Automatic harvest and cable road layout planning for multiple objectives

JUFRO Conference Freiburg 2017

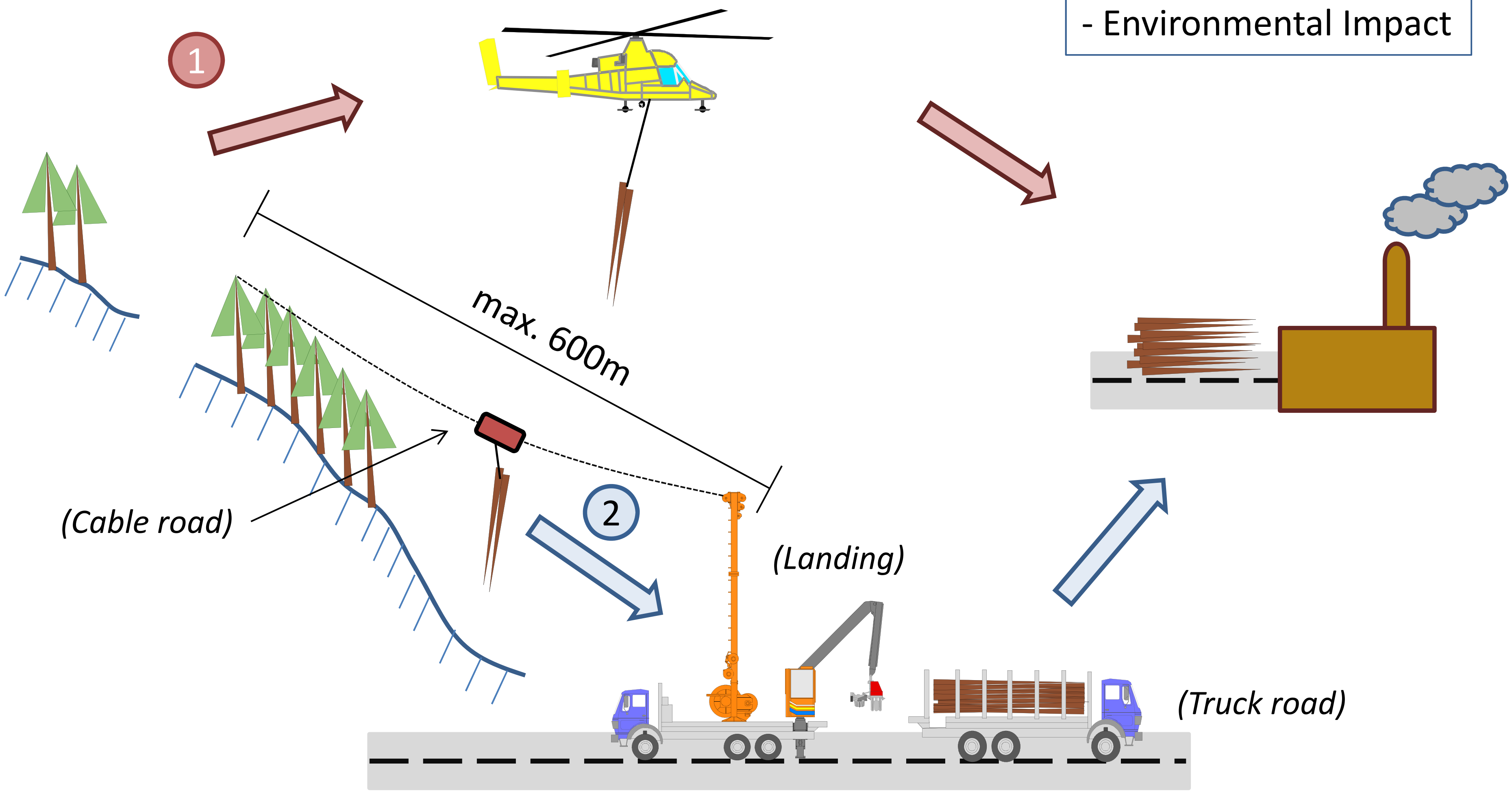
Leo Bont, WSL, Switzerland

Hans Rudolf Heinimann , ETH Zurich, Switzerland

Richard L. Church , UC Santa Barbara, California - USA

Problem

Minimize
- Cost
- Environmental Impact



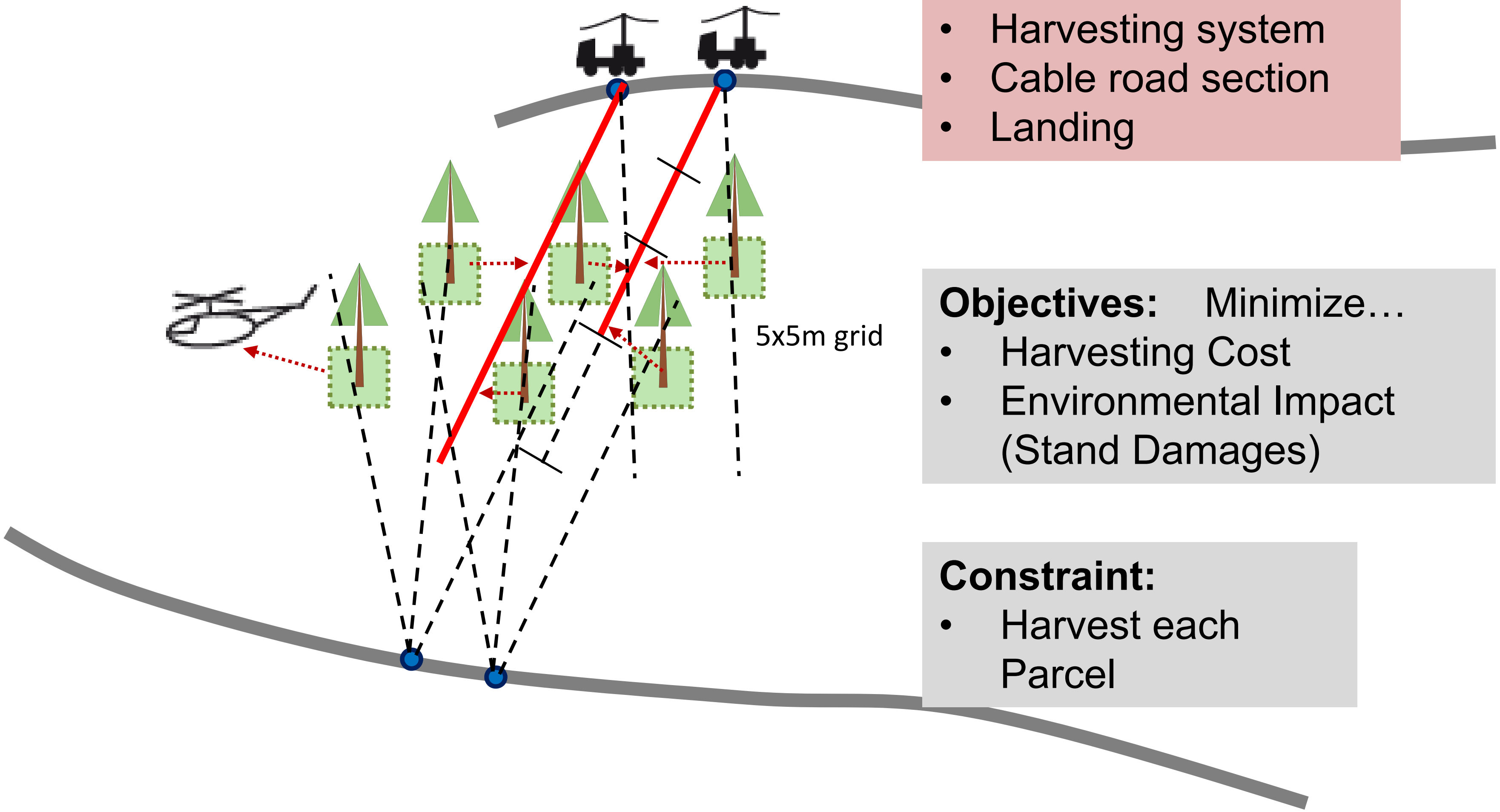
Objectives

- Automatic design of harvesting and cable road layout
- Adapted for European conditions / technology
- Multi objectives

Outline

1. Model development
2. Application
3. Conclusion

Harvest and Cable Road Layout - Problem

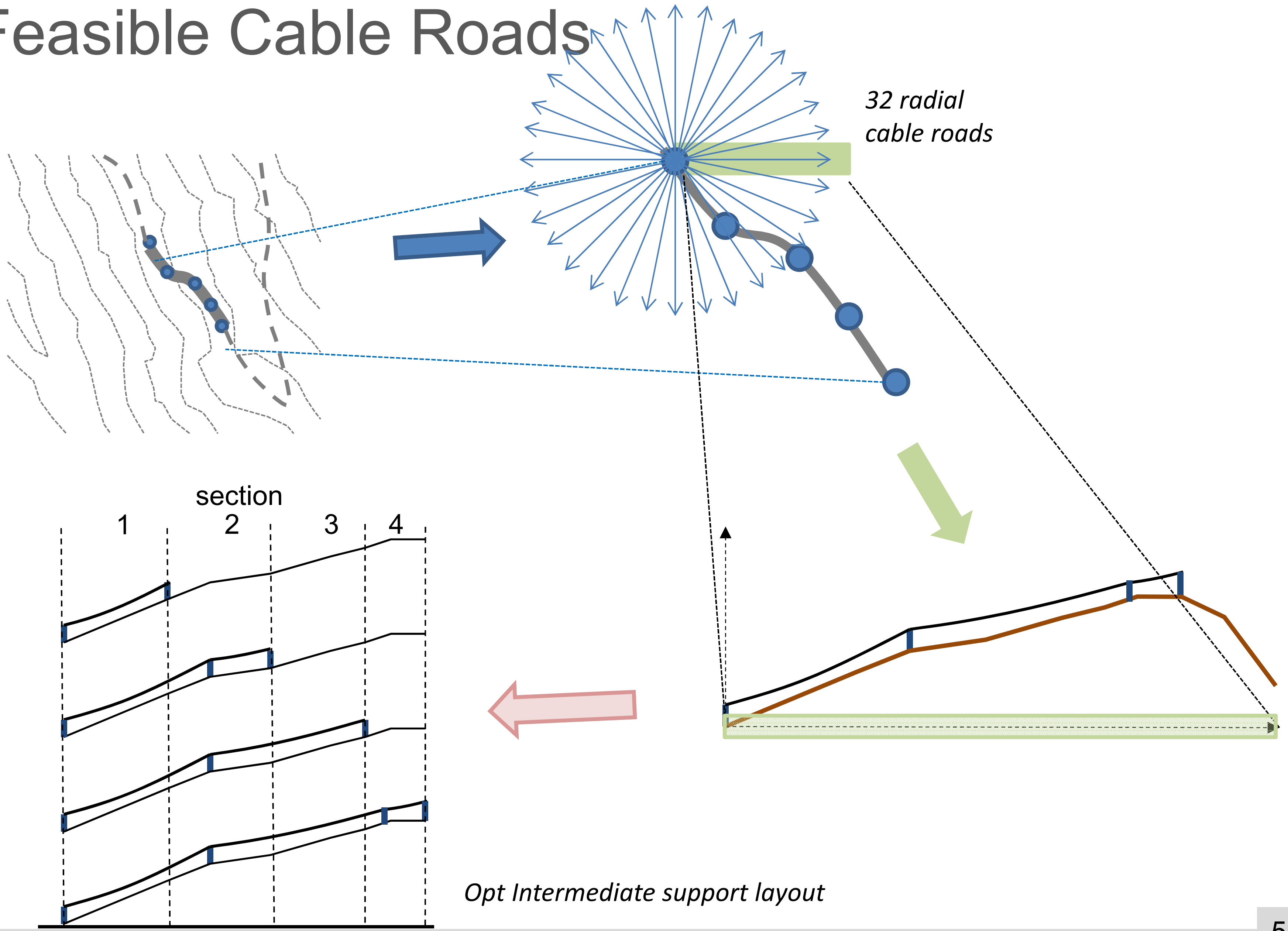


Decisions :
- Harvesting system
- Cable road section
- Landing

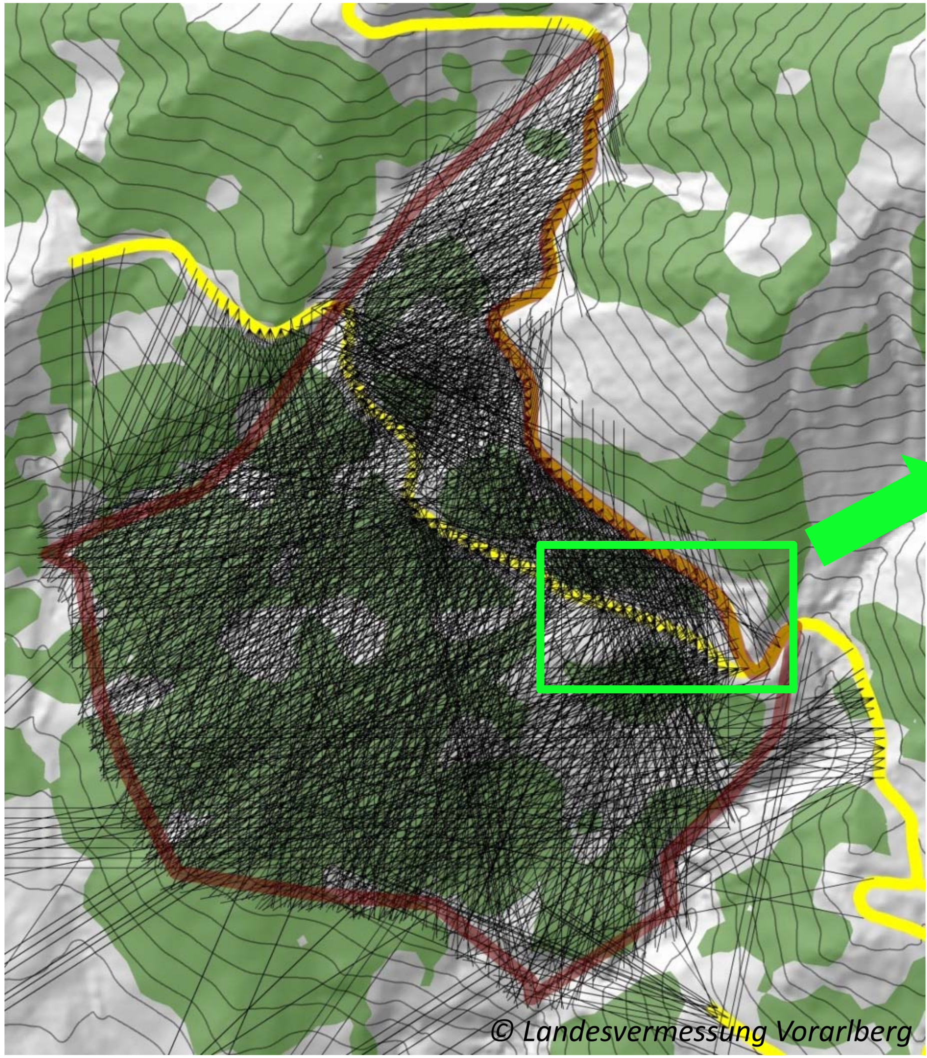
Objectives: Minimize…
- Harvesting Cost
- Environmental Impact (Stand Damages)

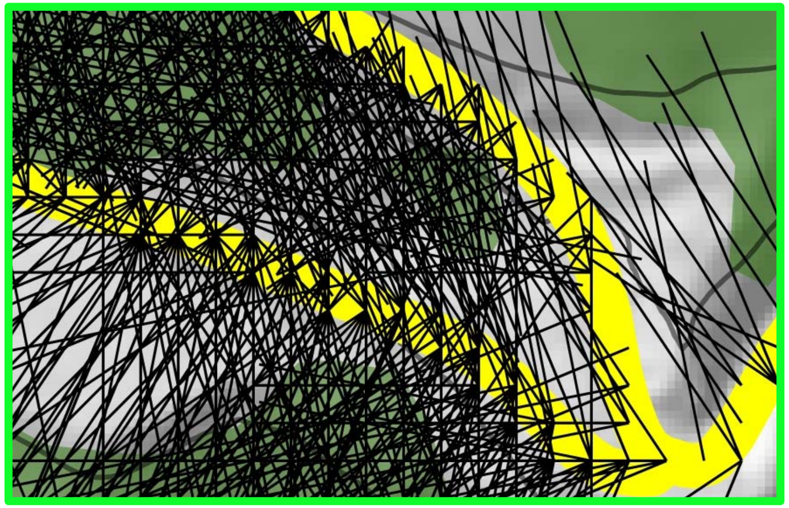
Constraint:
- Harvest each Parcel

Feasible Cable Roads



Feasible cable roads – Complexity





~ 2800 cable road sections
~ 5300 timber parcels (5x5m2)

~ 128’000 combinations TP – CR

Multi objective optimization

$$MIN \quad Z^{overall} = \underbrace{\lambda_C Z^C}_{Cost} + \underbrace{\lambda_{EI} Z^{EI}}_{Environmental\ Impact}$$

λ_X weight
Z^X objective function (standardized)
C cost
EI environmental impact

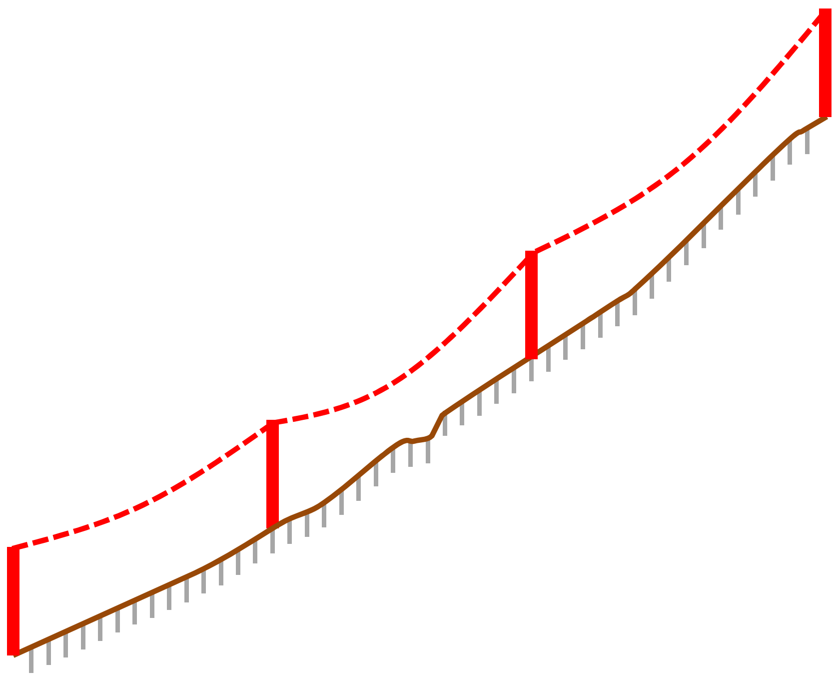
example.:
$\lambda_C = 1$
$\lambda_{EI} = 0$

$$\lambda_C + \lambda_{EI} = 1$$

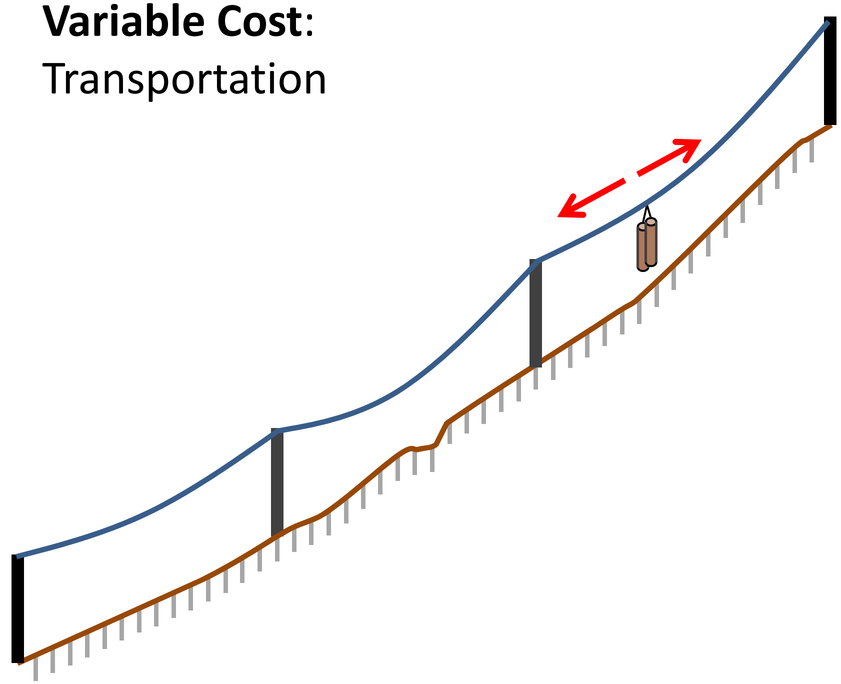
Objective: Cost

Minimize wood extraction cost [CHF]

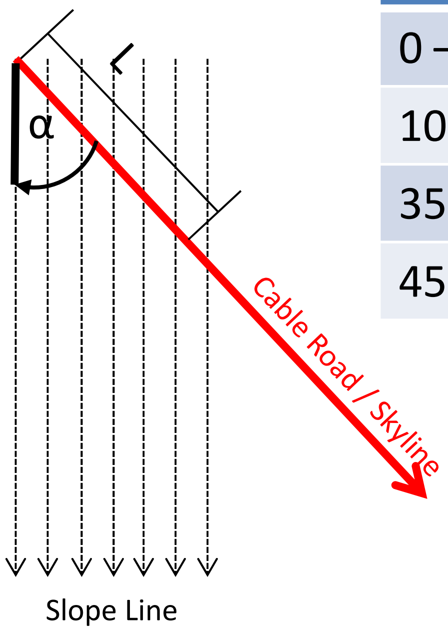
Fixed Cost:
Set Up- and Dismantling



Variable Cost:
Transportation



Environmental Impact: Penalty for angle between skyline and slope line



Angle (α)	Penalty
0 – 10°	L * 0.5
10 – 35°	0
35 – 45°	L * 0.5
45 – 90°	L * 2

Lateral Yarding

Nightmare for workers &

Critical aisle in slope line

Avalanches (Frehner et al 2005)

Slope	Length of aisle in slope line
> 30°	< 60m
> 35°	< 50m
> 40°	< 40m
> 45°	< 30m

Surface landslides (Frehner et al 2005)

Type of unconsolidated rock	Critical slope
Marl and clay soils	from 25°
Average soil properties without soil wetness	from 30°
Good (water-) permeable soils	from 35°

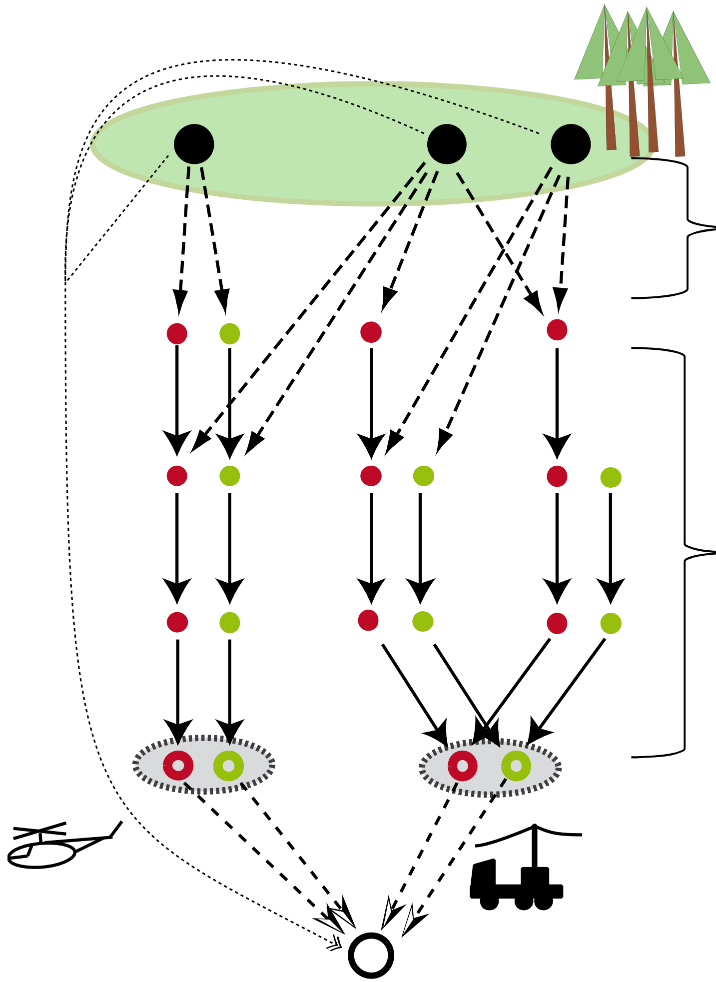
Snow creeping (Leuenberger 2002)

Slope	conditions
From 25° - 50°	smooth, grass-grown hillsides

Rock fall (Frehner et al 2005)

slope	Type of movement
30 – 35°	Rolling or sliding
> 35°	Rolling, sliding, jumping

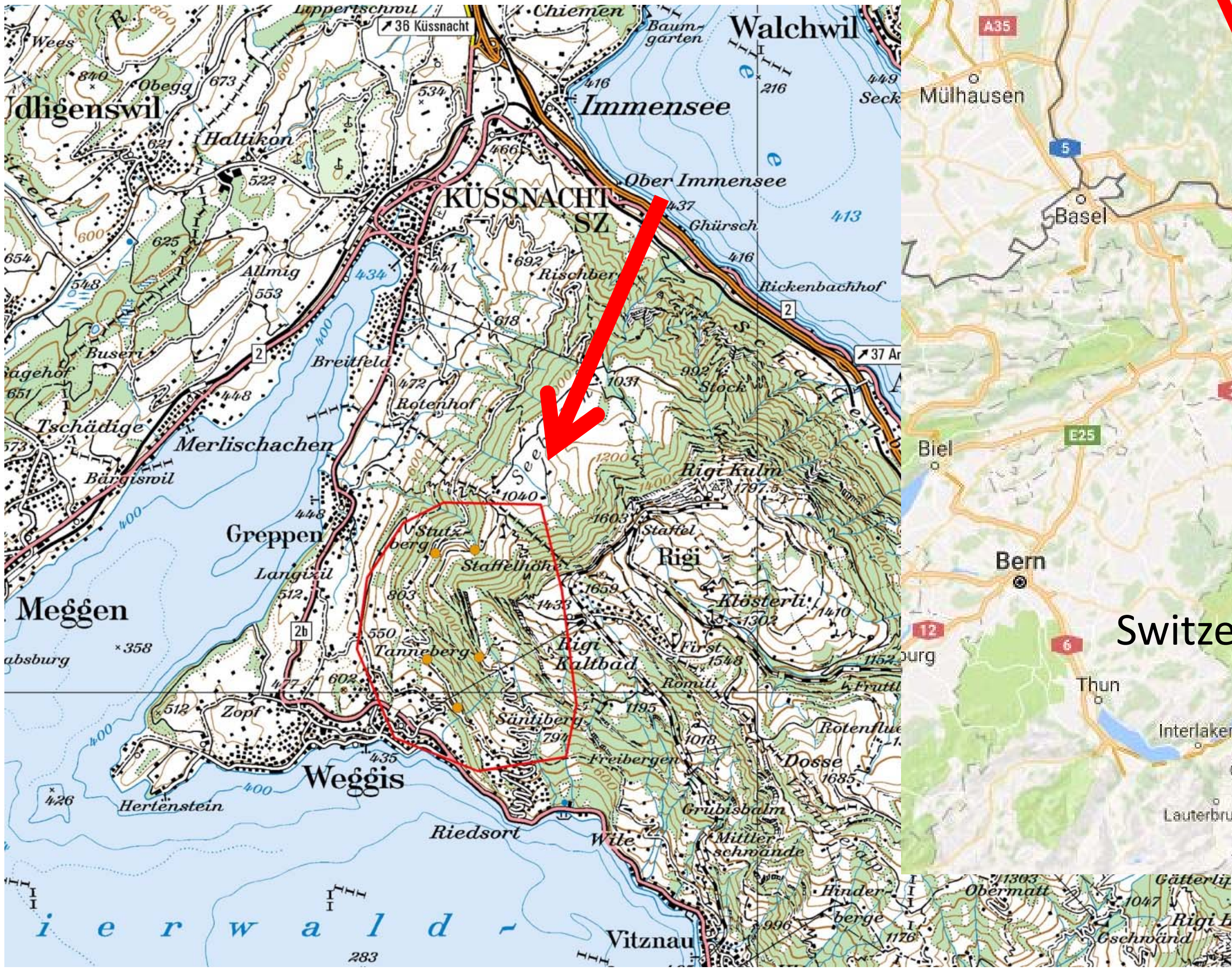
Optimization technique



Arc	Arc Weight
Timber P. - Cable Road	Variable Cost
Cable road section	Fix Cost / Environmental Impact

Mixed Integer Linear Programming:
10m grid resolution, 35 ha
about 300’000 variables → Time = 8 min.
Application Rigi: Between 1 min. and 1 hour

