technische universität
dortmund

Faculty of Business and Economics
Technology Studies Group

SIMCO
SIMULATION OF THE GOVERNANCE OF COMPLEX SYSTEMS

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FONCSI
Fondation pour une culture de sécurité industrielle

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Technology Studies Group

- established in 2002
  - 15 team members

- research projects
  - human-machine interaction
  - risk management in organizations
  - governance of socio-technical systems
  - modeling and simulation

- cooperation with
  - mechanical engineering, computer sciences, electrical engineering ...

Challenges

→ Governance

- stability
  - risks (e.g. pollution, congestion, blackout)
    - emergent, unintended system behaviour
  - out-of-control (e.g. AF-447)
  - growth (e.g. air transportation)
  - sustainability (e.g. road transportation)
- change
  - transformation (e.g. „Energiewende“, sustainable mobility)
- stability
  - during and after transformation

Governance of complex infrastructure systems

- modeling complex systems via ABMS
  - long tradition (e.g. Gilbert 2007)
- modeling governance
  - very rare (e.g. van Dam et al. 2013)
  - governability of complex system? (e.g. Luhmann 1990)
- research on infrastructure networks
  - engineering sciences (SUMO, MatSim ...)

Complexity

- ... emerges out of the interaction of a large number of heterogeneous agents
  - human actors, technical agents, social rules, societal institutions etc.
- ... generating dynamic system behaviour that can only partly be predicted
- non-linear processes
  - emergent system properties

Simulator „SimCo“

- simulation framework
  - *sociological* model of a socio-technical system
    - actions and interactions
    - agents (micro) and system (macro)
  - *spatial* dimension of infrastructure systems
    - boundary conditions
    - means for (intentionally) controlling the system

→ investigate the governability of complex infrastructure systems by means of ABMS

Content

1. Introduction ✓
2. Scope of the model
3. Inventory
4. Concept formalization
5. Model formalization
6. Software implementation
7. Verification and validation
8. Experimentation
9. Conclusion

ODD protocol, adapted version (Van Dam et al., 2013)

2. Scope of the model

- general-purpose framework
  - model and analyse interaction processes in networked systems
    - dynamic system behaviour
  - governance of complex, network-like infrastructure systems
    - modes of governance

2. Objectives of governance

risk management → *negative feedback*

- poor performance
- undesired effects (e.g. congestions, CO_2 emissions)
- system failure, catastrophies (e.g. blackout)

system transformation → *positive feedback*

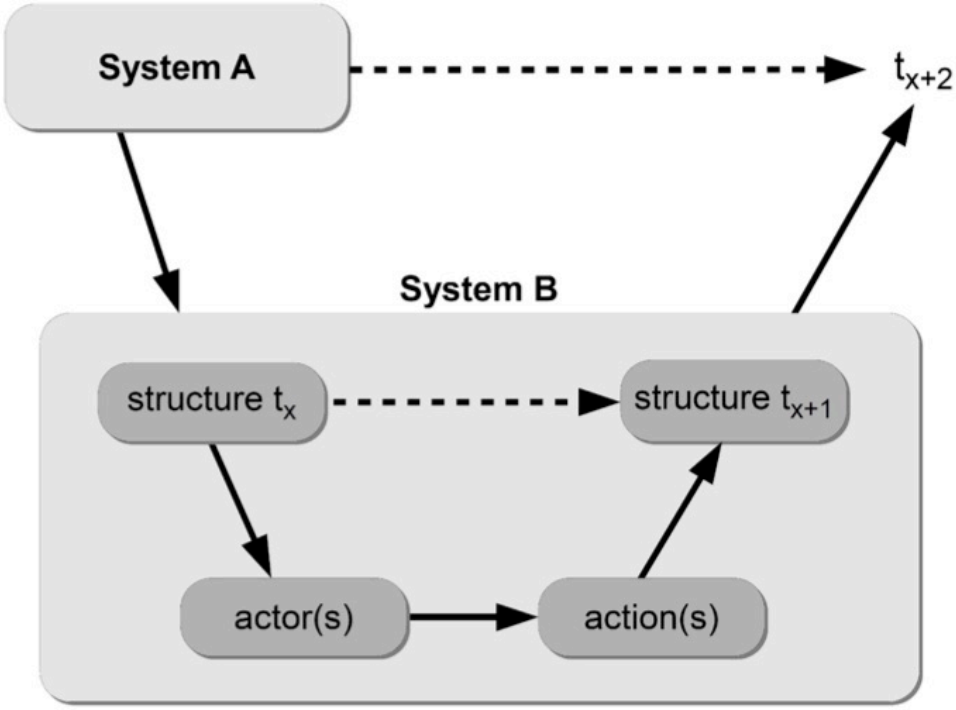
- energy system („Energiewende“)
- transportation

2. Governance

- a specific combination of the basic mechanisms of **control** and coordination in multi-level socio-technical systems

- objective: system (macro)
- "detour" via actors (micro)

Control mechanism



Weyer, Johannes; Adelt, Fabian; Hoffmann, Sebastian (2015): Governance of Complex Systems. A Multi-Level Model. TU Dortmund (Soziologisches Arbeitspapier 42). http://dx.doi.org/10.17877/DE290R-401)

