

#### 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.



#### 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



#### Slide 4

#### Background

- Phase out scheme:
  - 10 years
  - 90 aircraft

• Item data:



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





# Slide 6 Slide 6 Matrix simulation results $t_{COL} = 0.00$ 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



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 Slide 7 Matrix simulation results $t_{COL} = 1.00$ years





# Slide 8 Matrix simulation results $t_{COL} = 1.08$ years





# Slide 9 Slide 9 Matrix simulation results $t_{COL} = 1.17$ years





# Slide 10 Slide 10 Matrix simulation results $t_{COL} = 1.42$ years





# Slide 11 Slide 11 Matrix simulation results $t_{COL} = 1.58$ years





# Slide 12 Slide 12 Matrix simulation results $t_{COL} = 1.83$ years





# Slide 13 Slide 13 Matrix simulation results $t_{COL} = 2.00$ years





# Slide 14 Slide 14 Matrix simulation results $t_{COL} = 2.17$ years





# Slide 15 Slide 15 Matrix simulation results $t_{COL} = 2.50$ years





# Slide 16 Slide 16 Matrix simulation results $t_{COL} = 2.67$ years





# Slide 17 Slide 17 Matrix simulation results $t_{COL} = 2.75$ years





# Slide 18 Slide 18 Matrix simulation results $t_{COL} = 2.83$ years





# Slide 19 Slide 19 Matrix simulation results $t_{COL} = 2.92$ years





# Slide 20 Slide 20 Matrix simulation results $t_{COL} = 3.25$ years





# Slide 21 Slide 21 Matrix simulation results $t_{COL} = 3.33$ years





# Slide 22 Slide 22 Matrix simulation results $t_{COL} = 3.58$ years





# Slide 23 Slide 23 Matrix simulation results $t_{COL} = 3.67$ years





#### Slide 24 Slide 24 Matrix simulation results $t_{COL} = 3.83$ years





# Slide 25 Matrix simulation results $t_{COL} = 4.00$ years





# Slide 26 Slide 26 Matrix simulation results $t_{COL} = 4.17$ years





# Slide 27 Matrix simulation results $t_{COL} = 4.25$ years





# Slide 28 Slide 28 Matrix simulation results $t_{COL} = 4.33$ years





# Slide 29 Slide 29 Matrix simulation results $t_{COL} = 4.58$ years





# Slide 30 Slide 30 Matrix simulation results $t_{COL} = 4.75$ years





# Slide 31 Slide 31 Matrix simulation results $t_{COL} = 4.83$ years





# Slide 32 Slide 32 Matrix simulation results $t_{COL} = 5.17$ years





# Slide 33 Slide 33 Matrix simulation results $t_{COL} = 5.25$ years





# Slide 34 Matrix simulation results $t_{COL} = 5.42$ years





# Slide 35 Matrix simulation results $t_{COL} = 5.58$ years





# Slide 36 Slide 36 Matrix simulation results $t_{COL} = 5.75$ years




# Slide 37 Slide 37 Matrix simulation results $t_{COL} = 5.83$ years





# Slide 38 Matrix simulation results $t_{COL} = 6.17$ years





# Slide 39 Slide 39 Matrix simulation results $t_{COL} = 6.25$ years





# Slide 40 Slide 40 Matrix simulation results $t_{COL} = 6.50$ years





# Slide 41 Slide 41 Matrix simulation results $t_{COL} = 6.58$ years





# Slide 42 Slide 42 Matrix simulation results $t_{COL} = 6.67$ years





# Slide 43 Matrix simulation results $t_{COL} = 6.75$ years





# Slide 44 Matrix simulation results $t_{COL} = 6.83$ years





# Slide 45 Matrix simulation results $t_{COL} = 6.92$ years





# Slide 46 Slide 46 Matrix simulation results $t_{COL} = 7.33$ years





# Slide 47 Matrix simulation results $t_{COL} = 7.42$ years





# Slide 48 Matrix simulation results $t_{COL} = 7.67$ years





# Slide 49 Slide 49 Matrix simulation results $t_{COL} = 7.75$ years





# Slide 50 Slide 50 Matrix simulation results $t_{COL} = 7.92$ years





# Slide 51 Slide 51 Matrix simulation results $t_{COL} = 8.33$ years





Slide 52

## Solution subspaces $S_1$ , $S_2$ , ... , $S_{10}$

#### $t_{COL} = 8.33$ years

Solution bounds for stop time COL=8.33 years



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







## **Brute Force (4000 h)**





# Optimization by using a Genetic Algorithm





Slide 57

## **Genetic Algorithm**



#### Slide 58 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=0, S=100, M=0.1, Minloost= 24 793 142 SEK, Optistop time COL= 7.92 years  $C(\boldsymbol{t}_{CP}, \boldsymbol{t}_{COL})^{T}$ 1.00+07 t<sub>PMi</sub>  $t_{CM_i}$ 10 2 Ŭ ñ.



