Automated stand delineation and strip road generation based on harvester location data

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Big data from forest machines

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Summary

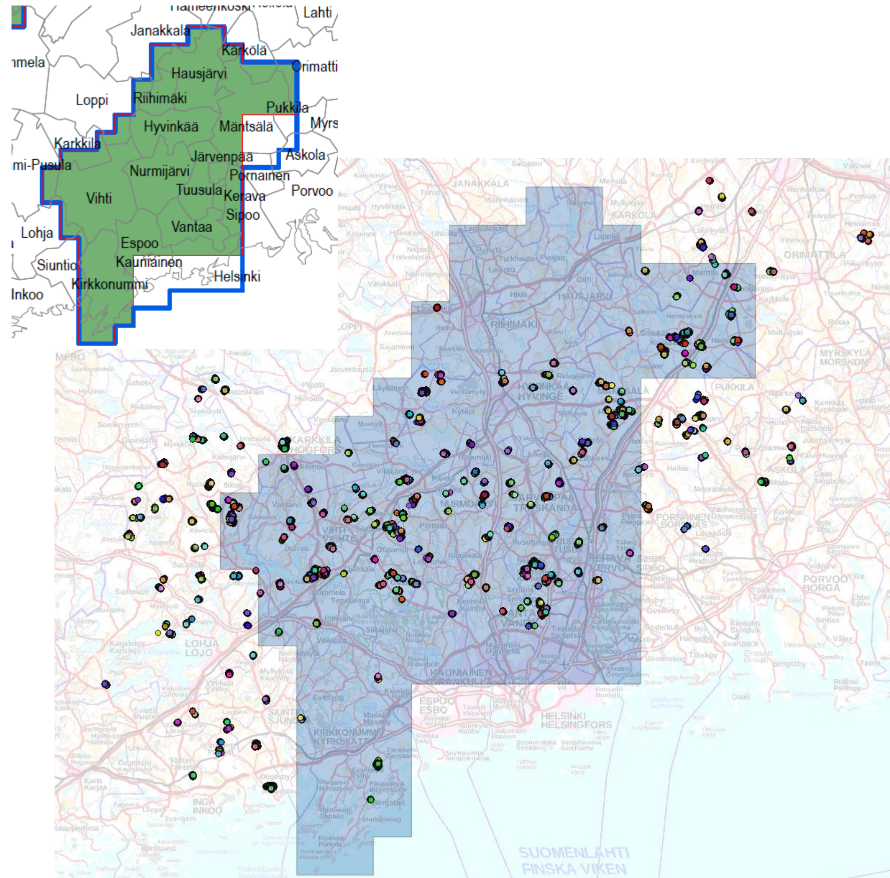
- Objective of the study was to create an automated method for generating stand delineation and strip roads based on position measurements of a harvester.
- The data contained operative harvesting objects ($N_{objects}$= 455) from a laser inventory area in Southern Finland.
- The developed method is a multi-stage entity, which separates stands from external strip roads leading to them, produces stand delineations, handles adjacent, intersecting stands and provides strip road networks at the stands.
- The results are good based on visual inspection – a more detailed comparison with reference stand delineations and reference stand strip roads will be published later.
- The stand delineation method can be used in operative updating of the forest inventory. The stand strip roads can be used in to estimate the quality of harvesting.

Objective

- The objective of this study was to create an automated processing method for harvester data, which can be used in updating of forest inventory data. The method aimed to cover
  - formation of unambiguous stands from the object information and location data,
  - recognition and separation of external strip roads leading to stands,
  - delineation of stands by forming the stand polygons,
  - handling the adjacent, intersecting stands to obtain solid stand boundaries, and
  - create a strip road network for stands to estimate the total length, area and average spacing of strip roads.
- The study was based on the following data:
  - Location of harvester during tree cut (from harvester)
  - Object identifiers and starting time of harvest (from harvester)
  - Cutting type (from forest companies)