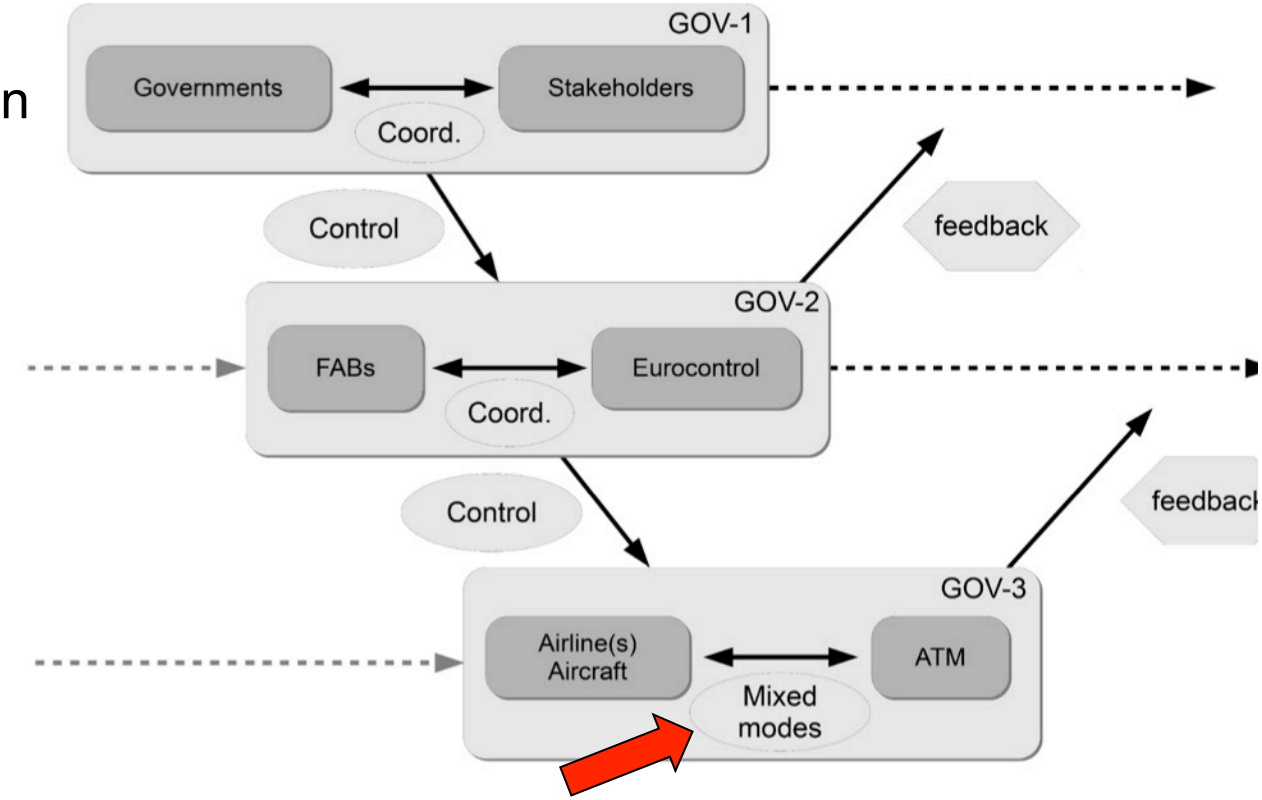
2. Multi-level governance

sample of large-scale infrastructure systems (case study ATC/SES)

GOV-1: coordination processes in negotiation systems

GOV-2: regulation of functional societal systems

GOV-3: operational control of the systems



horizontal arrows: coordination
vertical arrows: control

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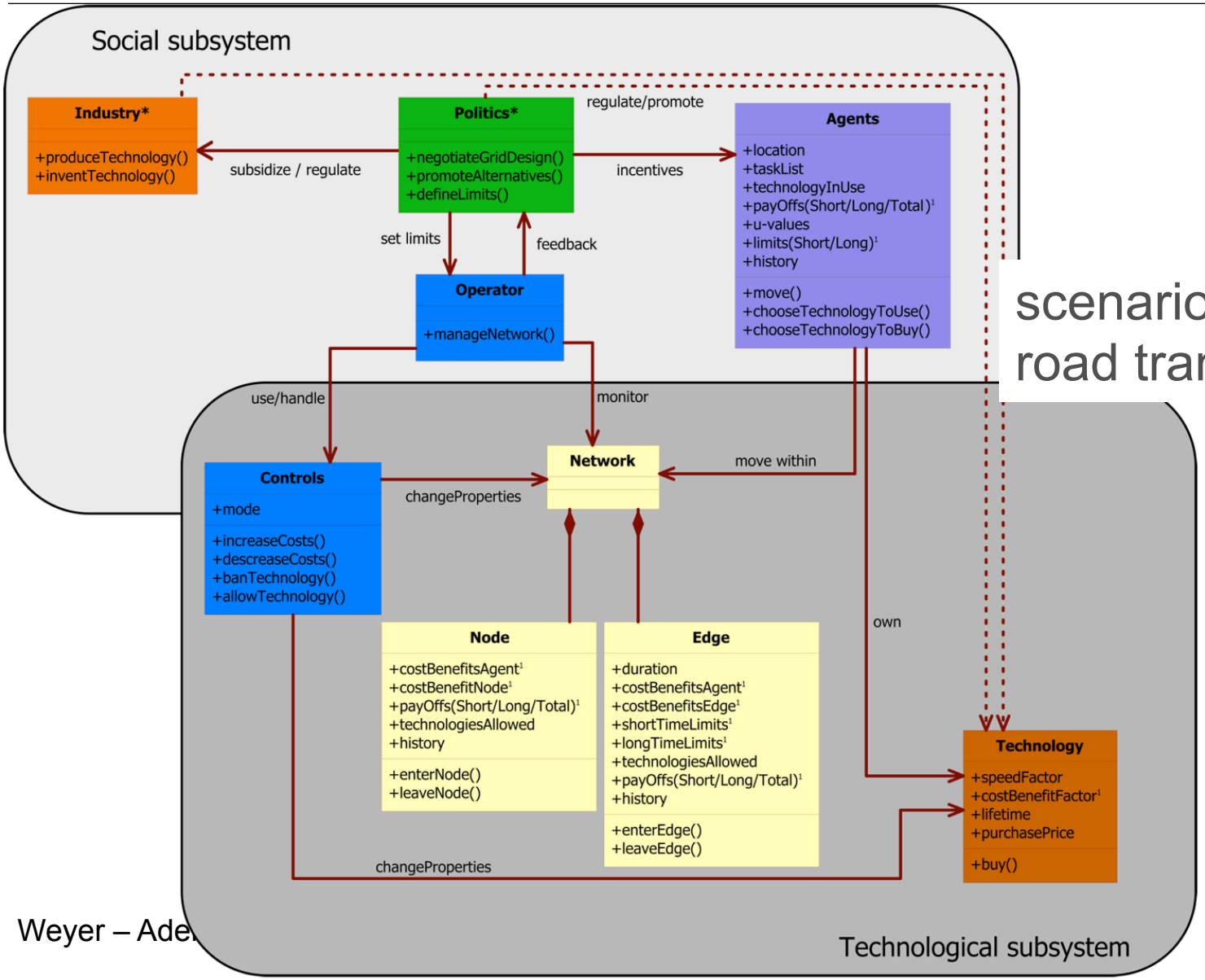
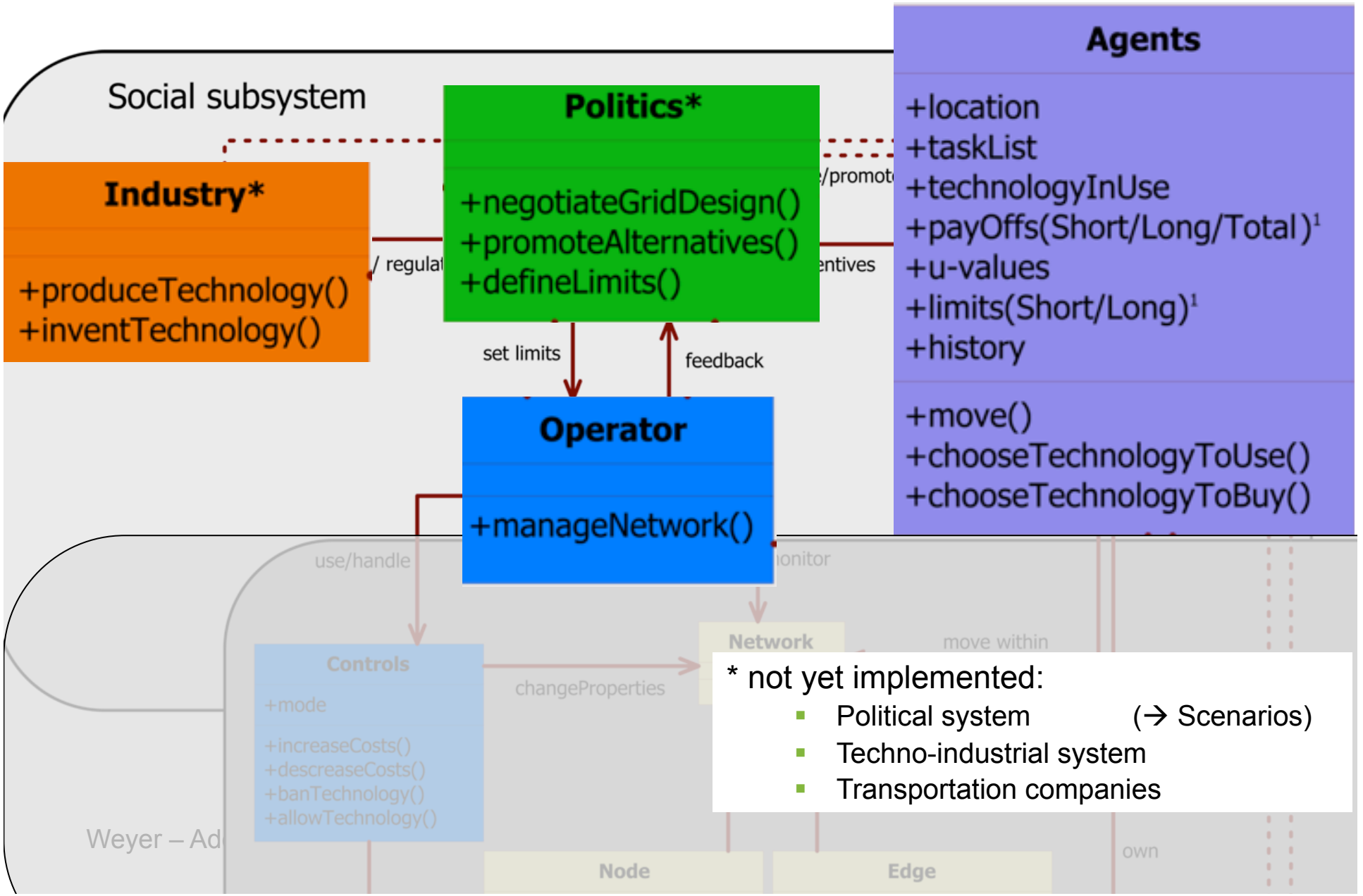
3. Inventory: Overview