#### Slide 59 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=1, S=100, M=0.1, Min cost= 24 793 142 SEK, Opt stop time COL= 7.92 years





## Slide 60 Genetic Algorithm (100 samples) $\Delta T=1000 h$





## Slide 61 Genetic Algorithm (100 samples)

I=3, S=100, M=0.1, Minicost= 24 735 342 SEK, Optistopitime COL= 7.92 years





## Slide 62 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=5, S=100, M=0.1, Minicost= 24,689,242 SEK, Optistopitime COL= 7.92 years





## Slide 63 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=6, S=100, M=0.1, Minicost= 24,639,042 SEK, Optistopitime COL= 7.92 years





## Slide 64 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=7, S=100, M=0.1, Minloost= 24 587 742 SEK, Optistopit me COL= 7.92 years





## Slide 65 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=8, S=100, M=0.1, Minicost= 24 571 742 SEK, Optistopit me COL= 7.92 years





## Slide 66 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=9, S=100, M=0.1, Minlocst= 24 512 444 SEK, Optistopit me COL= 7.92 years





## Slide 67 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=10, S=100, M=0.1, Min cost= 24,454,847, SEK, Optistopitime CCL= 7.02 years





## Slide 68 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=11, S=100, M=0.1, Min cost= 24:451,847,SEK, Optistopitime CCL= 7.62 years





## Slide 69 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=12, S=100, M=0.1, Min cost= 24:451 847 SEK, Optistopitime CCL= 7.62 years





## Slide 70 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=12, S=100, M=0.1, Min cost= 24,395,409,SEK, Optistopitime CCL= 7.62 years





## Slide 71 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=14, S=100, M=0.1, Min cost= 24 374 409 SEK, Opt stop time CCL= 7.62 years





## Slide 72 Genetic Algorithm (100 samples) ΔT=1000 h

I=15, S=100, M=0.1, Min cost= 24 374 409 SEK, Opt stop time CCL= 7.02 years




#### Slide 73

# **Genetic Algorithm (100 samples)**

I=16, S=100, M=0.1, Min cost= 24 374 409 SEK, Optistopitime CCL= 7.92 years





#### Slide 74

# **Genetic Algorithm (100 samples)**

I=17, S=100, M=0.1, Min cost= 24 302 C91, SEK, Optistopitime CCL= 7.92 years





#### Slide 75 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=18, S=100, M=0.1, Min cost= 24 246 791 SEK, Optistopitime CCL= 7.62 years





### Slide 76 Genetic Algorithm (100 samples) ΔT=1000 h

I=19, S=100, M=0.1, Min cost= 24 245 591 SEK, Optistopitime CCL= 7.92 years





### Slide 77 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

l=20\_S=100, M=0.1, Min cost= 24 242 491 SEK, Opt stop time CCL= 7.02 years





#### Slide 78 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=21 S=100, M=0.1, Min cost= 24 225 591 SEK, Optistopitime CCL= 7.62 years





#### Slide 79 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=22, S=100, M=0.1, Min cost= 24 215 291, SEK, Optistopitime CCL= 7.62 years





## Slide 80 Genetic Algorithm (100 samples)

I=22, S=100, M=0.1, Min cost= 24 204 291 SEK, Opt stop time CCL= 7.62 years





### Slide 81 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=24, S=100, M=0.1, Min cost= 24, 191, 271, SEK, Optistopitime CCL= 7.02 years





## Slide 82 Genetic Algorithm (100 samples)

I=25: S=100, M=0.1, Min cost= 24,170,171; SEK, Optistopitime CCL= 7.92 years





## Slide 83 Genetic Algorithm (100 samples)

I=26, S=100, M=0.1, Min cost= 24, 170, 171, SEK, Optistopitime CCL= 7.62 years





## Slide 84 Genetic Algorithm (100 samples)

l=27\_S=100, M=0.1, Min cost= 24\_155.571 SEK, Optistopitime CCL= 7.62 years





### Slide 85 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=28\_S=100, M=0.1, Min cost= 24,150,771 SEK, Optistopitime CCL= 7.92 years





### Slide 86 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=29 S=100, M=0.1, Min cost= 24 150 771 SEK, Optistopitime CCL= 7.92 years





### Slide 87 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=30, S=100, M=0.1, Min cost= 24, 147,421, SEK, Optistopitime CCL= 7.62 years





