Improving Sustainability and Resilience of Transportation by Discrete Event Simulation-Based Risk Analysis

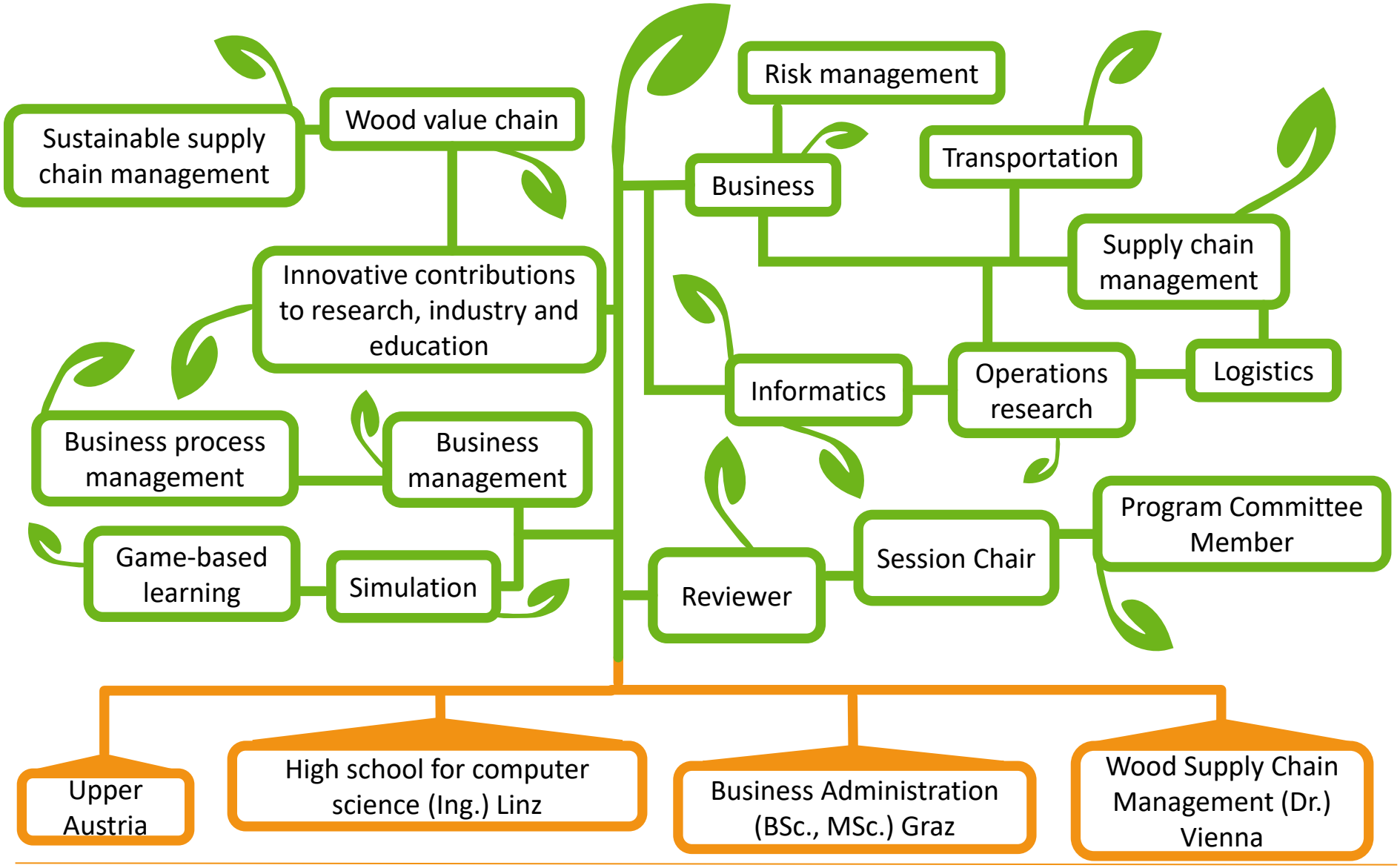
Christoph Kogler, May 18th 2023

TU Brno, Institute of Forensic Engineering, JUFOS Conference

AGENDA

- 1. INTRODUCTION
- 2. SIMULATION METHOD
- 3. WOOD SUPPLY CHAIN MANAGEMENT
- 4. SIMULATION MODEL EXAMPLES
- 5. FUTURE COOPERATION AND WSG COMPETITION

1 Activity Tree



1 Relevant Research Articles

- Kogler, C; Rauch, P (2023): **Lead time** and quality driven transport strategies for wood supply chains, Research in Transportation Business & Management, 47, https://doi.org/10.1016/j.rtbm.2023.100946
- Kogler, C; Schimpfhuber, S; Eichberger, C; Rauch, P (2021): **Benchmarking** procurement cost saving strategies for wood supply chains, Forests, 12(8), https://doi.org/10.3390/f12081086
- Kogler, C; Stenitzer, A; Rauch, P (2020): Simulating combined self-loading truck and **semitrailer** truck transport in the wood supply chain, Forests, 11(12), https://doi.org/10.3390/f11121245
- Kogler, C; Rauch, P (2020b): **Game-based workshops** for the wood supply chain facilitate knowledge transfer, International Journal of Simulation Modelling, 19(3), https://doi.org/10.2507/IJSIMM19-3-526
- Kogler, C; Rauch, P (2020a): **Contingency plans** for the wood supply chain based on bottleneck and queuing time analyses of a discrete event simulation; Forests, 11(4), 1–23, https://doi.org/10.3390/f11040396
- Kogler, C; Rauch, P (2019): A discrete event simulation model to test **multimodal** strategies for a greener and more resilient wood supply, Canadian J. of For. Res., 49(10), https://doi.org/10.1139/cjfr-2018-0542
- Kogler, C; Rauch, P (2018): Discrete event simulation of multimodal and unimodal transportation in the wood supply chain: a **literature review**, Silva Fennica, 52(4), https://doi.org/10.14214/sf.9984
- Kogler, C; Beiglböck, A; Rauch, P (und review): An **empirical survey** on salvage wood logistics in Austria
- Kogler, C; Maxera, P (under review): A literature review of supply chain analyses integrating discrete simulation modelling and **machine learning**

1 SELECTED AWARDS

TEACHING

- Nomination for the Ars Docendi (**State Award for Teaching**) by the rectorate and student council of the University of Applied Sciences Campus Vienna, 2023
- **Manfred Schwanninger Prize** for outstanding commitment to innovative and high-quality teaching and learning materials, BOKU, 2022
- Teaching Award, **best practice blended learning project**, University of Applied Sciences Campus Vienna, 2022
- Nomination for the Ars Docendi by the rectorate and BOKU student council as well as inclusion of the developed course in the **Atlas of Good Teaching** of the Federal Ministry of Education, Science and Research (https://bit.ly/3rsczao)

RESEARCH

- **Dissertation Award** in the category energy and mobility,
  Austrian Federal Ministry for Digital and Economic Affairs, 2022
- **Best Paper Award**, City of Vienna Jubilee Funds, 2021
- International Communication Grant, Austrian Research Association, 2020-2023
- **Berkeley-Austria** Exchange Fellowship,
  Austrian Marshall Plan Foundation, University of California, Berkeley, 2020
- **Czech Republic-Austria** Exchange Fellowship AKTION,
  Ministry of Education of the Czech Republic, Brno University of Technology, 2023

2 Simulation Method

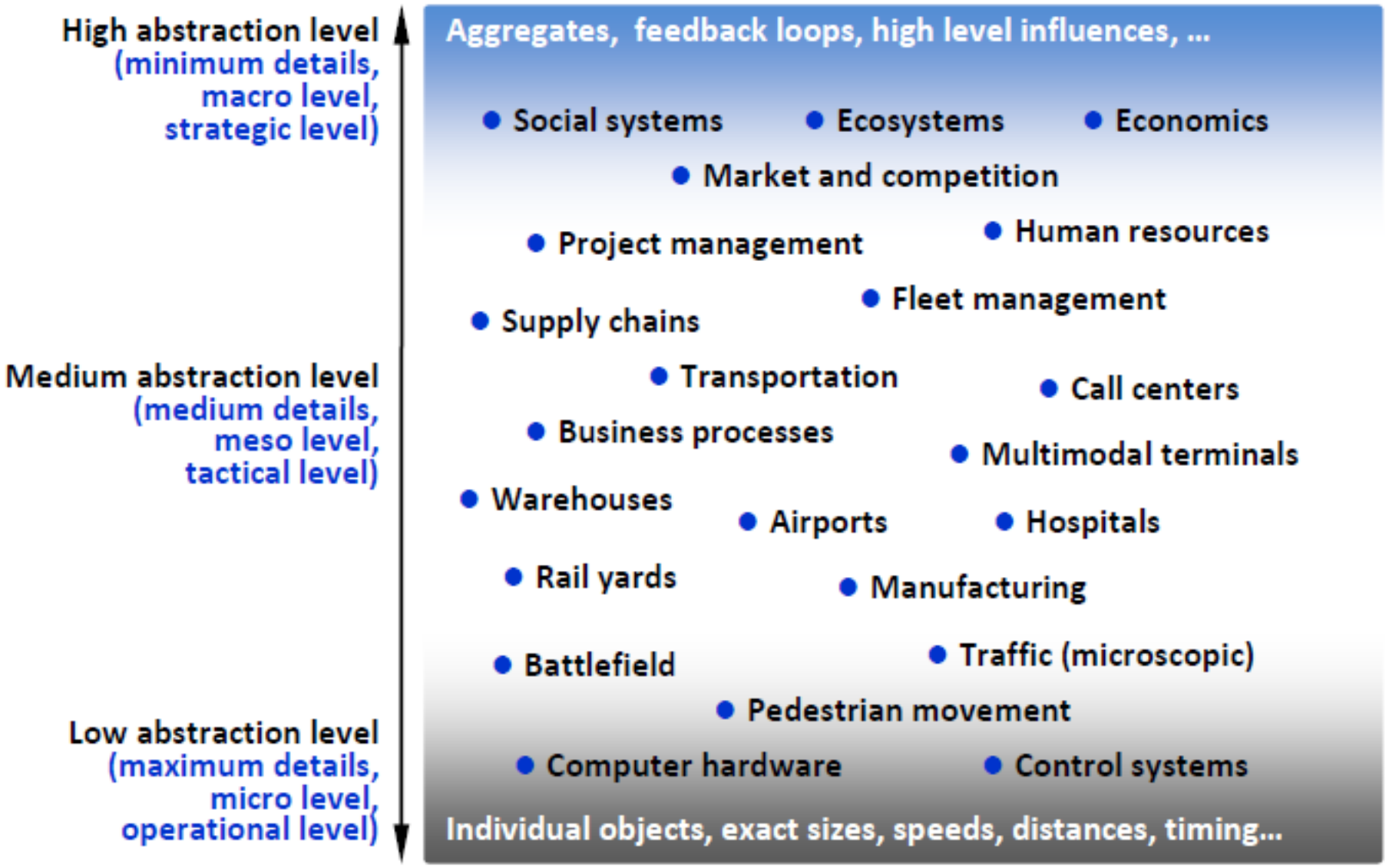
2 SIMULATION ADVANTAGES

- ✓ Provide **decision support** and solve real world problems, if **experiments with real objects** are difficult or **not possible** due to expense, danger, inefficiency, duration or other doubts
- ✓ **Analytic calculations** are complex (e.g., highly dynamic networks with unpredictable, simultaneous interaction) or **simply not possible**
- ✓ Simulation experiments facilitate a **better understanding** of the part of reality modelled
- ✓ Evaluating strategies in various **scenarios** to support decision making
- ✓ **Dynamic** (changing variables according to time) and **stochastic** (randomness of observations) systems
- ✓ Details and less relevant issues are **abstracted** to focus on important questions with **lower complexity**