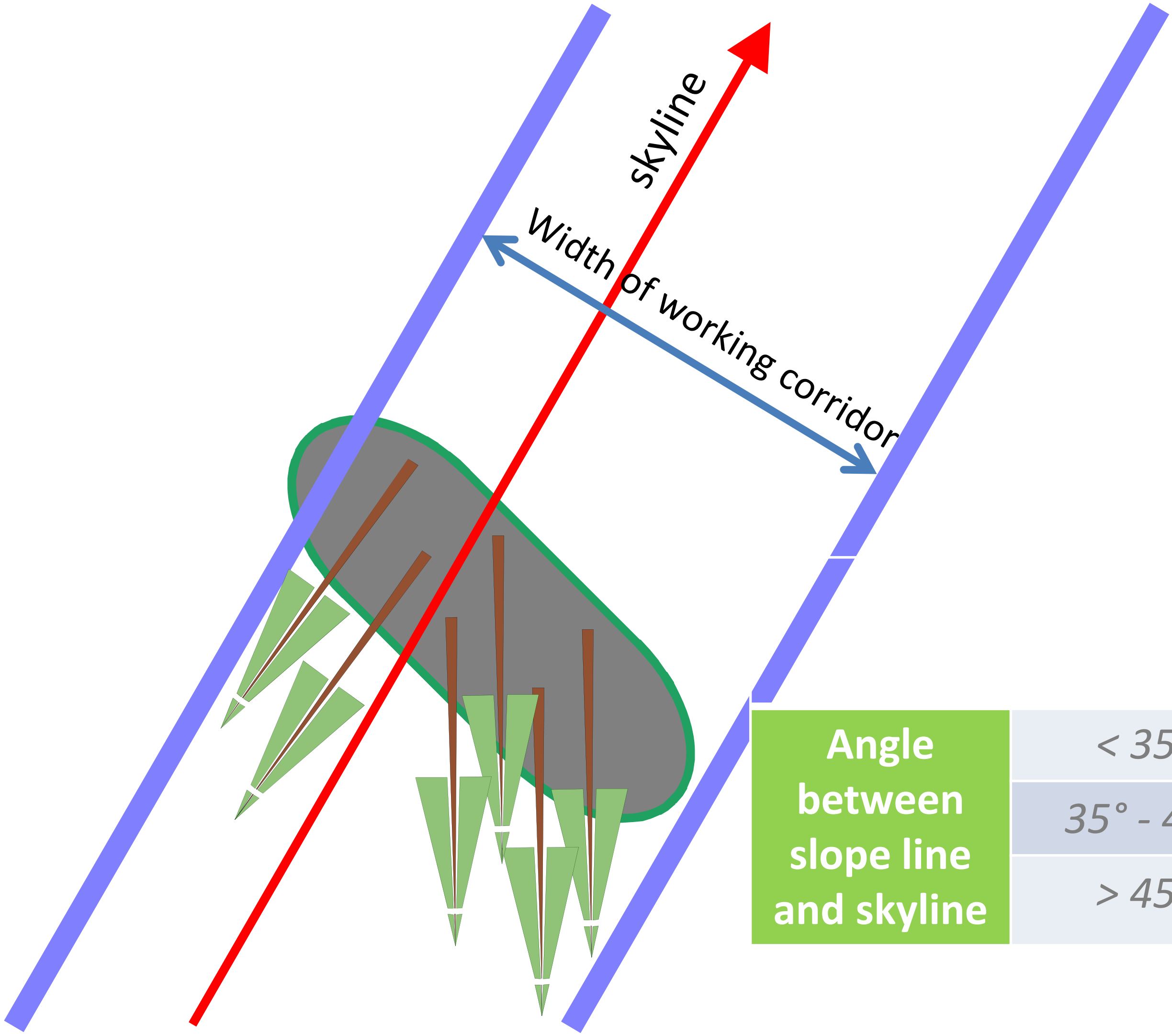
Application «Rigi»



Appropriate Landings

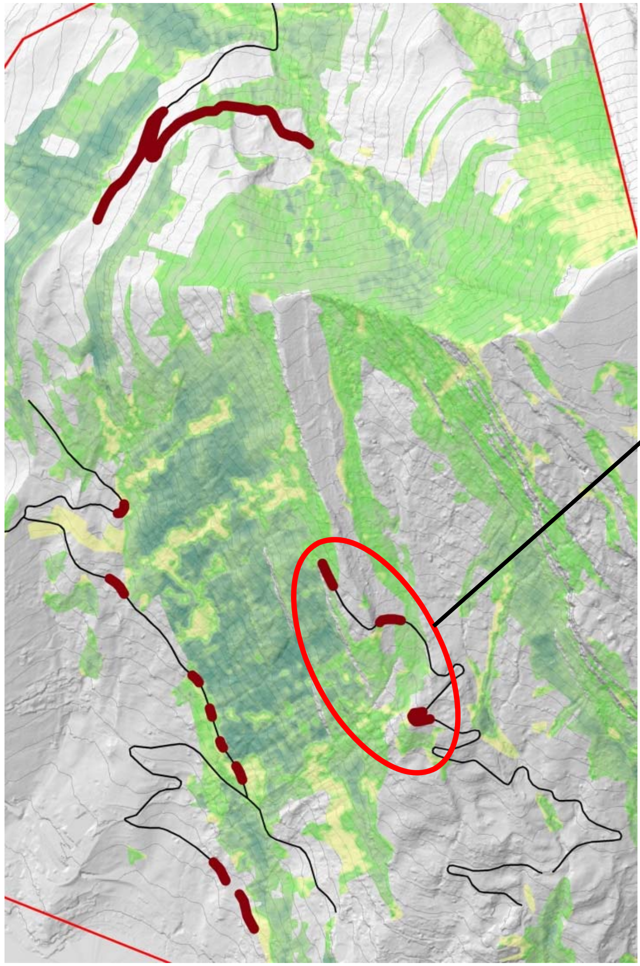
→ Reduces computation time

Specific adaptions: Width of working corridor



		Slope	
		0 – 30°	*> 30°*
Angle between slope line and skyline	*< 35°*	70m	55m
	35° - 45°	60m	50m
	> 45°	55m	50m

Specific Adaptions: Hauling Cost

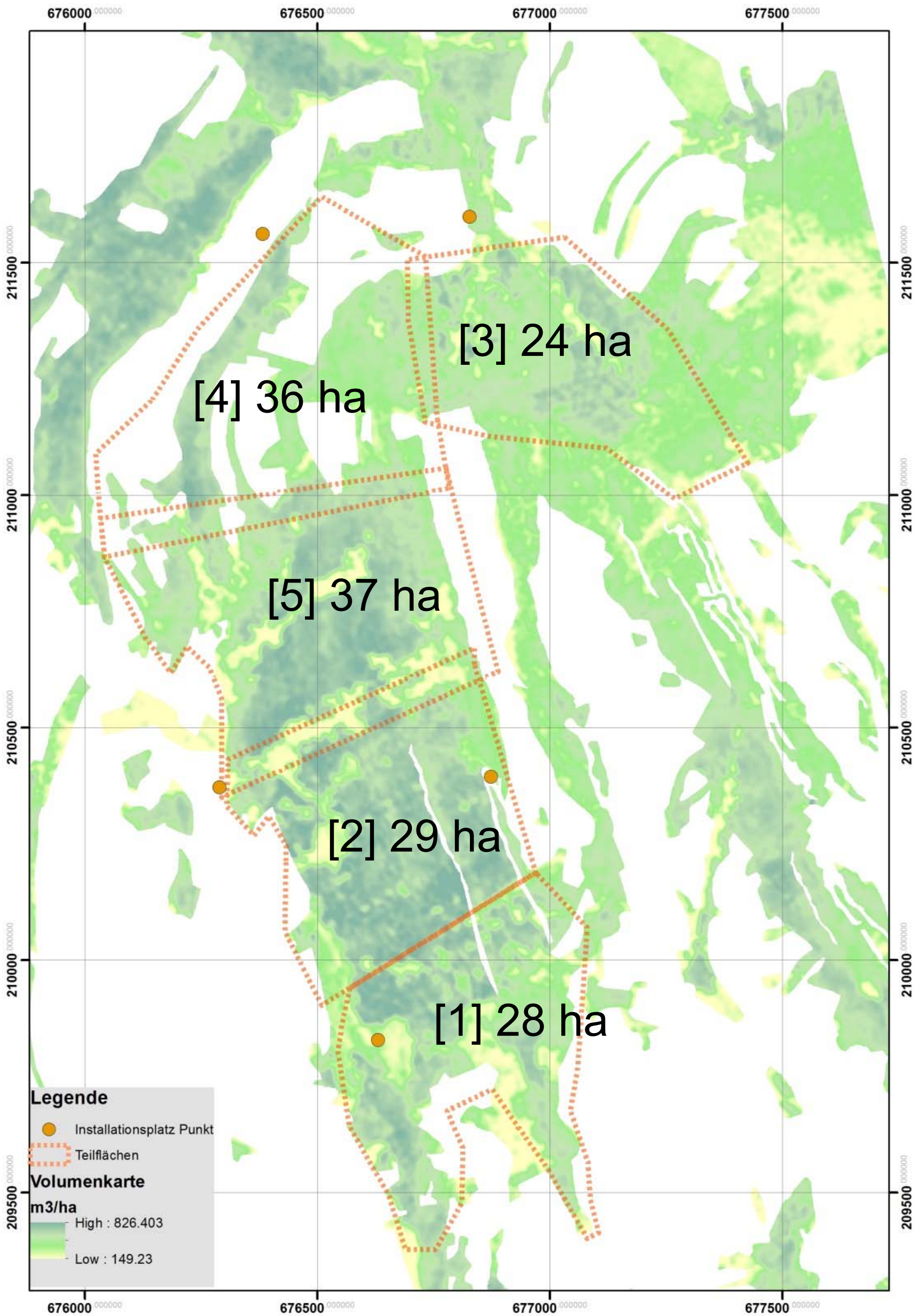


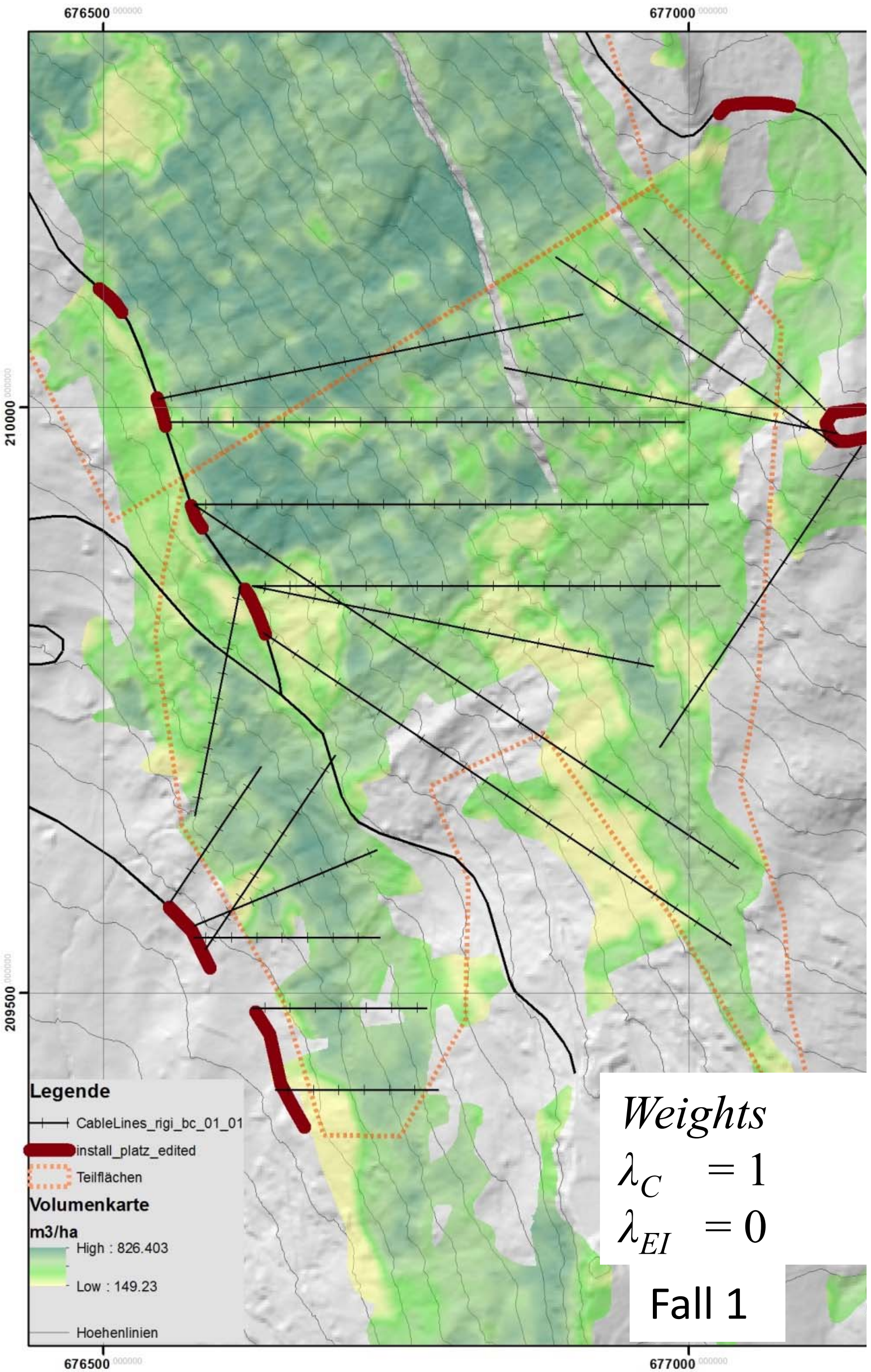
Bearing Capacity Limitation
[Transshipment Cost: + 15 CHF/m3]

Landings

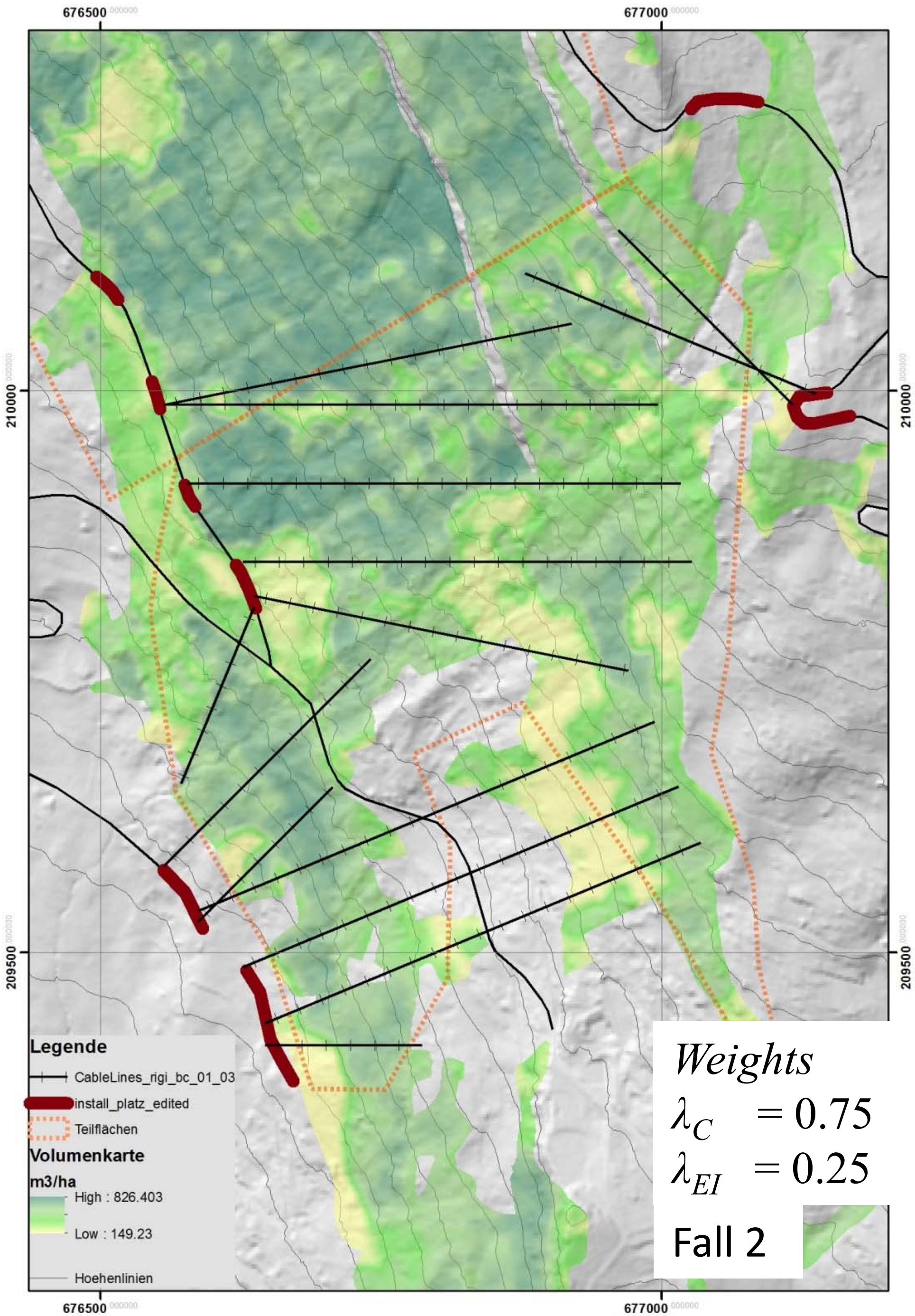
Truck Road

Volume & Sub Areas





676500
677000
210000
209500
Legende
CableLines_rigi_bc_01_01
install_platz_edited
Teilflächen
Volumenkarte
m3/ha
High : 826.403
Low : 149.23
Hoehenlinien
Weights
$\lambda_C = 1$
$\lambda_{EI} = 0$
Fall 1



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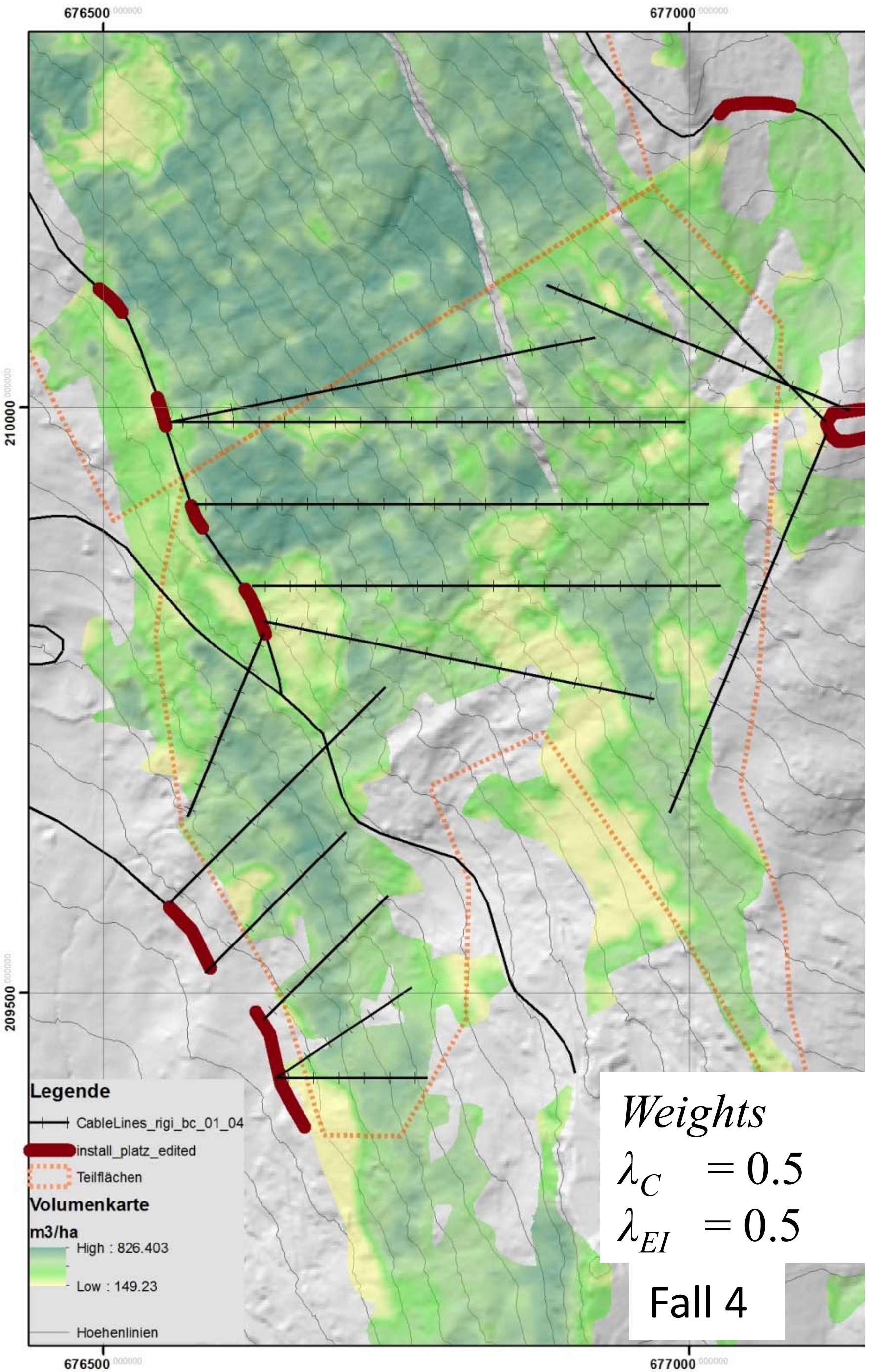
CableLines_rigi_bc_01_03
install_platz_edited
Teilflächen
Volumenkarte
m3/ha
High : 826.403
Low : 149.23
Hoehenlinien
Weights
$\lambda_C = 0.75$
$\lambda_{EI} = 0.25$
Fall 2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install_platz_edited
Teilflächen
Volumenkarte
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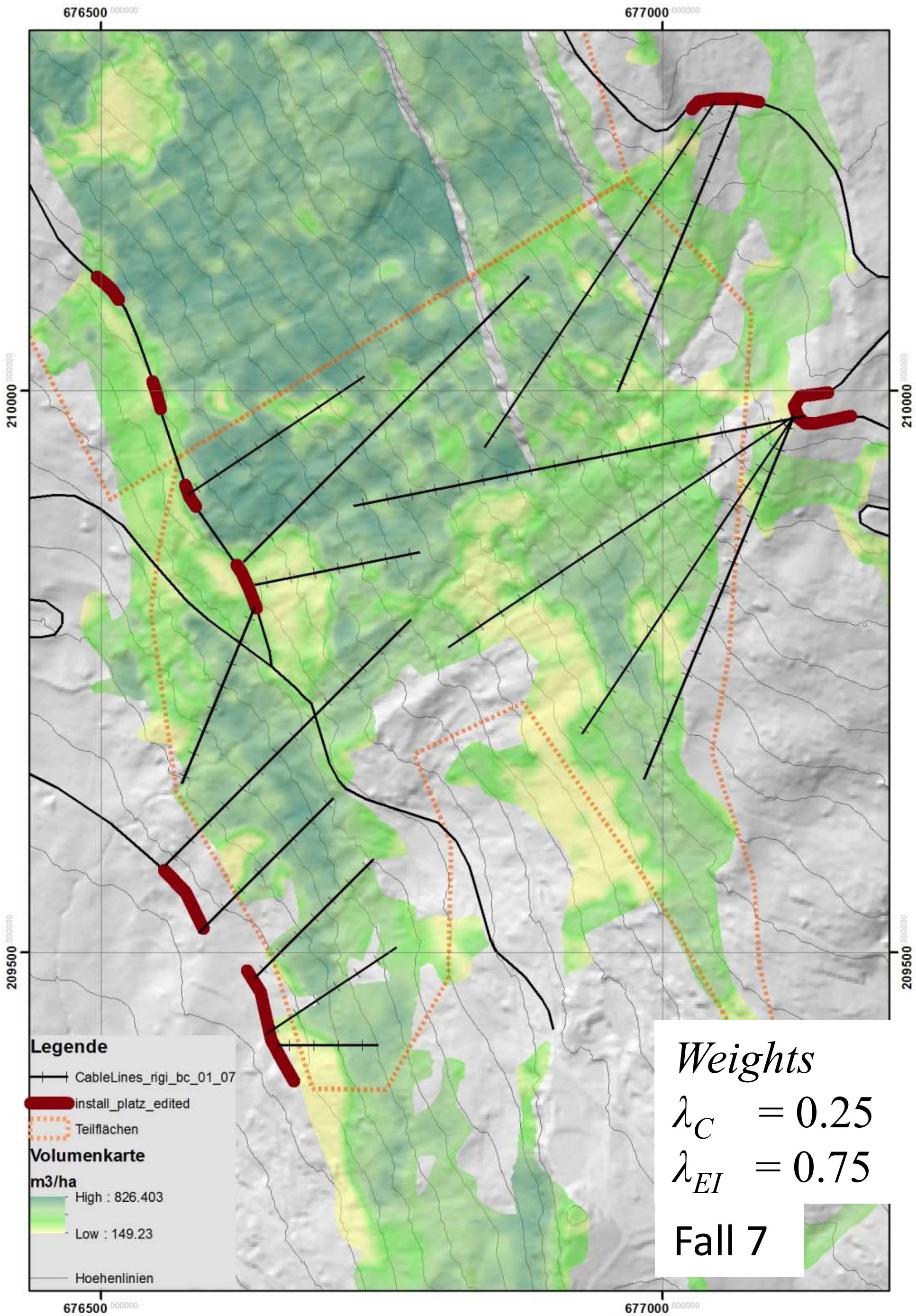
Low : 149.23
Hoehenlinien
Weights
$\lambda_C = 0.5$
$\lambda_{EI} = 0.5$
Fall 4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install_platz_edited
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Volumenkarte
m3/ha
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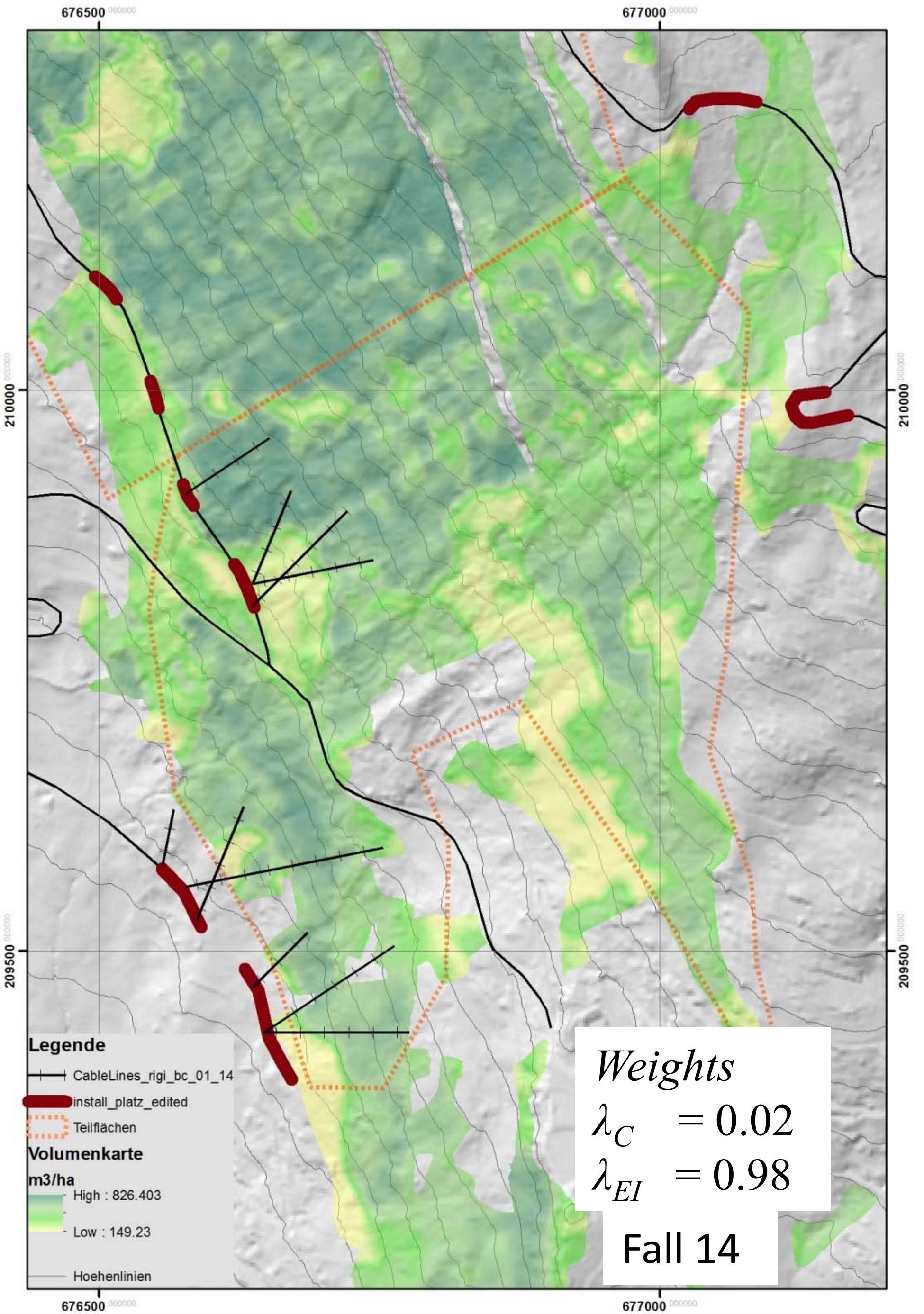
Low : 149.23
Hoehenlinien
Weights
$\lambda_C = 0.25$
$\lambda_{EI} = 0.75$
Fall 7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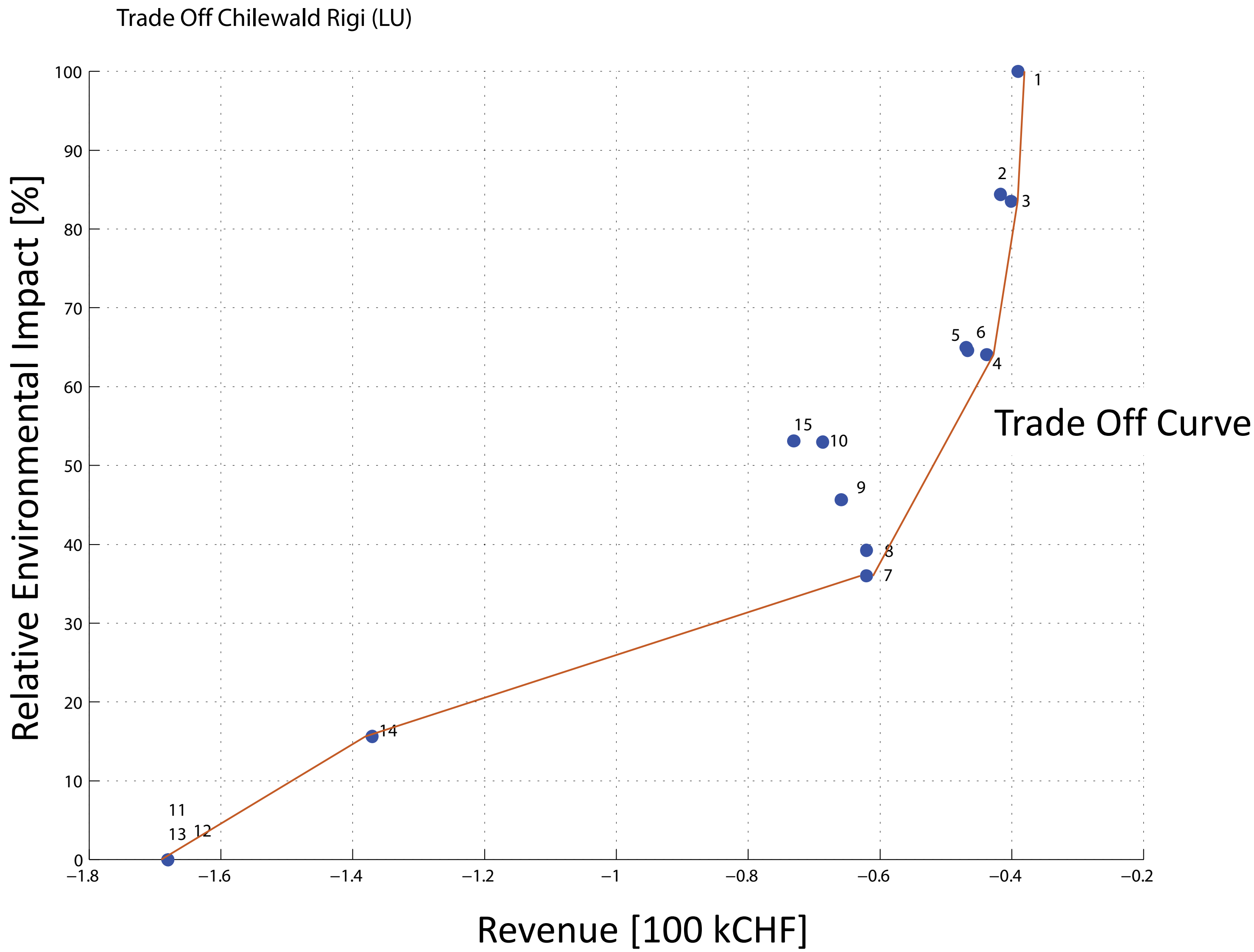
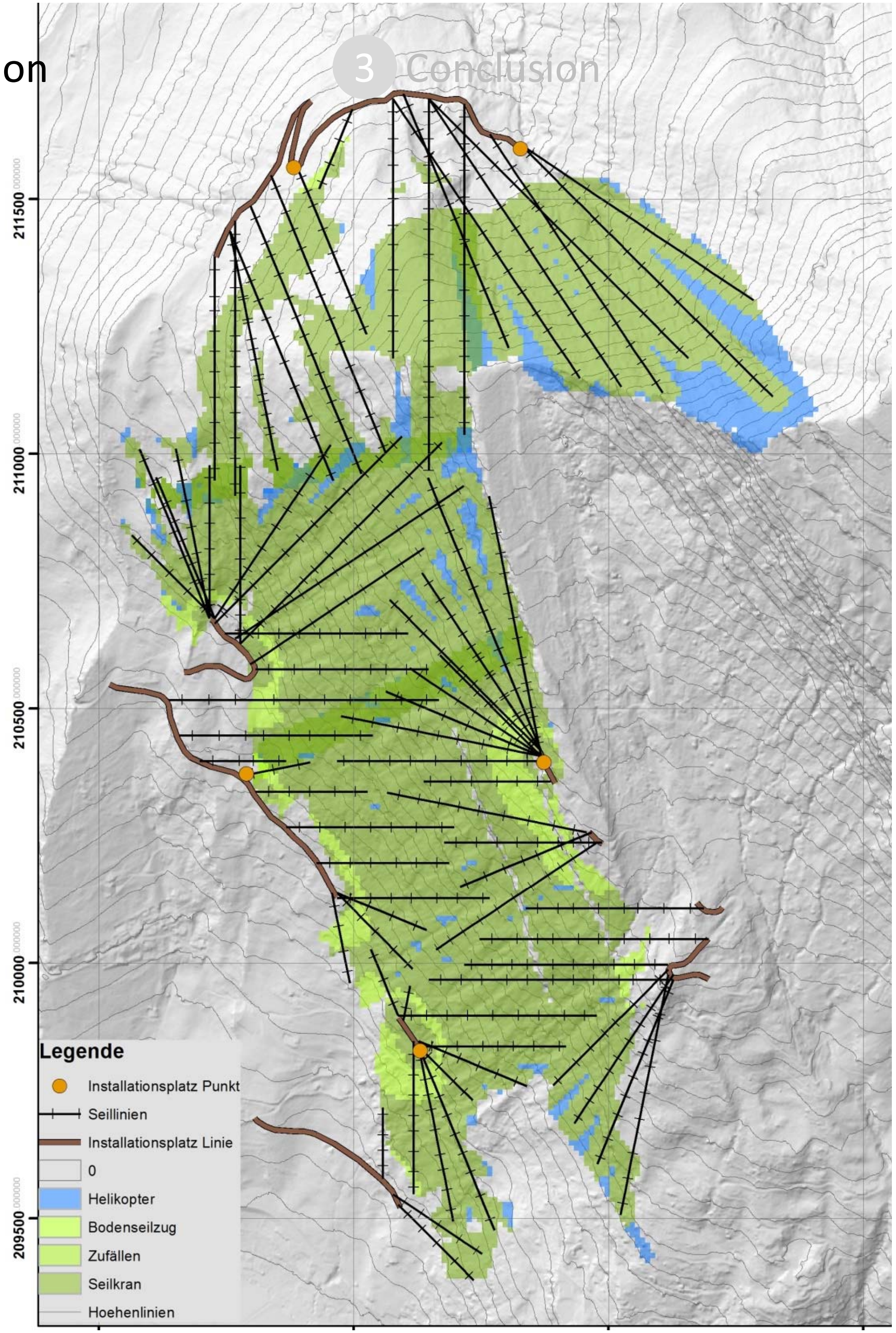
install_platz_edited
Teilflächen
Volumenkarte
m3/ha
High : 826.403
Low : 149.23
Hoehenlinien
Weights
$\lambda_C = 0.02$
$\lambda_{EI} = 0.98$
Fall 14