### Slide 88 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=31\_S=100, M=0.1, Min cost= 24,145 C41, SEK, Optistopitime CCL= 7.62 years





### Slide 89 Genetic Algorithm (100 samples) $\Delta T=1000 h$

1=32, S=100, M=0.1, Min cost= 24,141,241, SEK, Optistopitime CCL= 7.92 years





### Slide 90 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=32, S=100, M=0.1, Min cost= 24, 141, 241, SEK, Optistopitime CCL= 7.62 years





### Slide 91 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=34, S=100, M=0.1, Min cost= 24, 141, 241, SEK, Opt stop time CCL= 7.92 years





## Slide 92 Genetic Algorithm (100 samples)

I=35, S=100, M=0.1, Min cost= 24, 141, 241, SEK, Optistopitime CCL= 7.62 years





### Slide 93 Genetic Algorithm (100 samples)

I=36, S=100, M=0.1, Min cost= 24, 141, 241, SEK, Optistopitime CCL= 7.02 years





#### Slide 94 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=37, S=100, M=0.1, Min cost= 24,136,77°, SEK, Optistopitime CCL= 7.62 years





#### Slide 95 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=38, S=100, M=0.1, Min cost= 24, 135,891, SEK, Optistopitime CCL= 7.92 years





### Slide 96 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=39 S=100, M=0.1, Min cost= 24 116 171 SEK, Optistopitime CCL= 7.62 years





### Slide 97 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=40 S=100, M=0.1, Min cost= 24 116 171 SEK, Optistopitime CCL= 7.02 years





### Slide 98 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=41 S=100, M=0.1, Min cost= 24 116 171 SEK, Optistopitime CCL= 7.02 years





#### Slide 99 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=42\_S=100, M=0.1, Min cost= 24\_116 171 SEK, Optistopitime CCL= 7.02 years





### Slide 100 Genetic Algorithm (100 samples) $\Delta T$ =1000 h

I=42: S=100, M=0.1, Min cost= 24 116 171 SEK, Optistopitime CCL= 7.02 years





### Slide 101 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=44, S=100, M=0.1, Min cost= 24, 112,371, SEK, Optistopitime CCL= 7.92 years





## Slide 102 Genetic Algorithm (100 samples)

I=45\_S=100, M=0.1, Min cost= 24\_111 271 SEK, Optistopitime CCL= 7.62 years





### Slide 103 Genetic Algorithm (100 samples) $\Delta T$ =1000 h

I=46, S=100, M=0.1, Min cost= 24, 107,571; SEK, Optistopitime CCL= 7.02 years





### Slide 104 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=47\_S=100, M=0.1, Min cost= 24\_104 641 SEK, Optistopitime CCL= 7.62 years





### Slide 105 Genetic Algorithm (100 samples) ΔT=1000 h

I=48, S=100, M=0.1, Min cost= 24,104,641, SEK, Optistopitime CCL= 7.02 years





### Slide 106 Genetic Algorithm (100 samples) $\Delta T$ =1000 h

1=49: S=100, M=0.1, Min cost= 24:104.641; SEK, Optistopitime CCL= 7.92 years





### Slide 107 Genetic Algorithm (100 samples) $\Delta T$ =1000 h

1=50, S=100, M=0.1, Min cost= 24,104,641, SEK, Optistopitime CCL= 7.92 years





### Slide 108 Genetic Algorithm (100 samples) $\Delta T$ =1000 h

I=51 S=100, M=0.1, Min cost= 24 009 C41 SEK, Optistopitime CCL= 7.62 years




# Slide 109 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=52, S=100, M=0.1, Min cost= 24 000 C41, SEK, Optistopitime CCL= 7.02 years





# Slide 110 Genetic Algorithm (100 samples) ΔT=1000 h

I=52, S=100, M=0.1, Min cost= 24 097 C41, SEK, Optistopitime CCL= 7.02 years





# Slide 111 Genetic Algorithm (100 samples) $\Delta T = 1000 \text{ h}$

I=54 S=100, M=0.1, Min cost= 24 097 C41 SEK, Opt stop time CCL= 7.02 years





# Slide 112 Genetic Algorithm (100 samples)

I=55: S=100, M=0.1, Min cost= 24 097 C41; SEK, Optistopitime CCL= 7.62 years





# Slide 113 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=56, S=100, M=0.1, Min cost= 24 097 C41; SEK, Optistopitime CCL= 7.62 years





# Slide 114 Genetic Algorithm (100 samples)

I=57, S=100, M=0.1, Min cost= 24 097 C41, SEK, Optistopitime CCL= 7.62 years





# Slide 115 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=58, S=100, M=0.1, Min cost= 24 097 C41, SEK, Optistopitime CCL= 7.62 years





