4th International Conference on Flood Defence

TECHNISCHE UNIVERSITÄT DARMSTADT

ihwb

C. Hübner , D. Muschalla and M. W. Ostrowski

Mixed-Integer Optimization Of Flood Control Measures Using Evolutionary Algorithms

Outline

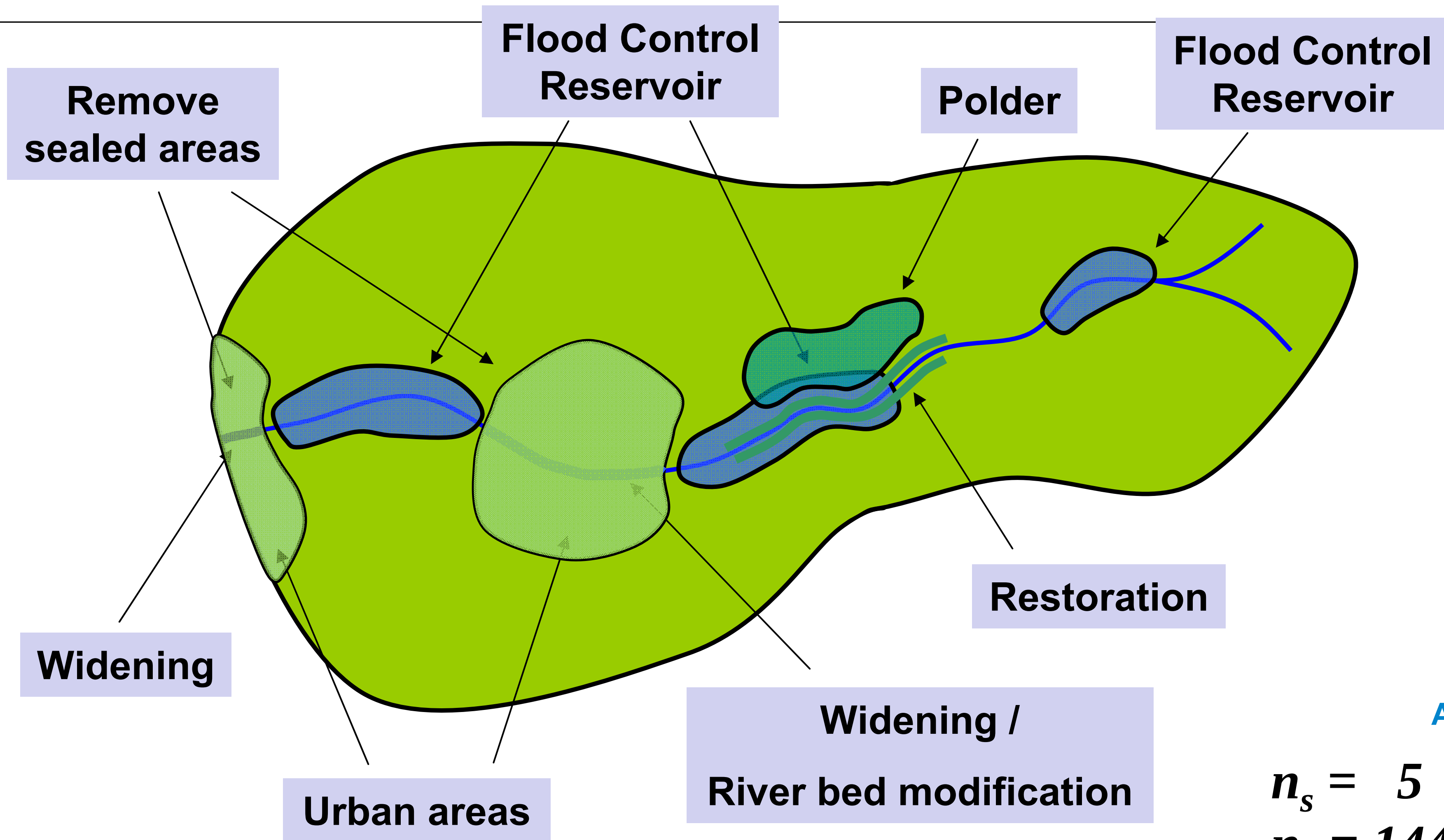
TECHNISCHE UNIVERSITÄT DARMSTADT

- Introduction
- Mixed-Integer Optimization
- Processes of ES-Optimization
- Pareto Optimal
- Results
- Conclusions