2 Simulation Types

- Static vs. **dynamic**
- Deterministic vs. **stochastic**
- **Continuous** (System Dynamics) vs. **discrete (Discrete Event, Agent-based)**

2 Simulation Application Areas



2 DISCRETE EVENT SIMULATION

- ✓ Straightforward model structure enabling the mapping of **business processes** and control of the system by **events**
- ✓ Powerful method to contribute to a **better understanding** of the wood supply chain
- ✓ **Complex interdependencies** of the wood supply chain can be modelled and visually **illustrated in an animation** to demonstrate model internals to **stakeholders**
- ✓ Results for different model configurations and **what-if analyses** can be computed and compared providing managers with valuable decision support (**effects of decision before real, costly system changes are made**)
- ✓ Intermediate abstraction level and **powerful software** (AnyLogic, Java) offer universal extendibility with regard to other simulation (agent-based, system dynamics) and optimization approaches

3 Wood Supply Chain Management

Wood Supply Chain

- Comprises growing, harvesting, extraction, transporting, storing, (pre-) processing, (re-)using and recycling of wood
- Complex dynamic network consisting of various actors and material-, service-, financing- and information flows
- Due to unpredictable and simultaneous interdependencies not easily controllable

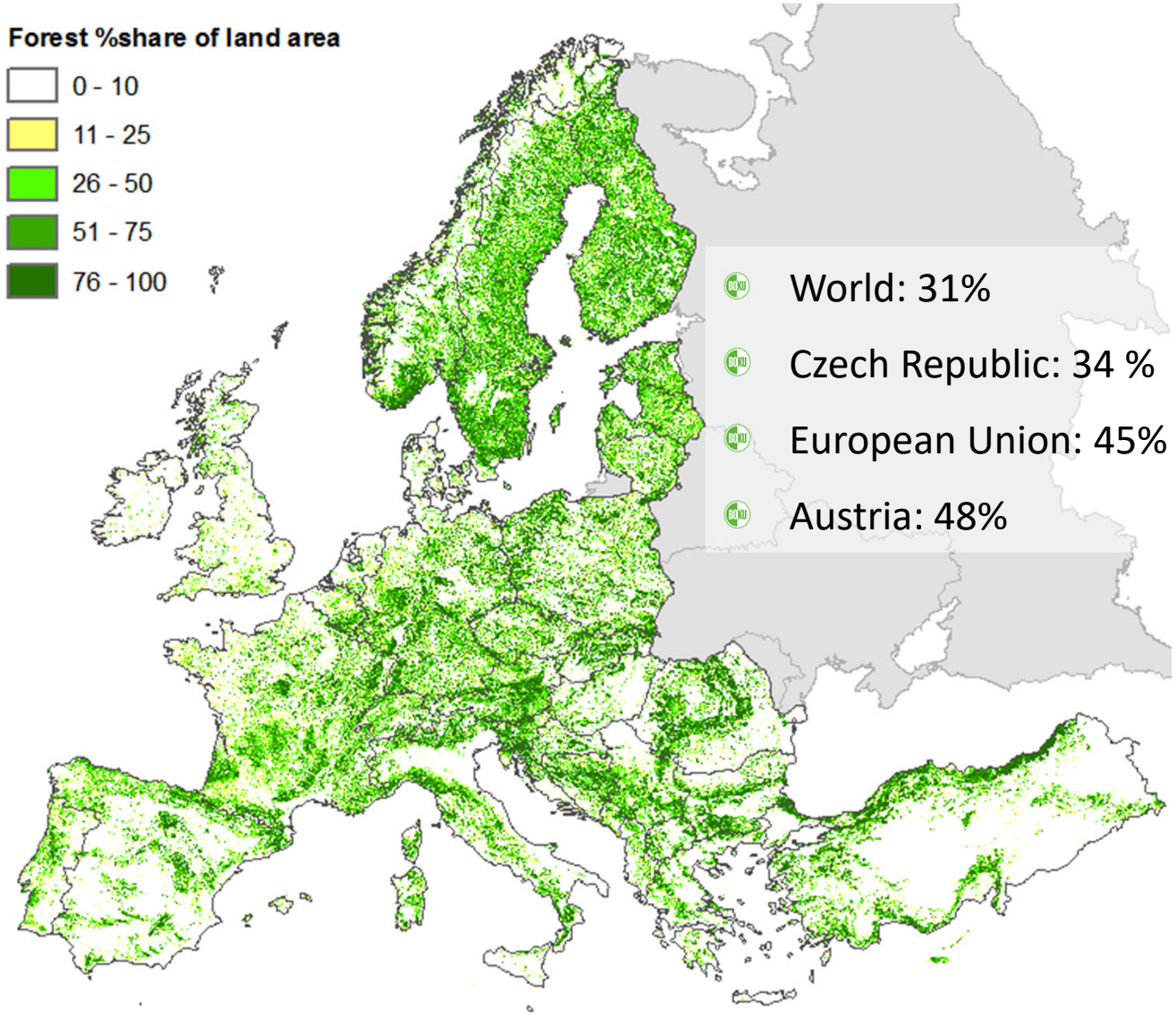
WSC Management

- Deals with relevant decisions to plan, design, operate, control and monitor the wood supply chain
- To improve sustainability and resilience from an economic, ecologic and social point of view
- Consider the competitiveness of the entire supply chain instead of optimization of the profit of individual actors (cherry picking: resulting in costs elsewhere)

WSC Research

- Focuses mainly on planning and design to improve the real world wood supply chain by operations research methods
- Simulation is an appropriate method to tackle the outstanding issues where analytic calculations fail or a straightforward model structure to communicate findings to stakeholders by animation is required

3 Land Area Covered with Forests



- World: 31%
- Czech Republic: 34 %
- European Union: 45%
- Austria: 48%

3 FORESTS IN AUT AND CZE

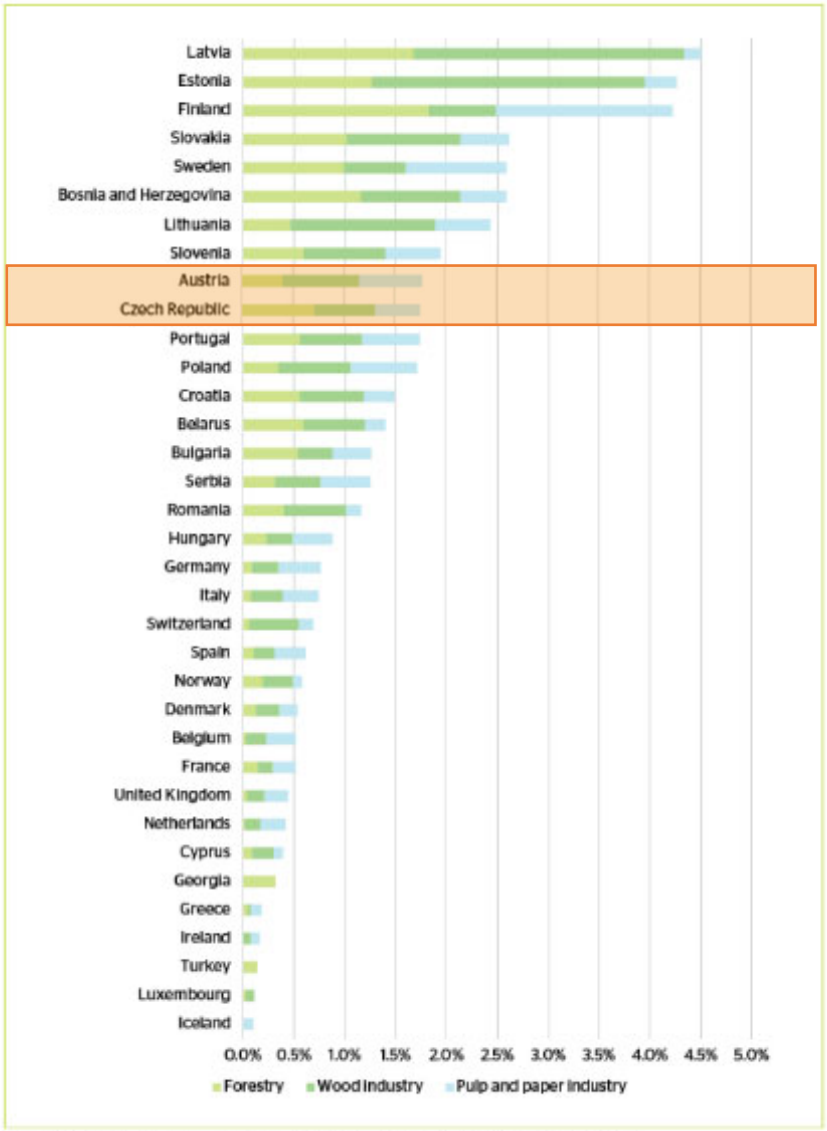


Figure 6.2-1: Contribution of the forest sector to gross domestic product, by country, 2015

