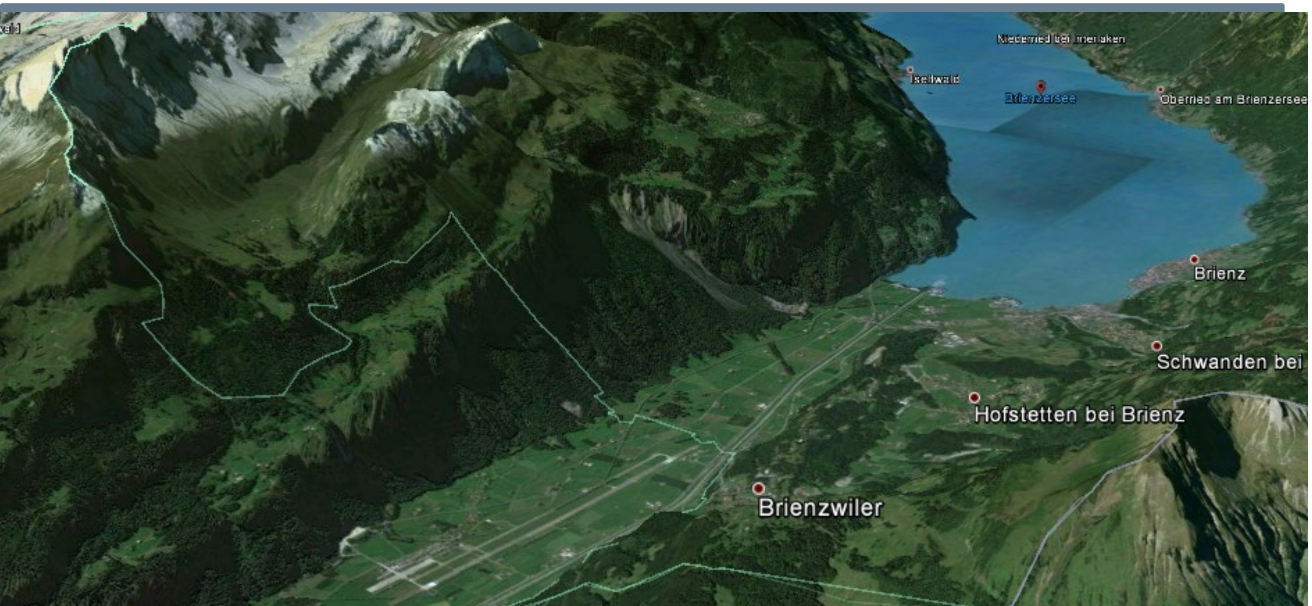
Berner
Fachhochschule

Consideration of near optimal forest road densities for Switzerland



FORMEC 2019 – Exceeding the Vision: Forest Mechanisation of the Future

Moritz Dreher, scientific collaborator
Bern University of Applied Sciences (BFH)
School of Agricultural, Forest and Food Sciences (HAFL)

Background situation of the project

- The sustainably exploitable wood utilisation potential shall be exhausted (forest policy 2020)
- Switzerland has one of the highest standing volumes in Europe Ø ca. $350m^3/ha$
- The annual increment is approx. 10 mio. m^3
- The current use is approx. 4.5 mio m^3

Forest roads are essential for providing access to forests and their wood. Forest road networks usually were established over several decades, always in accordance with logging, hauling and transport abilities of that planning and establishment period.

The redesign of the road network is crucial in relation with the efficiency of forest management and wood harvesting.

It is one of the most promising approaches, but to find the best situational solution is a challenging task especially in mountainous regions like in Switzerland.

Aim of the project

- Based on **newly available harvesting, skidding and transport options** it is a good idea to review actual configuration requirements of forest road networks
- A first step was done in this study, **intended to find ideal orientation values for forest road densities for larger areas** in Switzerland
- The analysis aim was to define **value ranges for the forest road networks** in respect of the existing forest patterns and terrain structures in 26 cantons and to elaborate a value range per canton
- This generated cantonal value ranges have then to be linked with corresponding **value ranges of construction costs** regarding the geological and terrain structures in the examined area
- In the end the *Federal Office for the Environment (FOEN)* **will elaborate an according funding system** underpinned by the findings of the project

