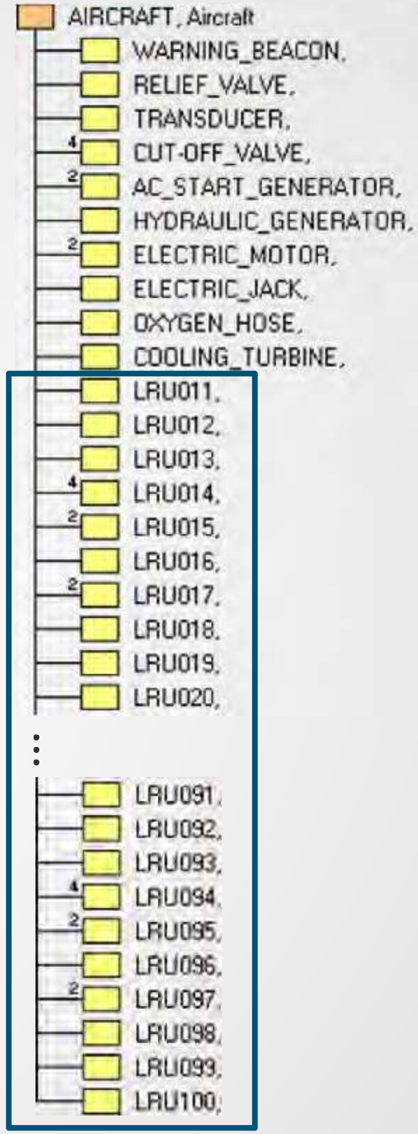
- Let’s now study a problem with **<u>100</u>** items with $\sim 10^{119}$ possible solutions
  - Number of atoms building up the earth: $\sim 10^{50}$
  - Number of atoms in the universe:· $\sim 10^{80}$

Can we scale?



Upscaling the scenario

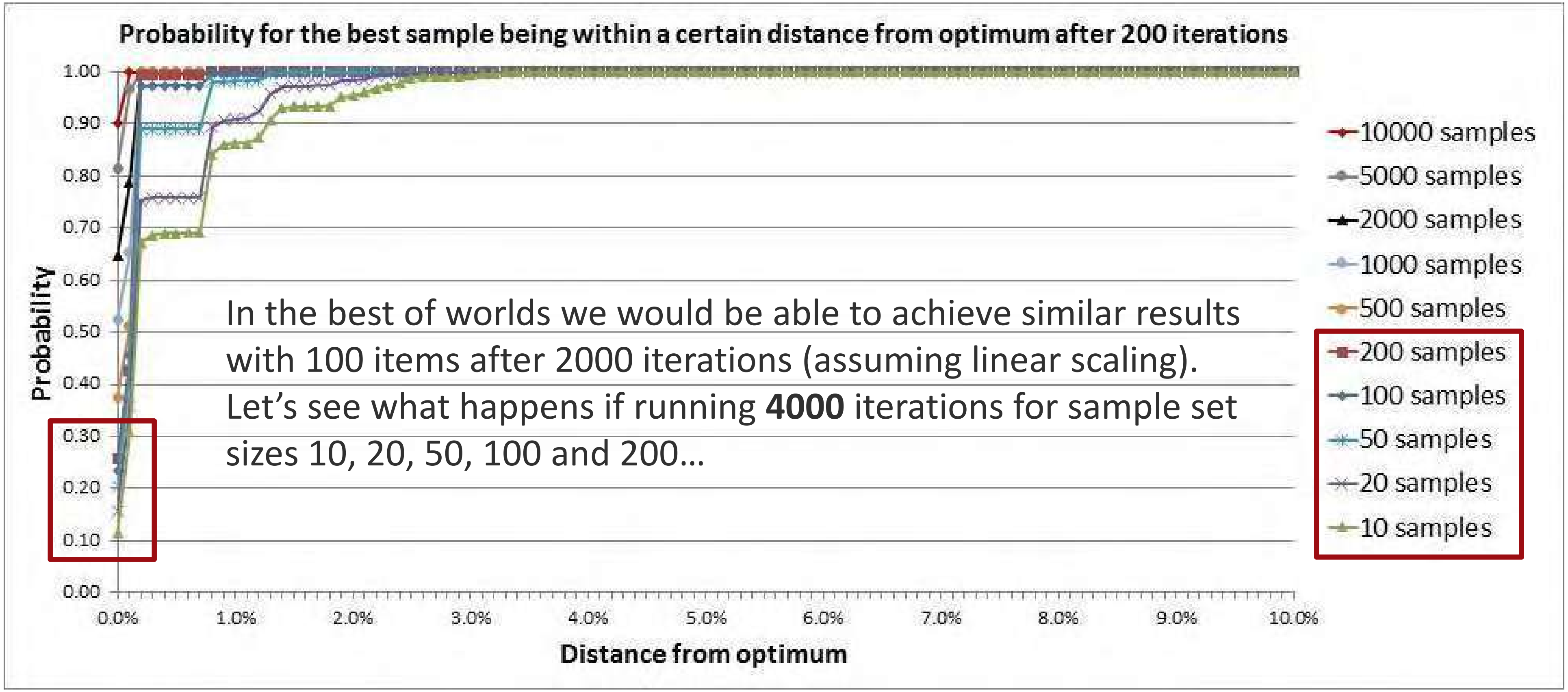




- Same scenario as with 10 items, but now 100 items

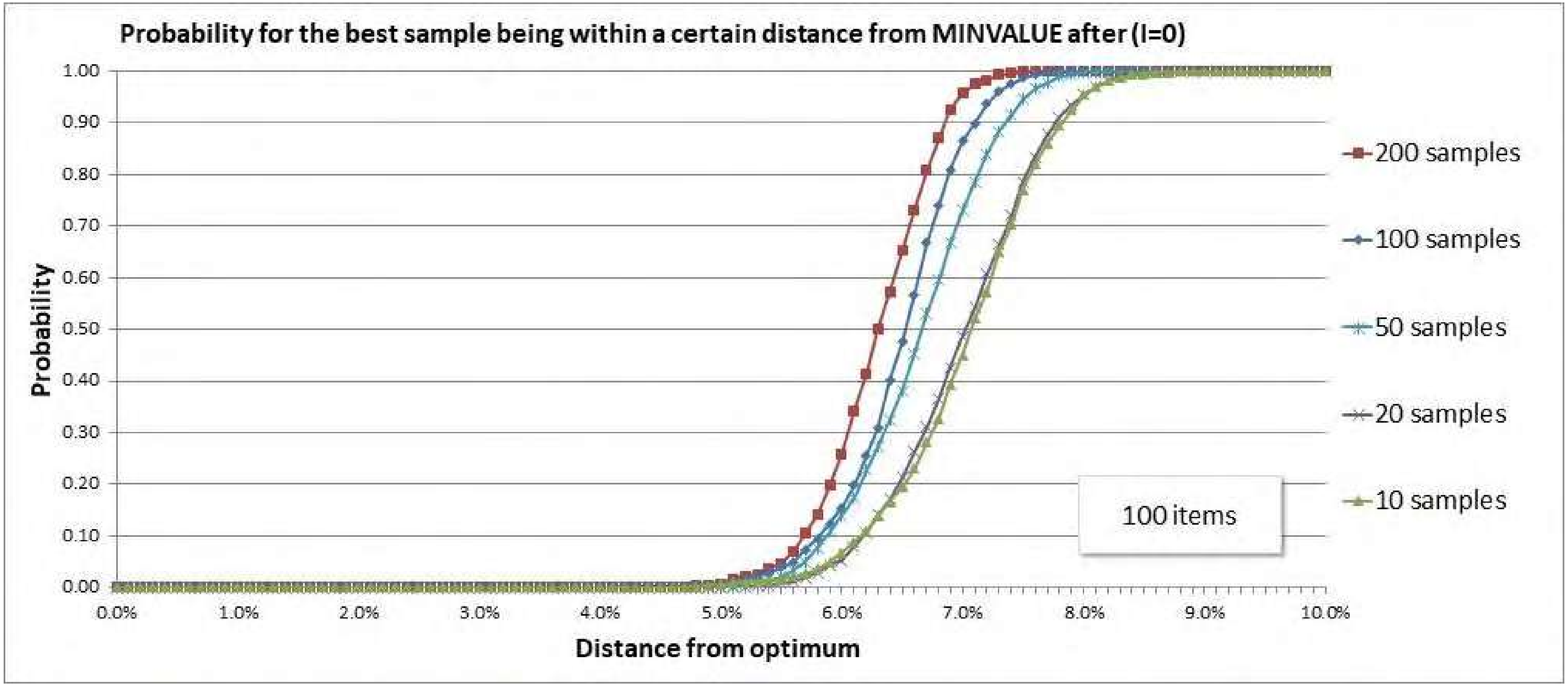
Systecon

Previous results: 10 items after 200 iterations…

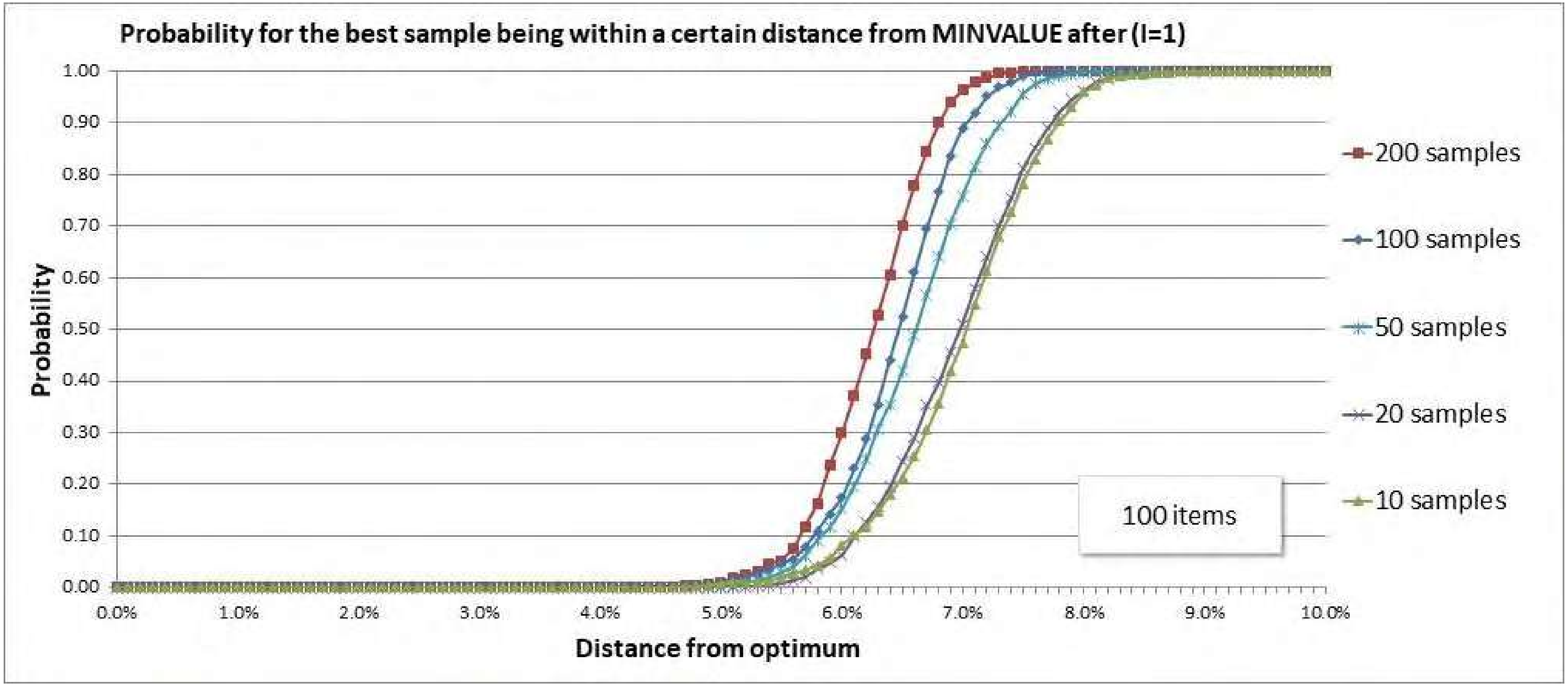


Systecon

Can we scale?

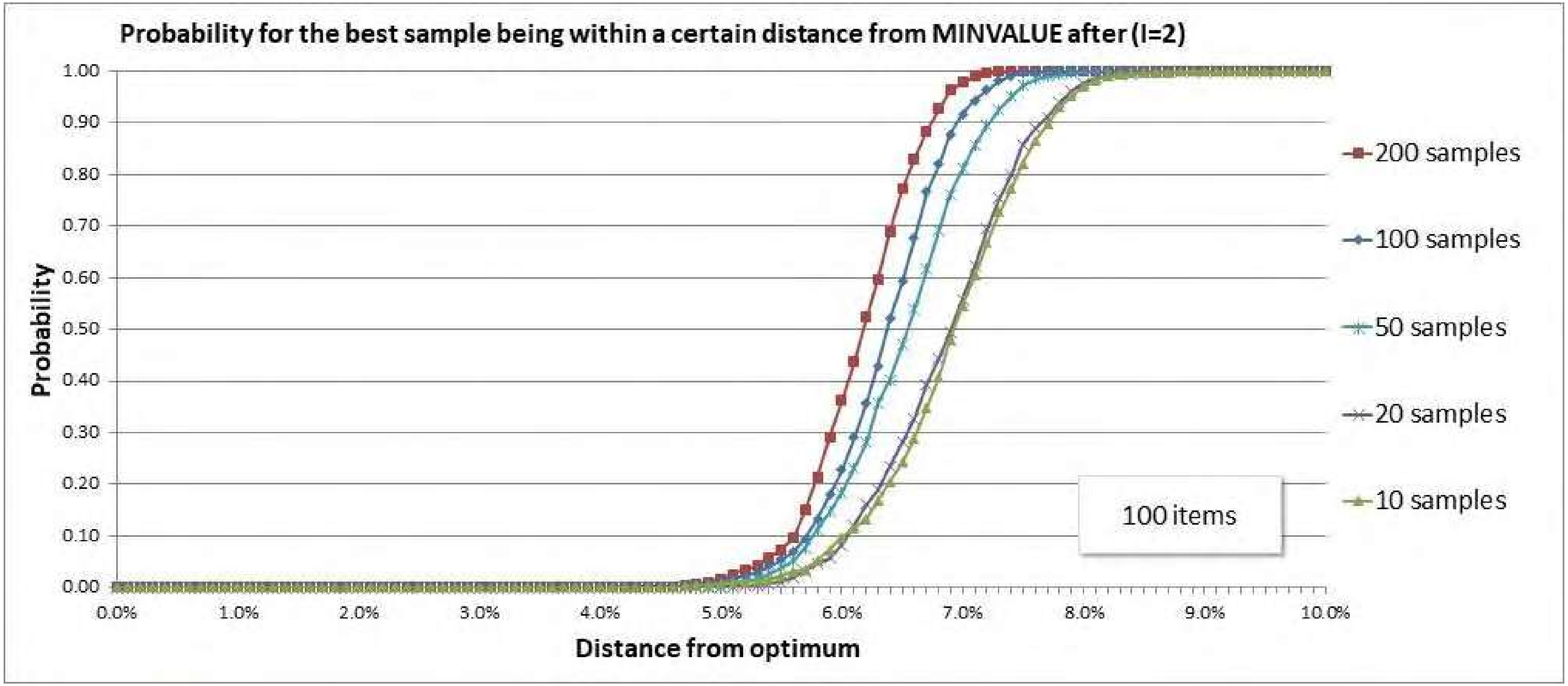

Probability for the best sample being within a certain distance from MINVALUE after (I=0)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?



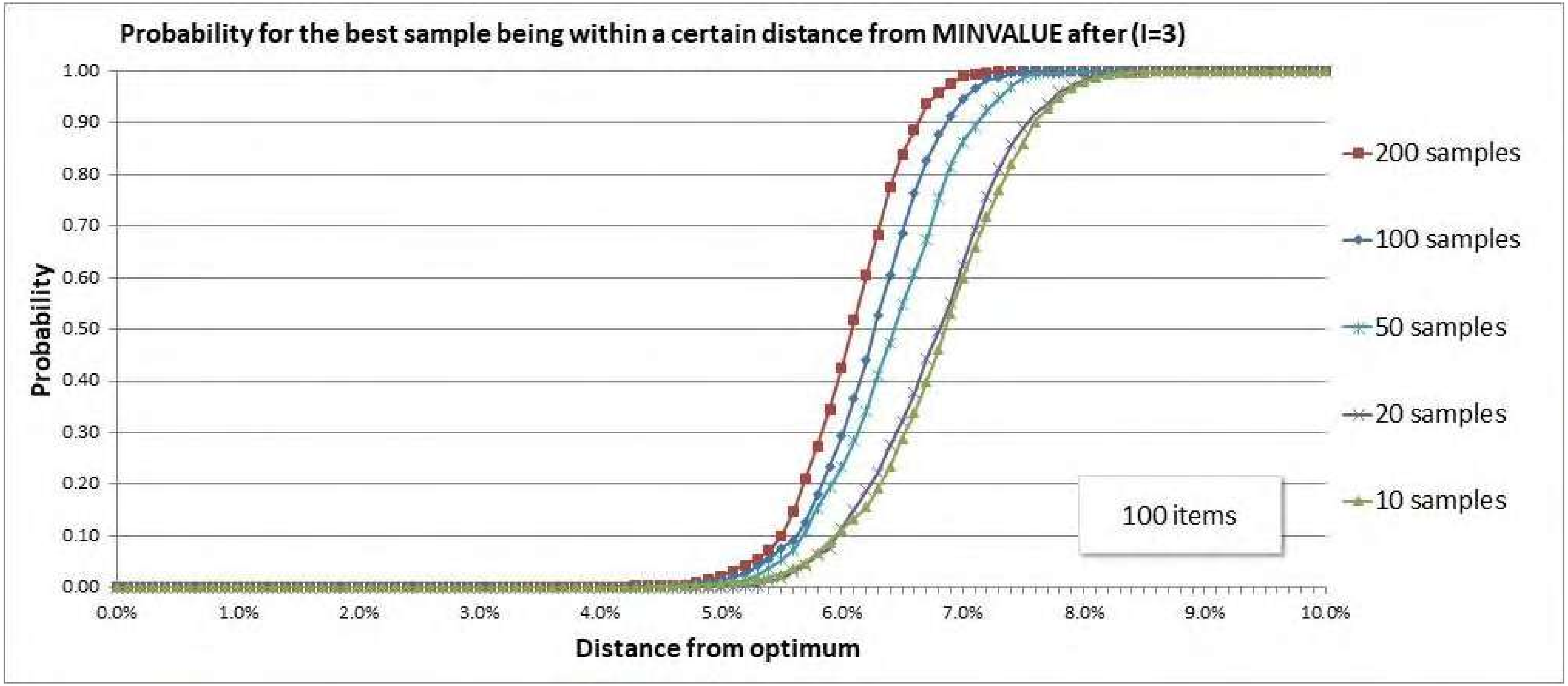
Systecon

Can we scale?

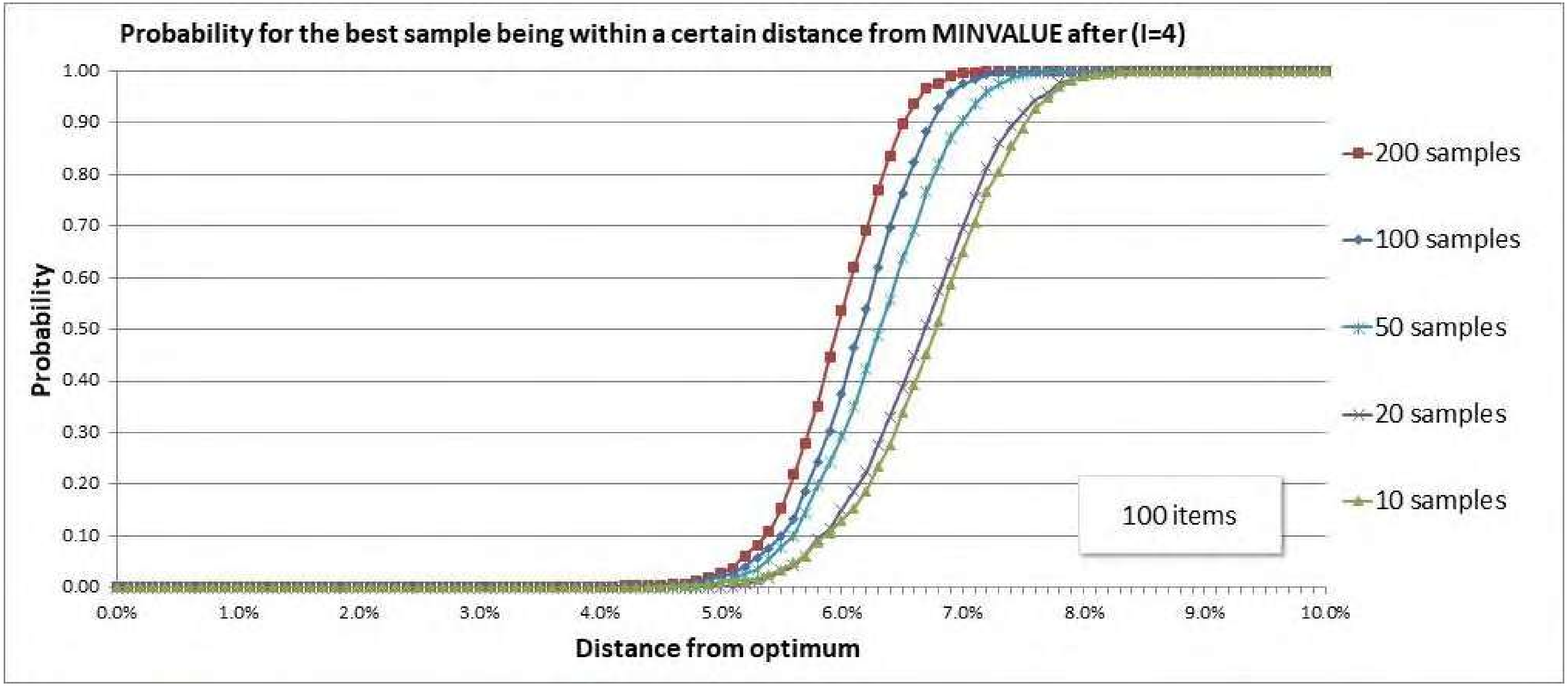


Systecon

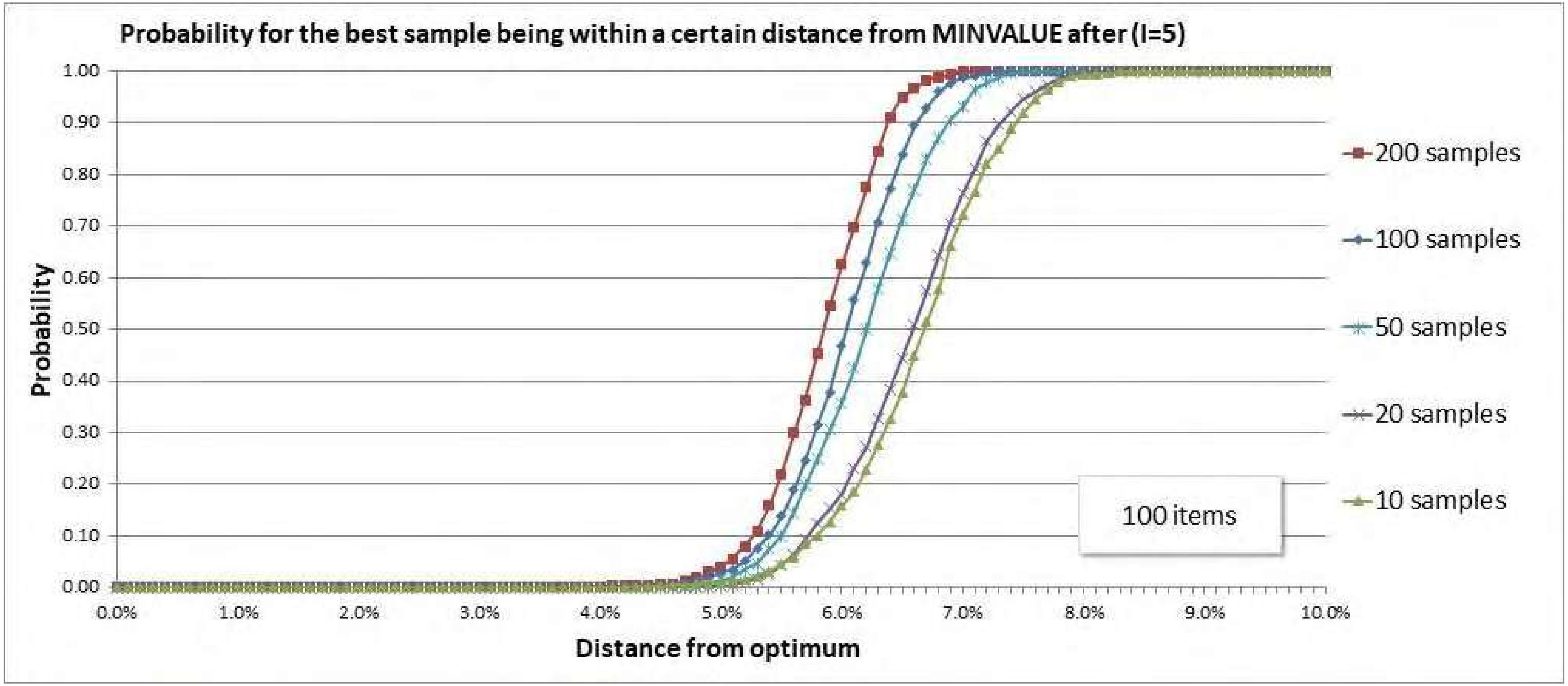
Can we scale?


Probability for the best sample being within a certain distance from MINVALUE after (I=3)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Probability
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

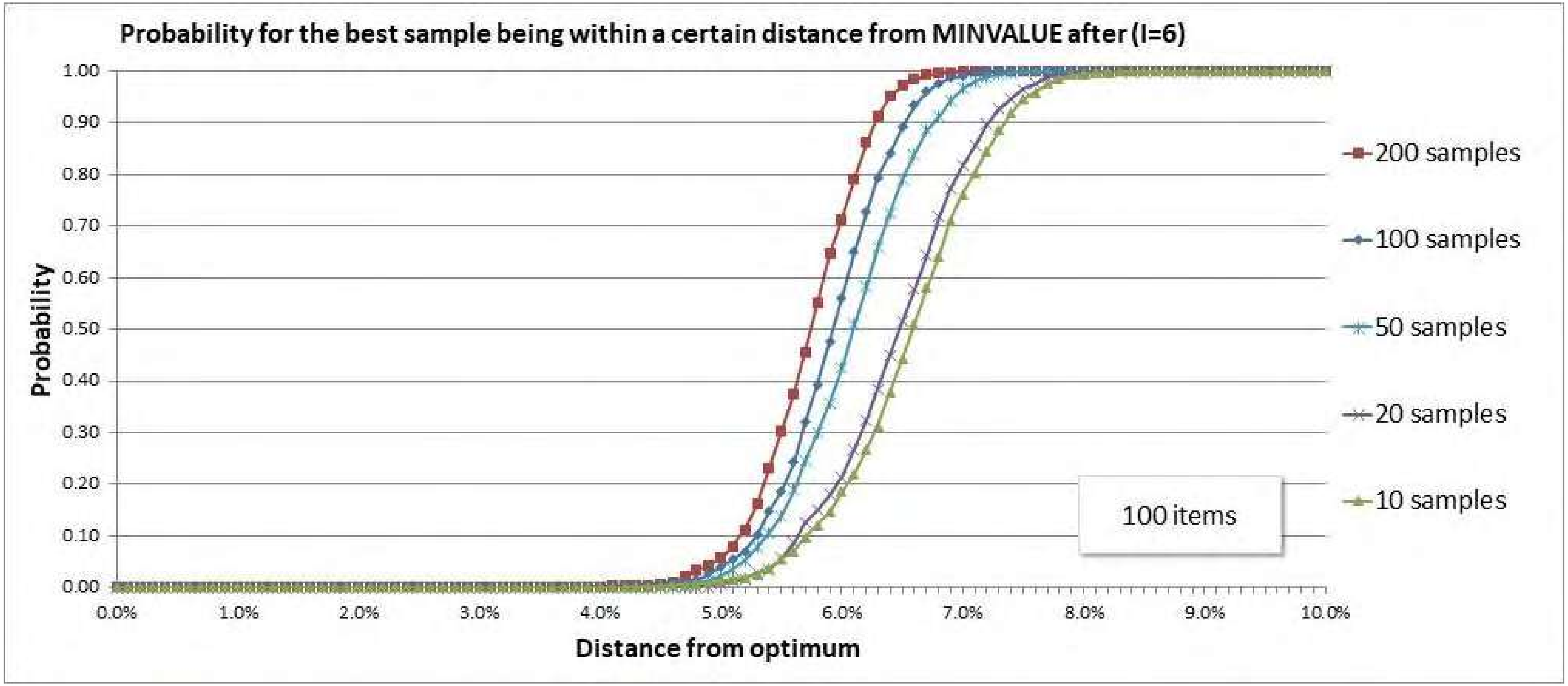
Can we scale?


Probability for the best sample being within a certain distance from MINVALUE after (I=4)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?

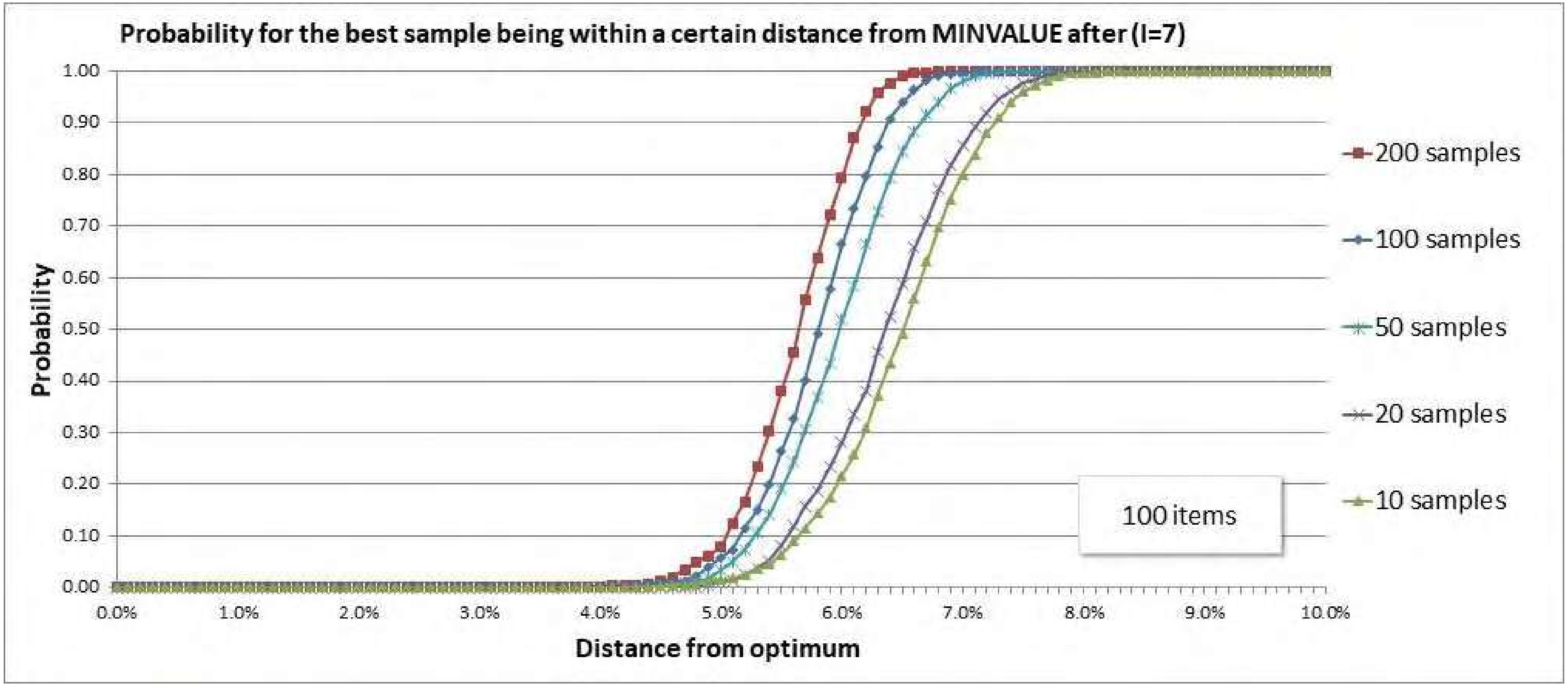

Probability for the best sample being within a certain distance from MINVALUE after (I=5)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Probability
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?

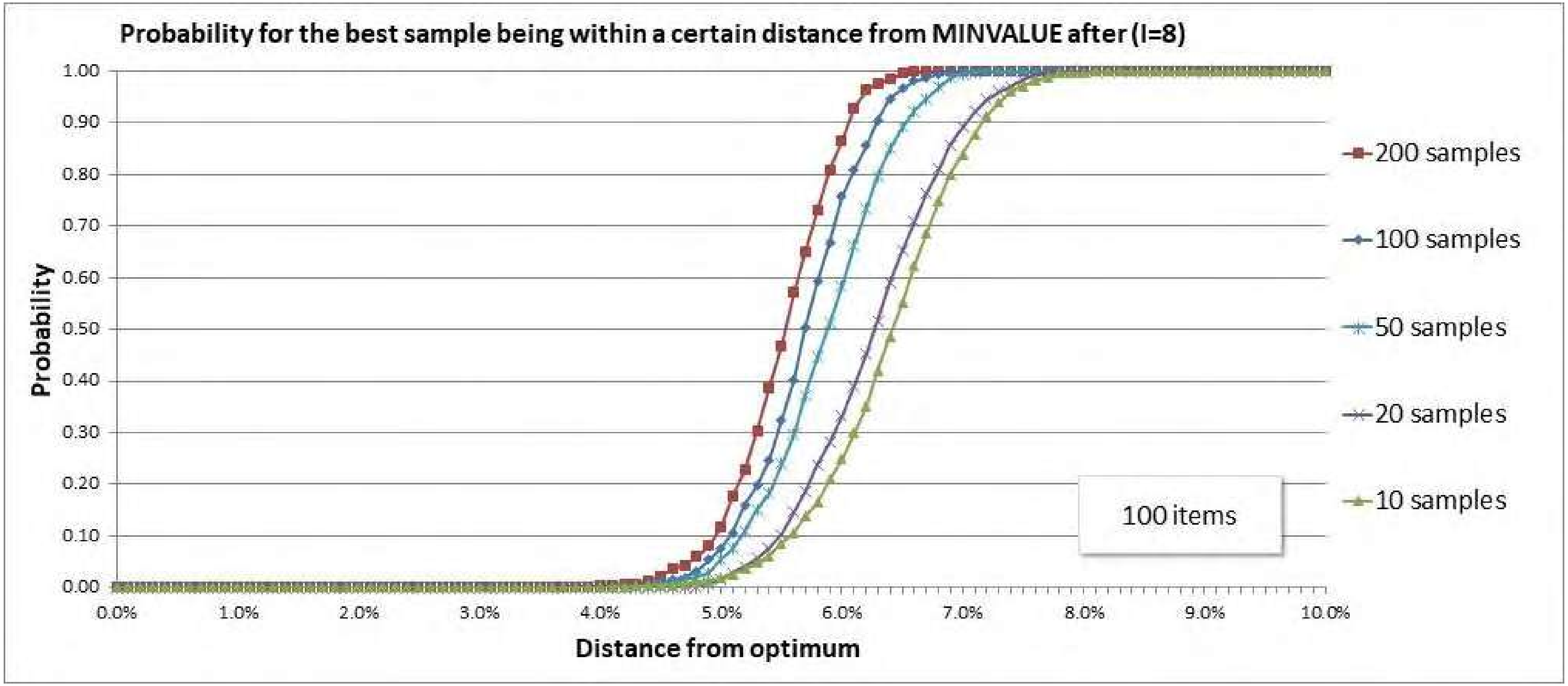


Systecon

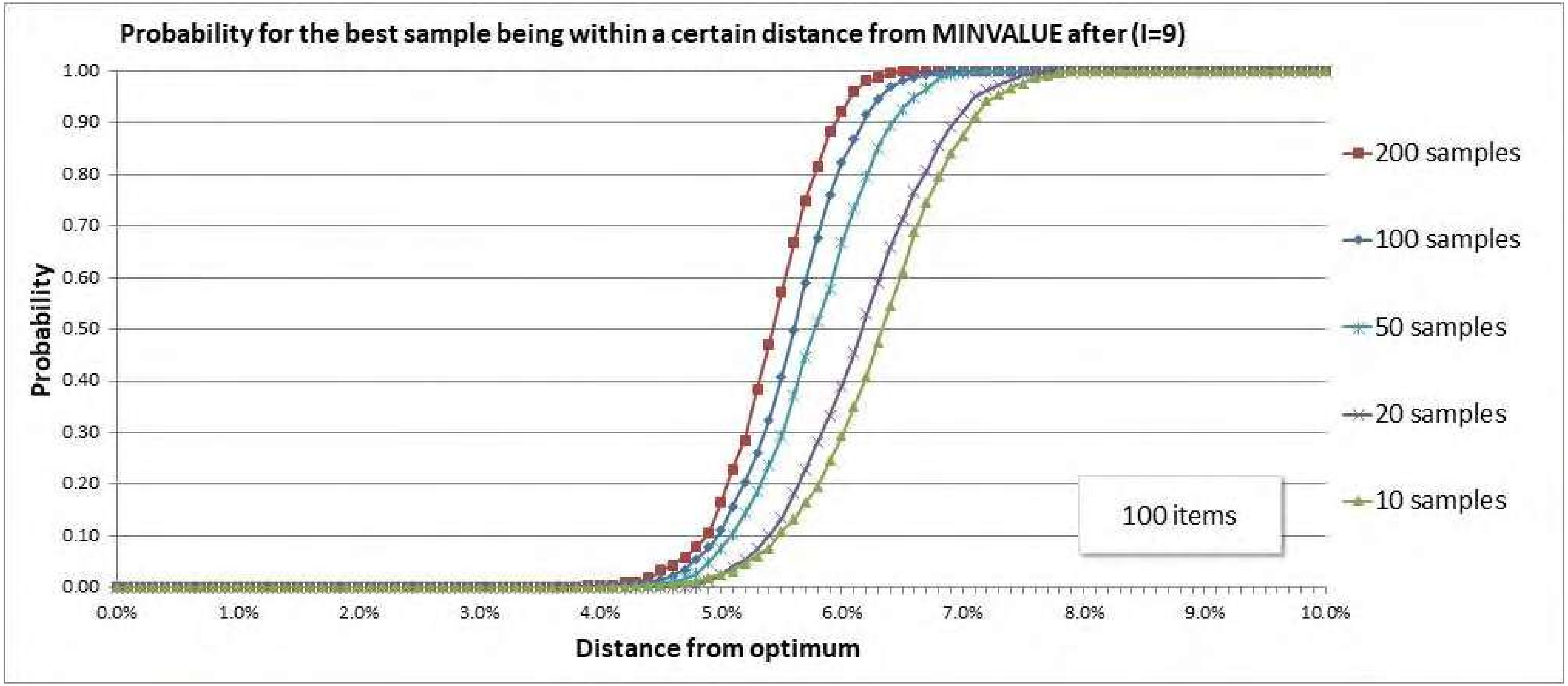
Can we scale?


Probability for the best sample being within a certain distance from MINVALUE after (I=7)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Probability
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?

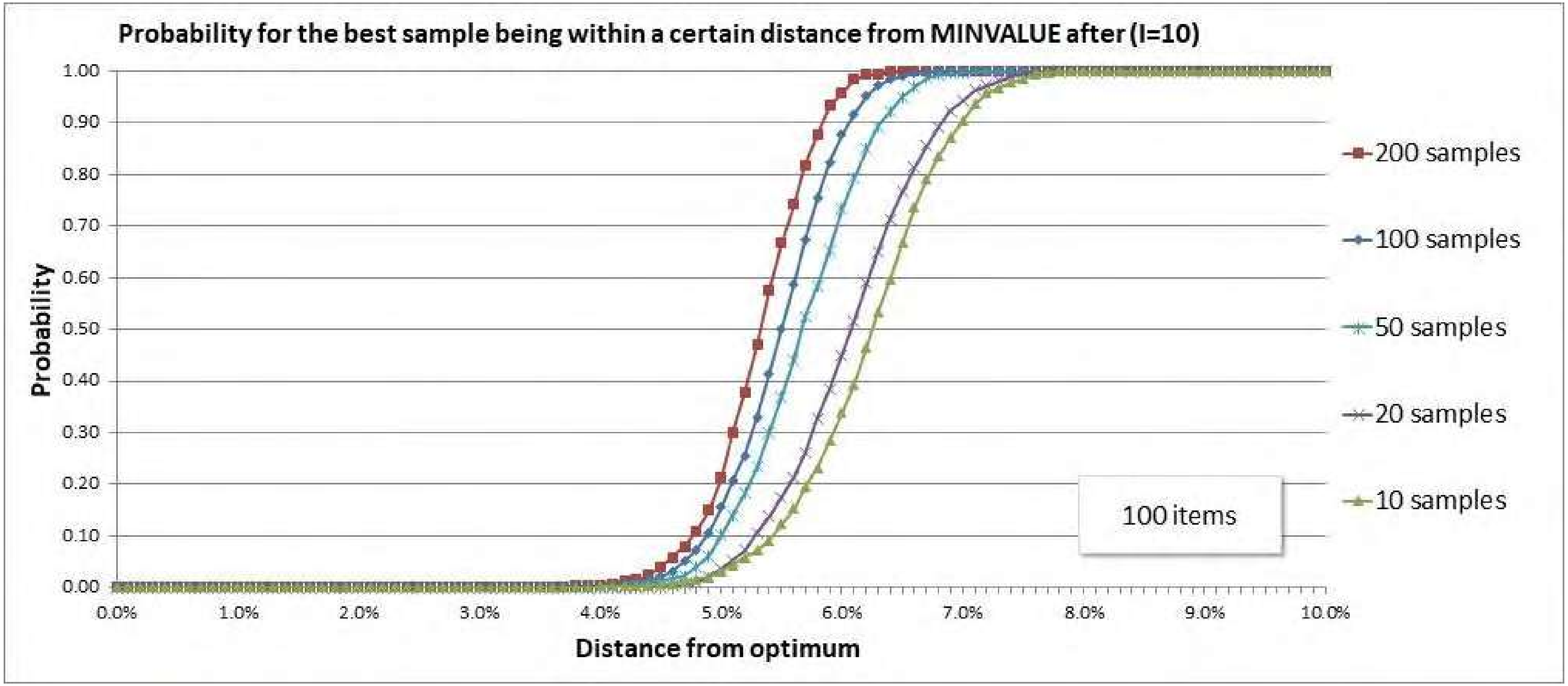

Probability for the best sample being within a certain distance from MINVALUE after (I=8)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?



