Optimizing the layout of an existing forest road network in trafficable terrian

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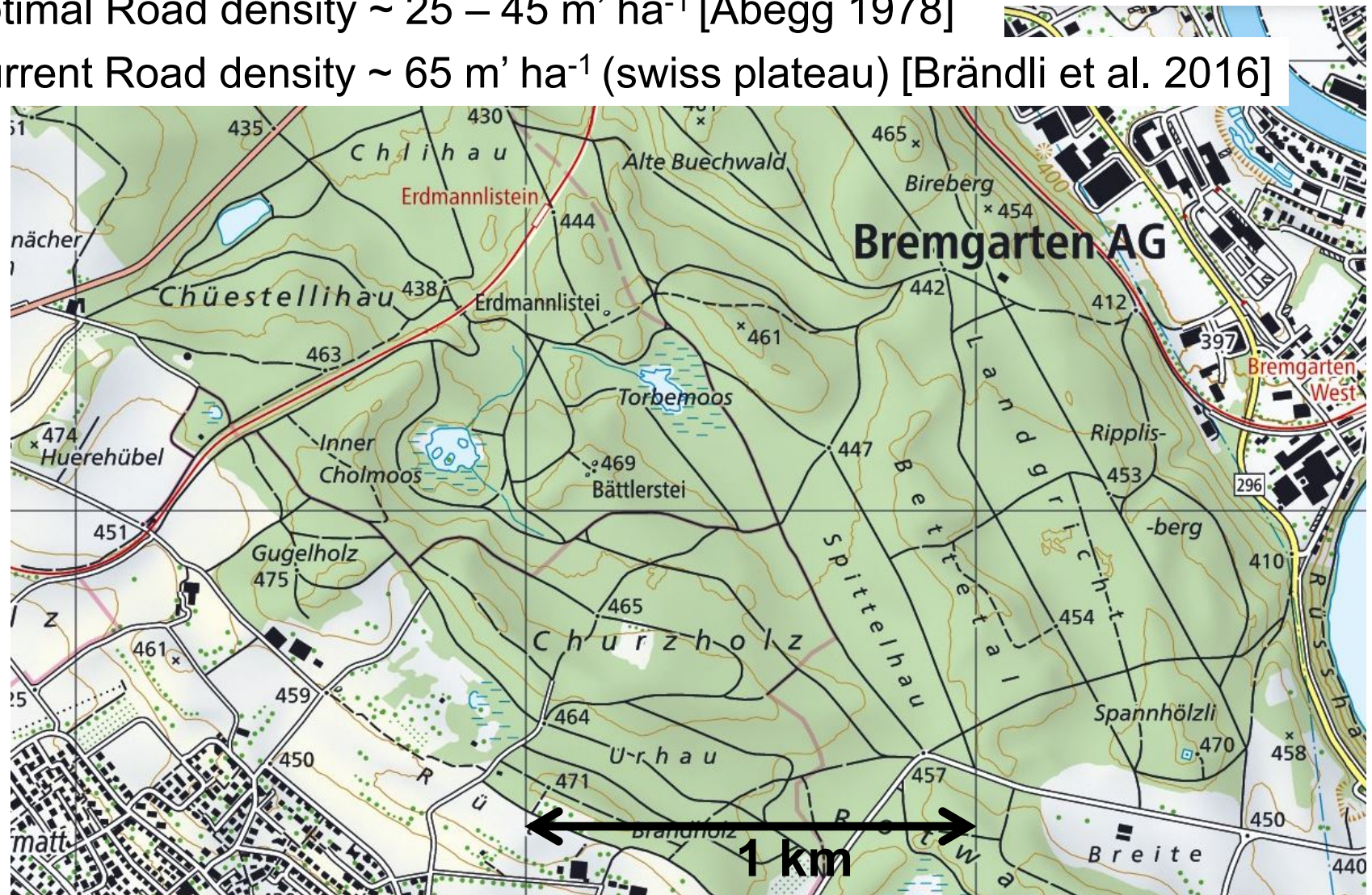
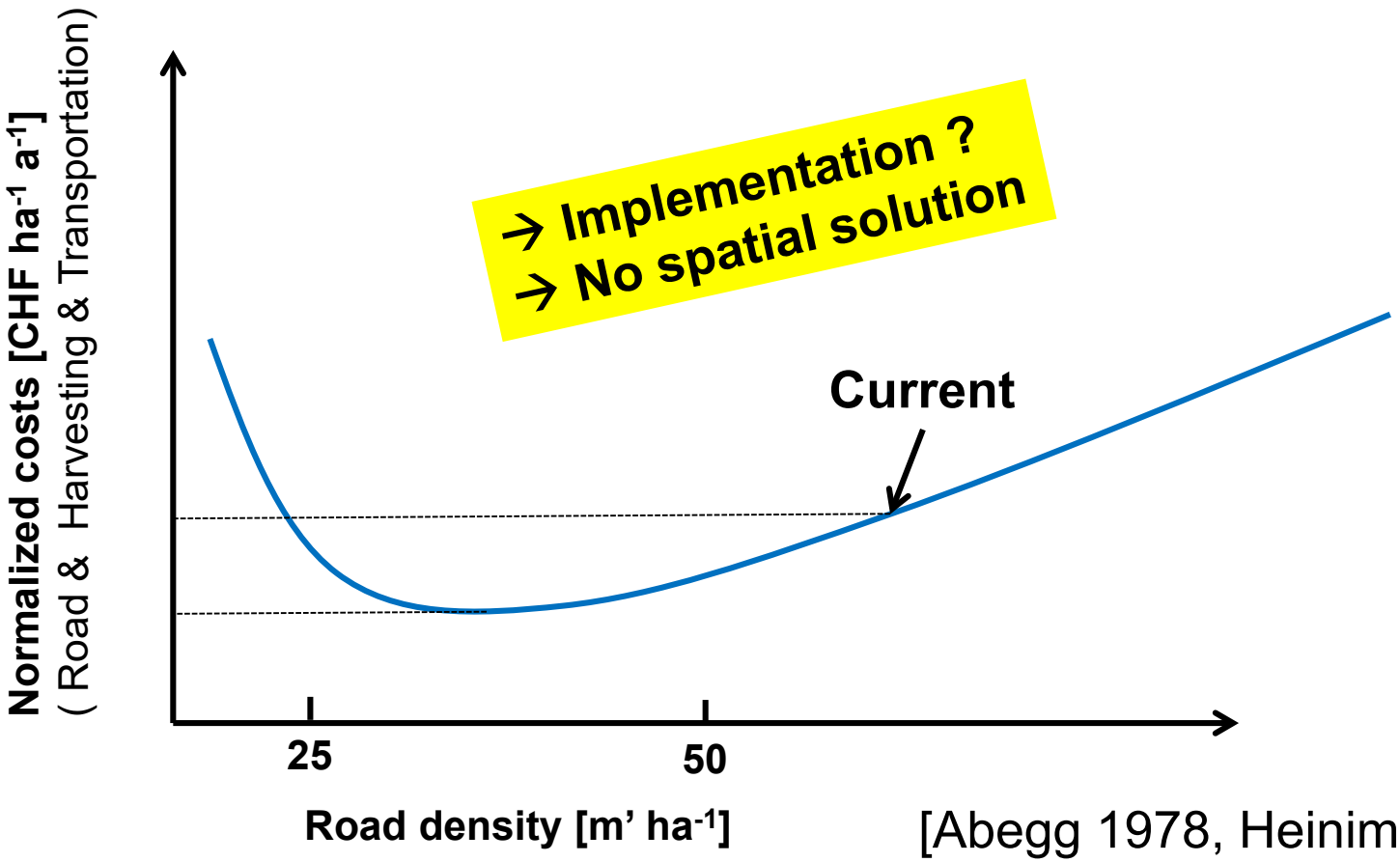
Problem: Forest roads to keep / shut down ?