Introduction

- Flood control should be considered integrated
- Resources should be used efficient and effective
- European Commission proposes new flood protection directive
- Costs Benefit is considered as key point
- Considering integrated flood control rises the modeling complexity
- Optimization of a huge bandwidth of flood control strategies is at present limited

Introduction



A

$n_s = 5$

$n_c = 144$

Introduction

TECHNISCHE UNIVERSITÄT DARMSTADT

- (HUGHES 1971) Optimierung der Abgabestrategien durch **Lagrange Multiplikatoren**
- (MEYER-ZURWELLE 1975) Optimierung der Abgabestrategien von Hochwasserspeichersystemen durch **Dynamische Programmierung (DP)**
- (BOGÁRDI 1979) Optimierung der Ausbaureihenfolge von Hochwasserrückhaltebecken durch **Branch-and-Bound** Verfahren
- (BAUMGARTNER 1980) Optimierung Hochwasser-Steuerungsprozesse durch **reduzierte Gradienten Verfahren**
- (MAYS & BEDIENT 1982), (BENNETT & MAYS 1985) und (TAUR ET AL. 1987) setzen Dynamische Programmierung zur Optimierung von HWS-Maßnahmen ein
- (ORMSBEE, HOUCK, & DELLEUR 1987) erweitern die Anwendung der **Dynamischen Programmierung** auf **zwei** verschiedene Zielsetzungen.
- (OTERO ET AL. 1995) setzen **genetische Algorithmen**
- (LOHR 2001) optimiert Betriebsregeln Wasserwirtschaftlicher Speichersysteme mit **evolutionsstrategischen Algorithmen**.
- (BRASS 2006) optimiert den Betrieb von Talsperrensystemen allerdings mittels **Stochastisch Dynamischer Programmierung (SDP)**

Introduction

TECHNISCHE UNIVERSITÄT DARMSTADT

- Development of an **integrated Modeling System**, which allows multicriteria optimization of flood control strategies

Hydrologic Model BlueM$_R$	**+**	**BlueM$_{EVO}$ for Real Variables**	**+**	**BlueM$_{EVO}$ for Combinatorial Problems**

- Optimization of flood control measures according the type of the measure, its location and its specific parameters
- Enable **„a posteriori“ decision making** by the use of multicriteria evolutionary optimization and Pareto Optimal Solutions
- The use of evolutionary algorithms allows optimization without reducing the complexity of the models

Mixed-Integer Optimization

- **Continuous variables**
  These are variables that can change gradually in arbitrarily small steps

- **Ordinal discrete variables**
  These are variables that can be changed gradually but there are minimum step size
  (e.g. discretized levels, integer quantities)

- **Nominal discrete variables**
  These are discrete parameters with no reasonable ordering
  (e.g. discrete choices from an unordered list/set of alternatives, binary decisions).

Mixed-Integer Optimization

TECHNISCHE UNIVERSITÄT DARMSTADT

Objective Function: $$f\left(r_1,\ldots,r_{n_r},z_1,\ldots,z_{n_z},d_1,\ldots,d_{n_d}\right)\rightarrow \min$$

with:

Continuous variables: $$r_i \in \left[r_i^{\min}, r_i^{\max}\right] \subset \mathbf{R}, i=1,\ldots,n_r$$

Ordinal discrete variables: $$z_i \in \left[z_i^{\min}, z_i^{\max}\right] \subset \mathbf{Z}, i=1,\ldots,n_z$$

Nominal discrete variables: $$d_i \in D_i = \left\{d_{i,1},\ldots,d_{i,|D_i|}\right\}, i=1,\ldots,n_d$$