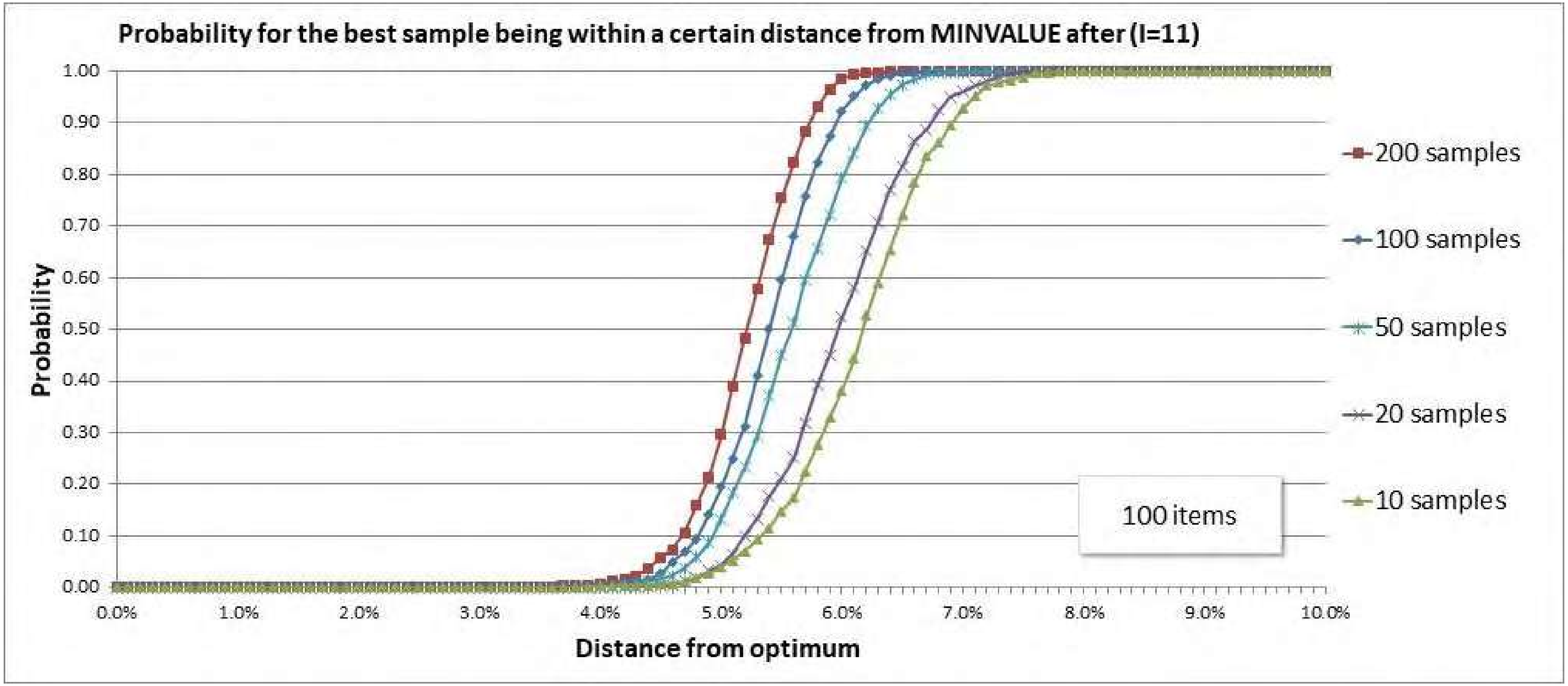
Systecon

Can we scale?

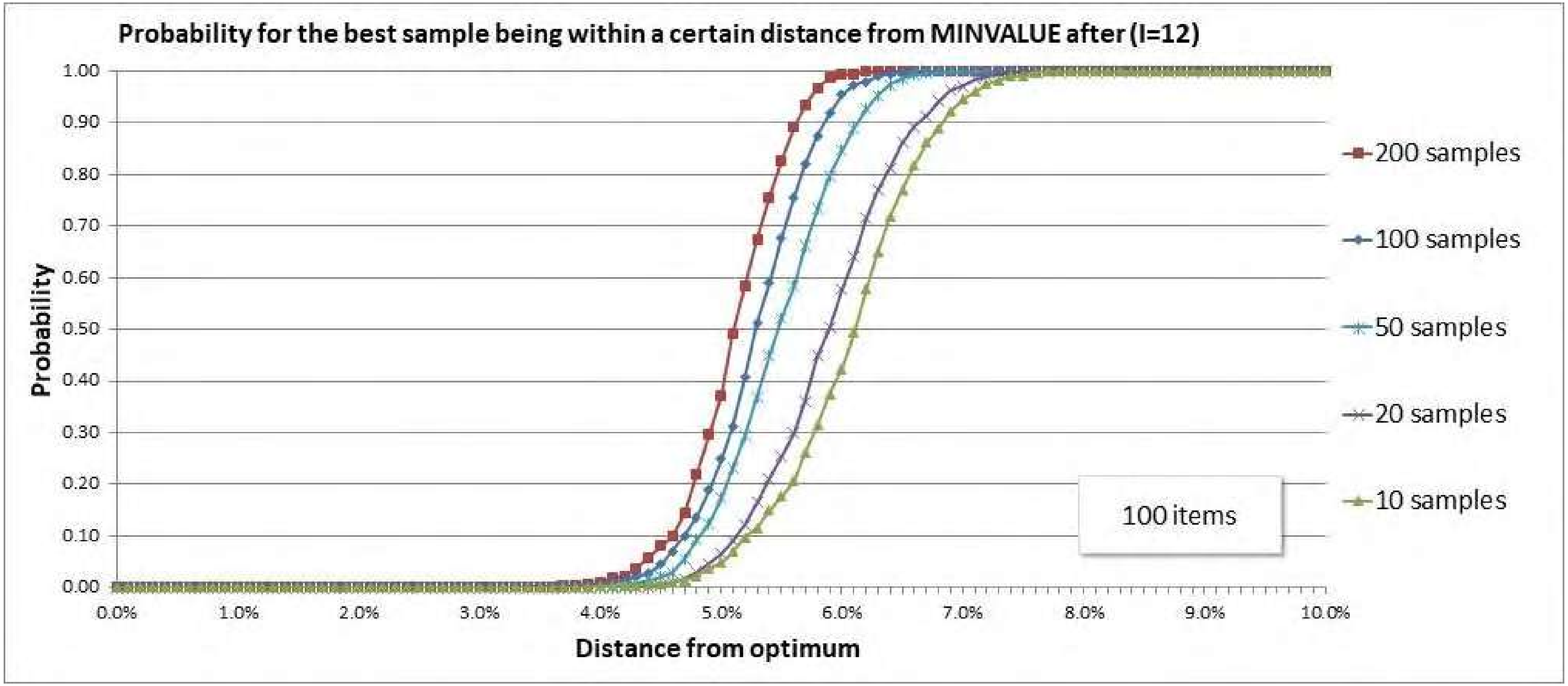


Systecon

Can we scale?

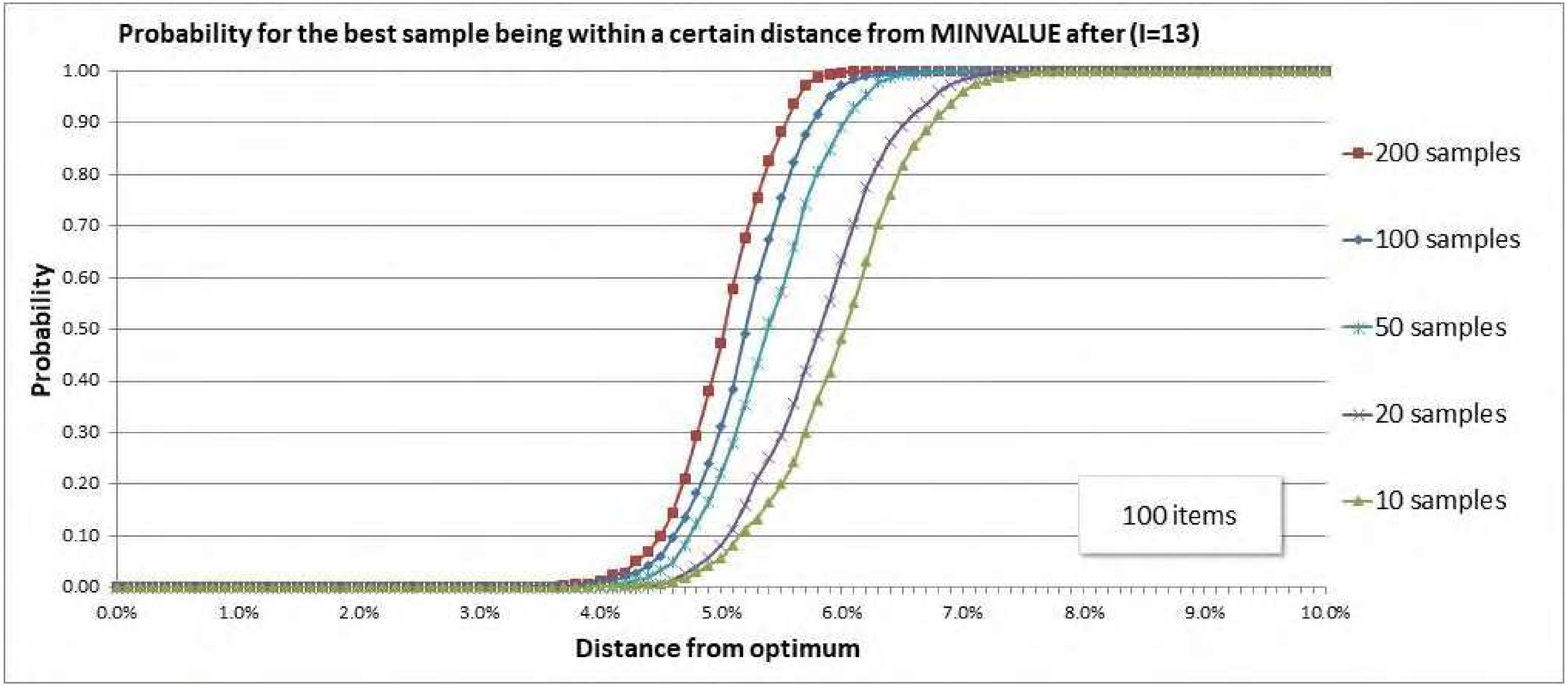

Probability for the best sample being within a certain distance from MINVALUE after (I=11)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?



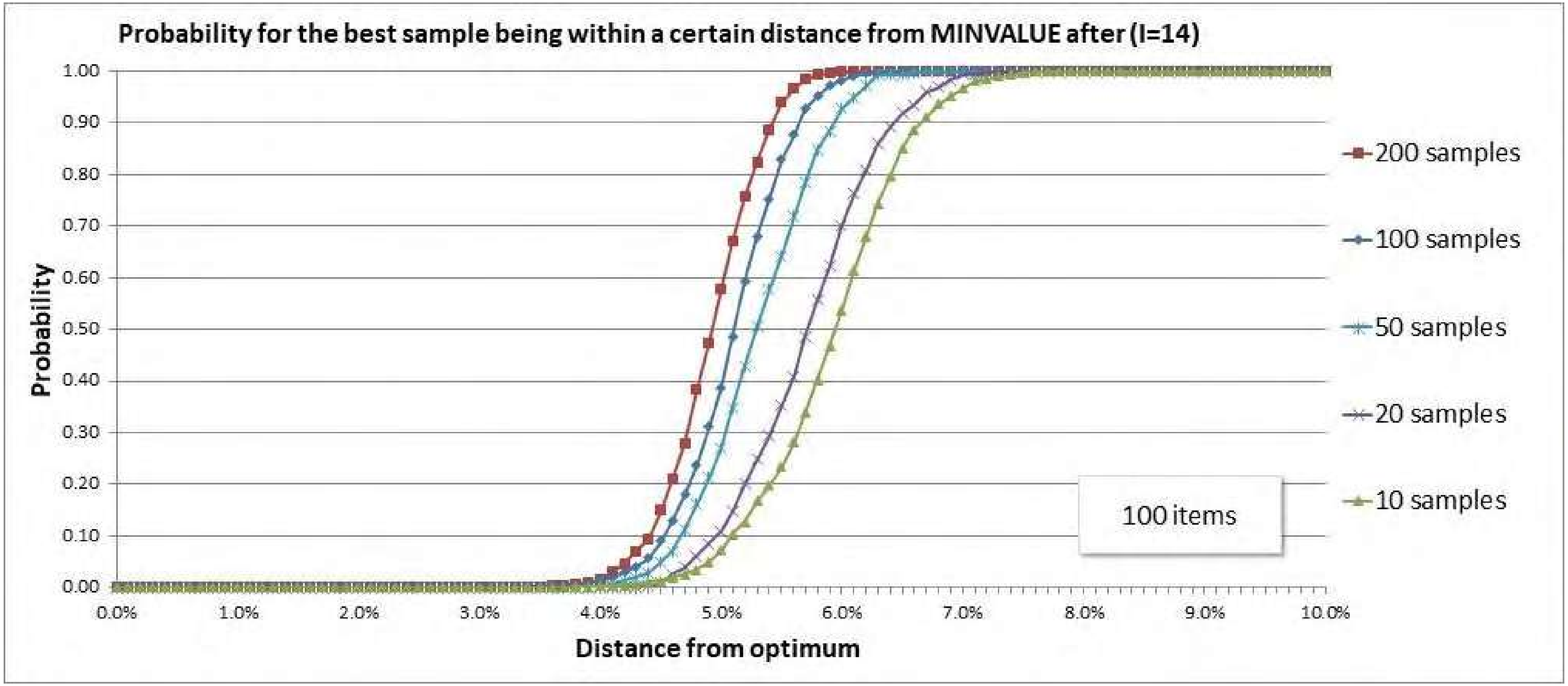
Systecon

Can we scale?



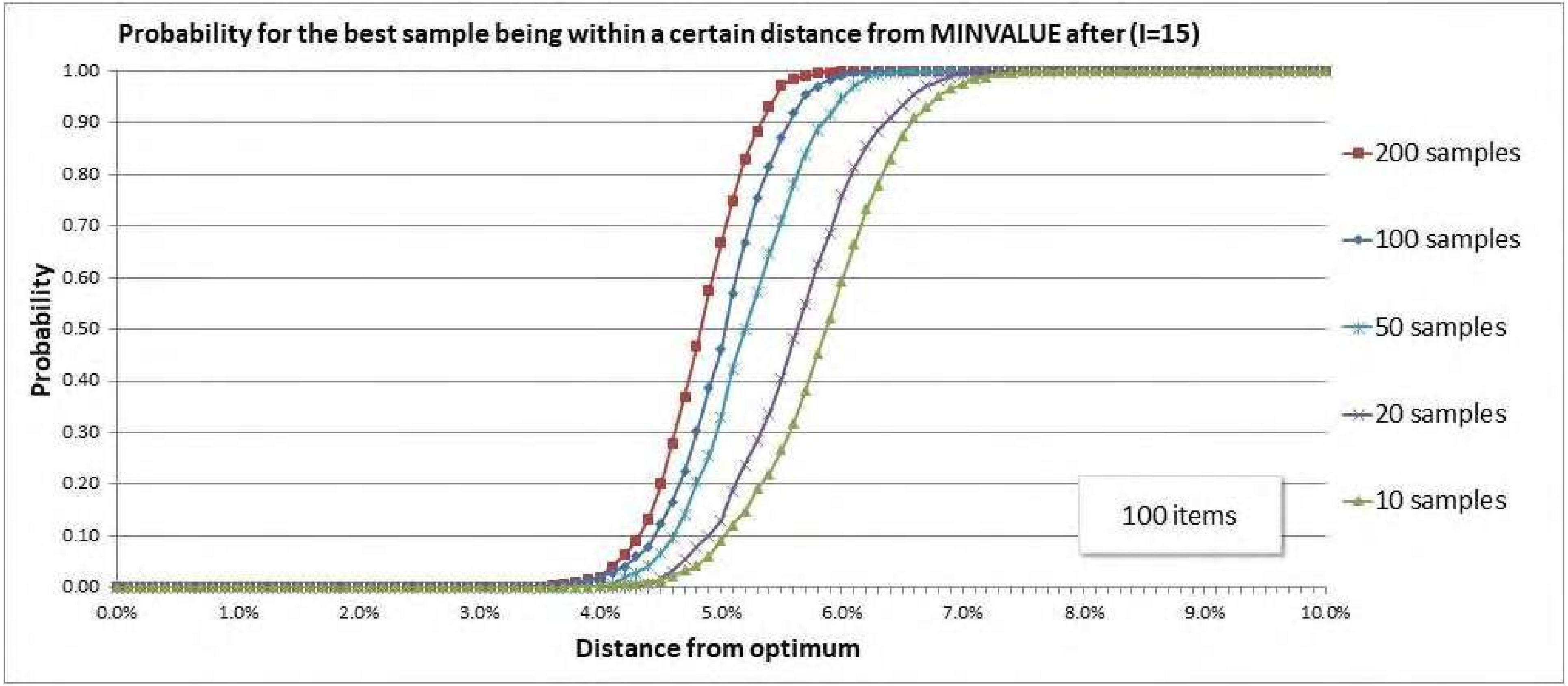
Systecon

Can we scale?



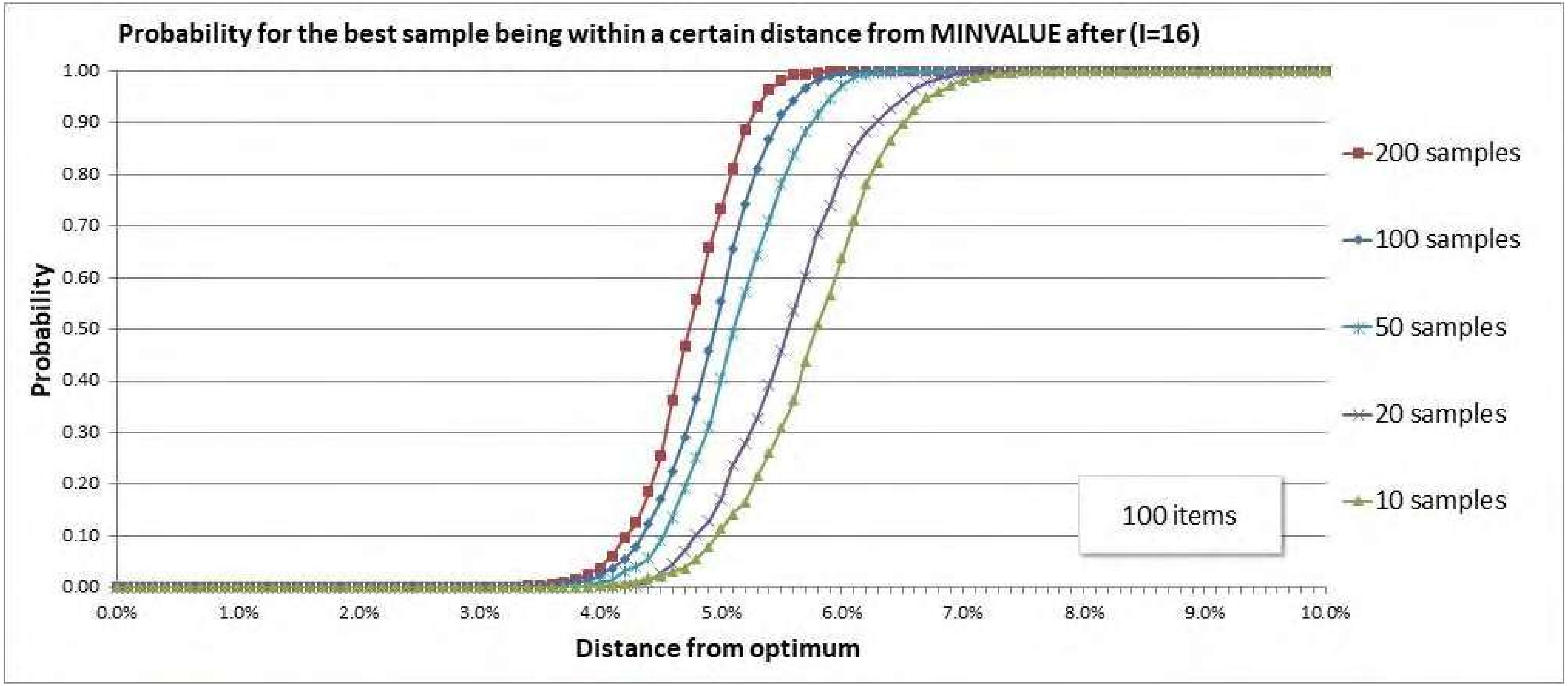
Systecon

Can we scale?

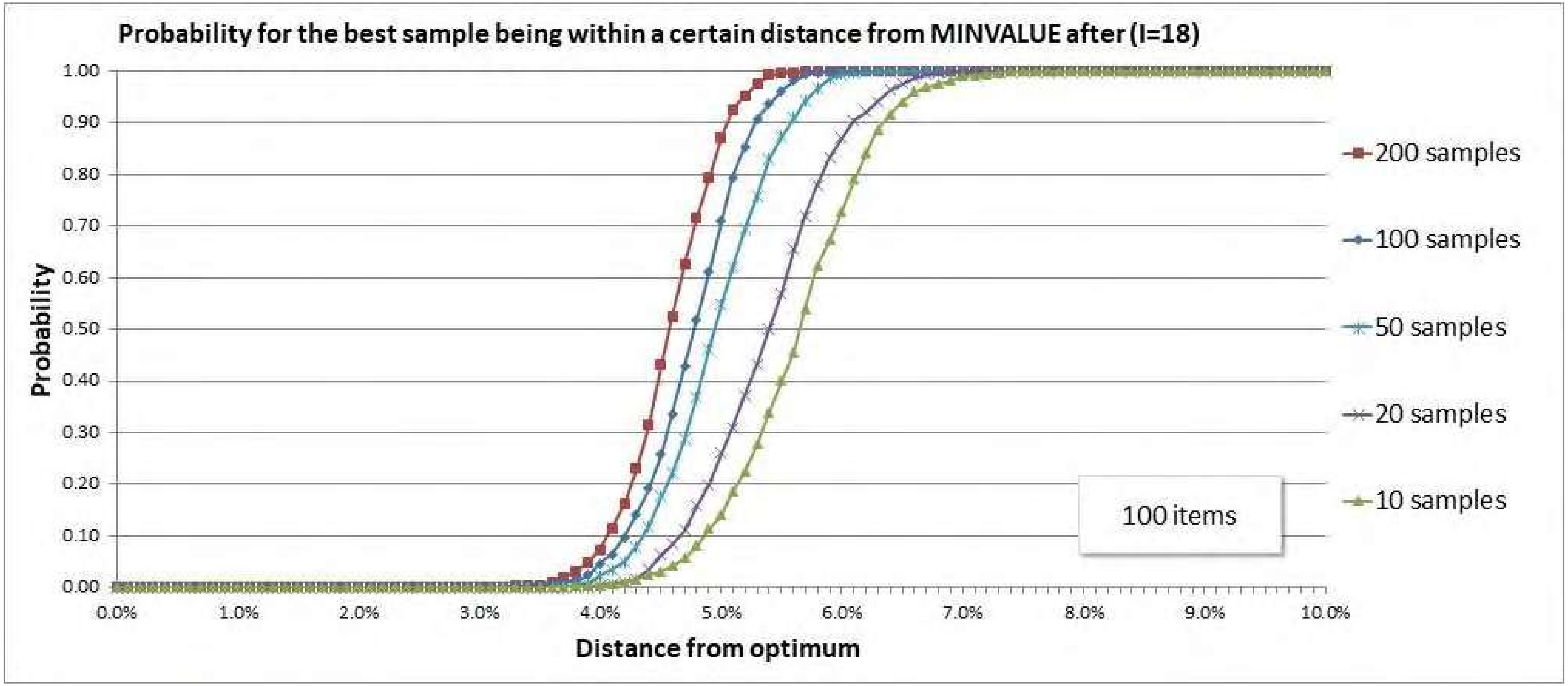


Systecon

Can we scale?

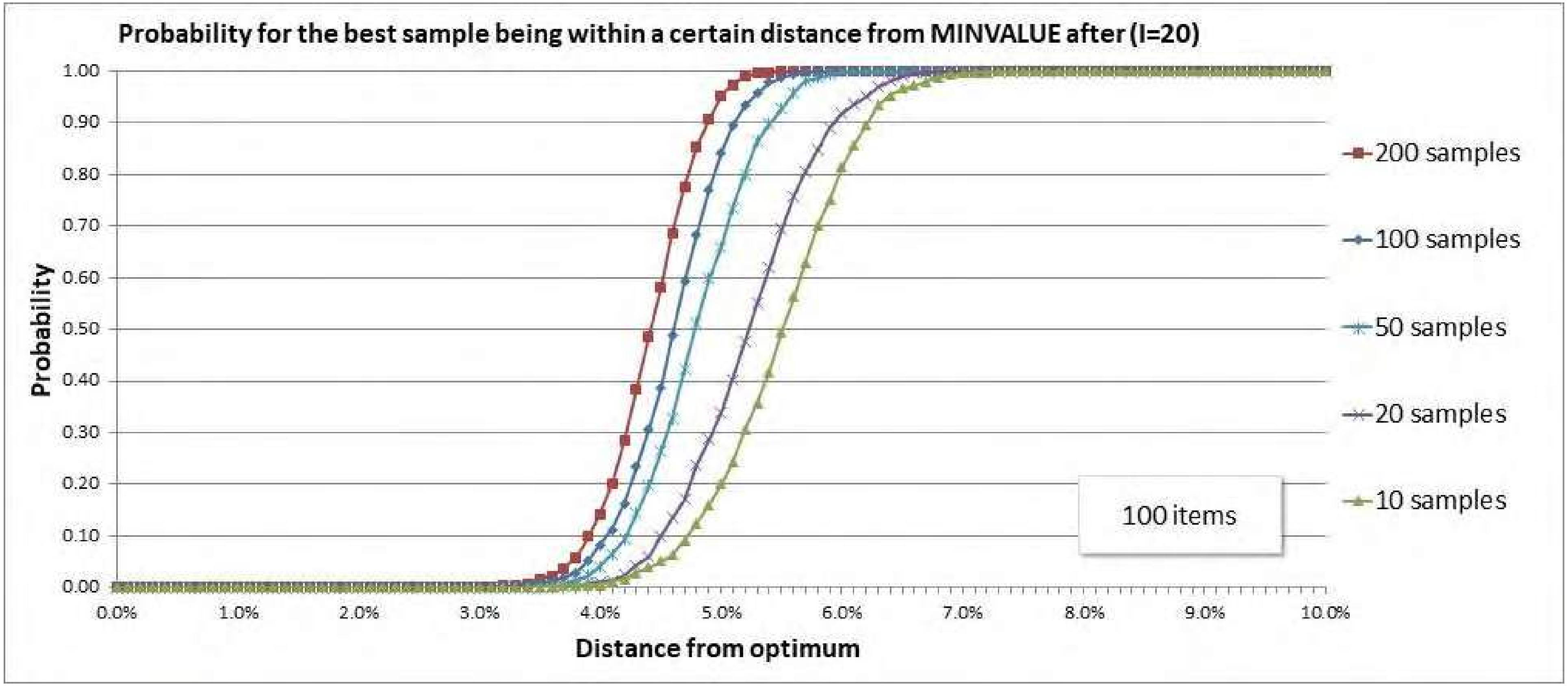

Probability for the best sample being within a certain distance from MINVALUE after (I=16)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?

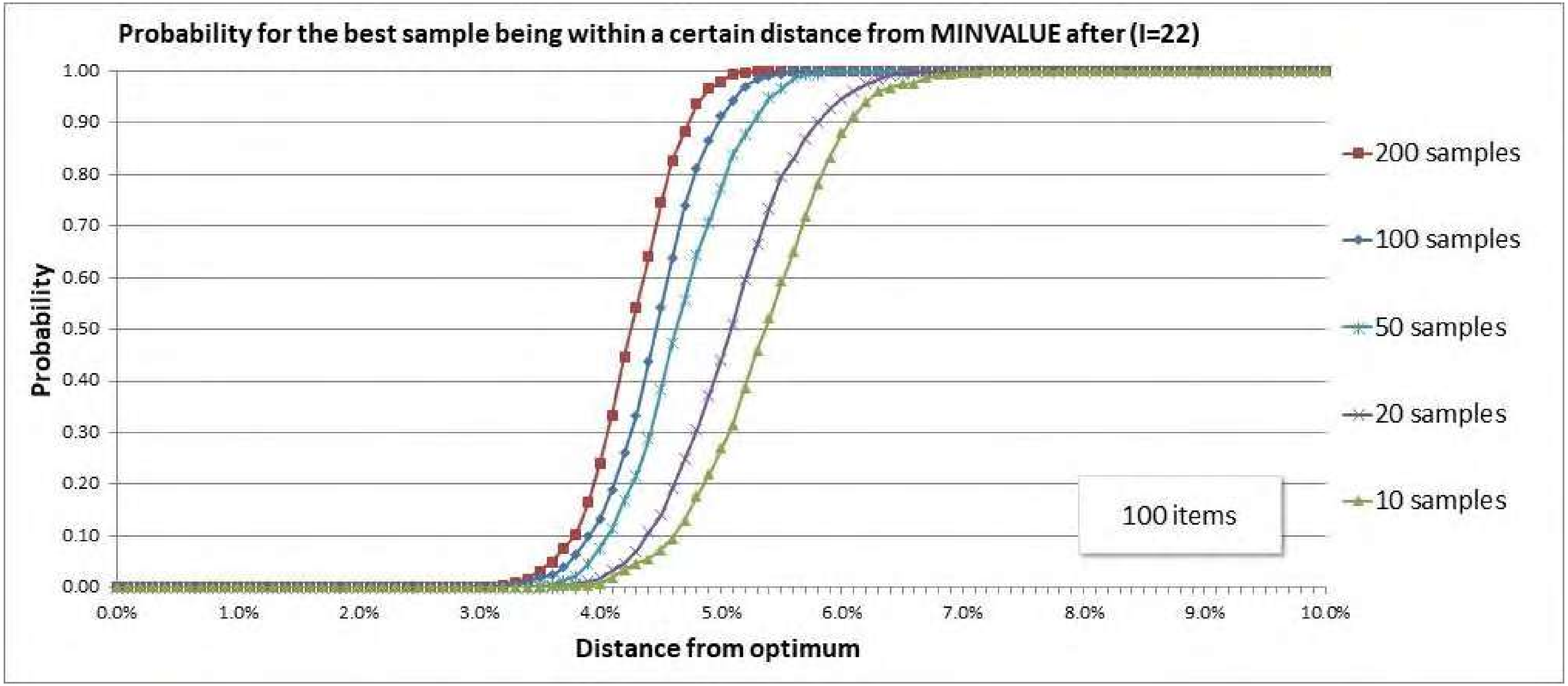


Systecon

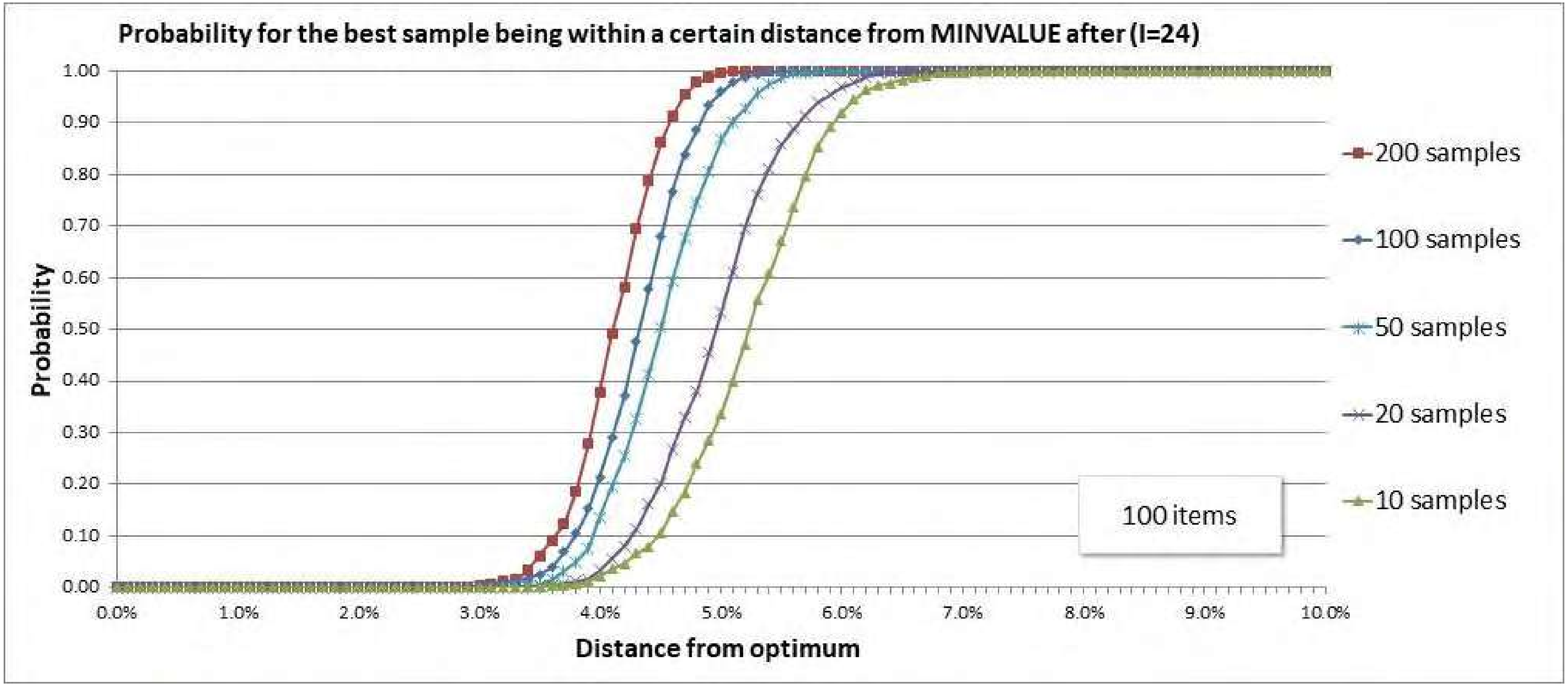
Can we scale?


Probability for the best sample being within a certain distance from MINVALUE after (I=20)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?

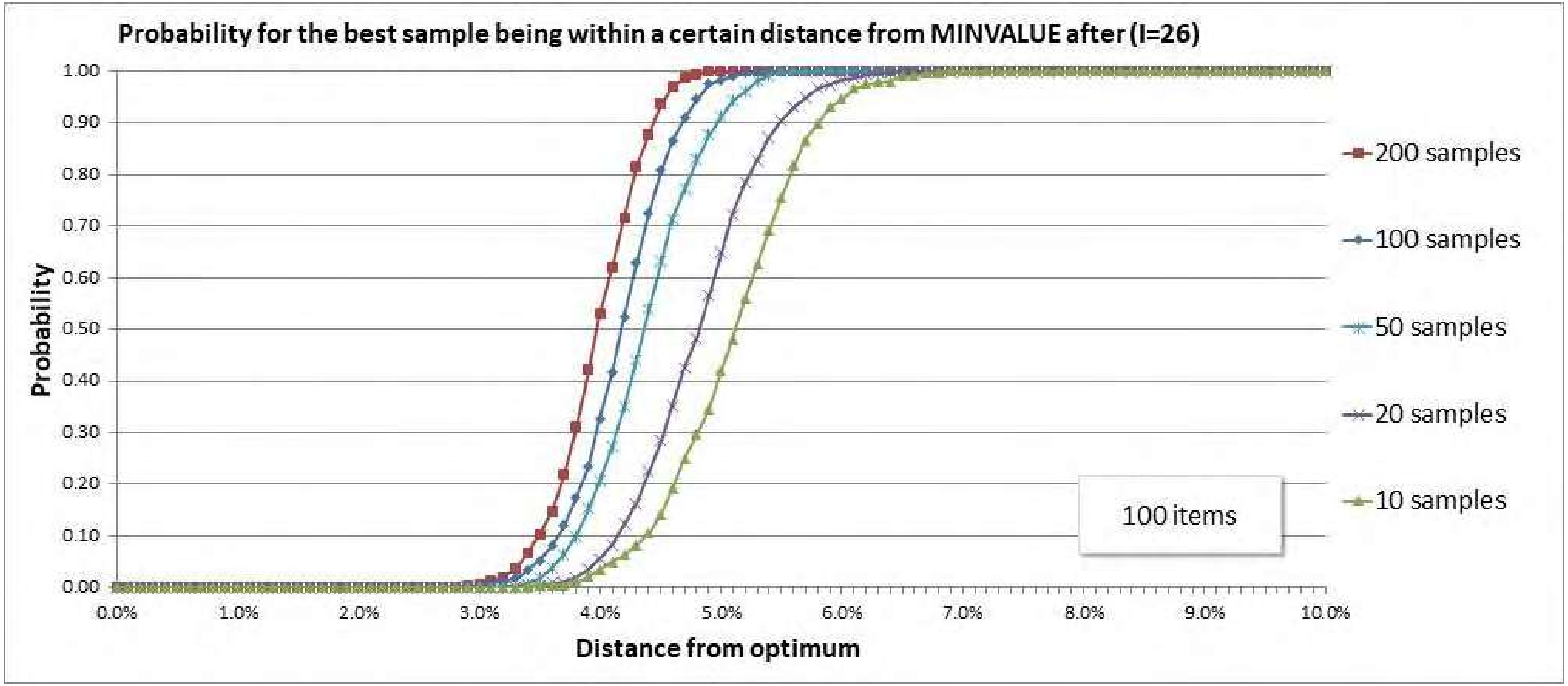

Probability for the best sample being within a certain distance from MINVALUE after (I=22)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Probability
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?



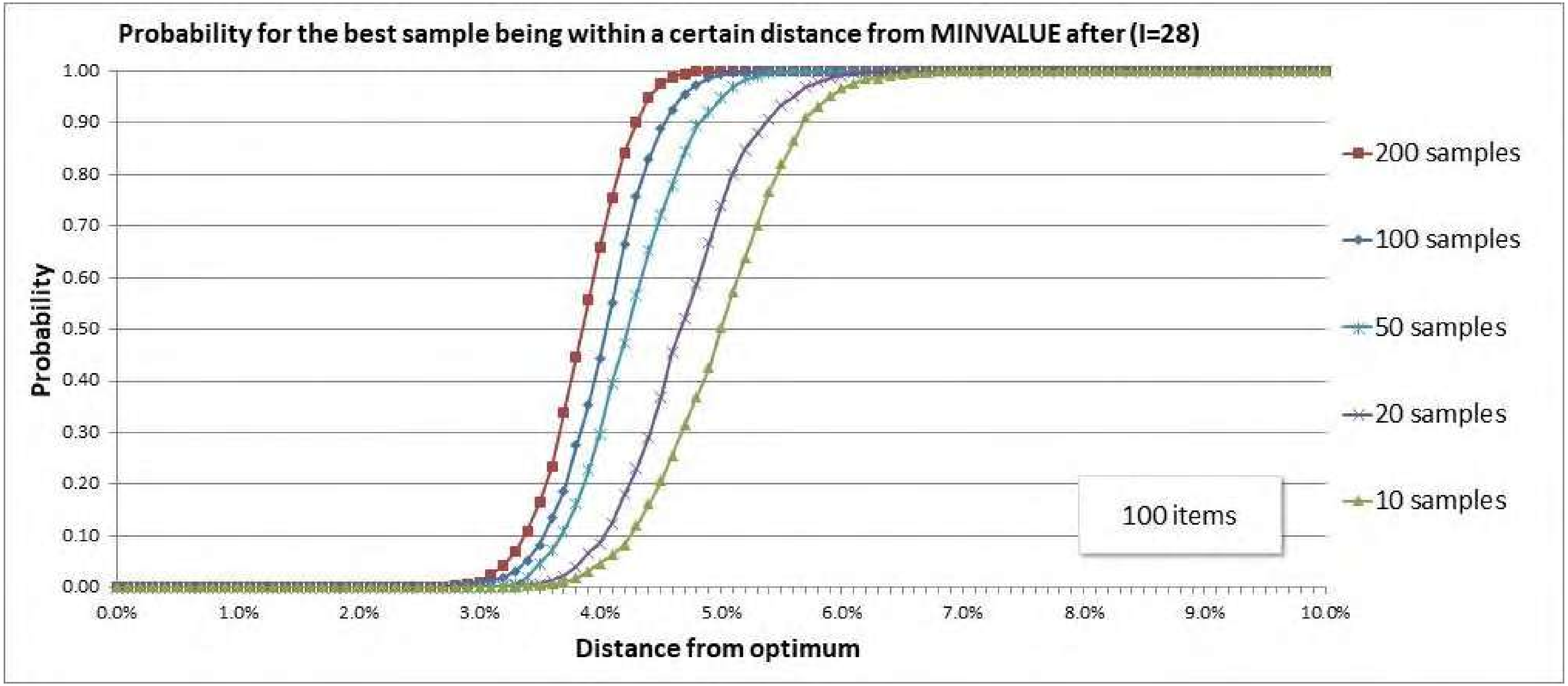
Systecon

Can we scale?

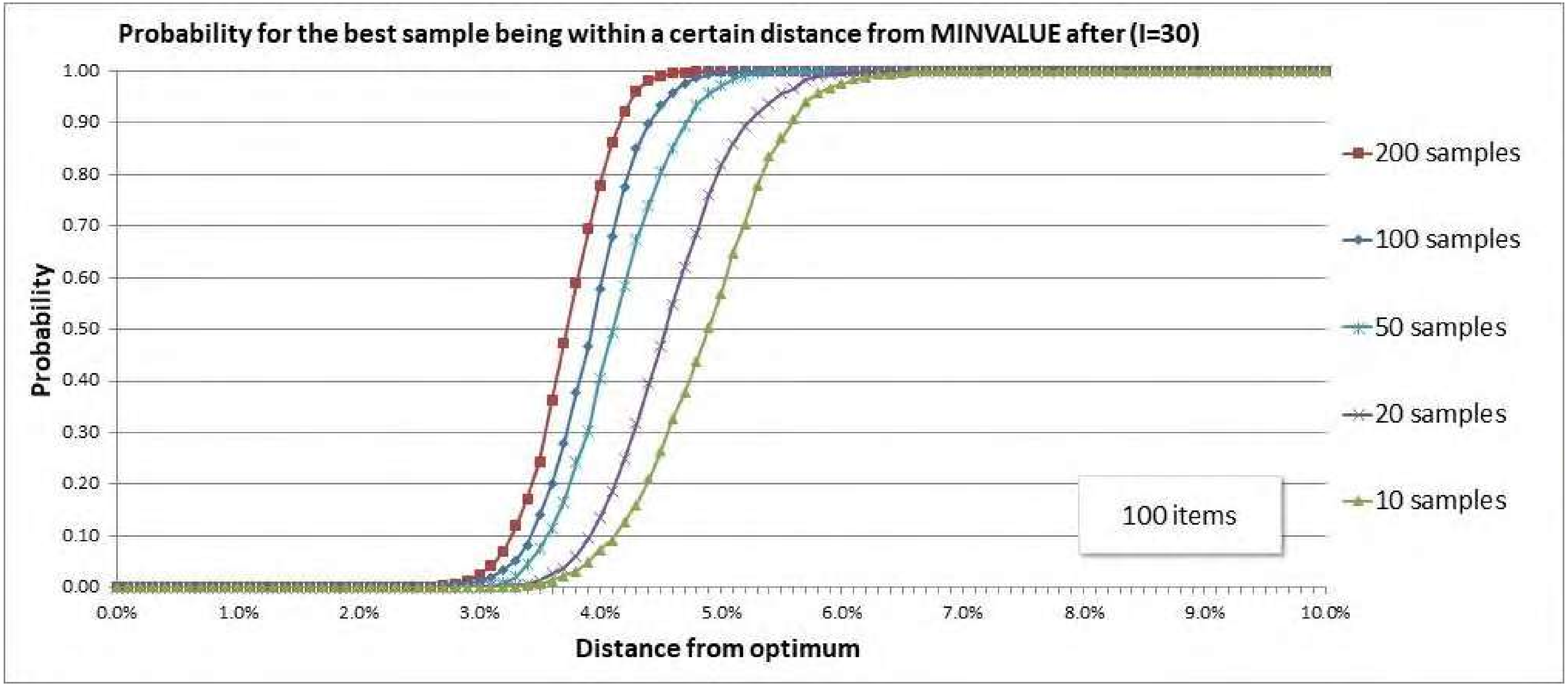


Systecon

Can we scale?