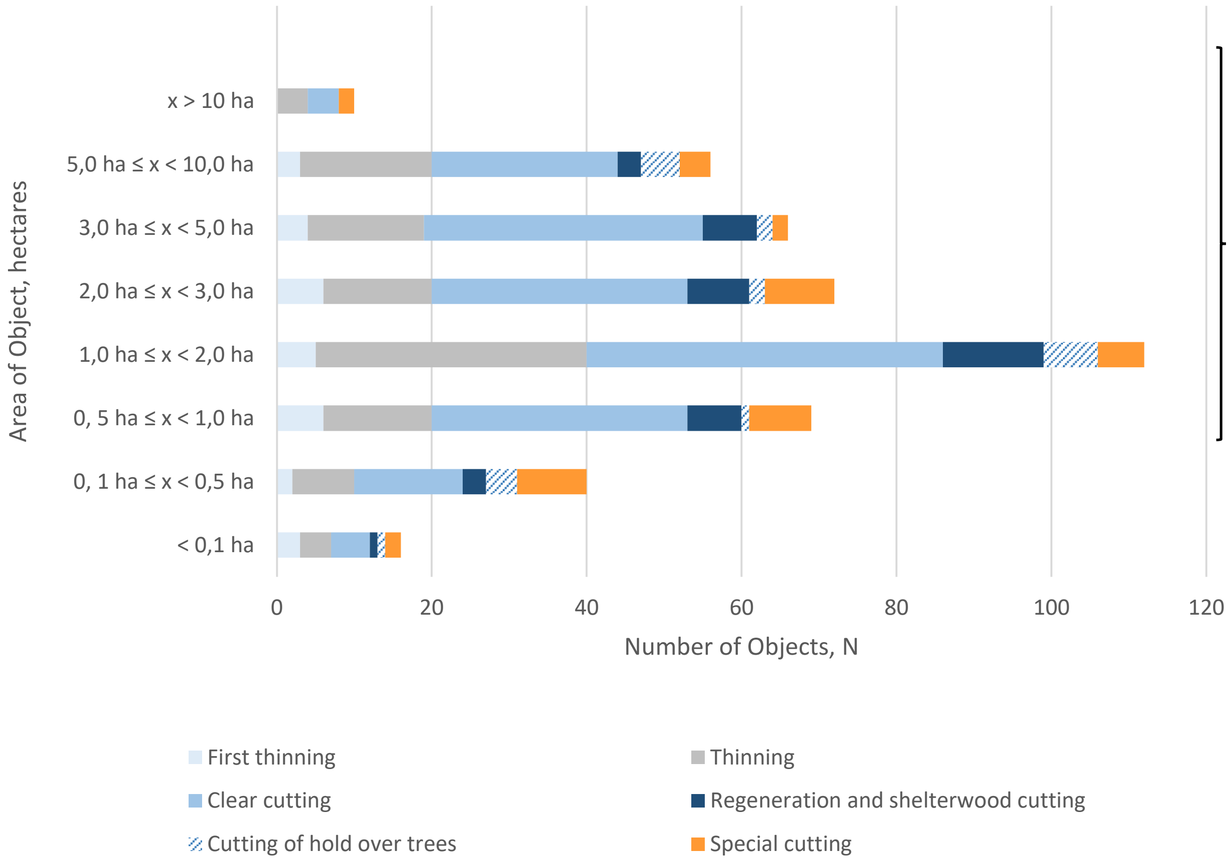
Data

- The data was collected from six harvesters from one laser inventory area of Finnish forest center, covering the capital region. It contained operative harvesting objects ($N_{objects}$=455), and was collected during 8/2015-9/2016.
- The cutting types and size distribution of the objects are presented in the next slide.



Basemap © National land survey of Finland 2018, Delineation of inventory area © Finnish forest center 2016

The size distribution of harvested objects ($N_{objects}$ =455)



$N_{objects}$ = 377
(> 0,5 ha)

Harvested stems, N_{stems} = 634656
Harvested objects, $N_{objects}$ = 455
Objects > 0,5 hectares
$N_{objects}$ = 377

Obs! Special cuttings includes also change of land use and cutting of windblown timber.