A

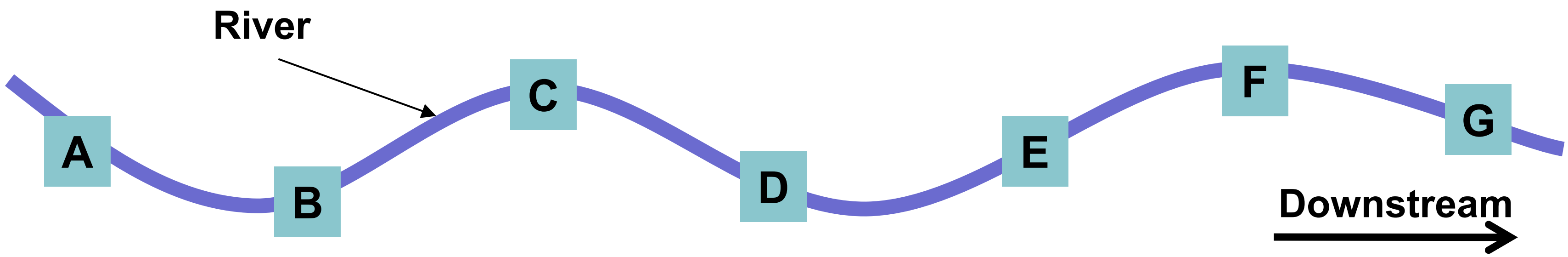
Processes of ES-Optimization

TECHNISCHE UNIVERSITÄT DARMSTADT

Continuous variables	Nominal discrete variables
Selektion ($\mu + \lambda$)	
Reproduktion ▪ Selektiv ▪ Multi-Rekombination (x/x) ▪ Multi-Rekombination (x/y)	**Reproduktion** ▪ Order Crossover (OX) ▪ Cycle Crossover (CX) ▪ Partially-Mapped Crossover (PMX)
Mutation ▪ Rechenberg ▪ Schwefel	**Mutation** ▪ RND Switch ▪ Dyn RND Switch
Evaluation by the use of BlueM$_R$	

A

Nominal discrete Problem & Mixed-Integer Optimization



A	B	C	D	E	F	G
0 M A	0 M A	0 M A	0 M A	0 M A	0 M A	0 M A
1 M B	1 M B	1 M B	1 M B	1 KM	1 M B	1 M B
2 KM	2 M C	2 KM	2 M C		2 M C	2 KM
	3 KM		3 KM		3 M D	
					4 KM	