Trade Off on Sub - Area 1



Chosen Solution



Scientific / Practical Contribution

- Scientific Innovation
  - Efficient MILP (weighted benefit covering) formulation
    → Math. Optima detected
  - Environmental impact considered (Multi objective)
  - Flexible cable road length mapped
- Application Benefit
  - Solves real size (<0.4 km^2) problem to optimality
  - Maps silvicultural requirements
  - Alpine harvesting technology

Thank you for your attention!

Forest Operations in Environmentally Sensitive Areas in Europe and the United States

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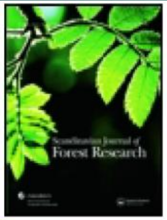
Authors:

- Dalia Abbas, Ph.D., American University, USA
- Fulvio Di Fulvio, Ph.D., International Institute for Applied Systems Analysis, Austria
- Raffaele Spinelli, Ph.D., CNR IVALSA, Italy

Contact details:
Email: daliaabbas@yahoo.com
Tel. 6128190567

Source



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European and United States perspectives on forest operations in environmentally sensitive areas

Dalia Abbas , Fulvio Di Fulvio & Raffaele Spinelli

Introduction

- The management literature on forest operations sustainability in environmentally critical and sensitive areas in both Europe and the United States tends to focus on ecosystem services protection, planning prior and during harvest, using remote sensing to map sensitive areas, and the need for least impact operations. However, rarely is there a mention of the need to integrate environmental conditions with the appropriate technology, and the operators' safety considerations.

Purpose

- Identify the connections between protecting the ecosystem, safe operational practices and technology.

Environmentally Sensitive Areas (ESAs) Definition

- Critical areas with conditions that require special treatment within which operations are subject to limitations, restrictions, or prohibited all together, to promote better ecosystem services and avoid ecosystem damage.
- Those conditions include: steep soil, wet soils, both steep and wet soils, nutrient deficient sites, rocky sites, waterways, fire hazards, wildlife, biodiversity and habitat.

Photos: WI DNR, Smithsonian, remote bulldozer, countryside network

Why are those Conditions Critical?

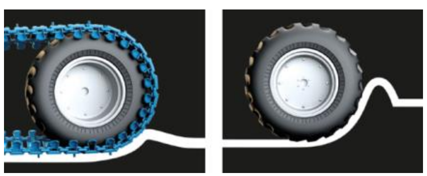
- They are costly and cause lands to be removed out of production, soil erosion, compaction, rutting, reduced vegetation and organic matter, hard on the operator and the equipment, loss of aesthetic and cultural values, and loss of wildlife and biodiversity.

Timber Harvesting Guidelines

- Typically address protective measures for soil, water, biodiversity and habitat requirements to conform with sustainability requirements.
- Rarely discuss the possible risk of injuries and stresses on operators and equipment due to the specific extra demanding working conditions.
- Rather stand and forest health are emphasized.

Technology used in ESAs






- More wheels and weight distribution to increase the contact areas and reduce pressure.
- homogeneous re-distribution of weight along the machine chassis
- Long reach cranes and winches
- Lighter and more compact machinery

Examples of positive (pros) and negative (cons) technical solutions in sensitive areas that impact the environmental and operating conditions

Technological Solution	Pros	Cons
Light and small machinery	Lower ground pressures Narrower driving paths	Lower productivity Less visibility Less stability
Increase the number of wheels	Lower ground pressure Easier crossing of obstacles	Reduced maneuverability in sharp turnings
Long reach cranes	Increase the spacing of driving paths and consequently reduce the number of forest tracks	Heavier and more expensive machinery as carriers More difficult focusing on long reach which increases stress on operators
Tethered (winch-assist) machines	Reduce the soil disturbance and increase the machine stability Reduce the risks for forest operators	Increase of operational costs compared to conventional machinery
Cable yarding	Reduce the ground impacts by limiting traffic of heavy machinery on the forest soil.	Increase of extraction costs More operators on the ground exposed to risks of accidents

The Role of Operators

- Follow all guidelines or best management practices for the site – largely ecological in nature.
- Avoid repeated passes and multiple site entries by heavy equipment.
- Select and use appropriate equipment matched to site and operations, such as low-impact logging techniques.
- Typically are the owners of equipment and are responsible for their own operating and safety needs, but there is no incentive to do so.

Working in Environmentally Sensitive Conditions is Costly

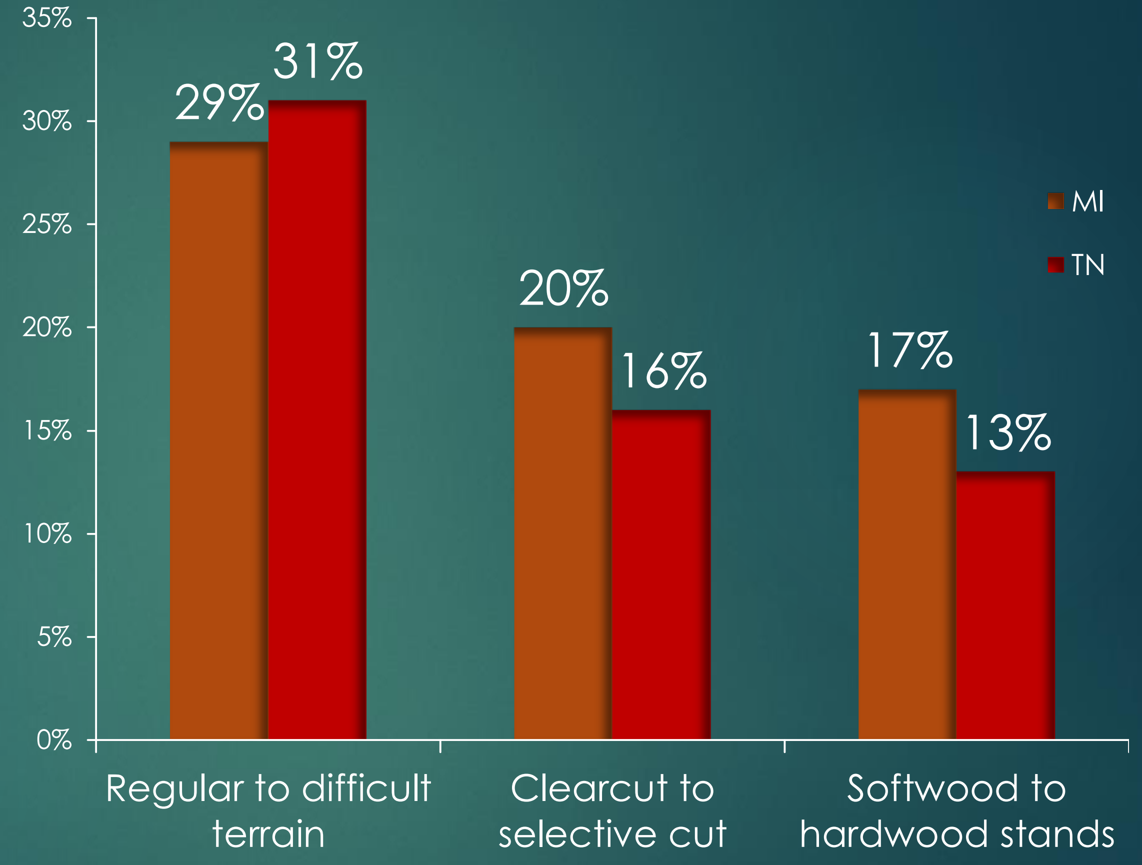
THE EFFECT OF STEEPNESS, TERRAIN TYPE, CUT TYPE AND SPECIES ON THE OPERATIONS’ COST IS NOT INSIGNIFICANT

Examples of European investigations

Technical cost of harvesting may be 75% higher for steep terrain, compared with flat or rolling terrain (Spinelli and Magagnotti 2011)

Contract rates are 60–80% higher for cable-based harvesting than for ground-based harvesting (Spinelli et al. 2016).

Examples of United States Investigations



Source: Abbas et al. 2014 and Abbas and Clatterbuck 2015

Examples that connect operating in sensitive sites, with the environmental, equipment and operator risks include:

Condition of Harvest	Environmental Effect	Operator Risks	Equipment Risk
Steep terrain	Erosion	Height and gravity risks	Tipping equipment
Hilly Terrain	Erosion	Height and gravity risks	Tipping equipment
Wet Terrain	Puddles, compaction	Operator and machine stuck, slippage	Stuck and sunken equipment
Rough terrain	Soil surface disturbance	Hitting obstacles, slippage	Damage due to hitting obstacles
Flat terrain	Rutting	Lower level of risk	Lower level of risk

Conclusion

The increase in demand for wood products, means that reaching out to more difficult environments is expected.

To operate and remove material from these sensitive sites is both beneficial but also problematic and costly.

The selection of equipment and tailoring the work conditions to terrain type, forest features and management objectives is critical.

The identification of training needs, and health and safety requirements for operators under these conditions is essential for the continuity of a healthy supply chain.

There is a further need to understand in operating conditions how to best integrate the details of environmental protection, technological appropriateness and the operator's safety.

Acknowledgement

- Every support that contributed to the completion of the study
- Exceptional coauthors
- Constructive reviews from the Scandinavian Journal of Forest Research peer reviewers
- Last, but not least, you for being here.

Thank you for your attention!

Vielen Dank für Ihre Aufmerksamkeit!

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Email: saleh@american.edu

ETH zürich

A spatially explicit harvest scheduling model for optimal management of rockfall protection forests

Sabrina Maurer, ETH Zürich

Dr. Jochen Breschan, ETH Zürich

Prof. Dr. Hans Rudolf Heinimann, ETH Zürich

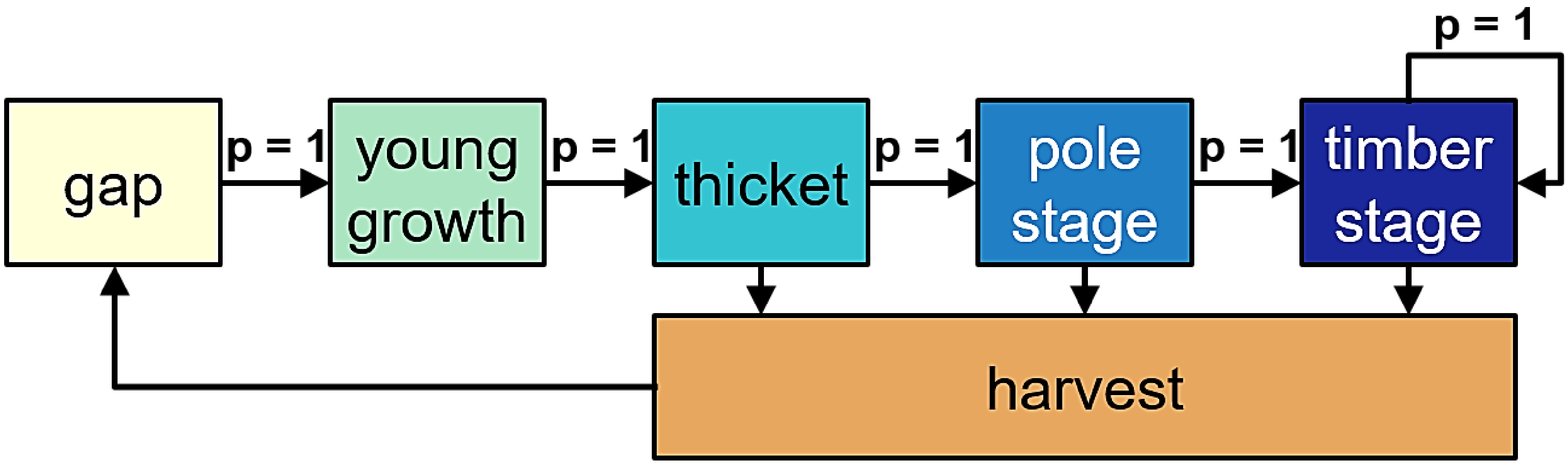
Research questions

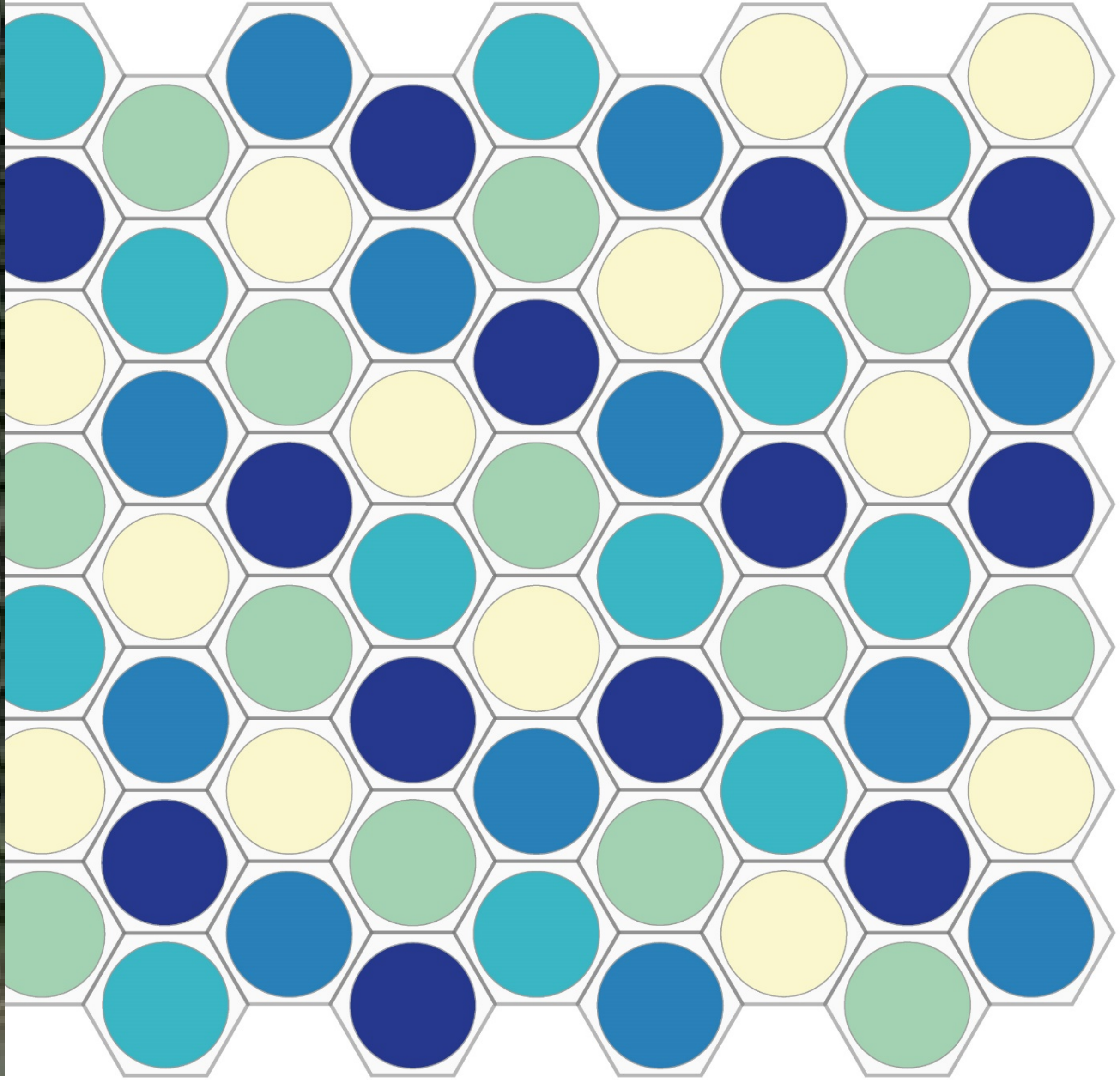
How can we optimally **arrange the gaps** in terms of **space** and **time**

1. for a constantly high protective effect?

2. for a cost-efficient harvesting?