Elaboration of near optimal road densities and value ranges for construction costs in Switzerland

- The study uses a two-step methodology, which results in an orientational or **recommended road density value per plot**

- The first step generates road density values per sample area (based on expert analysis)

- These values are then summarized in to different value ranges in the subsequent GIS based cluster analysis in the generalization step

- Within the set approach **already existing forest road networks were excluded from the contemplation as they can be considered as fully amortized,** furthermore they often do not reflect nowadays needs in road delineation, due to their construction time long ago

Elaboration of near optimal road densities and value ranges for construction costs in Switzerland

- The newly elaborated forest road networks are based on an expert analysis. The **experts were considering the forest patterns, terrain structures (map-based), latest harvesting and transport technologies** in their model road network solution per test area

- The resulting database is therefore highly influenced by forest operations related production factors, thus providing a comparison set towards further needs as coming from other inquiries like tourism, agriculture or water management

- Overall **73 sites** with an extent of **11 km^2** each, containing mainly forested areas, were placed with the minimal condition of one site per canton. The sites were analysed in this second step with the aid of GIS. Several layers were investigated and **over 30 variables** were incorporated and calculated to reflect the variability of structural features

Overview of the 73 sites

Overview of the system boundaries

- Truck movable roads: New road construction minimal **width 3.5 m**, portable tonnage **40 tons**
- Focus on the economical and resource political forest management
- Further forest functions are not included in the investigation
- The existing road infrastucture is not included in the investigation (amortised)
- **New road infrastructures are planned based on the best-practices regarding timber harvesting concepts**
- Fine road infrastructure is not included in the investigation

Overview of the system boundaries regarding road construction

Basis of decision-making	Slope-inclination classes
Complete freedom of road construction	0-15 %
Impeded road construction for ground-based procedures	15-50 %
Road construction for rope-based procedures	50-75 %
Impeded road construction for rope-based procedures	75-100 %
Excluded from road construction	>100 %

Overview of the harvesting concept boundaries

Harvester + Forwarder	Max. haulage distance 1200m, max. slope 25 %
Ground rope drag	Max. haulage distance 100m, max. slope 60 %
Harvester + Forwarder with traction wind	Max. haulage distance 450m, max. slope 60 %
Yarder	Max. haulage distance 300m, max. slope120 %
Mountain harvester	Max. haulage distance 400m, max. slope 120 %
Movable cable crane	Max. haulage distance 800m, max. slope 120 %
Conventional cable crane	Max. haulage distance 1500m (sonder condiction distances 2500m), max. slope 120 %
Not opend areas resp. helicopter based	All other areas

Elaboration of near optimal road densities and value ranges for construction costs in Switzerland

- In the second step an **exploratory regression was computed** to generate a model able **to explain the elaborated road densities** by taking into consideration the geological, terrain and forest land structures

- This provides the required **relationship** between the regarded **variables** and the generated **road densities** in Switzerland

- This analysis framework was implemented in **RStudio** to make the linkage between the variables and the model enabling the **assignment** of new (uninvestigated by experts) sites **into the defined road density clusters**

- In that way it is possible to calculate a value range for a reasonable road density needed for a specific site to assure a sufficient forest exploitation without any need for manual survey by experts or exploring the areas in the field

- The actual status is that the calculation of the value range can be made adequately for the cantons Berne and Argovia

Elaboration of near optimal road densities and value ranges for construction costs in Switzerland

- To enable the successful implementation of the approach throughout Switzerland it has become evident that additional variables have to be incorporated to achieve the objective appropriately

- To enable the assessment of the occurring forest road construction costs on-site, a collection from *the Federal Office for the Environment (FOEN)* is used which contains many forest road construction projects and their new construction costs

- Additionally, data from tree Swiss cantons (Berne, Grisons and Fribourg) were included in the analysis. In total around 1500 projects since 1993 were selected for the investigation. Ziesak and Tschamun (2012) have analysed the described dataset and used 5 clusters reflecting different regional characteristics (alps, south side of the alps, prealpes, jura and midlands)

- In the context of this study the new construction costs regarding forest roads without hard cover are essential (N=545)

Elaboration of near optimal road densities and value ranges for construction costs in Switzerland