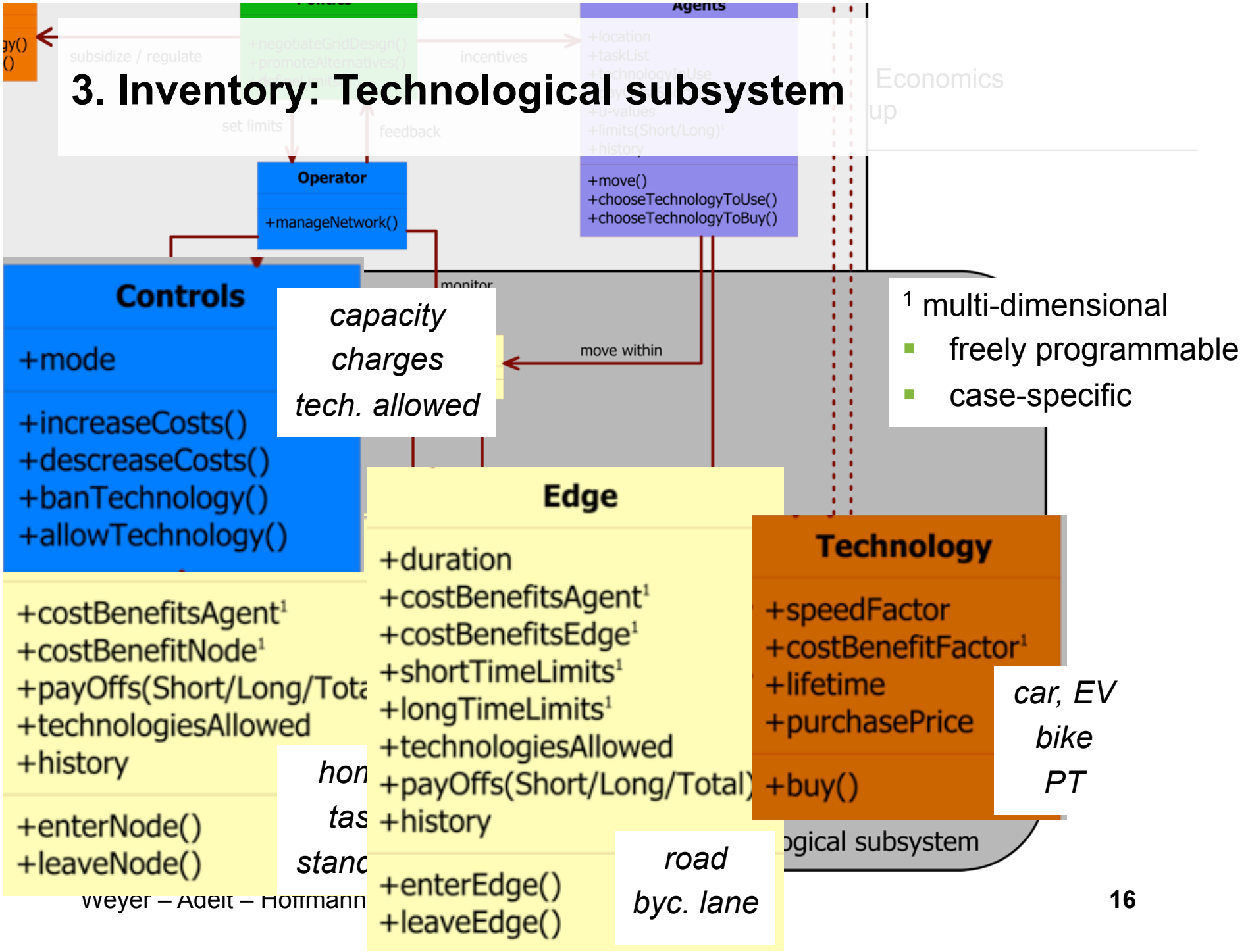


scenario
road transportation

3. Inventory: Social subsystem



3. Inventory: Technological subsystem



[1] multi-dimensional
- freely programmable
- case-specific

3. Interactions

- Social interactions
  - user – user
  - user – operator (indirectly)
  - producer – user
  - politics – user
- Technological interactions
  - edge – node
  - technology – edge/node
  - controls – technology/edge/node

3. **Interactions** (cont.)