Forest dynamic



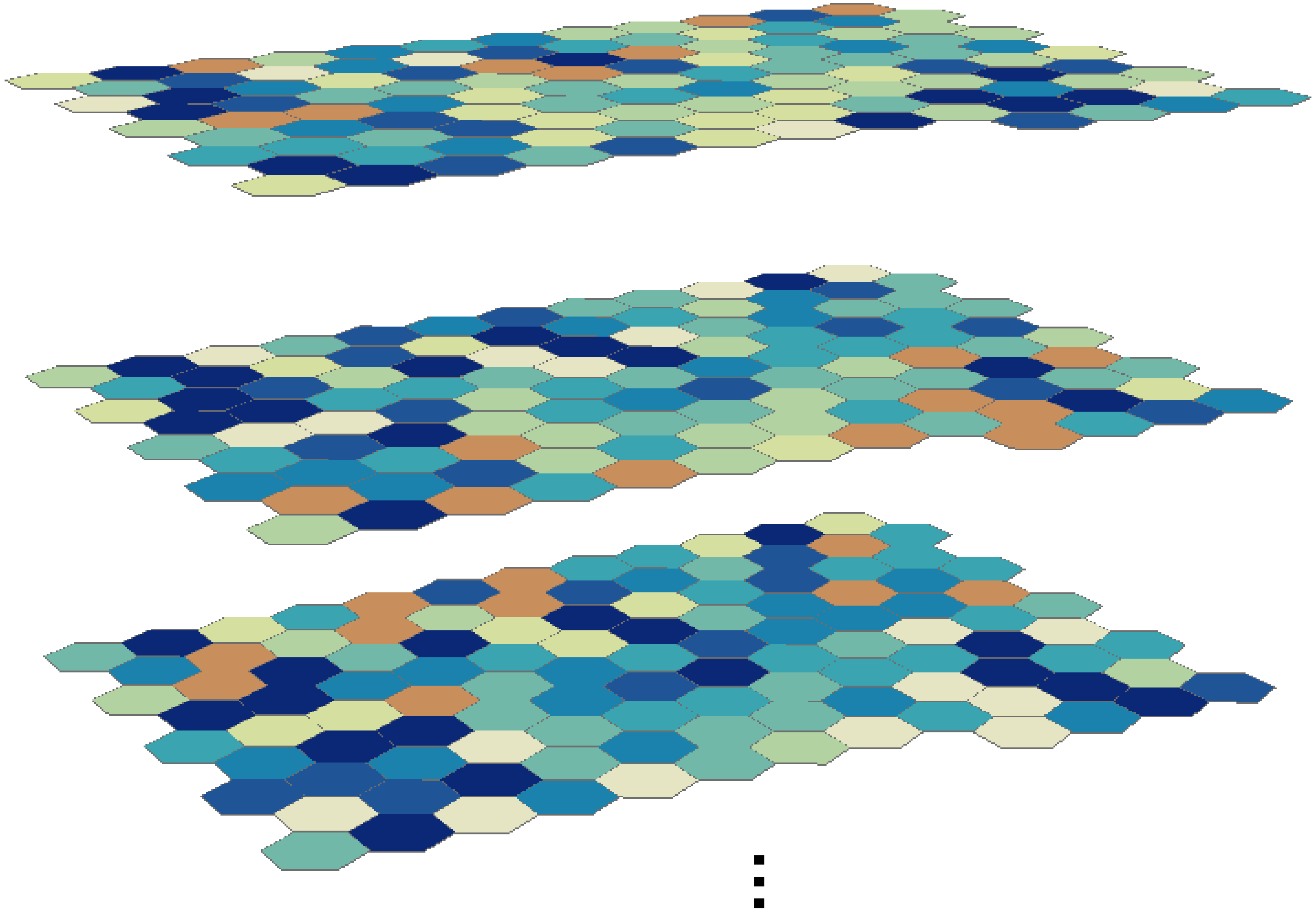


period 1

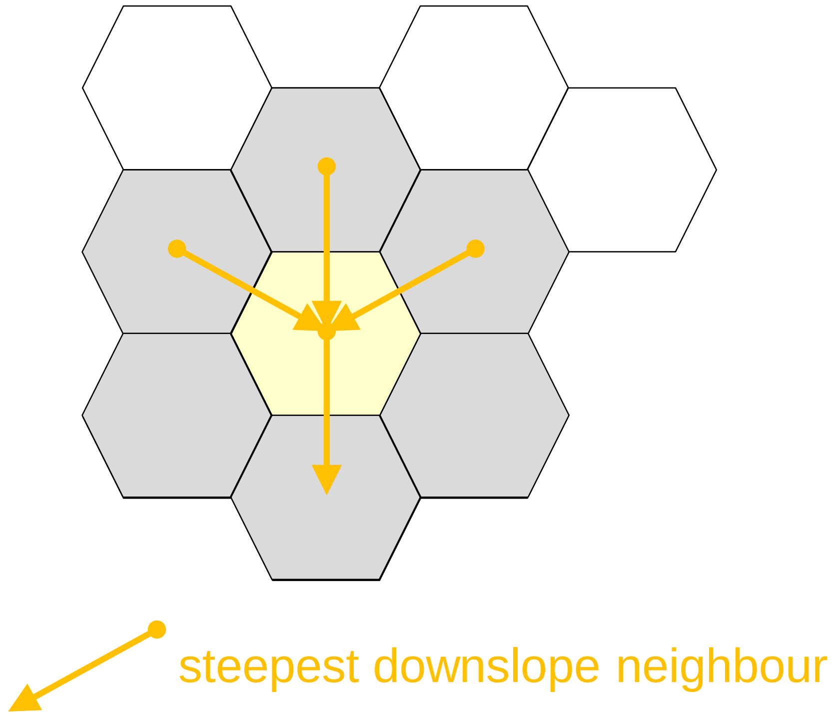
period 2

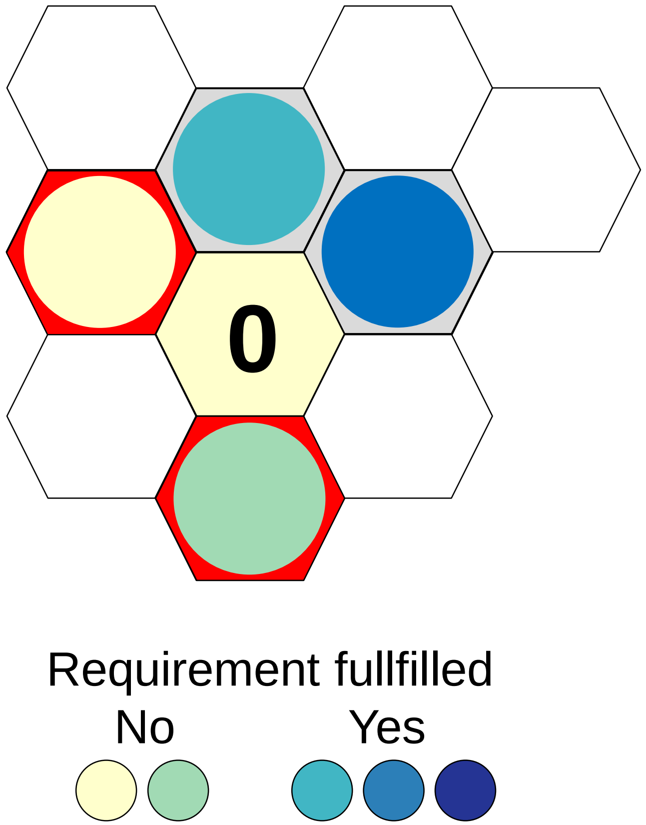
period 3

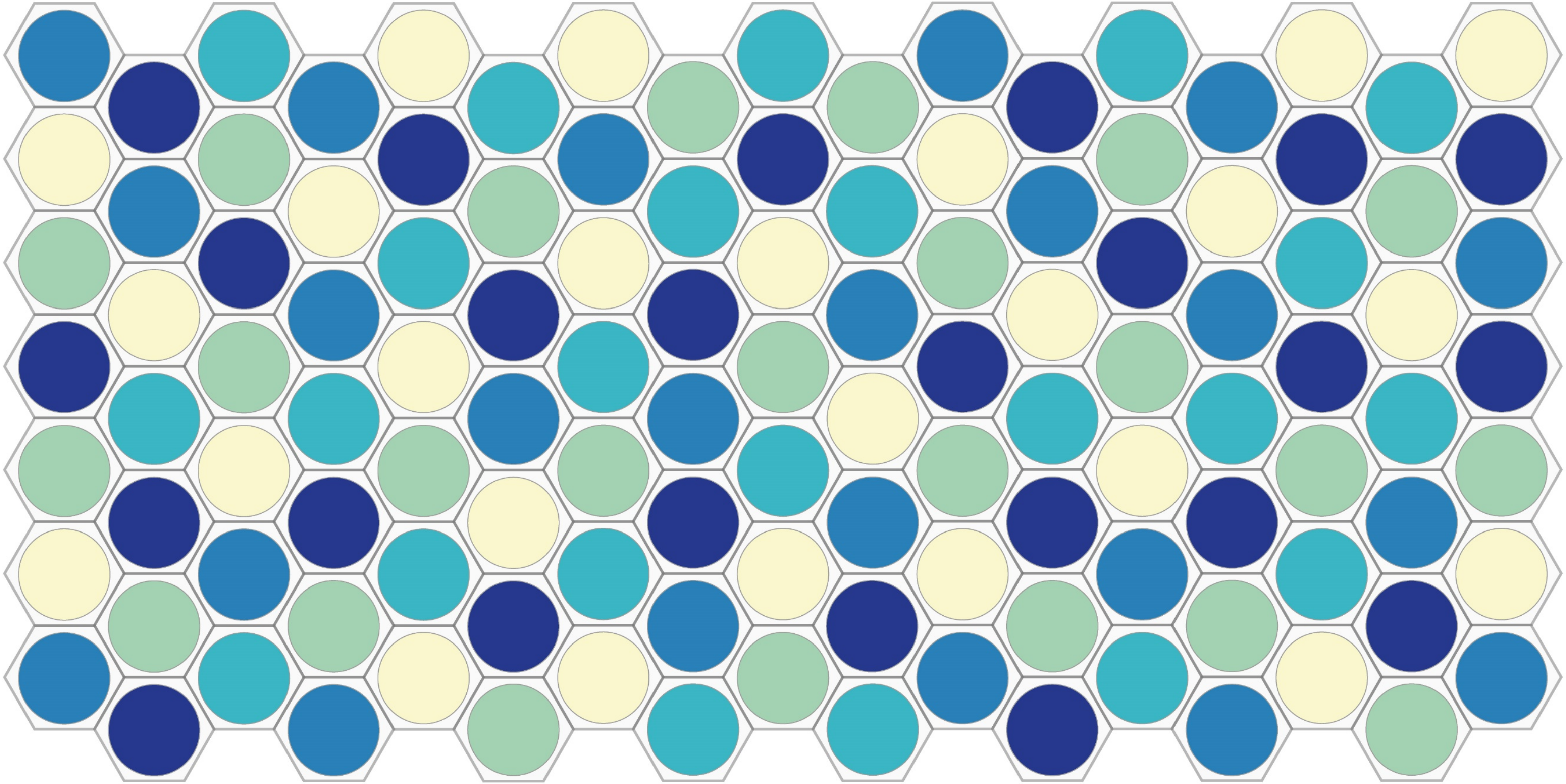
⋮

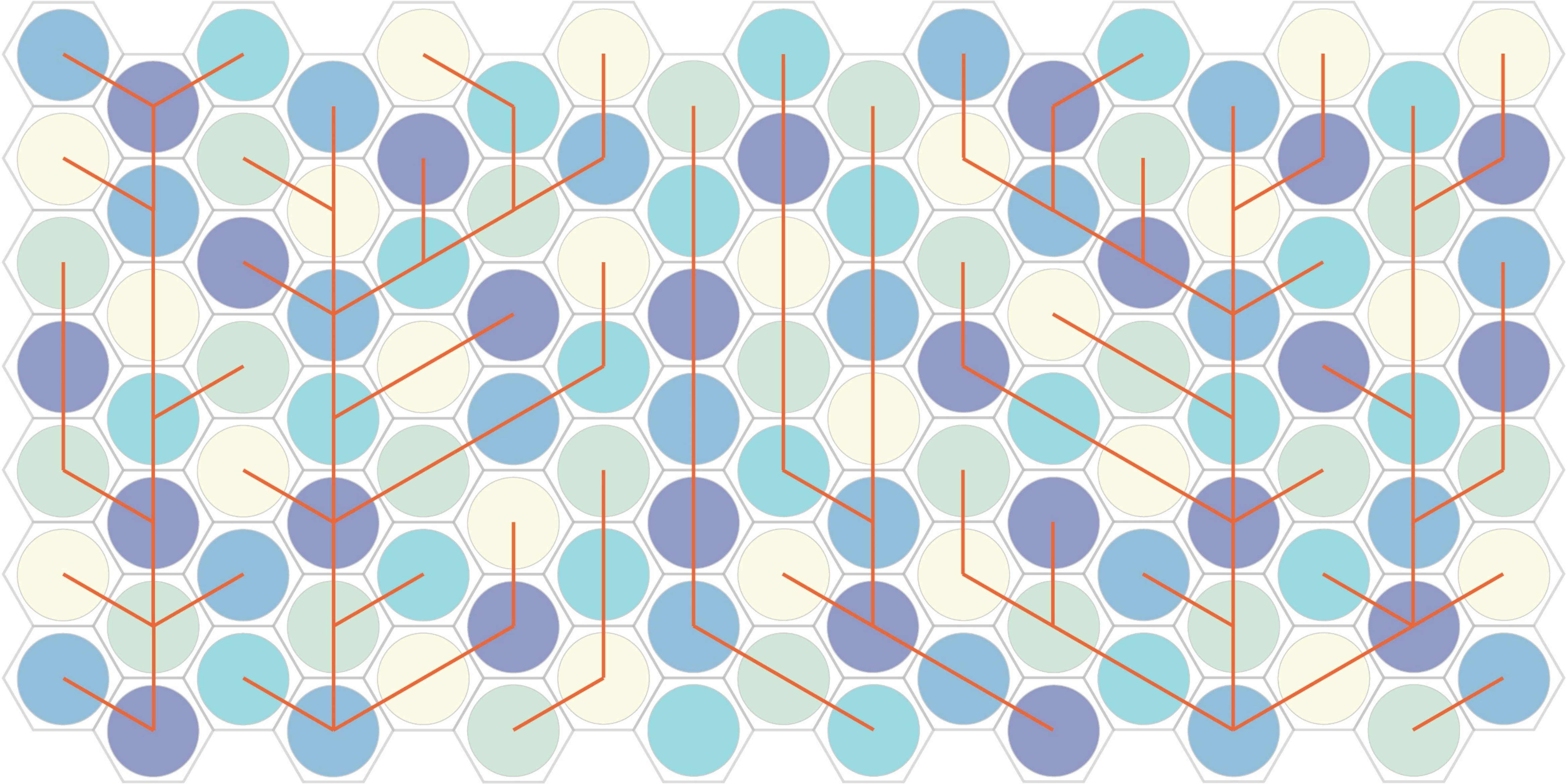


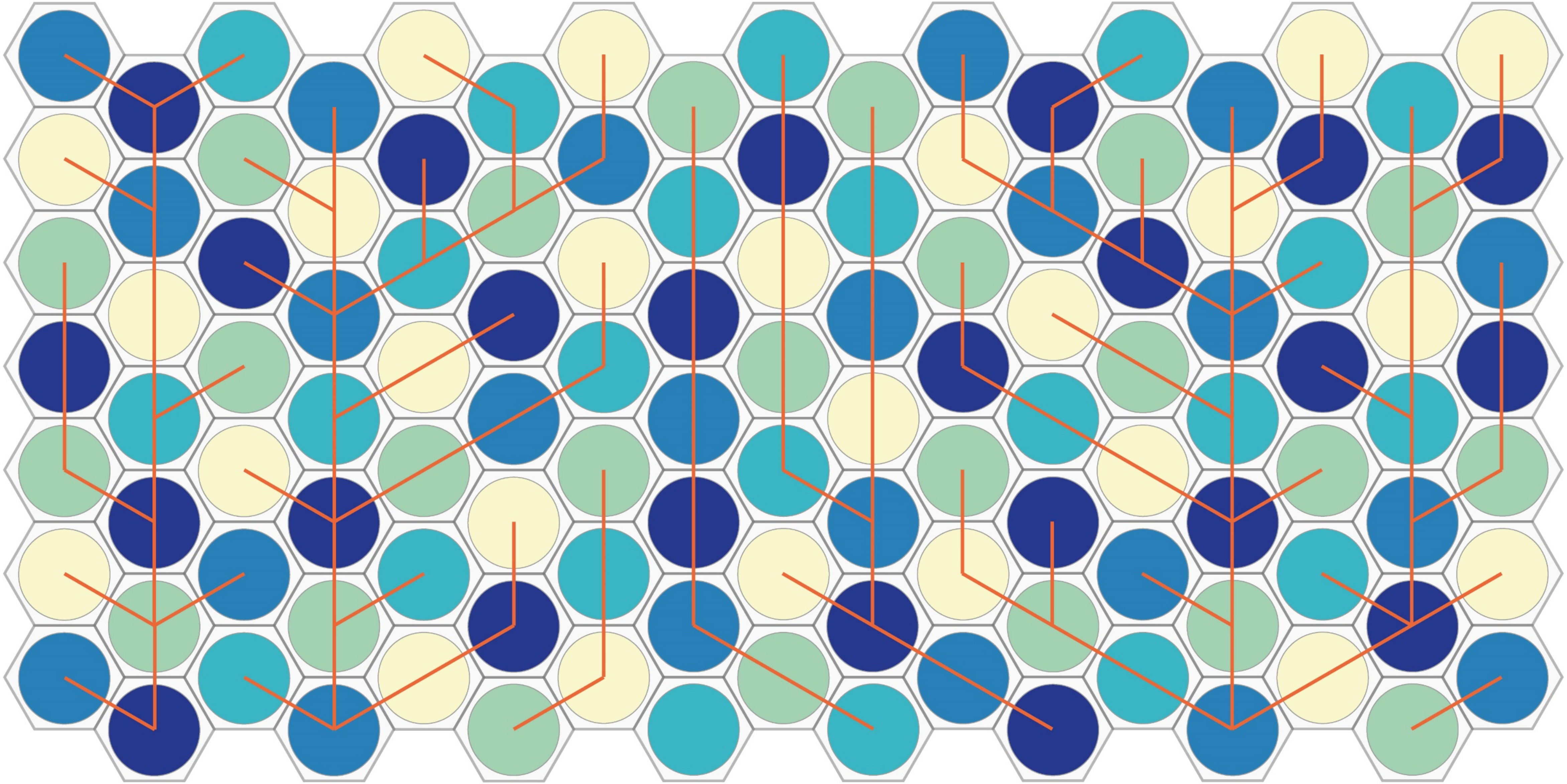
Protection effect

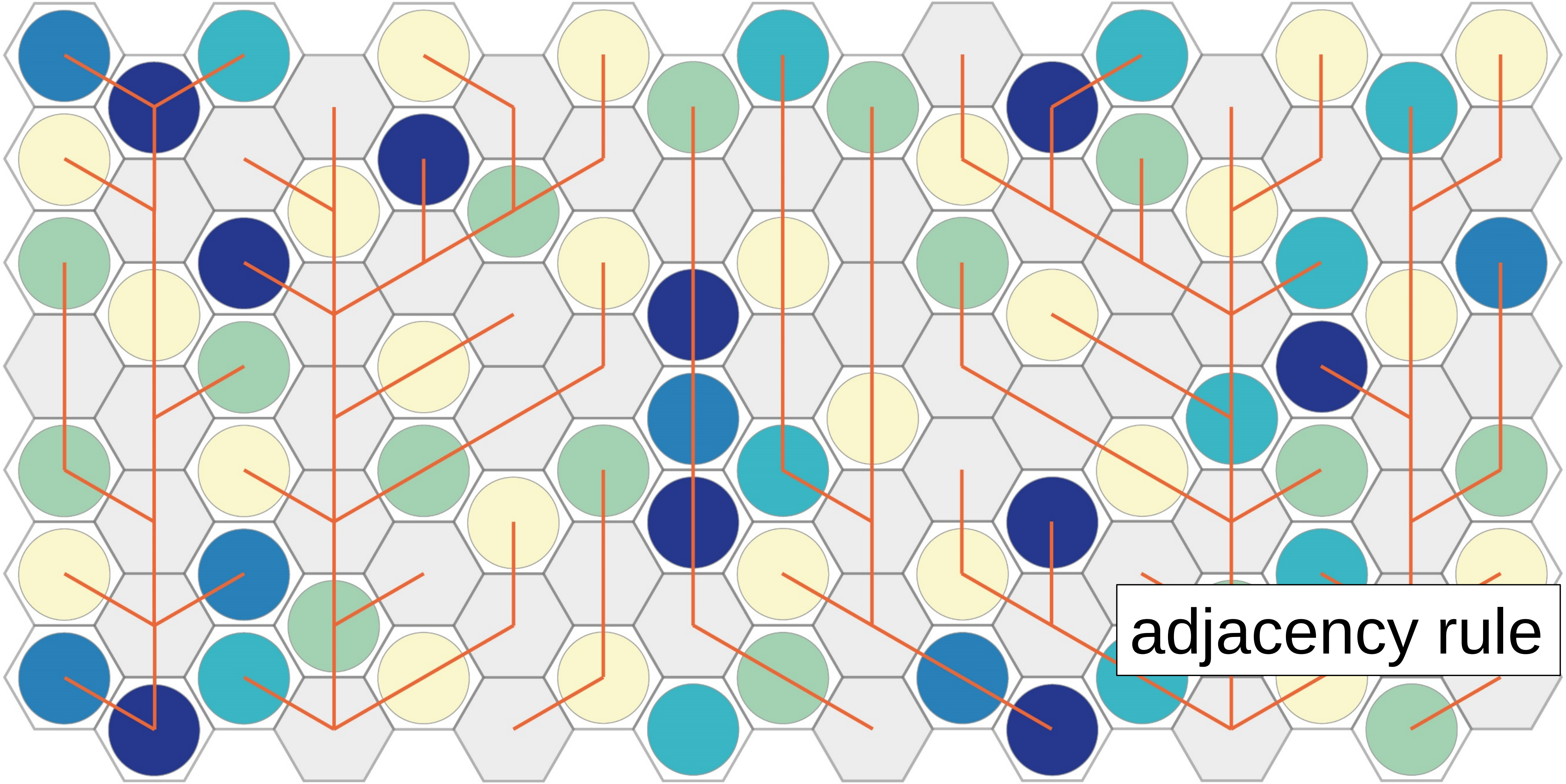


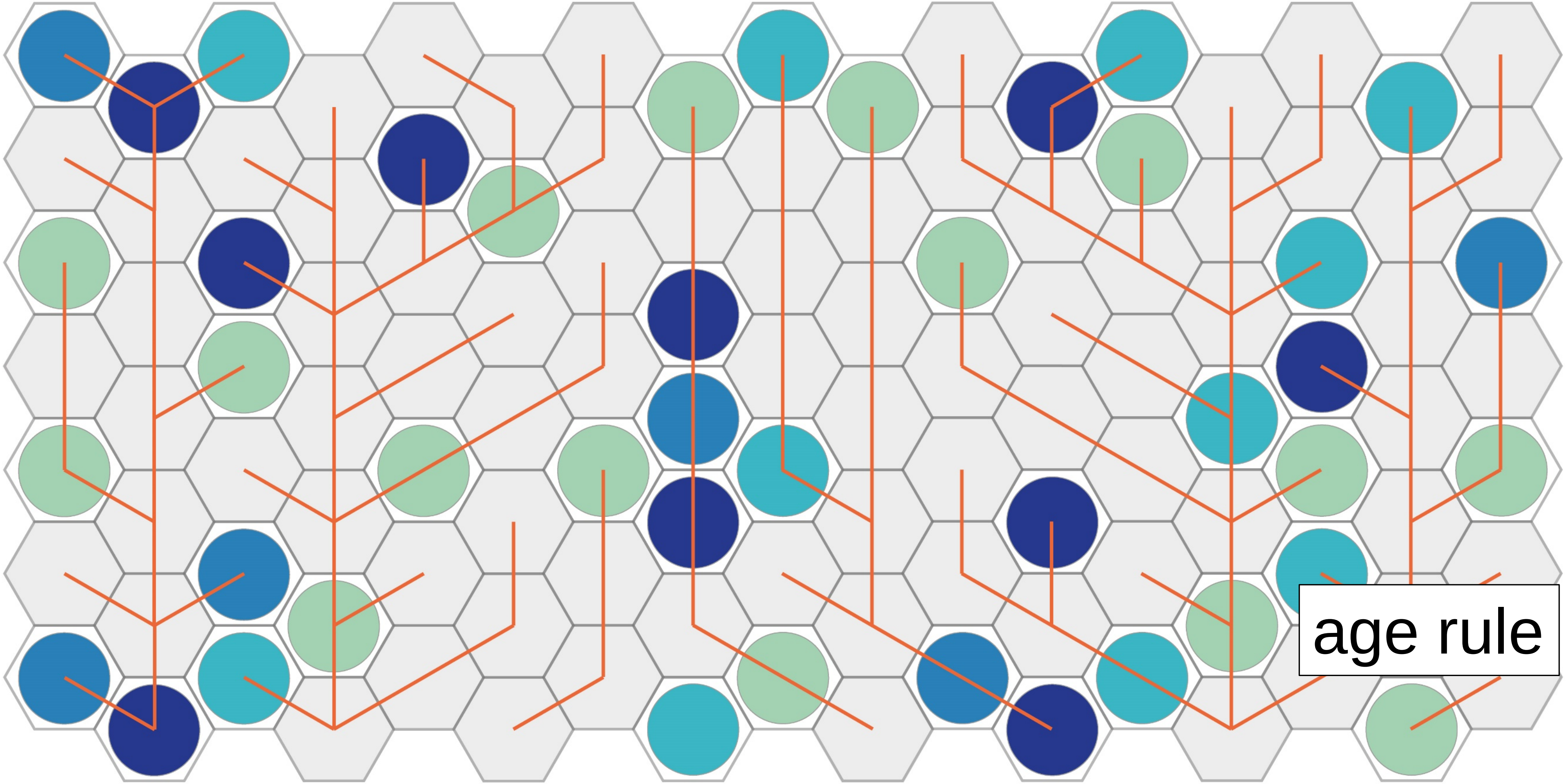




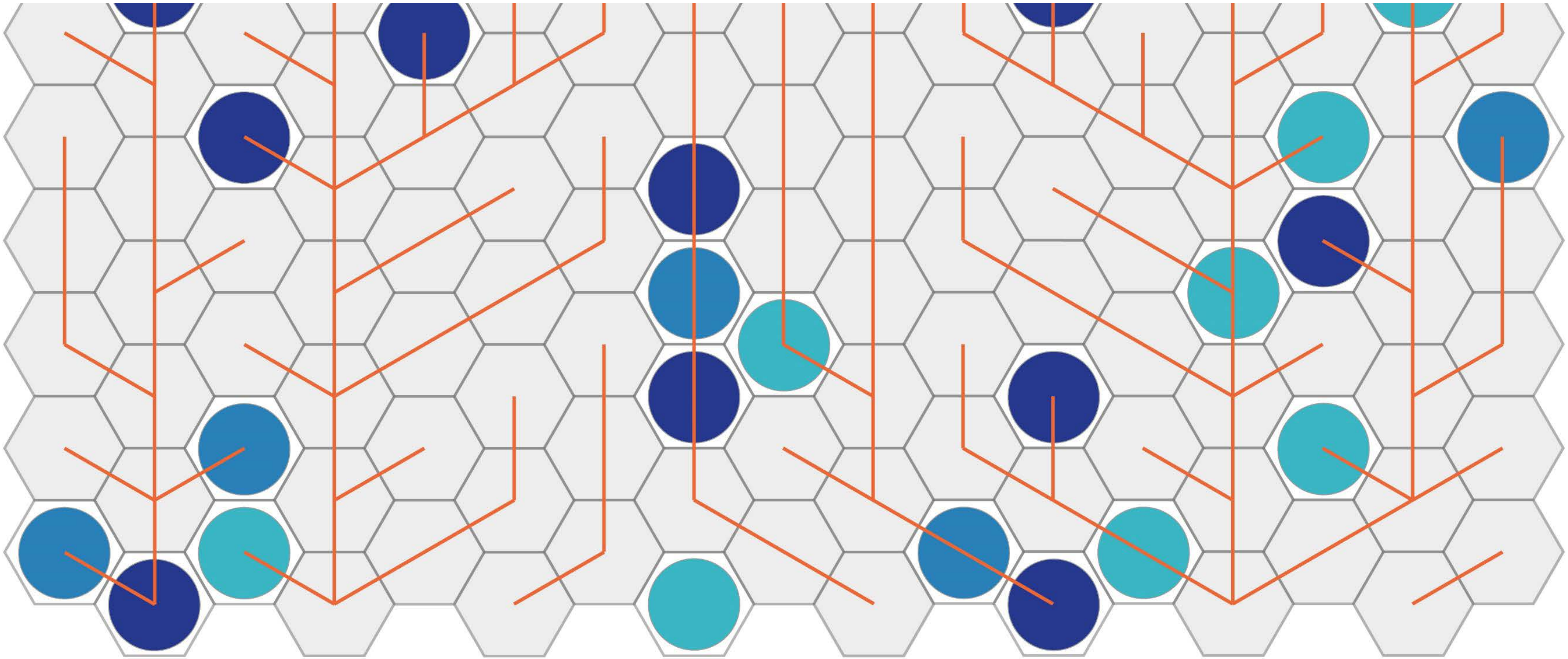




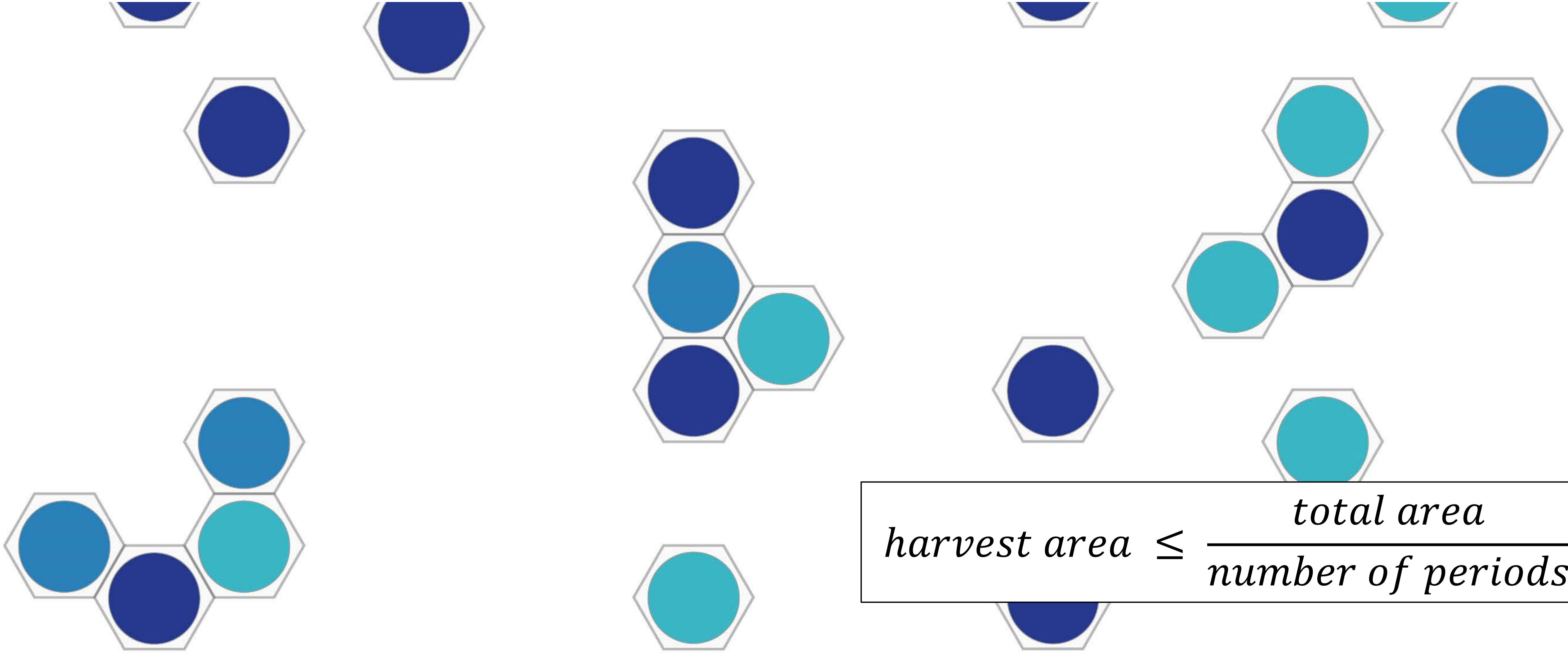

adjacency rule


age rule

Harvestable hexagons subject to natural hazard processes



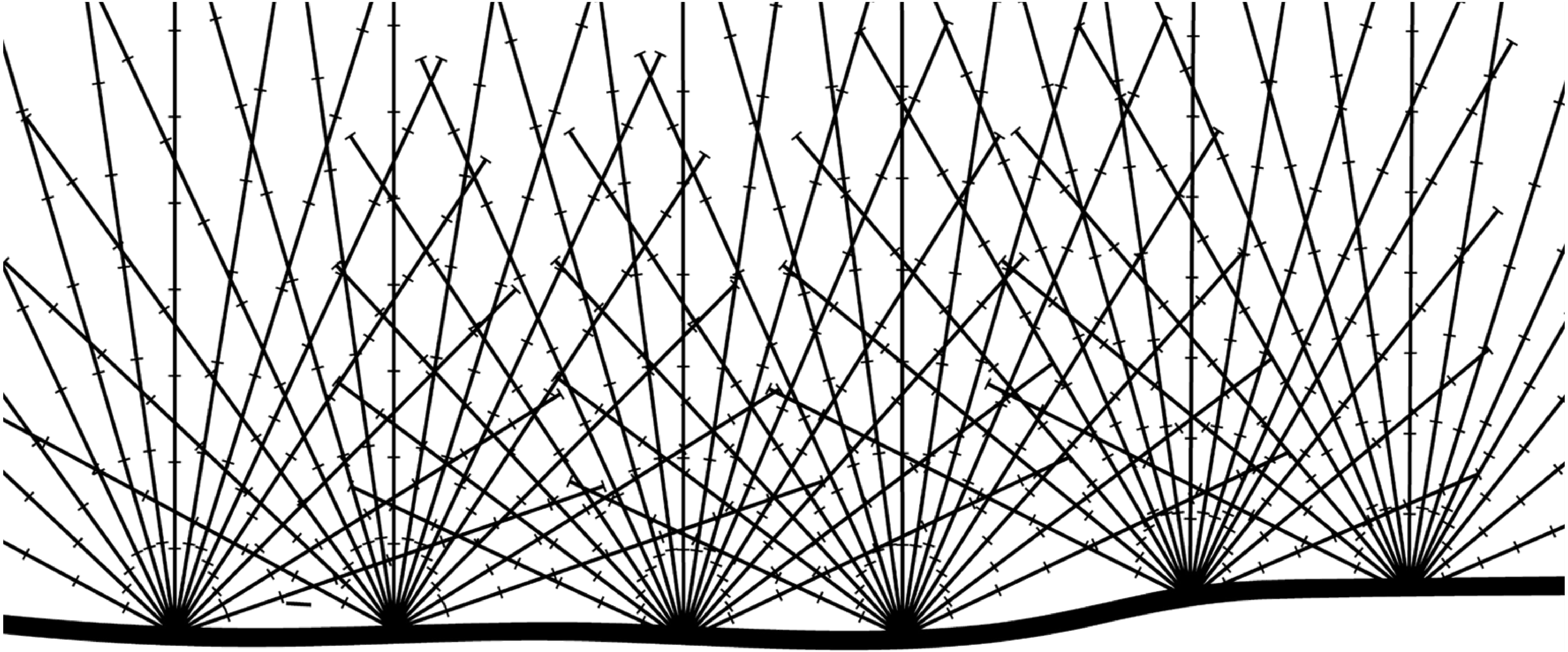
Continuous regeneration initiation



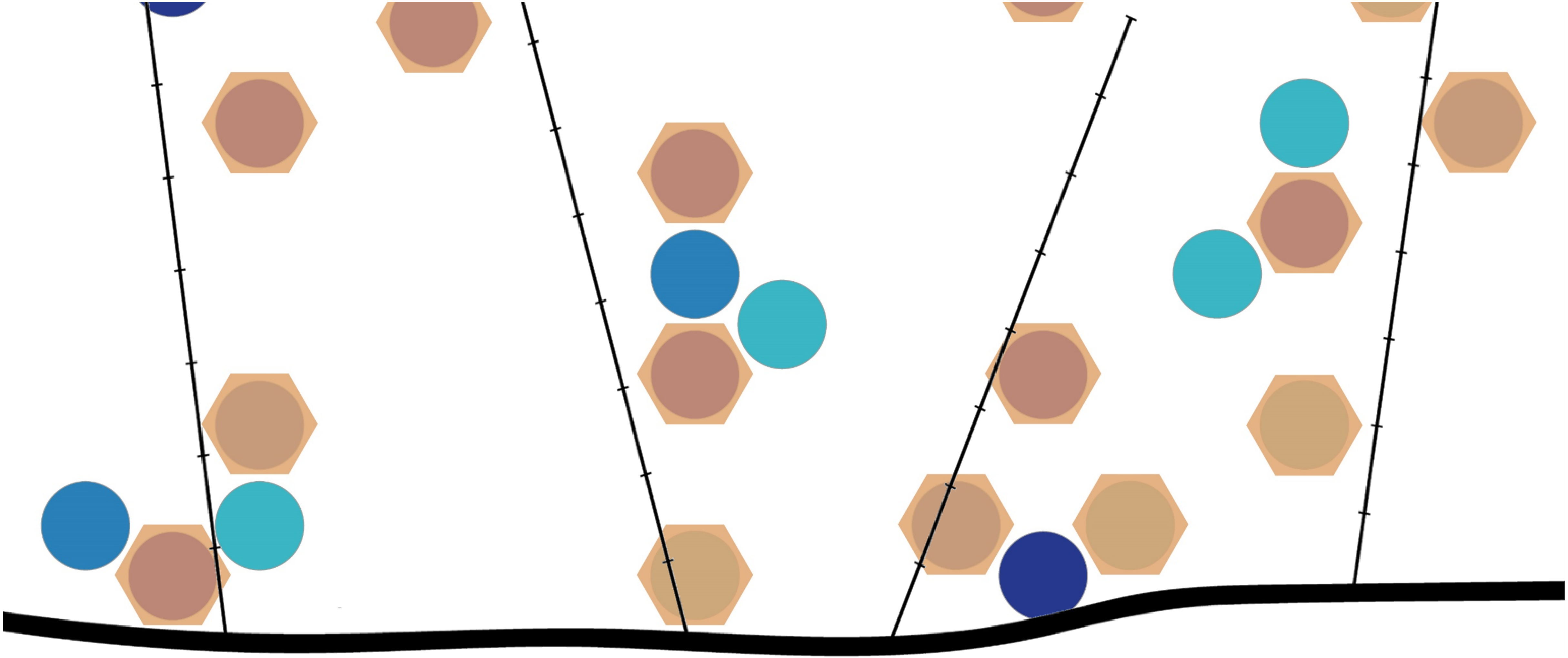
$$harvest\ area \leq \frac{total\ area}{number\ of\ periods}$$

Harvesting technique

Set of possible cable lines



Choosing the optimal combination



Mixed integer programming model

MAX protection effect

MIN management costs

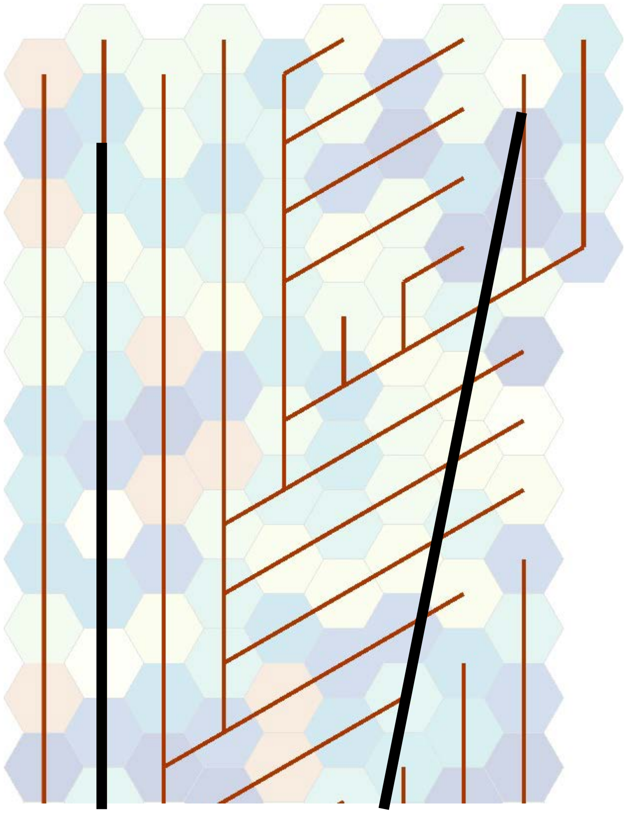
Subject to

- forest dynamic rules
- harvesting rules
- adjacency rules

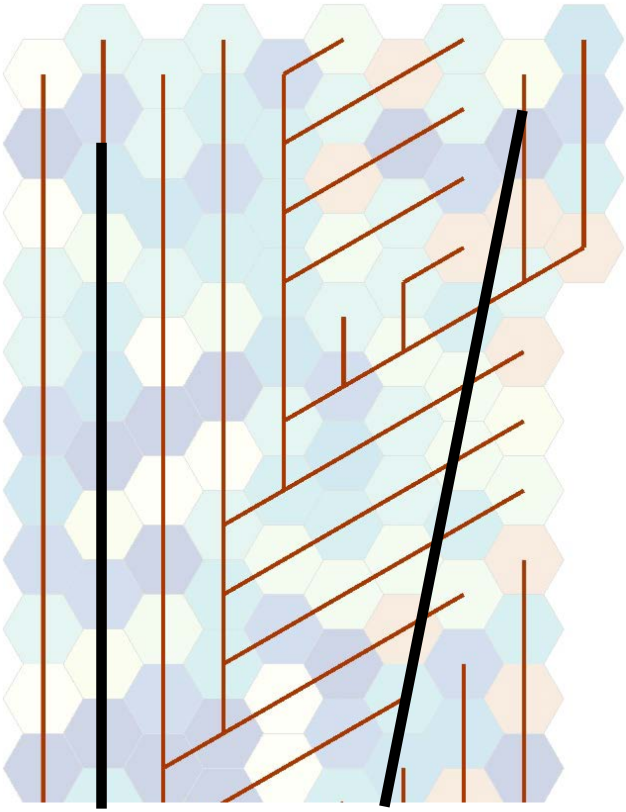
Result

- 192 units à 200m2 ($\approx 4ha$)
- 10 periods
- 8 ageclasses
- 2 cable roads
- 32656 integer variables

period 1



period 2



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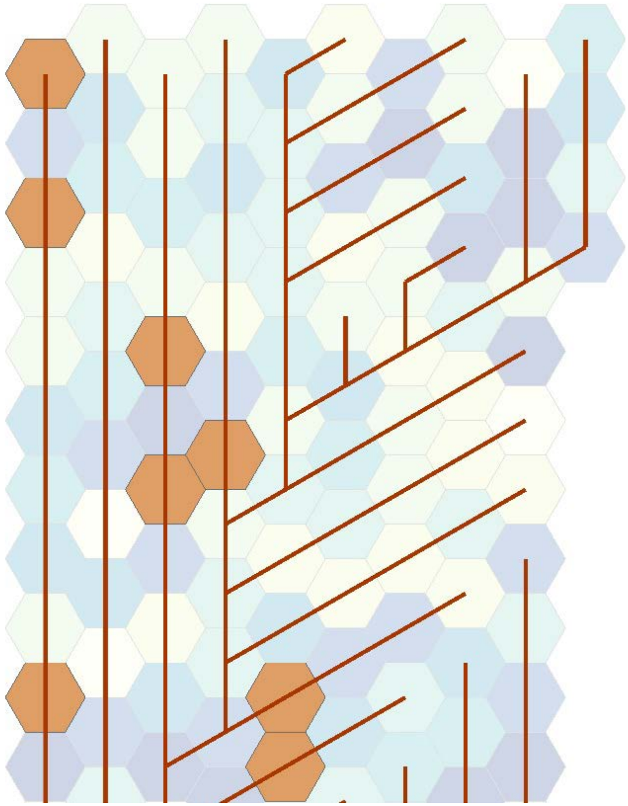
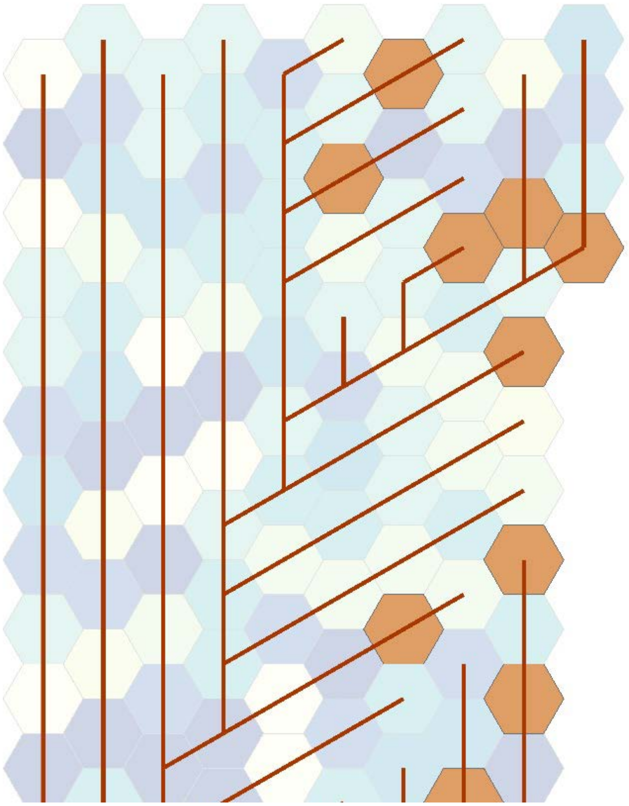


period 2



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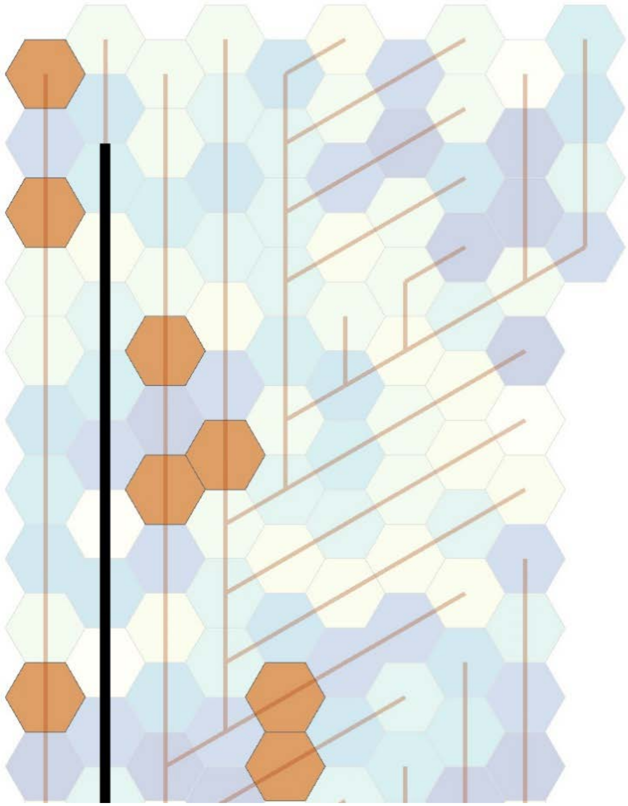