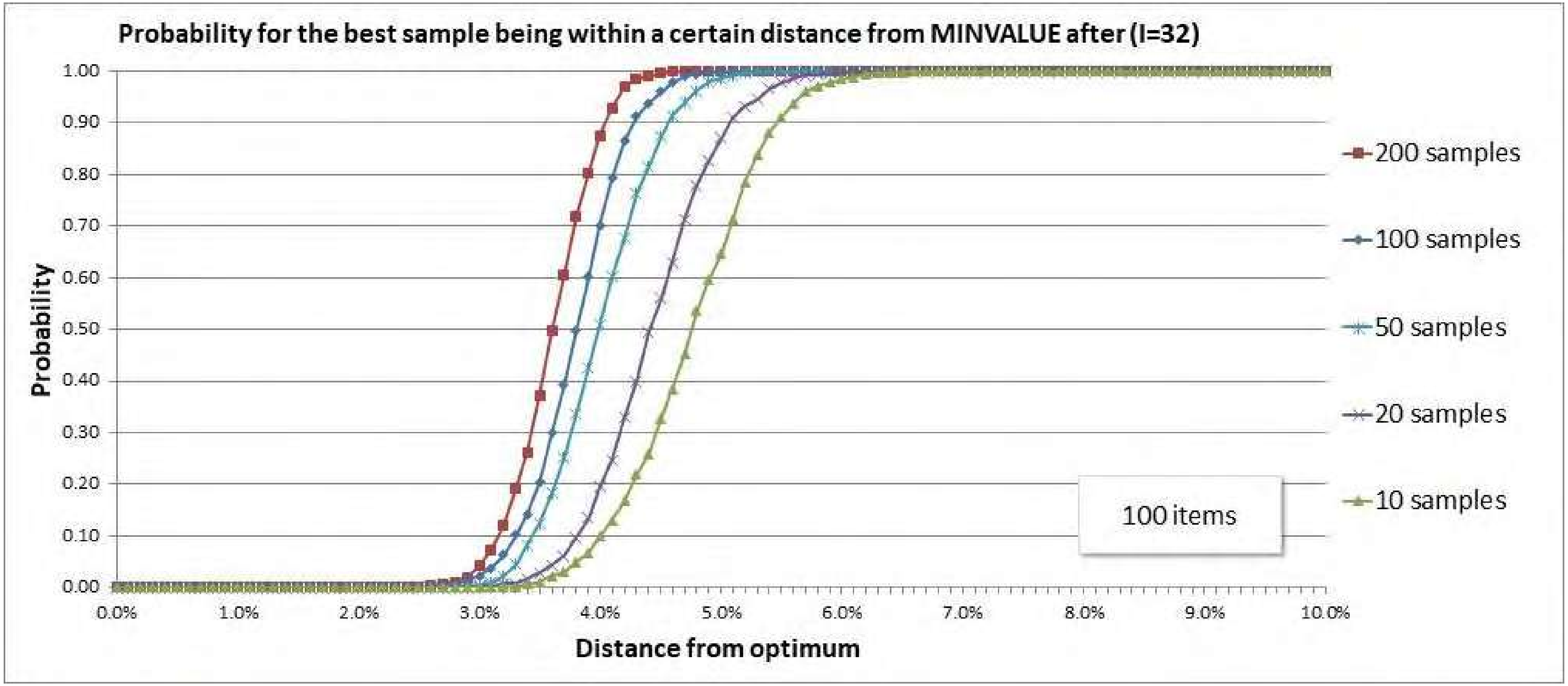

Probability for the best sample being within a certain distance from MINVALUE after (I=28)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?



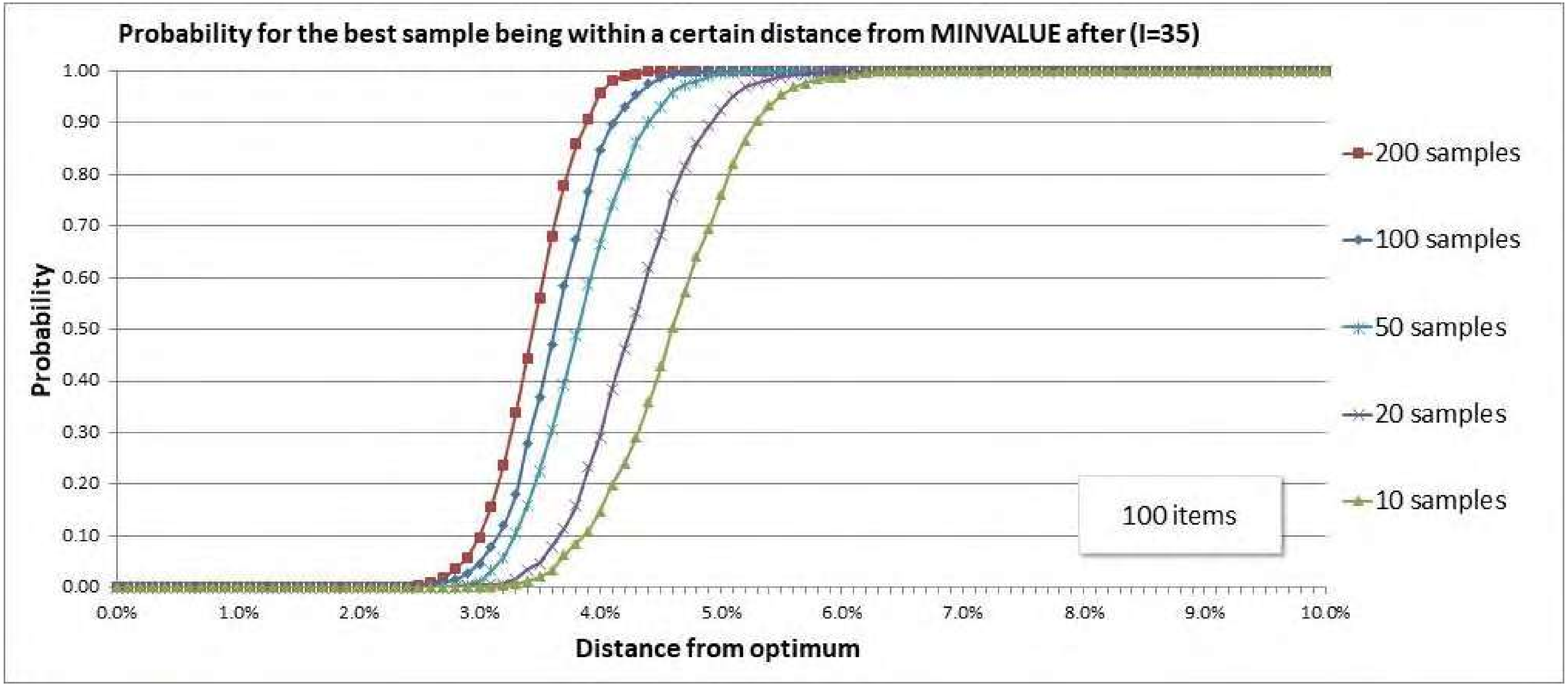
Systecon

Can we scale?



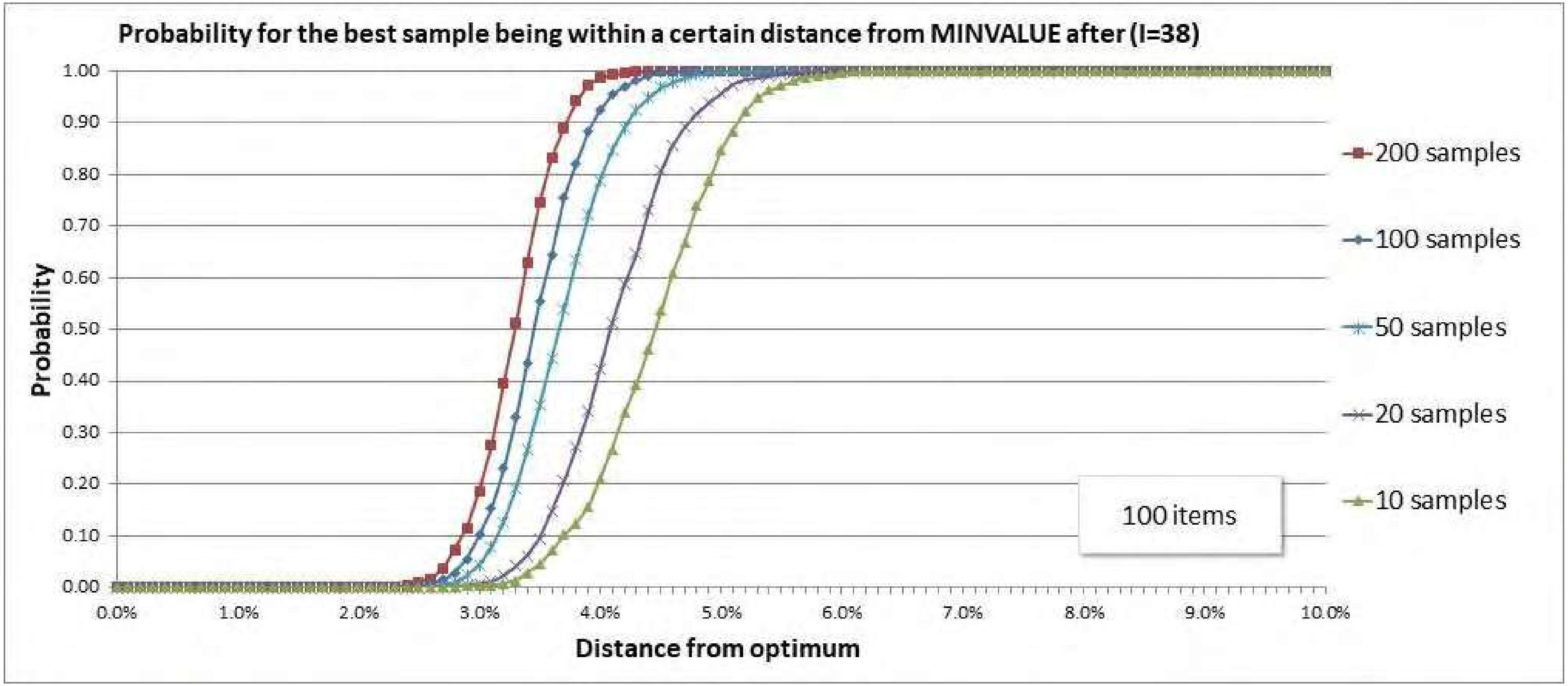
Systecon

Can we scale?

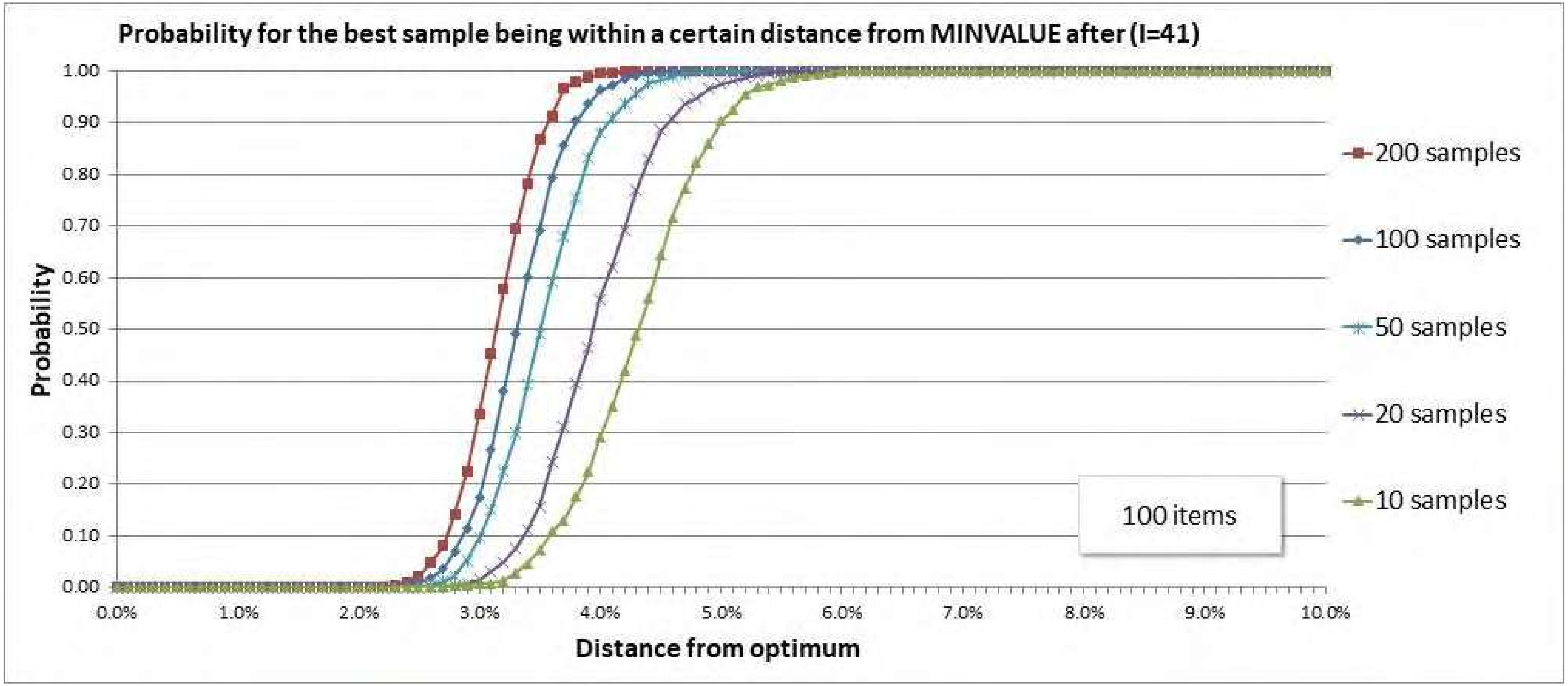


Probability for the best sample being within a certain distance from MINVALUE after (I=35)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?

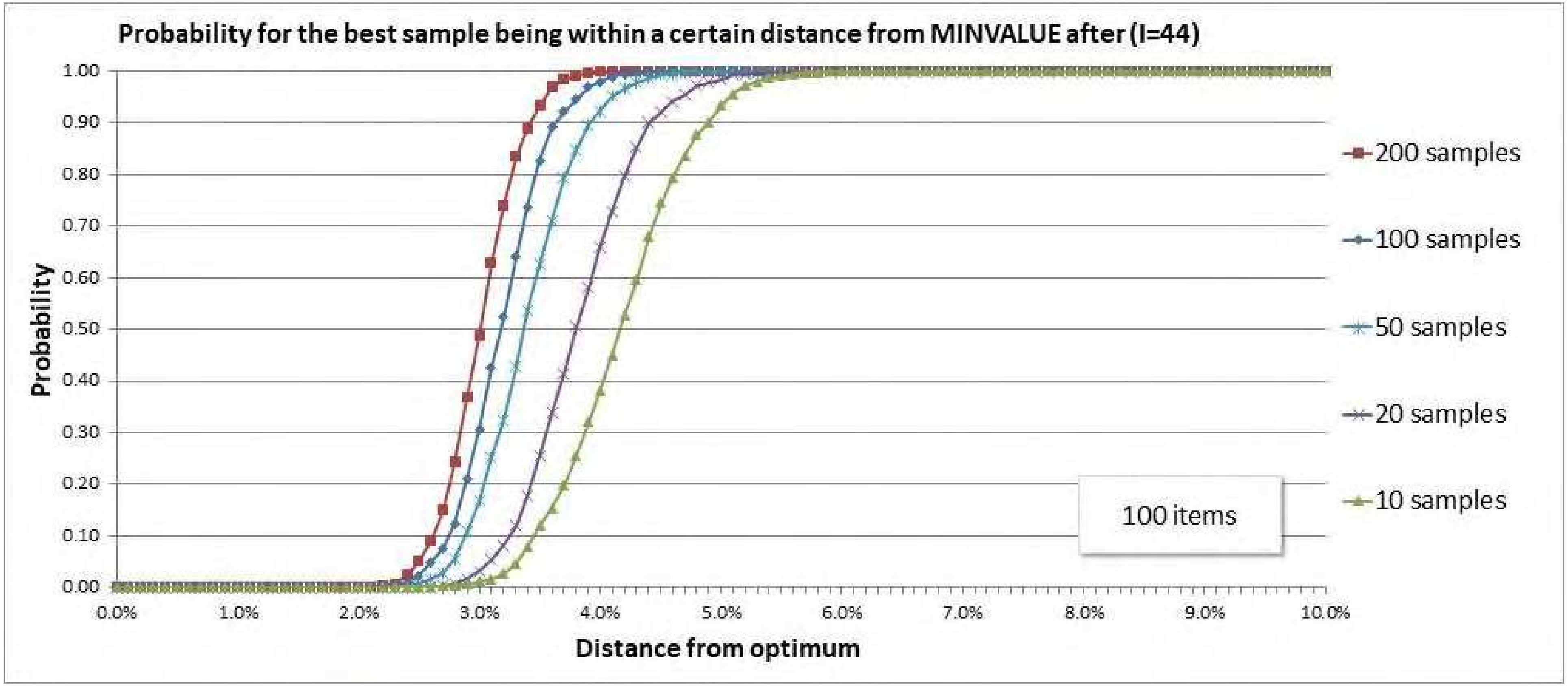

Probability for the best sample being within a certain distance from MINVALUE after (I=38)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?



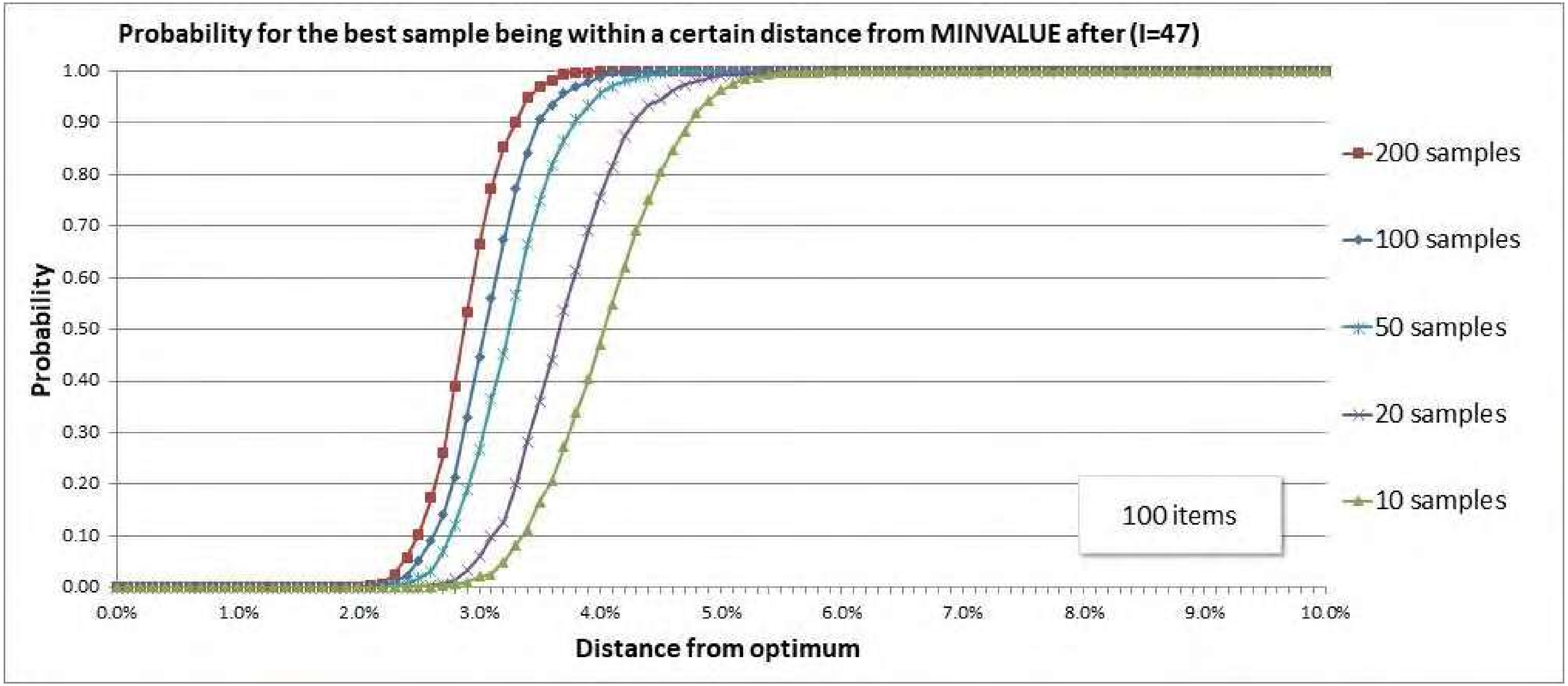
Systecon

Can we scale?



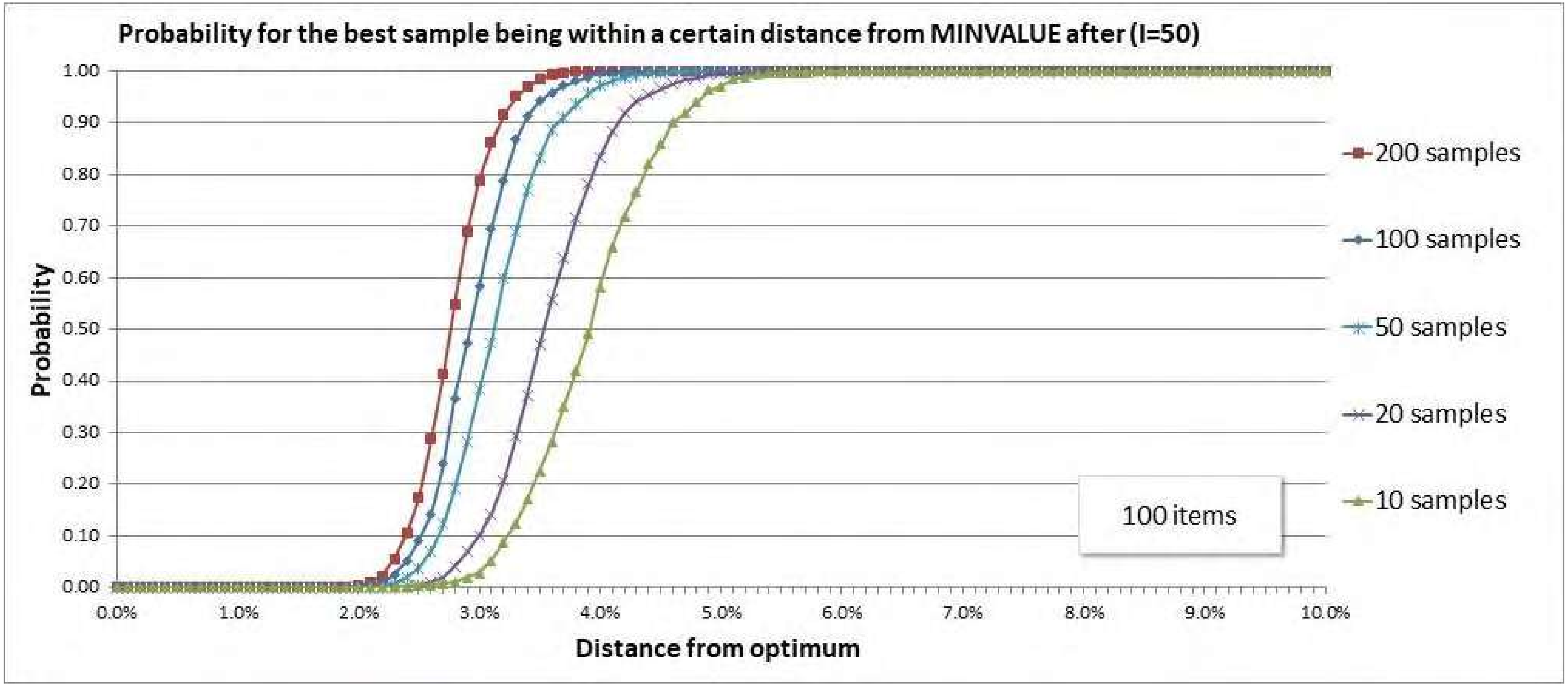
Probability for the best sample being within a certain distance from MINVALUE after (I=44)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?

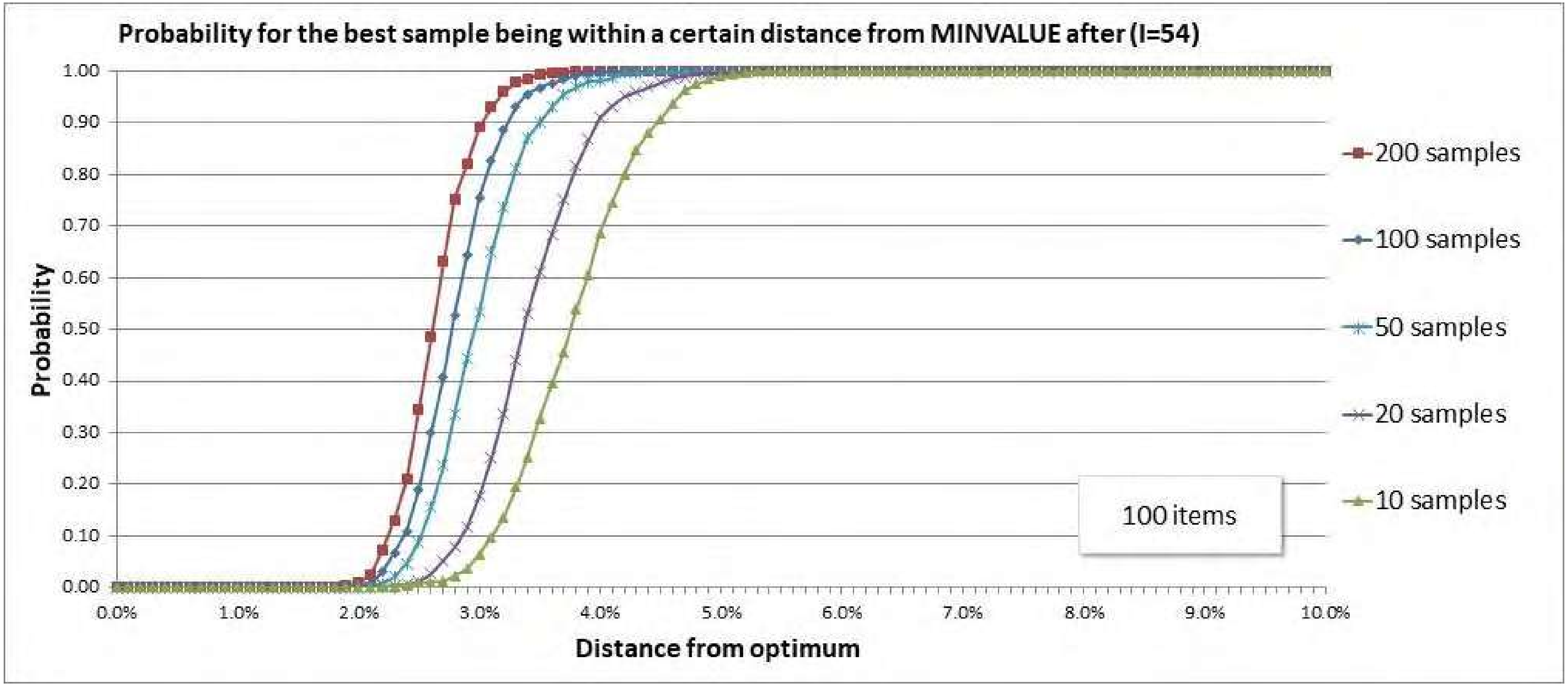


Systecon

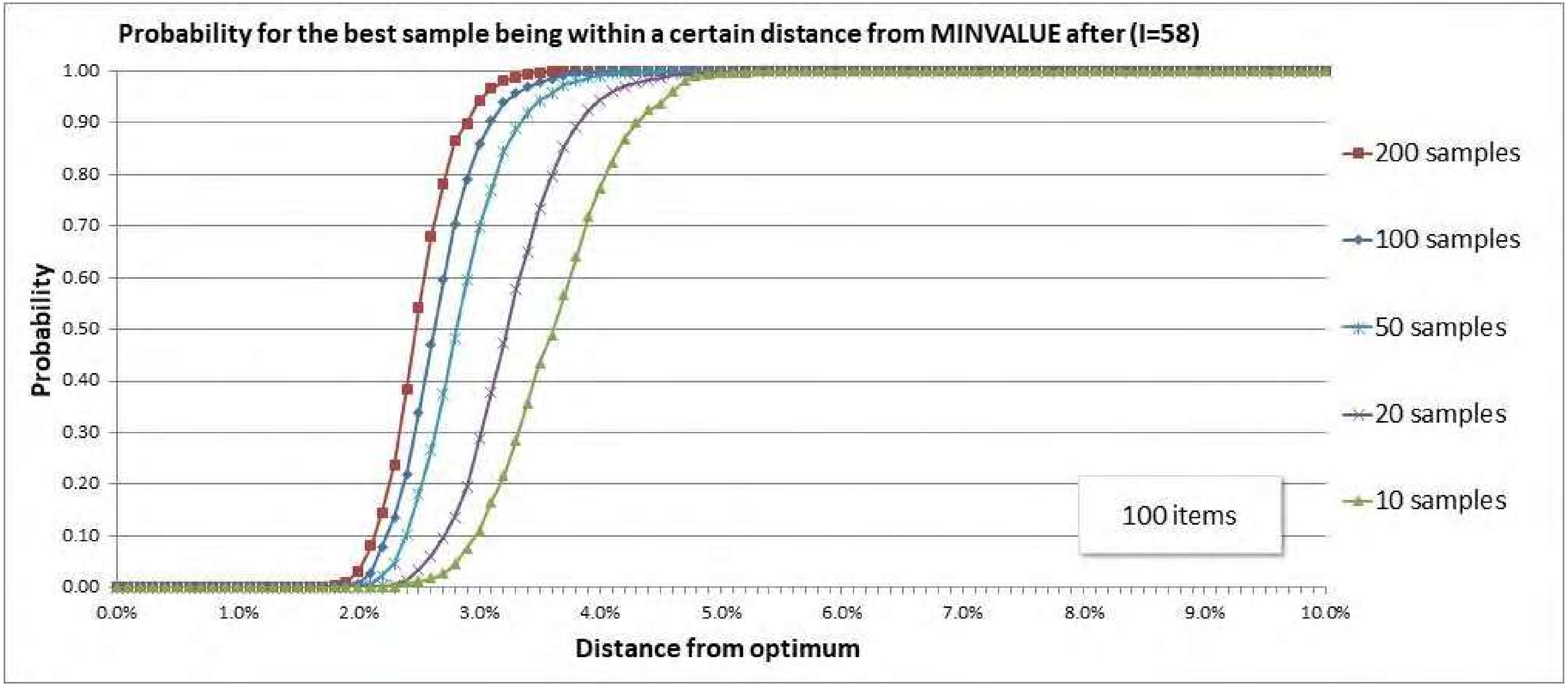
Can we scale?


Probability for the best sample being within a certain distance from MINVALUE after (I=50)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?

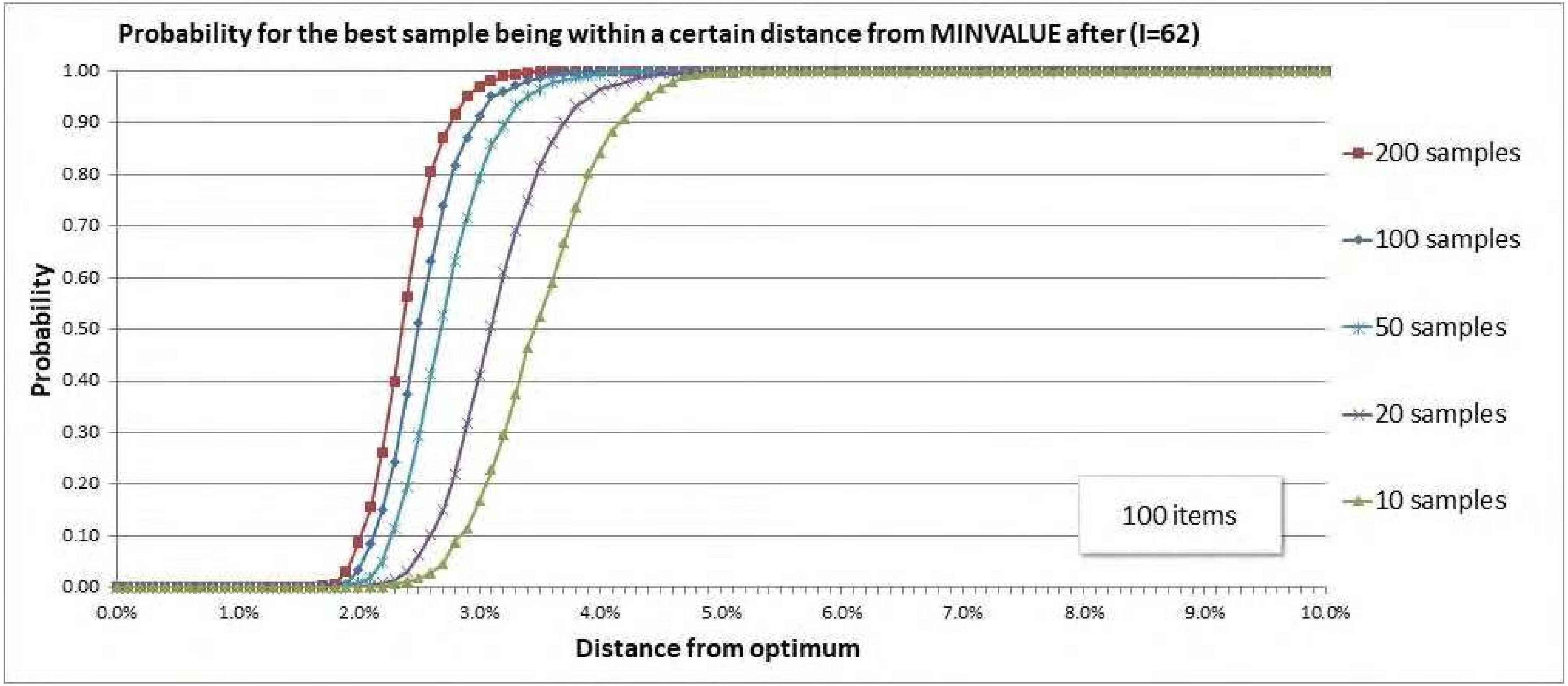

Probability for the best sample being within a certain distance from MINVALUE after (I=54)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?

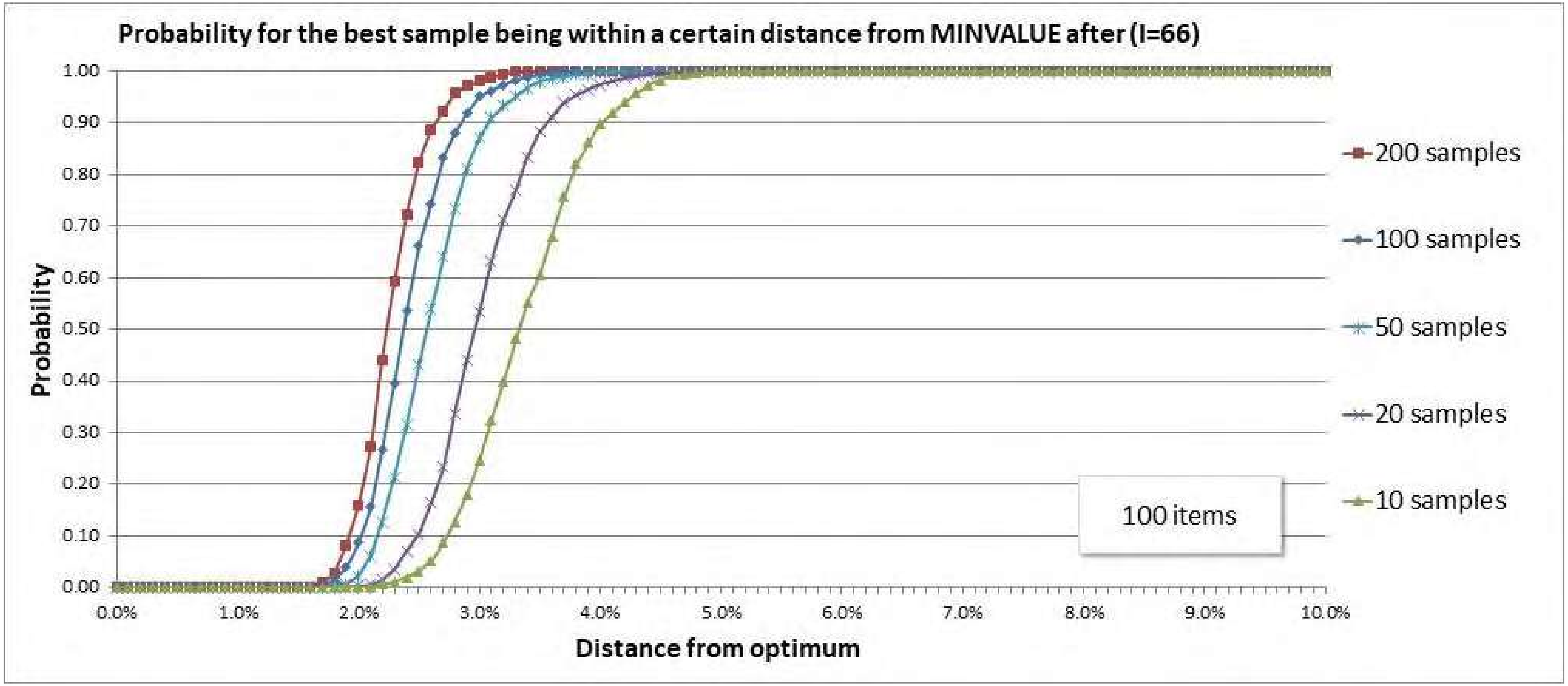


Systecon

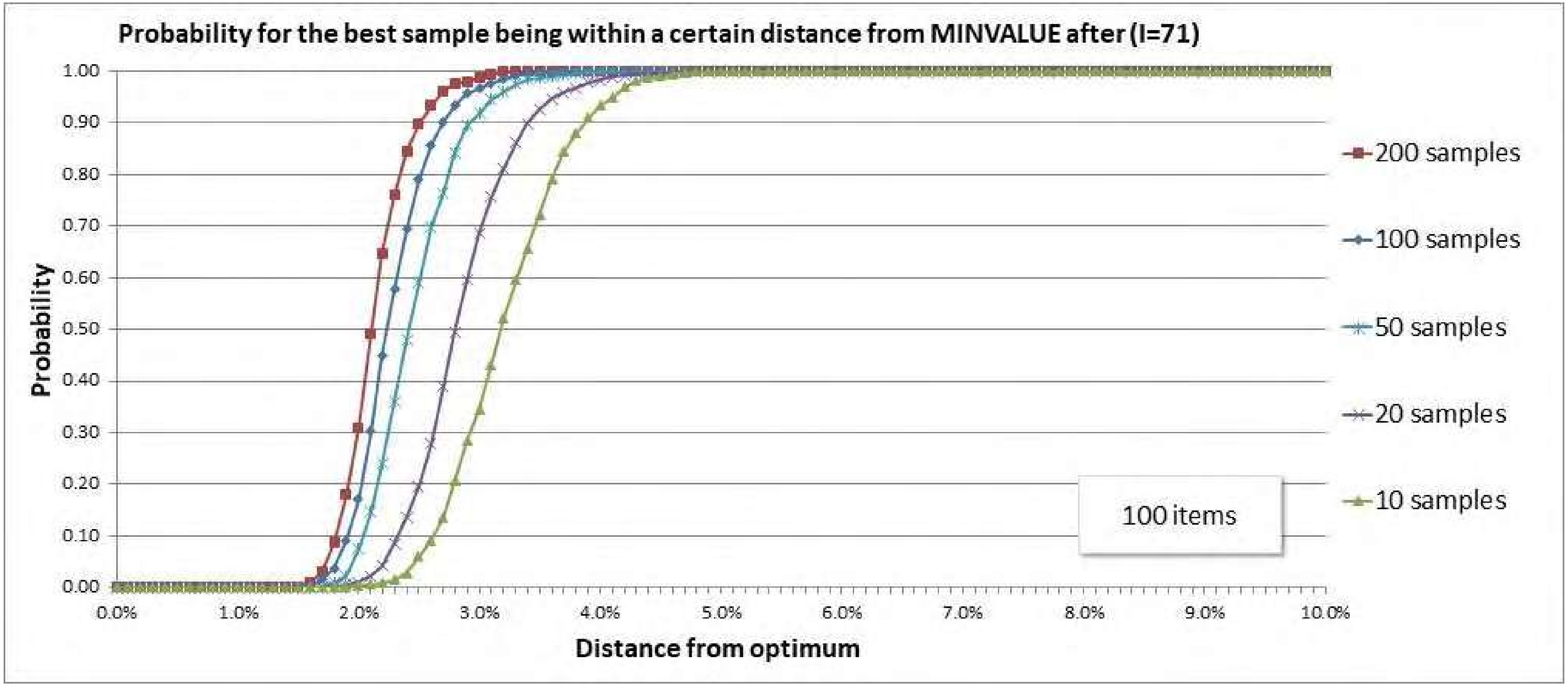
Can we scale?


Probability for the best sample being within a certain distance from MINVALUE after (I=62)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

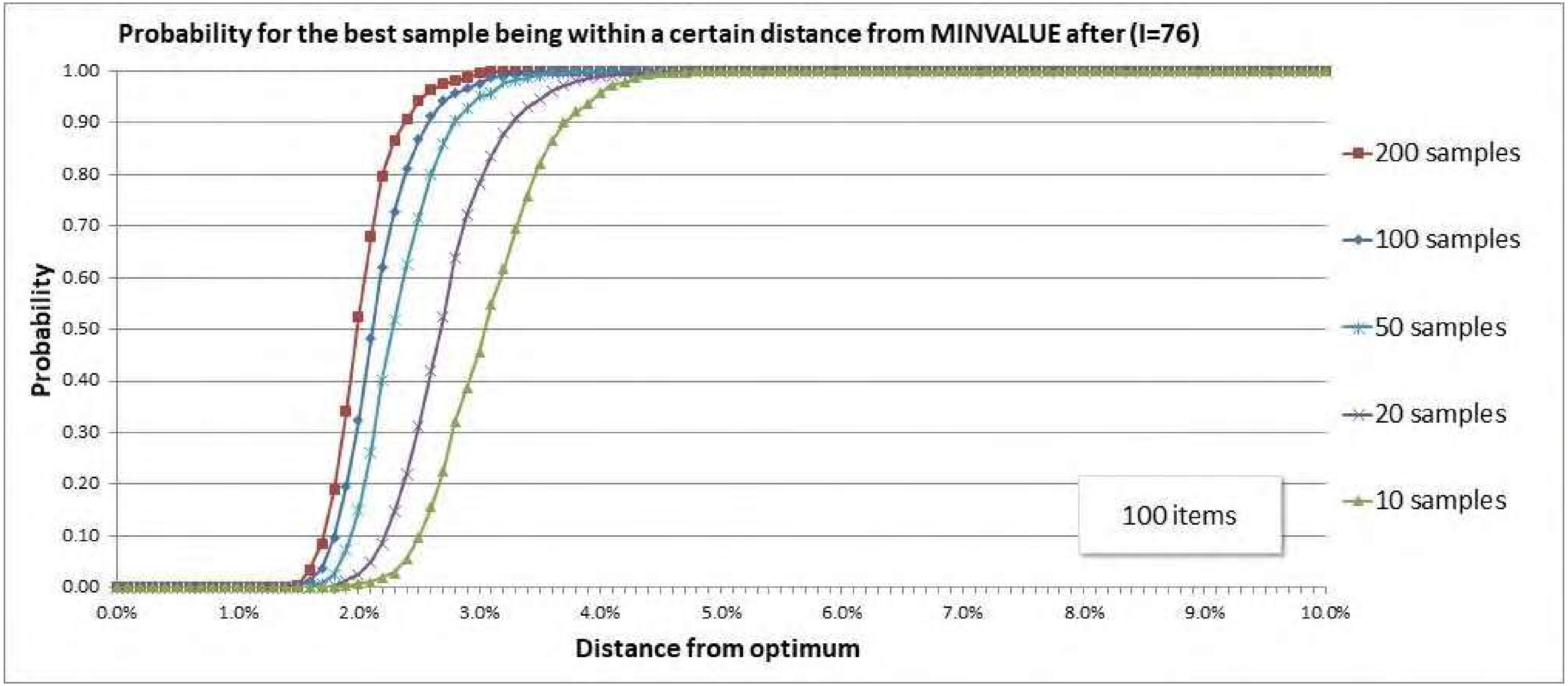
Can we scale?


Probability for the best sample being within a certain distance from MINVALUE after (I=66)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?