- Socio-technical interactions
  - agents – node/edge *(capacity, pollution)*
  - node/edge – agents *(charge, reward, data)*
  - agents – technology *(investment, daily use)*
  - technology – agents *(move fast or environmental friendly)*
  - controls – agents *(charges, bans ...)*

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(state variables see Section 3)

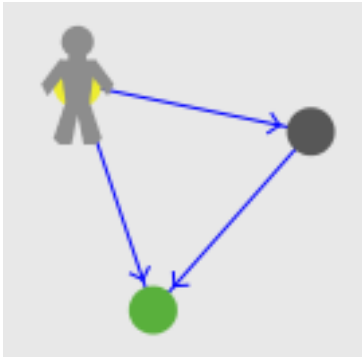
ODD protocol, adapted version (Van Dam et al., 2013)

4. Concept formalization: Controls

- Operator intervenes, if limits are exceeded
  - short-/long-term limits
  - determined by politics
- Control
  - damp down fluctuation → stability
  - amplify fluctuation → change
- Modes of governance
  - self-coordination *(monitoring)*
  - soft control *(e.g. raising charges)*
  - strong control *(e.g. banning technologies)*

4. Concept formalization: Agents‘ decision making

- agents move through network
  - fulfill tasks
  - select nodes with high utility
  - use technologies
  - constrained by state of network
- sociological theory of action
  - macro-micro-macro model
  - bounded rationality
  - individual preferences and goals
  - multiple evaluation criteria → subjective expected utility



$$SEU_i = \sum_{j=1}^{n} p_{i,j} \cdot u_j$$

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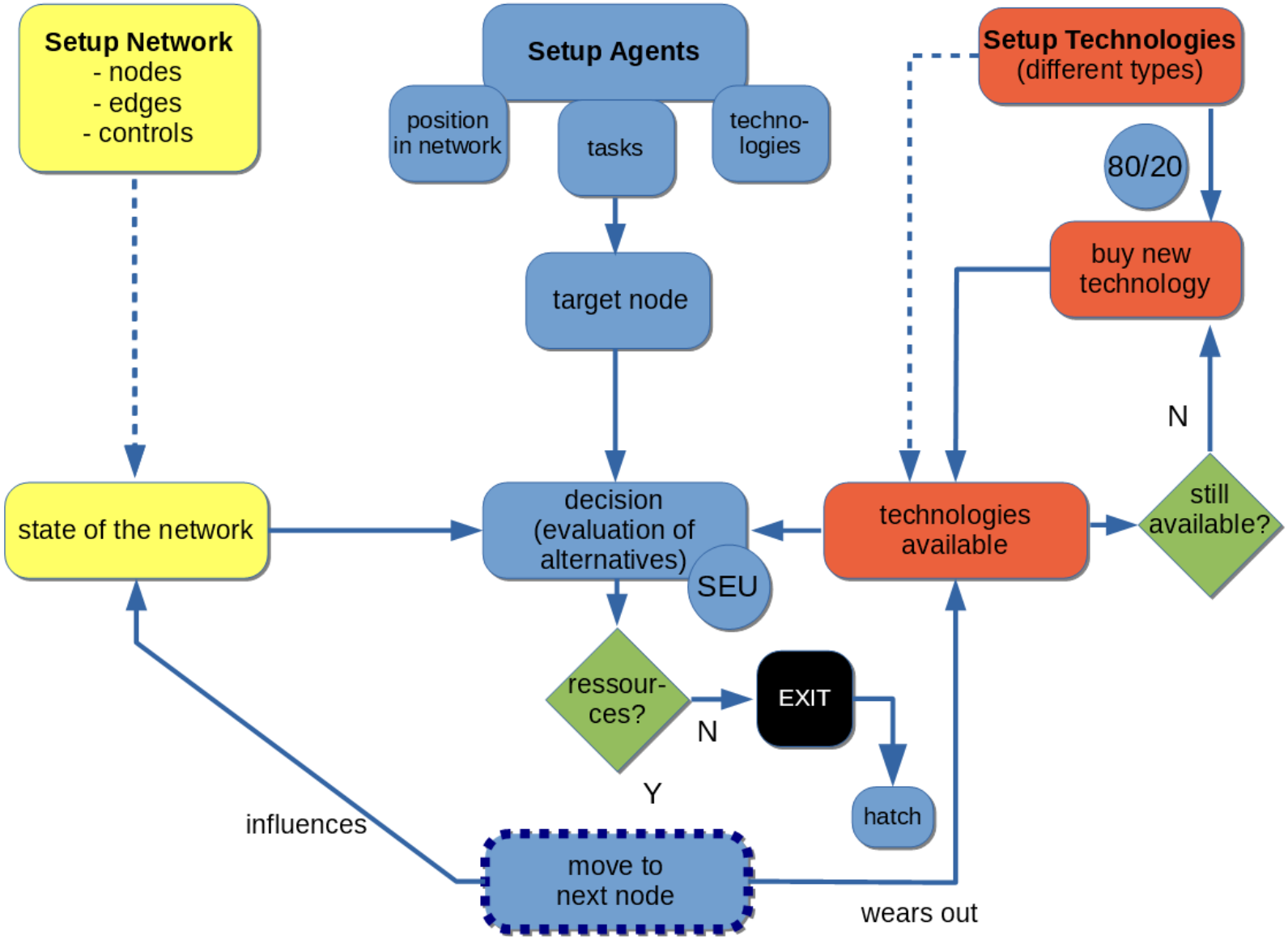
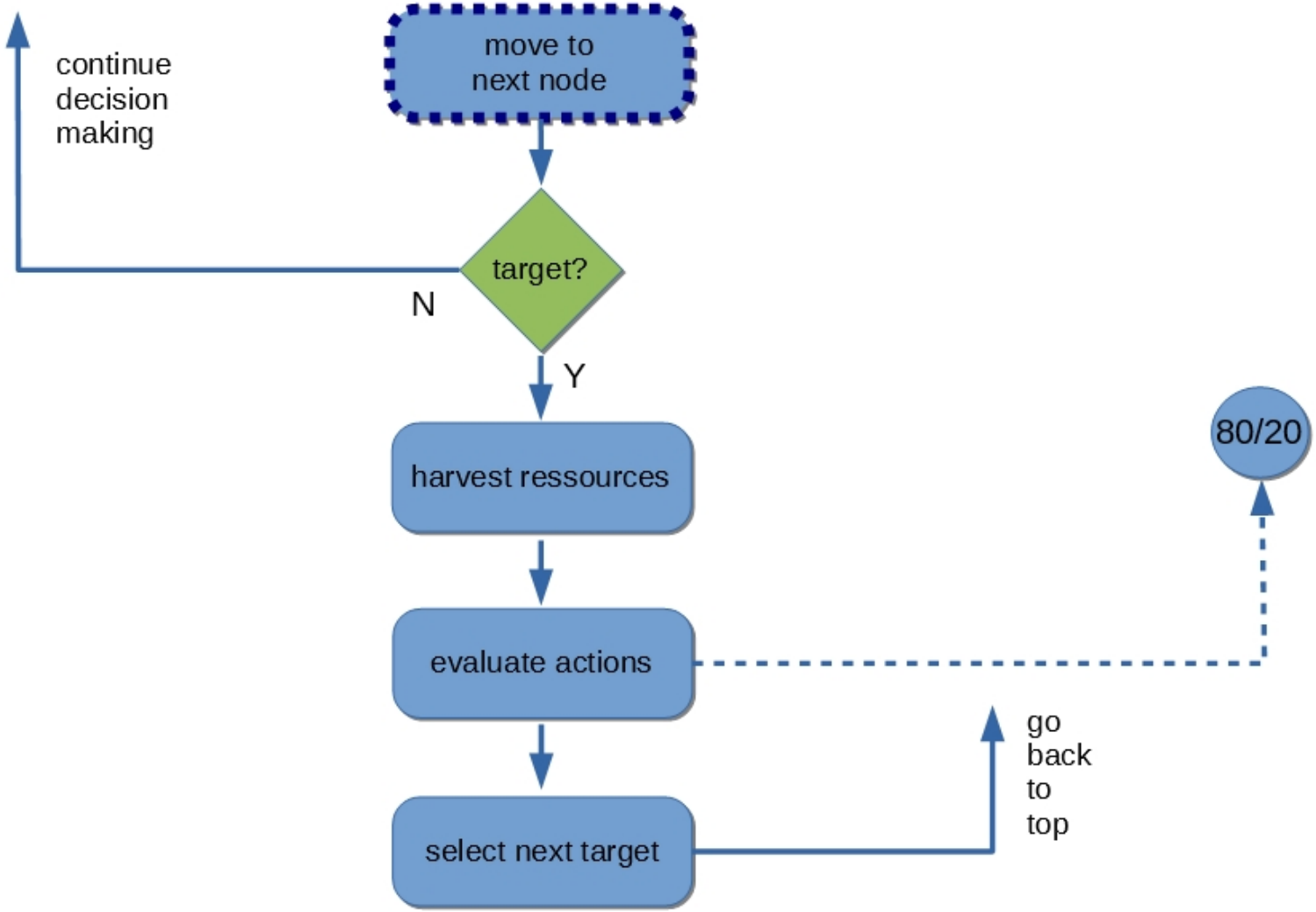
5. Model formalization