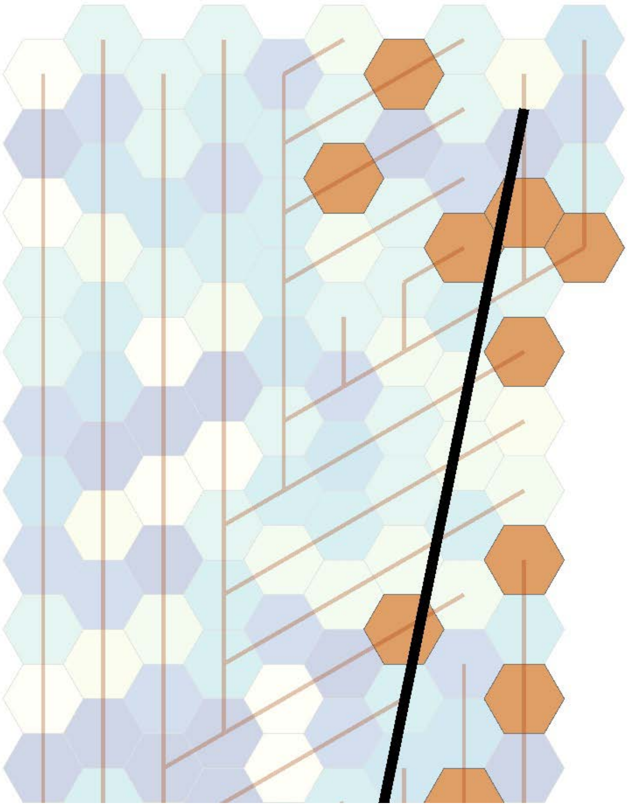


period 2



Conclusions / Improvements

Conclusions:

- The model can find an optimal spatial arrangement of gaps over several time steps

Further development is needed regarding:

- Computing time
- Planning for large areas
- Mortality

Thank you for your attention!

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Freiburg, Germany

Cable tension monitoring and setup time of winch assisted single-grip harvesters and forwarders in steep terrain operations

D3 – Eco-friendly harvesting operations in mountainous terrains

Franz Holzleitner, Thomas Holzfeind, Maximilian Kastner, Christian Kanzian
Institute of Forest Engineering, University of Applied Life Sciences Vienna

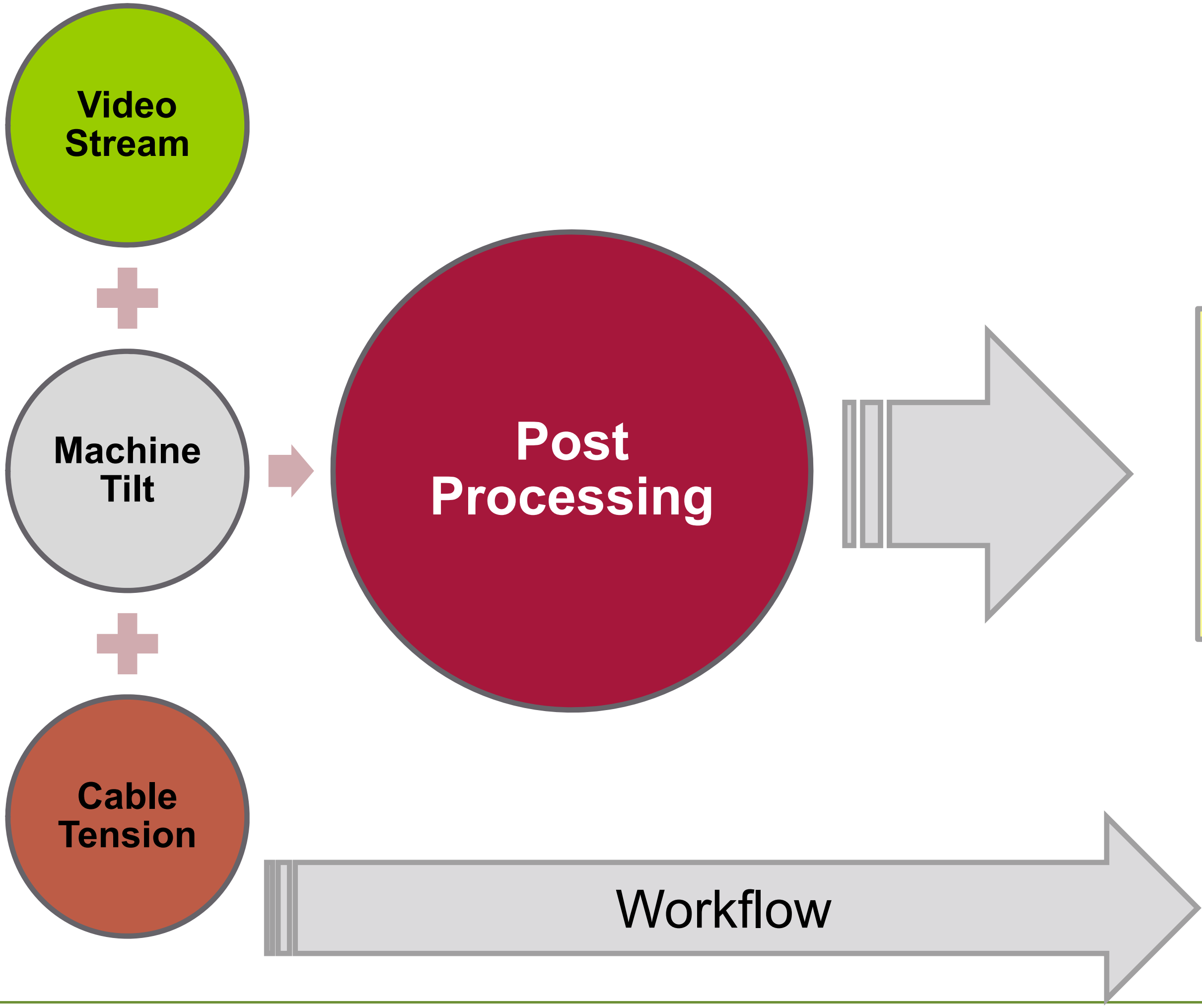
Background

- **Effectively** running timber harvesting operations in steep terrain is a complex task
- Winch assisted machinery offer new opportunities
  - in terms of cost **efficiency**
  - **safety** issues
  - and **gentle “driving”**
- Number of operating machines is growing rapidly

Objectives

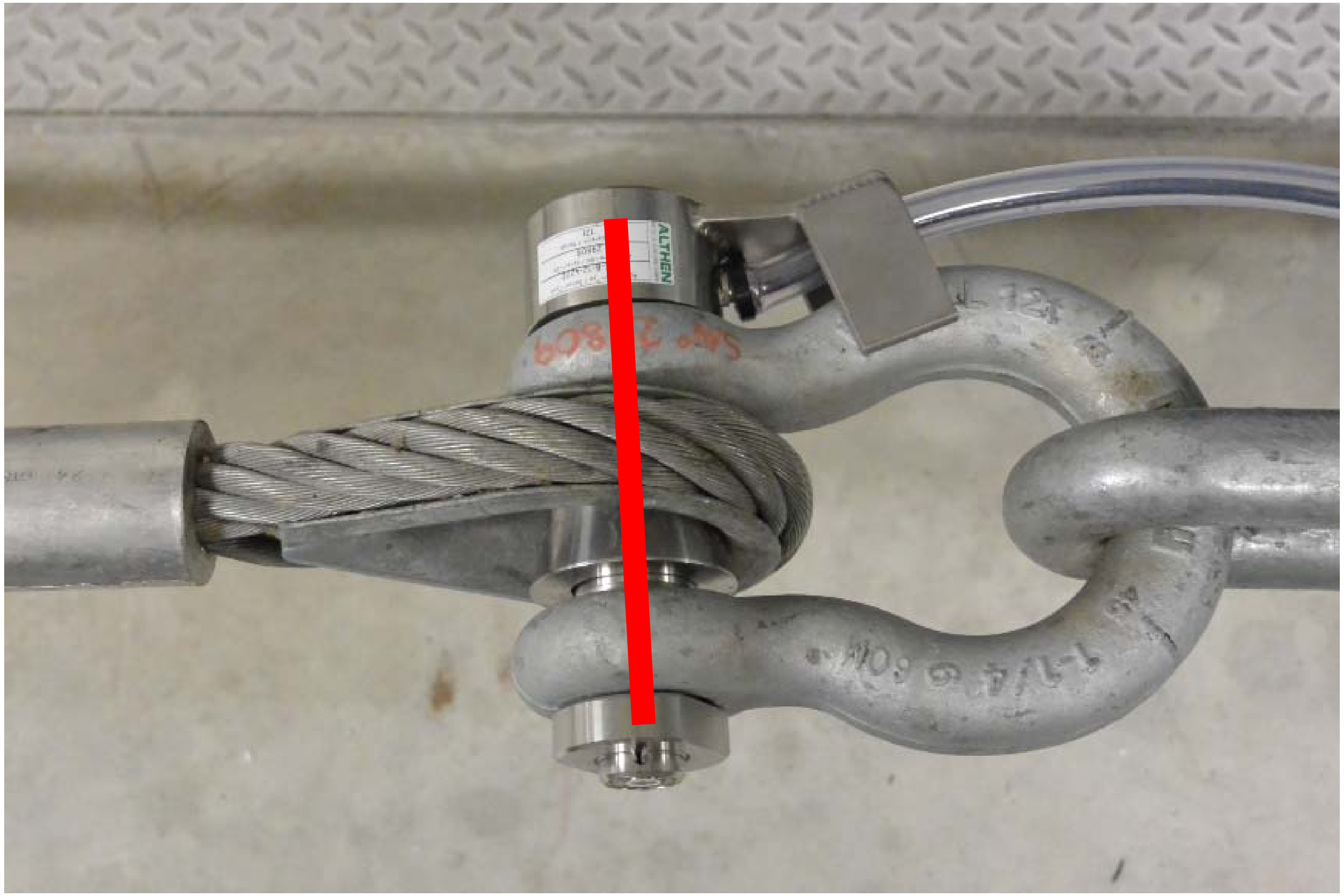
- To develop **guidelines** for fully mechanized harvesting operations in steep terrain
- Goals in detail:
  - monitor **cable tension** in steep terrain harvesting operations
  - analyse machine´s **productivity**
  - analyse **time consumption** for **cable rigging**

Study Concept



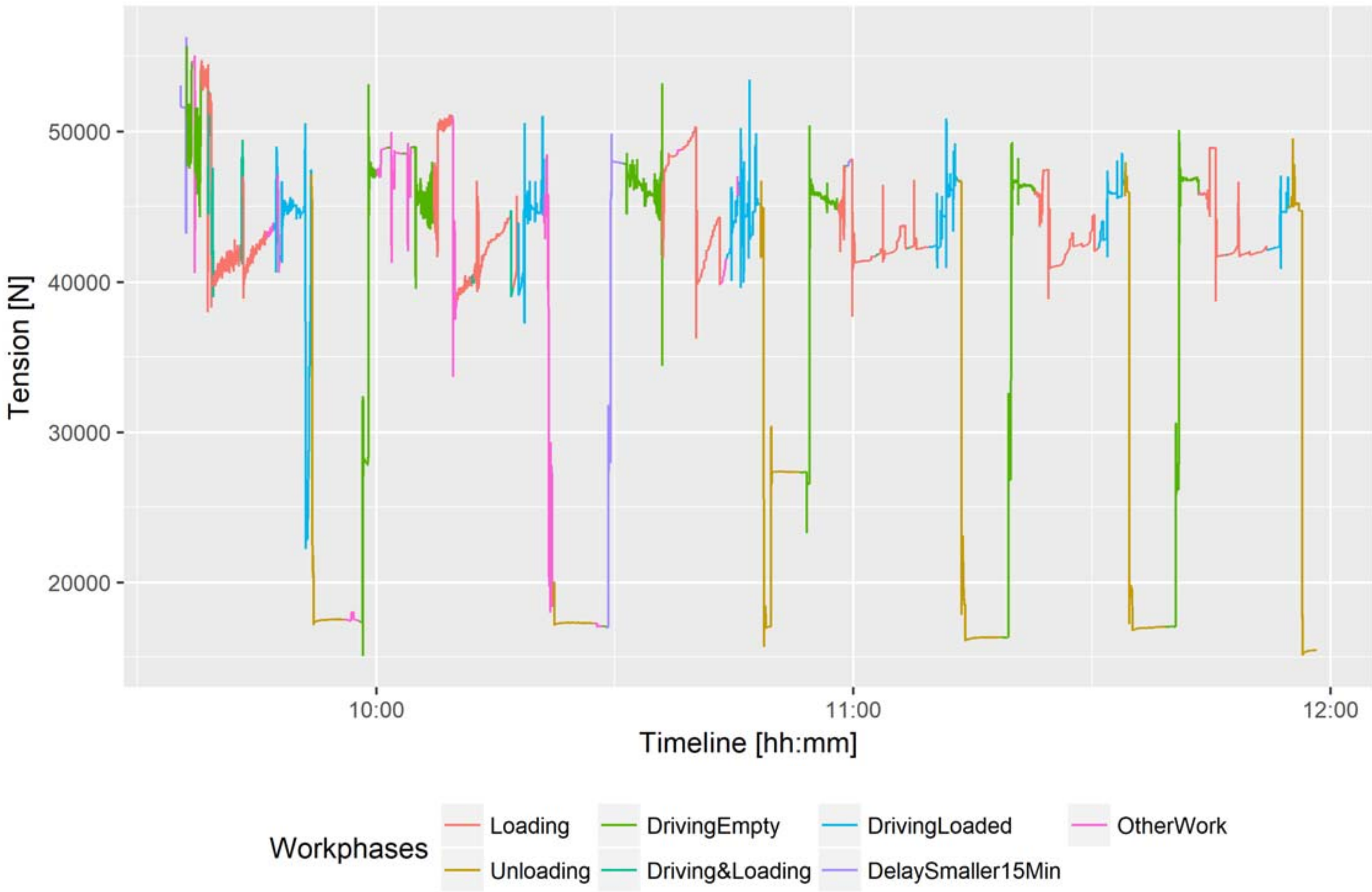
Cable Tension Sensor (1)

Cable Tension Sensor (2)