3 FORESTS IN AUT AND CZE

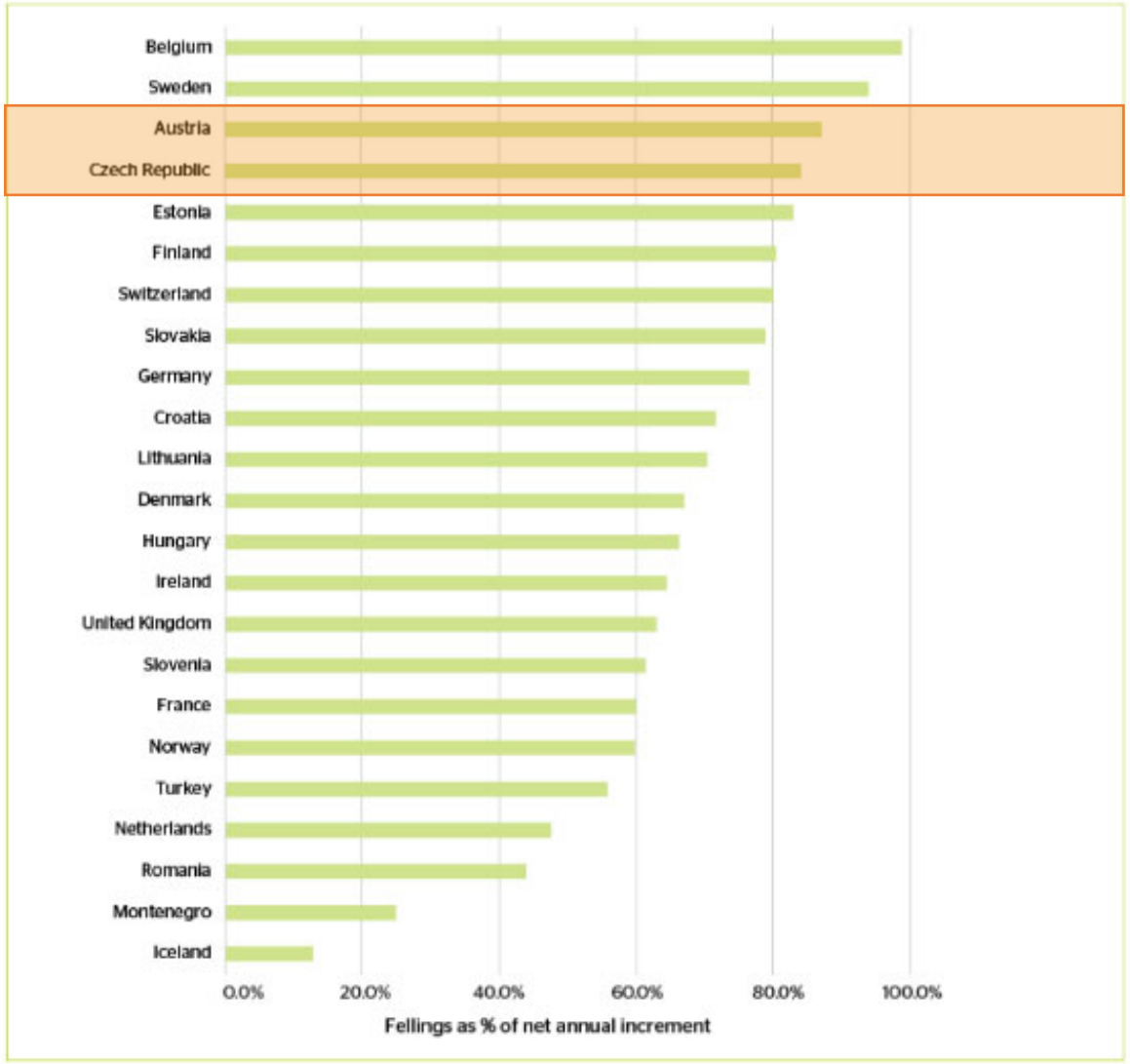


Figure 3.1-3: Fellings as a percentage of net annual increment, by countries, 2015

3 FORESTS IN AUT AND CZE

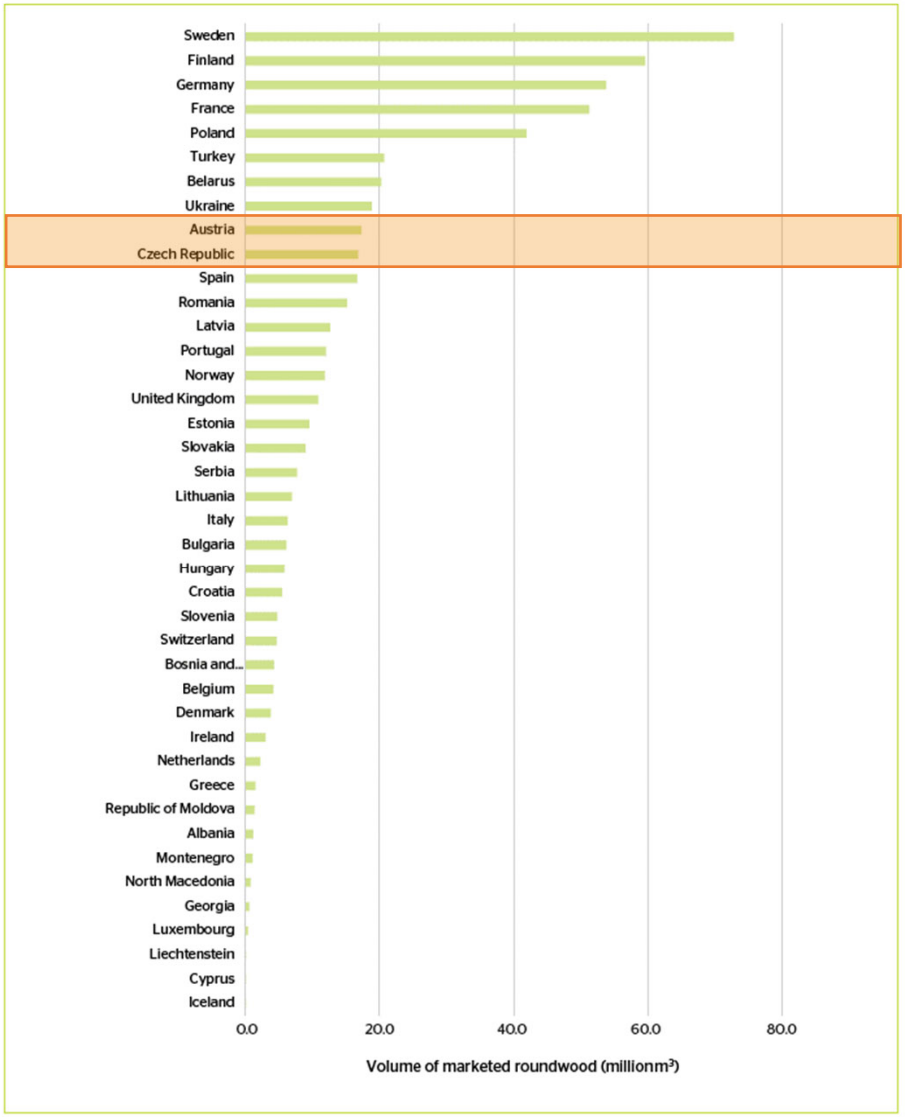


Figure 3.2-2: Volume of marketed roundwood, by countries, 2015 (averages 2013-2017)

3 Wood and Wooden Product Exports

Product : 44 Wood and articles of wood; wood charcoal

Table | Graph | Map | Companies

Download:

Select your indicators

HS4	Exporters	Value exported in 2021 (USD thousand)	Trade balance in 2021 (USD thousand)	Annual growth in value between 2017-2021 (%)	Annual growth in value between 2020-2021 (%)	Share in world exports (%)
	World	185,343,650	-5,206,447	6	39	100
⊞	Canada	22,528,265	18,675,004	9	68	12.2
⊞	China	18,613,077	-5,624,732	5	37	10
⊞	Germany	13,248,420	2,142,177	9	37	7.1
⊞	Russian Federation	11,748,518	10,942,856	7	43	6.3
⊞	United States of America	9,743,086	-25,776,988	-3	27	5.3
⊞	Austria	7,546,087	3,150,585	9	54	4.1
⊞	Sweden	6,596,190	4,249,029	10	52	3.6
⊞	Indonesia	4,925,173	4,470,059	3	30	2.7
⊞	Poland	4,773,454	1,726,990	-2	33	2.6
⊞	Belgium	4,639,809	407,146	12	39	2.5
⊞	Viet Nam	4,557,382	2,181,950	14	30	2.5
⊞	Brazil	4,494,977	4,365,530	10	43	2.4
⊞	Finland	4,463,650	3,232,346	5	59	2.4
⊞	New Zealand	3,899,073	3,455,414	1	33	2.1
⊞	Czech Republic	3,806,373	2,352,455	12	44	2.1

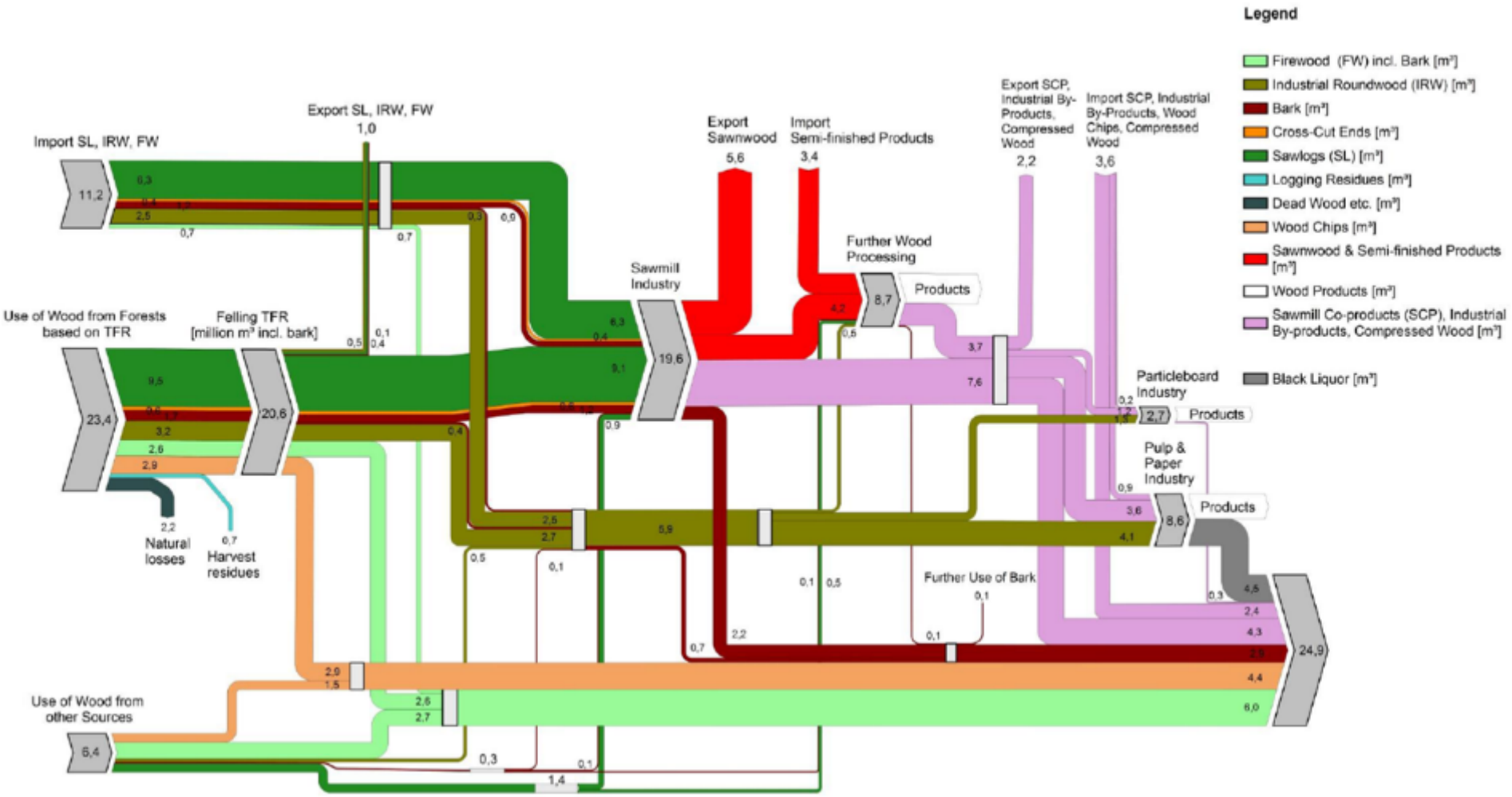
Area: Czech Republic: 79.000 km^2, Austria 84.000 km^2

Population: Czech Republic: 10,5 Mio., Austria 9 Mio.