1 3 0 2 0 2 1

Path Representation

Mixed-Integer Optimization

Partially Mapped Crossover Reproduction

Cut Points

Parent Path A:	1	3	0	2	0	2	1
Parent Path B:	2	0	2	3	1	4	0
Child:	2	0	0	2	0	4	0

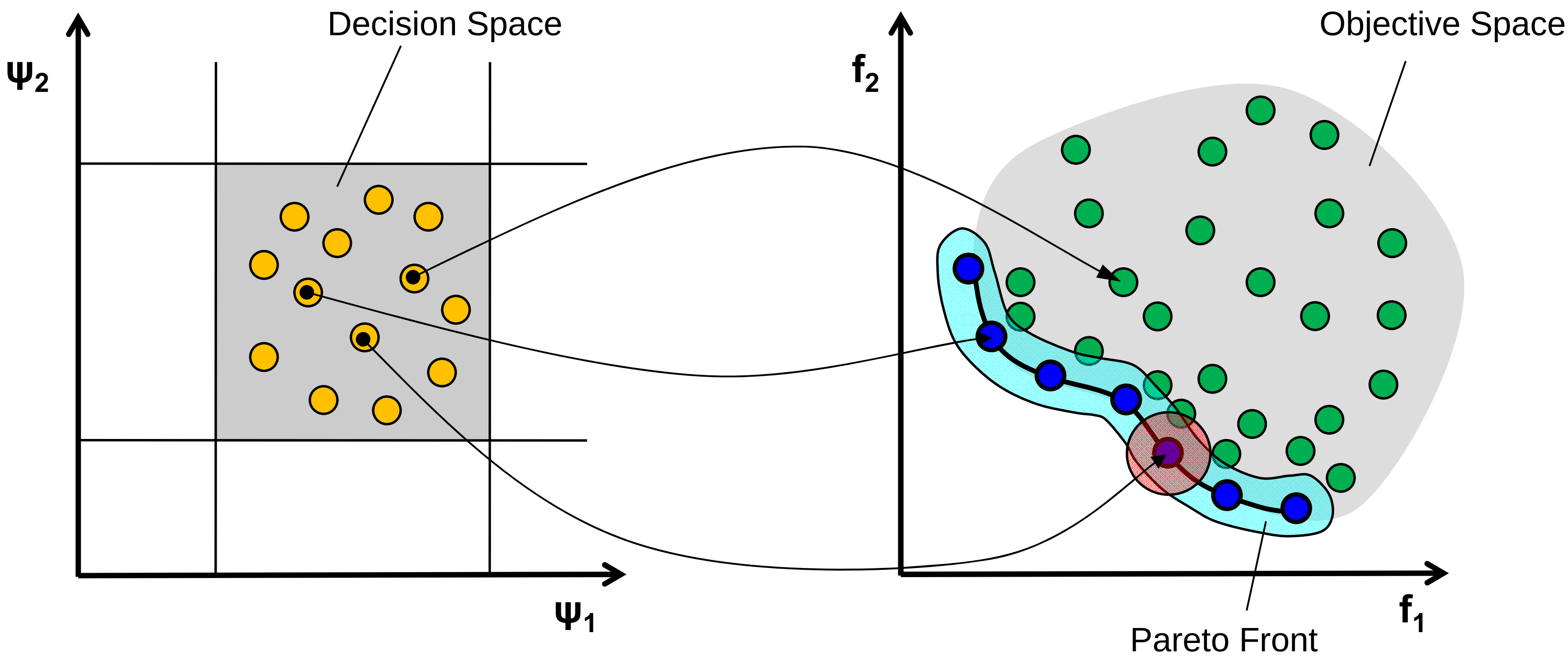
Sub Path Mutation

Child:	2	0	0	2	0	4	0
Mutated Child:	2	2	1	0	0	4	0

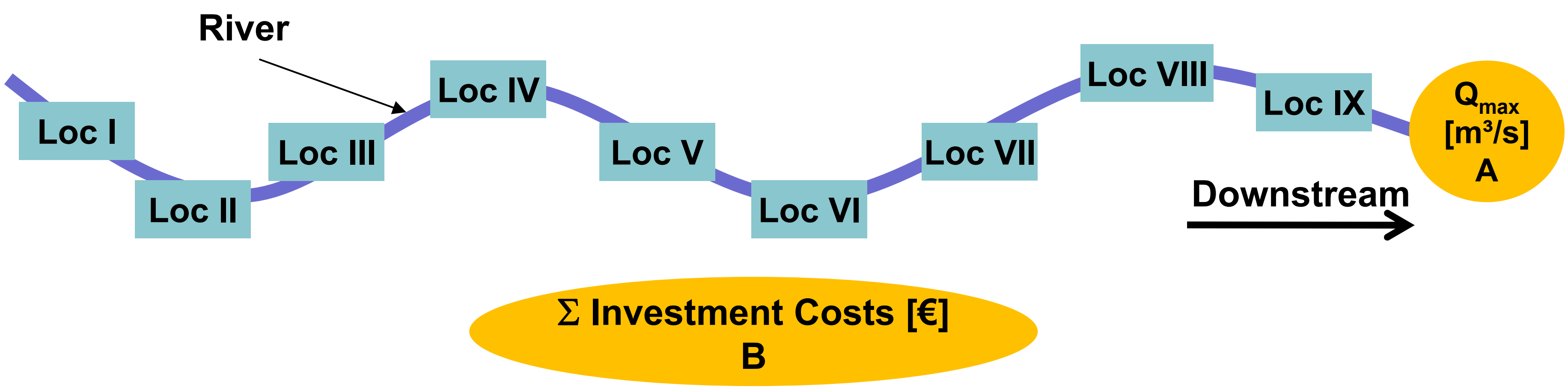
Pareto efficiency / Pareto optimality

- In case of mono-criteria problems only one exact solution
- Reduction of the multi-criteria problems to mono-criteria problems by the use of weighting vectors
- Subjective and arbitrary decisions
- In the case of flood control optimisation -> multicriteria problem
- No single solution
- Search for a set of solutions where each solution is optimal
- Aim is to find solutions where an improvement of an objective value can only be achieved by degradation of another objective value
- This set es called **Pareto efficiency** or **Pareto optimal**