# Slide 116 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=59 S=100, M=0.1, Min cost= 24 097 C41 SEK, Opt stop time CCL= 7.62 years





# Slide 117 **Genetic Algorithm (100 samples)** $\Delta T = 1000 h$

I=60\_S=100, M=0.1, Min cost= 24 079 171\_SEK, Optistopitime CCL= 7.62 years





# Slide 118 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=61, S=100, M=0.1, Min cost= 24 077 171; SEK, Optistopitime CCL= 7.62 years





# Slide 119 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=62\_S=100, M=0.1, Min cost= 24 077 171 SEK, Optistopitime CCL= 7.92 years





# Slide 120 Genetic Algorithm (100 samples) ΔT=1000 h

I=62, S=100, M=0.1, Min cost= 24 077 171 SEK, Optistopitime CCL= 7.92 years





# Slide 121 Genetic Algorithm (100 samples)

I=64, S=100, M=0.1, Min cost= 24 073 191 SEK, Optistopitime CCL= 7.92 years





# Slide 122 Genetic Algorithm (100 samples)

I=65, S=100, M=0.1, Min cost= 24 068 291, SEK, Optistopitime CCL= 7.92 years





# Slide 123 Genetic Algorithm (100 samples)

I=66, S=100, M=0.1, Min cost= 24 061 591 SEK, Optistopitime CCL= 7.62 years





# Slide 124 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=67, S=100, M=0.1, Min cost= 24 061 591 SEK, Optistopitime CCL= 7.92 years





# Slide 125 Genetic Algorithm (100 samples) $\Delta T$ =1000 h

I=68, S=100, M=0.1, Min cost= 24 061 591 SEK, Optistopitime CCL= 7.62 years





# Slide 126 Genetic Algorithm (100 samples) $\Delta T$ =1000 h

I=69, S=100, M=0.1, Min cost= 24 061 591 SEK, Optistopitime CCL= 7.62 years





# Slide 127 **Genetic Algorithm (100 samples)** $\Delta T = 1000 h$

I=70, S=100, M=0.1, Min cost= 24 061 591 SEK, Optistopitime CCL= 7.92 years





# Slide 128 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=71\_S=100, M=0.1, Min cost= 24 061 591 SEK, Optistopitime CCL= 7.62 years





# Slide 129 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=72\_S=100, M=0.1, Min cost= 24 061 591 SEK, Opt stop time CCL= 7.62 years





# Slide 130 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=72, S=100, M=0.1, Min cost= 24 061 591 SEK, Opt stop time CCL= 7.02 years





# Slide 131 Genetic Algorithm (100 samples)

l=74 S=100, M=0.1, Min cost= 24 061 591 SEK, Opt stop time CCL= 7.02 years





#### Slide 132 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=75, S=100, M=0.1, Min cost= 24 061 591 SEK, Optistopitime CCL= 7.92 years





# Slide 133 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=76, S=100, M=0.1, Min cost= 24 061 591 SEK, Optistopitime CCL= 7.02 years





# Slide 134 Genetic Algorithm (100 samples)

I=77, S=100, M=0.1, Min cost= 24 061 591 SEK, Optistopitime CCL= 7.62 years





# Slide 135 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=78\_S=100, M=0.1, Min cost= 24 061 591 SEK, Optistopitime CCL= 7.62 years





# Slide 136 Genetic Algorithm (100 samples) $\Delta T$ =1000 h

I=79, S=100, M=0.1, Min cost= 24 061 591, SEK, Optistopitime CCL= 7.62 years





# Slide 137 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=80\_S=100, M=0.1, Min cost= 24 081 591 SEK, Opt stop time CCL= 7.92 years





# Slide 138 Genetic Algorithm (100 samples) $\Delta T$ =1000 h

I=81, S=100, M=0.1, Min cost= 24 059 441; SEK, Optistopitime CCL= 7.92 years





### Slide 139 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=82, S=100, M=0.1, Min cost= 24 059 441 SEK, Optistopitime CCL= 7.92 years





# Slide 140 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=82, S=100, M=0.1, Min cost= 24 059 441 SEK, Optistopitime CCL= 7.92 years





# Slide 141 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=84, S=100, M=0.1, Min cost= 24 059 441; SEK, Opt stop time CCL= 7.92 years