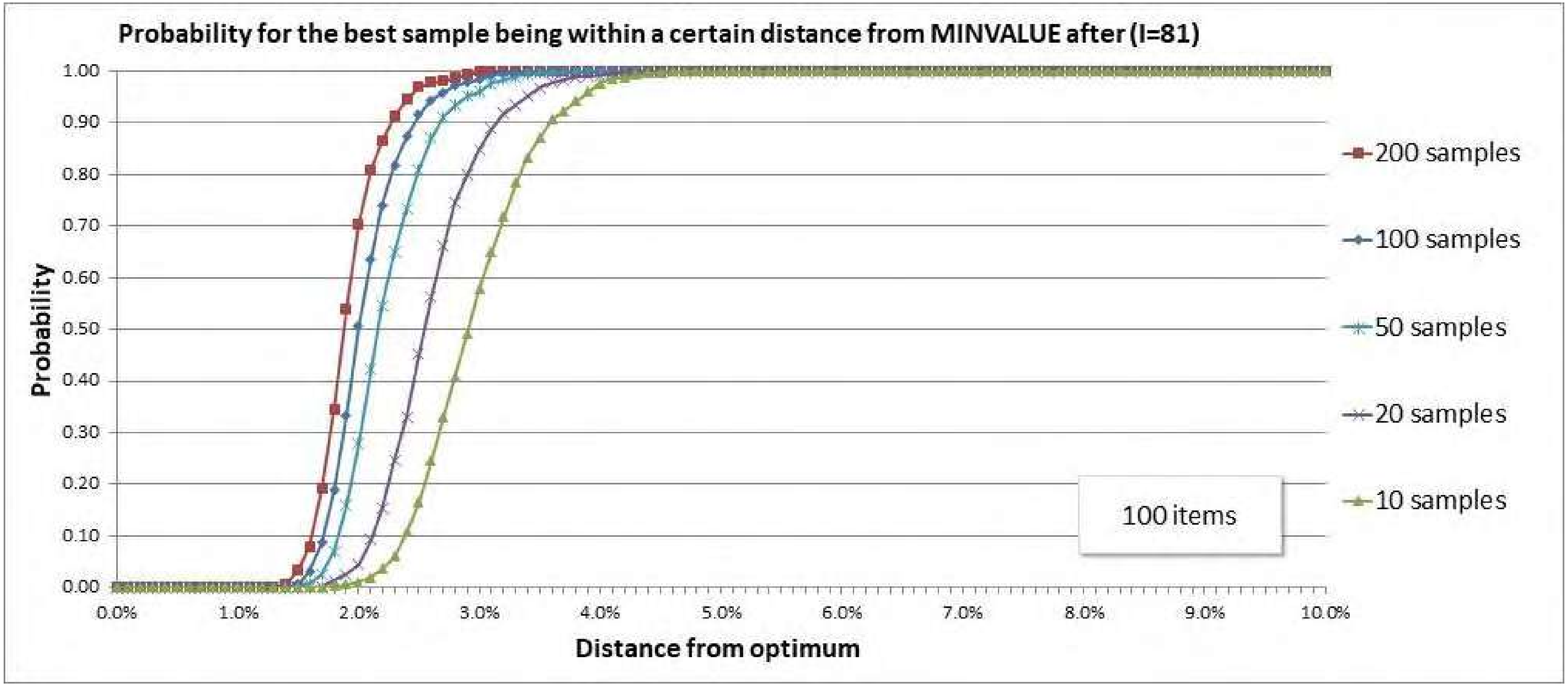

Probability for the best sample being within a certain distance from MINVALUE after (I=71)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?



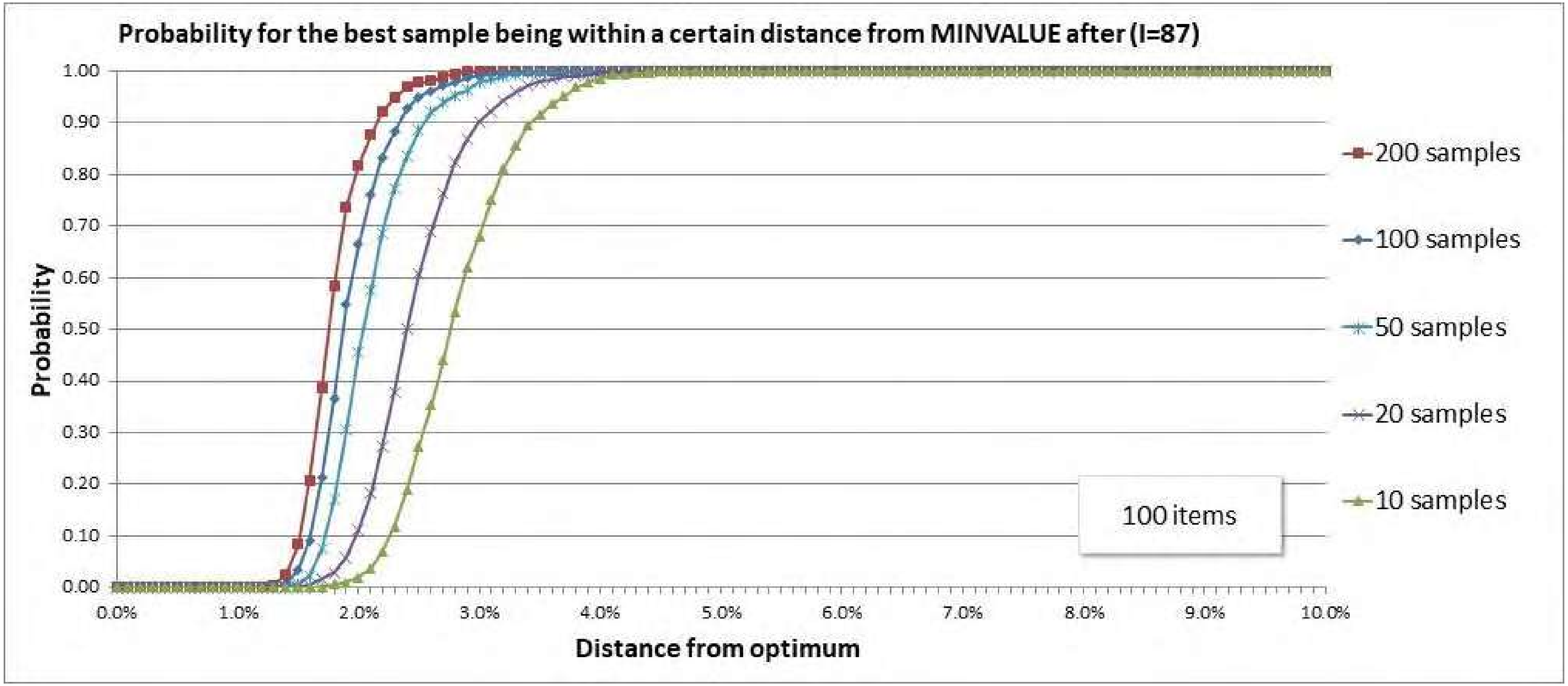
Systecon

Can we scale?



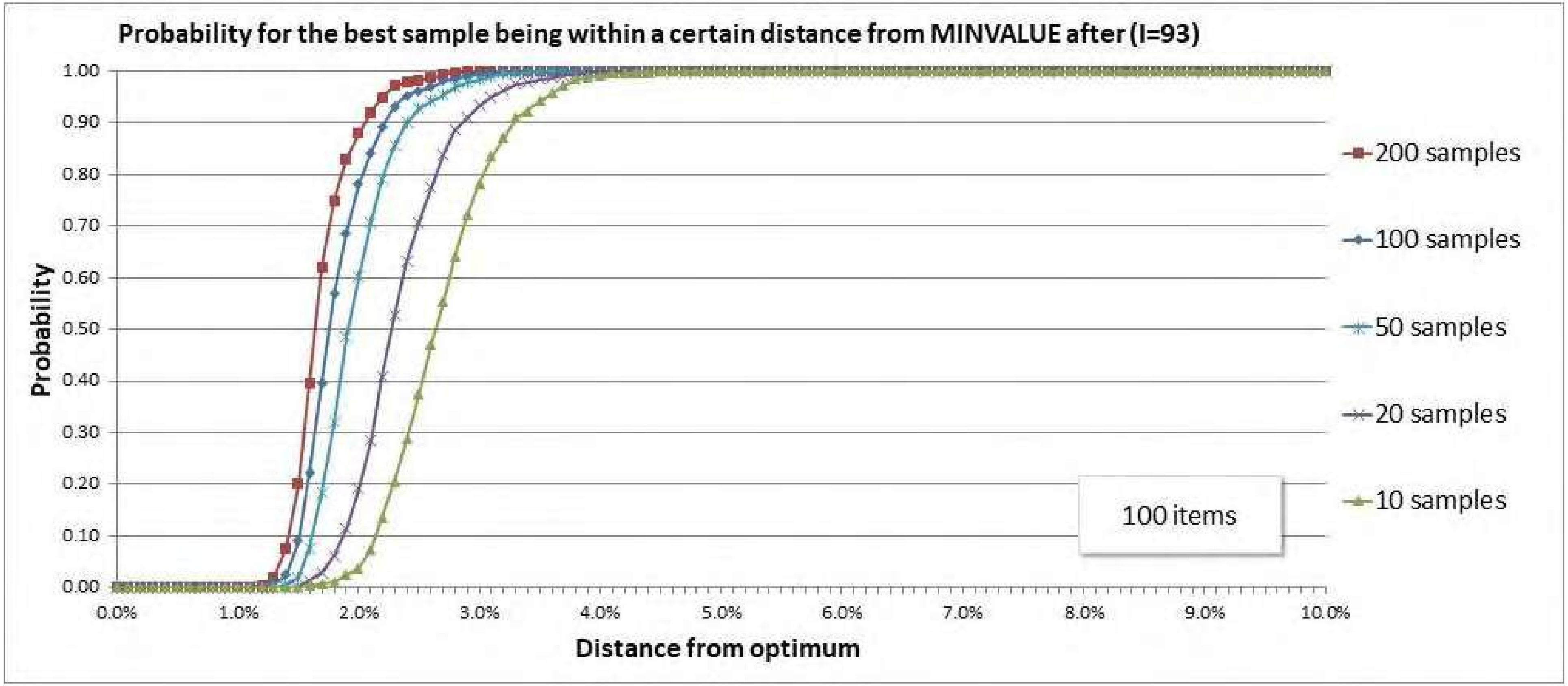
Systecon

Can we scale?

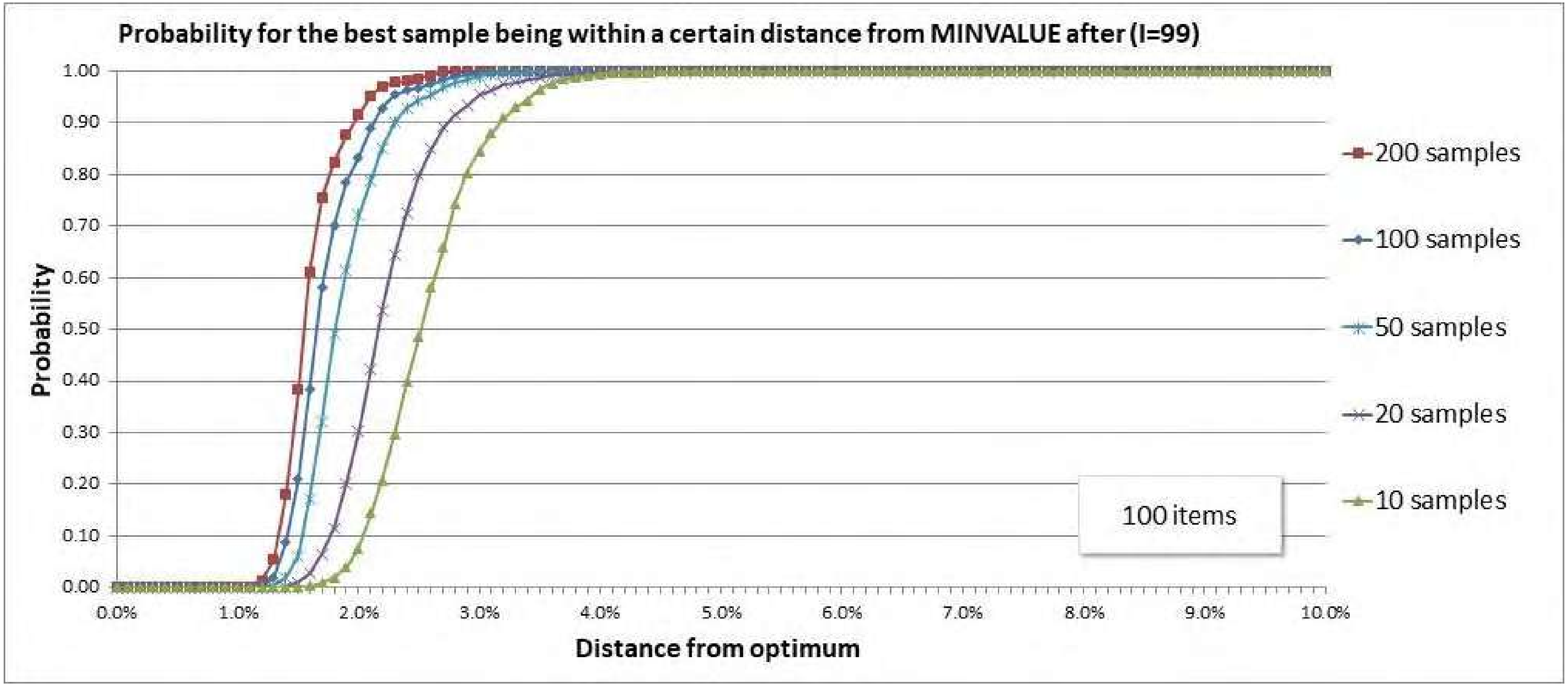


Probability for the best sample being within a certain distance from MINVALUE after (I=87)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Probability
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

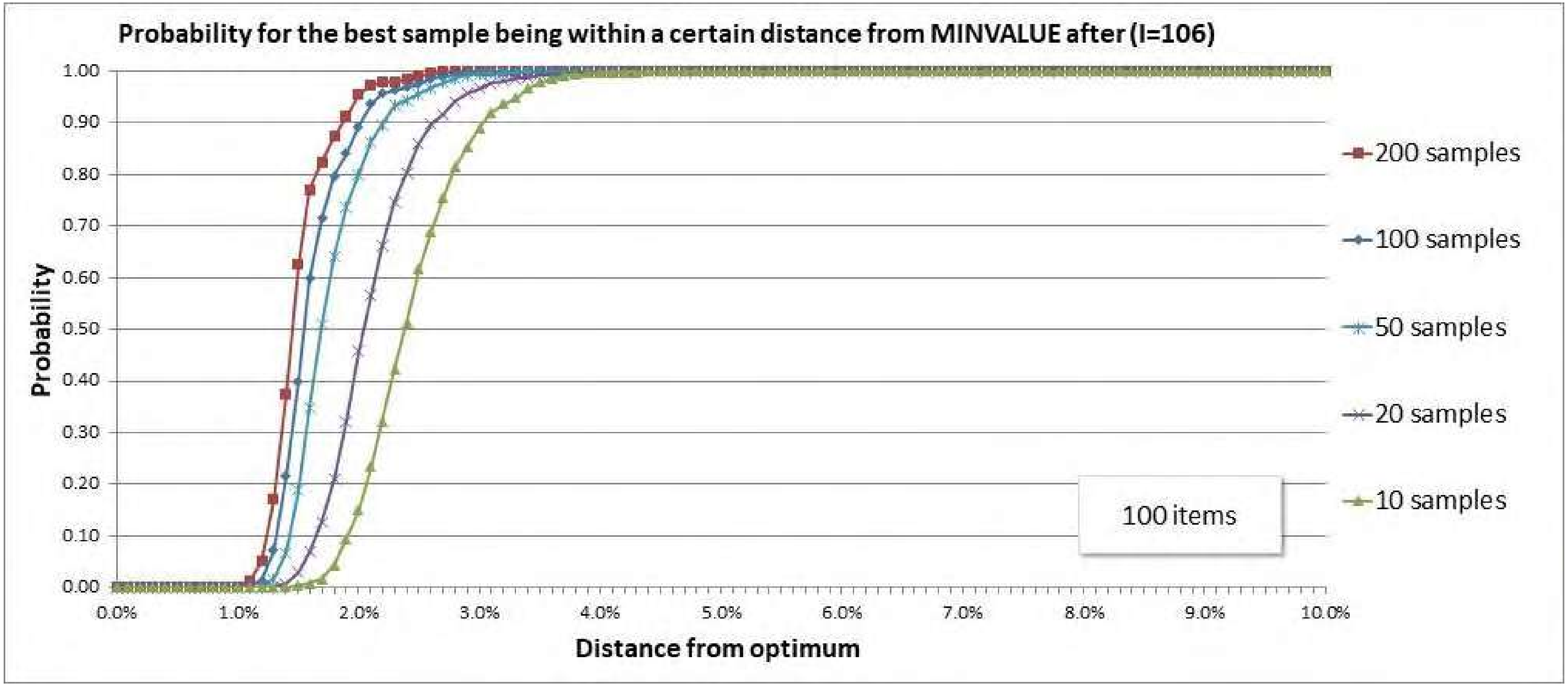
Can we scale?


Probability for the best sample being within a certain distance from MINVALUE after (I=93)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?

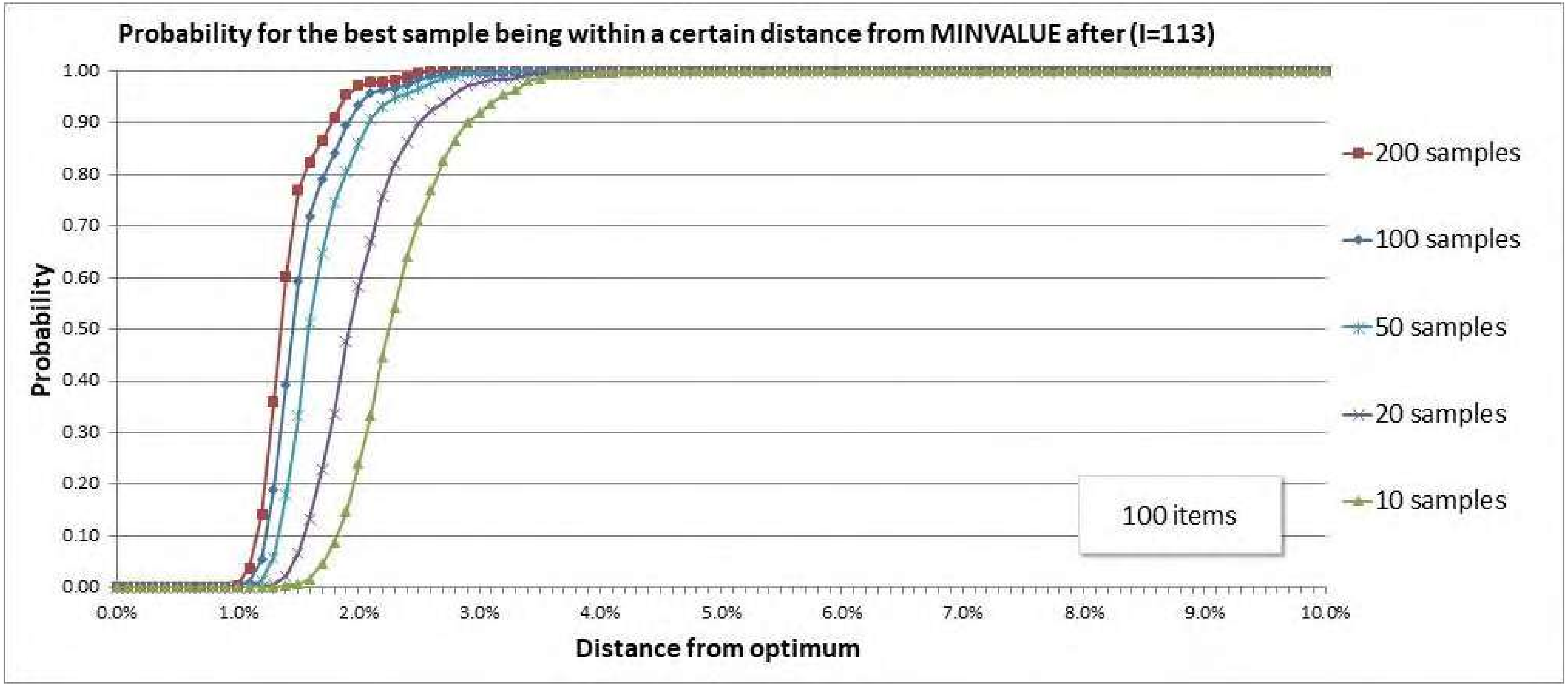

Probability for the best sample being within a certain distance from MINVALUE after (I=99)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?



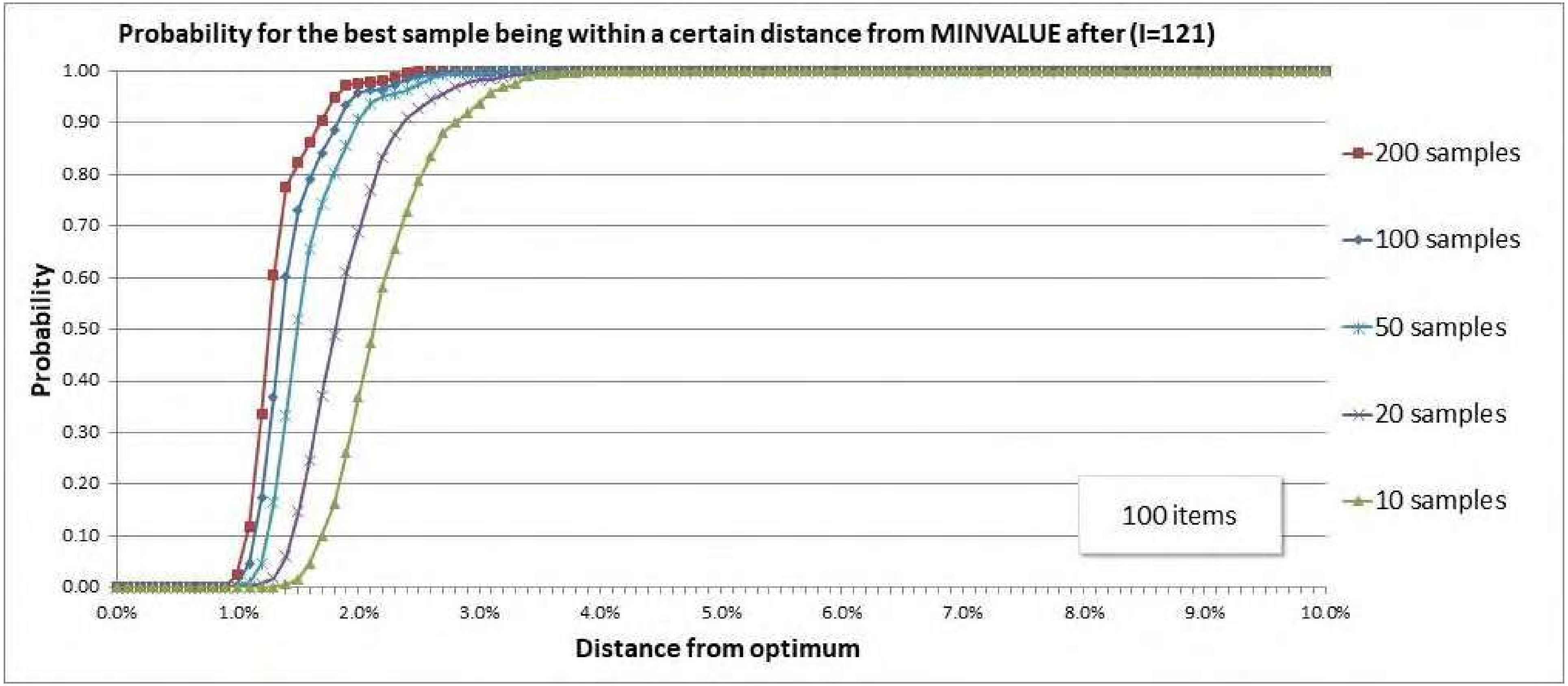
Systecon

Can we scale?



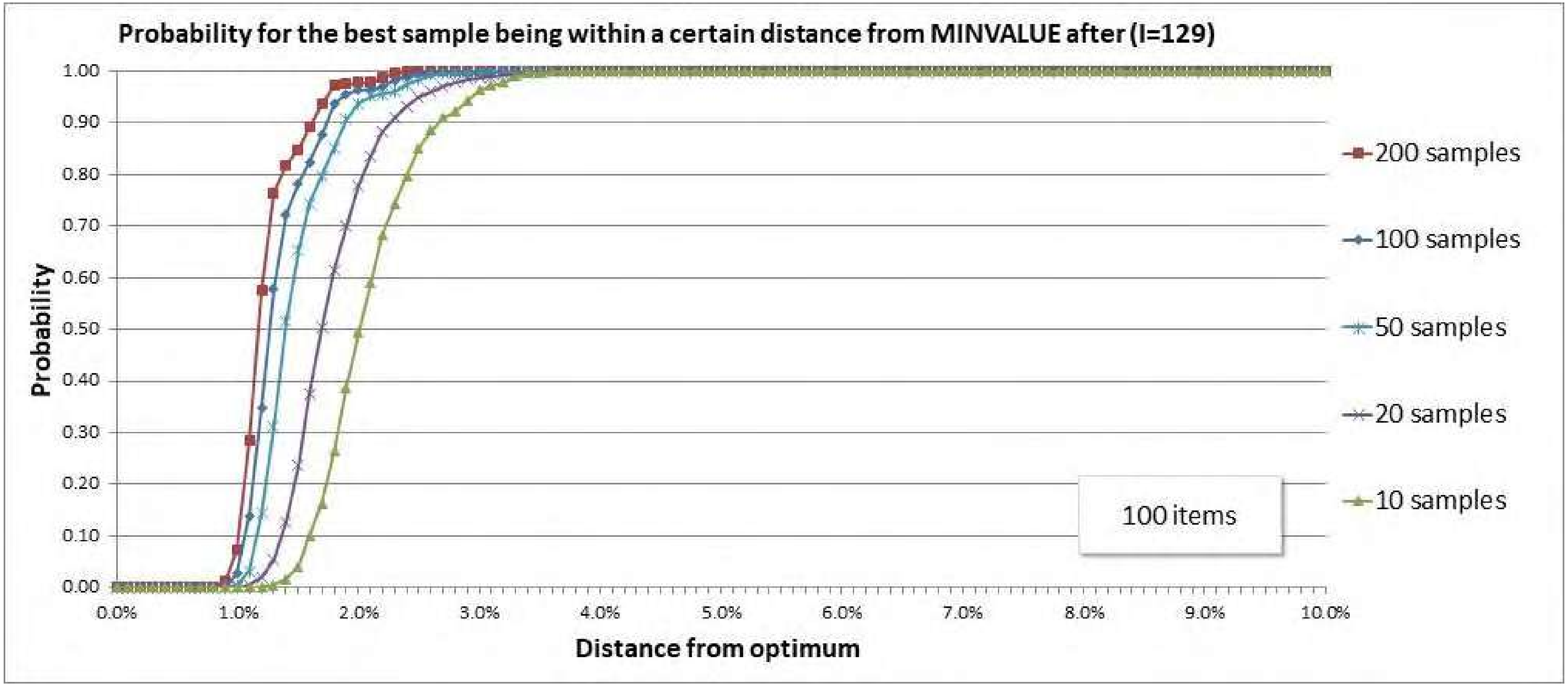
Systecon

Can we scale?



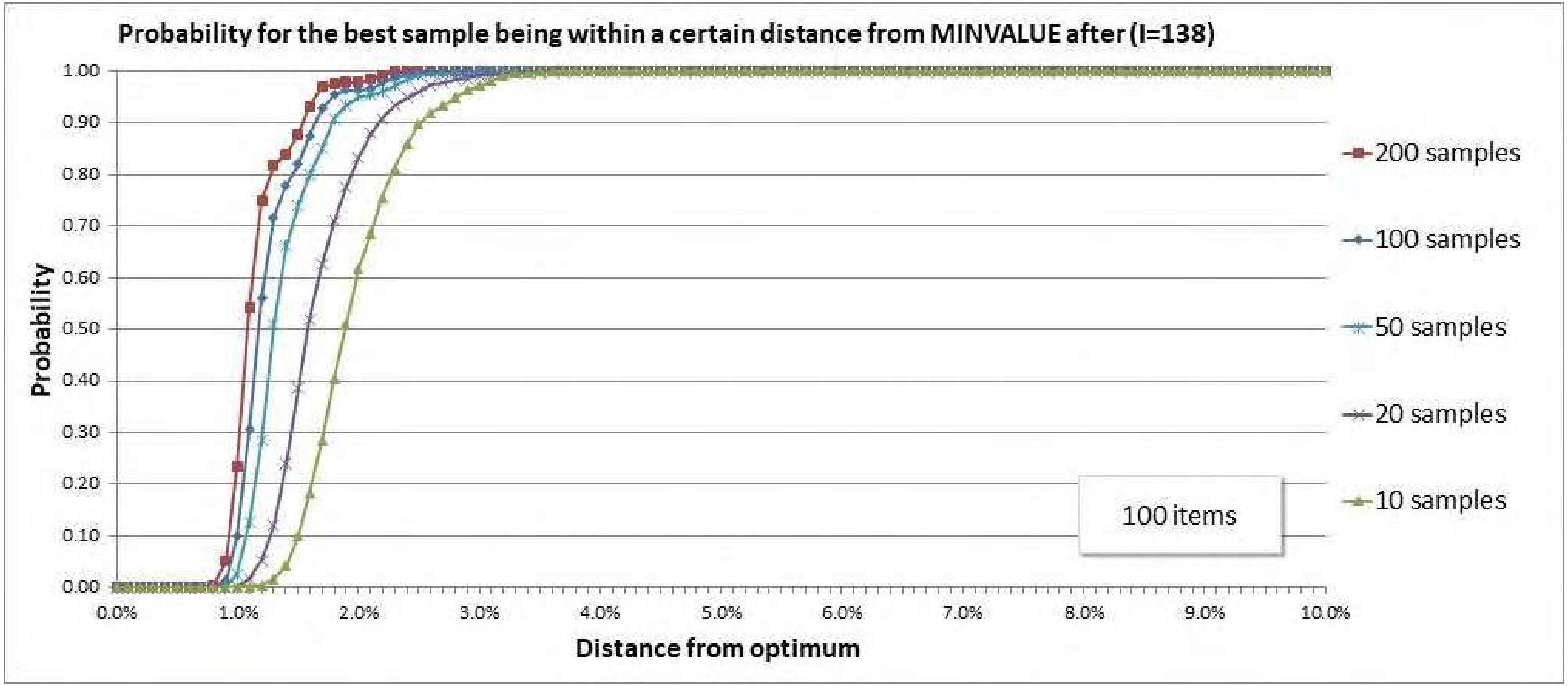
Systecon

Can we scale?



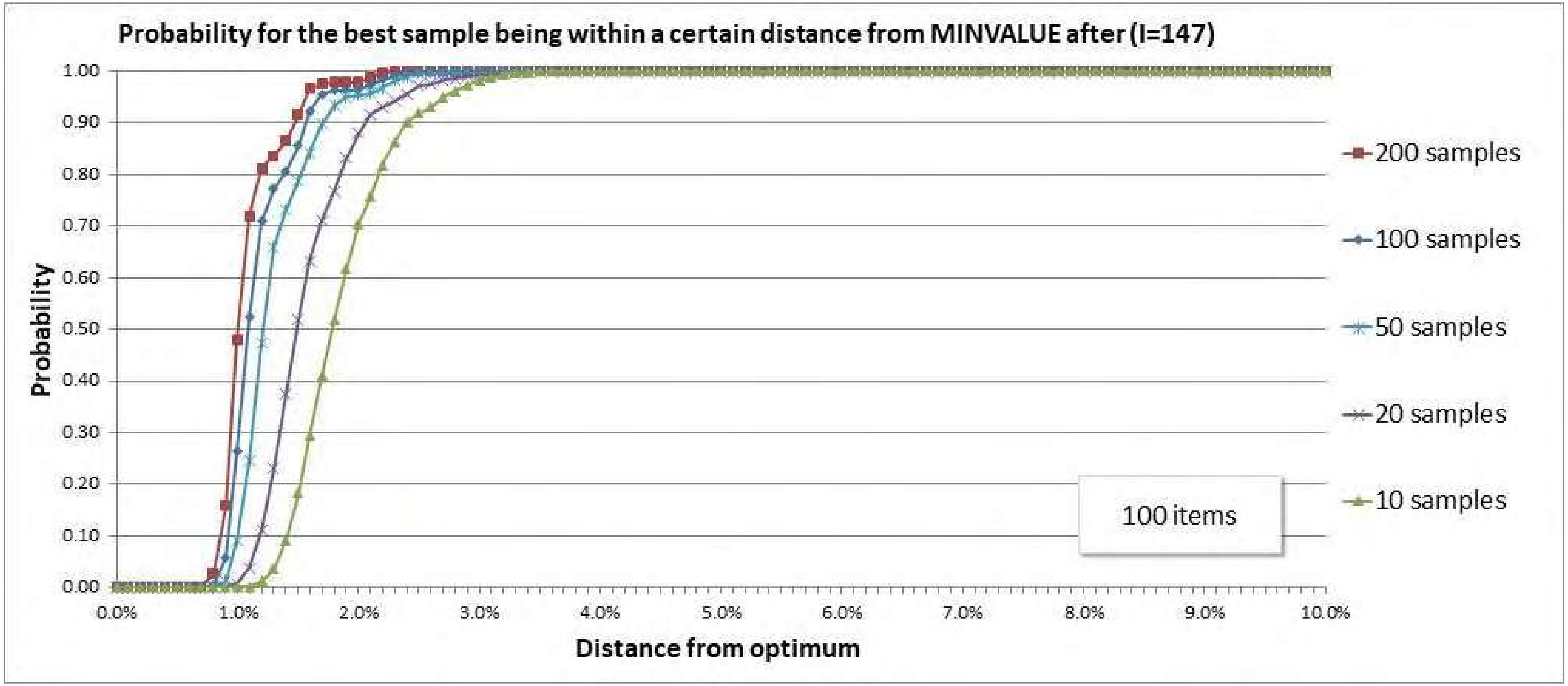
Systecon

Can we scale?



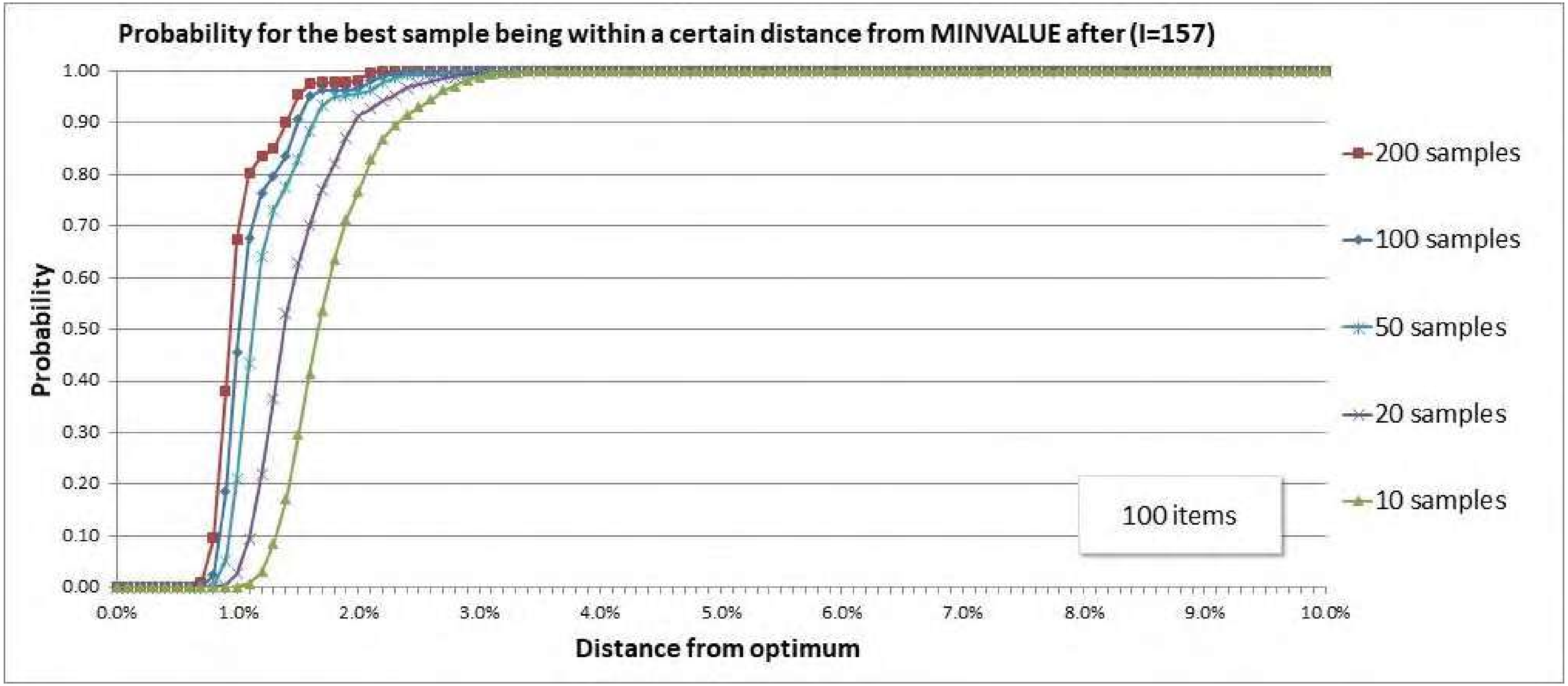
Systecon

Can we scale?



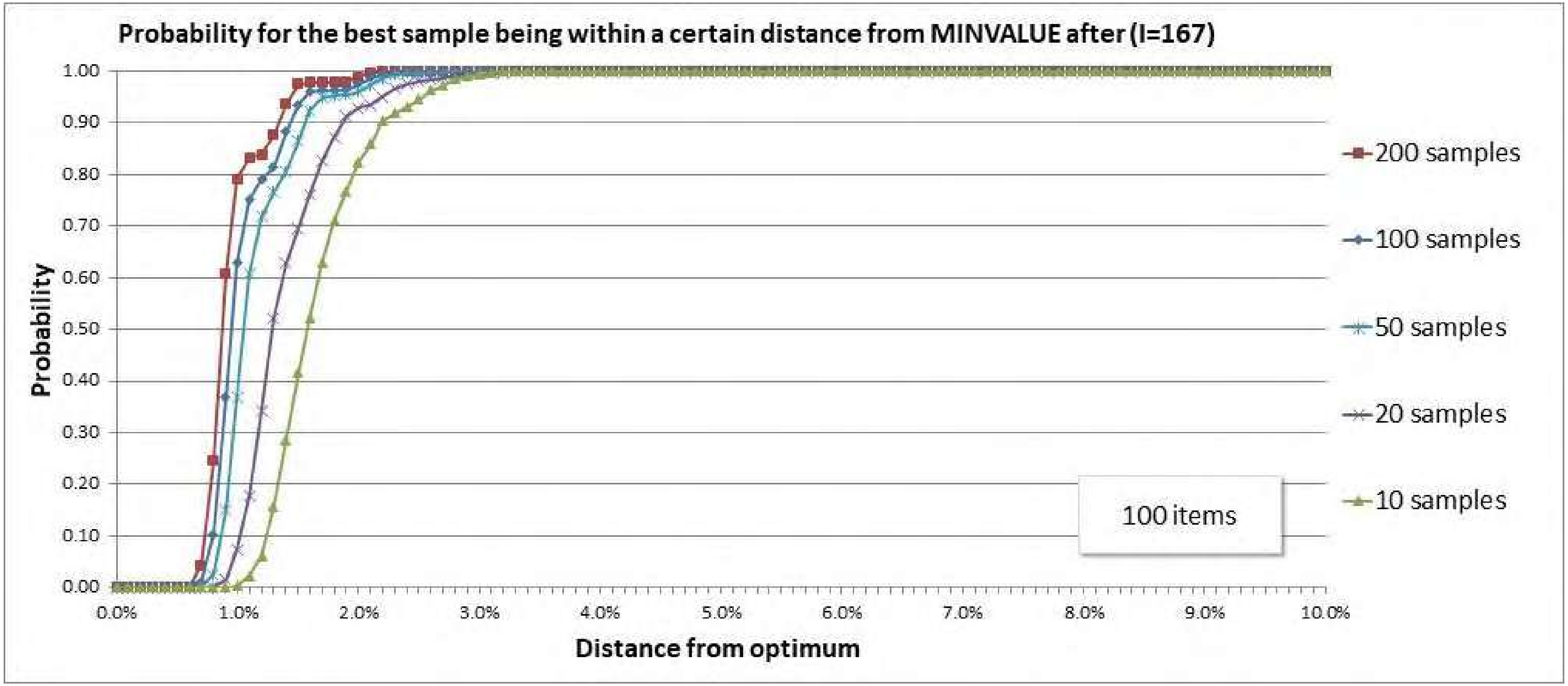
Systecon

Can we scale?



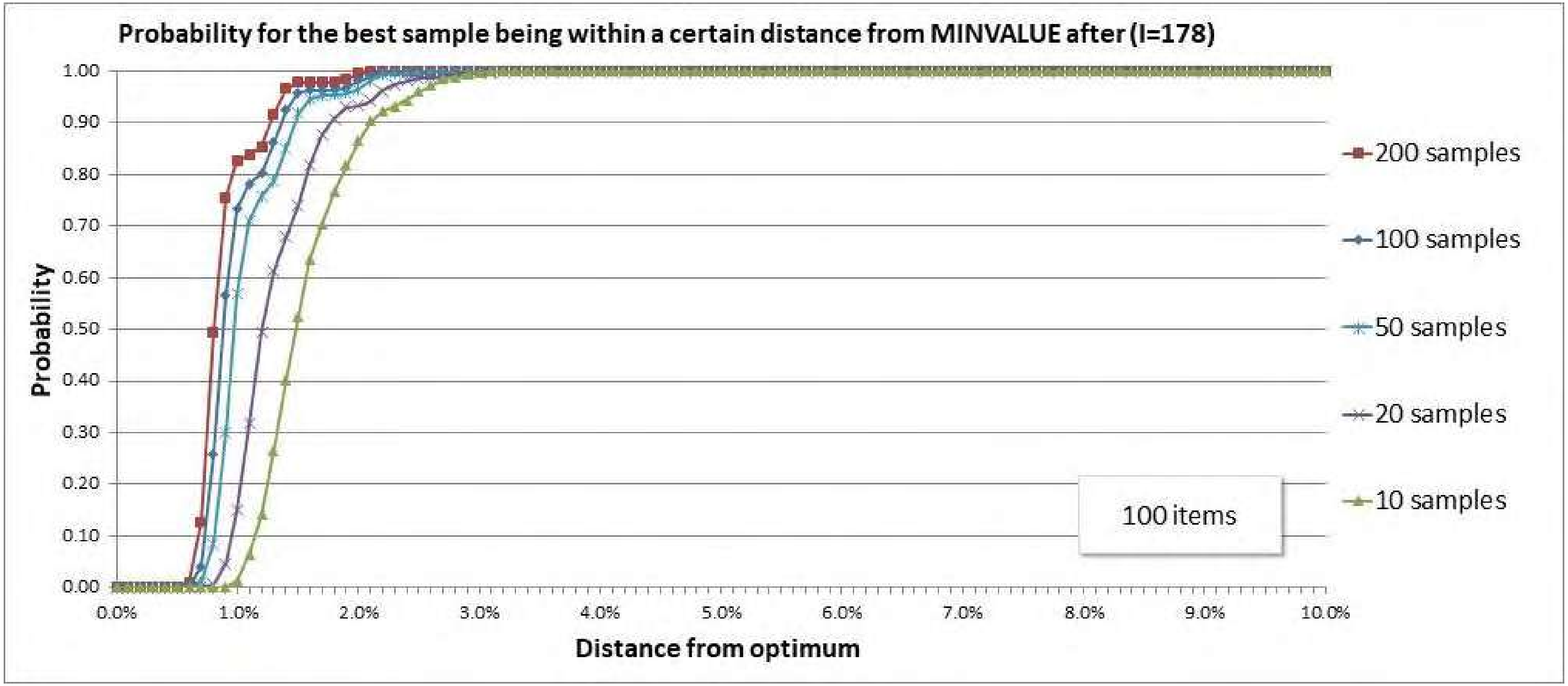
Systecon

Can we scale?