Optimal Road density ~ 25 – 45 m' ha^{-1} [Abegg 1978]

Current Road density ~ 65 m' ha^{-1} (swiss plateau) [Brändli et al. 2016]

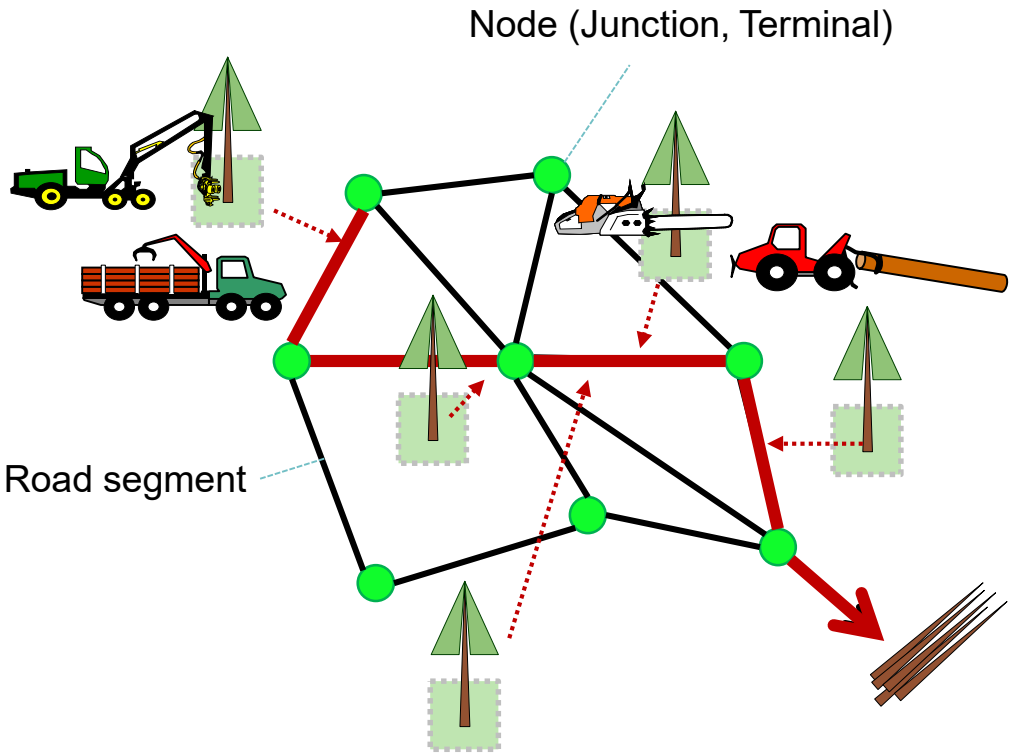


Optimal Range of Road Density



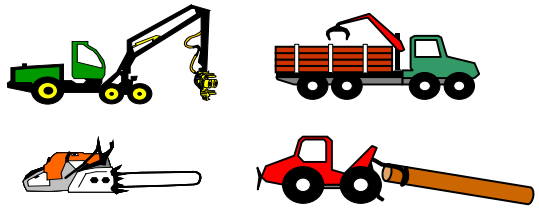
[Abegg 1978, Heiniman 1998]