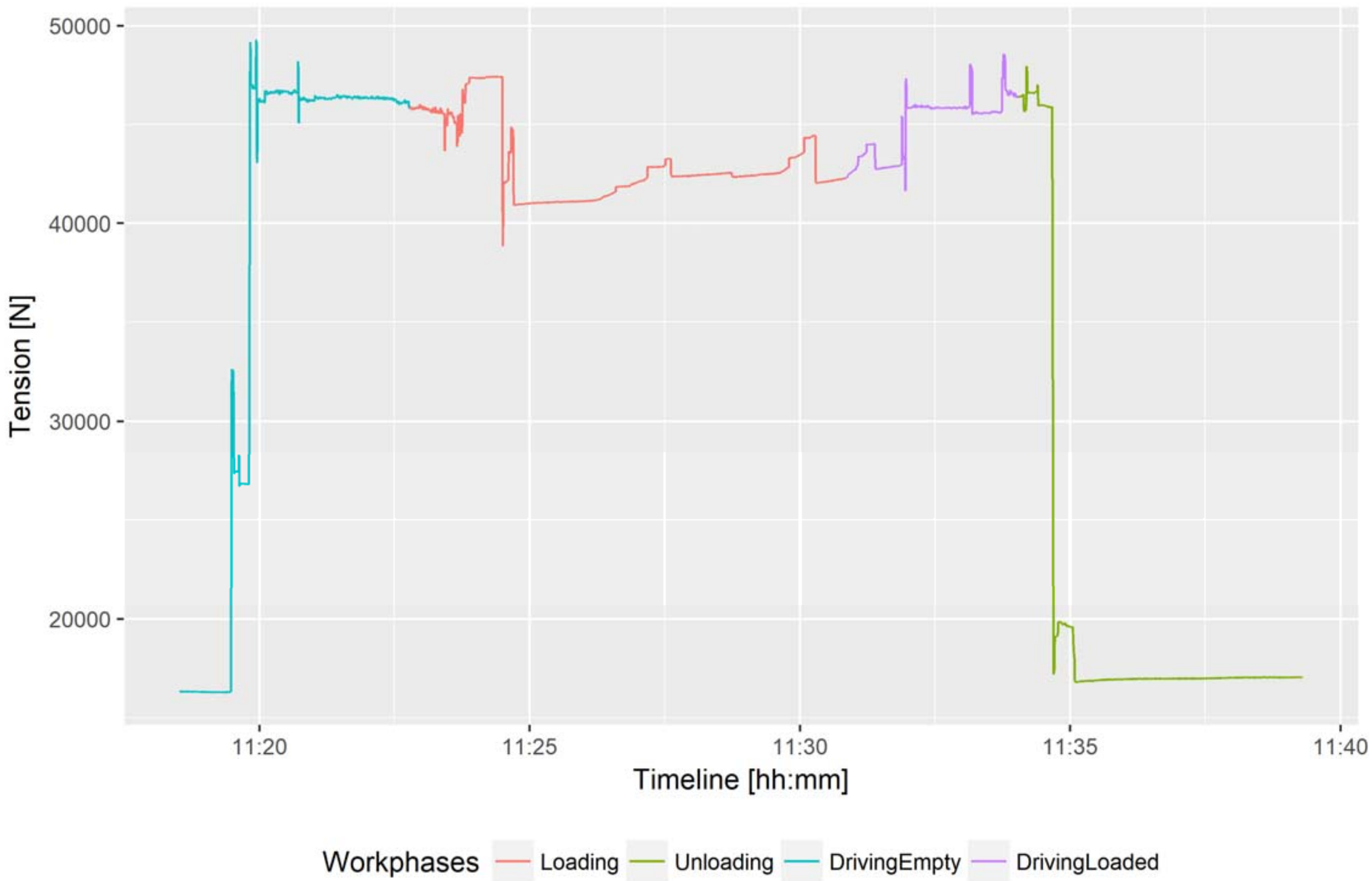


Cable Tension - Forwarder

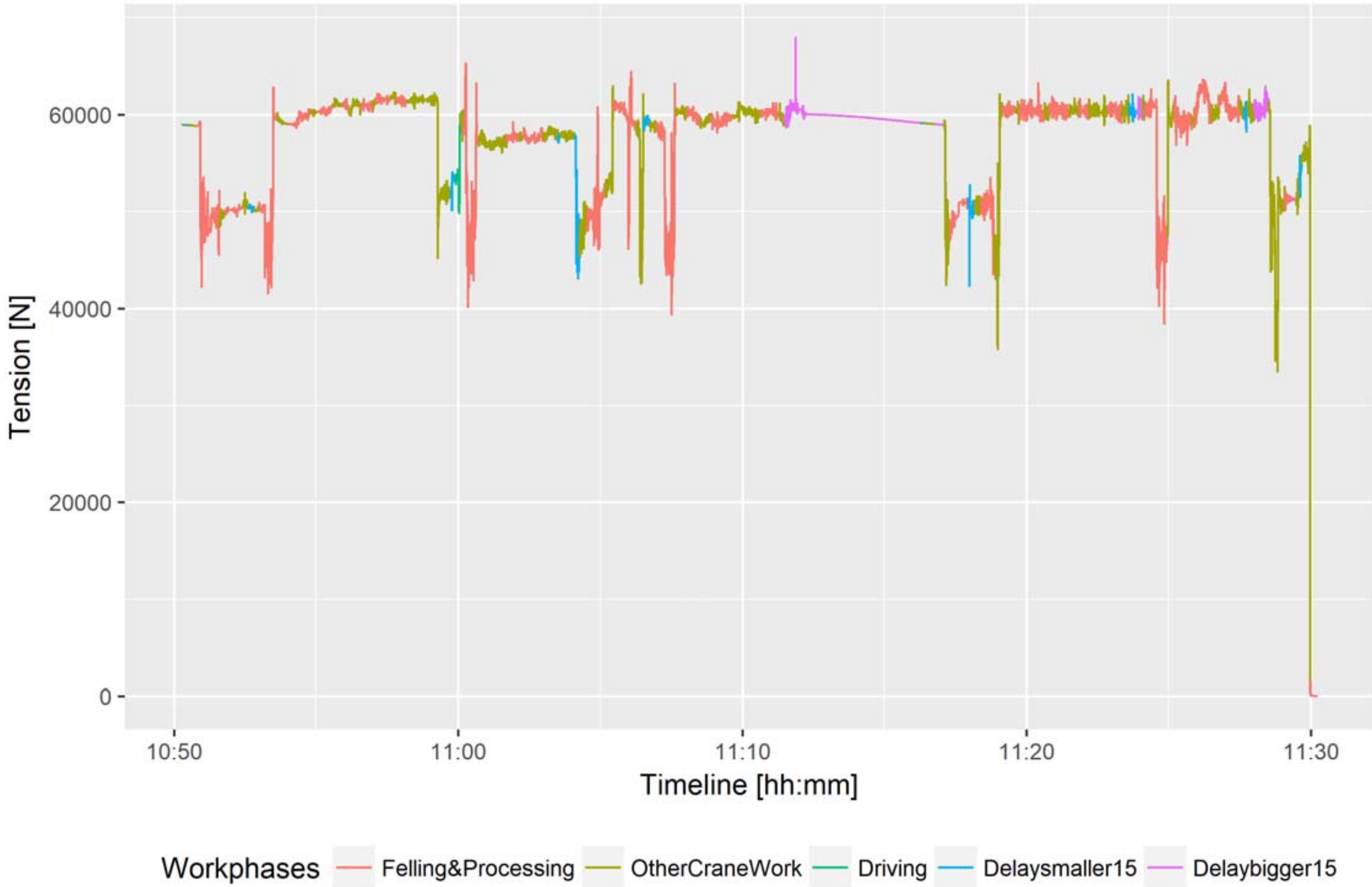
2.5 hours = 900.000 rows



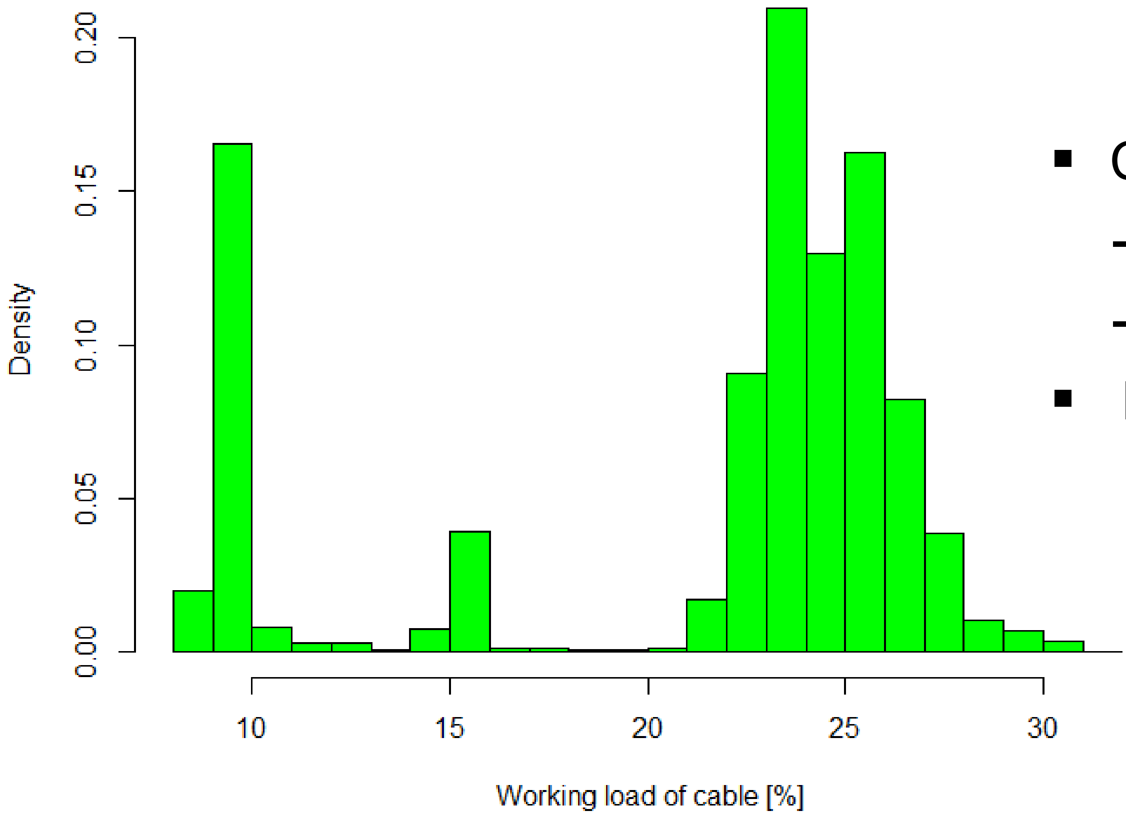
Cable Tension - Forwarder



Cable Tension - Harvester



“Safe Working Load”



- Cable:
  - 14 mm
  - 181 kN MBF
- Pulling Force Winch: 9t

Time consumption for rigging

- Forwarder (Holzfeind, 2017):
  - Average rigging time: 22 min
  - 9.5 % share of total time

Next Steps

- Develop detailed **Input-Output-Model** regarding productivity and rigging time
- **Pushing** the new **analysis concept**
  - match **machine data** with **on-site data**
  - video-supported time-and-motion studies
  - cable tension measurements
  - and long term process analysis for rigging activities

BBI Project No. 720757
Tech4Effect

Outlook – Near Future

- **Efficient use** of multi-sensor based process analysis
- **Strengthen** knowledge through cooperation (FP-Innovations/EU-project Tech4Effect)
- Include additional questions
  - machine-soil-interaction
  - anchoring
  - wear of the cable
  - stress and strain

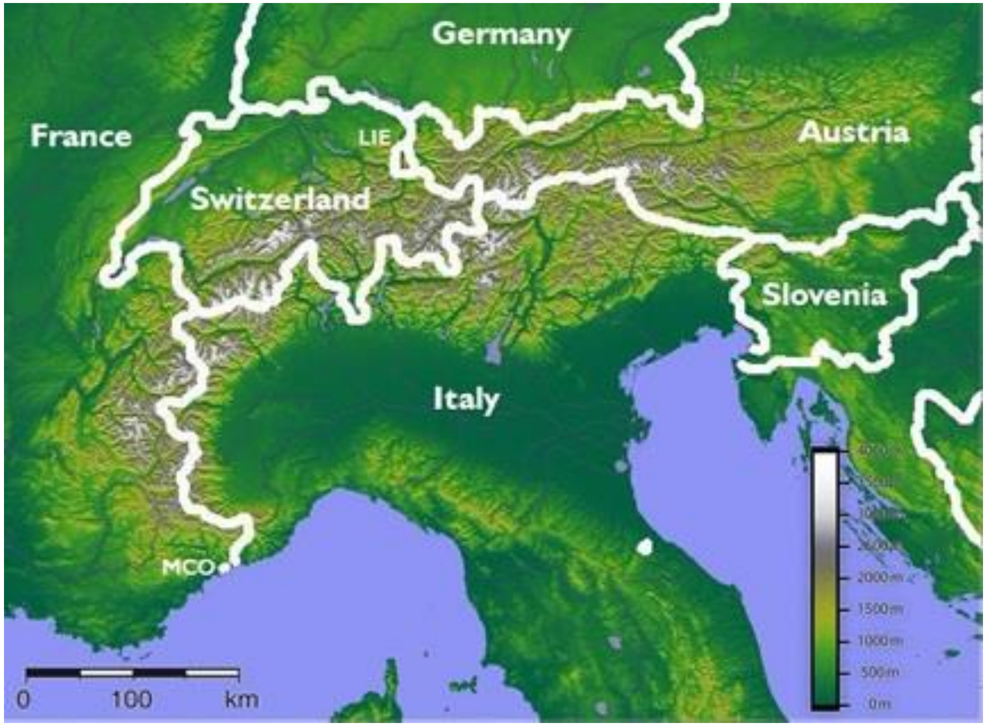

JOHN DEERE
www.huber-tazreiter.at
Thank you for your attention!

Cable logging in the Italian Alps: survey of operations and machine fleet, business perspectives and contract rates

N. Magagnotti, R. Spinelli – CNR, Firenze - ITALY

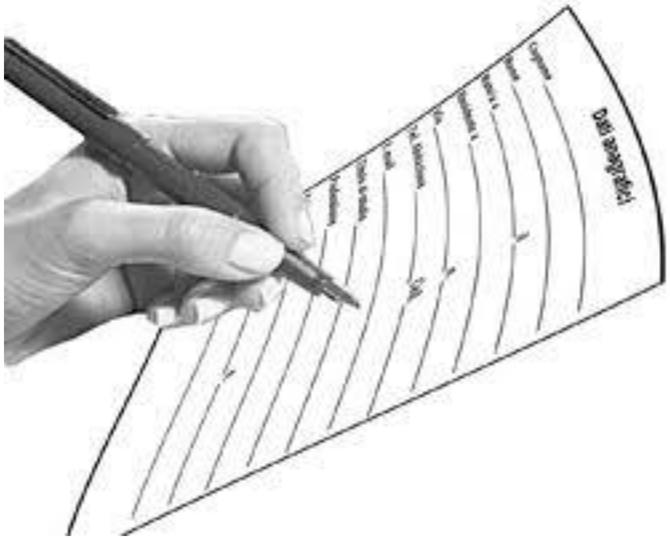
Italian Alps

- Italian Alps: 6 administrative regions
- complete region, not just Alpine portion



Study

- Company survey: habilitation registers
- Business outlook: one-on-one inteviews
- Cost: actual contracts



Yarders

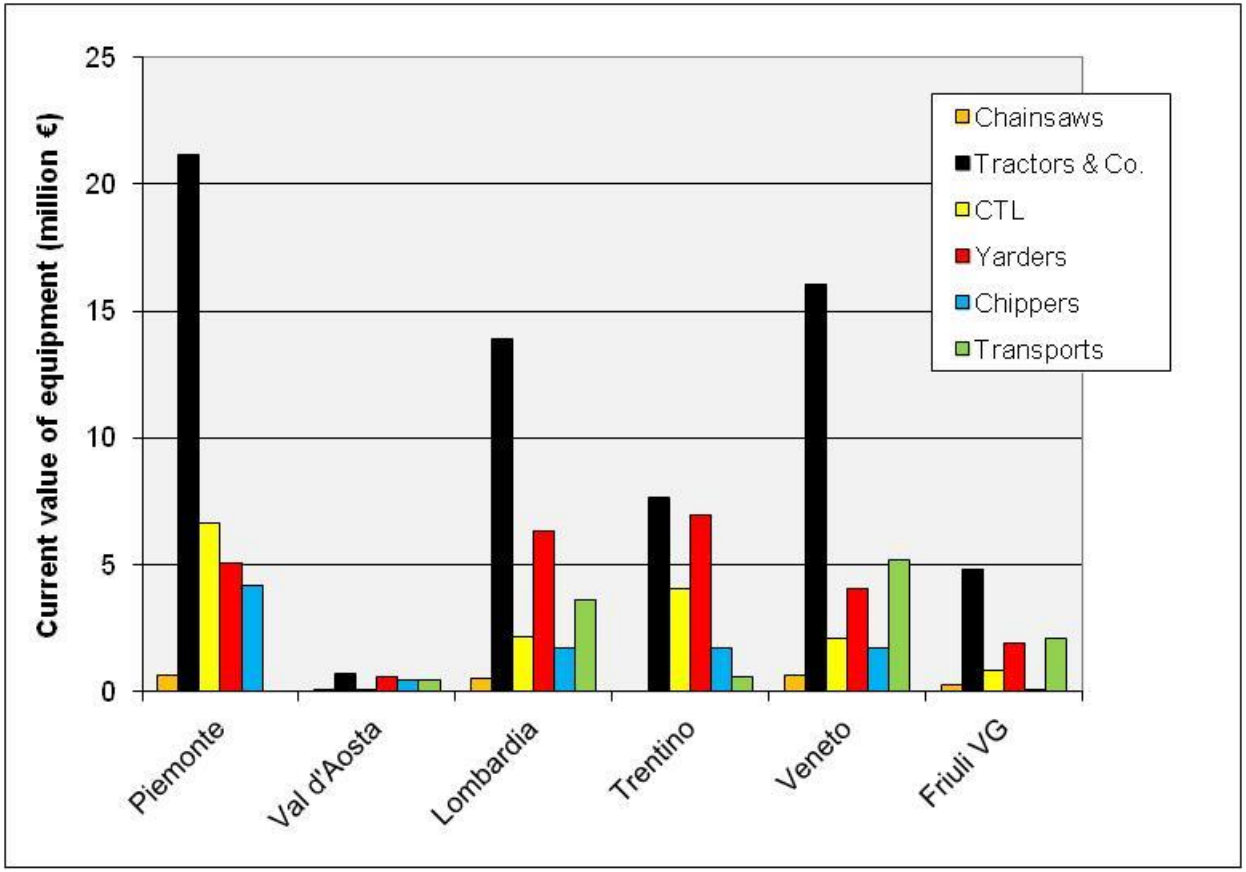
- Much competence, in all Regions
- 359 yarders
- 1 company in 4 is equipped and capable
- 70% Italian made
- 3 main manufacturers

Companies	1206
Workforce	3563
Annual harvest	3300000 m^3
Tractors	1872
Yarders	359
Processors	56
Actual value	130 M€

All types and sizes

Importance

- Second only to tractors



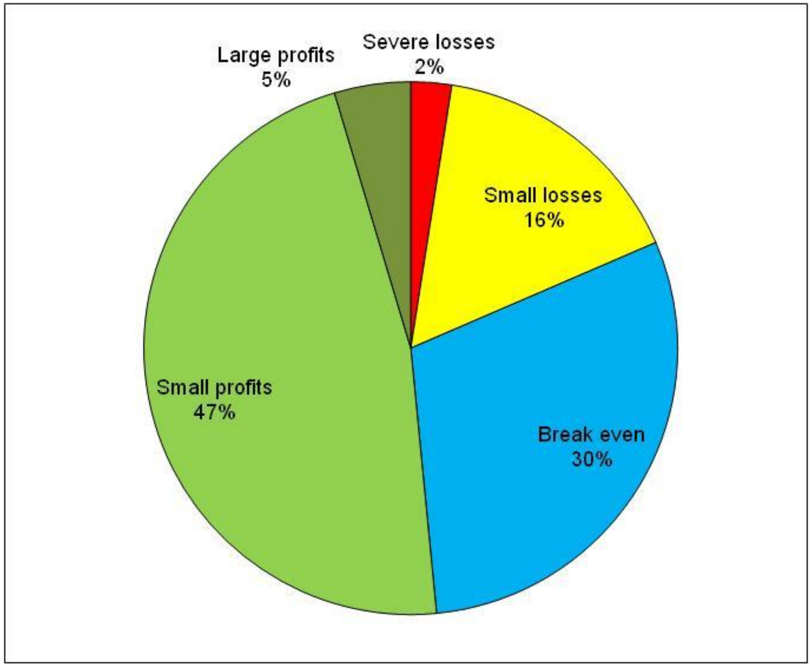
Trends

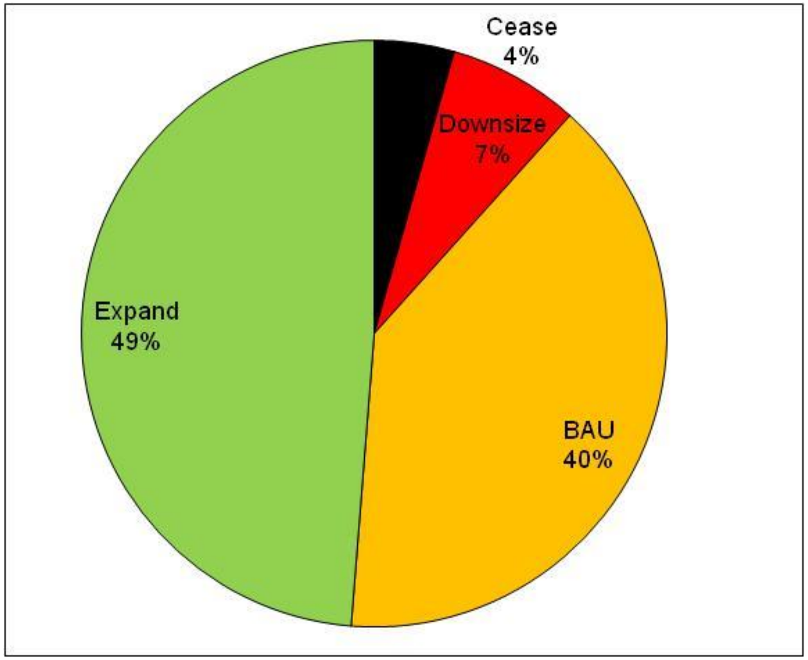
- Towers (35%) are newer (6 vs. 15 years)
- Companies with a yarder cut 4100 vs 2300 m^3/y
- Target slightly larger lots (678 vs. 565 m^3)

Parameter	Unit	Region						All regions pooled
		Piemonte	Val d'Aosta	Lombardia	Trentino	Veneto	Friuli VG	
Yarders	n	60	8	105	73	68	45	359
Sleds	n	34	6	78	39	45	28	230
Towers	n	26	2	27	34	23	17	129
Towers	%	43	25	26	47	34	38	36
Yarding capacity[1]	% of companies	11	55	44	41	19	31	24
Age (sleds)	years	11	6	17	17	22	14	15
Age (towers)	years	4	4	5	4	7	12	6
Age difference[2]	*p*-value	.0041	.8465	<.0001	<.0001	<.0001	.3887	<.0001
Skyline length (sleds)	m	n/a	n/a	1300	1300	n/a	1100	1270
Skyline length (towers)	m	n/a	n/a	600	850	n/a	650	750
Length difference[2]	*p*-value	n/a	n/a	<.0001	<.0001	n/a	.0012	<.0001

Business performance

- Survey of >300 companies





85% family tradition, >70% will continue

Business performance

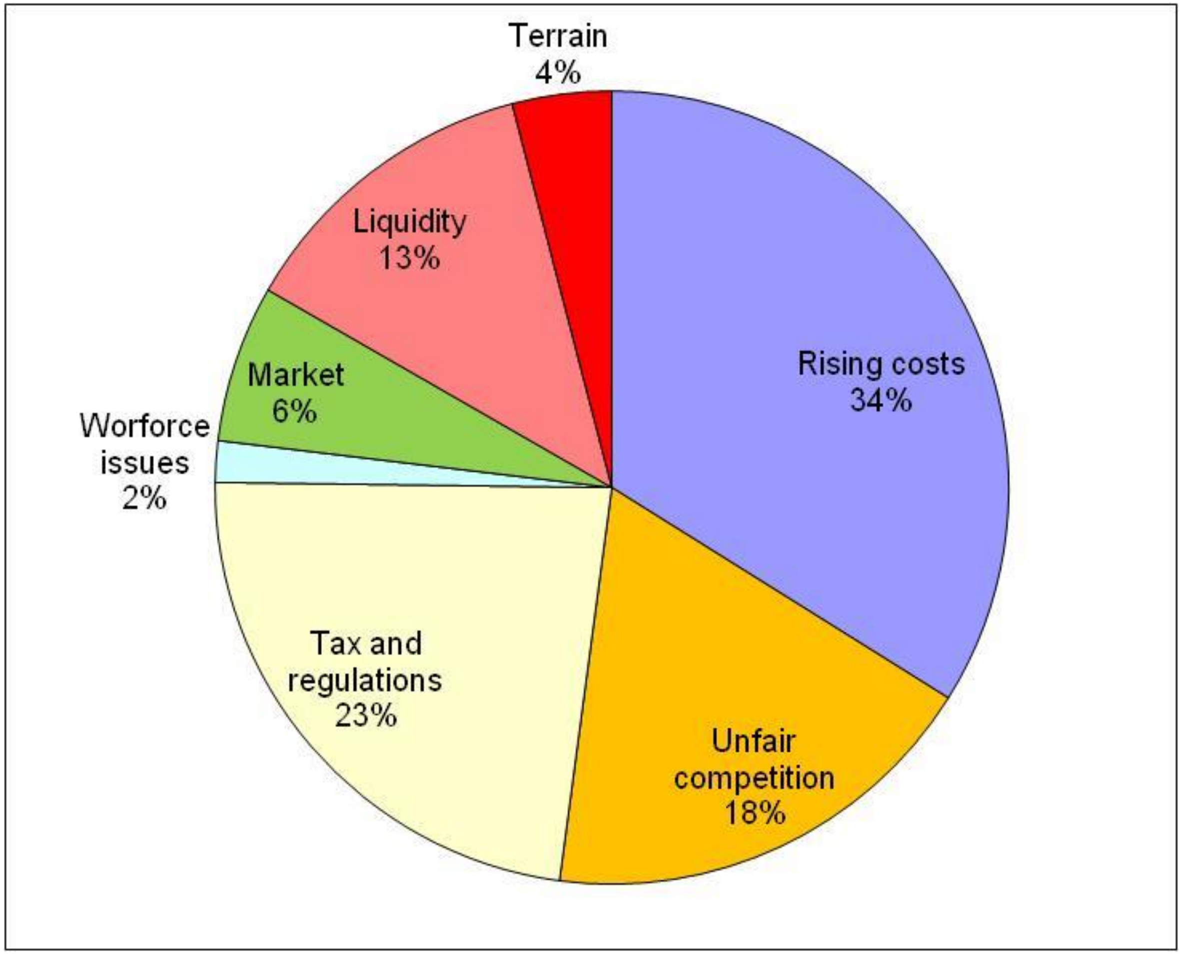
- No relation between technology and performance
- …but different success factors for yarders

Key success factors by technology type.

Technology type	Ground-based	Cable-yarding
Organization	6%	**15%**
PR	8%	7%
Capital	10%	**4%**
Products	7%	4%
Professionalism	19%	27%
Equipment	27%	23%
Hard work	13%	14%
Work quality	10%	6%
$\chi 2$	14.954	$p = 0.037$

Note: numbers in bold denote the strongest contributors to the $\chi 2$ score.

Terrain not a limiting factor!