1. Setup
   - network (nodes, edges, controls)
   - heterogeneous agents (at different nodes)
   - technologies
2. First loop: agents‘ routine choices (→)
   - daily
3. Second loop: replacement of technology (→)
   - occasionally
4. Third loop: system management (infrastructure policy)

5. Agents‘ choices



5. Agents‘ choices (cont.)



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6. Software implementation

ABMS

- agents
- rules
- landscape

NetLogo (https://ccl.northwestern.edu/netlogo)

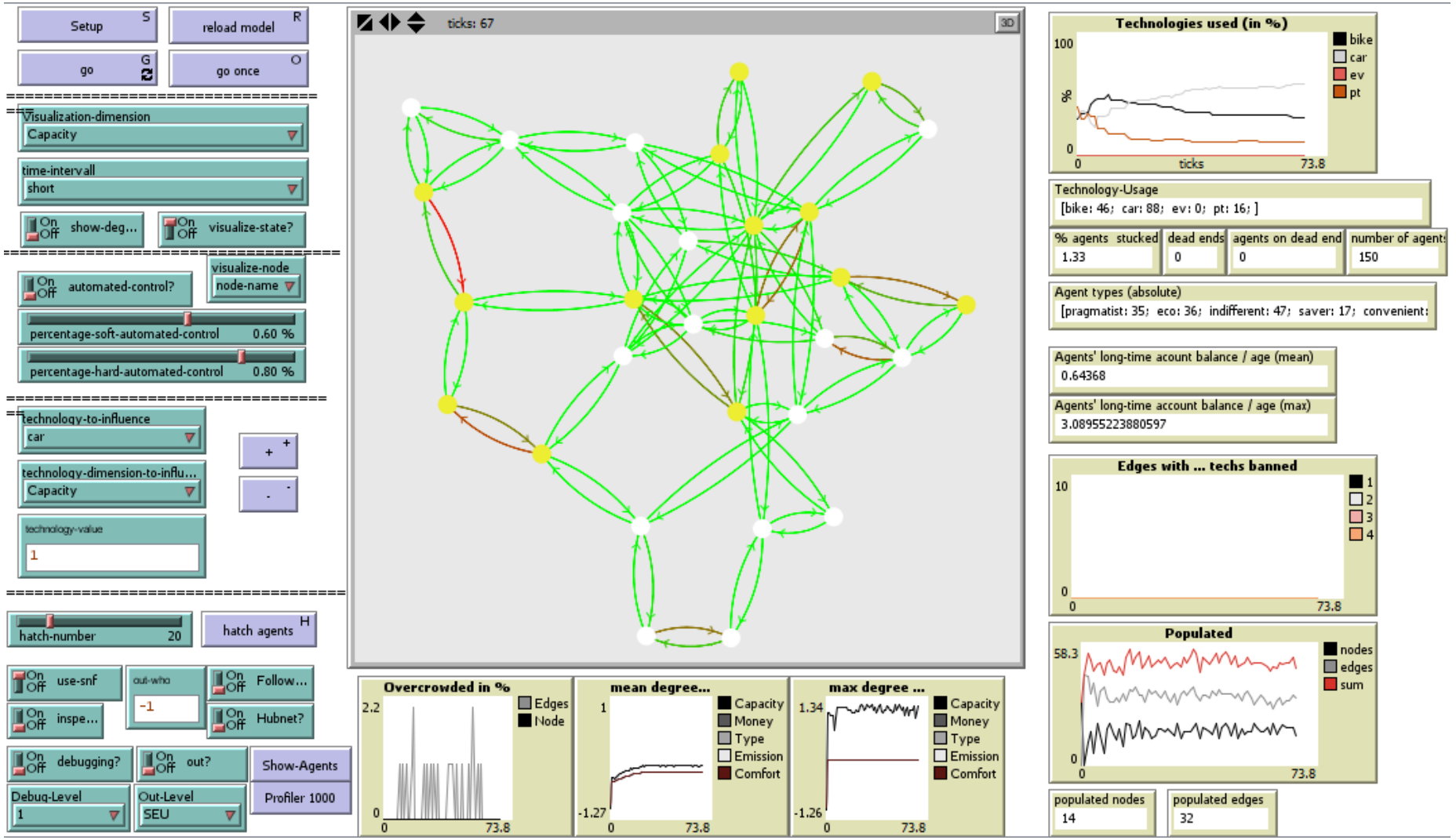
- widespread in social sciences

Scenario generator

Output organization

- GUI (→) – interface for human probands
- stats extension → CSV → SPSS

6. GUI SimCo


Setup
reload model
go
go once
Visualization-dimension
Capacity
time-intervall
short
show-deg...
visualize-state?
automated-control?
visualize-node
node-name
percentage-soft-automated-control 0.60 %
percentage-hard-automated-control 0.80 %
technology-to-influence
car
technology-dimension-to-influ...
Capacity
technology-value
1
hatch-number 20
hatch agents
use-snf
out-who
-1
Follow...
inspe...
Hubnet?
debugging?
out?
Show-Agents
Debug-Level
1
Out-Level
SEU
Profiler 1000
ticks: 67
Technologies used (in %)
bike
car
ev
pt
ticks
Technology-Usage
[bike: 46; car: 88; ev: 0; pt: 16;]
% agents stucked
1.33
dead ends
0
agents on dead end
0
number of agents
150
Agent types (absolute)
[pragmatist: 35; eco: 36; indifferent: 47; saver: 17; convenient:
Agents' long-time acount balance / age (mean)
0.64368
Agents' long-time account balance / age (max)
3.08955223880597
Edges with ... techs banned
Overcrowded in %
Edges
Node
mean degree...
max degree ...
Capacity
Money
Type
Emission
Comfort
Populated
nodes
edges
sum
populated nodes
14
populated edges
32

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ODD protocol, adapted version (Van Dam et al., 2013)

7. Verification and validation

1. (technical) verification
   - fuzzy-like selection algorithm added
2. „validation“ → congruence with real system