- Unfortunately, **this 5 regional clusters can not directly be used as explanatory** because when estimating the near optimal road densities, the geological and terrain structure variability appeared higher within these regions than between them. This means also that there has to be found another way to connect the construction costs with the near optimal road densities than by allocating them to one of the 5 regions. At the moment the most expedient way to do so is under examination (soil volume movement needed, probability for solid rock)

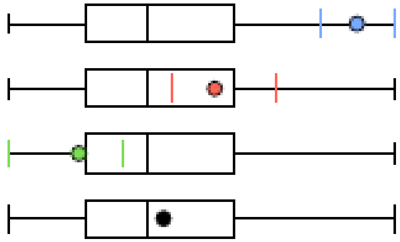
- After the successful implementation of a sufficient interface approach, in a subsequent step BFH will support *the Federal Office for the Environment (FOEN)* the design process to define the according system of contributions based on the two different kinds of value ranges and their viable linkage

Clustering of the sites 1 – 36 (cantons Berne and Argovia)

Variable-Wise Summary

LFM_HA_TG: R2 = 0.89

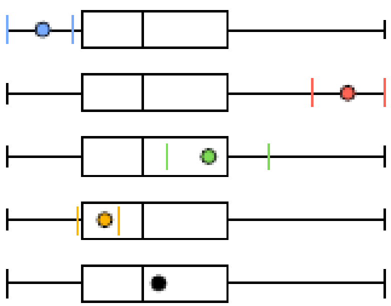
Group	Mean	Std. Dev.	Min	Max	Share
1	17.5739	0.9636	16.2309	18.9191	0.1915
2	12.4078	1.1307	10.8208	14.6184	0.2705
3	7.4609	1.3290	4.8798	9.0416	0.2964
Total	10.5421	3.6573	4.8798	18.9191	1.0000