Automated stand delineation

1. Data collection at harvester, preprocessing (STM, HPR) and object-wise ID generation
2. Transfer into GIS program and projection of coordinates from WGS84 to ETRS FIN35TM
3. Separation of stands and external strip roads, and stand-wise ID generation (algorithm I)
4. Stand delineation (algorithm II)
5. Updating stand delineations for intersecting stands (algorithm III)
6. Final stand delineation and calculation of stand areas

Algorithm I

1) Recognition of external strip roads leading to stands
2) Recognition of spur trails
3) Formation of stands and stand ID generation

Algorithm II

1) Delaunay –triangulation and selection of stand area
2) Buffering of stands

Algorithm III

1) Recognition of intersecting stands
2) Splitting and dividing of intersections between the stands
3) Filling and merging of small empty slots into stands

Finalization

1) Inclusion of strip road trees into intersecting stands
2) Buffering of external strip roads
3) Calculation of areas for stands and for external strip roads

Preprocessing of data

- The harvester data was preprocessed for the automated stand delineation process
  - The STM files were extracted into a database using Metsäteho's extraction programs
  - Cutting type data was collected separately, unified and manually added to the objects. In the future, the HPR file is expected to contain the cutting type information. **The automated method requires, that the object has one cutting type.**
  - During preprocessing, unique labels are produced: object-wise ”ObjectID” and stem-wise ”StemNumber”

Object information:

- Identifiers
- Starting time
- Cutting type

These are assumed to be homogeneous within one object

→

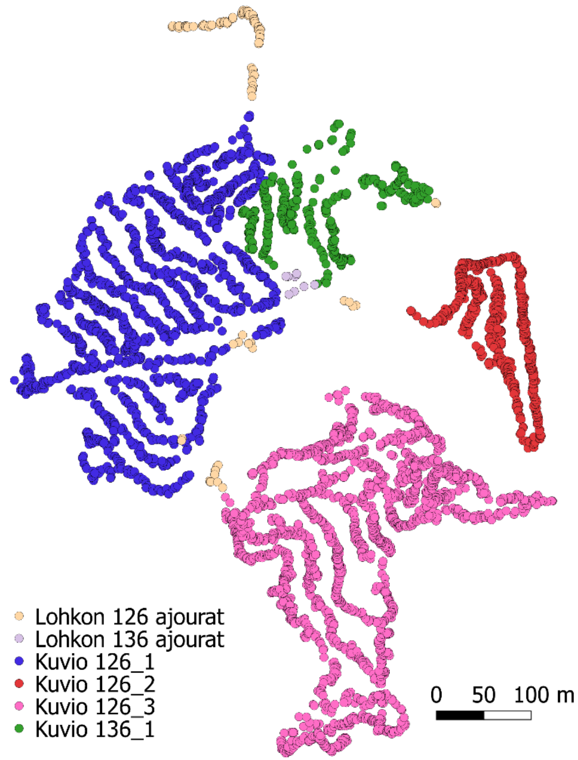
Preprocessed stem information to automated stand delineation:

- Identifiers
- Stem coordinates
- Starting time
- Cutting type
- ObjectID
- StemNumber

(ObjectID, StemNumber:) These parameters are used in further process to identify uniquely the objects and the stems