3 Austrian Wood Value Chain

- **172,000 companies** along the value chain of forestry, wood and paper generate an annual production value of €12 billion
- **Worldwide Top 3 position** in wood export value per capita or country size
- **Strongly contributes** to achieve SDGs, Aichi Biodiversity Targets and Paris Climate Agreement
- **Examples for value added wood products**: glued structural timber components**,** wood constructions, prefabricated wooden houses, windows, doors, wooden floors, furniture, ski
- **Examples for mass products**: wood raw materials, sawn soft- and hardwood wood, wood chips, wood fuels, pellets, pulp and paper, wood-based panels

3 Wood Flows in Austria



All values given in million cubic meter (x35 for cubic feet)

3 General Problem Setting

Austria is a global leader in the field of

forest operations (cable crane logging on steep slope terrain),

advanced **wood energy systems** (pellets, biomass) and

value added **wood building products** (cross laminated timber)

BUT

High wood-procurement costs

due to **inefficient supply chains**

suffering from **risks** and **natural disturbances**

CONSEQUENTLY

The Austrian wood supply chain

needs to catch up regarding

professional supply chain management

(compared to other industries or nations)

3 WOOD SCM IN AUSTRIA

- **Traditional sector**, conservative, critical/resistant to change, small family-run businesses
- **Market power** (wood price highly influenced by windstorms) switches constantly between big forest owners (e.g. Austrian Federal Forests) and industry (purchasing group for paper) – difficult for small forest owners, sawmills, logging companies, truck and rail carrier
- **Cherry picking** and trench warfare of individual competing actors (instead of a focus on the overall supply chain performance in order to compete with other supply chains)
- Management is based on gut decisions, **rule of thumbs**, and simple Excel spreadsheets (collecting high amounts of data but not yet used for decision support, due to bad data quality and missing analytical skills)
- No (professional) wood supply chain **manager positions** (plan, design, operate, control and monitor wood supply chains and manage their material-, service-, financing- and information flows) but talented wood traders and truck carrier

3 CURRENT CHALLENGES

Windstorms followed by **bark beetle infestations**

produce high volumes of salvage wood,

which have to be quickly transported out of the forest

to limit further damage or wood value loss

(results in high wood procurement costs, long lead- and truck queuing times)

Other natural disturbances:

ice breaks treetops, avalanches, heavy rain, high snow cover

Supply chain risks such as

supply disruptions (bottlenecks, train wagon or truck availability, machine breakdowns) or

demand disruptions (delivery stops of mills, market prices changes, limited inventory)

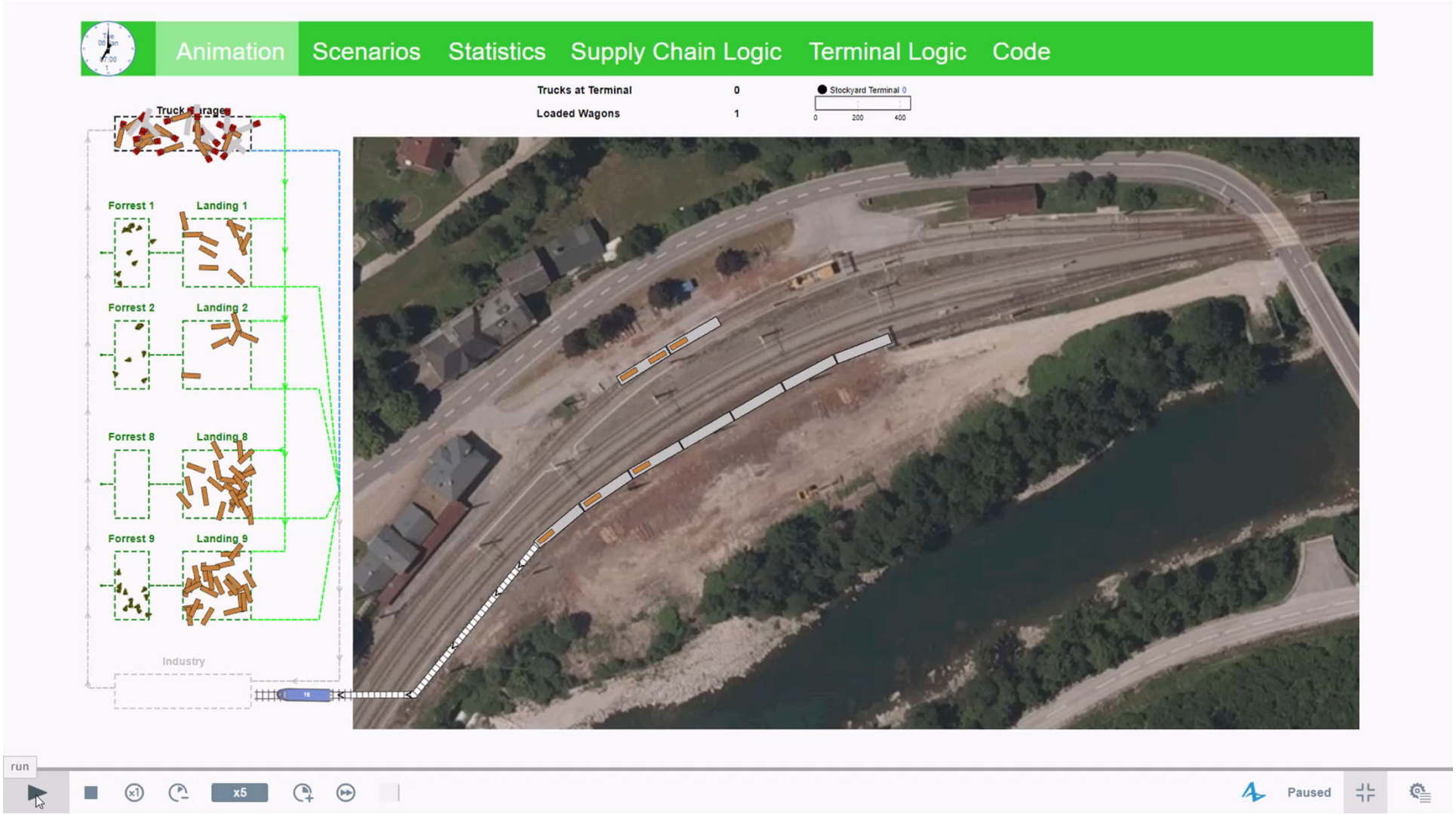
cause long recovery time to reach again a stable wood flow through the chain

(no contingency planning benchmarks)

3 LACK OF PROFESSIONAL SCM

- **Limited** cooperativeness between actors, short term contracts/planning, rapid price shifts
- Security of supply is **dropping** (critical bottleneck of crane truck drivers and carriers)
- Locational **disadvantages** (working hours, limited truck load to 40t vs. 60t in Scandinavia)
- **Reliability** of train carrier (number of available train terminals and wagons, prices)
- **Missing** risk management and contingency planning (empirical knowledge)
- **Uncertainties** according to important KPIs such as queuing- and lead times, logistic-capacity bottlenecks, stock levels, utilizations
- **Lack** of data driven decision support and customized software solutions