Problem: Road Network Design



Decisions:

- Set of road segments (Keep / Shut down)



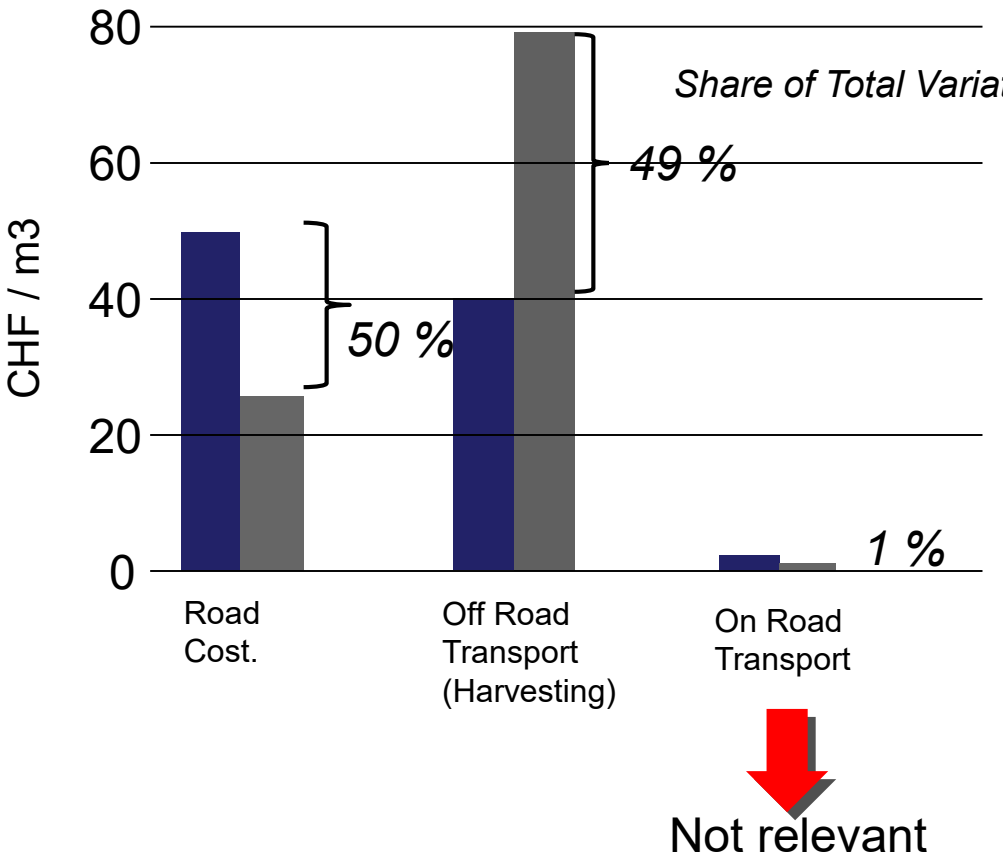
- Harvesting technique & path

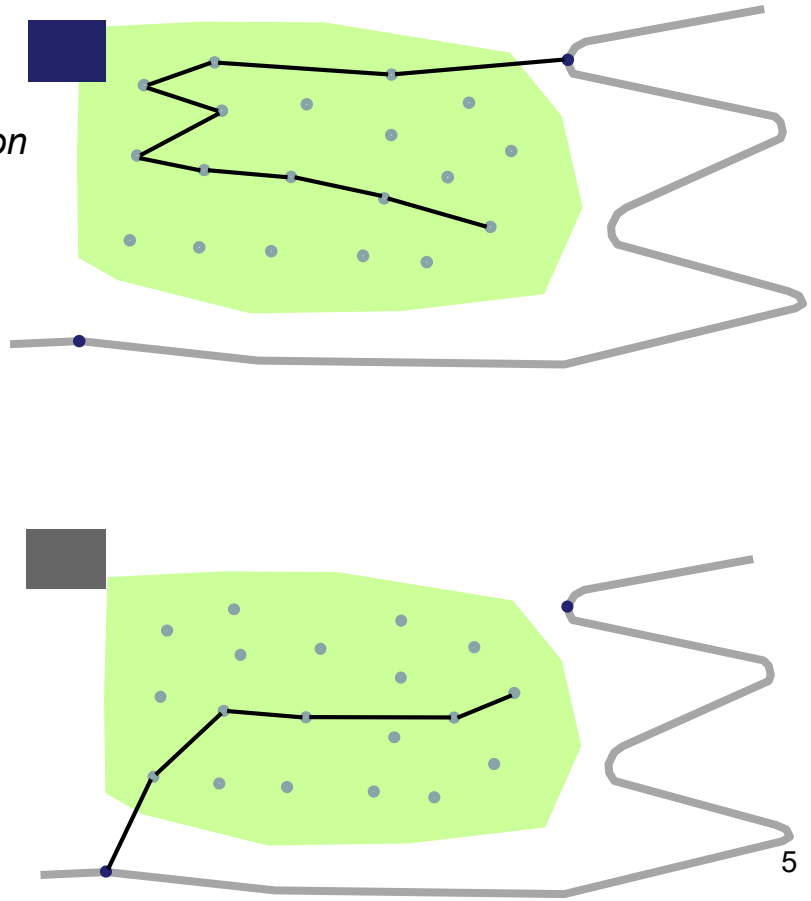
[**Constraints**]
Harvest Each Parcel

Optimization objectives

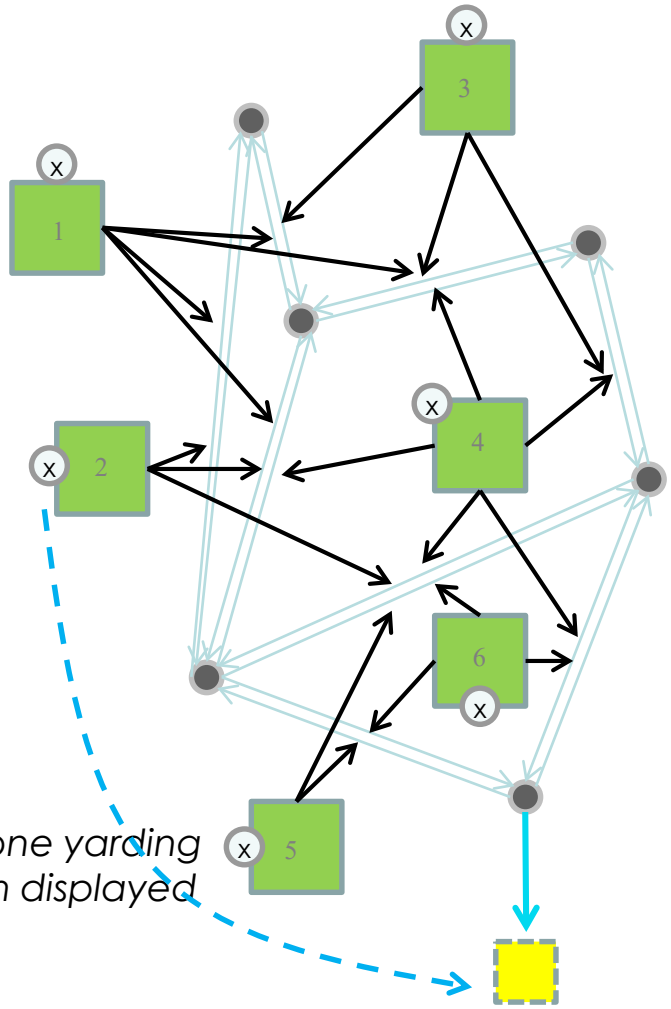
Minimize

1) Off Road Transport Cost
2) Road Cost (Construction, Upgrade, Maintenance)
3) ~~On Road Transport~~





Network representation



Construction

- Road segment
- Exit Road segment
- Node

Off road transport

- skidding route
- Alternative Harvesting

Objec.: Min !

Interfaces

- Timber parcel (TP)
- Virtual pile (VP)

Constr.: Link all TP → VP

Objective Function

Mixed Integer Linear Programming

Road Segments

Harvesting / Alternative

Min: $$\sum_{r \in R} c_r^{RS} y_r^{RS} + \sum_a c_a^S y_a^S + \sum_{b \in G} \sum_i c_{ib} x_{ib}$$

Road Cost

Extraction Cost

Constraints (Simplified)

$$\sum_{b \in G} x_{ib} = 1$$

Each timber parcel i has to be harvested

$$\sum_{r \in M_i^b} y_r^{RS} \geq x_{ib}$$

$$y_r^{RS} + y_{r-1}^{RS} \leq 1$$

$$y_r^{RS} + y_{r-1}^{RS} + y_z^{RS} + y_{z-1}^{RS} - y_a^S \leq 1$$

Constrains Timber Flow from Timber Parcels to Exit and construction of the road segments