Cost of harvesting

- No larger lots for Italian CY
- More expensive than GB
- Value of wood ca. 70 € m^{-3}

		France		Italy	
		Ground	Cable	Ground	Cable
	n	198	42	140	63
Tract size	ha	**8.23**	9.64	10.05	9.99
Lot size	m3	454	**997**	540	586
Removal	m3 ha-1	107	120	**70**	**75**
Tree size	m3 tree-1	1.77	1.72	1.48	1.35
Distance	m	884	484	250	301
Contract rate	€ m-3	**27.3**	**48.2**	**38.1**	**43.6**

Conclusions

- Significant competence available
- Adapted to terrain and silviculture
- Ongoing studies on:

  fuel use reduction

  replication possibility

  ergonomics and safety

- Contacts: magagnotti@ivalsa.cnr.it

Abs.-No Id 1224

Short span logging cable systems in steep terrains:

Running skyline and simple standing skyline systems oriented for small scale forestry

Suzuki Y.[1], Yoshimura T.[2], Aoki H.[1], Yamasaki S.[3], Yamasaki T.[3]

[1] Kochi University, Japan

高知大学 Kochi University

[2] Shimane University, Japan

[3] Kochi Prefectural Forest Technology Center, Japan

Background: Logging machines in Japan

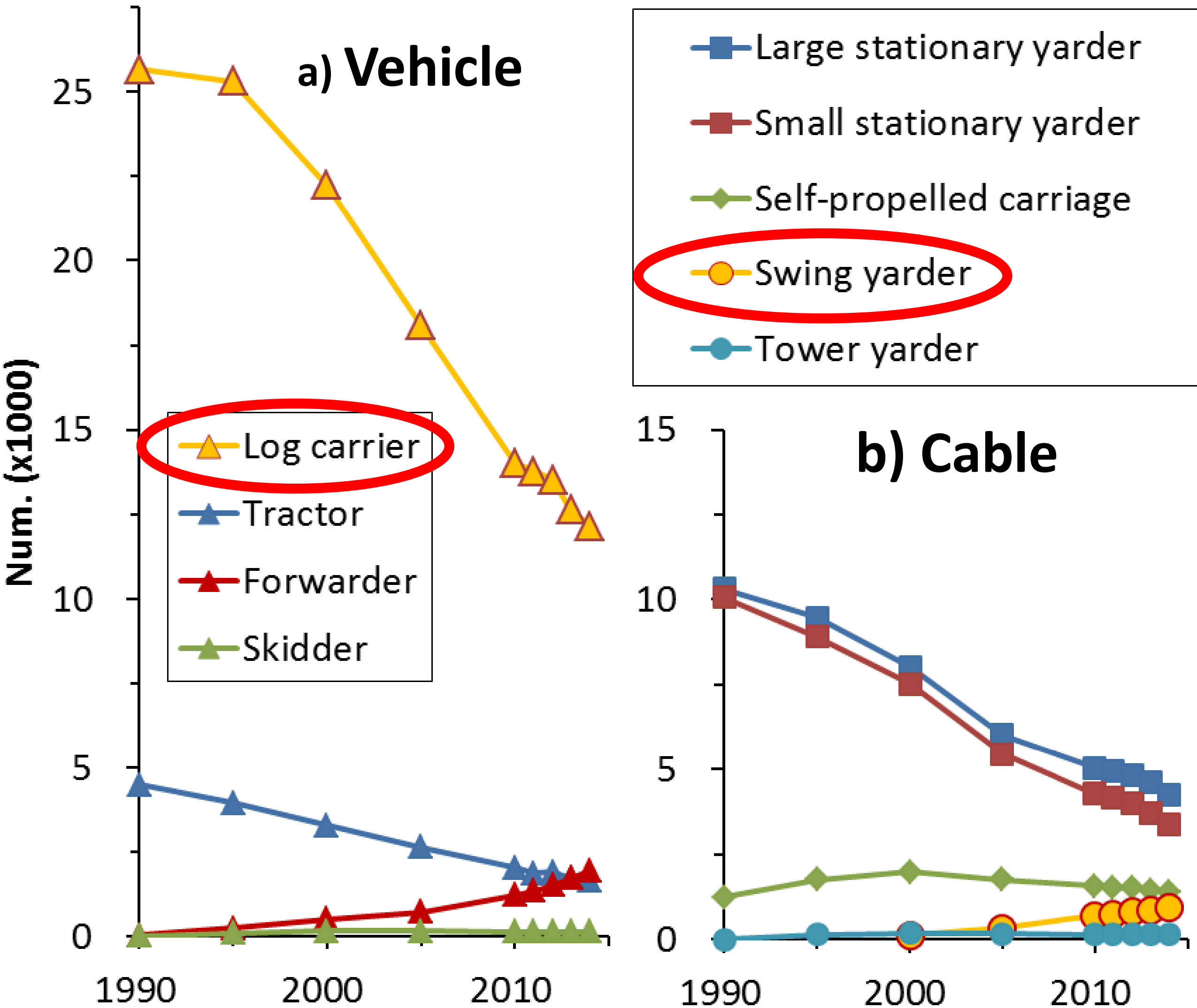


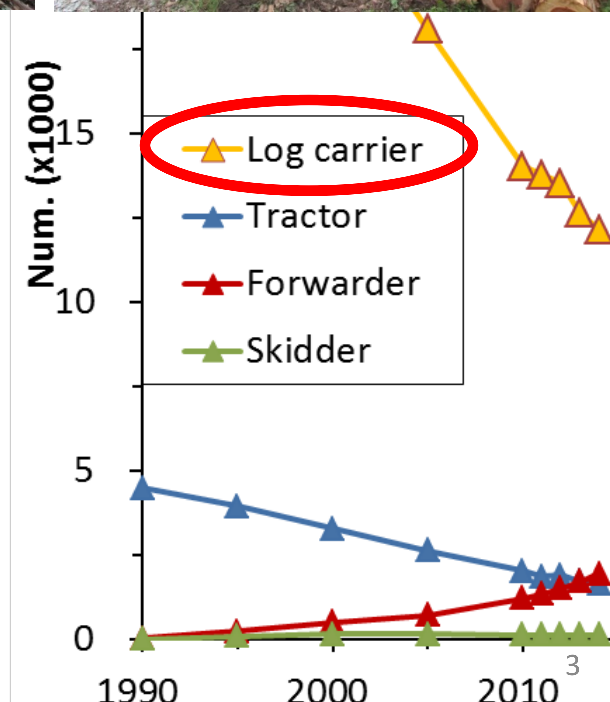
Figure. Number of logging machines in Japan

Source: Forestry Agency (2016)

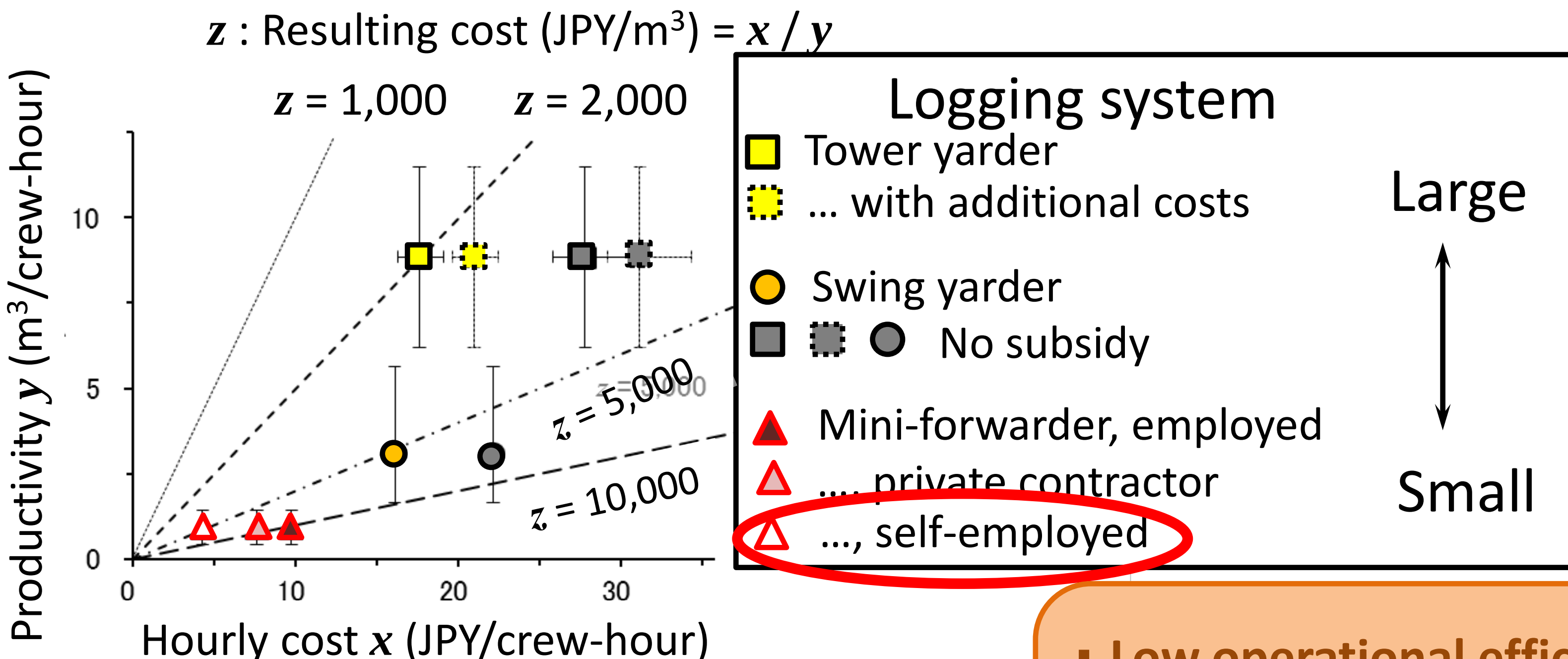
- Vehicle based
  - **Log carrier** declining, but still many
  - Small scale oriented
  - Winch equipped
- Cable system
  - Stationary yarder declining
  - **Swing yarder** increasing
- **Both** are reasonable to purchase

Log carrier (Mini-forwarder)

- Capacity: 0.5-2t
- Transporting logs on spur roads
- Single drum winch and/or radio control
- Cable system up to 50m span



Log carrier (Mini-forwarder): Balance of investment and efficiency



- Low operational efficiency
- Low investment
- With self-employee, good cost balance

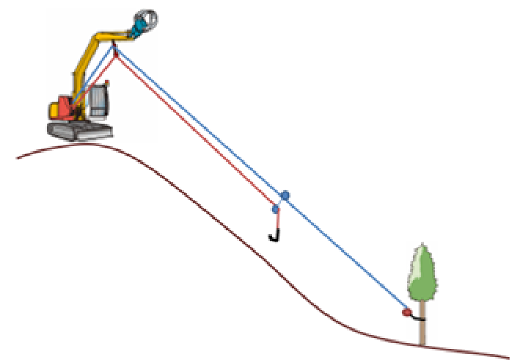
- Large scale system
  - High investment, high efficiency: Low cost
- Small scale system
  - Low investment, low efficiency: Employed – High cost,

    Self-employed – Low cost

Figure source: Suzuki, Y., Setiawan, A.H. and Gotou, J. (2015) Timber harvesting systems in Japan's aging plantation forests: Implications for investment in construction of forest road networks. Journal of the Japan Forest Society 97(4):(in press)(in Japanese with English summary).; This slide was presented at COFE (2015)

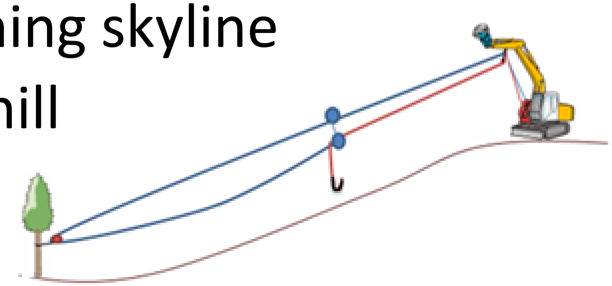
Swing yarder (Japanese style)

- Slack line

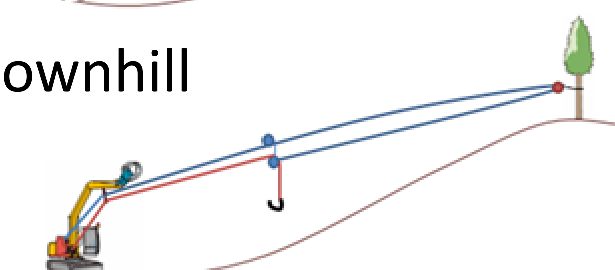


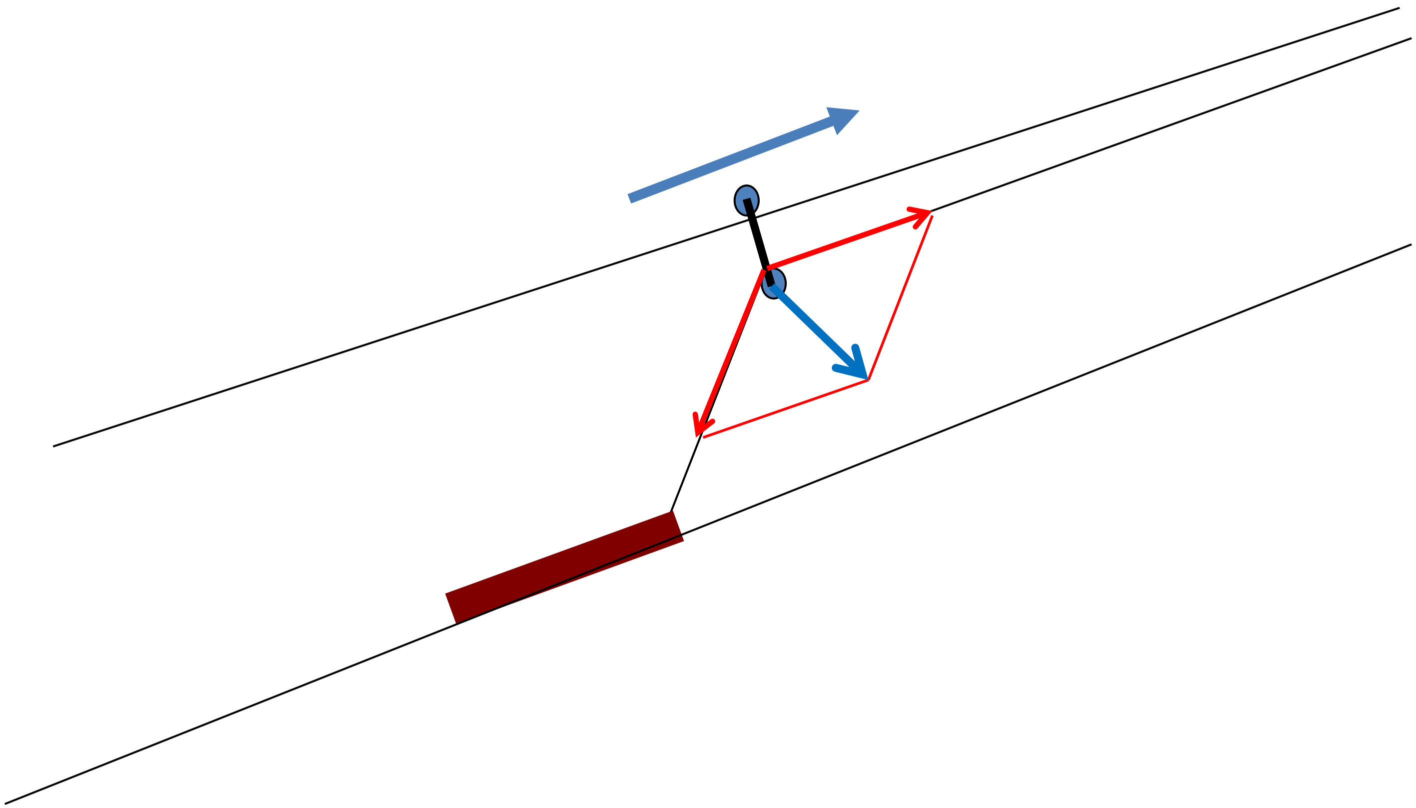
- Construction machine based
  - Popular use
- 2 drums
- Up to 100m span
- Slack line or running skyline
- Simple carriage
  - Bad for lateral yarding

- Running skyline
  - Uphill



  - Downhill





Mini-forwarder: Rigging methods

Double boosting force

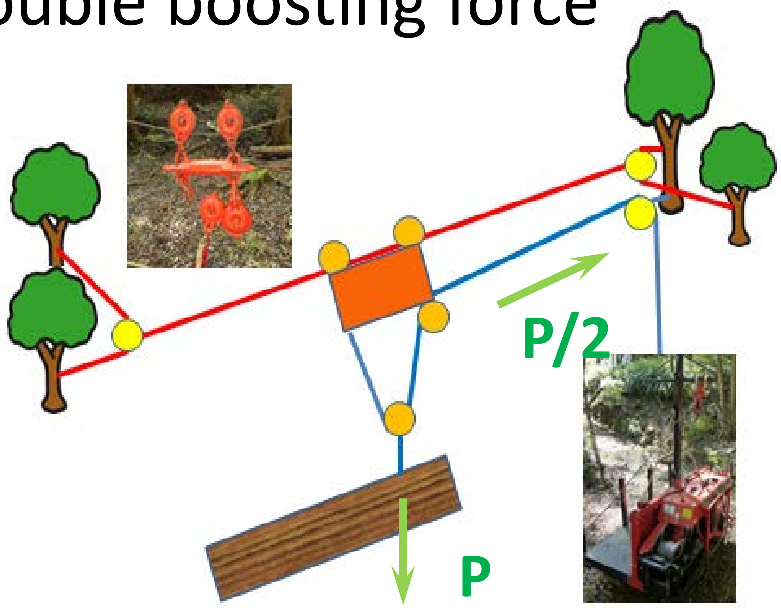


Figure 2. Schematic diagram of double boosting force method (Miyoshi)

Triple boosting force

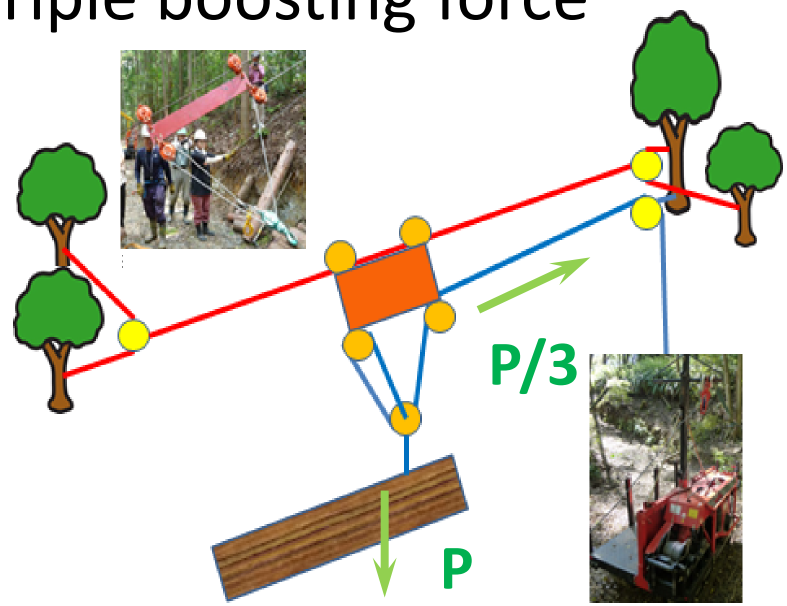


Figure 3. Schematic diagram of triple boosting force method (Tosa-no-mori)

- Miyoshi method: Double boosting force
- Tosa-no-mori method: Triple boosting force

Force balance at carriage

Swing yarder method
(Single boosting)

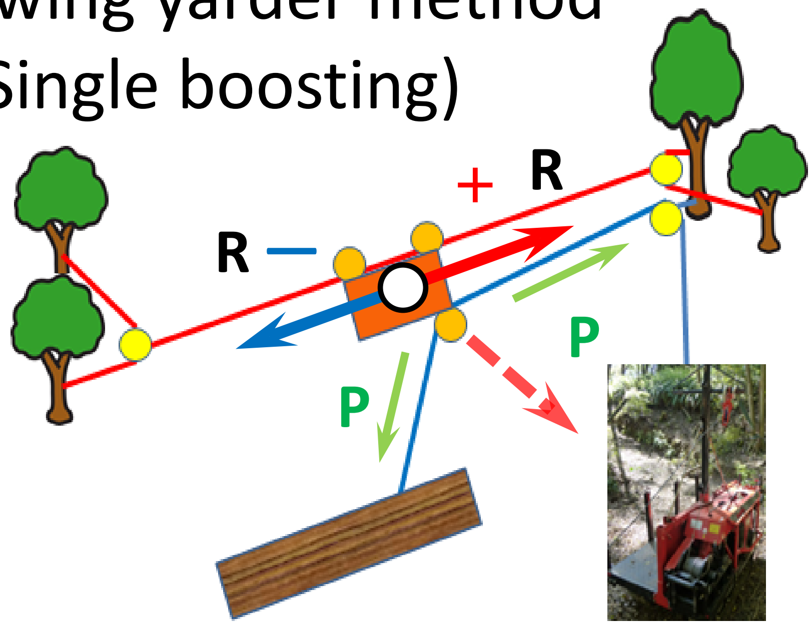


Figure 1. Schematic diagram of Swing yarder method

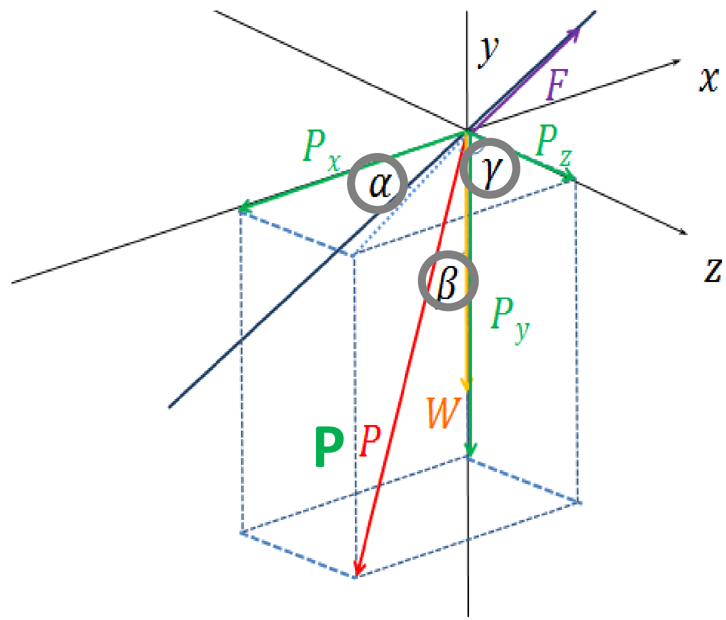
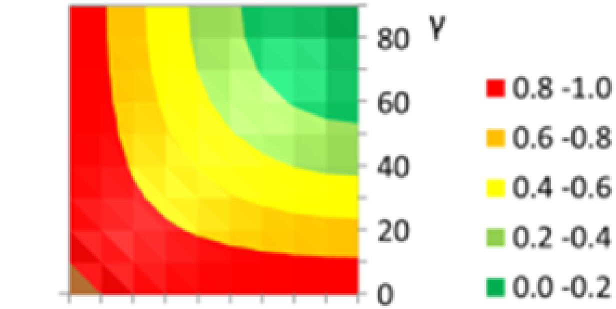
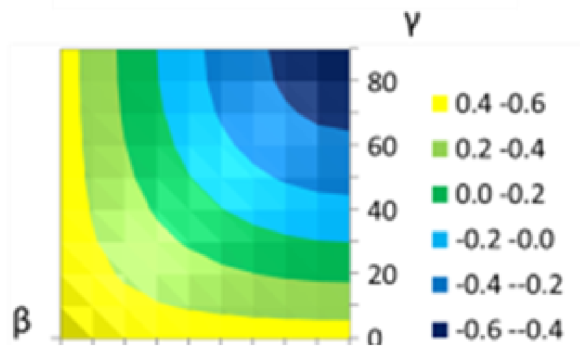


Figure 6. The force applied on the carriage when α ≠ 0

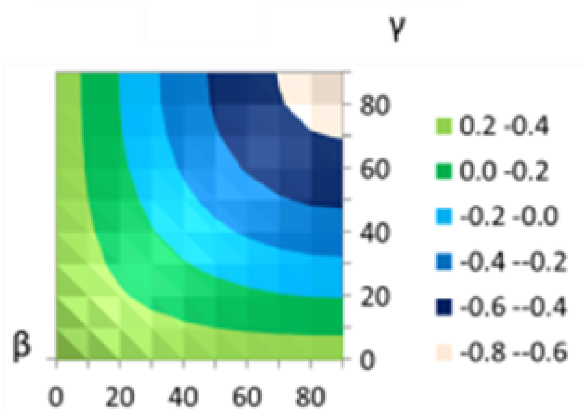
- Resultant force **R** at carriage along skyline
  - If **R** is **minus**, carriage is stable while lateral pulling
- Angles (Parameters)
  - α: inclination, β & γ: lateral pulling direction of **P**



Single boosting force



Double boosting force

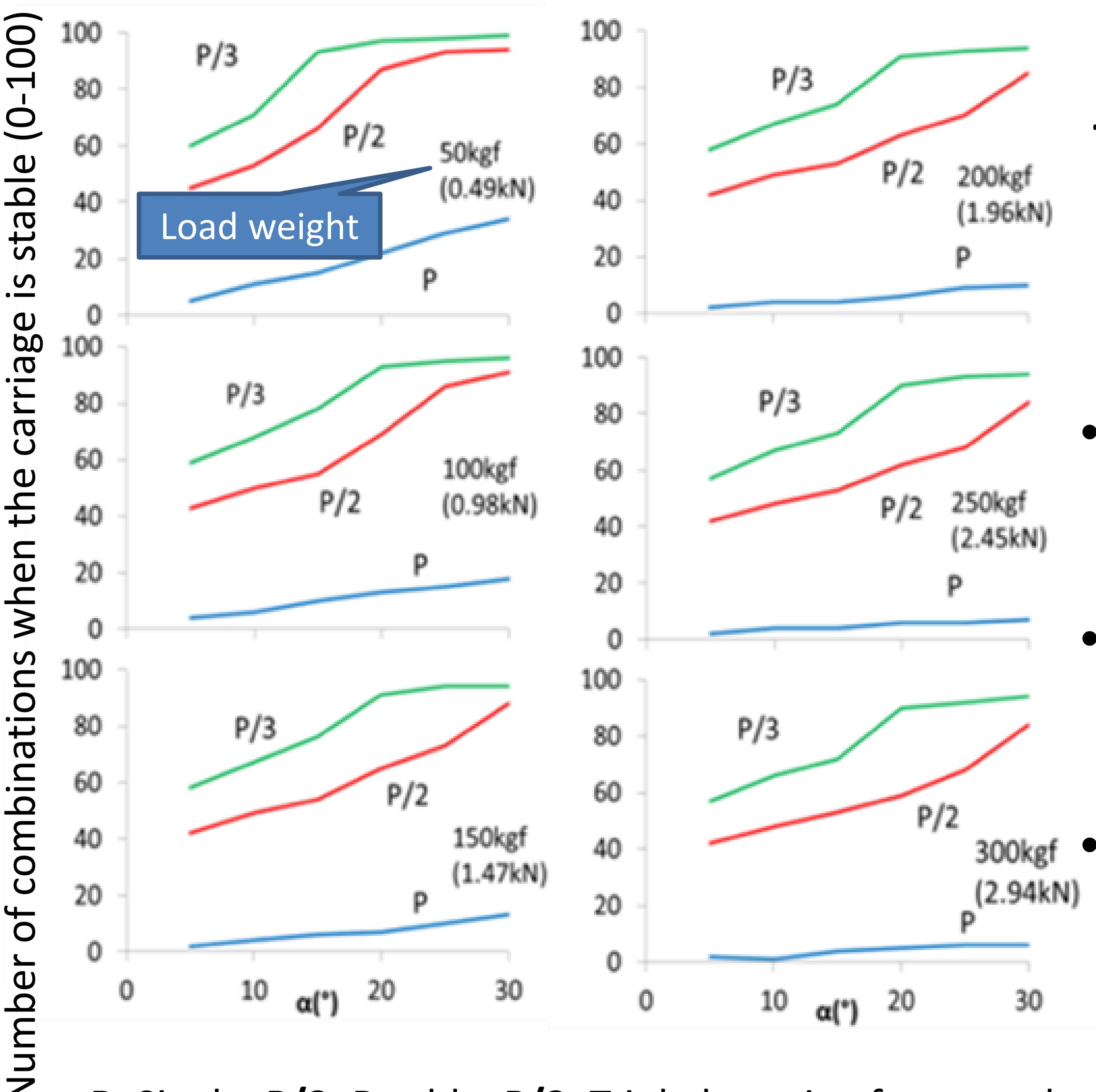


Triple boosting force

Stability of the carriage in case of α = 0°

- α: inclination of skyline
- β&γ: lateral pulling direction
- If **R** is **minus (Blue area)**, carriage is stable
- Stability
  - Single < Double < Triple
- Unstable: Clamping is required

Stability of the carriage in case of α ≠ 0°



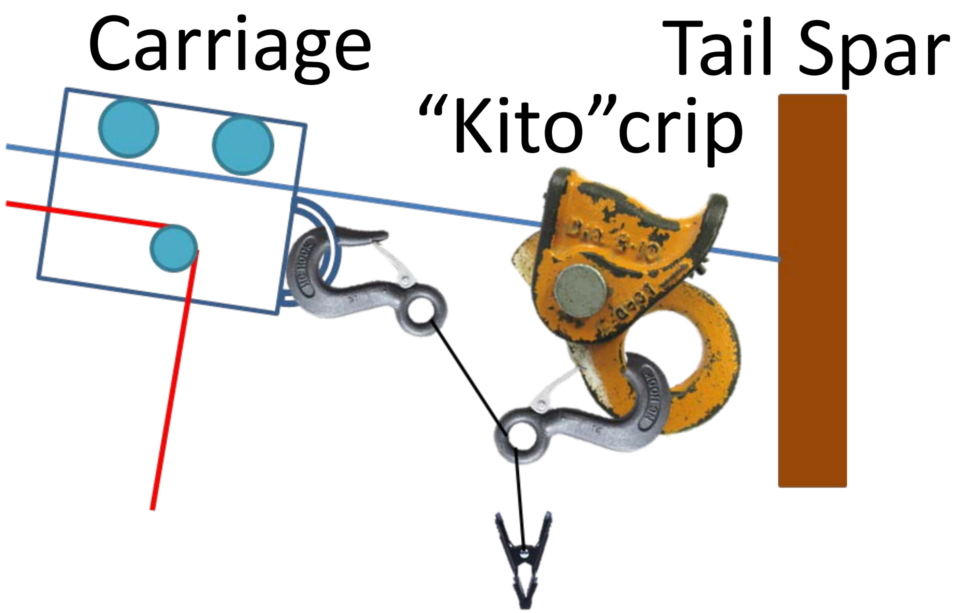
- Num. of parameter combination: 100
- V-Axis: Num. of Stable combination
- H-Axis: α (deg.)