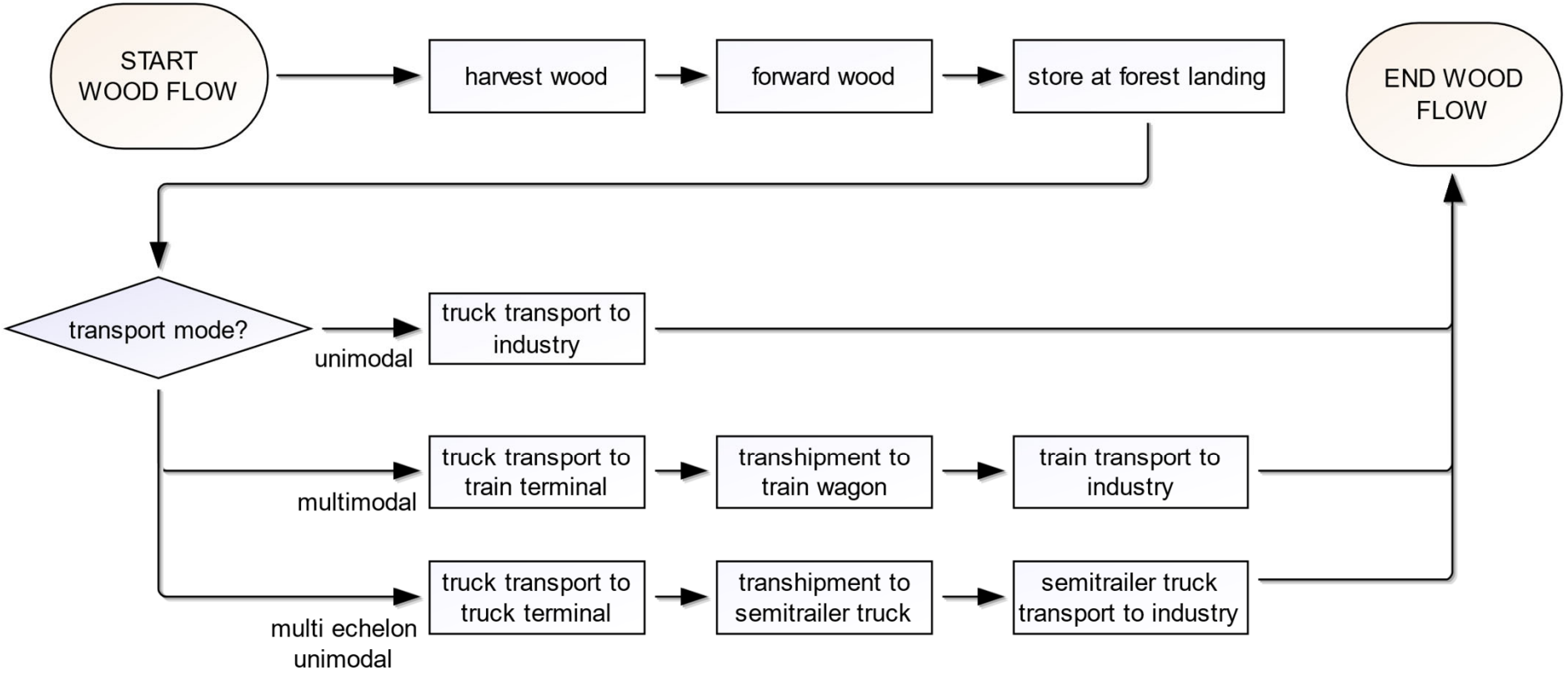
4 DES Models Examples



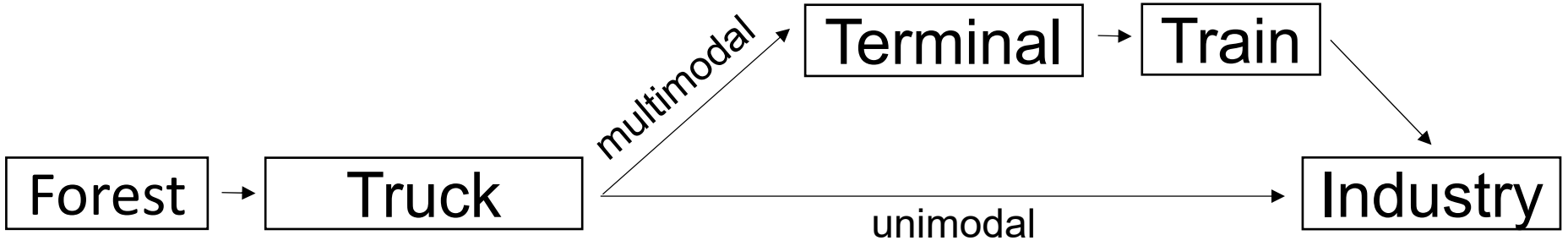
4 DES Model

Challenge	Solution
"Natural disturbances challenge the management of the Austrian wood supply chain due to irregularities in wood harvest and transport!"	"Innovative multimodal system via rail and truck terminals offer the potential to increase buffer capacity and to reduce CO_2 emissions."
"Should wood be transported unimodal, multi echelon unimodal or multimodal?"	"A simulation model allows to test new strategies to support decisions."
"It is difficult to measure network capacity and detect bottlenecks to ensure efficient and smooth flows in the chain!"	"The simulation model shows the maximal capacities and points out, which parts are the most critical ones."
"Only rough estimations exist about real lead- and queuing times in Austria!"	"In a discrete event simulation every entity (log) can be tracked to calculate KPIs for different scenario settings."

4 TRANSPORT MODES



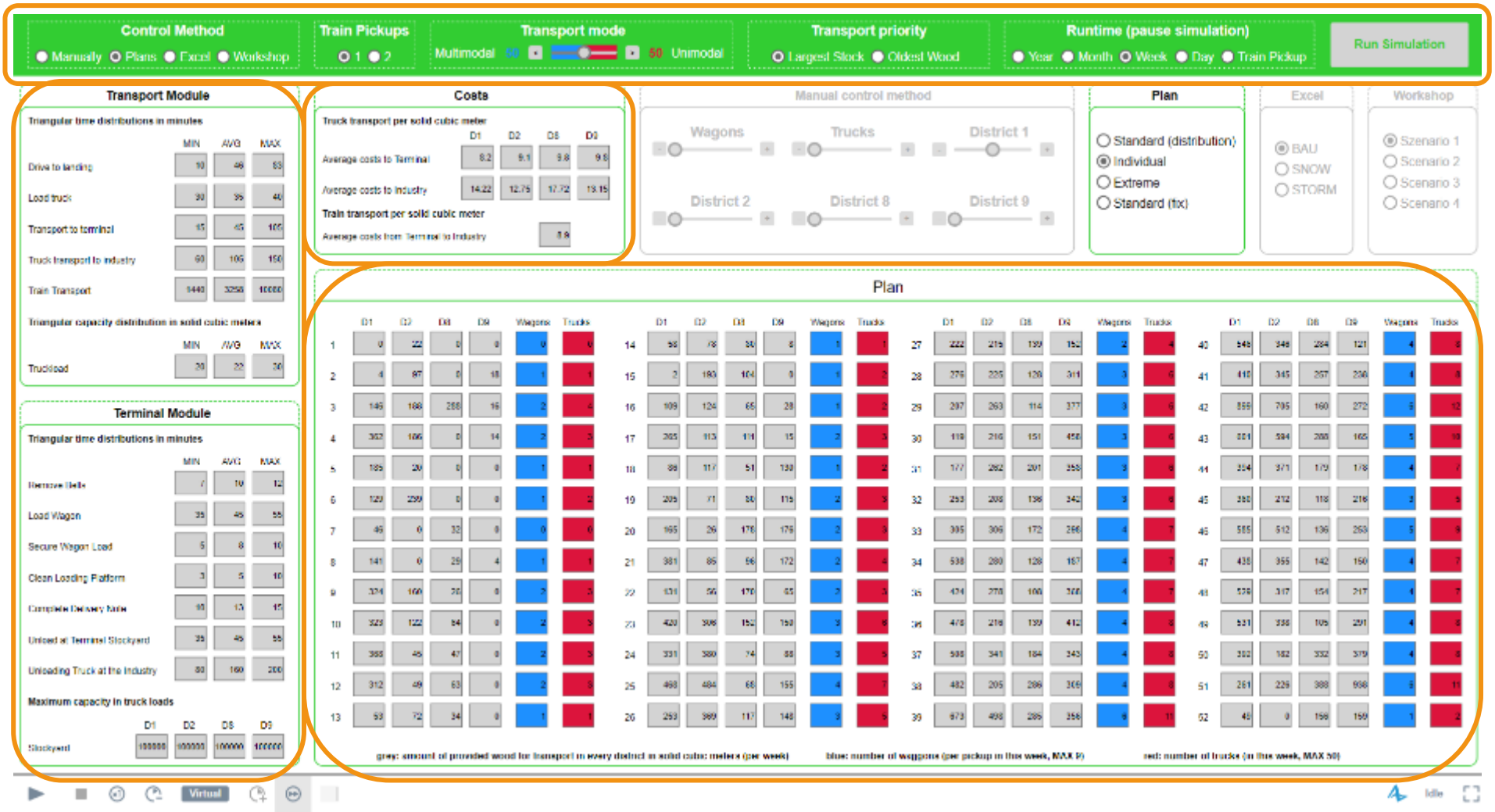
4 Multimodal Wood Transport



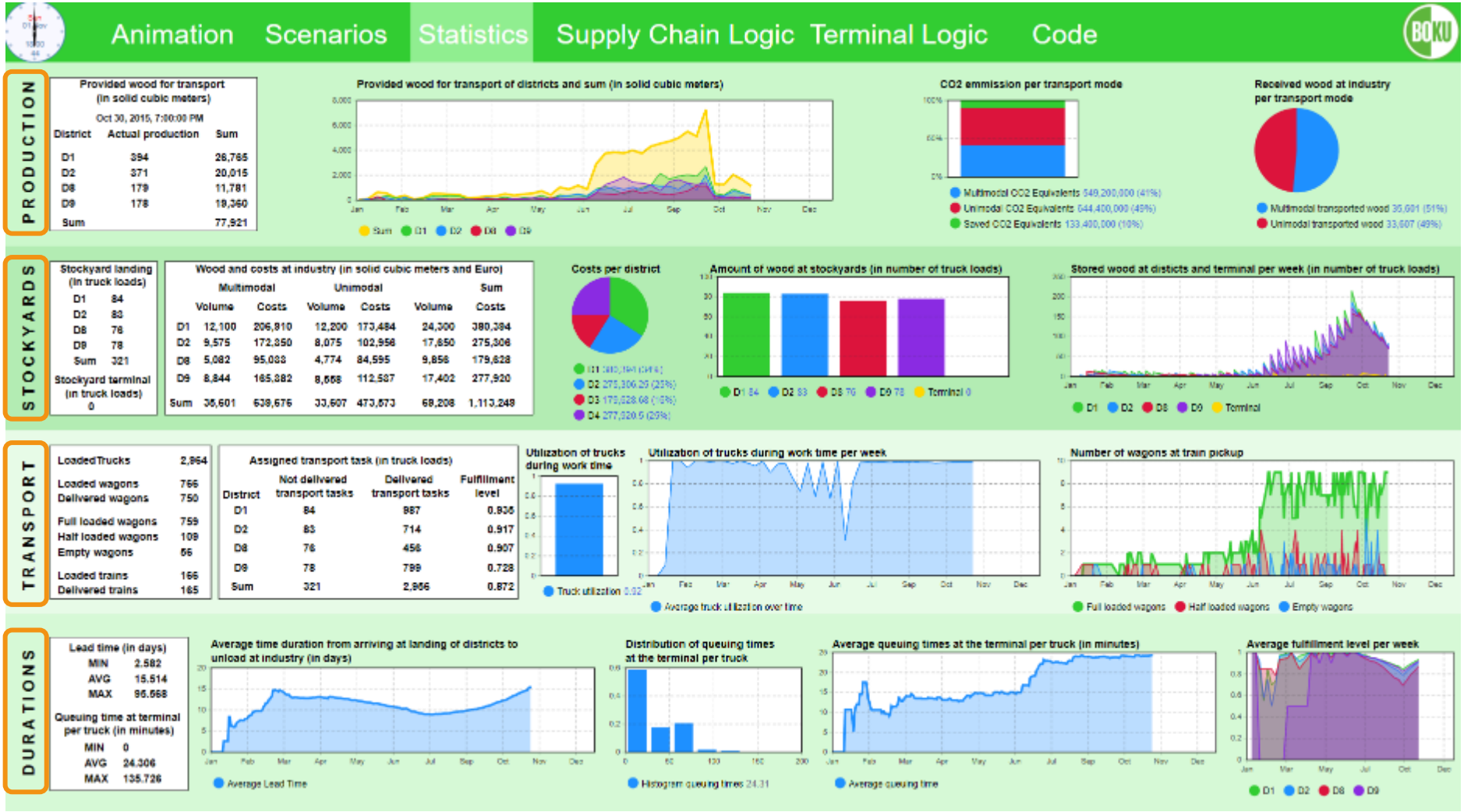
6 Views

- Animation
- Scenarios
- Statistics
- Supply Chain Logic
- Terminal Logic
- Code