# Slide 142 Genetic Algorithm (100 samples)

I=85, S=100, M=0.1, Min cost= 24 059 441 SEK, Optistopitime CCL= 7.92 years





# Slide 143 Genetic Algorithm (100 samples) $\Delta T = 1000 h$

I=86\_S=100, M=0.1, Min cost= 24 059 441 SEK, Opt stop time CCL= 7.92 years





# Slide 144 Genetic Algorithm (100 samples)

I=87, S=100, M=0.1, Min cost= 24 059 441, SEK, Optistopitime CCL= 7.62 years




### Slide 145 Genetic Algorithm (100 samples) ΔT=1000 h

I=88, S=100, M=0.1, Min cost= 24 059 441, SEK, Optistopitime CCL= 7.62 years





### Slide 146 Genetic Algorithm (100 samples) $\Delta T$ =1000 h

I=89, S=100, M=0.1, Min cost= 24 059 441 SEK, Opt stop time CCL= 7.92 years





### Slide 147 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=90, S=100, M=0.1, Min cost= 24 059 441, SEK, Optistopitime CCL= 7.62 years





### Slide 148 Genetic Algorithm (100 samples) $\Delta T$ =1000 h

I=91\_S=100, M=0.1, Min cost= 24 059 441 SEK, Optistopitime CCL= 7.92 years





### Slide 149 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=92, S=100, M=0.1, Min cost= 24 059 441, SEK, Opt stop time CCL= 7.92 years





### Slide 150 Genetic Algorithm (100 samples) $\Delta T$ =1000 h

I=93\_S=100, M=0.1, Min cost= 24 059 441 SEK, Opt stop time CCL= 7.62 years





### Slide 151 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=94 (S=100, M=0.1, Min cost= 24 059 441 (SEK, Opt stop time CCL= 7.02 years





## Slide 152 Genetic Algorithm (100 samples)

I=95, S=100, M=0.1, Min cost= 24 059 441 SEK, Optistopitime CCL= 7.92 years





### Slide 153 Genetic Algorithm (100 samples) $\Delta T$ =1000 h

I=96\_S=100, M=0.1, Min cost= 24 059 441 SEK, Opt stop time CCL= 7.92 years





### Slide 154 Genetic Algorithm (100 samples) $\Delta T$ =1000 h

I=97, S=100, M=0.1, Min cost= 24 059 441, SEK, Optistopitime CCL= 7.92 years





#### Slide 155 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=98, S=100, M=0.1, Min cost= 24 059 441, SEK, Optistopitime CCL= 7.62 years





### Slide 156 Genetic Algorithm (100 samples) $\Delta T=1000 h$

I=99, S=100, M=0.1, Min cost= 24 059 441; SEK, Optistopitime CCL= 7.62 years





#### Slide 157

# **Genetic Algorithm (100 samples)**

 $\Delta T$ =1000 h

- Found solution: -  $C_{min} = 24.06$  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



#### Slide 158 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h





#### Slide 159 Genetic Algorithm (2000 samples) ΔT=1000 h





### Slide 160 Genetic Algorithm (2000 samples) ΔT=1000 h





### Slide 161 Genetic Algorithm (2000 samples) ΔT=1000 h

I=3, S=2000, M=0.1, Min cost= 24 371 111 SEK, Optistopitime CCL= 7.92 years





### Slide 162 Genetic Algorithm (2000 samples) ΔT=1000 h

I=5, S=2000, M=0.1, Min cost= 24 288 361 SEK, Opt stop time CCL= 7.92 years





### Slide 163 Genetic Algorithm (2000 samples) ΔT=1000 h

I=6, S=2000, M=0.1, Min cost= 24 288 261 SEK, Optistopitime CCL= 7.92 years





### Slide 164 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

I=7, S=2000, M=0.1, Min cost= 24 280 561 SEK, Optistopitime CCL= 7.92 years





### Slide 165 Genetic Algorithm (2000 samples) ΔT=1000 h

I=8, S=2000, M=0.1, Min cost= 24 254 021 SEK, Optistopitime CCL= 7.92 years





### Slide 166 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

I=9, S=2000, M=0.1, Min cost= 24 233 361 SEK, Optistopitime CCL= 7.92 years





### Slide 167 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=10, S=2000, M=0.1, Min cost= 24 233 361 SEK, Opt stop time CCL= 7.92 years





### Slide 168 Genetic Algorithm (2000 samples) ΔT=1000 h

=11, S=2000, M=0.1, Min cost= 24 230 241 SEK, Opt stop time CCL= 7.92 years





### Slide 169 Genetic Algorithm (2000 samples) ΔT=1000 h

=12, S=2000, M=0.1, Min cost= 24 227 761 SEK, Opt stop time CCL= 7.92 years





### Slide 170 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=13, S=2000, M=0.1, Min cost= 24 227 761 SEK, Opt stop time CCL= 7.92 years