Variable-Wise Summary

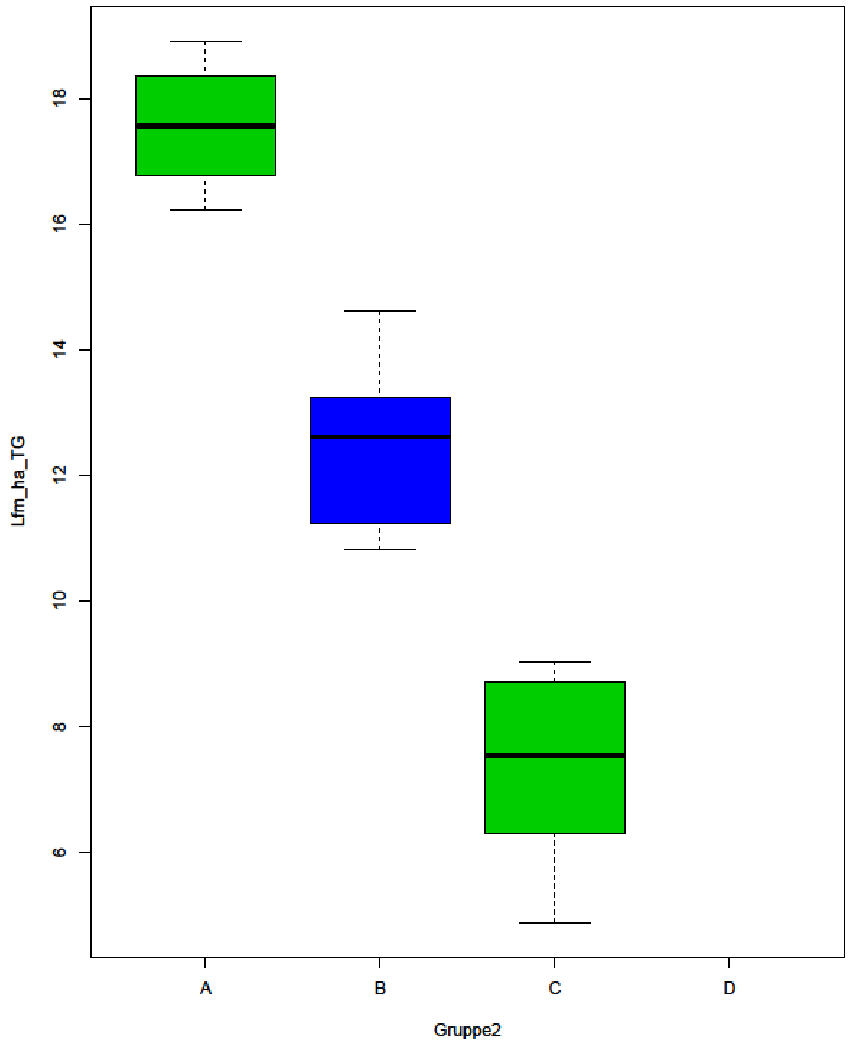
LFM_HA_TG: R2 = 0.94

Group	Mean	Std. Dev.	Min	Max	Share
1	6.2372	0.8235	4.8798	7.3805	0.1781
2	17.5739	0.9636	16.2309	18.9191	0.1915
3	12.4078	1.1307	10.8208	14.6184	0.2705
4	8.5486	0.4683	7.5454	9.0416	0.1066
Total	10.5421	3.6573	4.8798	18.9191	1.0000



Clustering of the sites 1 – 36 (cantons Berne and Argovia)

4 Clusters



Overview of investigated variabels

Road density_ha_TG
Road density_ha_forest
Road length_TG
Road length_forest
Forest area_m^2
Forest edge_m
Sub area_m^2
dH_Max
dH_Range
dH_Mean
dH_STD
Slope_Proz_Max
Slope_Proz_Range

Slope_Proz_Mean
Slope_Proz_STD
Slope_5Kl_Majority
Aspect_8Kl_STD
SHAPE_Length
SHAPE_Area
Slope_Kl_1
Slope_Kl_2
Slope_Kl_3
Slope_Kl_4
Slope_Kl_5
Aspect_Kl_1
Aspect_Kl_2

Aspect_Kl_3
Aspect_Kl_4
Aspect_Kl_5
Aspect_Kl_6
Aspect_Kl_7
Aspect_Kl_8
Forest area_per_forest edge
Forest edge_per_forest area
Joint points

Overview of the complete Model and the clustering in to the 4 groups due to 6 identified variabels

Groupe ~ Forest surface_m^2 + dH_MEAN + Slope_Kl_2 + Aspect_Kl_6 + Forest surface_per_forest edge + forest edge_per_forest surface

	A	B	C	D
A	3	0	0	1
B	1	11	4	0
C	0	2	13	0
D	0	0	0	1

Correct prediction:
A as A predicted 75%
B as B predicted 85%
C as C predicted 77%
D as D predicted 50%

Incorrect prediction:
1D as A predicted
1A + 4C as B predicted
2B as C predicted
0 as D predicted

Correct prediction with blur (also neighboring class):

A as A or B predicted 100%
B as A or B oder C predicted 100%
C as B or C predicted 100%
D as C or D predicted 100%

The areas of the cluster D can get excreted , on request, beforehand due the terrain variabels «Slope_KL1» or «Slope_Proz_STD

Group-affiliation in the original data
A*4/B*13/C*17/D*2

Prediction Model with Cross Validation

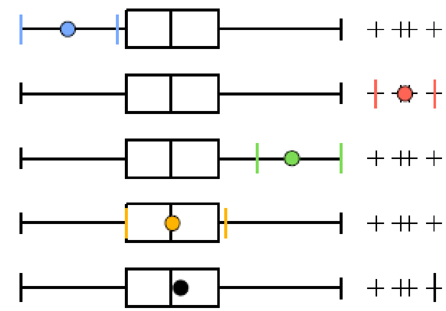
	A	B	C	D
A	2	1	0	1
B	2	8	6	1
C	0	4	11	0
D	0	0	0	0

Clustering of the sites 1 – 73 (all over Switzerland)