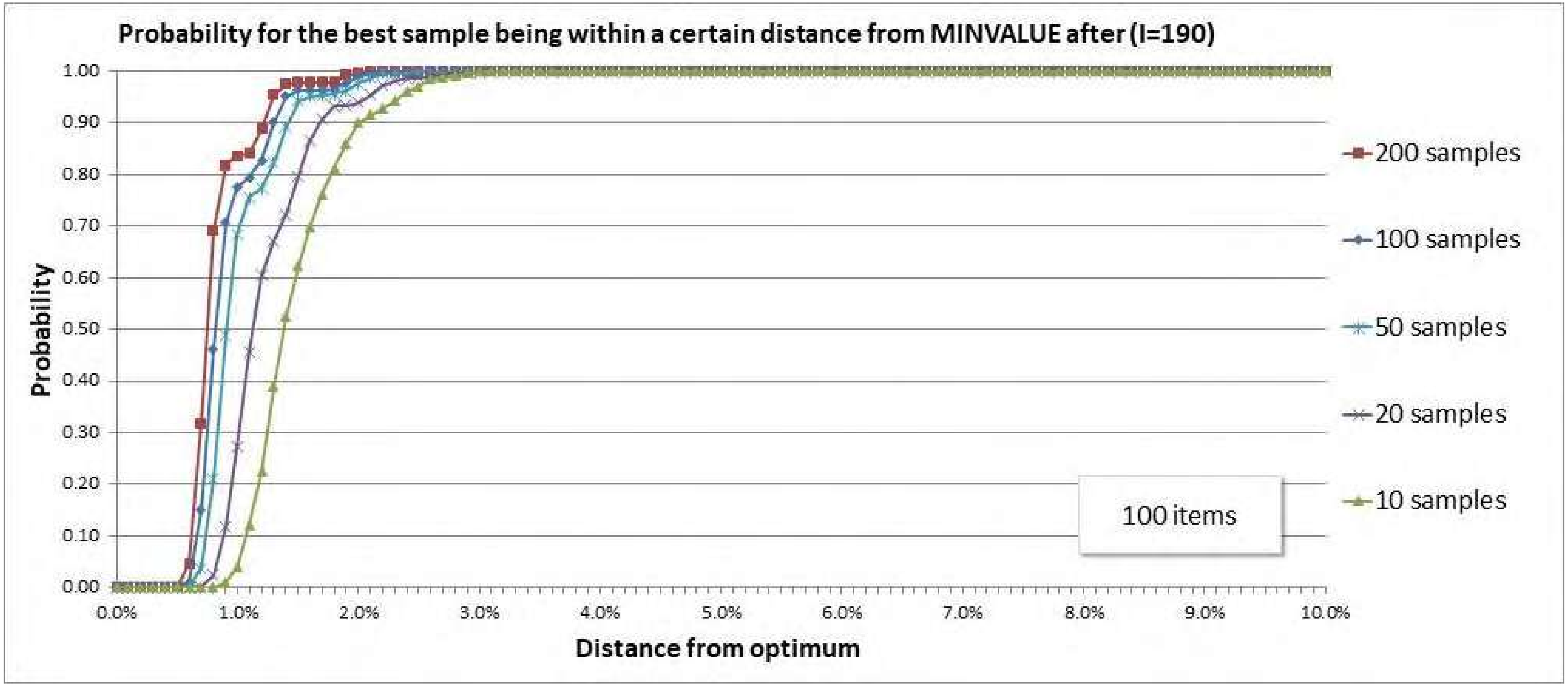
Systecon

Can we scale?



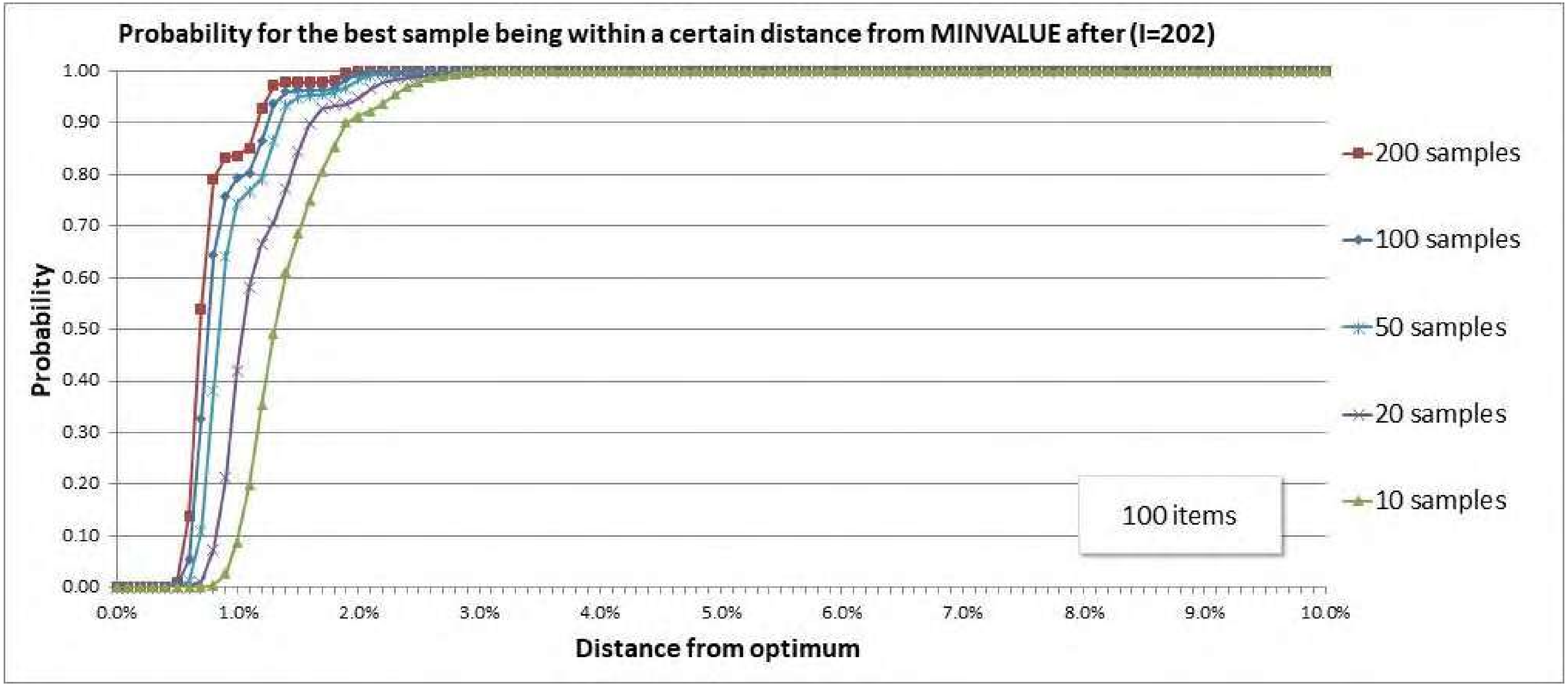
Systecon

Can we scale?

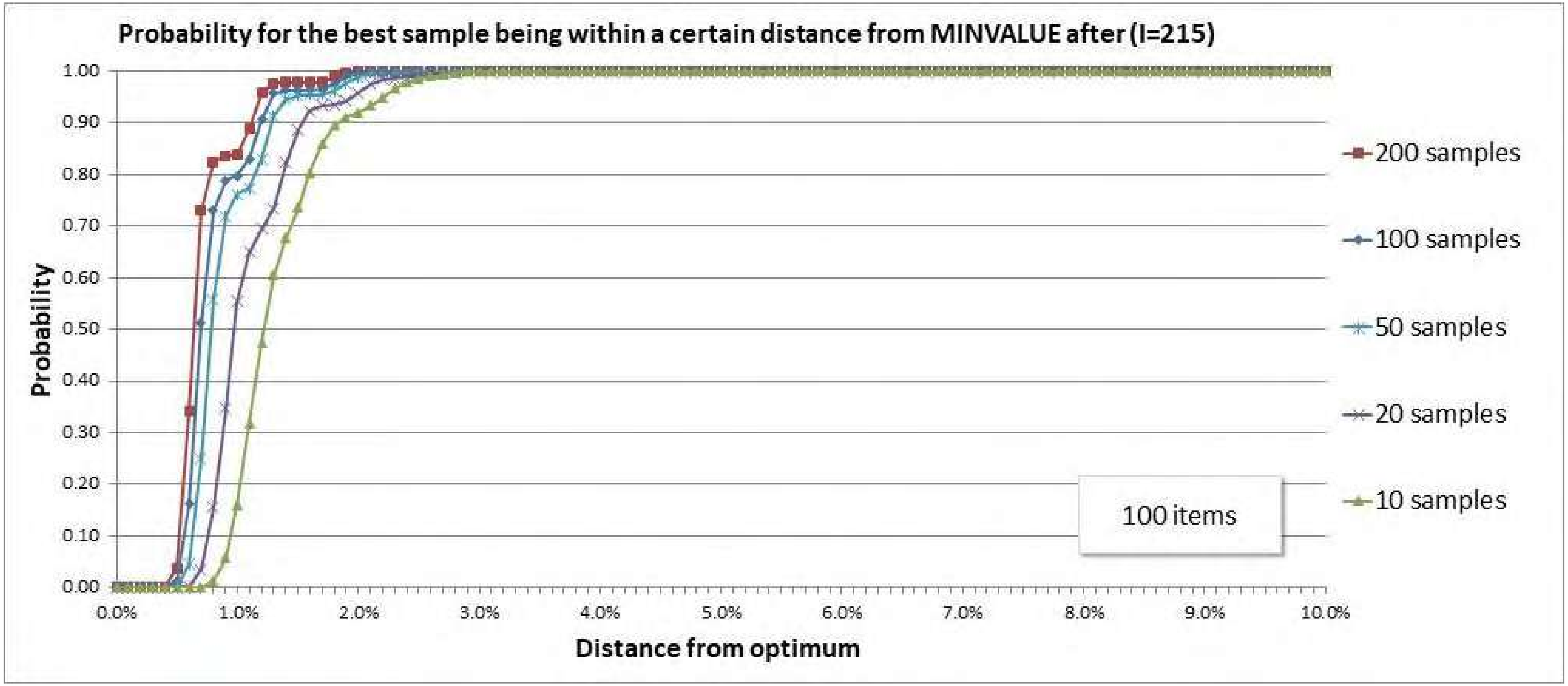


Systecon

Can we scale?

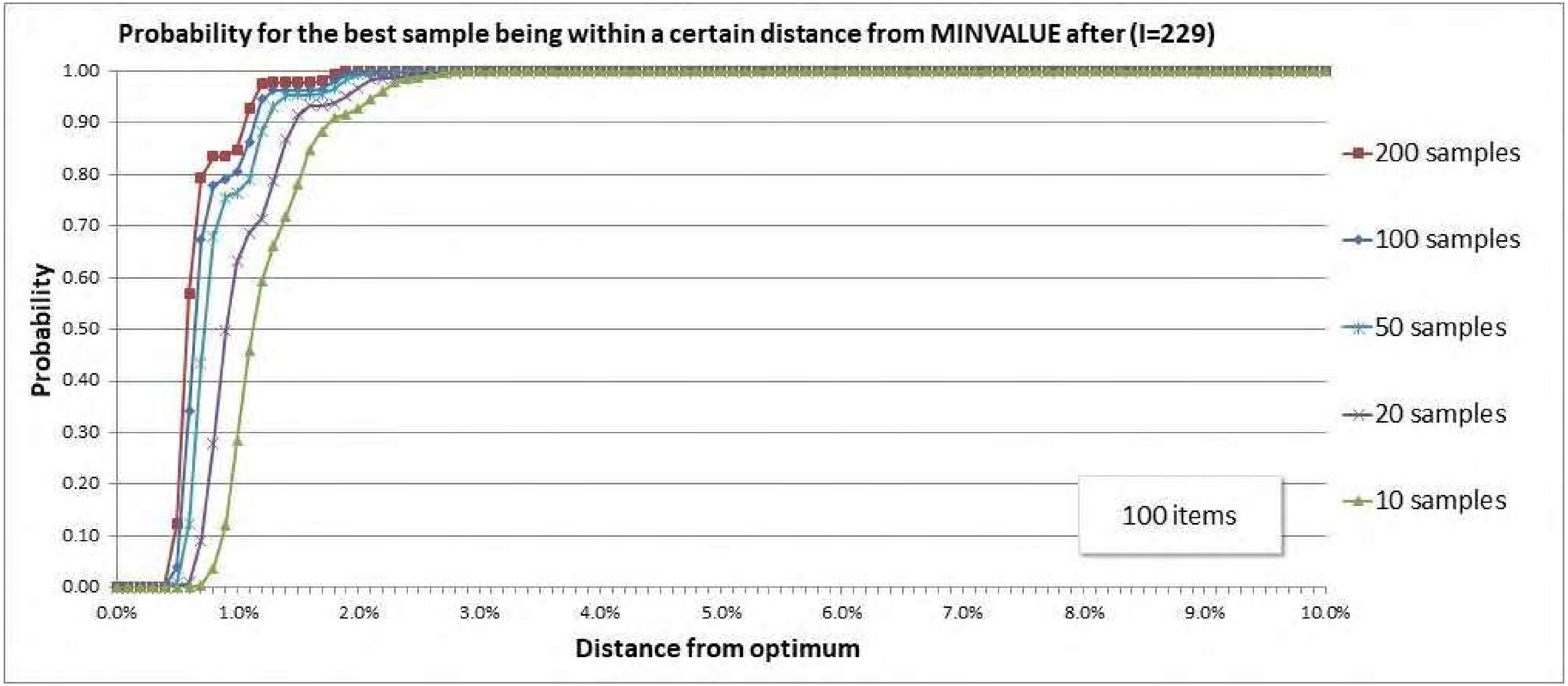

Probability for the best sample being within a certain distance from MINVALUE after (I=202)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?



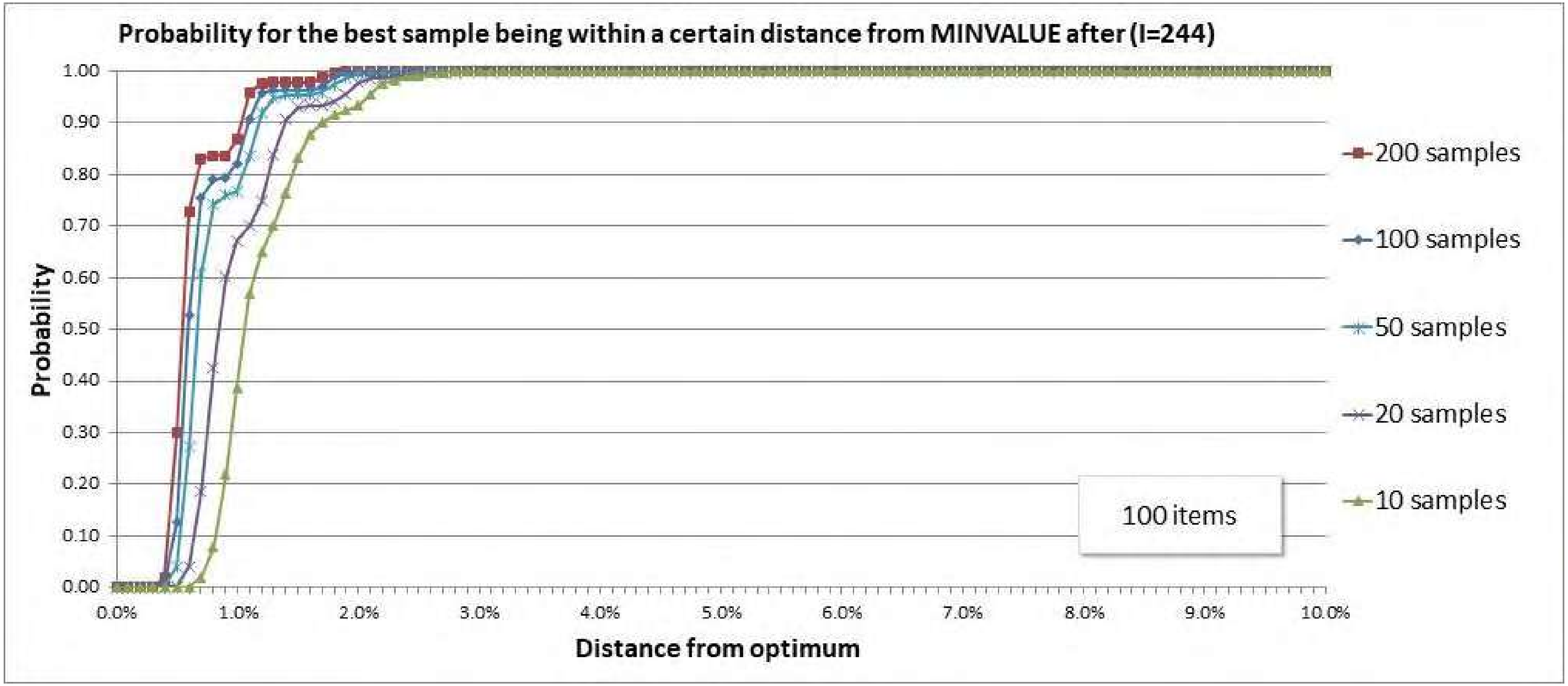
Probability for the best sample being within a certain distance from MINVALUE after (I=215)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Probability
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?

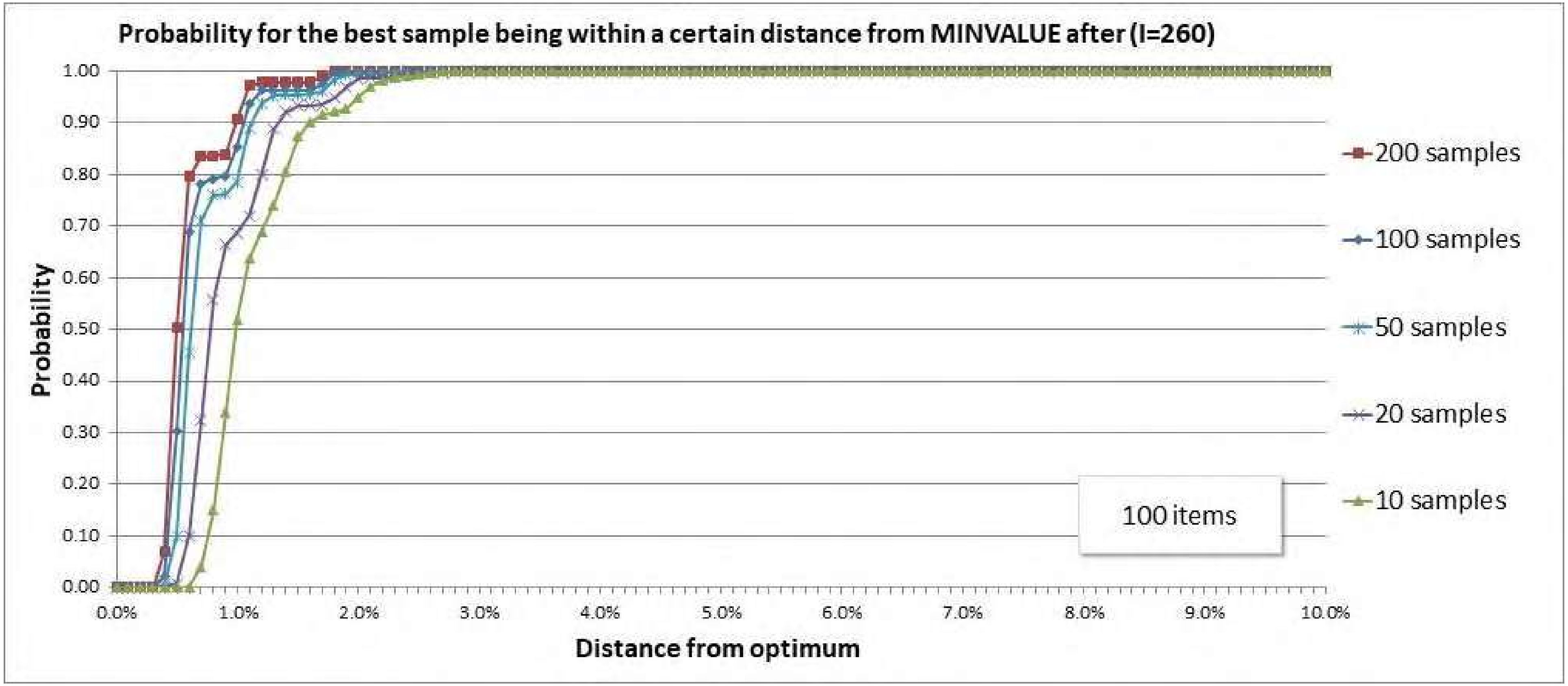


Systecon

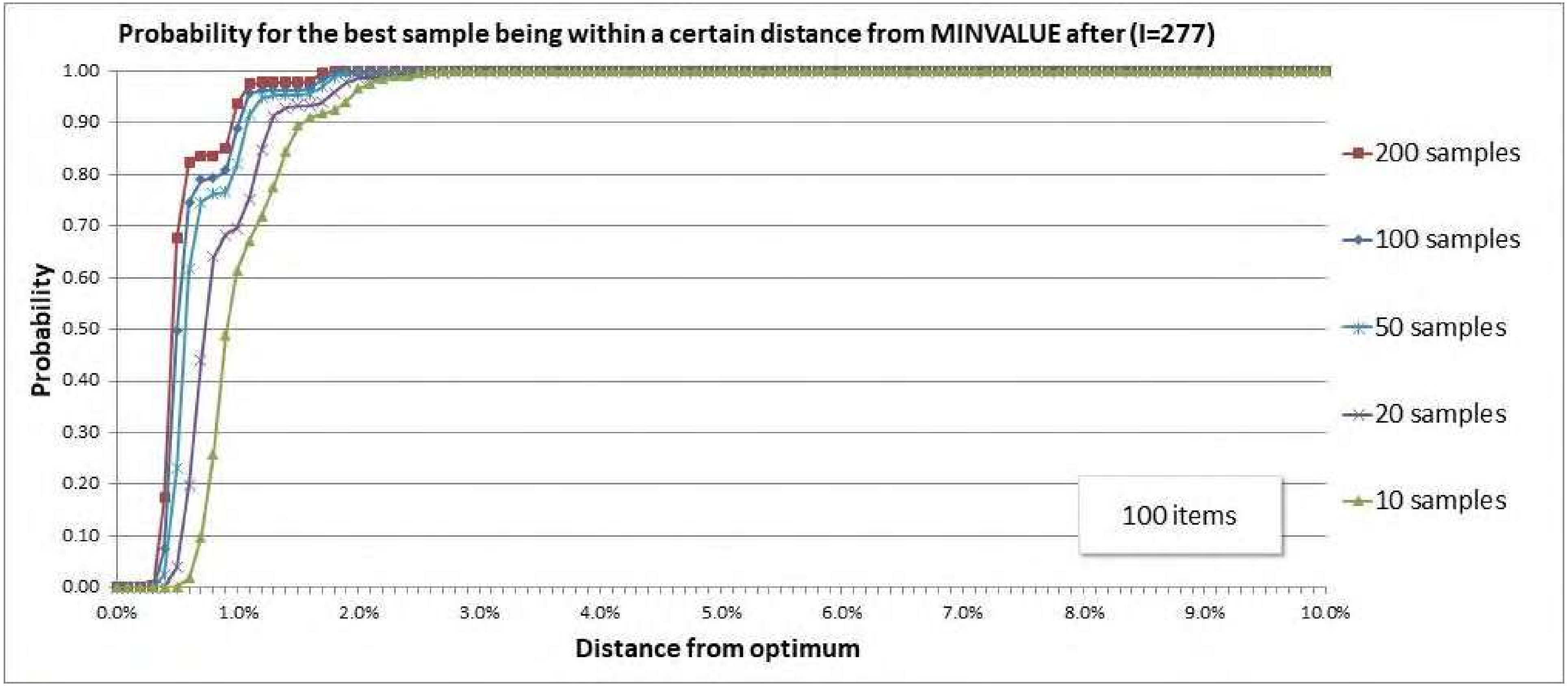
Can we scale?


Probability for the best sample being within a certain distance from MINVALUE after (I=244)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?

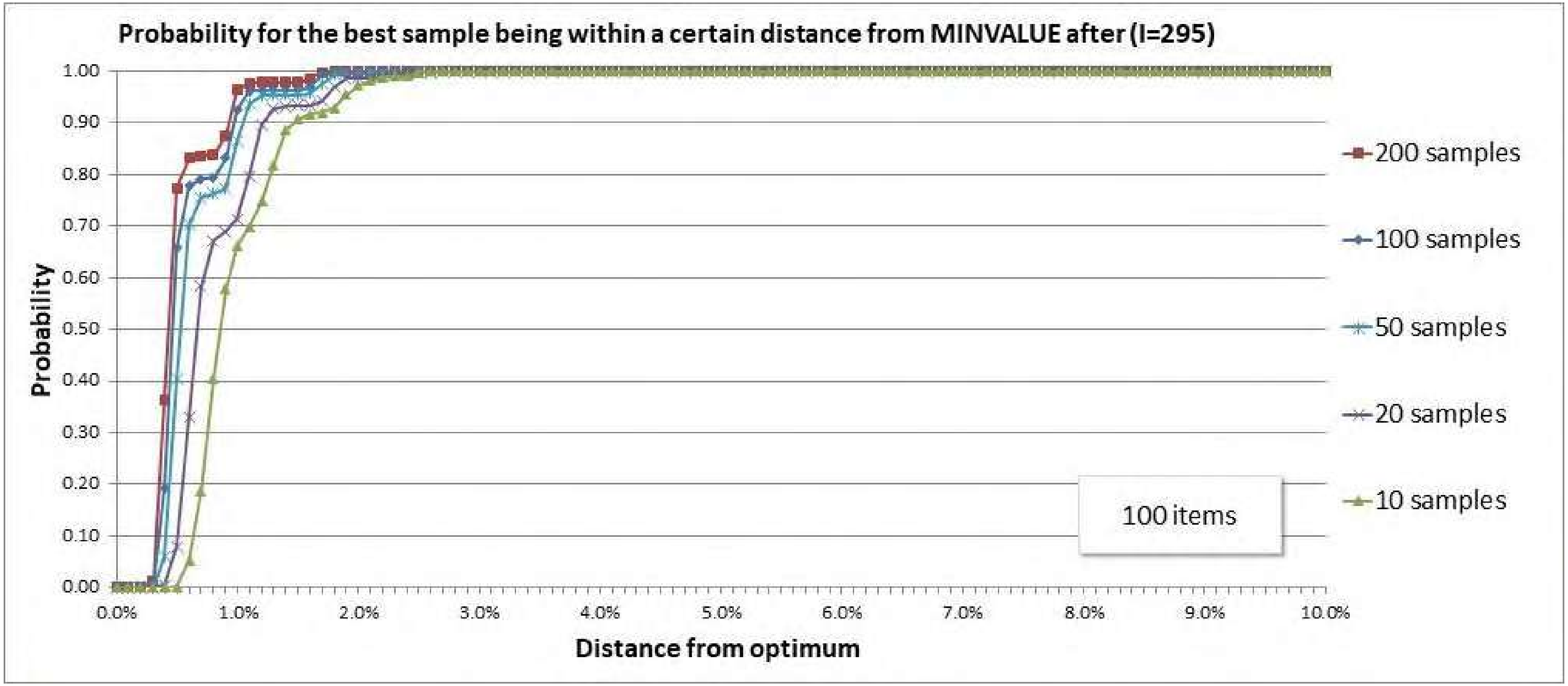

Probability for the best sample being within a certain distance from MINVALUE after (I=260)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Probability
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?

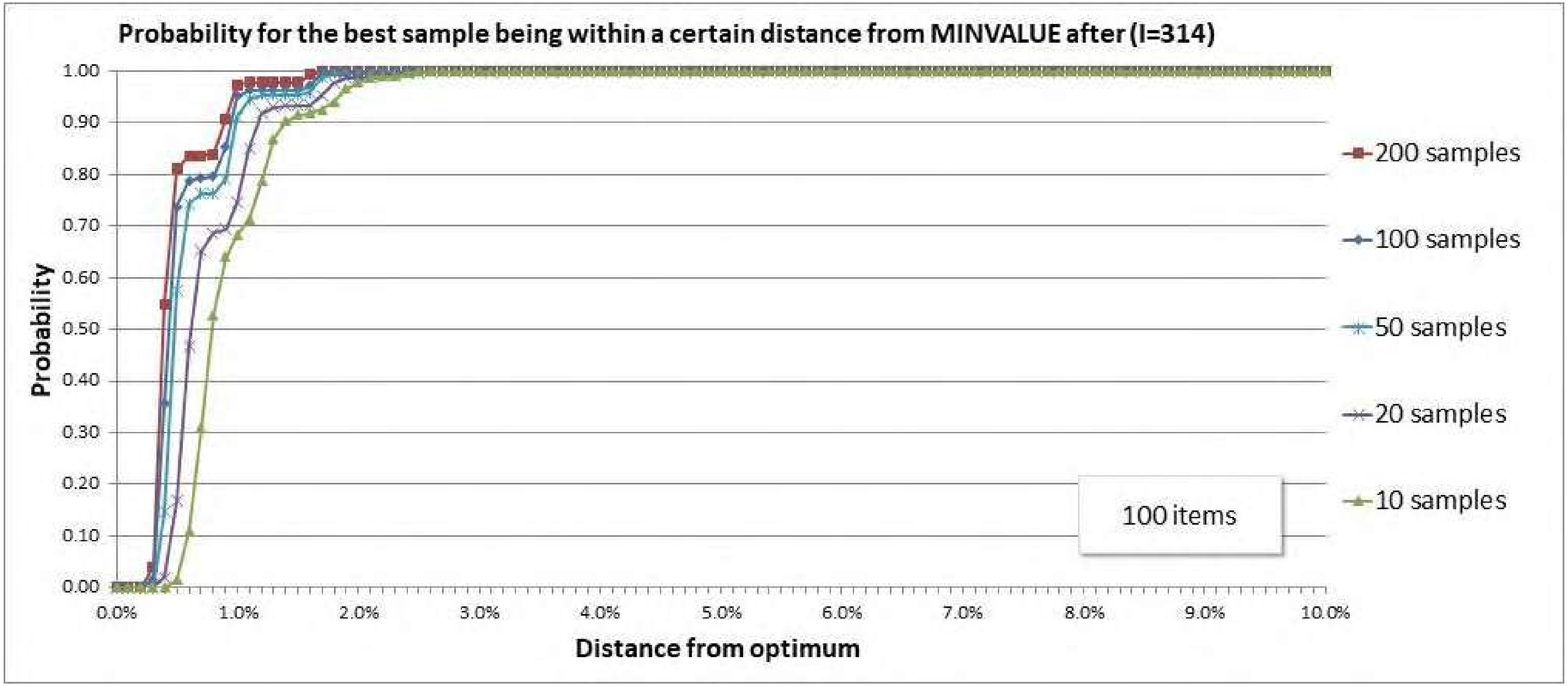


Systecon

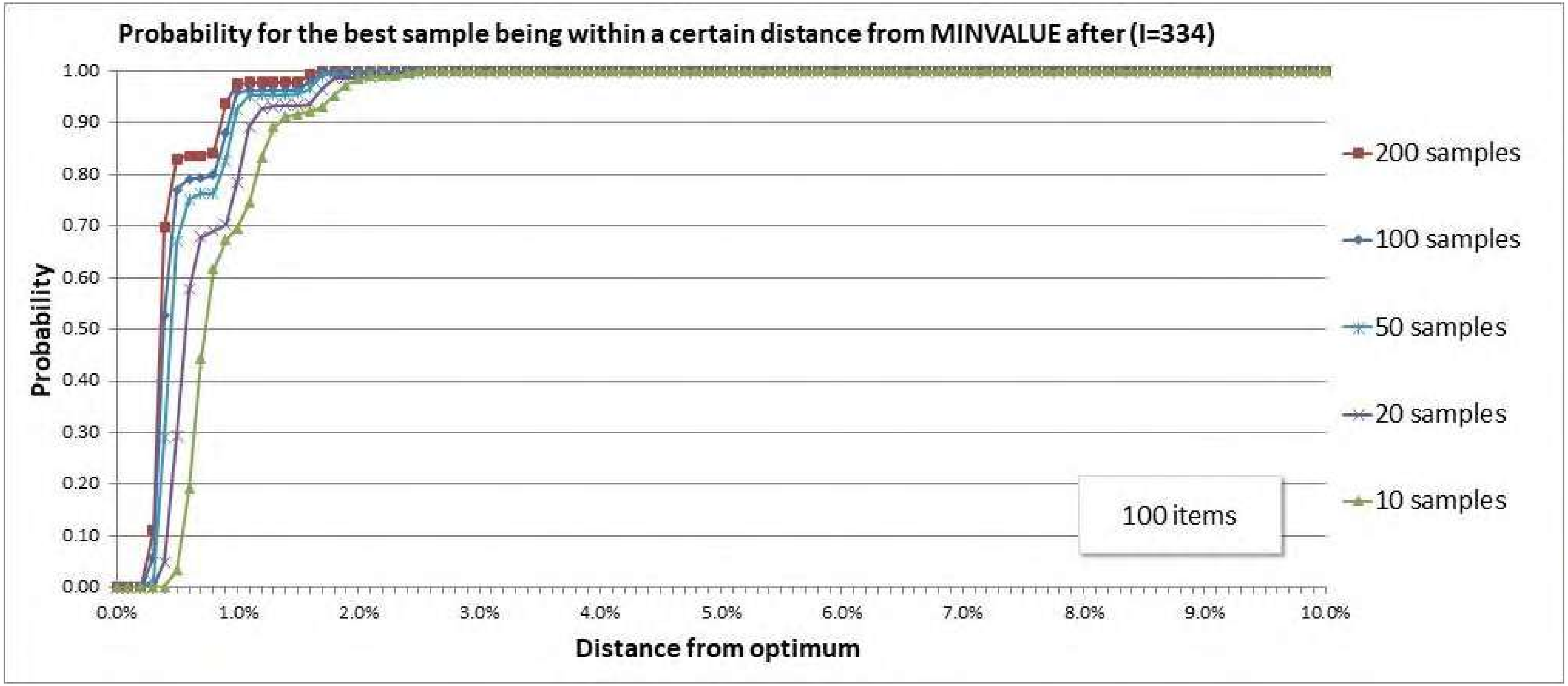
Can we scale?


Probability for the best sample being within a certain distance from MINVALUE after (I=295)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Probability
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

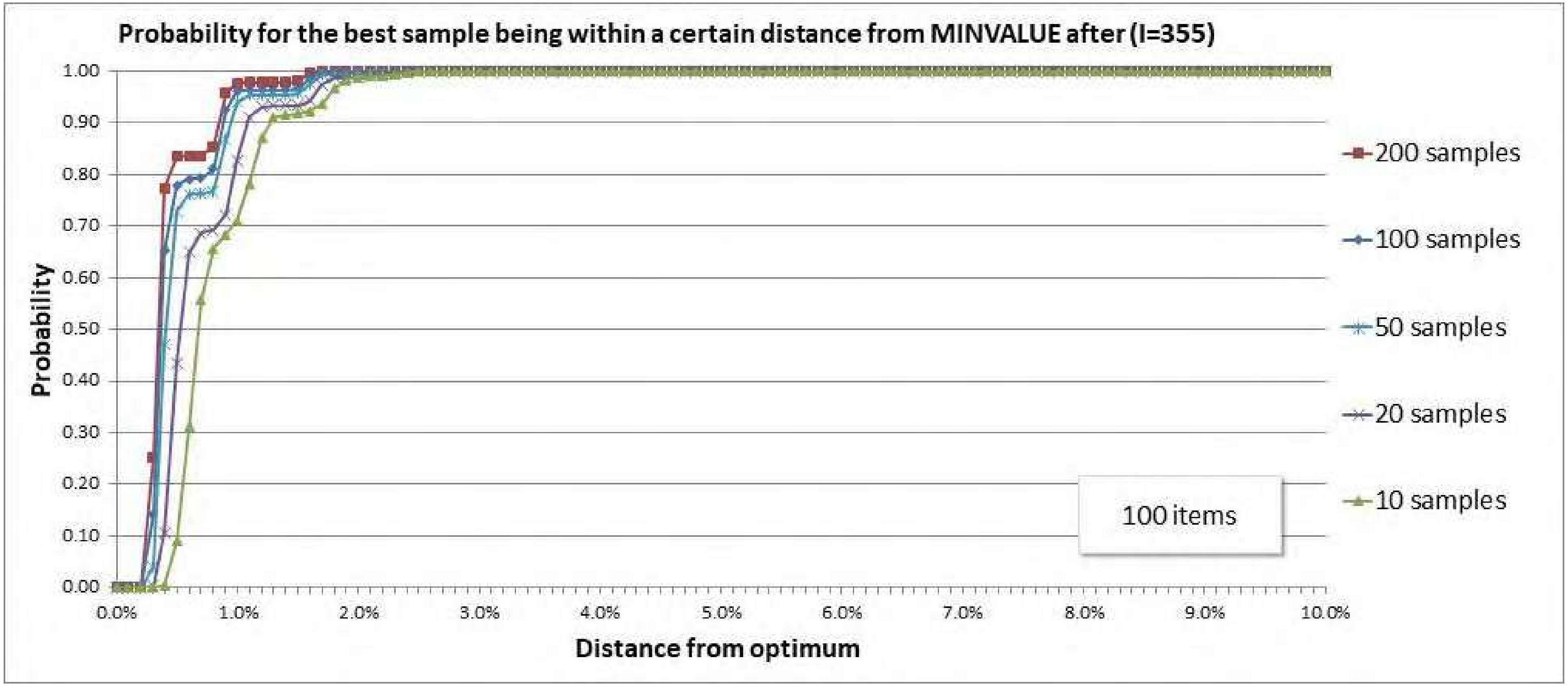
Can we scale?


Probability for the best sample being within a certain distance from MINVALUE after (I=314)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

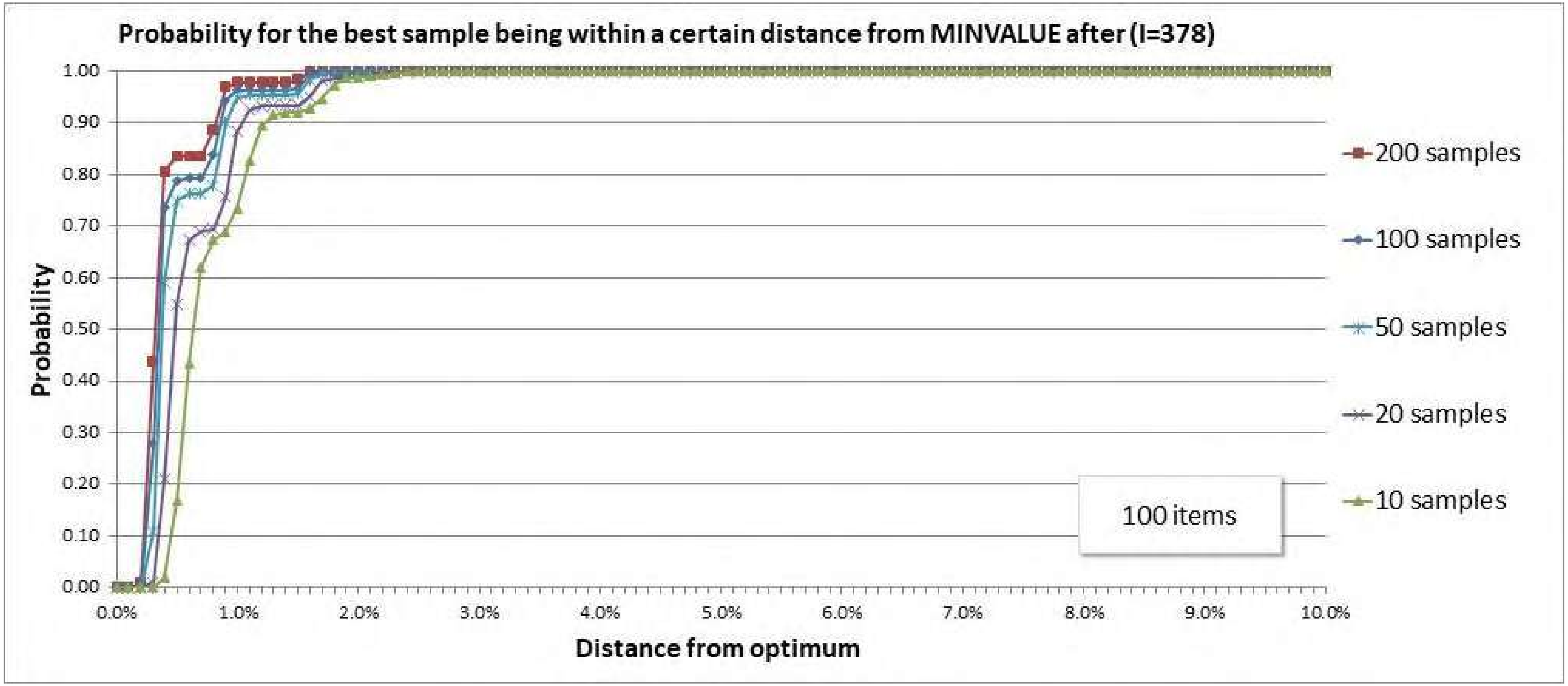
Can we scale?


Probability for the best sample being within a certain distance from MINVALUE after (I=334)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?

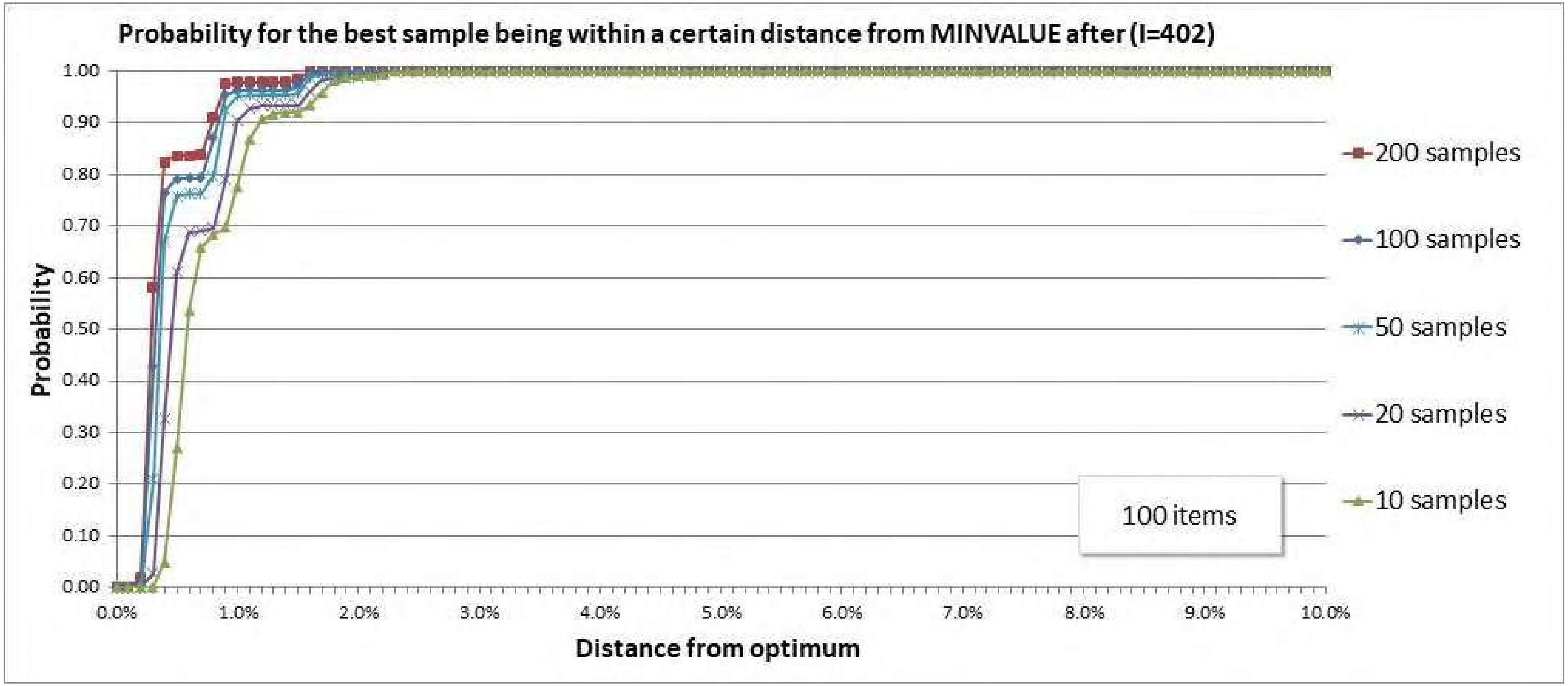

Probability for the best sample being within a certain distance from MINVALUE after (I=355)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Probability
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?