   - urban traffic scenario
   - mid-sized German town
   - issue of regime change
3. tests and parameter variation
   - low numbers of agents leaving the simulation
   - cost-covering account balance
4. (stable) basic scenario (→)

7. Realistic* base scenario

	Type	Number
Nodes	Home	204
	Task	236
	Standard	160
	Total	600
Edges	Shared-small	984
	Shared-big	110
	Car-only	104
	Bike-only	3
	PT-only	110
	Total	1312
Agents	Pragmatic	750
	Eco	450
	Indifferent	1.350
	Penny Pincher	450
	Convenient	1.500
	Total	6000

*** three options**

- survey-based (too optimistic)
- equally distributed
- realistic

7. Agent types

Agent types	Cheap	Fast	Eco-friendly	Comfort-able	N=506
Pragmatist	3.7	**6.8**	2.4	1.2	119
Eco	4.4	2.0	**7.6**	1.9	123
Indifferent	4.0	4.6	2.8	4.2	157
Saver	**9.0**	4.7	3.7	0.7	58
Convenient	0.6	**6.4**	0.2	**6.8**	49

- Clusters based on mean rated goals (ranging from 1-10)
- Survey data (conducted 2014/15)
- adjustment of biases
  - additional “hidden goals” (mental frames)

7. Suitability of technologies

Technology	Fast	Cheap	Eco-friendly	Comfort-able
Public transport	3.15	4.85	**6.28**	3.67
Bike	4.06	**8.94**	**9.32**	3.30
Car (fossil-fuelled)	**6.08**	3.00	1.96	**6.72**
Electric vehicle	7.80	6.08	7.64	7.78

- Assessment regarding the achievement of goals (ranging from 1-10)
- Survey data (conducted 2014/15)

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8. Regime change in road transportation

modes of governance

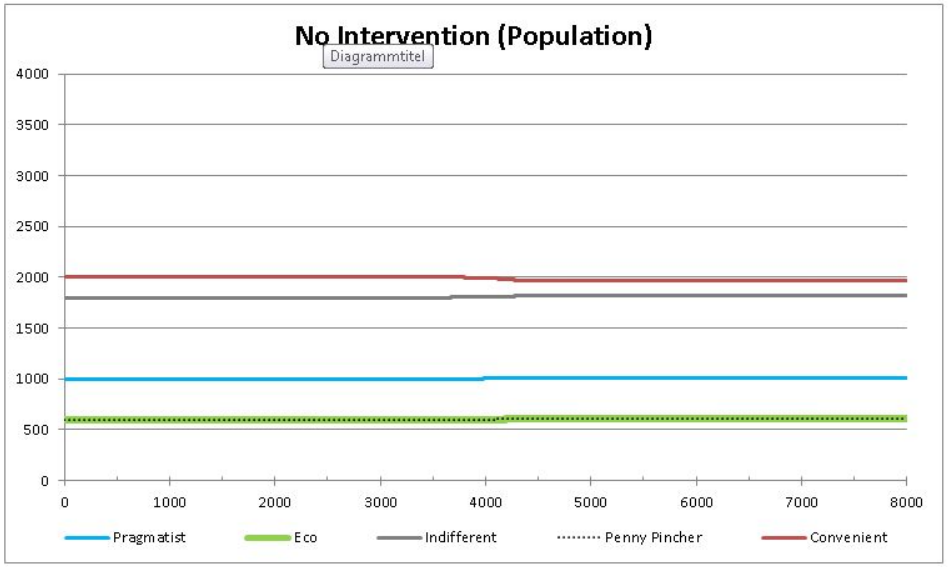
1. no intervention (= base scenario)
2. soft control: road pricing
   - congestion charging, emission pricing, cordon schemes
     - raising and lowering again
3. strong control: ban of the car
   - temporal, spatial
     - re-allowing after short-time („day“)
4. combination of soft and strong control
   - 60% of limit: soft measures
   - 80% of limit: (additional) strong measures

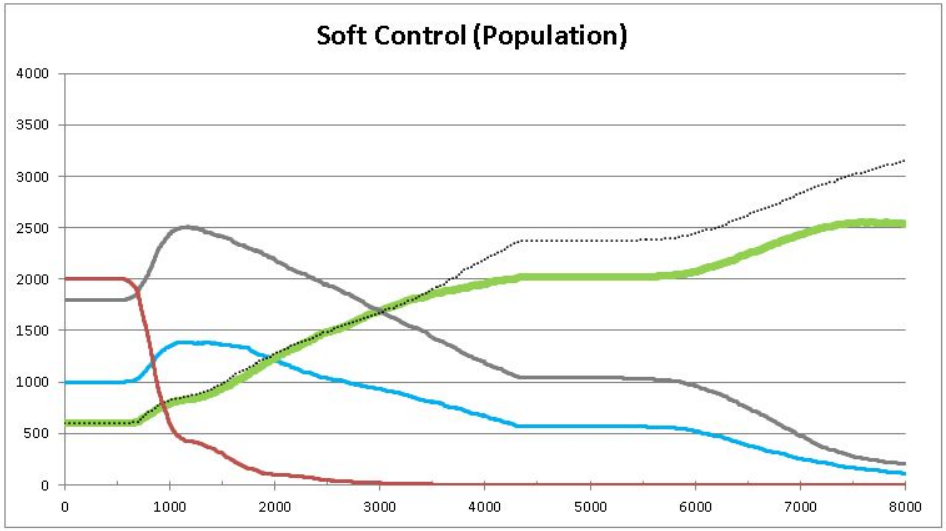
8. Basic governance experiments → transformation