### Slide 171 Genetic Algorithm (2000 samples) ΔT=1000 h

=14, S=2000, M=0.1, Min cost= 24 207 461 SEK, Opt stop time CCL= 7.92 years





### Slide 172 Genetic Algorithm (2000 samples) ΔT=1000 h

=15, S=2000, M=0.1, Min cost= 24,132,361 SEK, Optistopitime CCL= 7.92 years





### Slide 173 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=16, S=2000, M=0.1, Min cost= 24,182,361 SEK, Optistopitime CCL= 7.92 years





#### Slide 174 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=17, S=2000, M=0.1, Min cost= 24 177 441 SEK, Opt stop time CCL= 7.92 years





#### Slide 175 Genetic Algorithm (2000 samples) ΔT=1000 h

=18, S=2000, M=0.1, Min cost= 24 177 441 SEK, Opt stop time CCL= 7.92 years





### Slide 176 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=19, S=2000, M=0.1, Min cost= 24 159 561 SEK, Optistopitime CCL= 7.92 years





#### Slide 177 Genetic Algorithm (2000 samples) ΔT=1000 h

=20, S=2000, M=0.1, Min cost= 24 152 821 SEK, Opt stop time CCL= 7.92 years





### Slide 178 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=21, S=2000, M=0.1, Min cost= 24 152 821 SEK, Optistopitime CCL= 7.92 years





### Slide 179 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=22, S=2000, M=0.1, Min cost= 24 152 821 SEK, Optistopitime CCL= 7.92 years





### Slide 180 Genetic Algorithm (2000 samples) ΔT=1000 h

=23, S=2000, M=0.1, Min cost= 24, 141,961, SEK, Opt stop time CCL= 7.92 years




# Slide 181 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=24, S=2000, M=0.1, Min cost= 24, 130 811 SEK, Optistopitime CCL= 7.92 years





# Slide 182 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=25, S=2000, M=0.1, Min cost= 24,124,811 SEK, Optistopitime CCL= 7.92 years





# Slide 183 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=26, S=2000, M=0.1, Min cost= 24,124,811 SEK, Optistopitime CCL= 7.92 years





# Slide 184 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=27, S=2000, M=0.1, Min cost= 24 114 611 SEK, Optistopitime CCL= 7.92 years





# Slide 185 Genetic Algorithm (2000 samples) ΔT=1000 h

=28, S=2000, M=0.1, Min cost= 24,114,611, SEK, Optistopitime CCL= 7.92 years





# Slide 186 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=29, S=2000, M=0.1, Min cost= 24,104,611 SEK, Optistopitime CCL= 7.92 years





# Slide 187 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=30, S=2000, M=0.1, Min cost= 24 101 491 SEK, Opt stop time CCL= 7.92 years





# Slide 188 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=31, S=2000, M=0.1, Min cost= 24 098 061 SEK, Opt stop time CCL= 7.92 years





# Slide 189 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=32, S=2000, M=0.1, Min cost= 24 098 C61 SEK, Opt stop time CCL= 7.92 years





# Slide 190 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=33, S=2000, M=0.1, Min cost= 24 098 C61 SEK, Optistop time CCL= 7.92 years





# Slide 191 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=34, S=2000, M=0.1, Min cost= 24 097 811 SEK, Optistopitime CCL= 7.92 years





# Slide 192 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=35, S=2000, M=0.1, Min cost= 24 073 891 SEK, Opt stop time CCL= 7.92 years





# Slide 193 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=36, S=2000, M=0.1, Min cost= 24 070 671 SEK, Optistopitime CCL= 7.92 years





# Slide 194 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=37, S=2000, M=0.1, Min cost= 24 070 671 SEK, Opt stop time CCL= 7.92 years





# Slide 195 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=38, S=2000, M=0.1, Min cost= 24 070 671 SEK, Optistopitime CCL= 7.92 years





# Slide 196 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=39, S=2000, M=0.1, Min cost= 24 070 671 SEK, Opt stop time CCL= 7.92 years





## Slide 197 Genetic Algorithm (2000 samples) ΔT=1000 h

=40, S=2000, M=0.1, Min cost= 24 083 871 SEK, Opt stop time CCL= 7.92 years





# Slide 198 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=41, S=2000, M=0.1, Min cost= 24 083 871 SEK, Opt stop time CCL= 7.92 years





### Slide 199 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=42, S=2000, M=0.1, Min cost= 24 063 871 SEK, Opt stop time CCL= 7.92 years