4 Parameterization View



4 MANAGEMENT COCKPIT



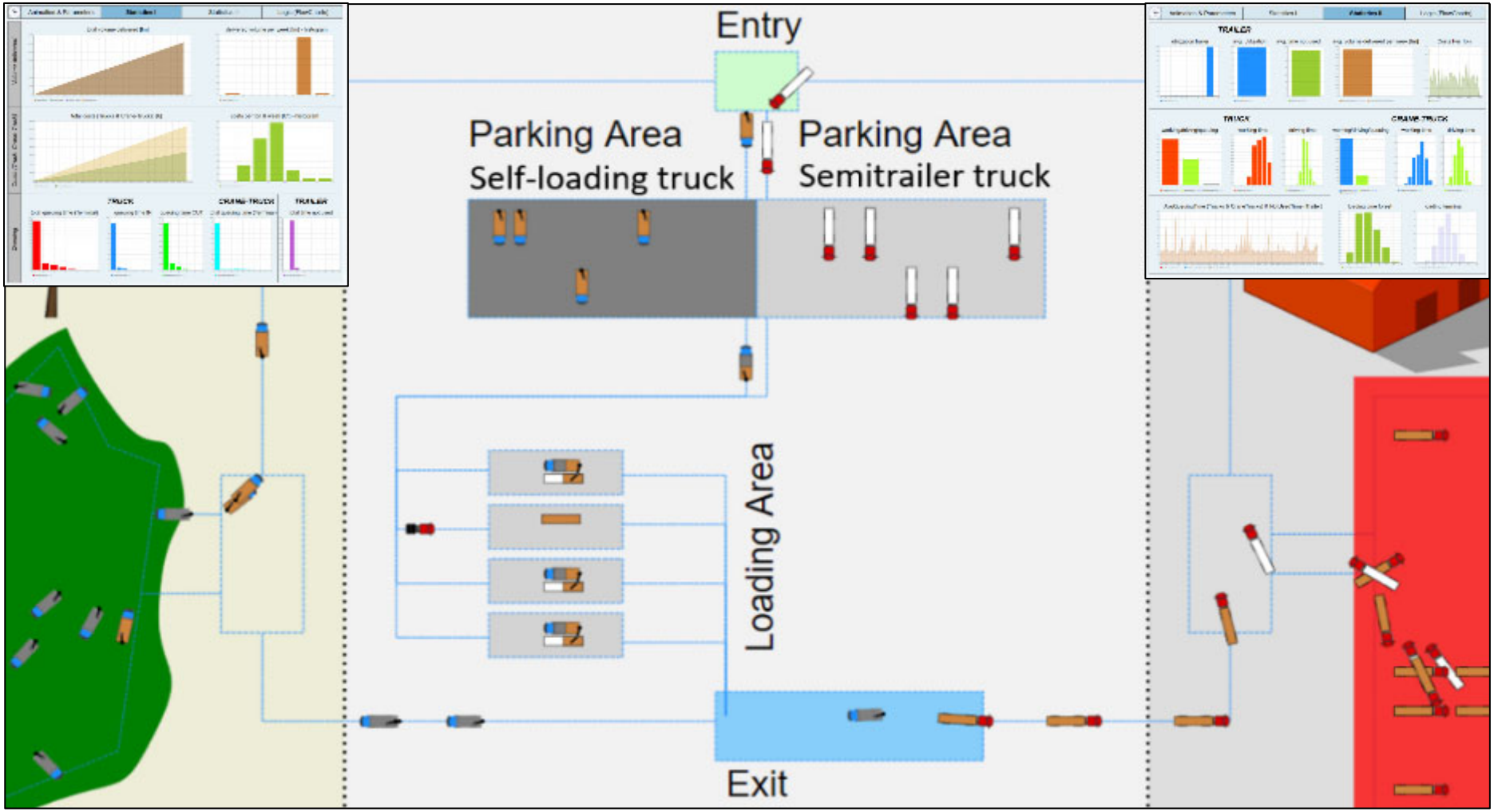
4 Areas of Application

BAU	**Improve business as usual** find best fits for default harvesting volumes and transport orders according to given key performance indicators (costs, lead time, utilization,…) and prevent bottlenecks
TEST	**Test new strategies** adopt to changed conditions and see effects of decision before real, costly system changes are made
RISK	**Manage risks** prepare contingency plans for natural disaster (windthrows), delivery stops of mills, machine breakdowns, no train wagon availability, legislative changes,…

Simulate different system configurations

- ✓ number, capacity and service periods of trucks
- ✓ number and timing of train pickups
- ✓ number, capacity and availability of wagons
- ✓ harvesting volumes
- ✓ transport orders
- ✓ parameter of time distributions for service, transport, processing,…
- ✓ strategy of job selection for trucks like low lead time, low stockyard, delivery precision,…

4 Multi Echelon Unimodal Transport



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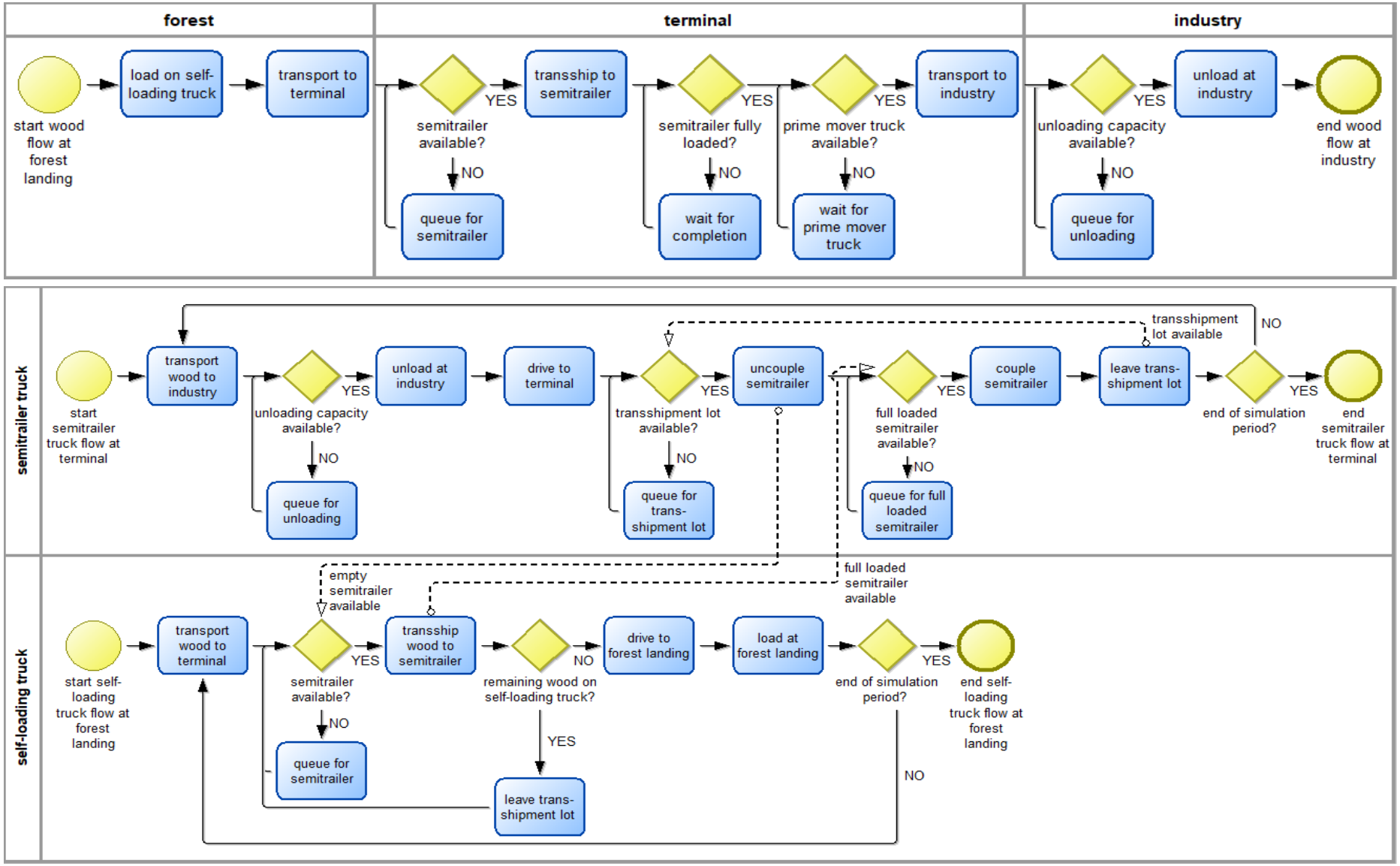
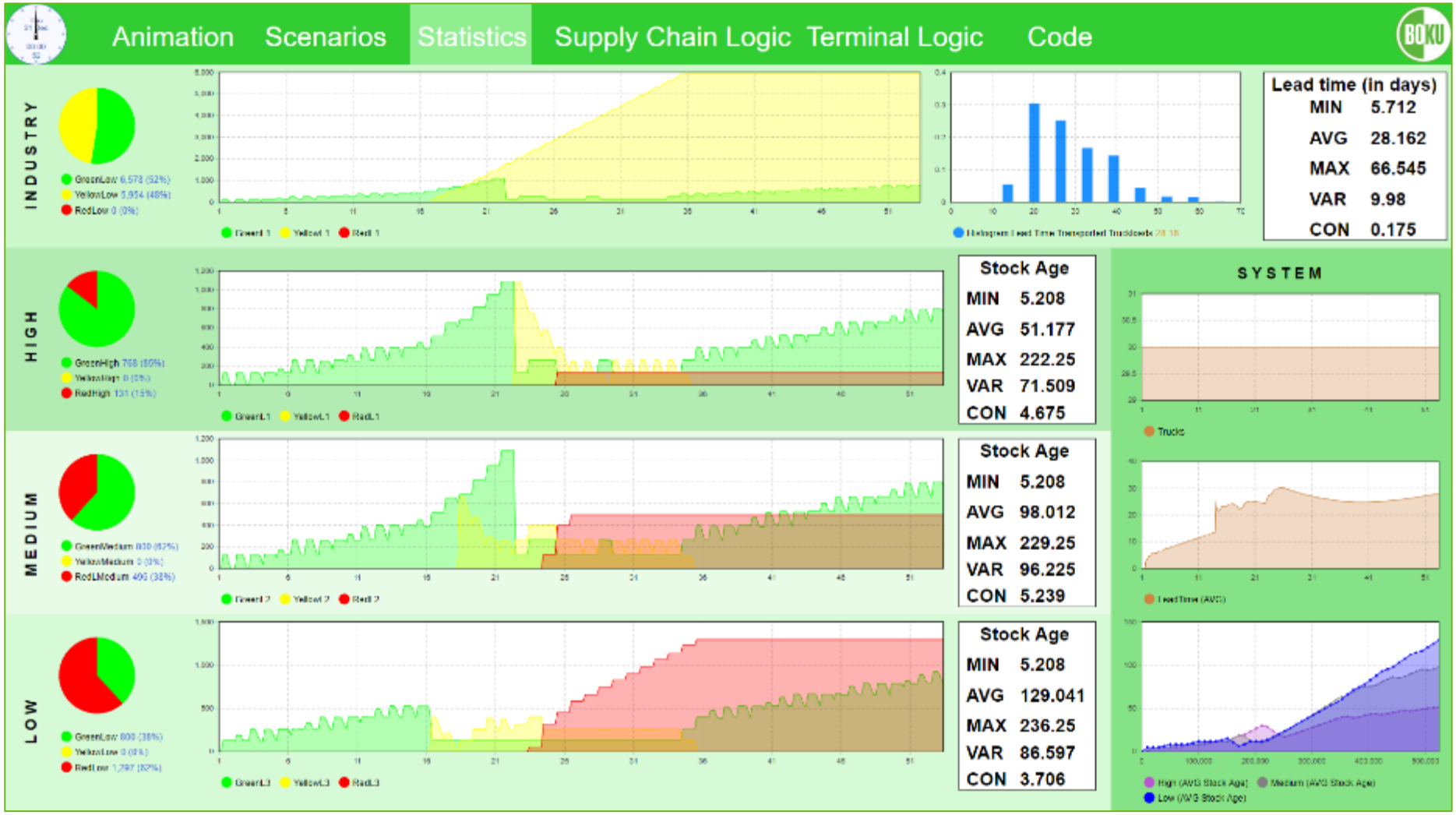


4 Multi Echelon Unimodal Transport

- Optimal results regarding the truck fleet deduced by full enumeration outperformed unimodal transport cost benchmarks for short, medium and long distances by **5.45%, 6.95% and 11.28%**, respectively.
- Results show significant cost savings with increasing terminal size for the same turnover, because of **shorter waiting times and increasing flexibility at the terminal**.
- Varying transport distance as well as terminal size and utilization scenarios provide valuable **decision support for contingency planning after natural disturbances** for various regions.
- In a multi echelon unimodal wood supply chain **less self-loading trucks are needed compared to a unimodal wood supply chain**, because of shorter transport times.
- **Higher truck payloads** increase this effect and reduce transport times, queuing times, costs as well as the number of self-loading trucks employed and consequently provide an additional strategic option to **mitigate truck driver bottlenecks after natural disturbances**.