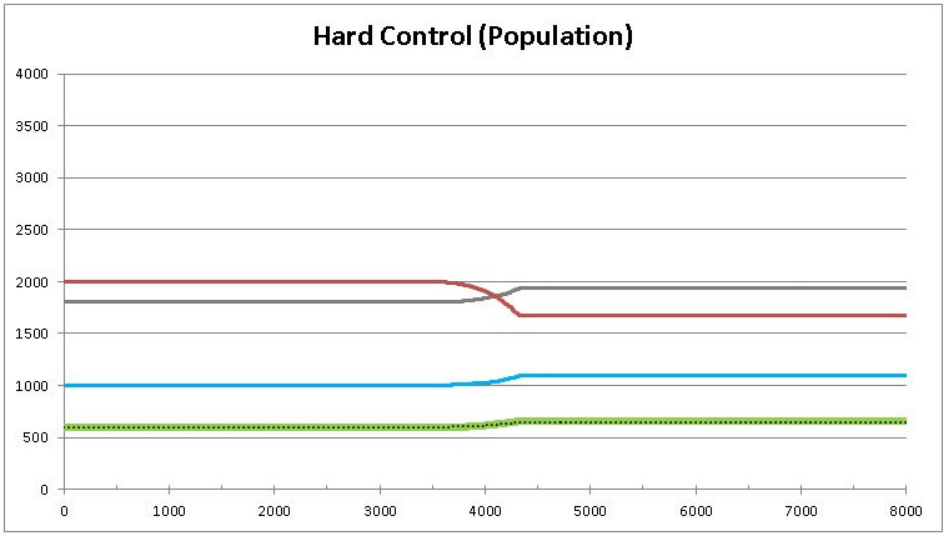
	Mean capacity utilization of edges	Mean pollution on edges (short)	Mean pollution on edges (long)	Usage of Bikes	Usage of Cars	Usage of Public transport
No control	21,4%	18,0%	33,3%	31,6%	62,5%	5,9%
Soft control	**15,8%**	**12,8%**	24,7%	46,0%	**37,5%**	**16,5%**
Strong control	19,1%	15,6%	28,9%	41,4%	52,1%	6,5%
Combined	16,4%	12,9%	**24,7%**	**49,9%**	39,0%	11,1%

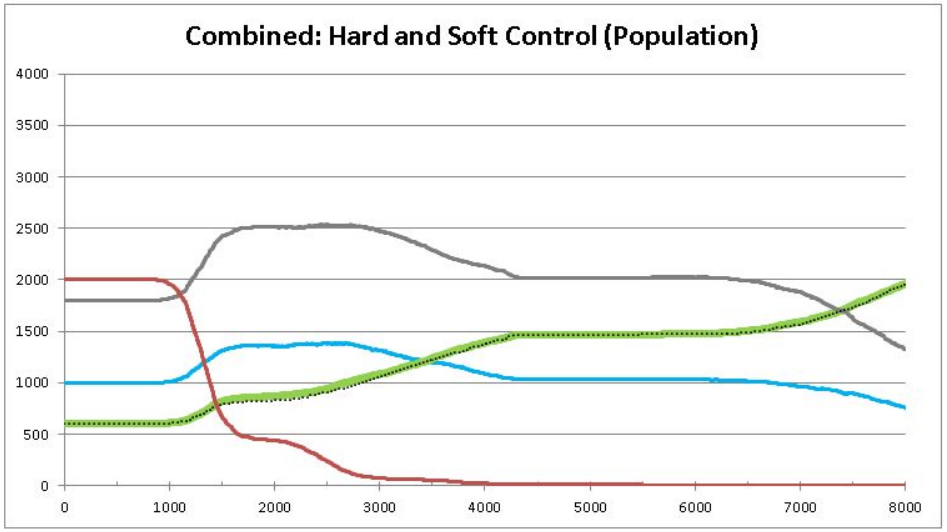
8. Agent population

blue: pragmatist green: eco
red: convenient grey: indifferent
dotted: penny pincher