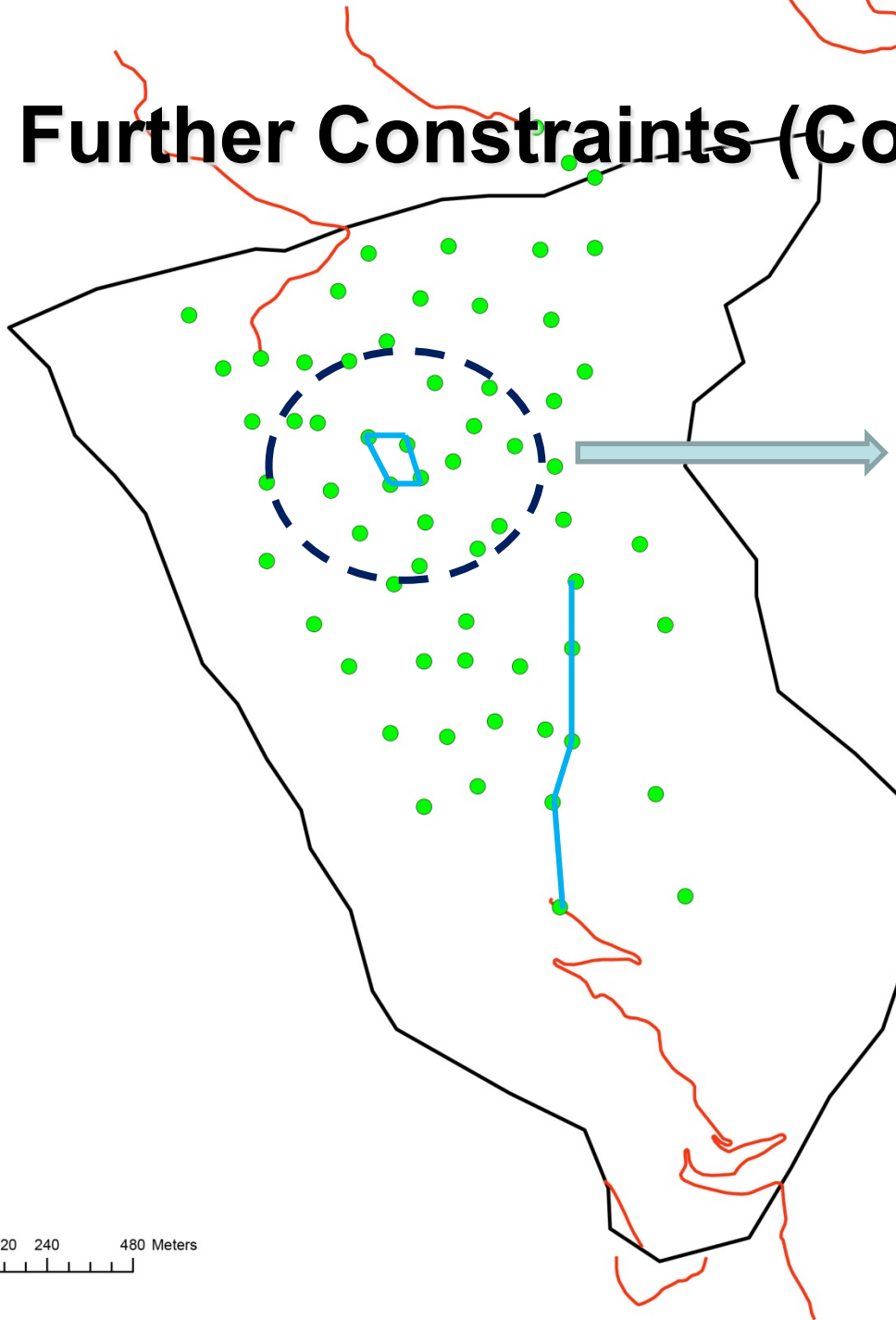
$$y_r^{RS} \in \{0,1\}$$

$$x_{ib} \geq 0$$

Variables:

y_r^{RS}: Construction Road Segment {1,0}
x_{ib}: Harvest Timber Parcel

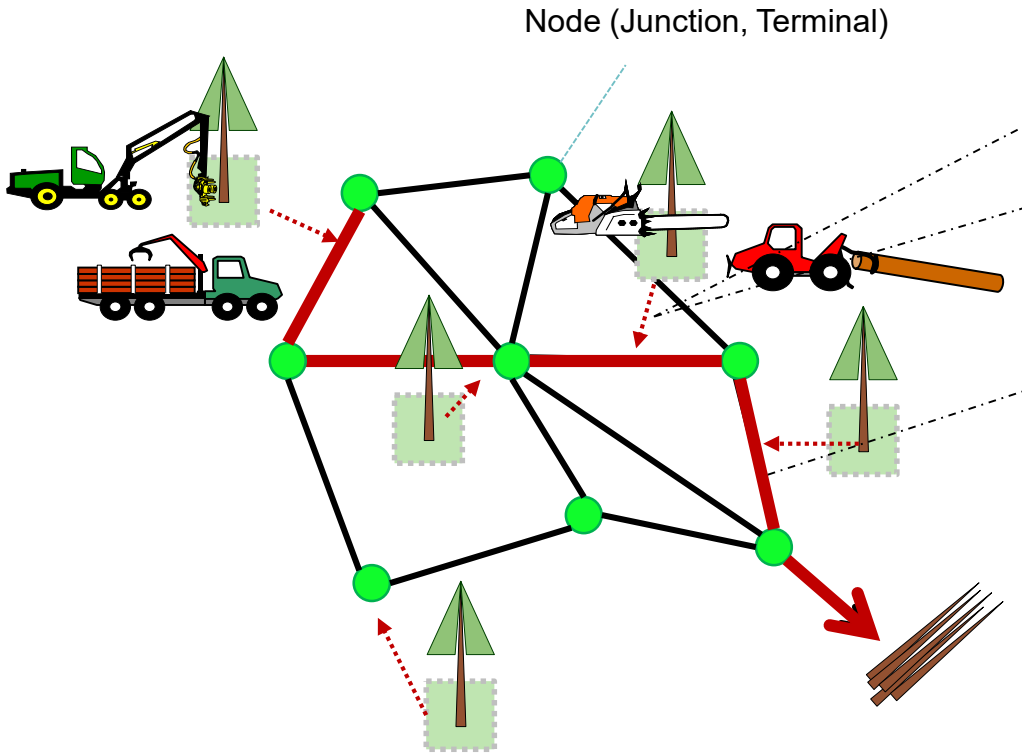
Further Constraints (Contiguity Constr.)