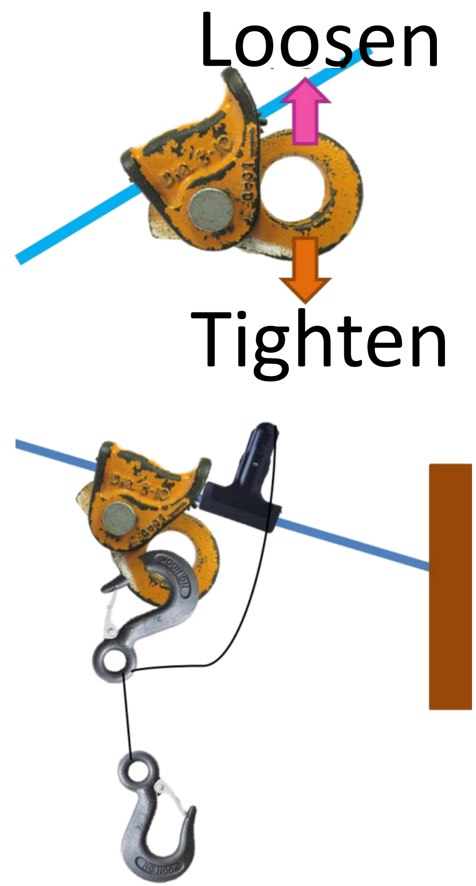
P: Single, **P/2**: Double, **P/3**: Triple boosting force method

Conclusions

- Triple boosting method is better than double boosting method, but difference is not so much large.
- Single boosting method (Swing yarder) always needs clamping in case of lateral yarding.
- Easy clamping method for swing yarder will be much help for swing yarder operation

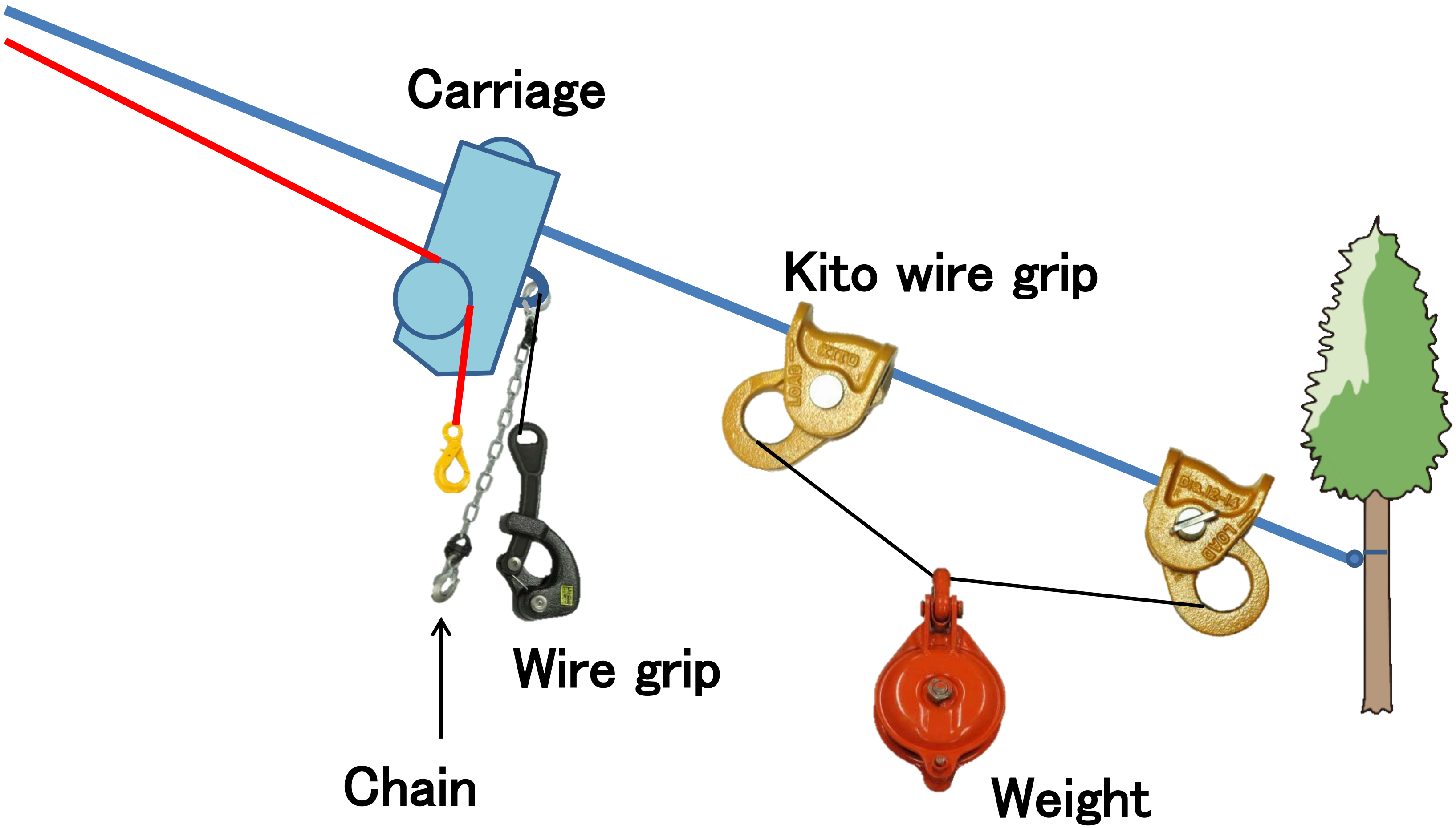
Easy clamping method for swing yarder



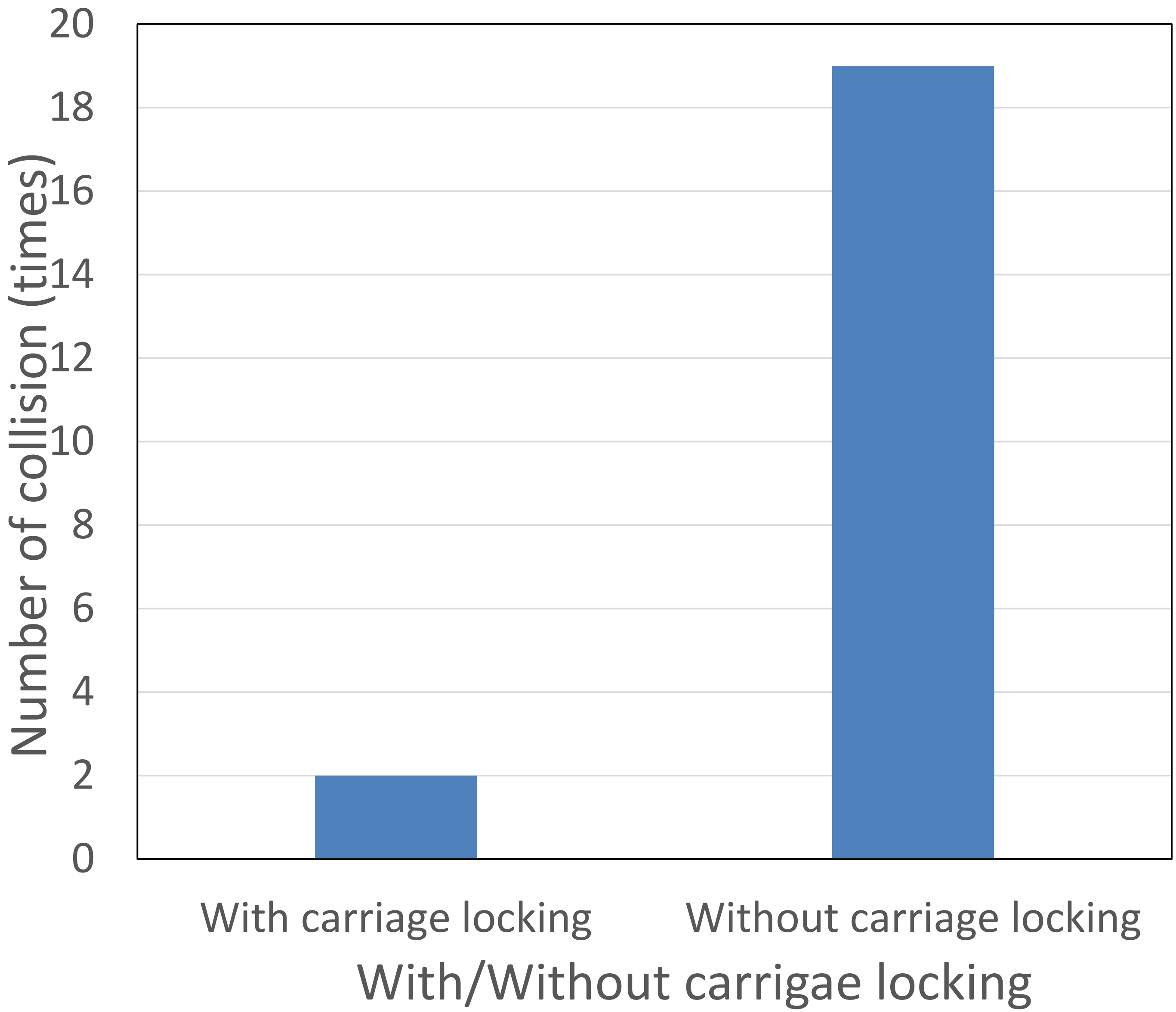


- “Kito” crip holds the carriage
- During lateral pulling
  - The crip is clamped by weight
- End of lateral pulling
  - Blowing the crip makes it free

Carriage locking mechanism: Revised



Presented in: "Joint Regional Meeting of IUFRO RG3.03.00 and RG3.06.00 in Asia, Matsuyama and Kochi, Japan: 24th-28th July 2017"

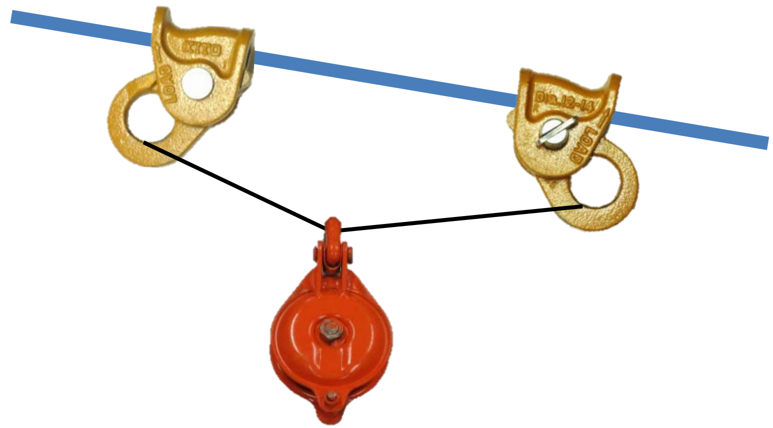


Number of collisions between a pulled log and standing tree

Further research

- Developing clamping method
- Testing, renovating
- Detailed force balance analysis and experiment
- Acknowledgements
  - JSPS KAKENHI Grant Numbers 16K07779 and 15H04508
  - Forest Mechanization Society Grant FY 2015-2016
  - “Biomass-TOSA” Grant of Kochi University

Kito wire grip



Open

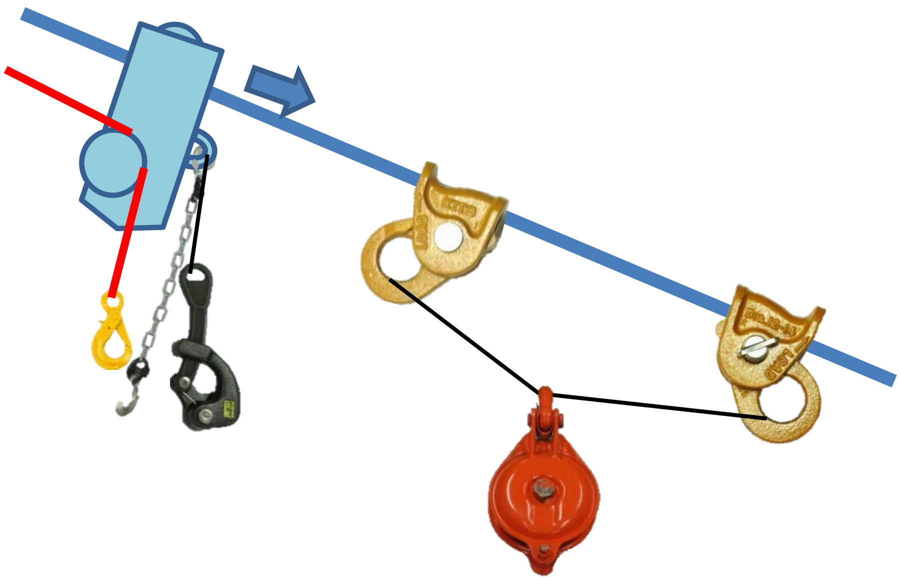
Closed

Function of wire grip

Gripping

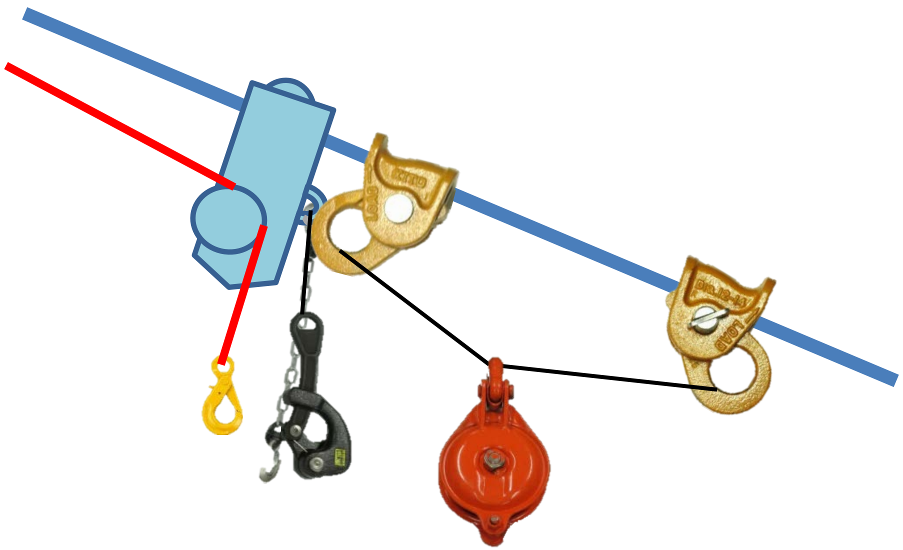
Releasing

①



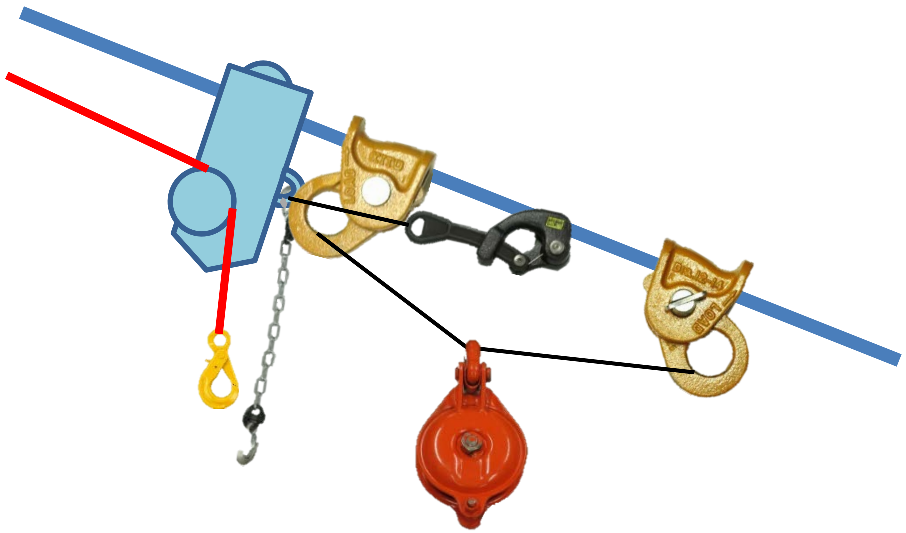
Carriage traveling downward

②



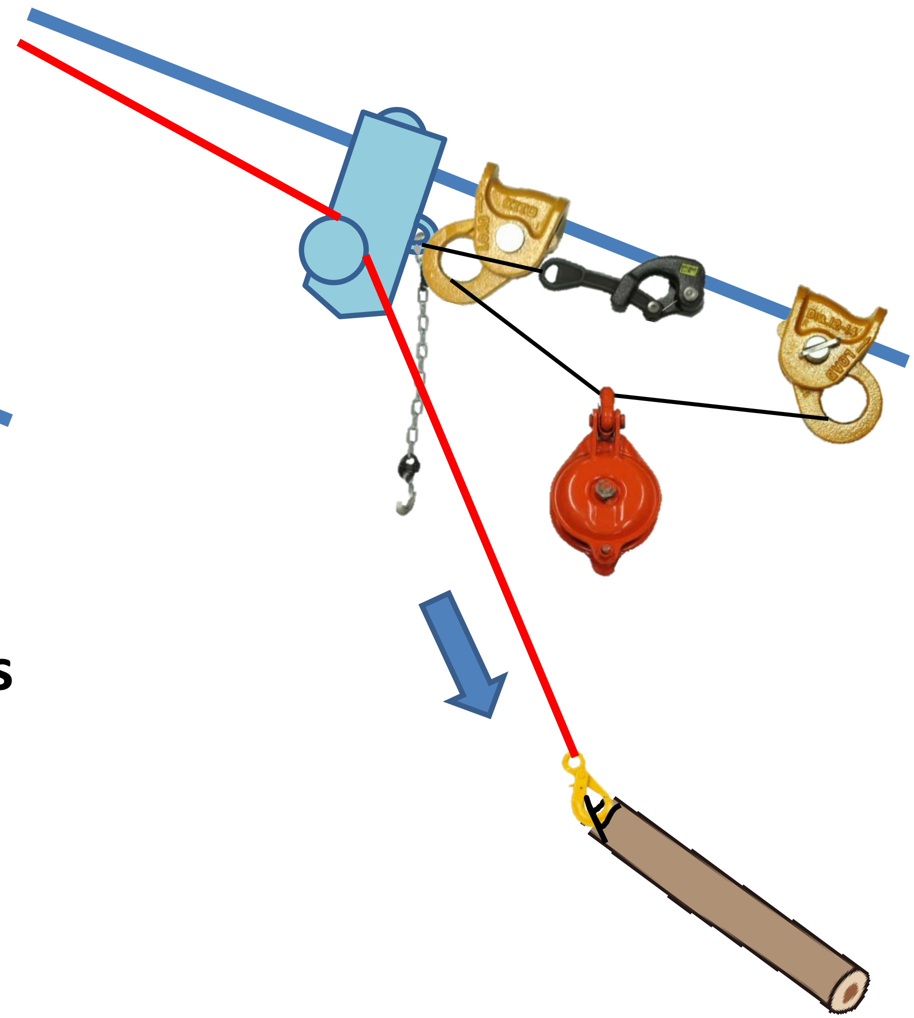
Carriage stops

③



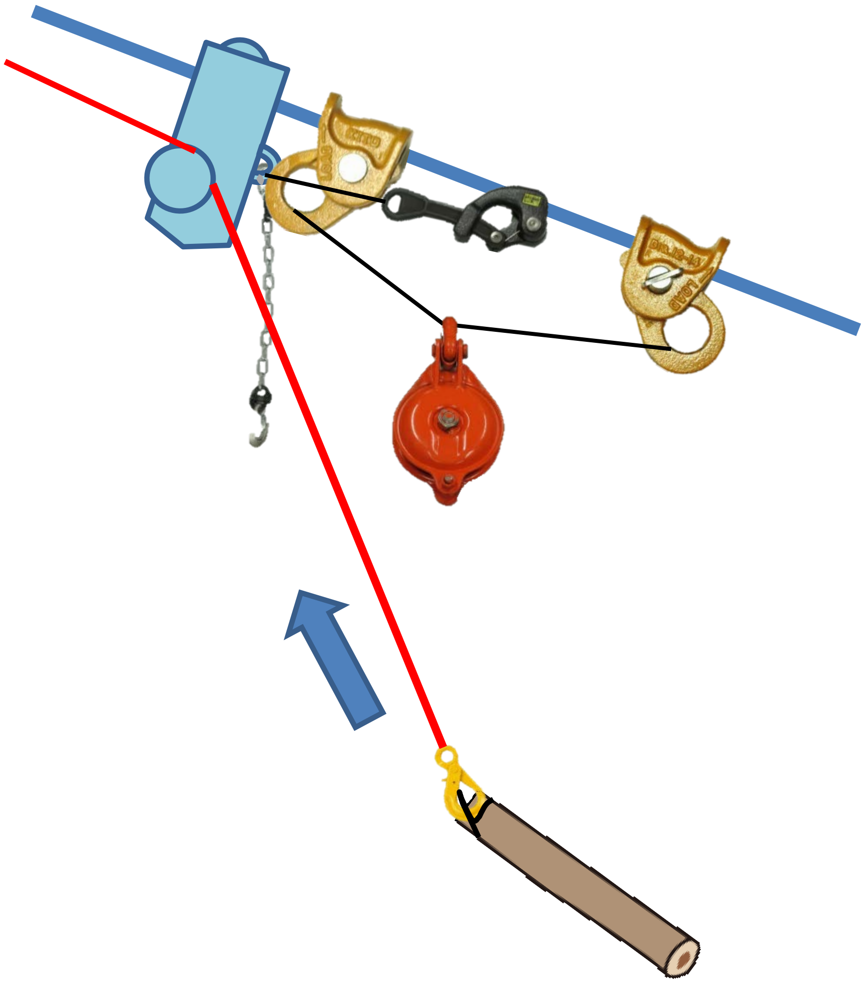
Skyline is lowered, and wire grip is attached to skyline

④



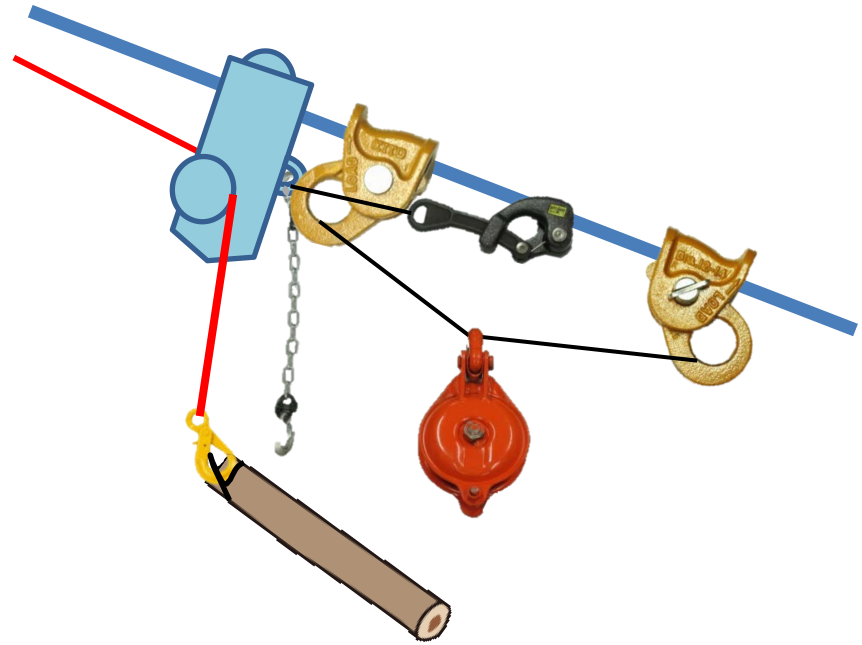
Main line is pulled out, and choker is set on log

⑤



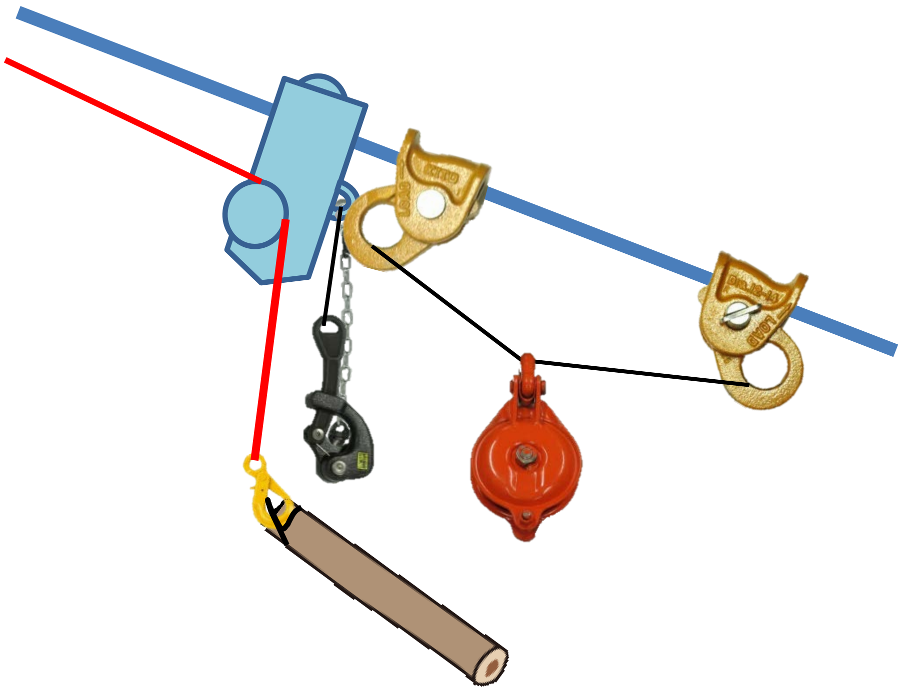
Pulling log to carriage

⑥



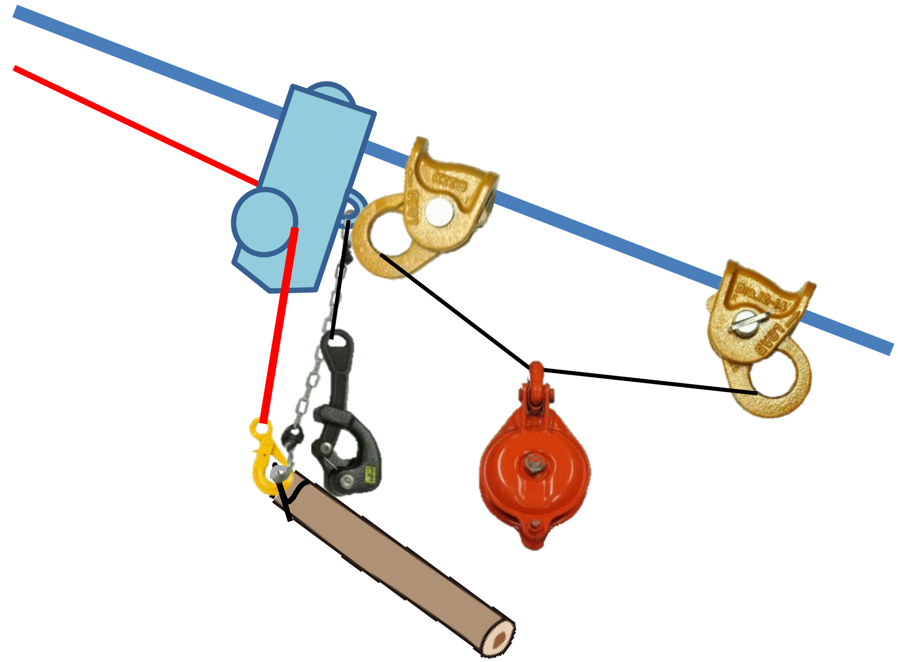
Log pulling is completed

⑦



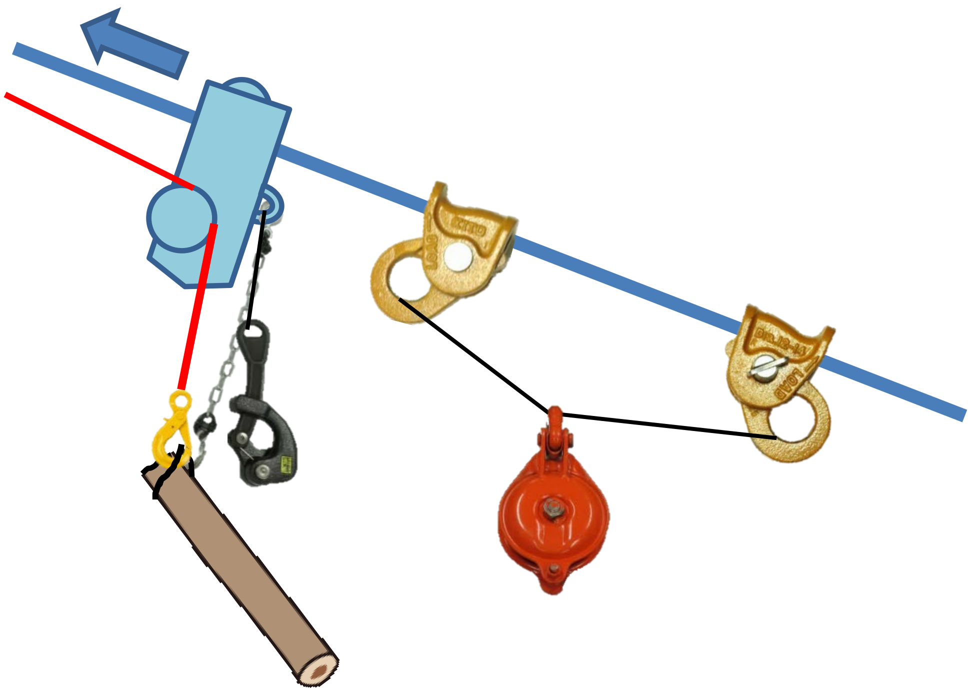
Removing wire grip from skyline

⑧



Chain is attached to log

⑨



Loaded carriage travelling upward