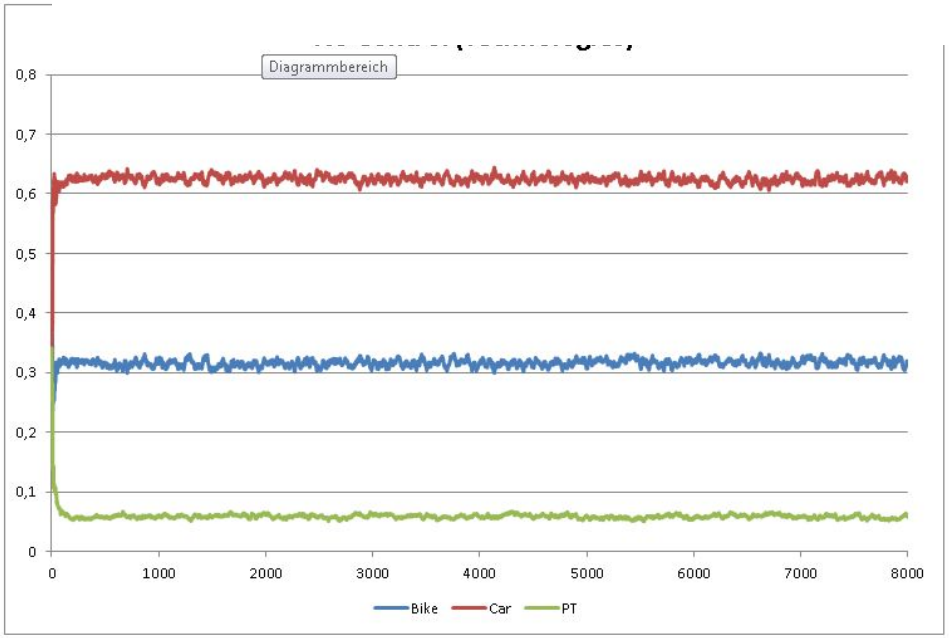


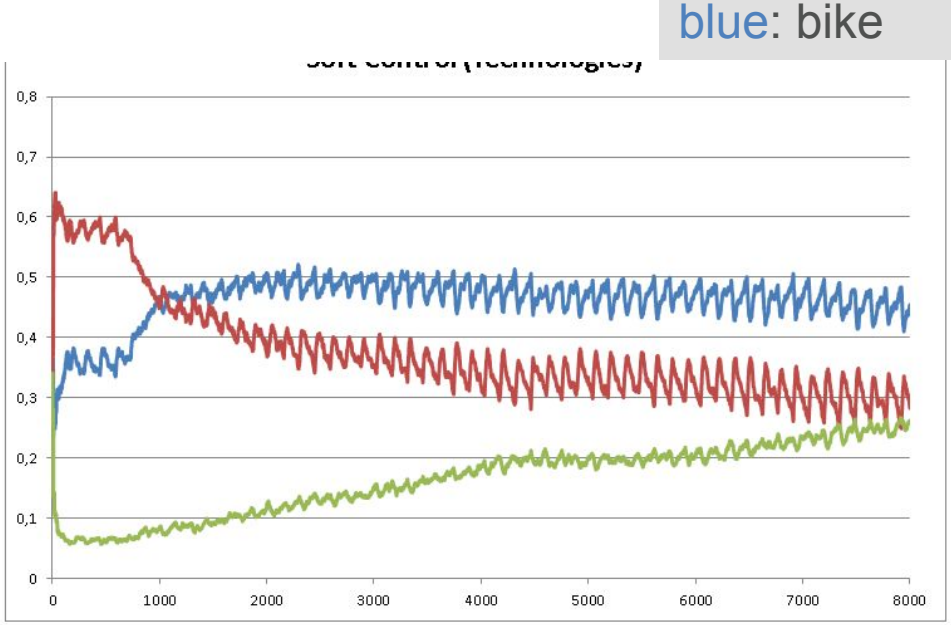


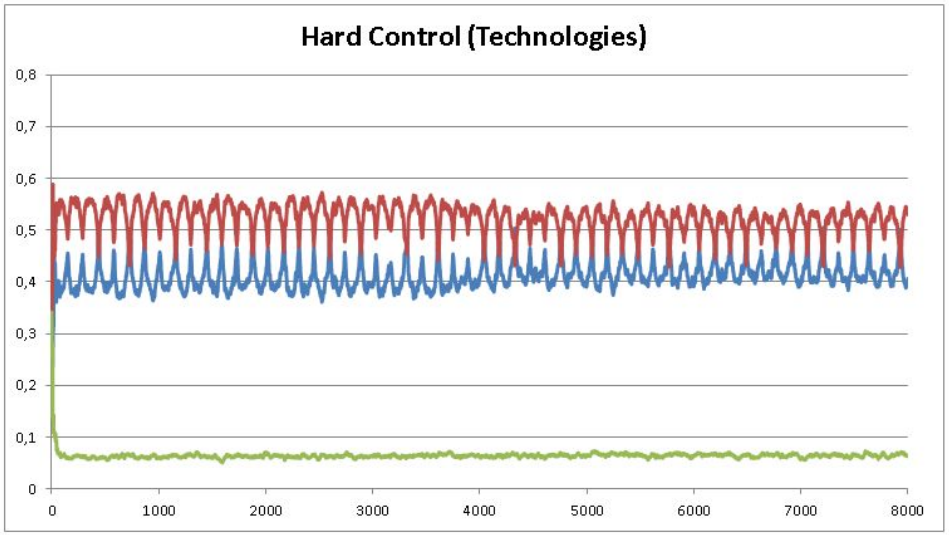


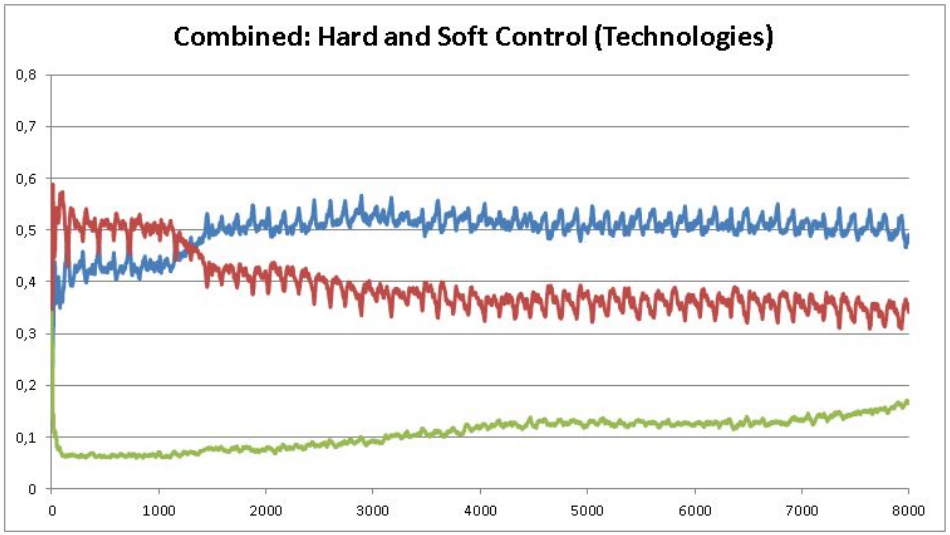
8. Technology usage

green: PT
red: car
blue: bike









8. Basic governance experiments → risk management

static interventions (mean values)

Intervention	Capacity utilization	Emissions (short time)	Emissions (long time)
Base scenario	21,6%	18,0%	33,4%
Comfort bike	17,3%	**13,2%**	**24,6%**
Comfort public transport	19,1%	16,5%	30,5%
Costs car	**16,7%**	13,3%	25,4%

8. Basic governance experiments
situational interventions (mean values)

Mode of governance	Capacity utilization	Emissions (short time)	Emissions (long time)
No control (base scenario)	21,6%	18,0%	33,4%
Soft control	18,2%	14,5%	27,7%
Strong control	19,5%	15,7%	29,2%
Combined	**18,0%**	**14,1%**	**26,9%**

8. Basic governance experiments
situational interventions (max network values)

Mode of governance	Capacity utilization	Emissions (short time)	Emissions (long time)
No control (base scenario)	25,7%	36,1%	71,1%
Soft control	25,7%	34,8%	60,4%
Strong control	**22,0%**	31,8%	63,1%
Combined	**22,0%**	**31,5%**	**58,6%**

8. Basic governance experiments

situational interventions (max edge values)

Mode of governance	Capacity utilization	Emissions (short time)	Emissions (long time)
No control (base scenario)	**120,5%**	251,8%	471,9%
Soft control	133,8%	244,8%	444,6%
Strong control	128,4%	**108,0%**	**202,1%**
Combined	132,6%	111,5%	204,9%

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9. Conclusion

- Combination
  - governance, infrastructure systems, ABMS
- Sociological theory of action

- SimCo framework
  - free of semantics
    - different scenarios
  - basic scenario
    - stable and reliable (parameter variation)

9. **Conclusion** (cont.)

- Objectives of investigation
  - risk management and/or system transformation
    - governance modes
  - what-if-question
    - experiments that cannot be performed in the real world

  - governability of complex socio-technical systems
    - unresolved debates in political sciences (cf. Grande 2012)

9. Limitations and further perspectives

- limitations
  - ...
- further experiments
  - disturbances: stability (and recovery)
  - alternatives: (e.g. via CarSharing)
  - experiments with human probands
  - additional modules
    - e.g. creation of technological alternatives
  - implementation of different theories of action

Thanks for your attention!

Weyer, Johannes, Fabian Adelt, Sebastian Hoffmann, Andreas Ihrig, 2017:
*Simulation of the of complex systems (SimCo). Basic concepts and preliminary scenarios (*submitted).

www.simco.wiwi-tu-dortmund.de (still under construction)