Algorithm I – separation of stands and external strip roads

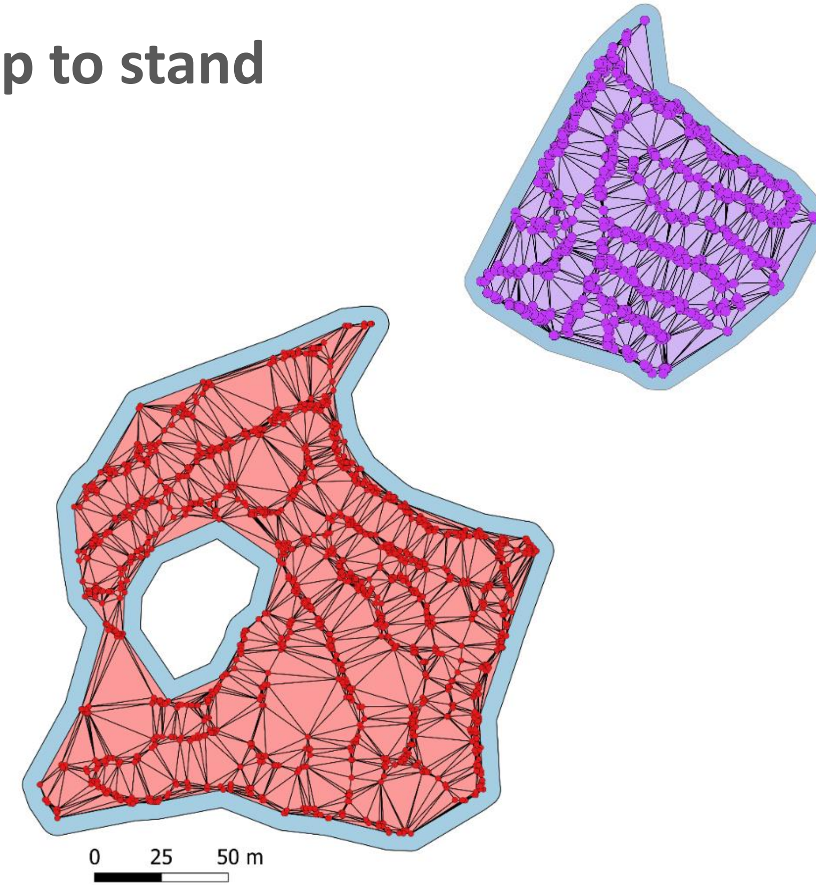
- The trees are labeled to belong to either the stands or external strip roads based on their location, resulting the stand-wise tree groups
- The spur trails are recognized, and added into the stand-wise tree groups
- The cutted areas (preliminary stands) are inspected if they contain different, but almost similar object identifiers



Algorithm II – from tree group to stand

- The starting point for stand delineation is the point data of stand-wise tree group, resulting from algorithm I
- The set of tree locations are triangulated using the Delaunay method
  - The tree locations close enough to each other are selected based on the triangulation
- A "raw version" of the stand is formed from the selected triangles, and then buffered outwards
  - The boom reaches certain length away from the machine
  - Using 6.5m buffer distance