Pareto Optimal



Use Case River Erft
Combinatorial Optimization

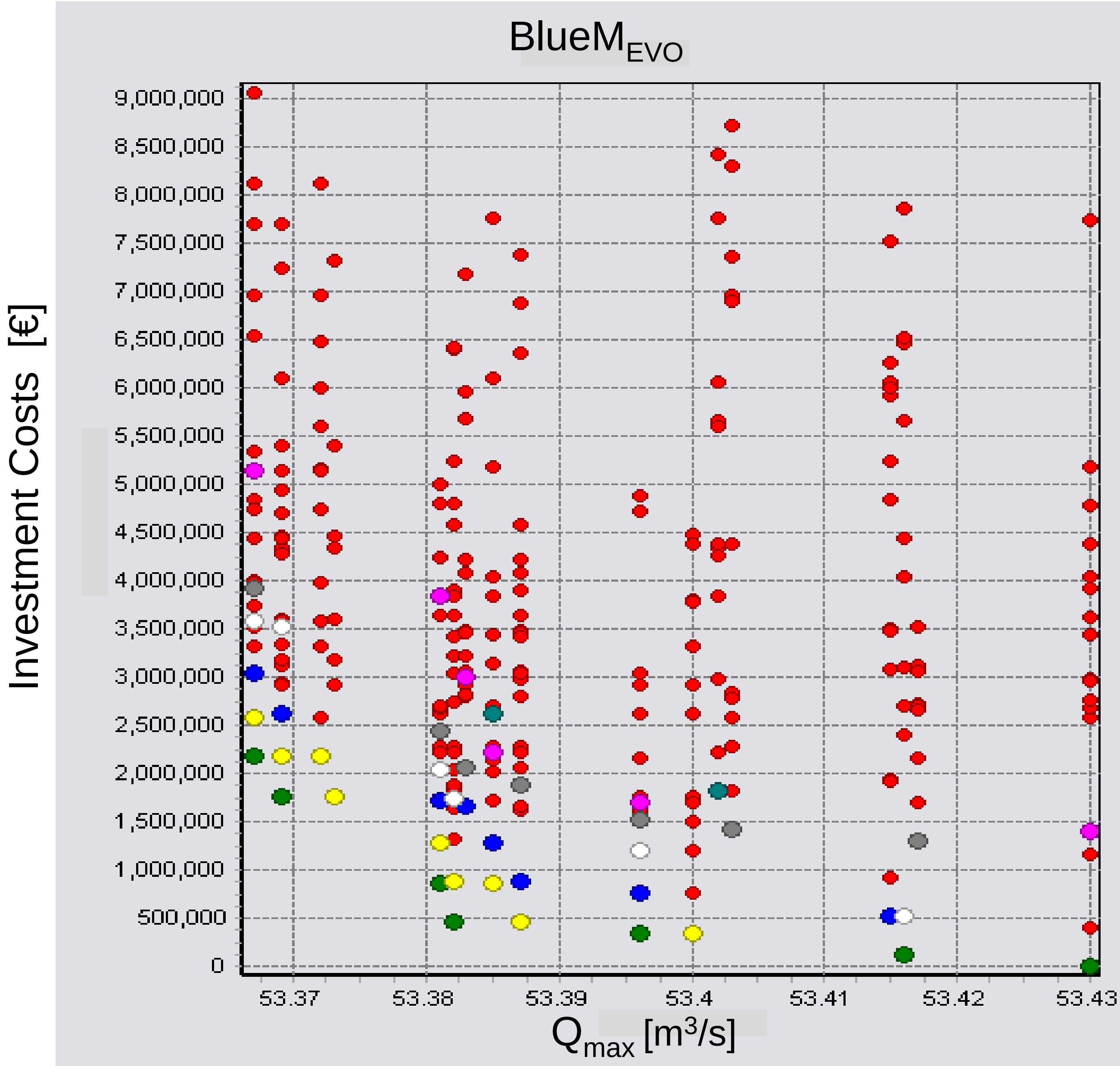


Objective A:
Minimization of the maximum discharge

$$z_a = \max_t \left[Q_t \right]$$

Objective B:
Reducing the Investment costs

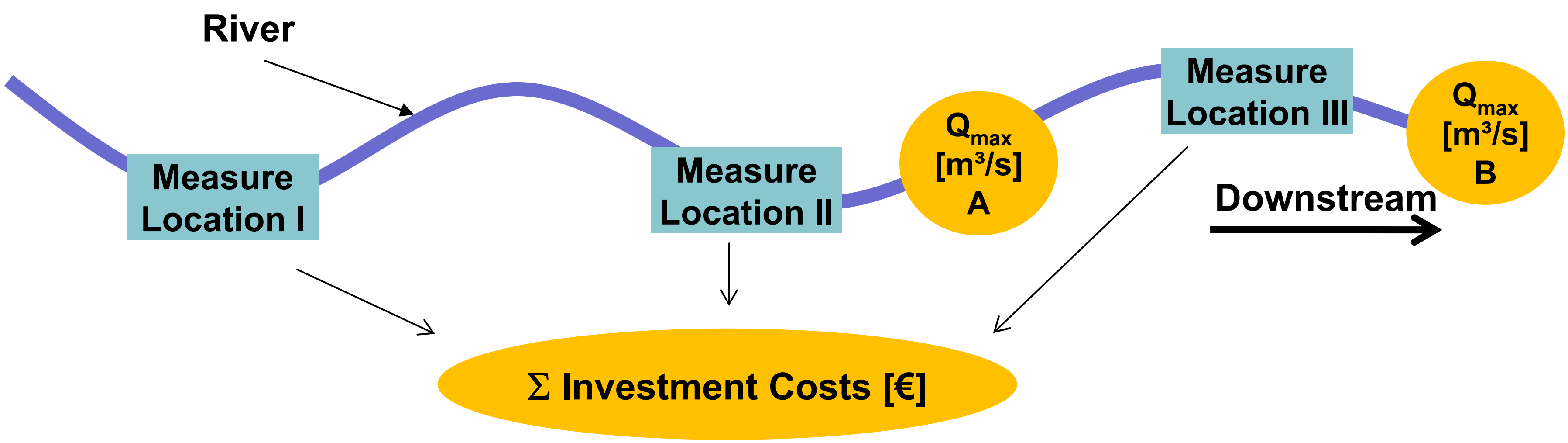
$$z_k = \sum_{n=1}^{N} C_n$$



TECHNISCHE UNIVERSITÄT DARMSTADT

Use Case Erft + Testsystem
Mixed-Integer Optimization

TECHNISCHE UNIVERSITÄT DARMSTADT



0	Basin	V, CS, …
1	Dike high.	
2	No Measure	

0	Polder	
1	Restauration	k_{st}, L, …
2	Bypass	
3	No Measure	