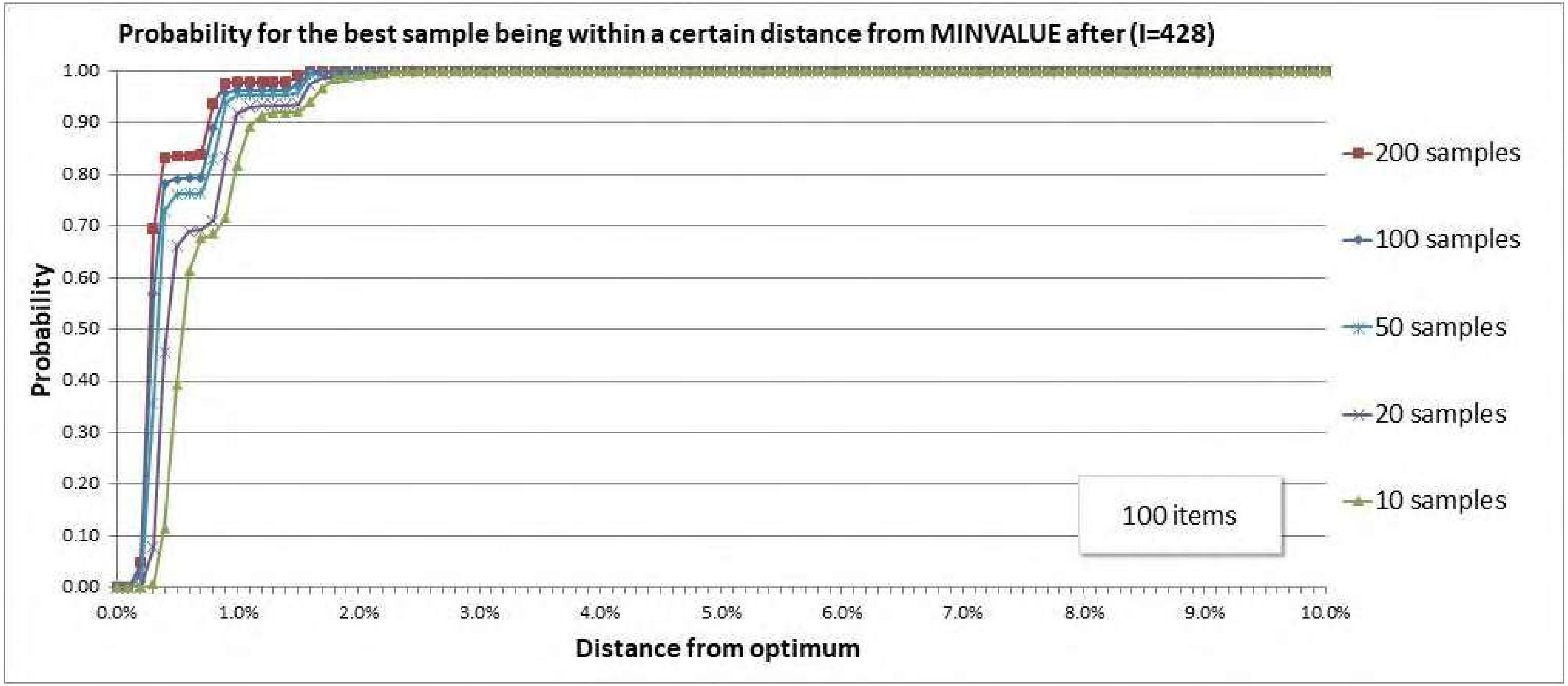
Probability for the best sample being within a certain distance from MINVALUE after (I=378)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?



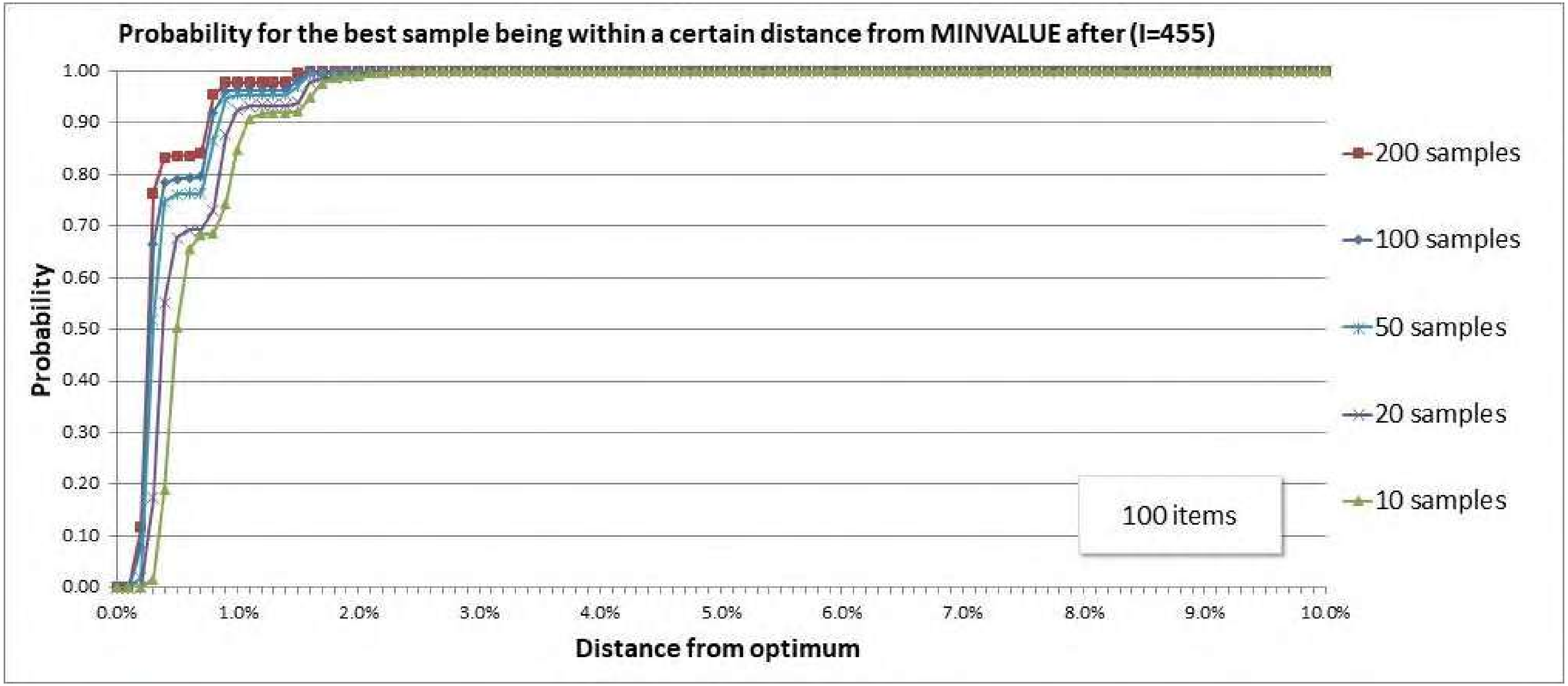
Systecon

Can we scale?



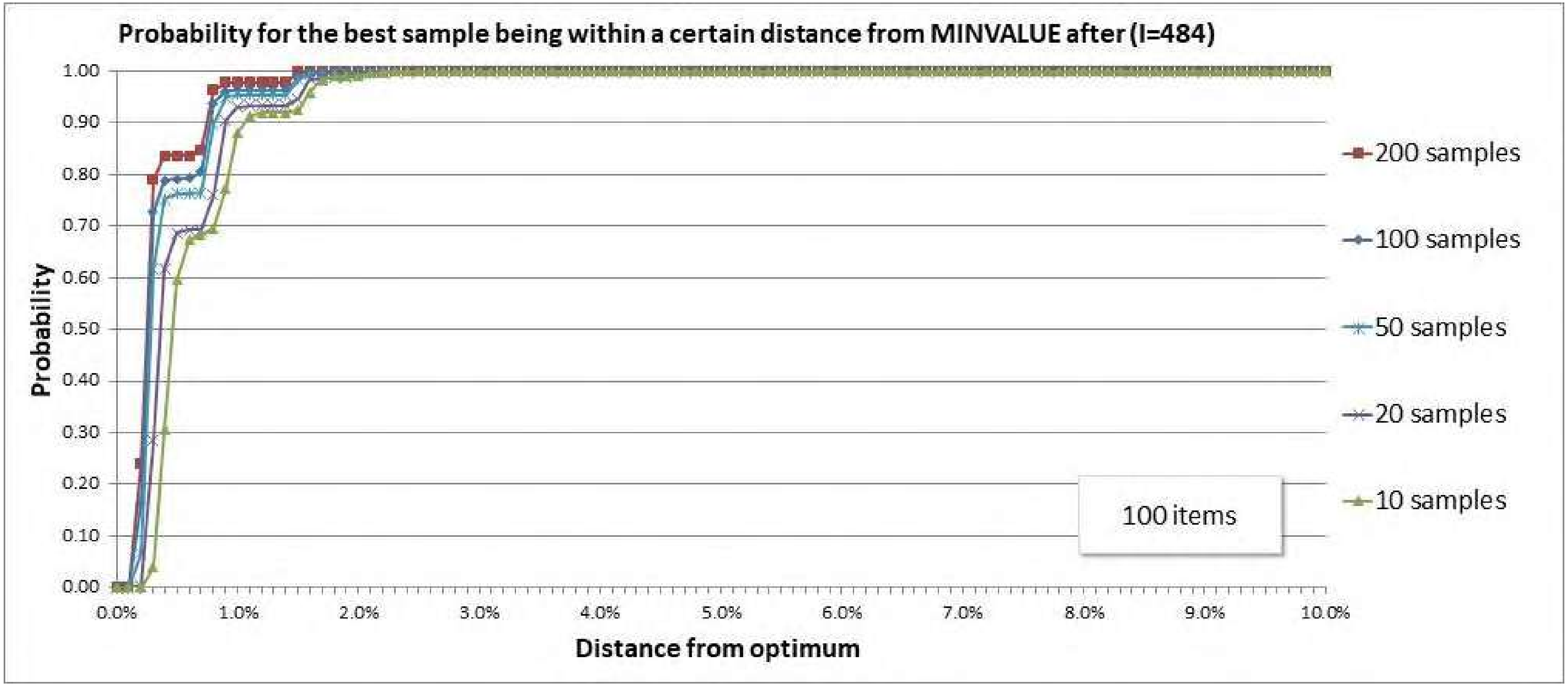
Systecon

Can we scale?

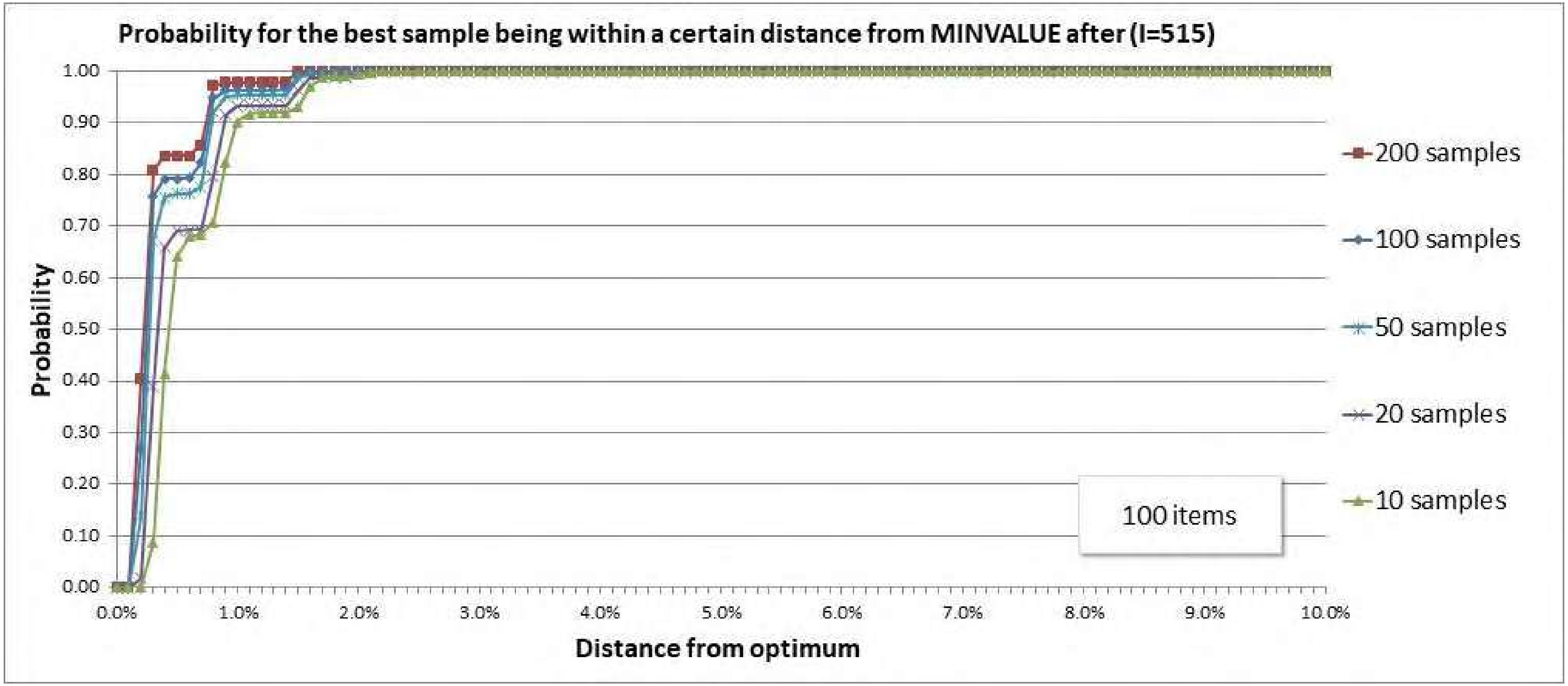


Systecon

Can we scale?

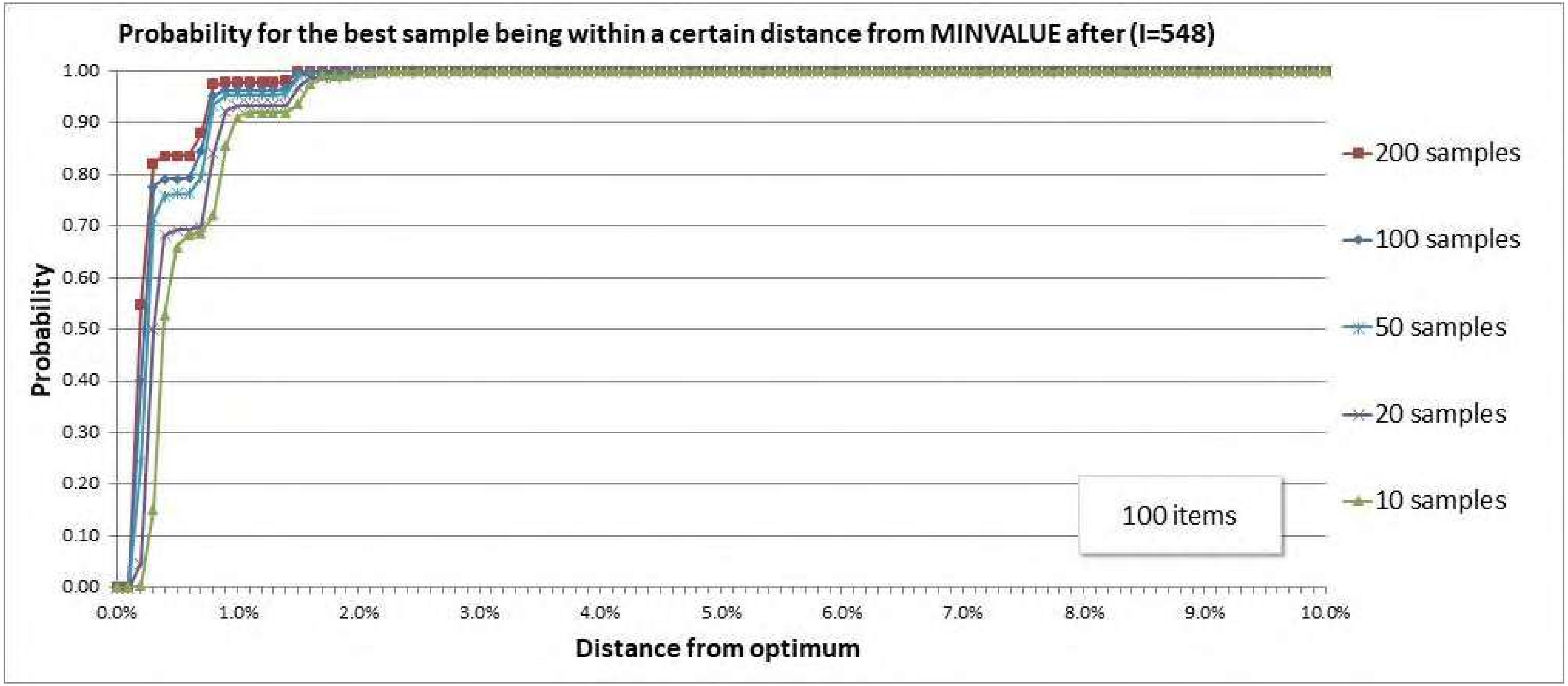

Probability for the best sample being within a certain distance from MINVALUE after (I=484)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?



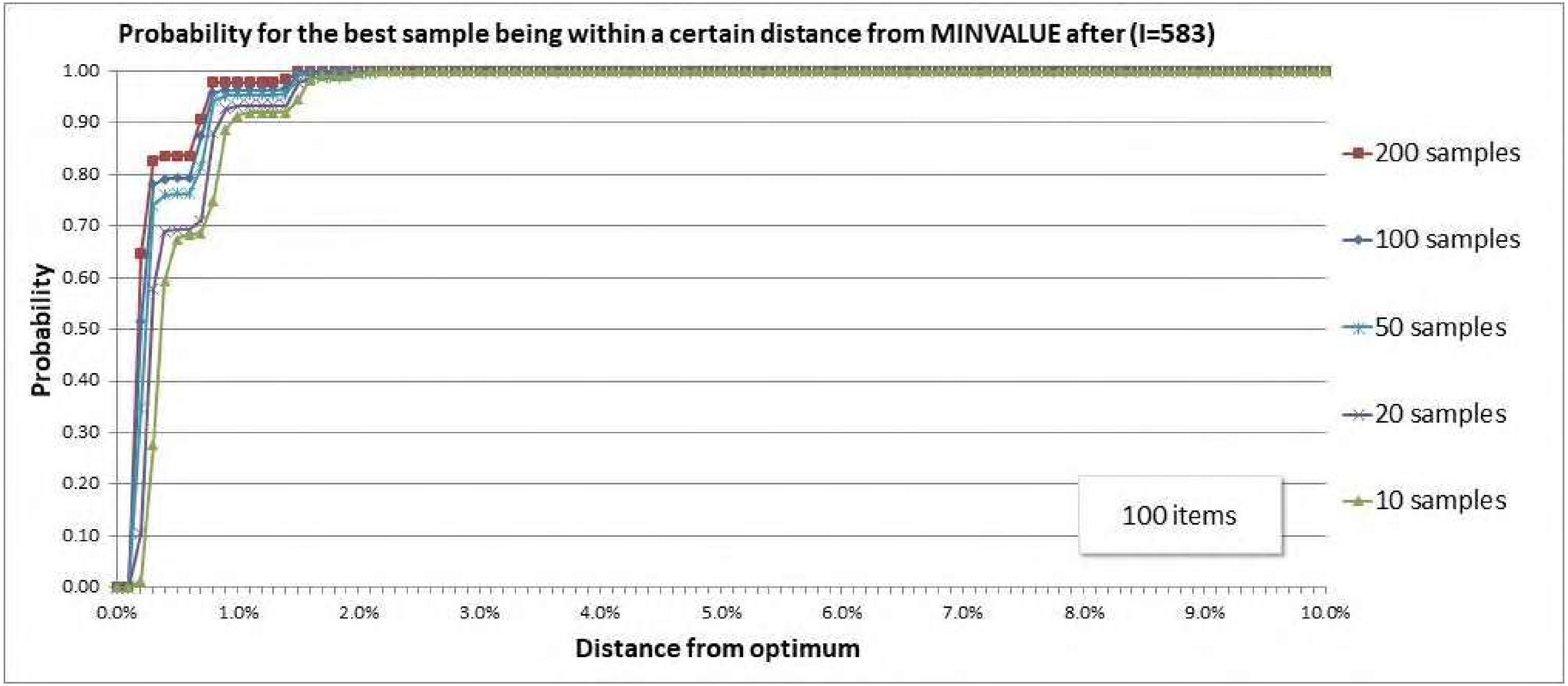
Systecon

Can we scale?

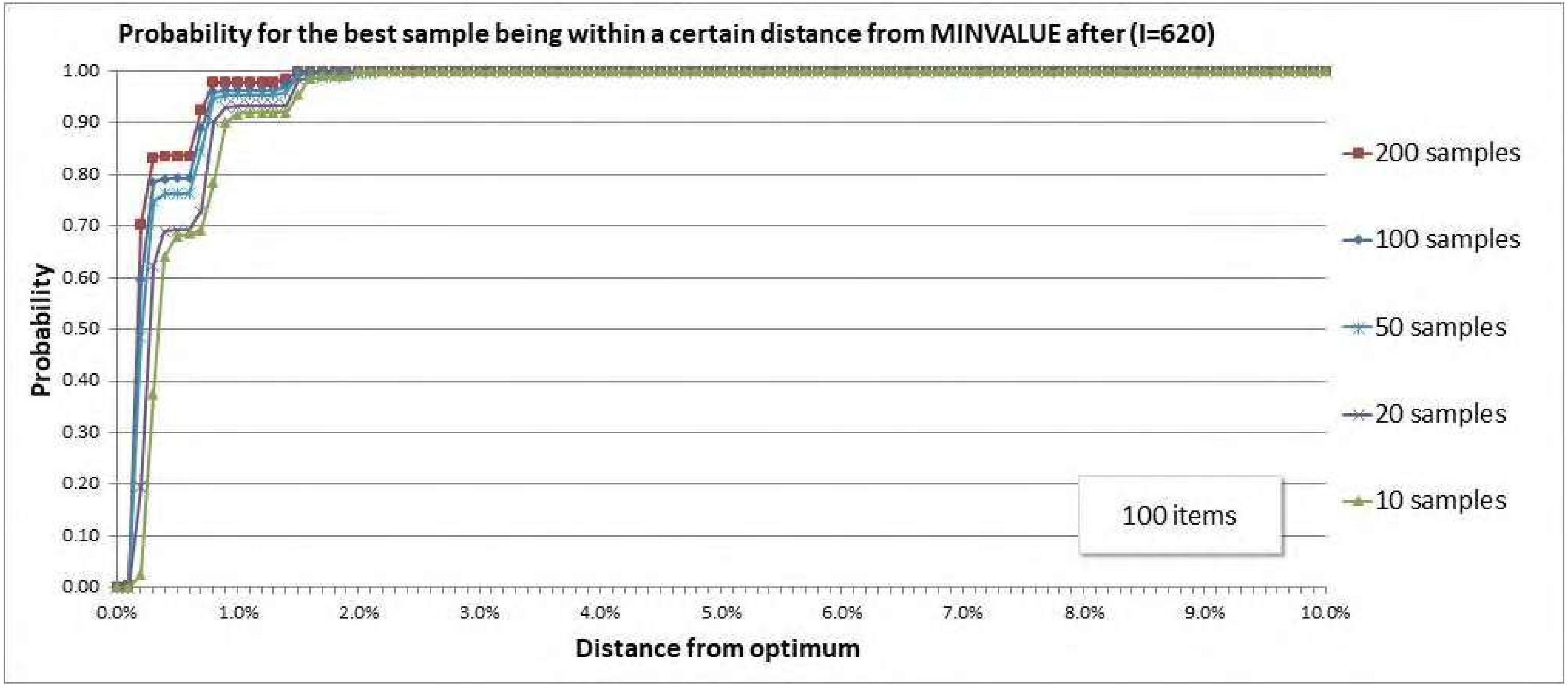


Systecon

Can we scale?

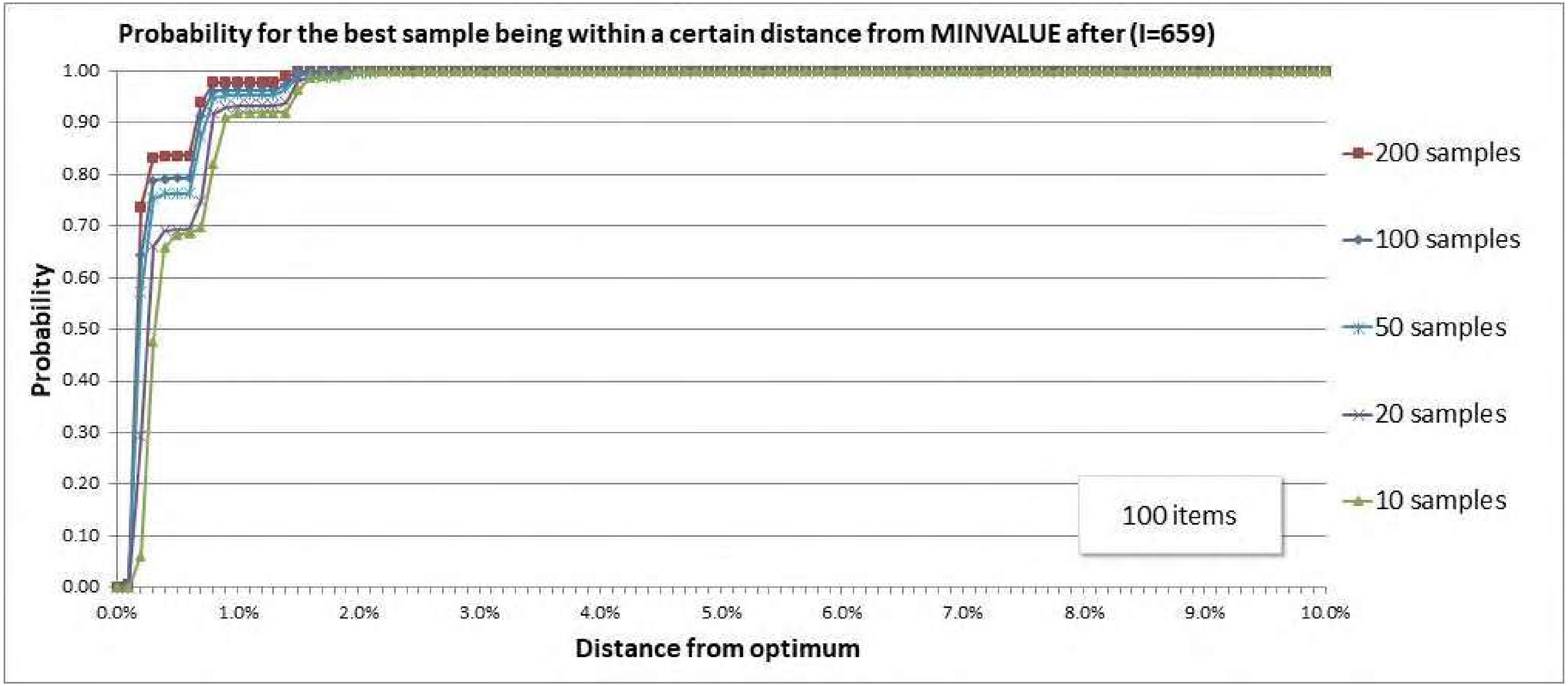

Probability for the best sample being within a certain distance from MINVALUE after (I=583)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Probability
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?

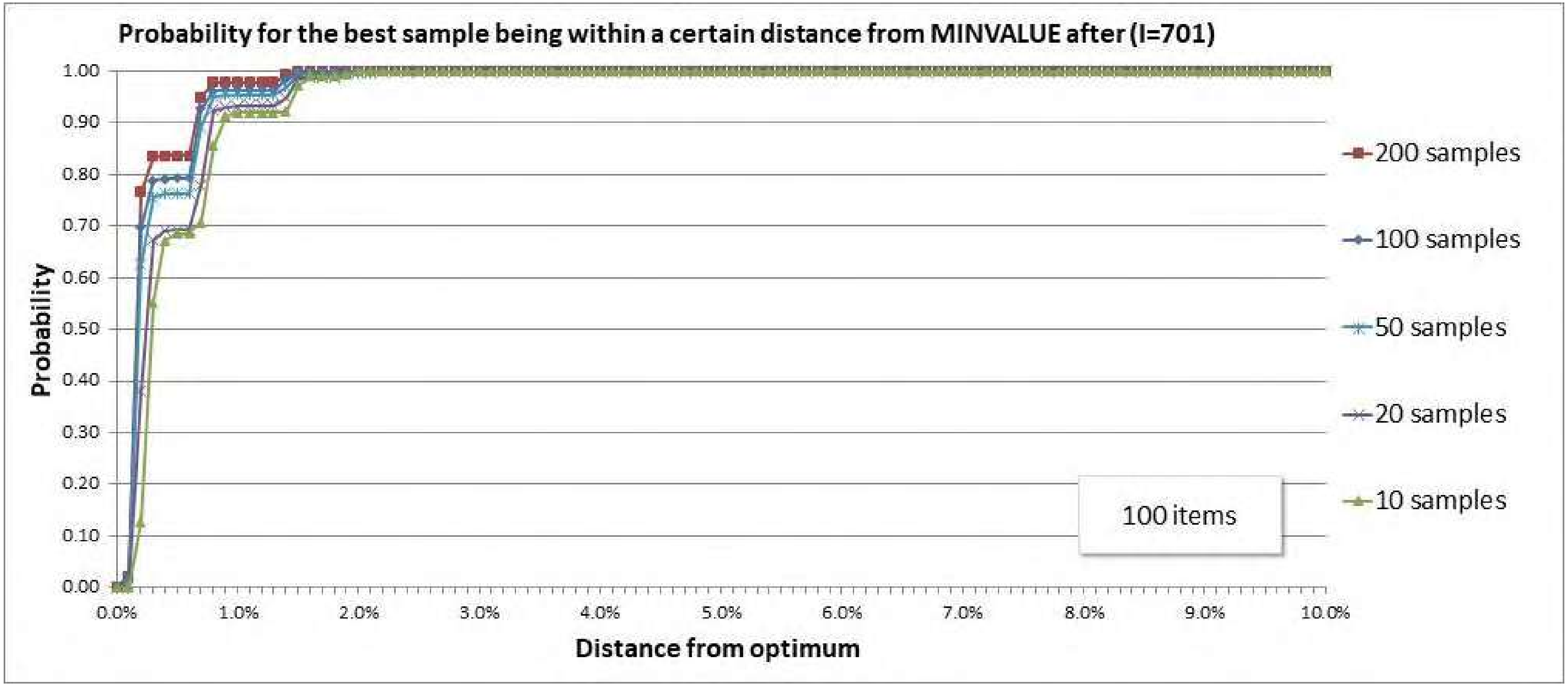


Systecon

Can we scale?

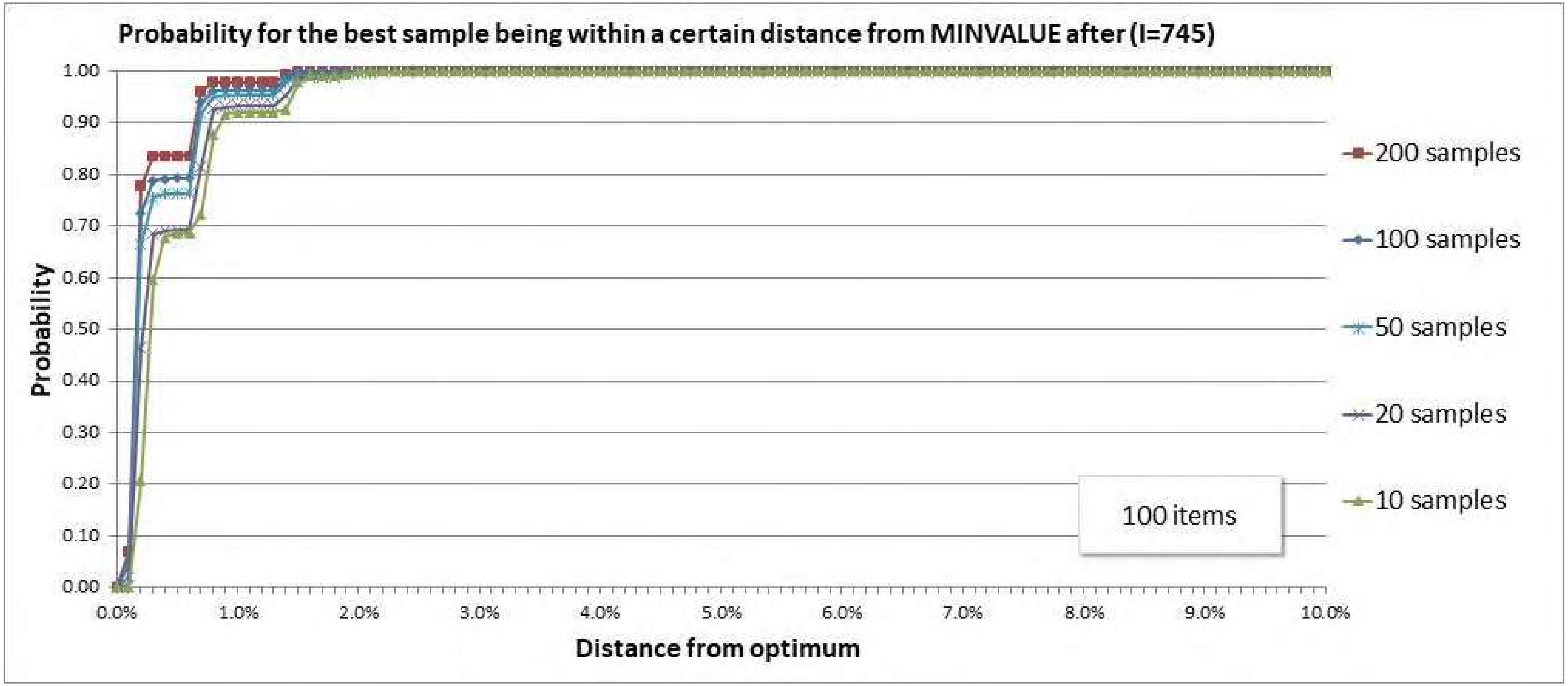

Probability for the best sample being within a certain distance from MINVALUE after (I=659)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?



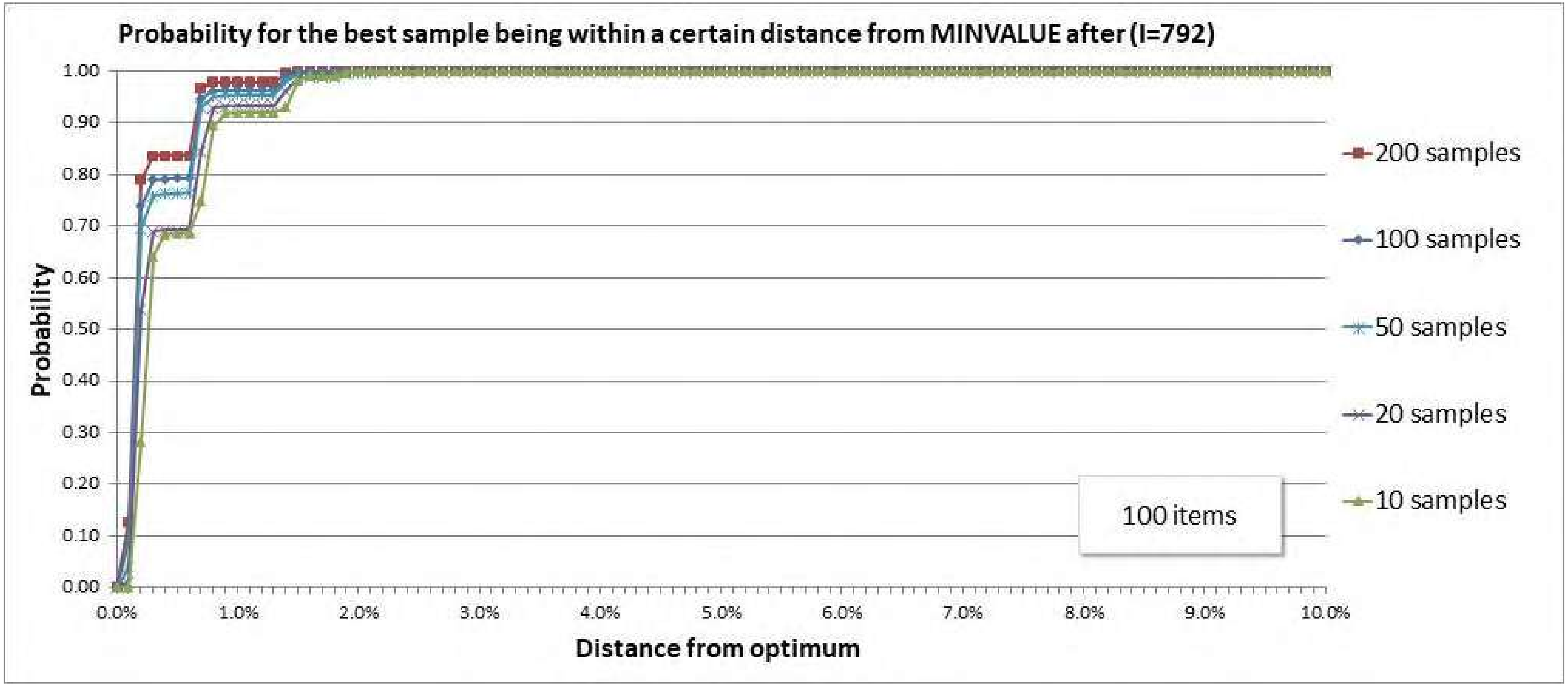
Systecon

Can we scale?

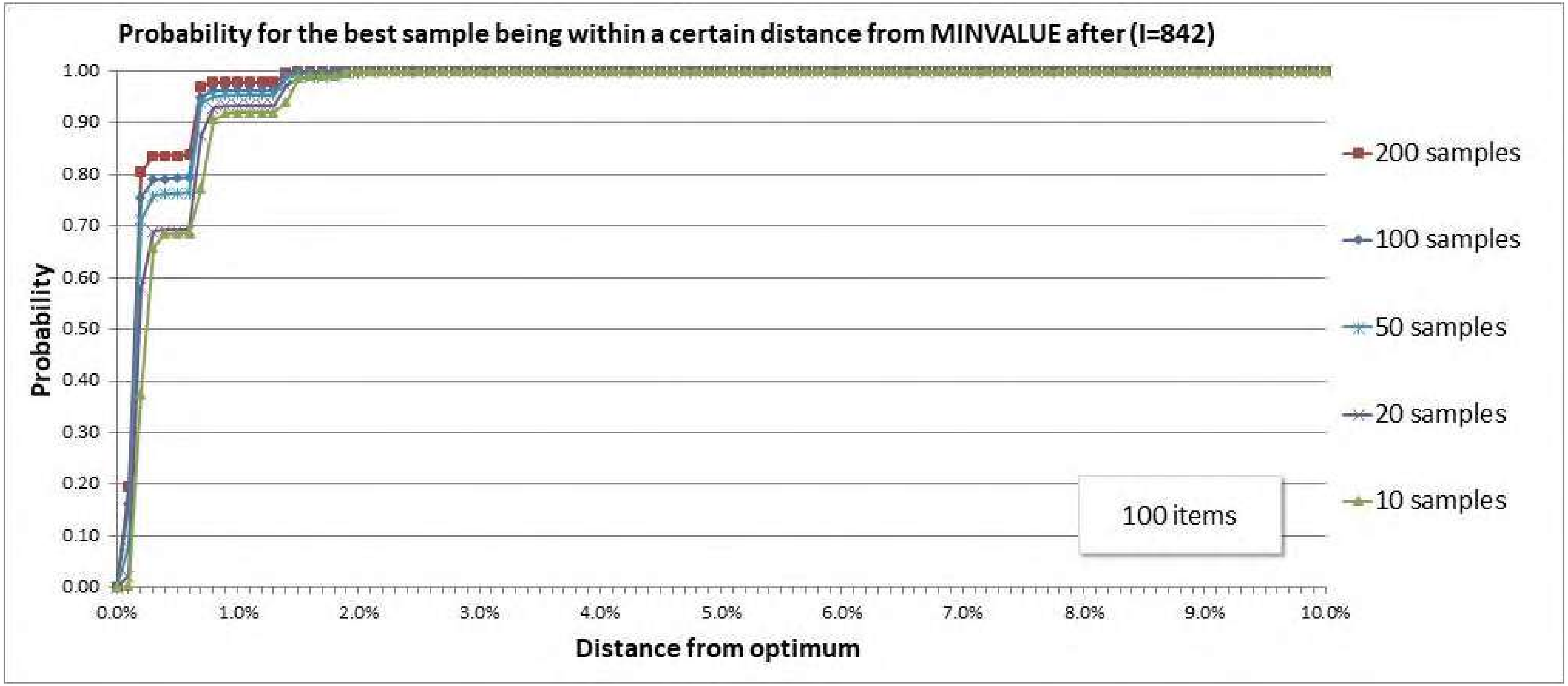


Systecon

Can we scale?

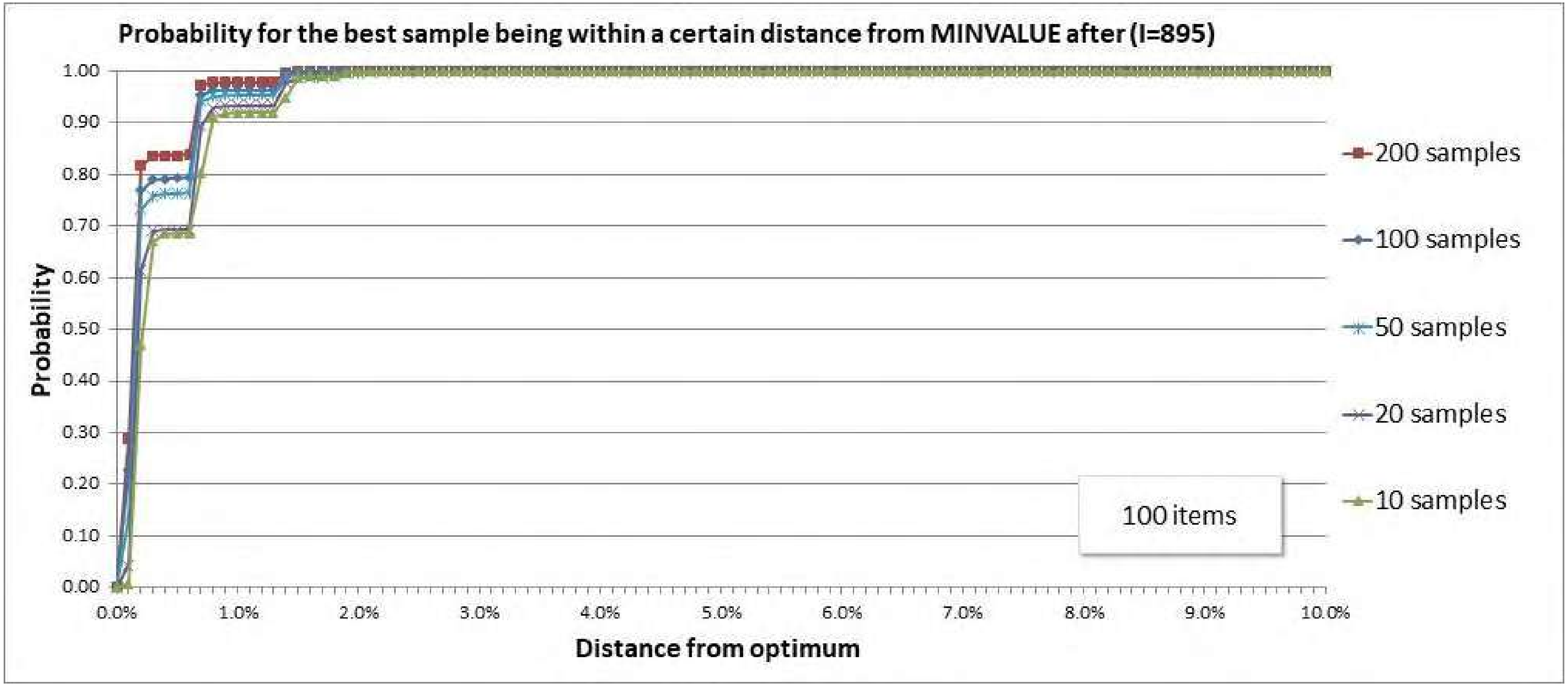

Probability for the best sample being within a certain distance from MINVALUE after (I=792)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Probability
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?