4 Quality-preserving Wood Transport

4 QUALITY-PRESERVING WOOD TRANSPORT



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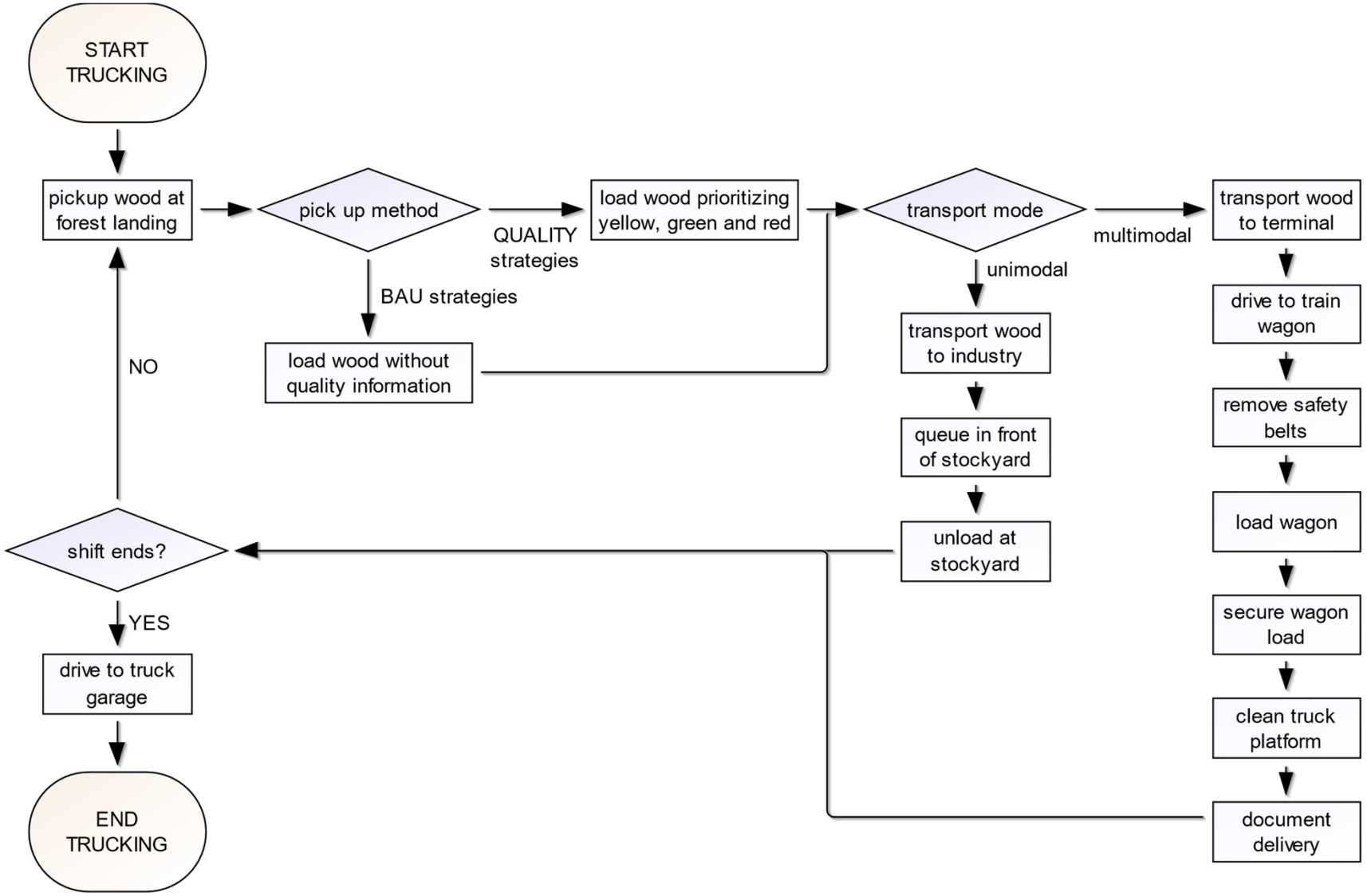

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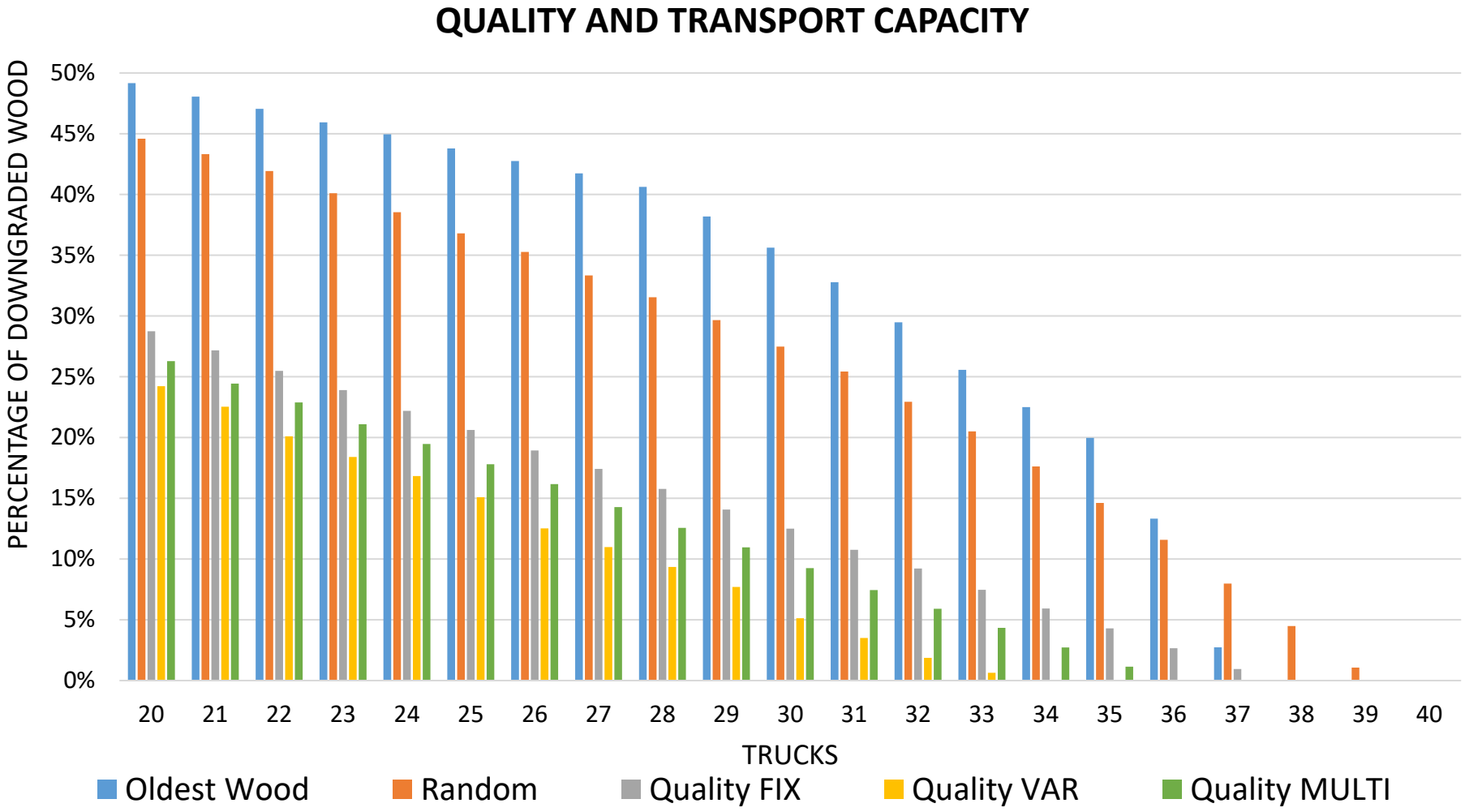
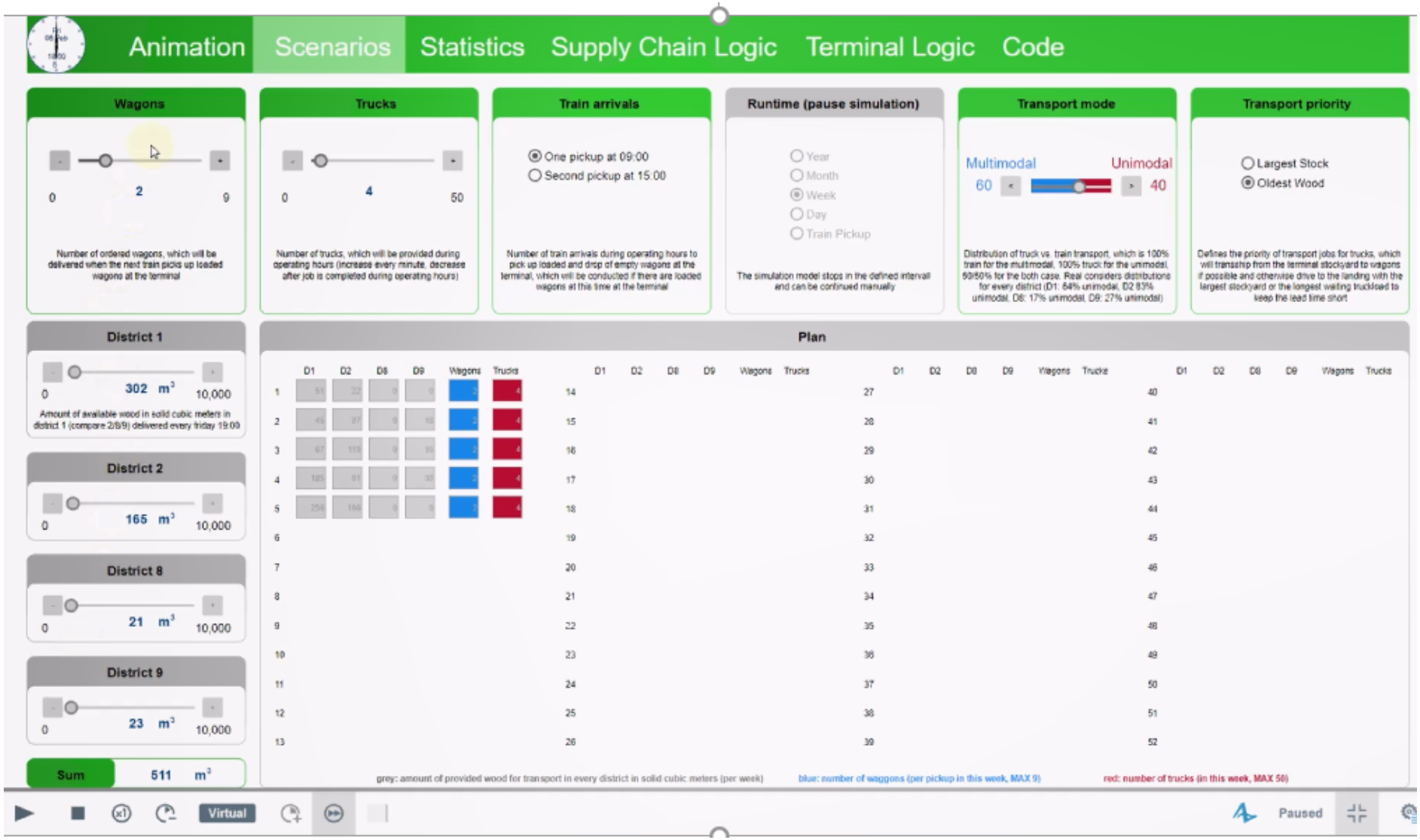