# Slide 200 Genetic Algorithm (2000 samples) ΔT=1000 h

=43, S=2000, M=0.1, Min cost= 24 063 871 SEK, Opt stop time CCL= 7.92 years





# Slide 201 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=44, S=2000, M=0.1, Min cost= 24 083 871 SEK, Opt stop time CCL= 7.92 years





# Slide 202 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=45, S=2000, M=0.1, Min cost= 24 083 871 SEK, Opt stop time CCL= 7.92 years





# Slide 203 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=46, S=2000, M=0.1, Min cost= 24 083 871 SEK, Opt stop time CCL= 7.92 years





# Slide 204 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=47, S=2000, M=0.1, Min cost= 24 083 871 SEK, Optistopitme CCL= 7.92 years





# Slide 205 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=48, S=2000, M=0.1, Min cost= 24 059 641 SEK, Opt stop time CCL= 7.92 years





# Slide 206 Genetic Algorithm (2000 samples) $\Delta T$ =1000 h

=49, S=2000, M=0.1, Min cost= 24 055 091 SEK, Optistopitime CCL= 7.92 years





# Slide 207 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=50, S=2000, M=0.1, Min cost= 24 053 871 SEK, Opt stop time CCL= 7.92 years





# Slide 208 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=51, S=2000, M=0.1, Min cost= 24 053 871 SEK, Opt stop time CCL= 7.92 years





# Slide 209 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=52, S=2000, M=0.1, Min cost= 24 053 871 SEK, Opt stop time CCL= 7.92 years





# Slide 210 Genetic Algorithm (2000 samples) ΔT=1000 h

=53, S=2000, M=0.1, Min cost= 24 053 871 SEK, Opt stop time CCL= 7.92 years





# Slide 211 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=54, S=2000, M=0.1, Min cost= 24 053 341 SEK, Optistopitime CCL= 7.92 years





# Slide 212 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=55, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.92 years





# Slide 213 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=56, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.92 years





# Slide 214 Genetic Algorithm (2000 samples) ΔT=1000 h

=57, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.92 years





# Slide 215 Genetic Algorithm (2000 samples) ΔT=1000 h

=58, S=2000, M=0.1, Min cost= 24 053 091 SEK, Opt stop time CCL= 7.92 years





# Slide 216 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=59, S=2000, M=0.1, Min cost= 24 053 091 SEK, Opt stop time CCL= 7.92 years




# Slide 217 **Genetic Algorithm (2000 samples)** $\Delta T$ =1000 h

=60, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Optistopitime CCL= 7.92 years





# Slide 218 Genetic Algorithm (2000 samples) ΔT=1000 h

=61, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.62 years





# Slide 219 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=62, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.92 years





# Slide 220 Genetic Algorithm (2000 samples) ΔT=1000 h

=63, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.92 years





# Slide 221 Genetic Algorithm (2000 samples) ΔT=1000 h

=84, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.62 years





# Slide 222 Genetic Algorithm (2000 samples) ΔT=1000 h

=35, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.62 years





# Slide 223 Genetic Algorithm (2000 samples) ΔT=1000 h

=66, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Optistop time CCL= 7.92 years





# Slide 224 Genetic Algorithm (2000 samples) ΔT=1000 h

=67, S=2000, M=0.1, Min cost= 24 053 091 SEK, Optistopitime CCL= 7.92 years





# Slide 225 Genetic Algorithm (2000 samples) ΔT=1000 h

=68, S=2000, M=0.1, Min cost= 24 053 091 SEK, Opt stop time CCL= 7.92 years





# Slide 226 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=69, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Optistopitime CCL= 7.92 years





# Slide 227 Genetic Algorithm (2000 samples) ΔT=1000 h

=70, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.92 years





# Slide 228 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=71, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.92 years





# Slide 229 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=72, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.92 years





# Slide 230 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=73, S=2000, M=0.1, Min cost= 24 053 091 SEK, Optistopitime CCL= 7.92 years





# Slide 231 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=74, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.92 years





# Slide 232 Genetic Algorithm (2000 samples) ΔT=1000 h

=75, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.92 years





# Slide 233 Genetic Algorithm (2000 samples) ΔT=1000 h

=76, S=2000, M=0.1, Min cost= 24 053 091 SEK, Opt stop time CCL= 7.92 years





# Slide 234 Genetic Algorithm (2000 samples) ΔT=1000 h

=77, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.92 years





# Slide 235 Genetic Algorithm (2000 samples) ΔT=1000 h

=78, S=2000, M=0.1, Min cost= 24 053 091 SEK, Optistopitime CCL= 7.92 years





# Slide 236 Genetic Algorithm (2000 samples) ΔT=1000 h

=79, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.92 years





# Slide 237 Genetic Algorithm (2000 samples) ΔT=1000 h

=30, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Optistopitime CCL= 7.92 years