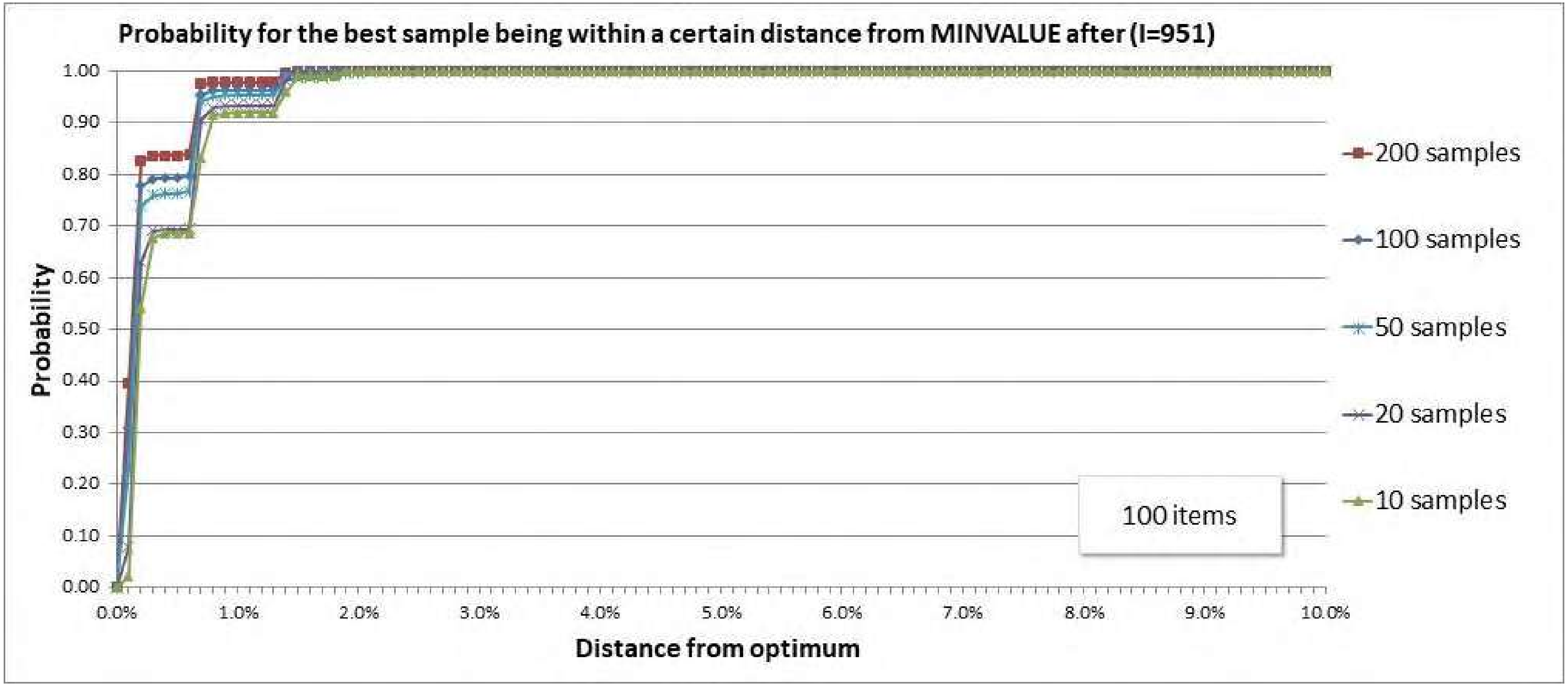


Systecon

Can we scale?

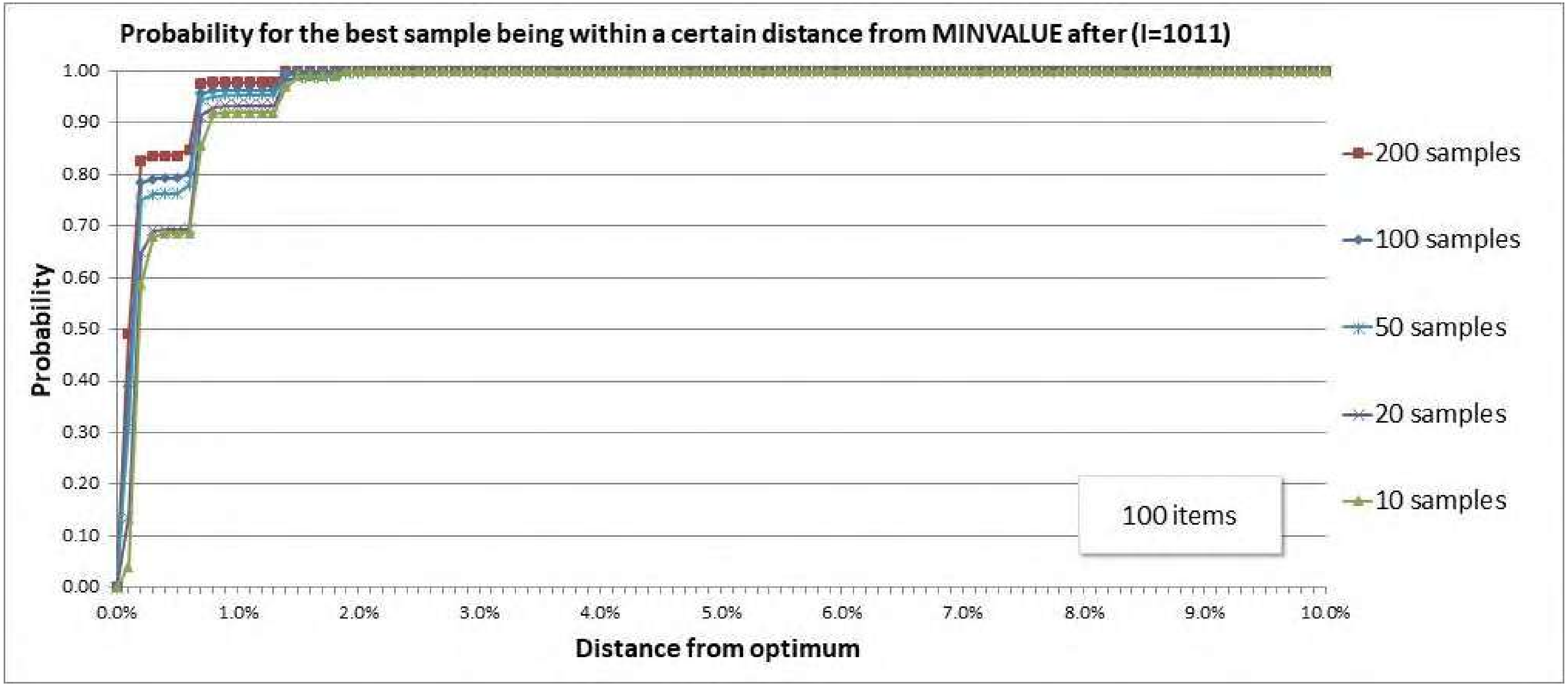

Probability for the best sample being within a certain distance from MINVALUE after (I=895)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?

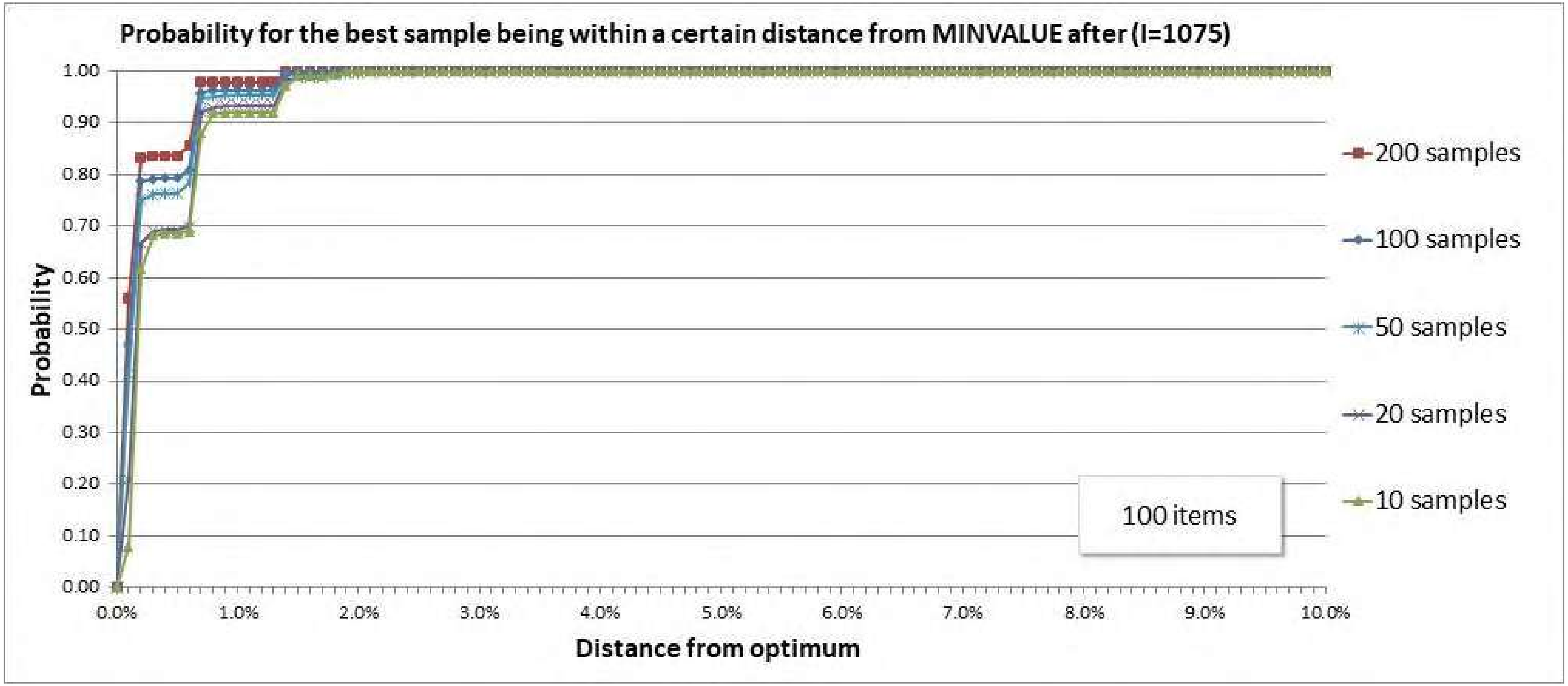


Systecon

Can we scale?

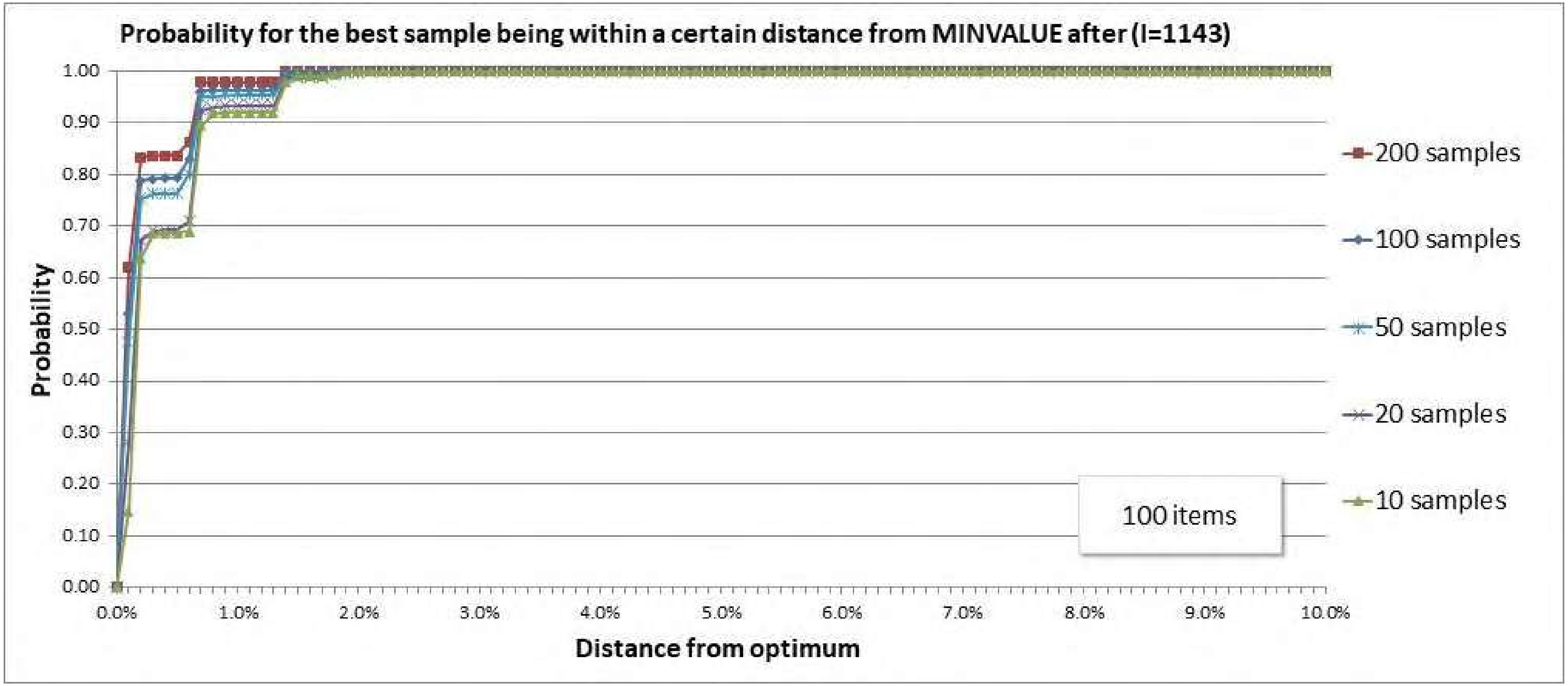

Probability for the best sample being within a certain distance from MINVALUE after (I=1011)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?



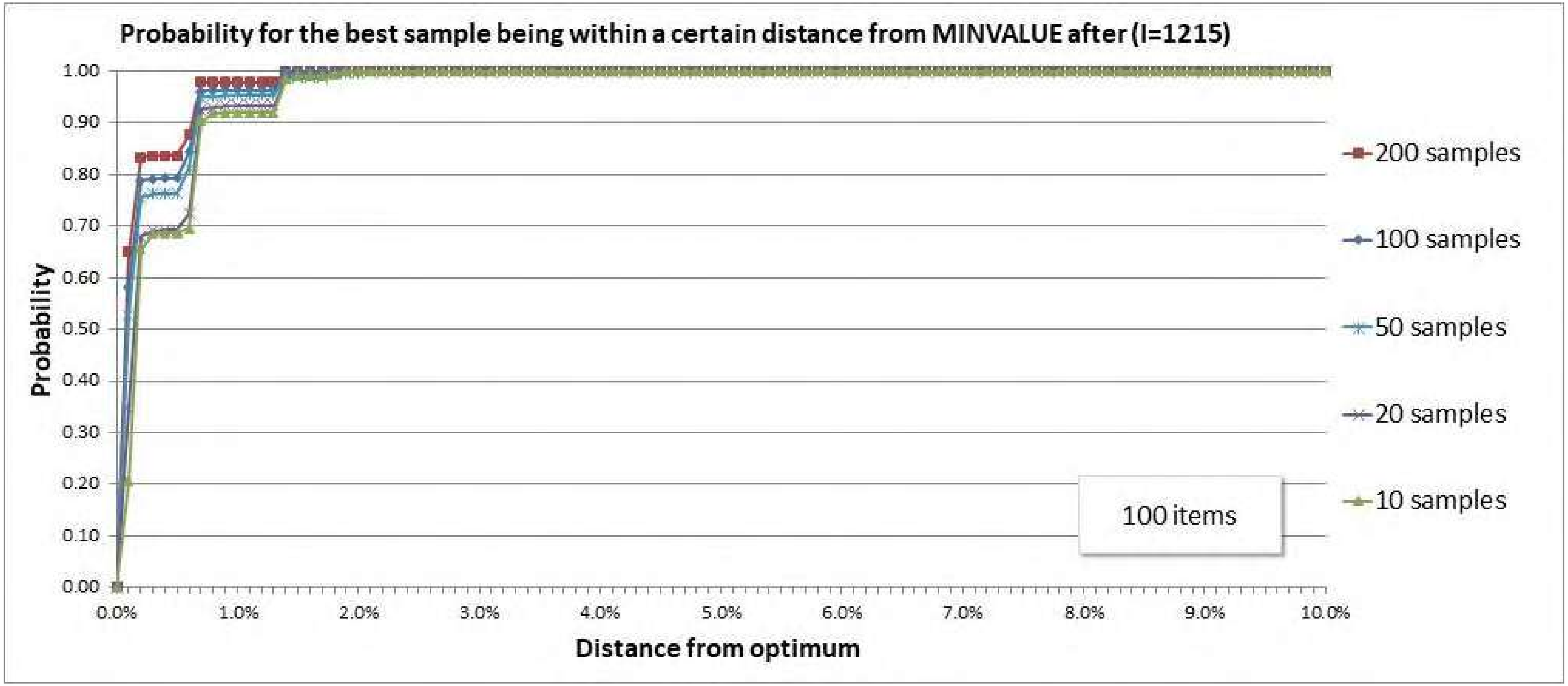
Systecon

Can we scale?

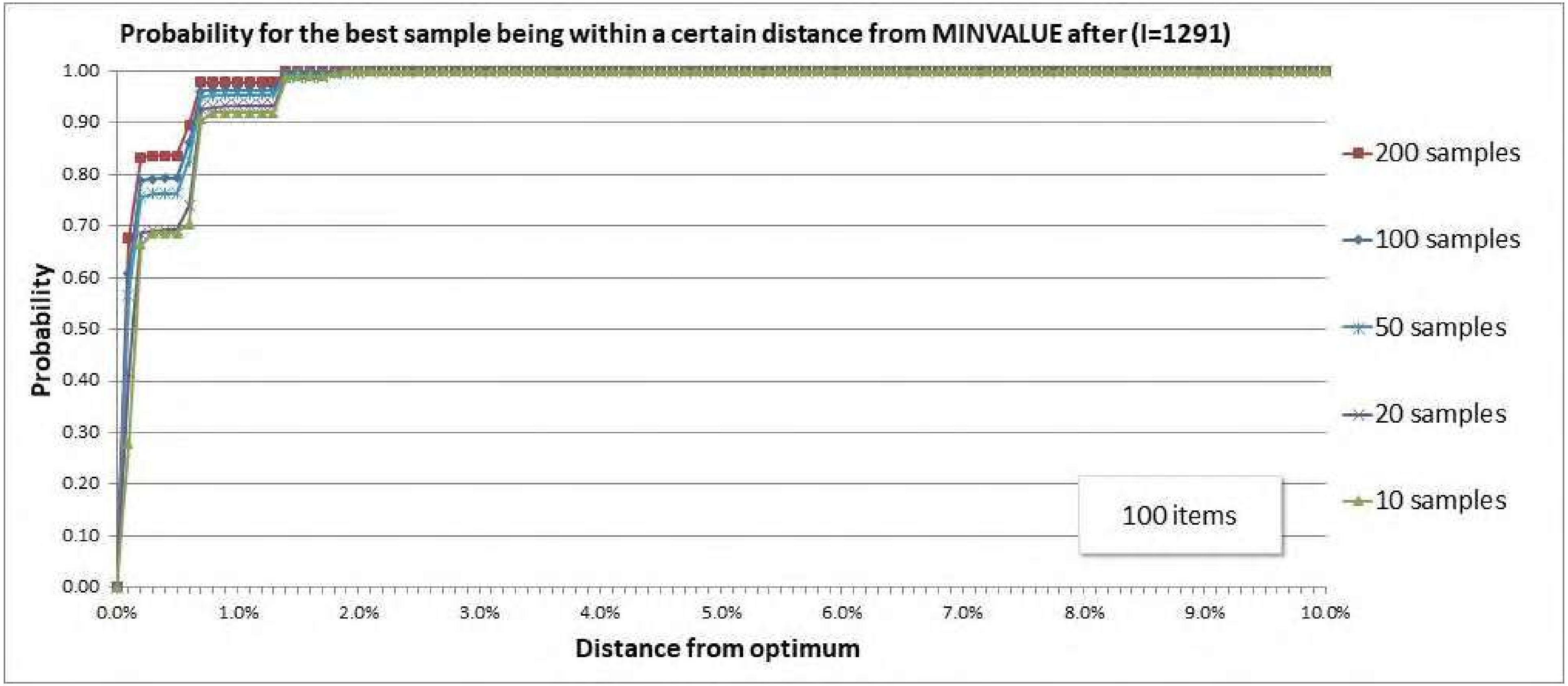


Probability for the best sample being within a certain distance from MINVALUE after (I=1143)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?

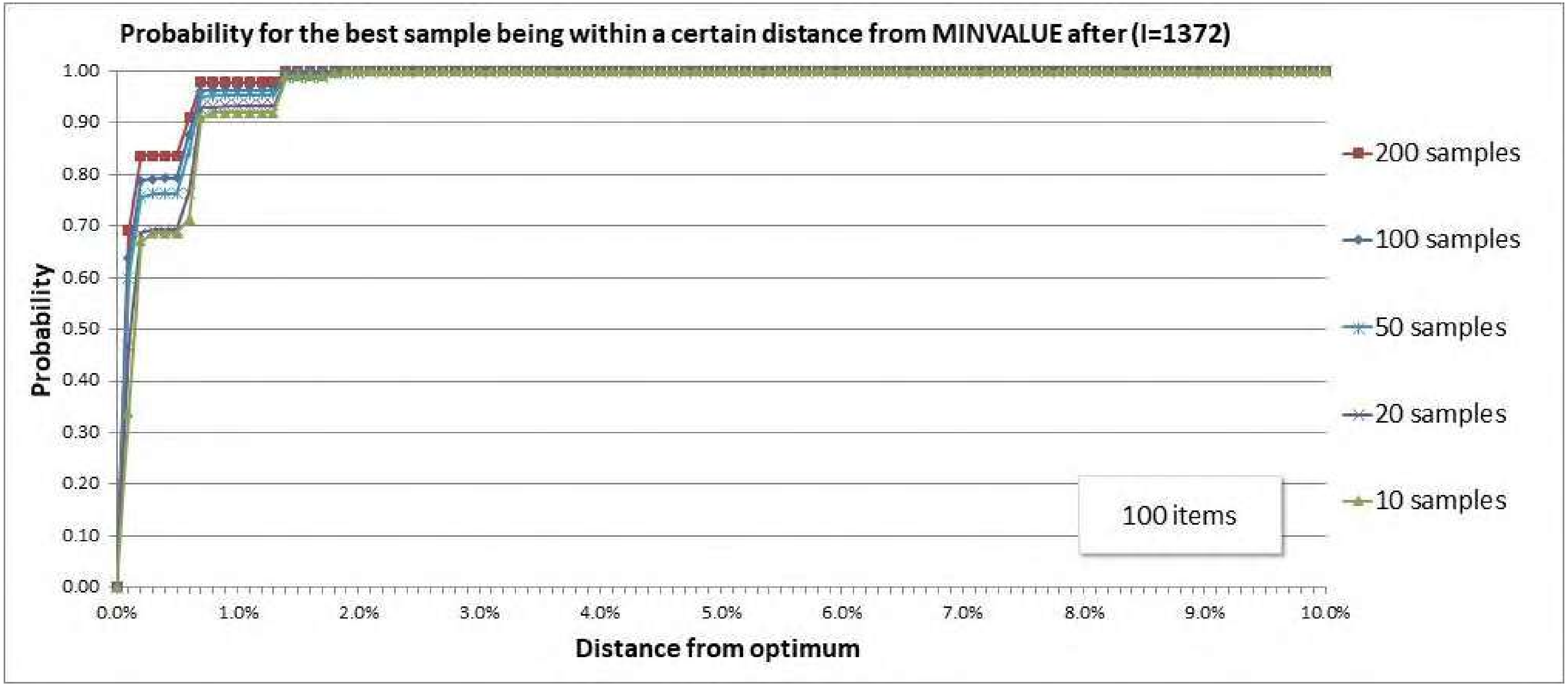

Probability for the best sample being within a certain distance from MINVALUE after (I=1215)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Probability
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?

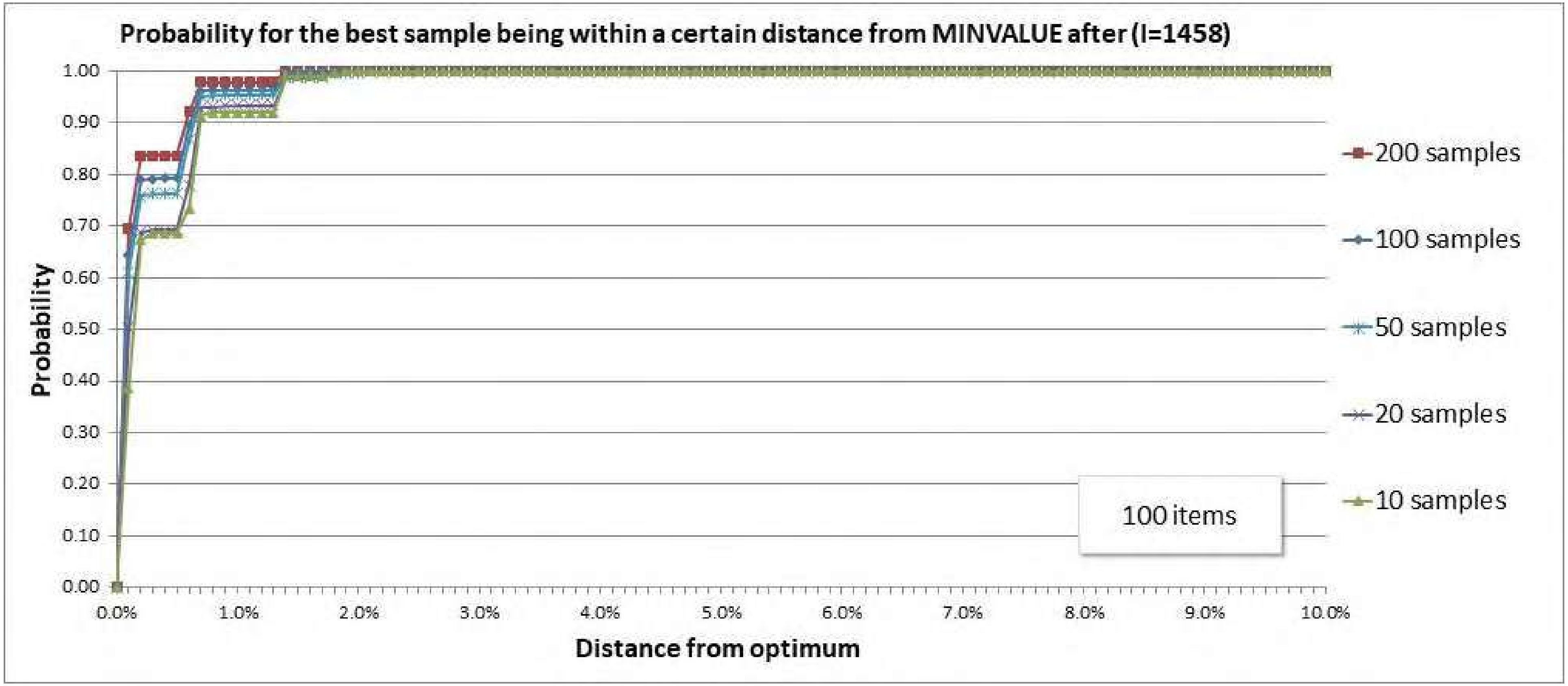


Systecon

Can we scale?

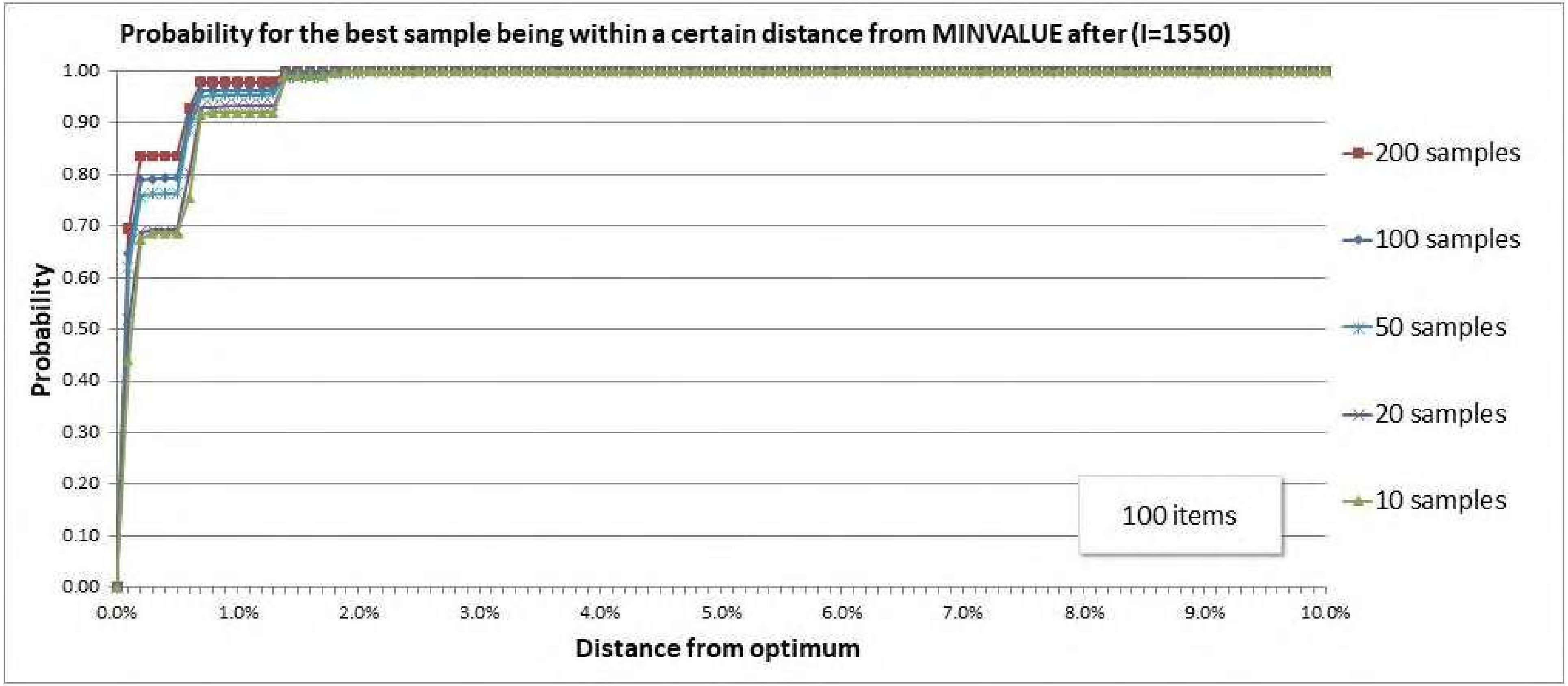

Probability for the best sample being within a certain distance from MINVALUE after (I=1372)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Probability
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?



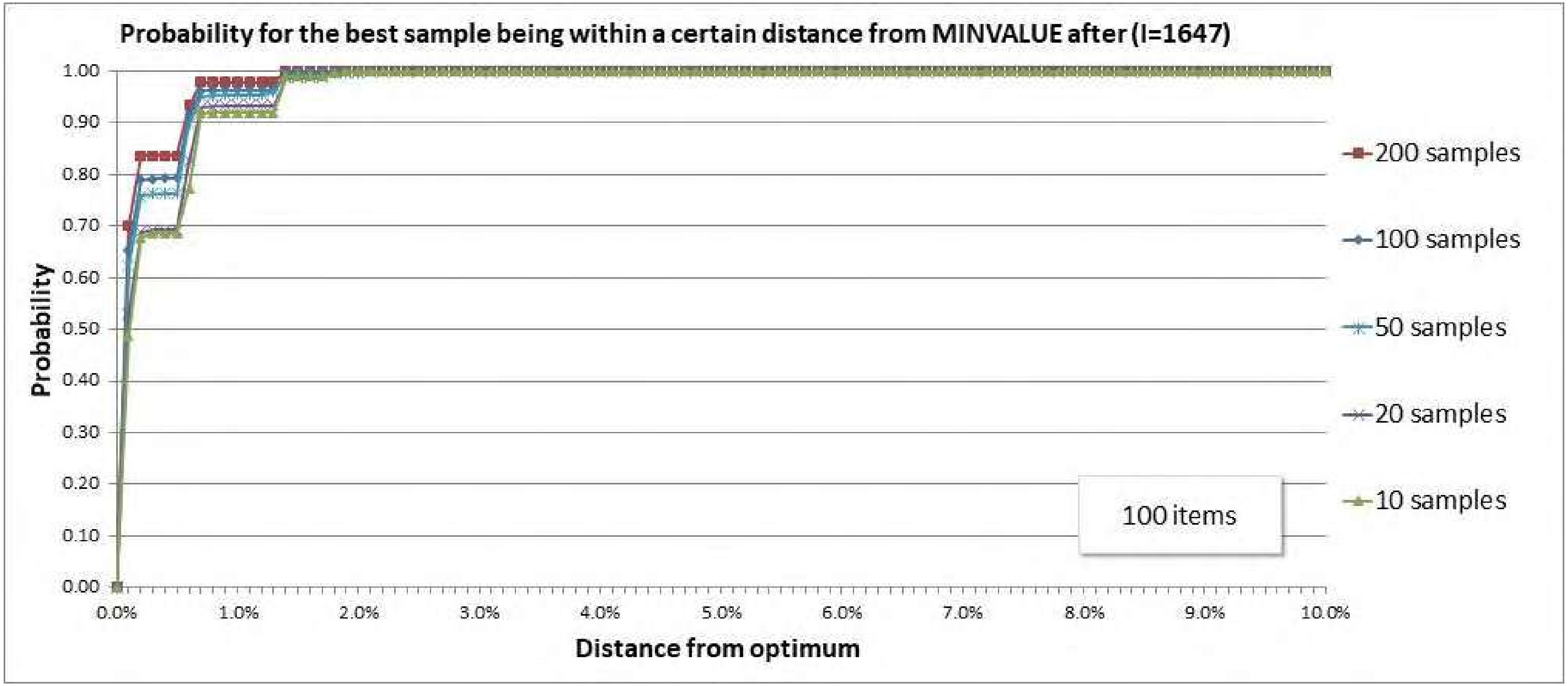
Systecon

Can we scale?



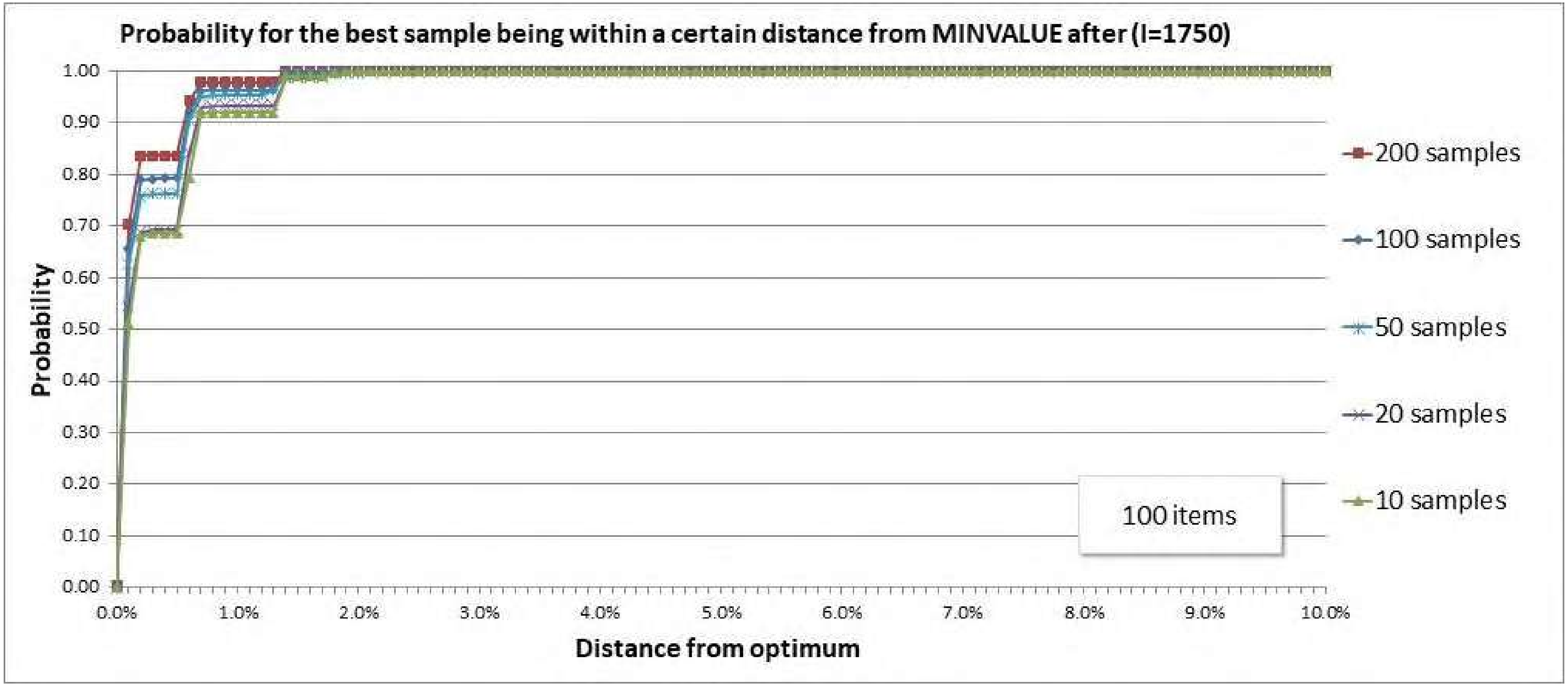
Systecon

Can we scale?



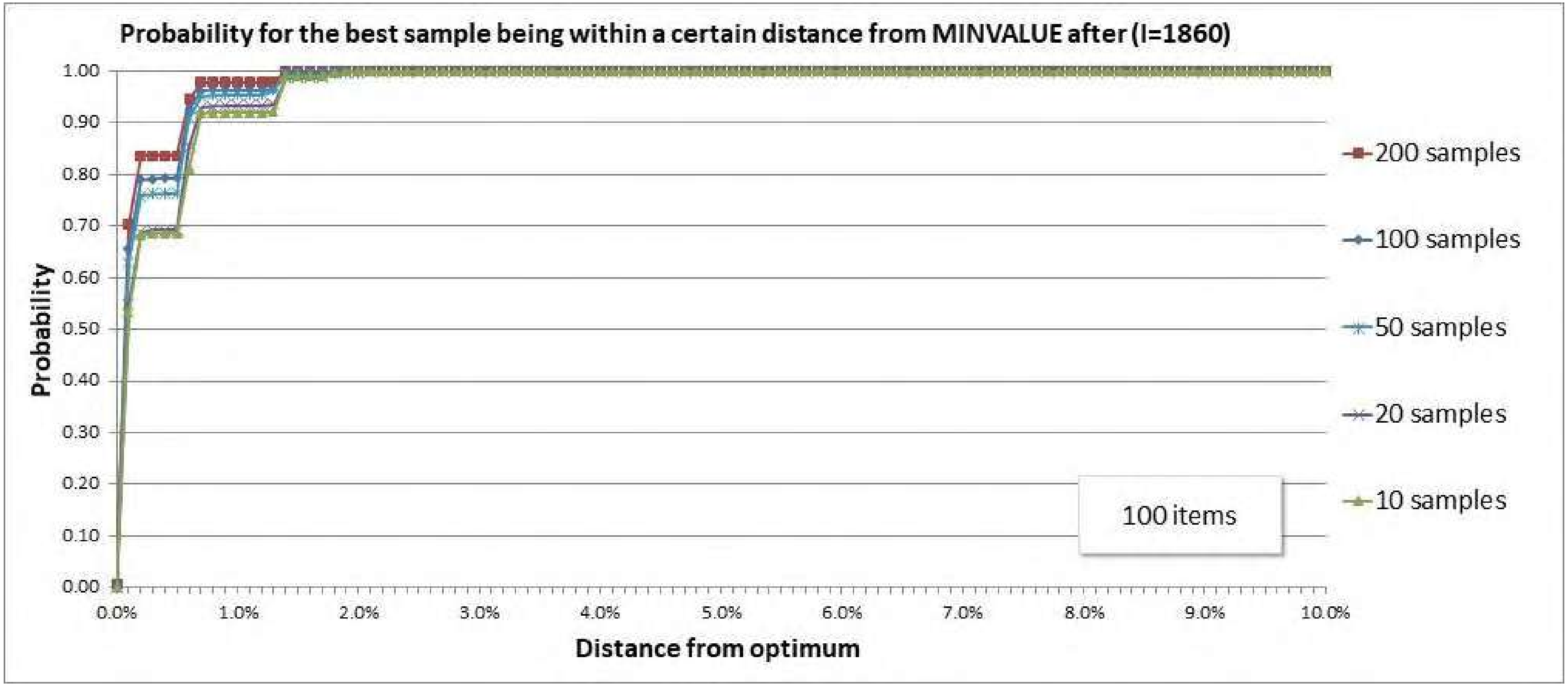
Probability for the best sample being within a certain distance from MINVALUE after (I=1647)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
100 items

Can we scale?



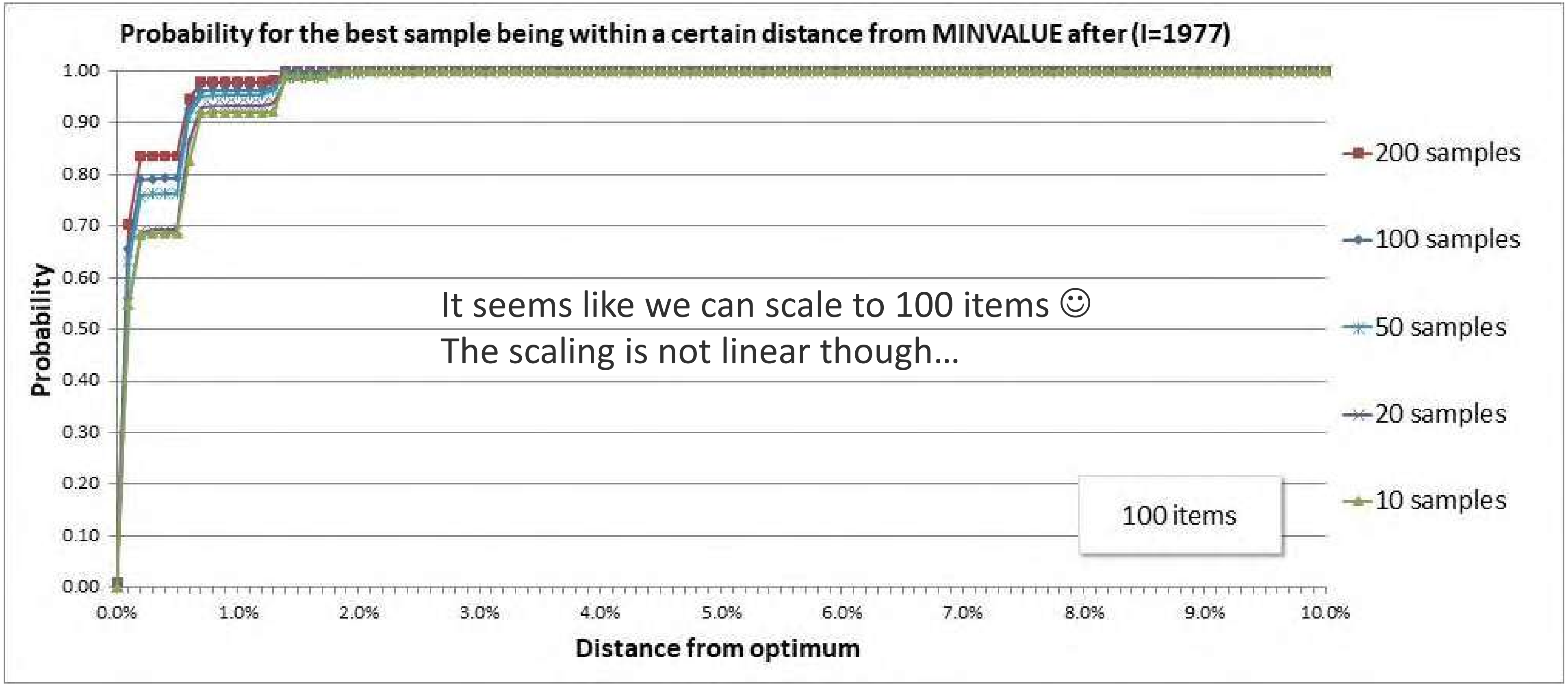
Systecon

Can we scale?