subtour not connected to superordinate road network

0 120 240 480 Meters

Model set up



Link feasible? Trafficability analysis

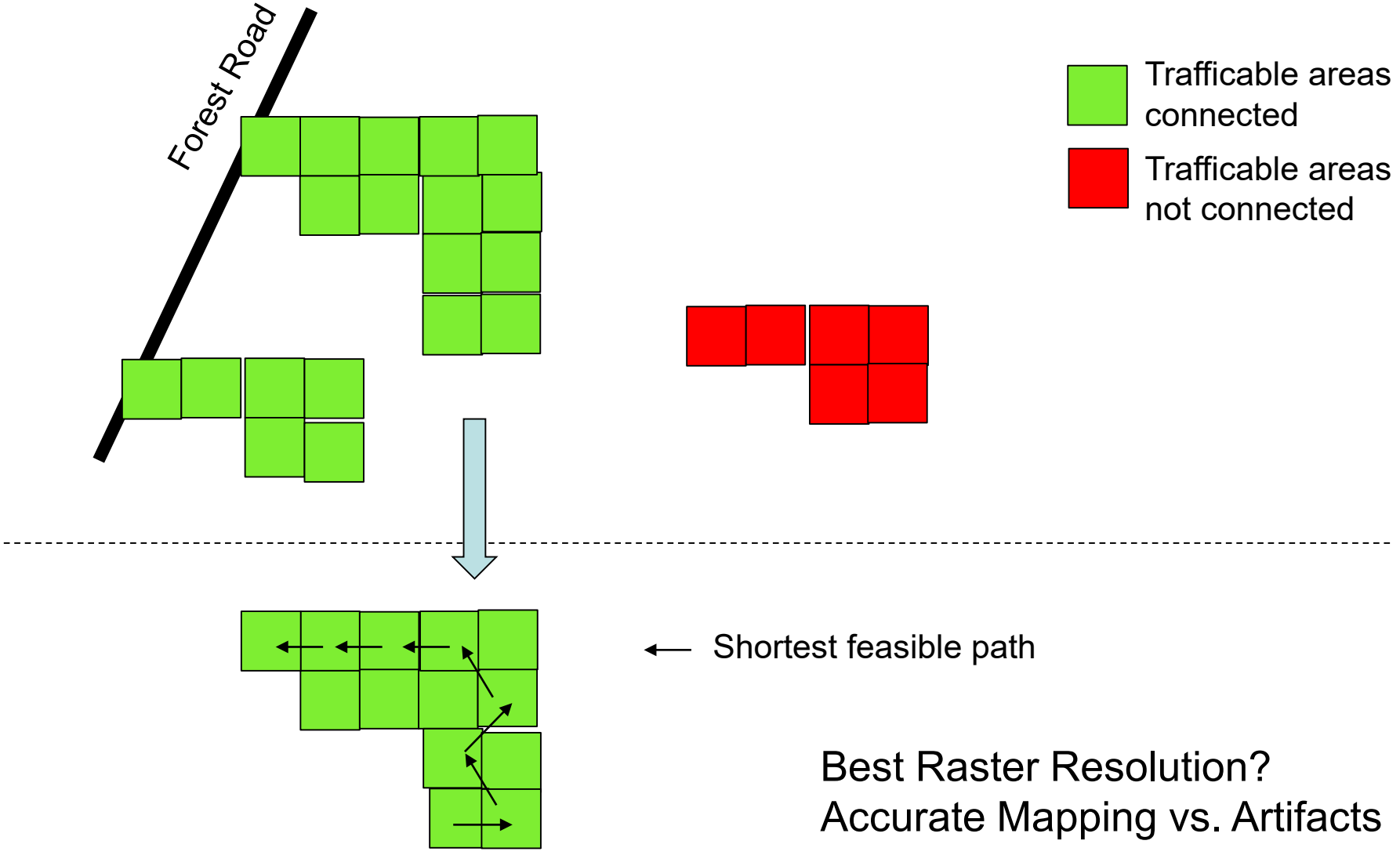
Harvesting Costs

Road Costs

Trafficability Analysis [I]

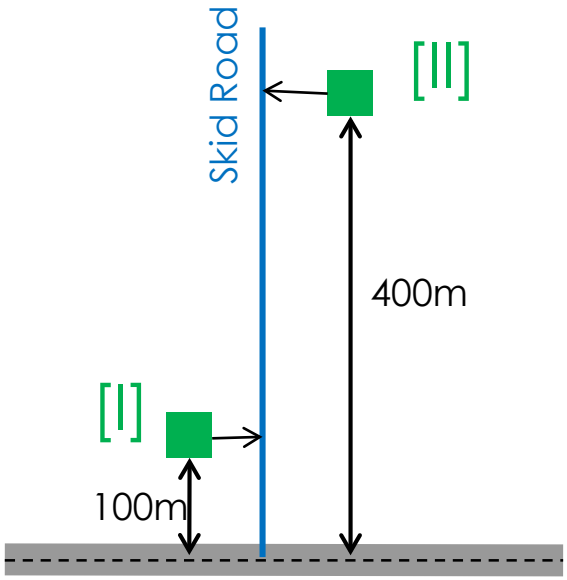
- Modelling Trafficability (Random Forest, Logistic Regression)
- NFI Sample Plots dataset (3500 plots)
- Main predictors: Slope, skeletal content, permeability and watering of the soils, terrain roughness
- Accuracy ~ 97 % (cross validated)