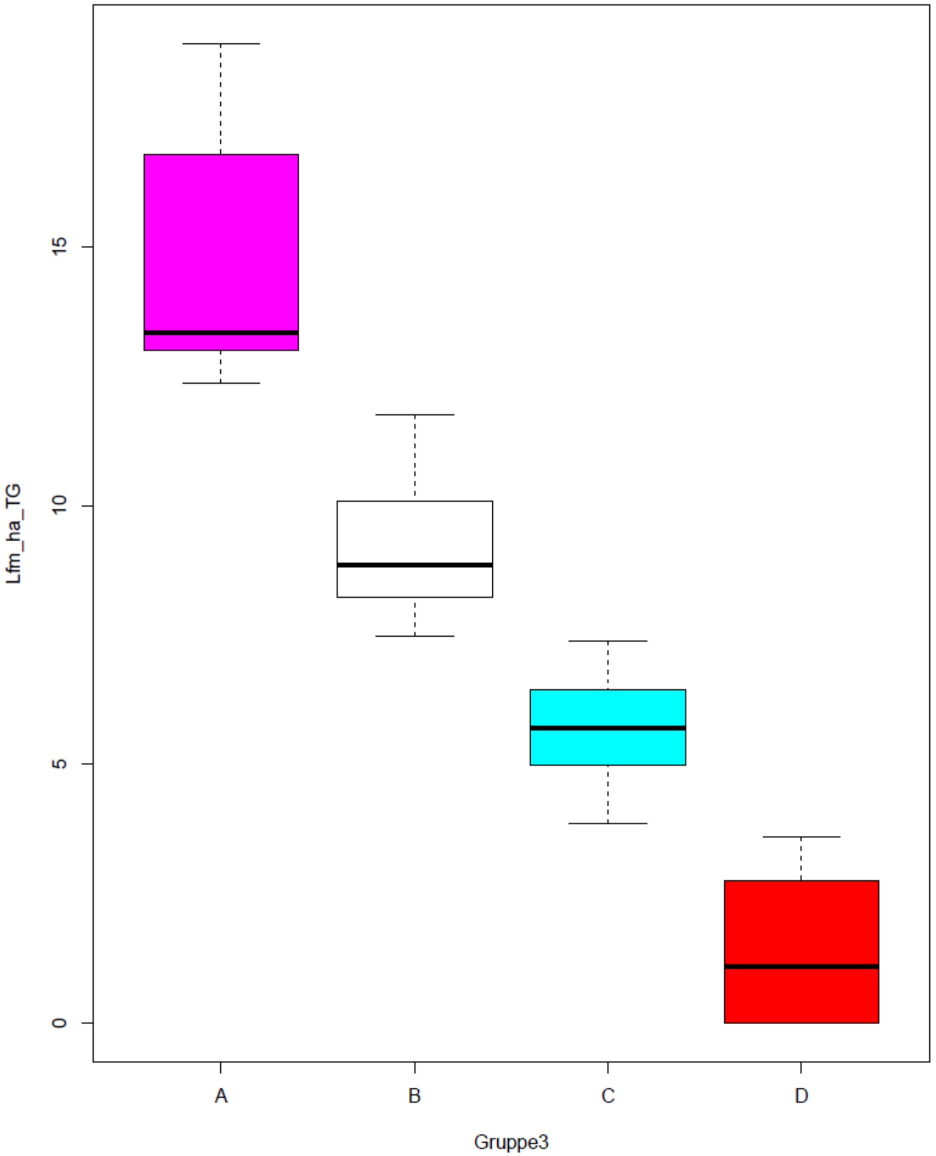
Variable-Wise Summary

LFM_HA_TG: R2 = 0.90

Group	Mean	Std. Dev.	Min	Max	Share
1	2.1645	1.6897	0.0000	4.4222	0.2337
2	17.5739	0.9636	16.2309	18.9191	0.1421
3	12.4078	1.1307	10.8208	14.6184	0.2007
4	6.9458	1.3560	4.8618	9.3543	0.2375
Total	7.3219	4.3517	0.0000	18.9191	1.0000



4 Clusters



Overview of investigated variabels

Road density_ha_TG
Road density_ha_forest
Road length_TG
Road length_forest
Forest area_m^2
Forest edge_m
Sub area_m^2
dH_Max
dH_Range
dH_Mean
dH_STD
Slope_Proz_Max
Slope_Proz_Range
Slope_Proz_Mean
Slope_Proz_STD

Slope_5Kl_Majority
Aspect_8Kl_STD
SHAPE_Length
SHAPE_Area
Slope_Kl_1
Slope_Kl_2
Slope_Kl_3
Slope_Kl_4
Slope_Kl_5
Aspect_Kl_1
Aspect_Kl_2
Aspect_Kl_3
Aspect_Kl_4
Aspect_Kl_5
Aspect_Kl_6