0	Basin	
1	Bypass	L, W, …
2	No Measure	

A

Use Case Erft + Testsystem
Mixed-Integer Optimization

TECHNISCHE UNIVERSITÄT DARMSTADT

Objective A:
minimization of the maximum discharge

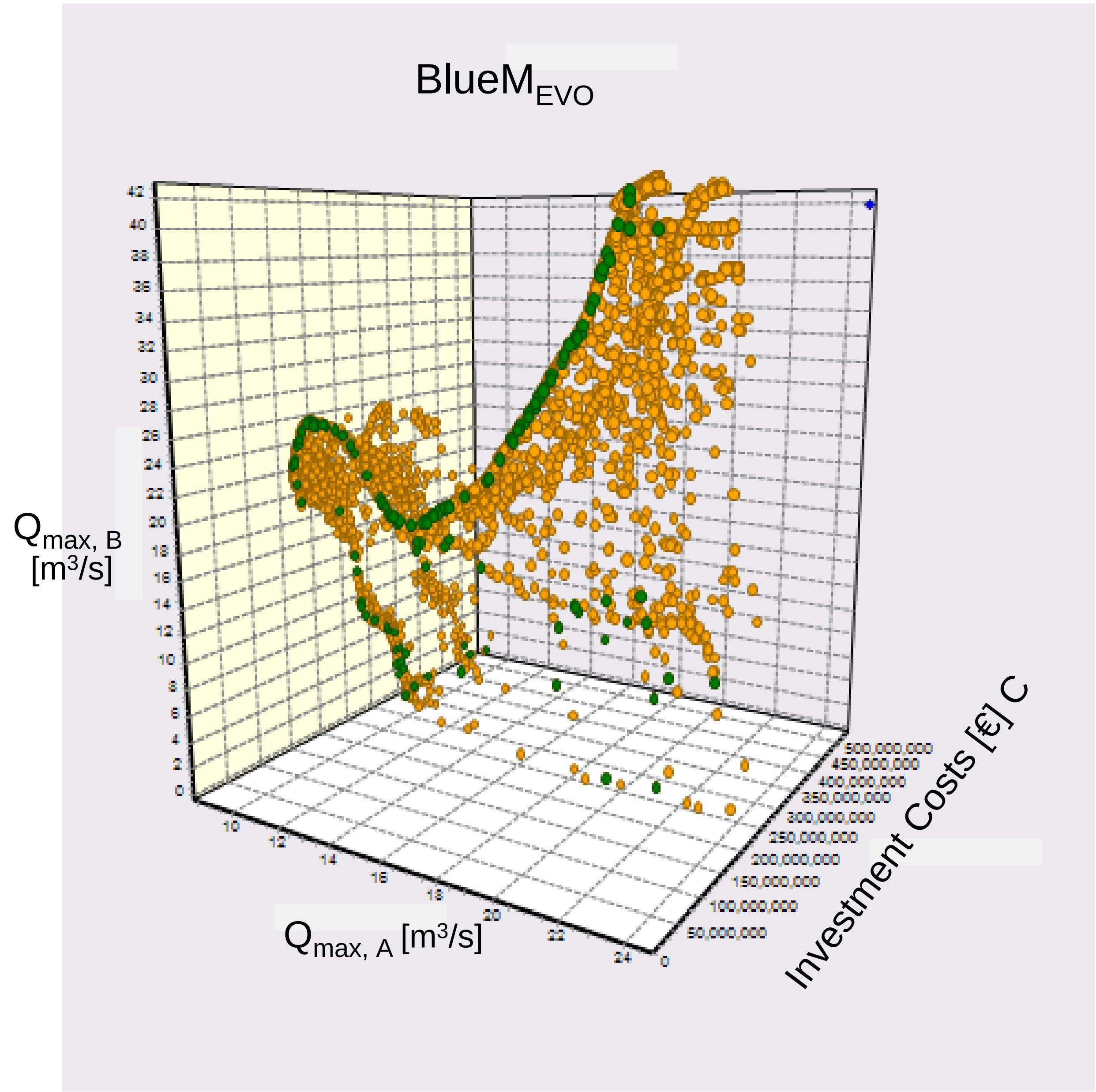
$$z_a = \max_t \left[Q_t \right]$$

Objective B:
minimization of the maximum discharge

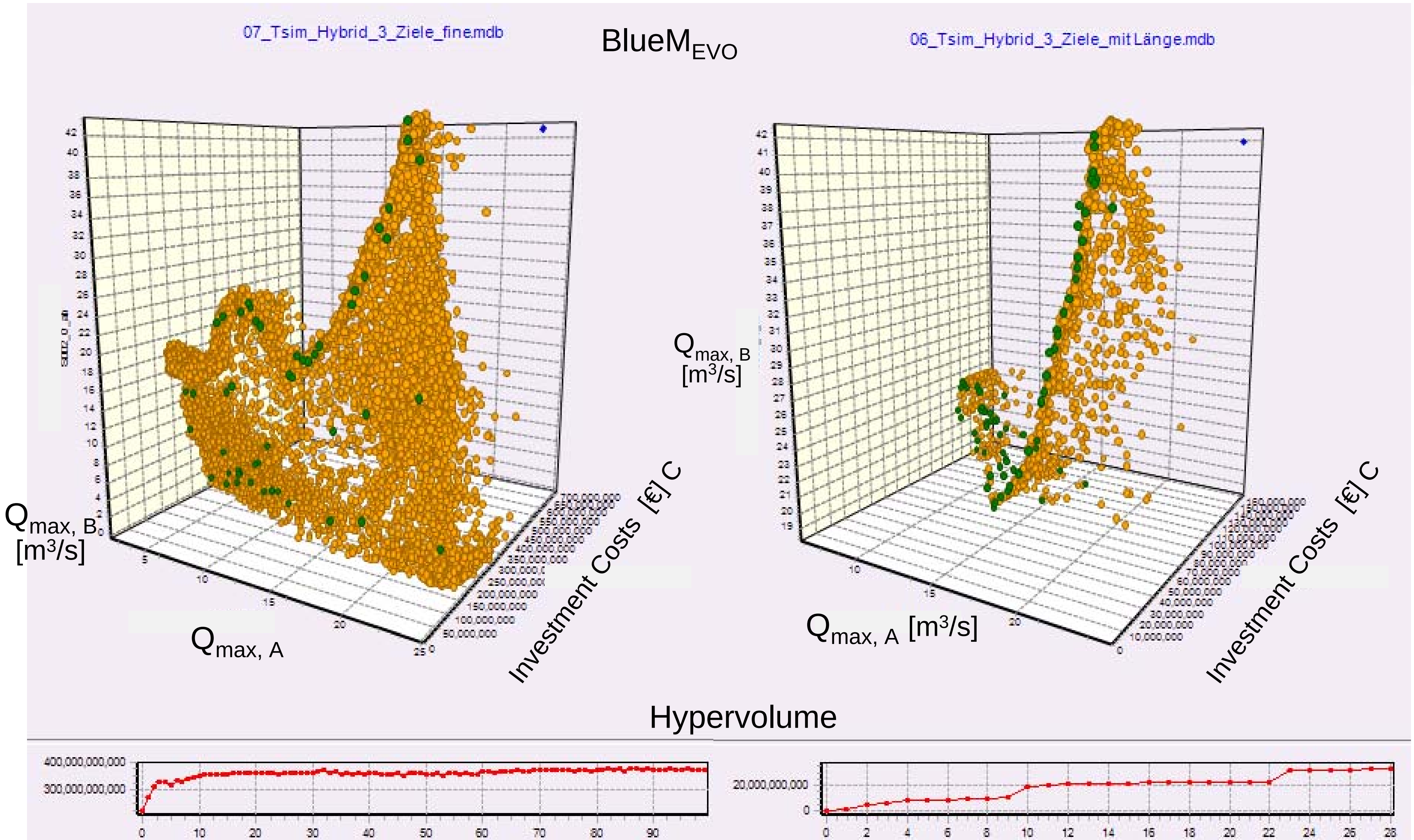
$$z_b = \max_t \left[Q_t \right]$$

Objective C:
Reducing the Investment costs

$$z_k = \sum_{n=1}^{N} C_n$$



TECHNISCHE UNIVERSITÄT DARMSTADT


BlueM$_{EVO}$
07_Tsim_Hybrid_3_Ziele_fine.mdb