4 QUALITY-PRESERVING WOOD TRANSPORT

- New transport strategies prioritizing wood at high devaluation risk prevent **57%** (Quality FIX), **67%** (Quality MULTI) and **73%** (Quality VAR) wood value loss in the case study region.
- Regression analyses proved that **lead time** is a significant predictor for the amount of downgraded wood, explaining over **98% of the variance of downgraded wood** in supply chains ($p < 0.001$).
- Roundwood quality loss is tolerable for lead times of up to **3 weeks**, but quality deteriorates substantially with longer lead times: 4 (5–10%), 5 (10–15%), 6 weeks (20–25%).
- **Multimodal wood transport** reduces supply chain risks (buffer capacity), supply chain challenges (bottleneck of self-loading truck drivers) and effects of climate crisis (CO_2 emissions)
- The developed virtual wood supply chain environment provides **robust decision support** for smart, resilient and sustainable wood supply chain management.

4 CONTINGENCY PLANNING WORKSHOP



5 COOPERATION GOALS AKTION AUT-CZE

GENERAL

Conduct research on simulation and artificial intelligence

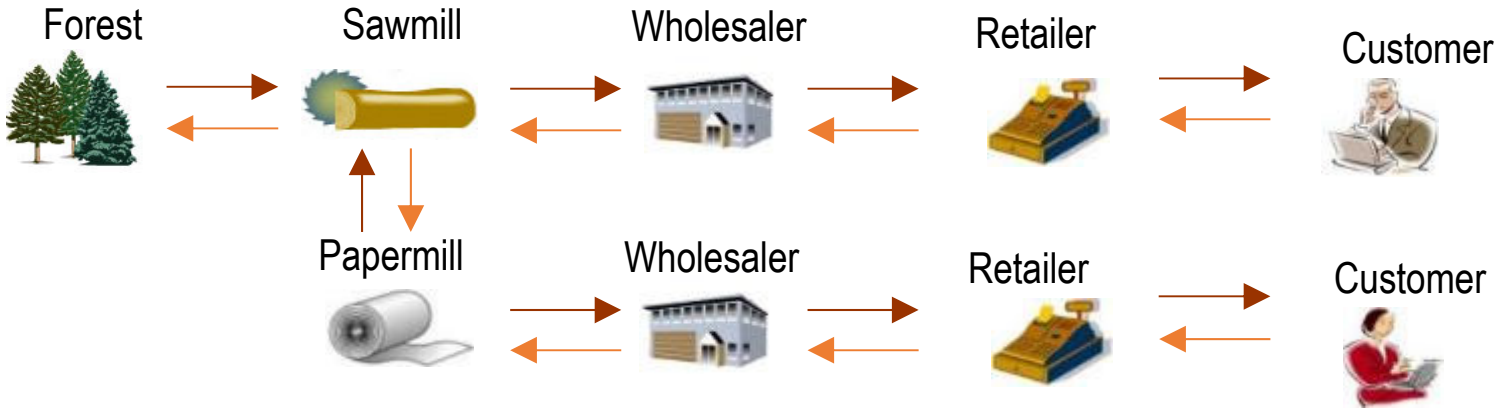
- Submitted: A literature review of supply chain analyses integrating discrete simulation modelling and machine learning
- Work in Progress: Freight Transportation and terminal logistics with discrete simulation
- Next steps: Forest crane truck risks analysis, SWOT analysis in the forest-based industry

SPECIFIC

- Research stays at the Institute of Production and Logistics at BOKU Vienna as well as the Institute of Forensic Engineering at TU Brno
- Applying for project funding: EU-EraNet, Interreg, AKTION
- Develop Teaching concepts for supply chain management and logistics: Example: Wood Supply Chain Competition 2024 in Brno?

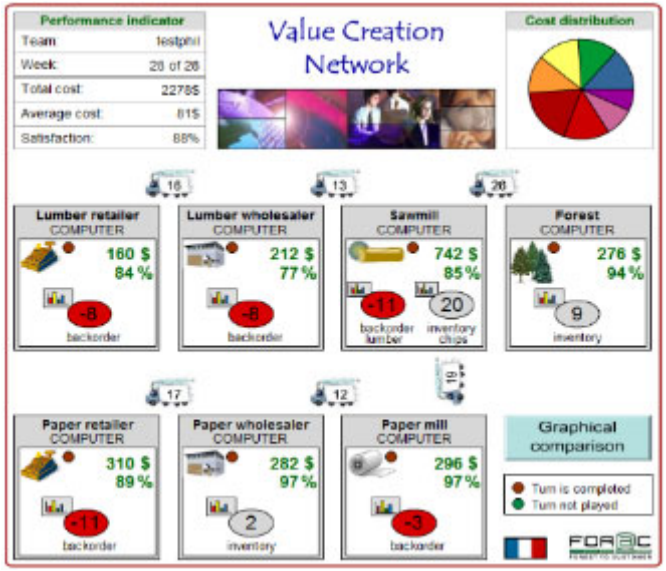
5 Wood Supply Game

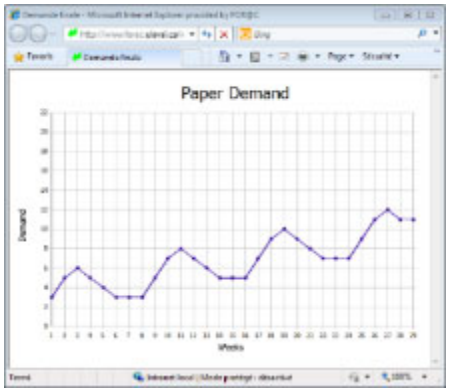
- Learning through **serious game**
- Supply chain simulation adapted (**FORAC**) from the MIT Beer Game
- Help understand the **bullwhip effect**
- Show the **benefits of collaboration** and information sharing
- Show that collective results of **working in silos** can be catastrophic
- Allows to experiment **team work** at management level

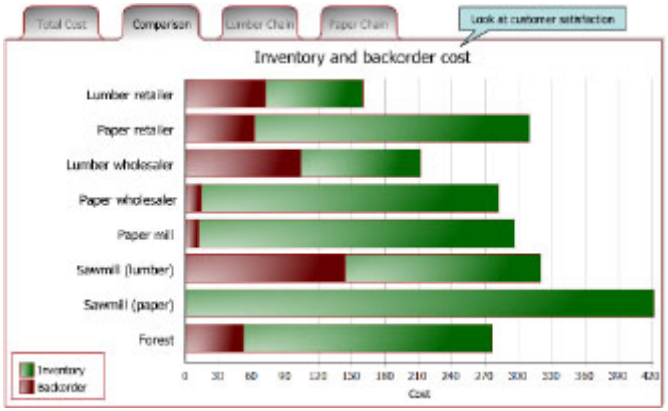


5 Wood Supply Game

- Each participant plays a **decision maker** in one company of the supply chain
- You **place orders** to your supplier to satisfy your own customer' orders
- You want to **minimize inventory and backorder costs**
- **Free online** serious game (www.forac.ulaval.ca/woodsupplygame)

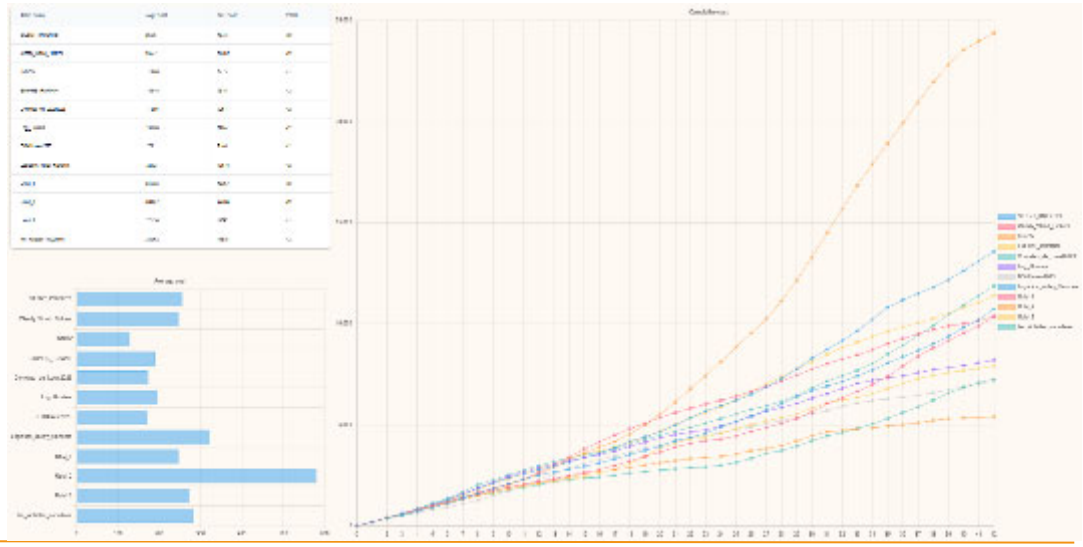






5 International Competition

- Game time (<12 hours) in a given day (next **April 2024**)
- To get prepared, teams **develop decision support tools** and strategies considering demand forcasting, inventory management, probability, and lean management
- In the past there were **teams from around the world** (Canada, Sweden, USA, South Africa, Austria, France, Finland and United Arab Emirate, Sri Lanka, Belgium, …)
- A web site show **teams progress in real time**



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[4] https://doi.org/10.14214/sf.9984

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[6] https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf

[7]https://www.trademap.org/Country_SelProduct.aspx?nvpm=1%7c%7c%7c%7c%7c44%7c%7c%7c2%7c1%7c1%7c2%7c1%7c1%7c2%7c1%7c1%7c1

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[17] https://doi.org/10.2507/IJSIMM19-3-526

[18] www.forac.ulaval.ca/woodsupplygame

QUESTIONS?

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- Supply Chain Management
- Discrete Event Simulation
- Business Process Modelling
- Wood-based Industry
- Transportation
- Logistics