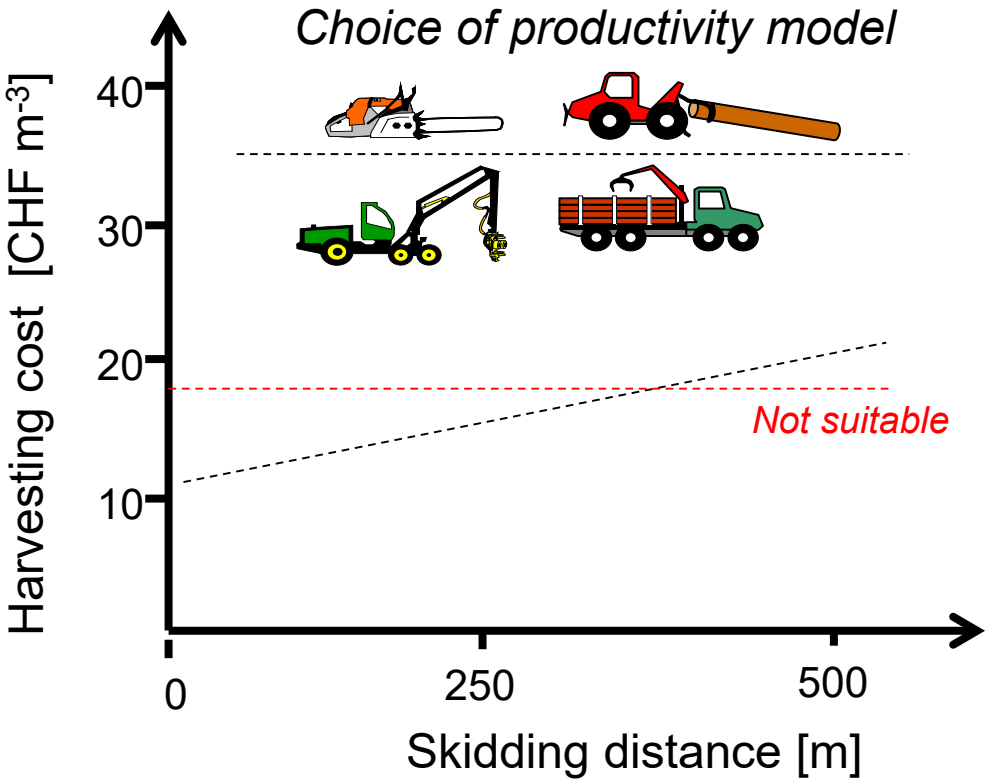
Trafficability Analysis[II]: Ensure Connectivity



Best Raster Resolution?
Accurate Mapping vs. Artifacts

Harvesting Cost

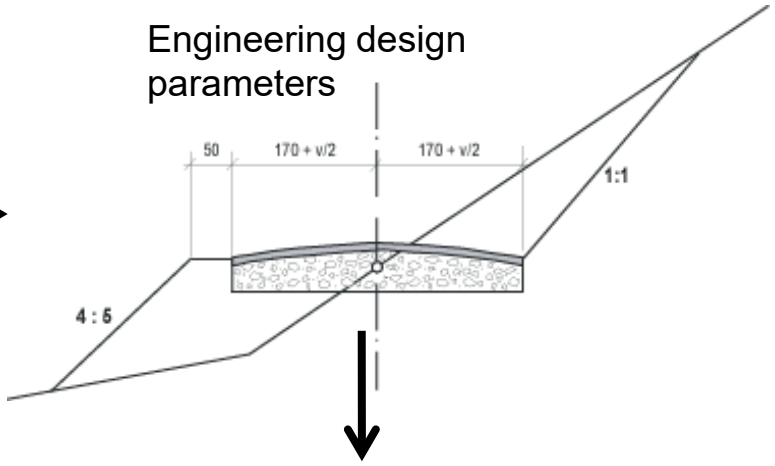




Road Standard / Cost

Terrain (DEM)