Aspect_Kl_7
Aspect_Kl_8
Forest area_per_forest edge
Forest edge_per_forest area
Joint points

Forest area_non forest
Forest area _total area
Forest area _circumference forest
Forest area _ha
Forest edge_km

Exploratory Regression Model

Choose 6 of 36 Summary

Highest Adjusted R-Squared Results

Passing Models

AdjR2	AICc	JB	K(BP)	VIF	SA	Model
0.576480	341.457453	0.983281	0.536624	3.723577	0.424512	

+SHAPE_LENGTH** -DH_MEAN*** +ASPECT_KL_3** +ASPECT_KL_5** -Forest area_total area*** -forest area_HA***

Overview of the complete Model and the clustering in to the 4 groups due to 6 identified variabels

Group ~ +SHAPE_LENGTH -DH_MEAN +ASPECT_KL_3 +ASPECT_KL_5 -forest area_total area -forest area_HA

Daten6.lda.p (Prediction Model)

	A	B	C	D
A	7	2	1	1
B	3	10	3	3
C	1	7	25	4
D	1	0	0	5

Correct prediction:
A as A predicted 58.3 %
B as B predicted 52.9 %
C as C predicted 86.2%
D as D prdicted 38.4%

Incorrect prediction:
2B + 1C + 1D as A predicted
3A +3C +3D as B predicted
1A + 7B +4D as C predicted
1A as D predicted

Correct prediction with blur (also neighboring class):

A as A or B predicted 83.3%
B as A or B or C predicted 100%
C as B or C or D predicted 96.6%
D as C or D predicted 69.2%

Group-affiliation in the original data
A*12/B*19/C*29/D*13

Prediction Model with Cross Validation

	A	B	C	D
A	7	2	1	1
B	3	9	6	3
C	1	8	20	4
D	1	0	2	5

Cross Validation has good results, this means the model is stable and is not overestimating itself due the own datas as background

Summary of results

- A clustering of the road densities can be made with GIS
- Due the variables a prediction model can be established
- The road densities can be explained to approx. 50%
- Due the linear discriminante analysis the prediction of the allocation of the terrain variables to a cluster is as follows
- 38.4 – 86.9%

Exploratory Regression Model

Choose 7 of 36 Summary

Highest Adjusted R-Squared Results

Passing Models

AdjR2	AICc	JB	K(BP)	VIF	SA	Model
0.516424	352.136216	0.367569	0.379293	6.112680	0.190765	

-SHAPE_AREA*** -DH_RANGE*** -SLOPE_KL_1** +SLOPE_KL_4*** +ASPECT_KL_6** -ASPECT_KL_7** -Forest area_circumference forest***

Overview of the complete Model and the clustering in to the 4 groups due to 7 identified variabels

Group ~ -SHAPE_AREA -DH_RANGE -SLOPE_KL_1 +SLOPE_KL_4 +ASPECT_KL_6 -ASPECT_KL_7 -forest area_circumference forest

Daten6.lda.p (Prediction Model)

	A	B	C	D
A	9	3	1	1
B	1	7	5	0
C	2	9	23	5
D	0	0	0	7

Correct prediction:

A as A predicted 75 %
B as B predicted 36.8 %
C as C predicted 79.3%
D as D predicted 53.8%

Incorrect prediction
3B + 1C +1D as A predicted
1A + 5C as B predicted
2A + 9B + 5D as C predicted
0 as D predicted

Correct prediction with blur (also neighboring class):

A as A or B predicted 83.3%
B as A or B or C predicted 100%
C as B or C or D predicted 96.6%
D as C or D predicted 92.3%

Group-affiliation in the original data
A*12/B*19/C*29/D*13

Prediction Model with Cross Validation

	A	B	C	D
A	9	4	1	1
B	1	3	5	0
C	2	12	23	6
D	0	0	0	6

Cross Validation has good results, this means the model is stable and is not overestimating itself due the own datas as background

Summary of results

- A clustering of the road densities can be made with GIS
- Due the variables a prediction model can be established
- The road densities can be explained to approx. 50%
- Due the linear discriminante analysis the prediction of the allocation of the terrain variables to a cluster is as follows
- 36.8 – 79.3%


THANKS FOR
YOUR
ATTENTION
ANY QUESTIONS?
NO? GREAT!