06_Tsim_Hybrid_3_Ziele_mit Länge.mdb
$Q_{max, B}$ [m³/s]
$Q_{max, A}$
$Q_{max, A}$ [m³/s]
Investment Costs [€] C
Hypervolume
400,000,000,000
300,000,000,000
20,000,000,000

Conclusions / Outlook

TECHNISCHE UNIVERSITÄT DARMSTADT

- Used model and optimization system BlueM$_R$ + BlueM$_{EVO}$ allows Optimization of flood control measures fast and reliable
- No restriction concerning the used model, because of the separation of modeling and optimization system
- Hydraulic interconnection and influence of the measures is always considered

- Defining the optimization variables is complex
- Fast and efficient scan of the hole solution space
- Algorithm is able to find the global optima
- Deliberate use of results

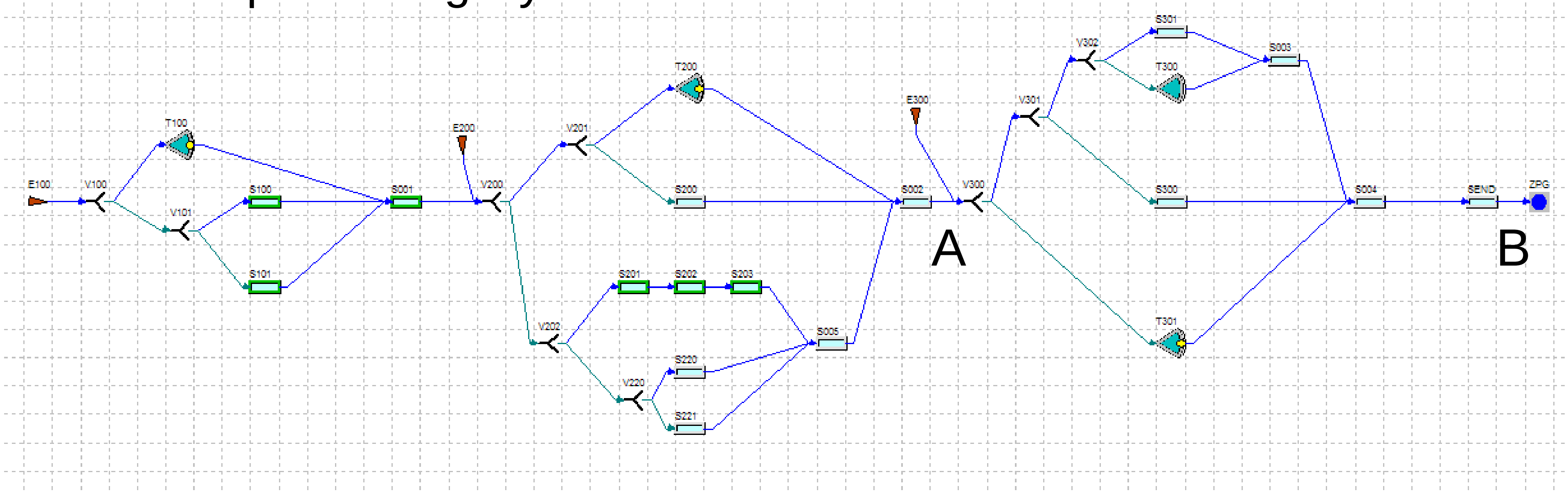
- Enhancement of the optimization algorithms for ordinal discrete variables
- Parallel optimization


Fin
Thank you very much
for your attention
www.nofdp.net
www.riverscape.eu
www.ihwb.tu-darmstadt.de
Christoph Hübner

Outline

TECHNISCHE UNIVERSITÄT DARMSTADT

Schema des Optimierungssystems



Optimierung der HW-Maßnahmen