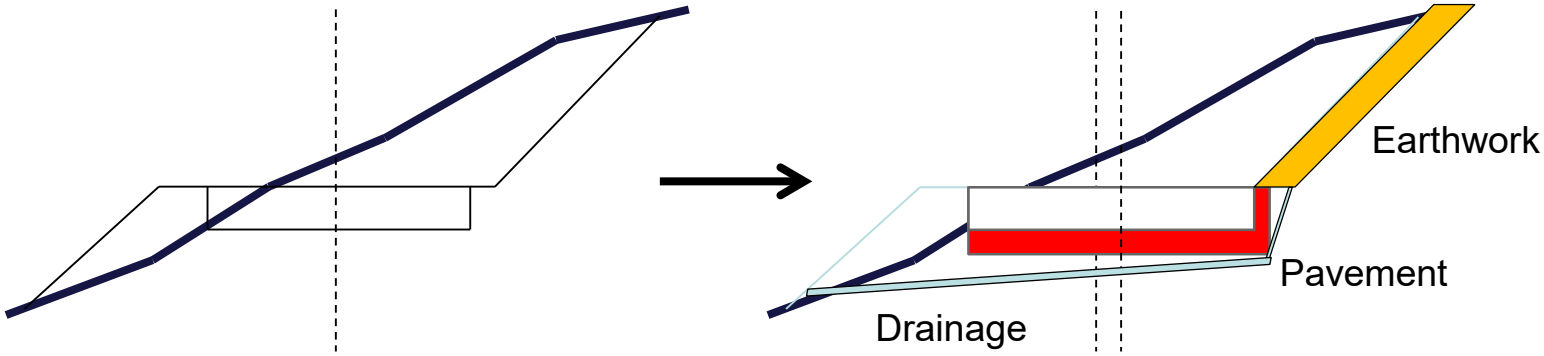
Geological Layer



Actual State

Upgrade State

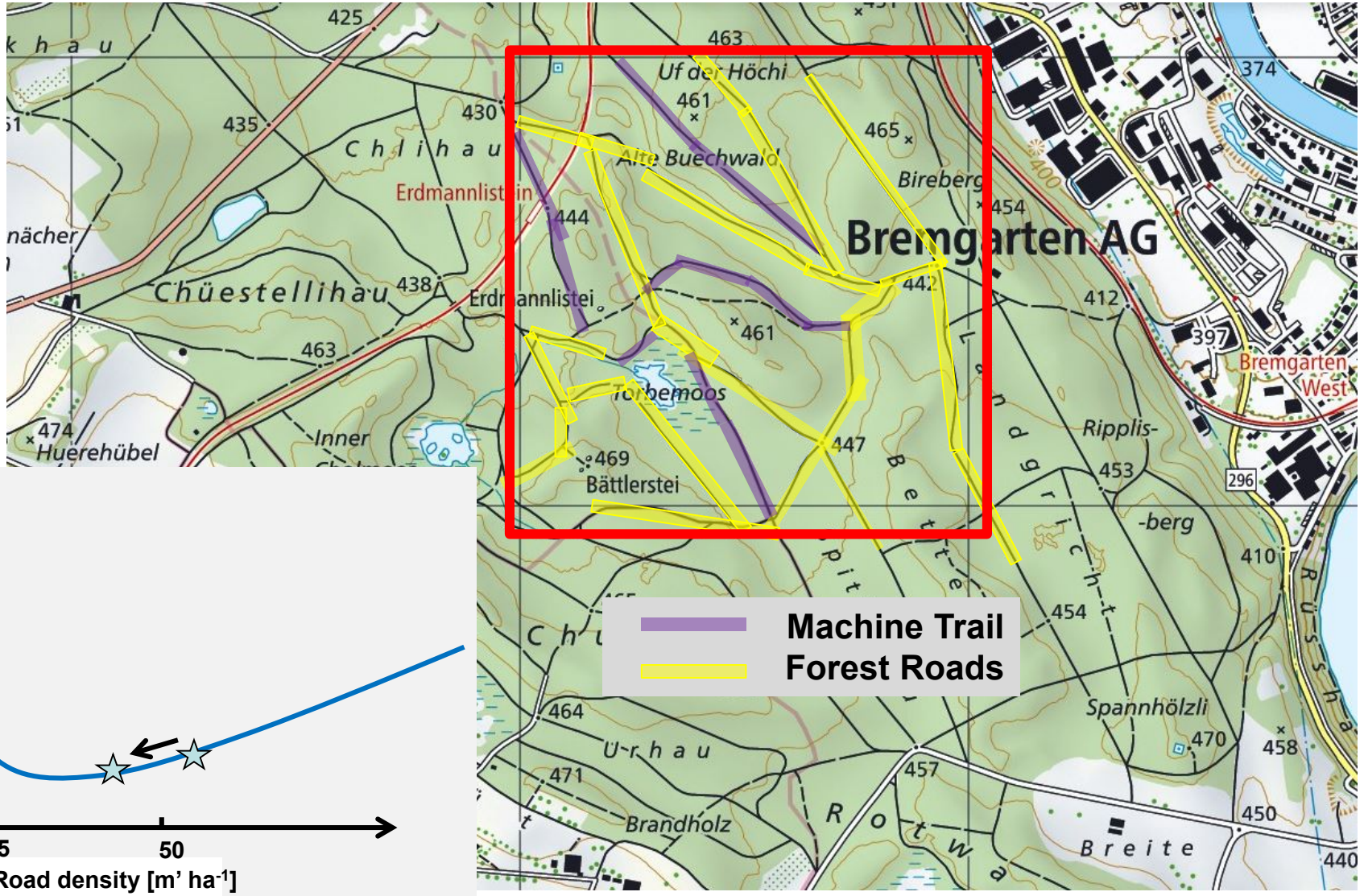
Upgrade



Maintenance

Flat Cost
[no model currently available]

Application



Application & Conclusions

- Model solves real size problems in reasonable time (1000 ha ~ 1 min)
- Reasonable results
- Some Parameters must still be derived (currently in work)

Outlook

- Including further aspects (travelling costs)
- Consider Climate change effects (trafficability further limited due to wet conditions / extreme events)
- Based on commercial solvers -> open source alternative?