# Slide 238 Genetic Algorithm (2000 samples) ΔT=1000 h

=31, S=2000, M=0.1, Min cost= 24 053 091 SEK, Opt stop time CCL= 7.92 years





# Slide 239 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=32, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.92 years





# Slide 240 Genetic Algorithm (2000 samples) ΔT=1000 h

=93, S=2000, M=0.1, Min cost= 24 053 C91 SEK, Opt stop time CCL= 7.62 years





# Slide 241 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=34, S=2000, M=0.1, Min cost= 24 051 191 SEK, Opt stop time CCL= 7.92 years





# Slide 242 Genetic Algorithm (2000 samples) ΔT=1000 h

=95, S=2000, M=0.1, Min cost= 24 051 191 SEK, Optistop time CCL= 7.92 years





# Slide 243 Genetic Algorithm (2000 samples) ΔT=1000 h

=36, S=2000, M=0.1, Min cost= 24 050 891 SEK, Opt stop time CCL= 7.92 years





# Slide 244 Genetic Algorithm (2000 samples) ΔT=1000 h

=97, S=2000, M=0.1, Min cost= 24 050 891 SEK, Optistopitime CCL= 7.92 years





# Slide 245 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=98, S=2000, M=0.1, Min cost= 24 050 891 SEK, Optistopitime CCL= 7.92 years





# Slide 246 Genetic Algorithm (2000 samples) ΔT=1000 h

=39, S=2000, M=0.1, Min cost= 24 050 891 SEK, Optistopitime CCL= 7.92 years





#### Slide 247

# **Genetic Algorithm (2000 samples)**

=90, S=2000, M=0.1, Min cost= 24 050 891 SEK, Opt stop time CCL= 7.92 years





# Slide 248 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=91, S=2000, M=0.1, Min cost= 24 048 391 SEK, Opt stop time CCL= 7.92 years





# Slide 249 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=92, S=2000, M=0.1, Min cost= 24 048 391 SEK, Opt stop time CCL= 7.92 years





# Slide 250 Genetic Algorithm (2000 samples) ΔT=1000 h

=93, S=2000, M=0.1, Min cost= 24 048 391 SEK, Opt stop time CCL= 7.92 years





# Slide 251 Genetic Algorithm (2000 samples) ΔT=1000 h

=94, S=2000, M=0.1, Min cost= 24 048 391 SEK, Optistopitime CCL= 7.92 years





# Slide 252 Genetic Algorithm (2000 samples) ΔT=1000 h

=95, S=2000, M=0.1, Min cost= 24 048 391 SEK, Opt stop time CCL= 7.92 years




### Slide 253 Genetic Algorithm (2000 samples) ΔT=1000 h

=96, S=2000, M=0.1, Min cost= 24 048 391 SEK, Optistopitime CCL= 7.92 years





### Slide 254 Genetic Algorithm (2000 samples) $\Delta T=1000 h$

=97, S=2000, M=0.1, Min cost= 24 048 391 SEK, Opt stop time CCL= 7.92 years





### Slide 255 Genetic Algorithm (2000 samples) ΔT=1000 h

=98, S=2000, M=0.1, Min cost= 24 048 291 SEK, Optistopitime CCL= 7.92 years





### Slide 256 Genetic Algorithm (2000 samples) ΔT=1000 h

=99, S=2000, M=0.1, Min cost= 24 046 241 SEK, Optistopitime CCL= 7.92 years





### Slide 257 **Genetic Algorithm (2000 samples)** $\Delta T = 1000 h$

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

otimum	item ib	СМ	<sup>L</sup> PM	
-	Warning Beacon	7.65 years	3.20 years	
05 MSEK	Relief Valve	6.62 years	4.11 years	
	Transducer	1.37 years	7.53 years	
2 years	Cut-Off Valve	7.53 years	3.88 years	1.
	A/C - Start Generator	7.65 years	5.82 years	MERCON .
	Hydraulic Generator	5.71 years	1.26 years	Politicus Con-
	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	

ant ont

- 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?



 $t_{CM_I}$ 
































































































































































































































































































































































































































































































































































































































































































































































































































- 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:  $\sim 10^{80}$





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



### Previous results: 10 items after 200 iterations...


















































































































































































































































































































































































































## 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



#### Phase-out maintenance optimization for an aircraft fleet

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#### ARTICLE INFO

#### ABSTRACT

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.

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Keywords: Phase out Maintenance Optimization Simulation Steepest descent Genetic algorithm

# Thank you for your interest!