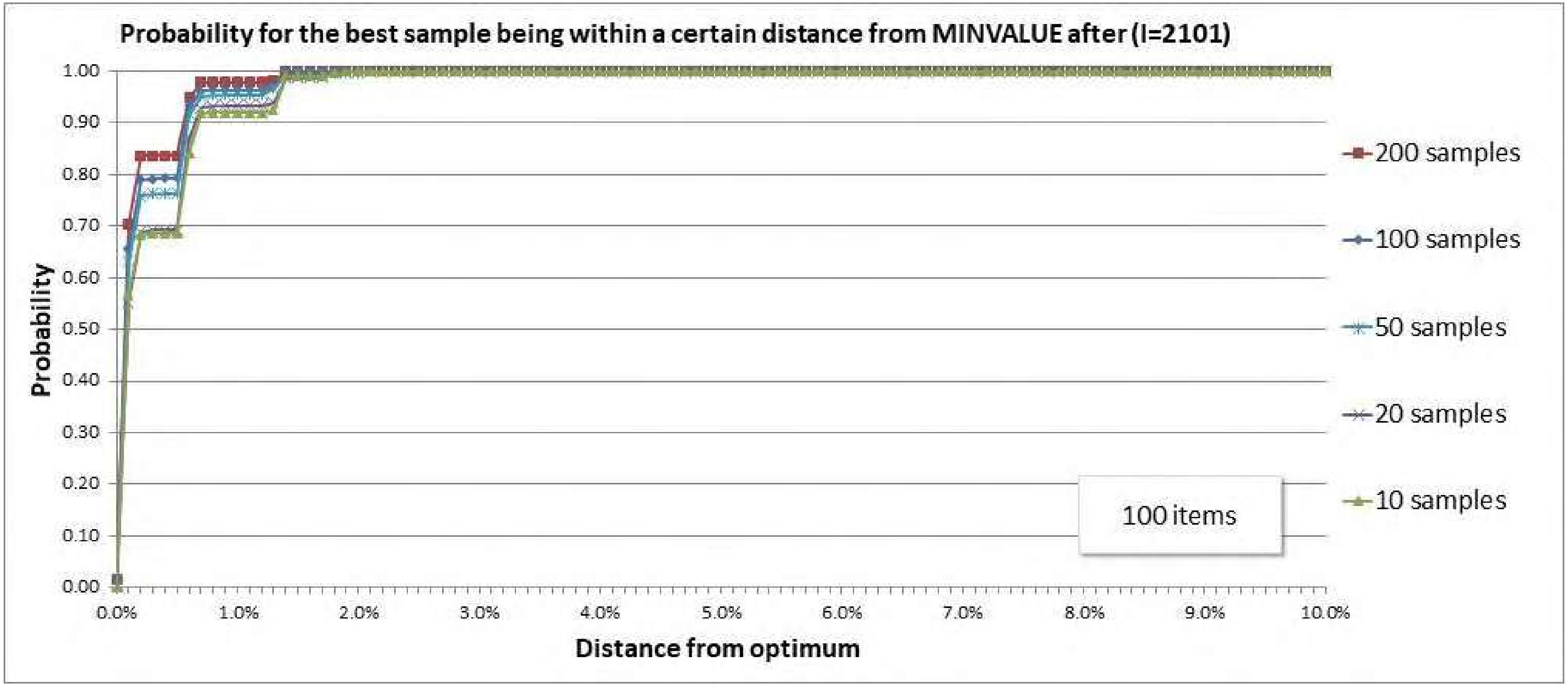


Systecon

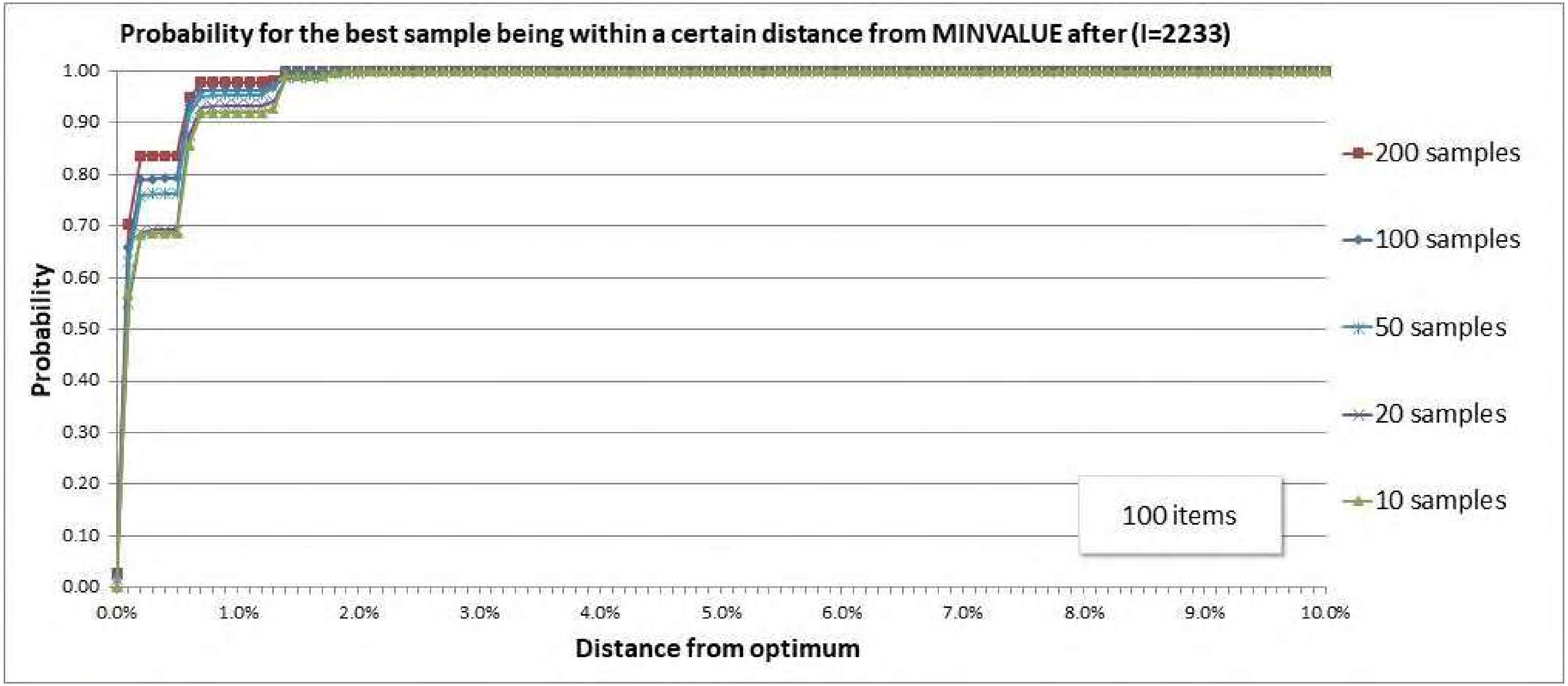
Can we scale?


Probability for the best sample being within a certain distance from MINVALUE after (I=1977)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Probability
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
200 samples
100 samples
50 samples
20 samples
10 samples
It seems like we can scale to 100 items ☺
The scaling is not linear though…
100 items

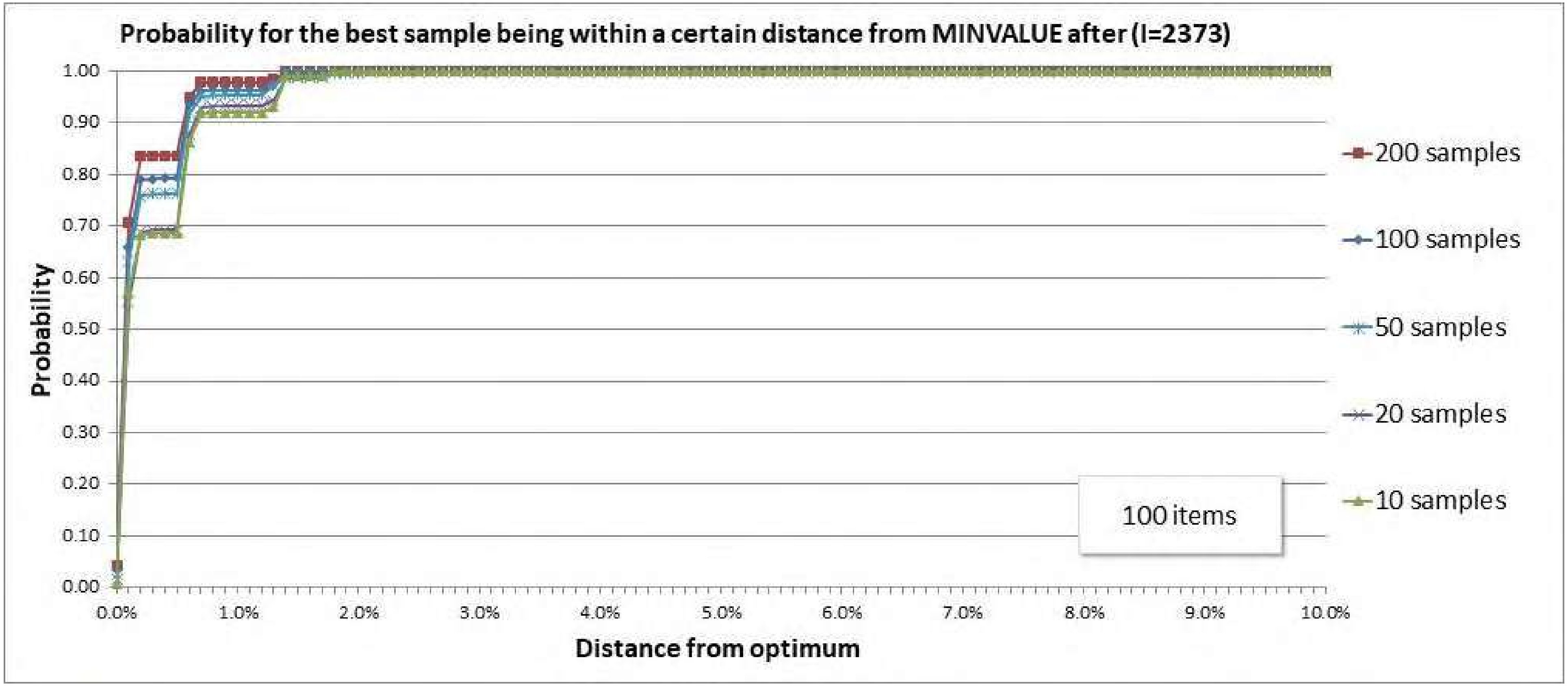
Can we scale?


Probability for the best sample being within a certain distance from MINVALUE after (I=2101)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Probability
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?

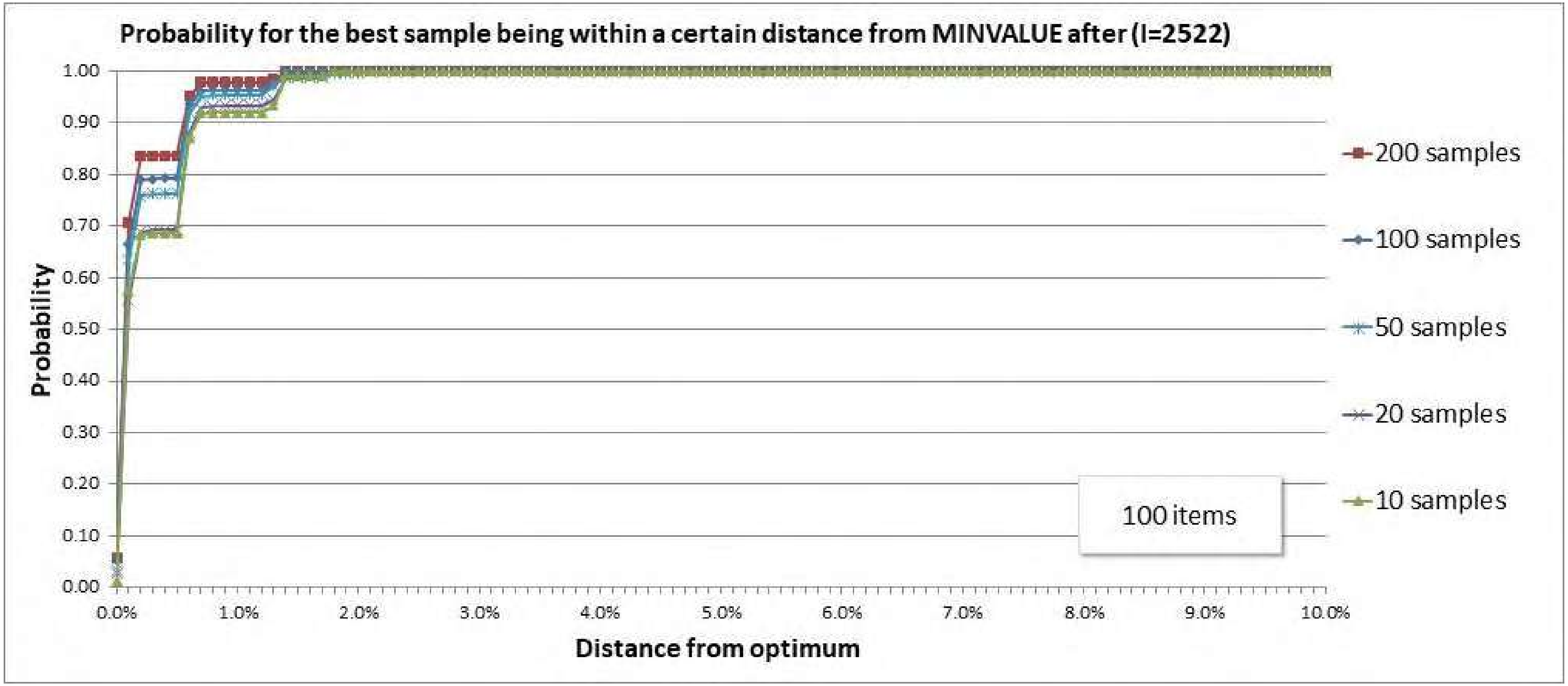

Probability for the best sample being within a certain distance from MINVALUE after (I=2233)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?



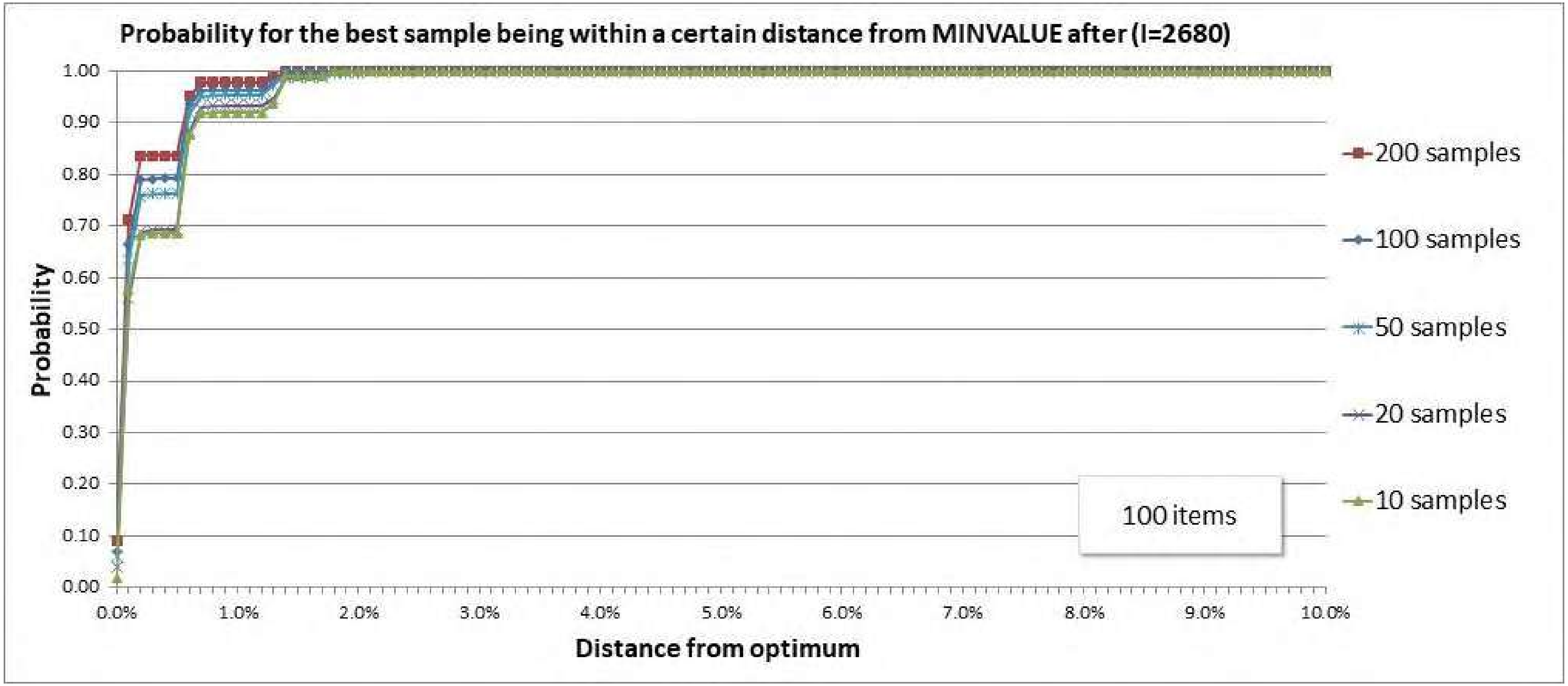
Systecon

Can we scale?



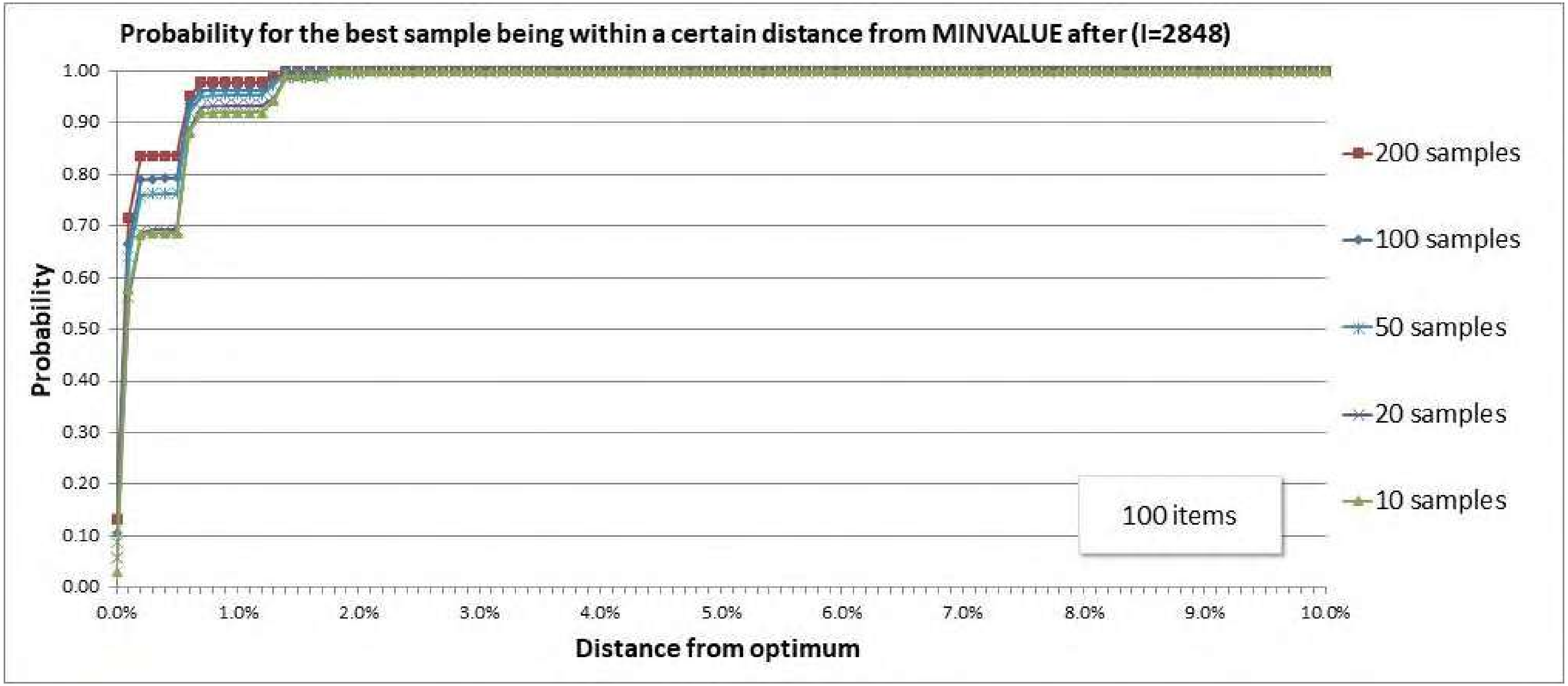
Systecon

Can we scale?

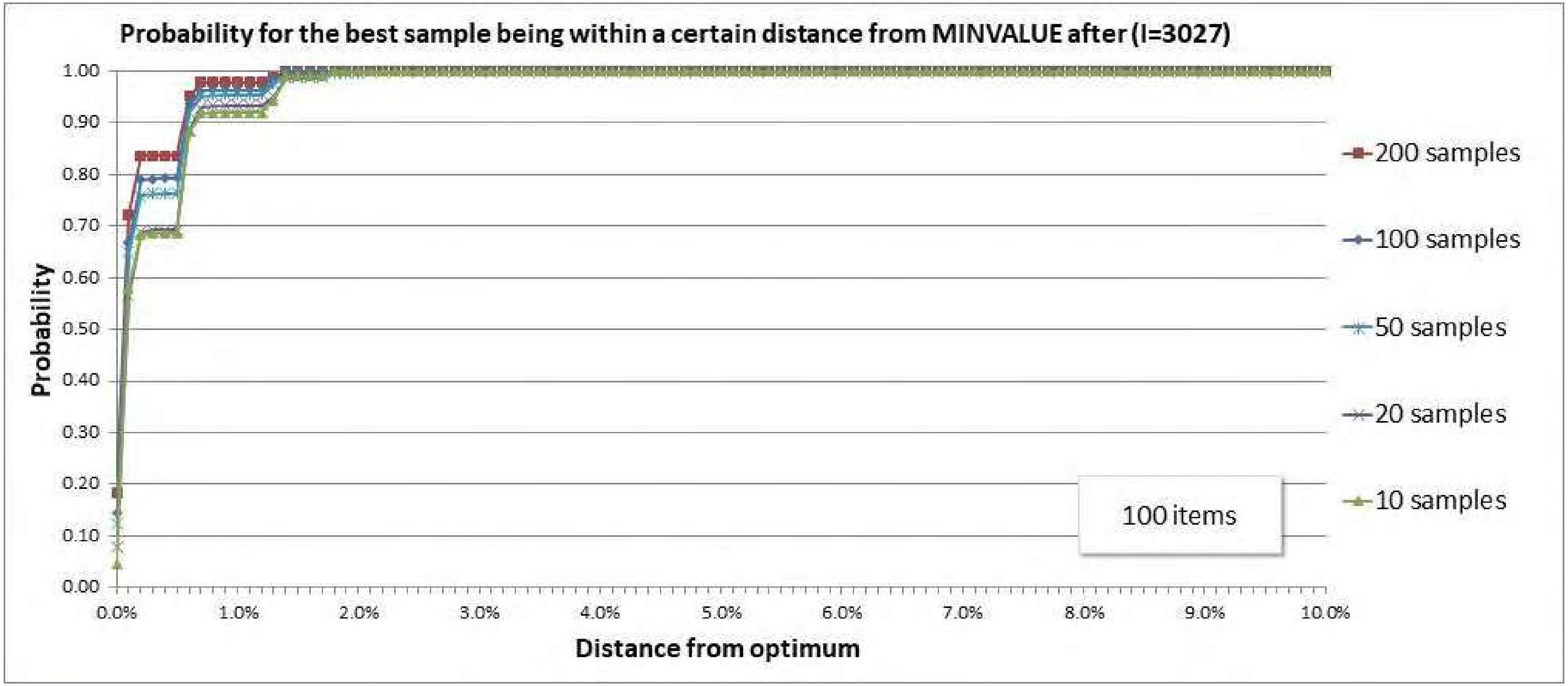


Systecon

Can we scale?

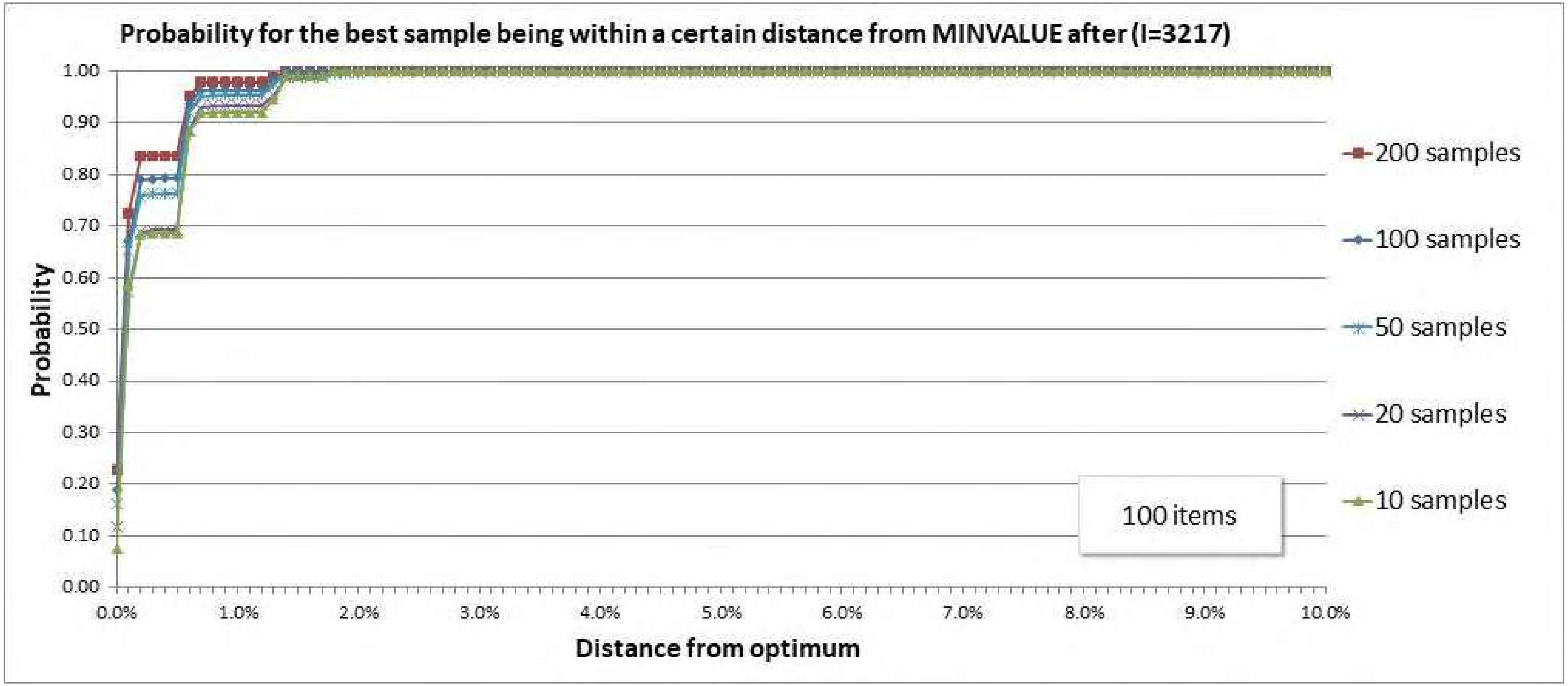

Probability for the best sample being within a certain distance from MINVALUE after (I=2848)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Probability
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?



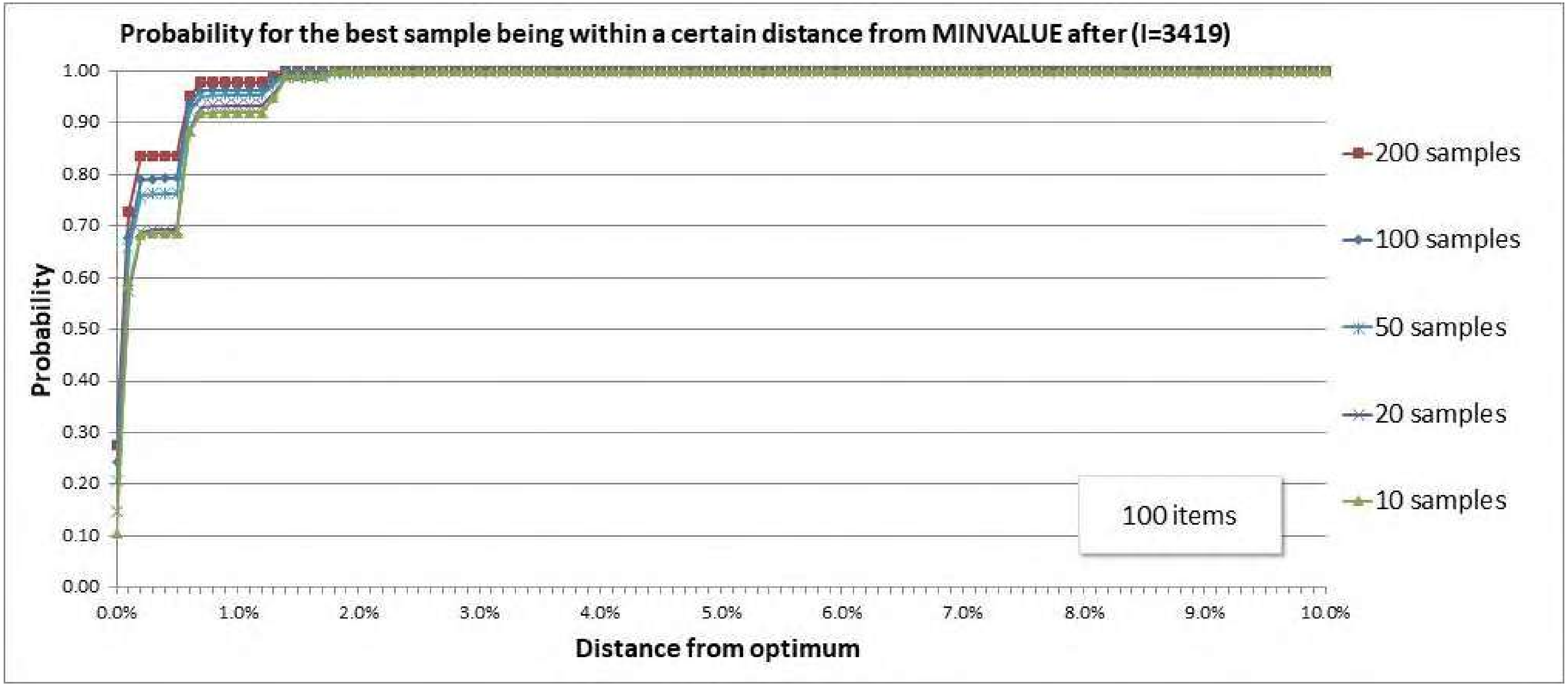
Systecon

Can we scale?

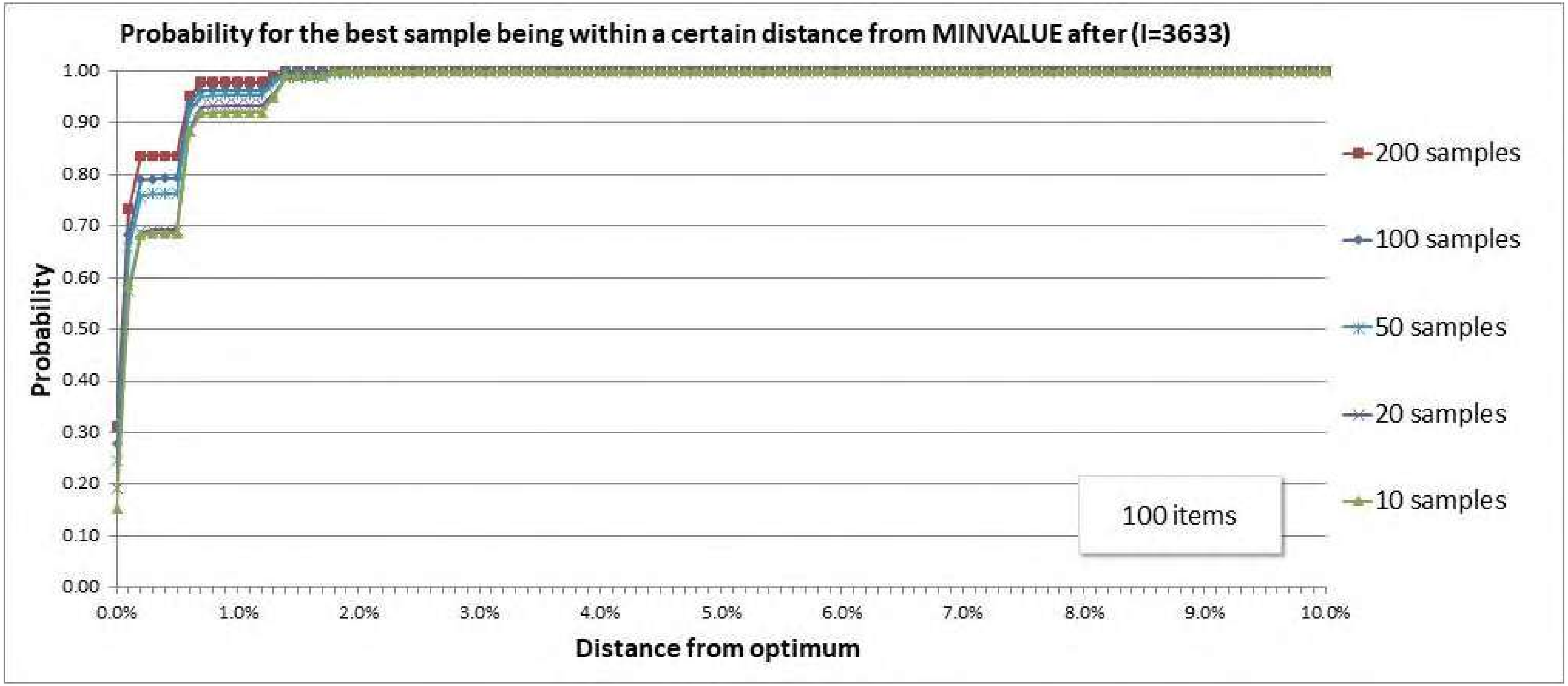


Systecon

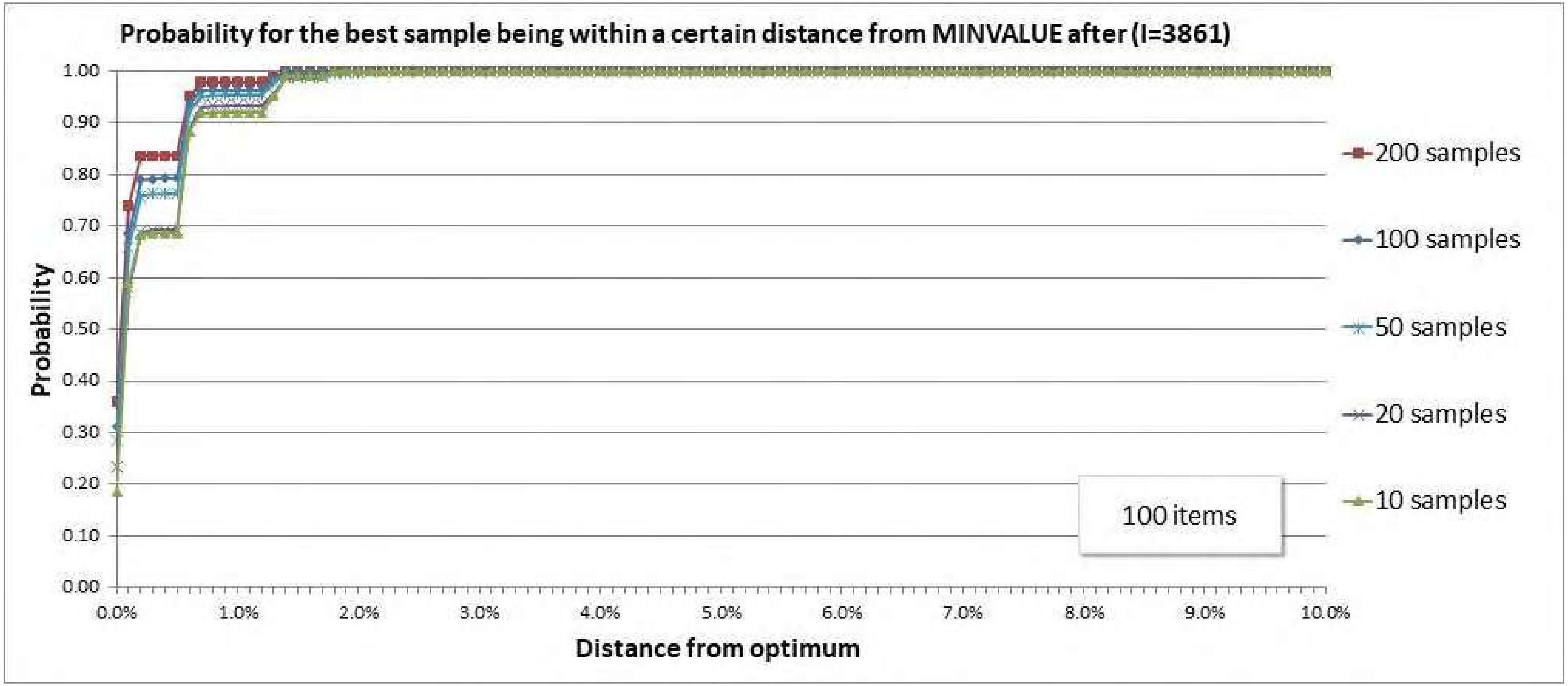
Can we scale?


Probability for the best sample being within a certain distance from MINVALUE after (I=3419)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?

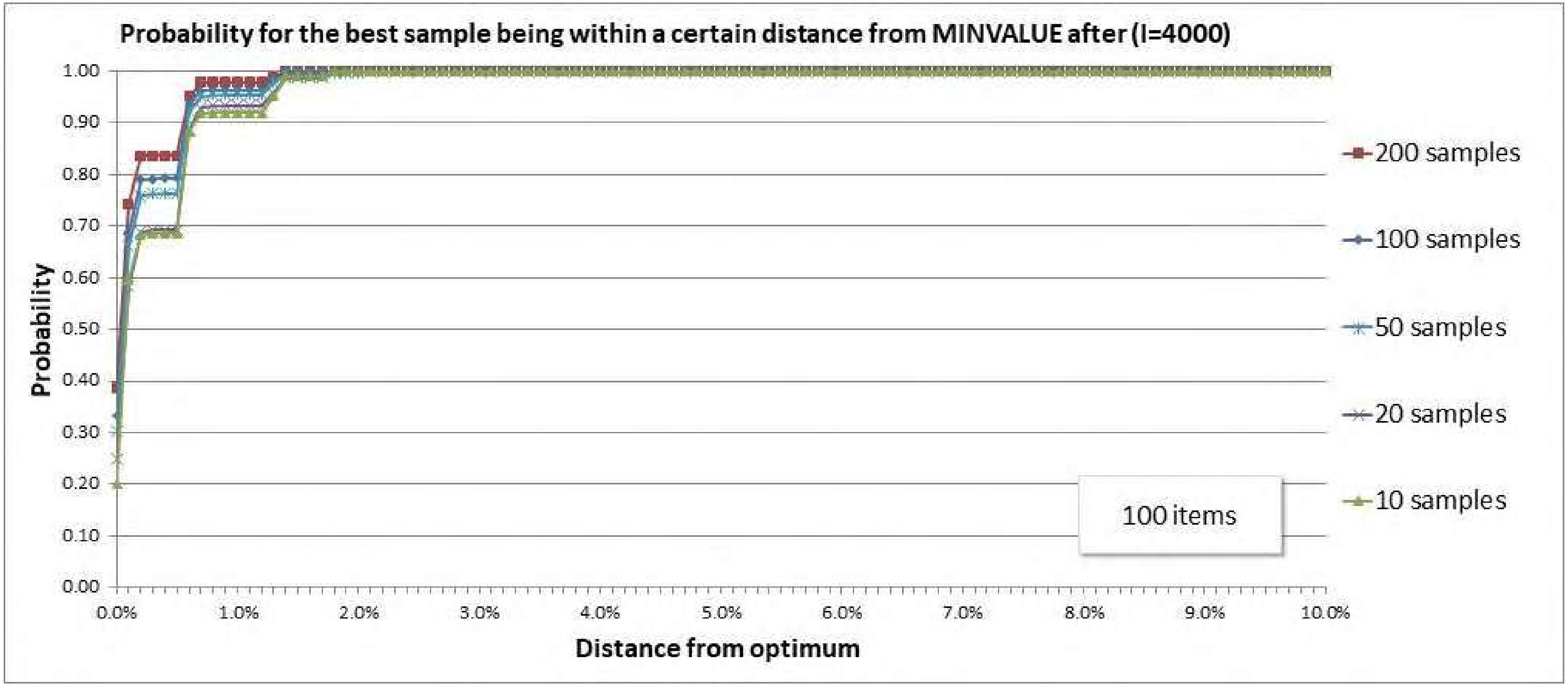

Probability for the best sample being within a certain distance from MINVALUE after (I=3633)
Probability
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.0%
1.0%
2.0%
3.0%
4.0%
5.0%
6.0%
7.0%
8.0%
9.0%
10.0%
Distance from optimum
100 items
200 samples
100 samples
50 samples
20 samples
10 samples

Can we scale?



Systecon

Can we scale?



- Same MINVALUE=174 550 398 SEK found in 40 % of the 1000 genetic algorithm trials using 200 samples (4000 iterations). No guarantee we found the optimum, but maybe!

Summary

- A method for phase-out optimization of an aircraft fleet has been presented, minimizing backorders and cost
- Optimal solution found for a scenario with 10 items using a genetic algorithm
- Possibly found the optimal solution for a scenario of 100 items

Future research

- The method is easily extended to also handle
  - Safety stock requirements (replace backorder requirement)
  - Simultaneous *phase in / phase out* scenarios where the old aircraft being phased out has common parts with the new aircraft being phased out
- Method is well suited for parallelization in order to support larger cases (100-1000 items)

Reference

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Phase-out maintenance optimization for an aircraft fleet

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A R T I C L E I N F O

Keywords:
Phase out
Maintenance
Optimization
Simulation
Steepest descent
Genetic algorithm

A B S T R A C T

This paper presents a novel approach for cost-effective optimization of stop-maintenance strategies for a set of repairable items (rotables). The optimization method has two steps. First, the novel concept of matrix simulations is introduced to locate the solution space of the optimization problem in question. Second, a genetic algorithm is applied to find the minimum cost solution. The combination of matrix simulations and genetic algorithm is shown to constitute a powerful method for solving the optimization problem in a fast manner. To demonstrate the efficacy of the proposed method, it is compared with a crude search, and a steepest descent algorithm. Our proposed method is faster than the crude search and also locates the optimum more often than the steepest descent search. The method is illustrated by applying it to a phase-out scenario of an aircraft fleet, where the optimal stop-maintenance strategy is determined for a set of rotables.

Thank you for your interest!

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