→ The polygon representing the harvested stand is obtained

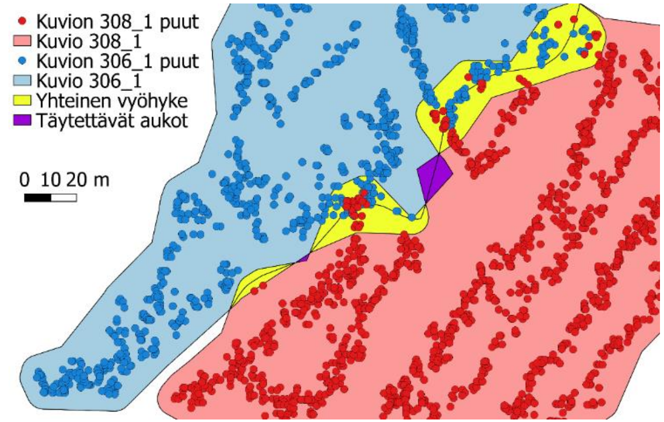


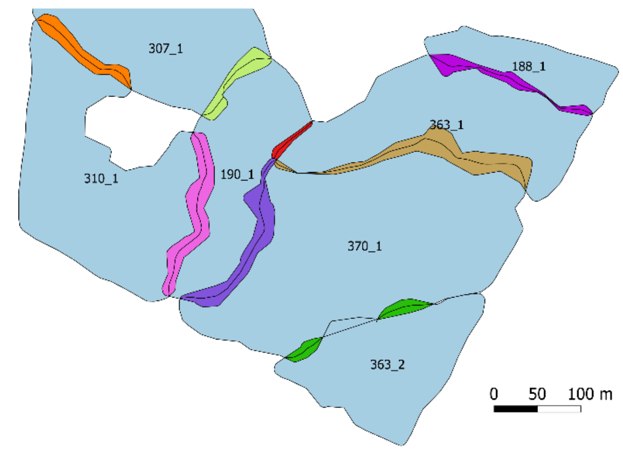
Sometimes a hole appears in the stand, corresponding to non-harvested areas over certain size.

Algorithm III – intersecting stand polygons

- The starting point is the stand delineations from algorithm II
- Sometimes the stand polygons intersect with adjacent stand polygons, forming an intersecting zone
  - GNSS inaccuracy may have displaced some trees, or the harvester may have cutted some trees from other stand
  - Roughly 20% of stands intersecting in this dataset
- The intersecting zone is split and divided for the stands
  - New stand boundary is created into the middle of the zone
  - → More accurate area for the stands
- The small empty slots between stands (less than 1000m^2) are removed by dividing them for the stands.

→ Solid stand boundaries for both stands are obtained





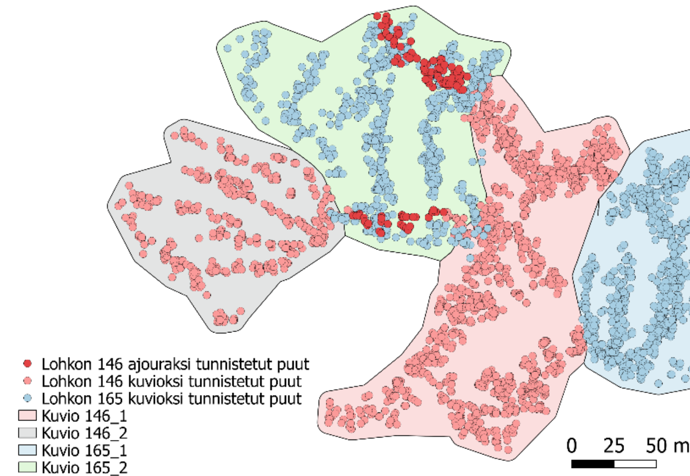
Finalization – external strip roads and final stand delineation

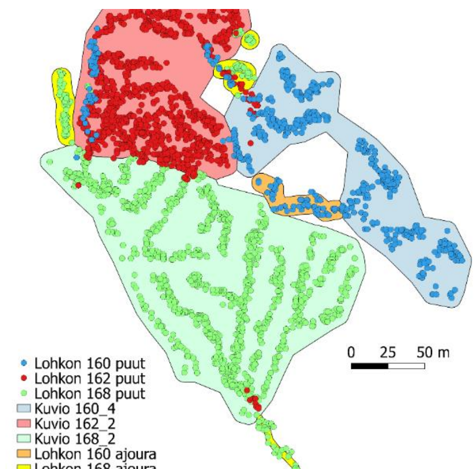
The harvested stand = stand delineation and the trees cutted from the stand

- The starting point for finalization:
  - Trees belonging to external strip roads from algorithm I
  - The solid stand delineations from algorithm III
- In this dataset, some of the trees belonging to external strip roads are located within some other stand. Then those trees are transferred to that stand's cutted tree data (cutting removal).
- The external strip road trees are merged into strip road parts and based on their tree density, the delineations and areas of the strip road parts are determined.
  - Smaller area is assigned for sparse strip roads
  - The dense strip roads can be either stands of one strip road, or merely dense external strip roads

→ Finalized stand and strip road delineations are obtained

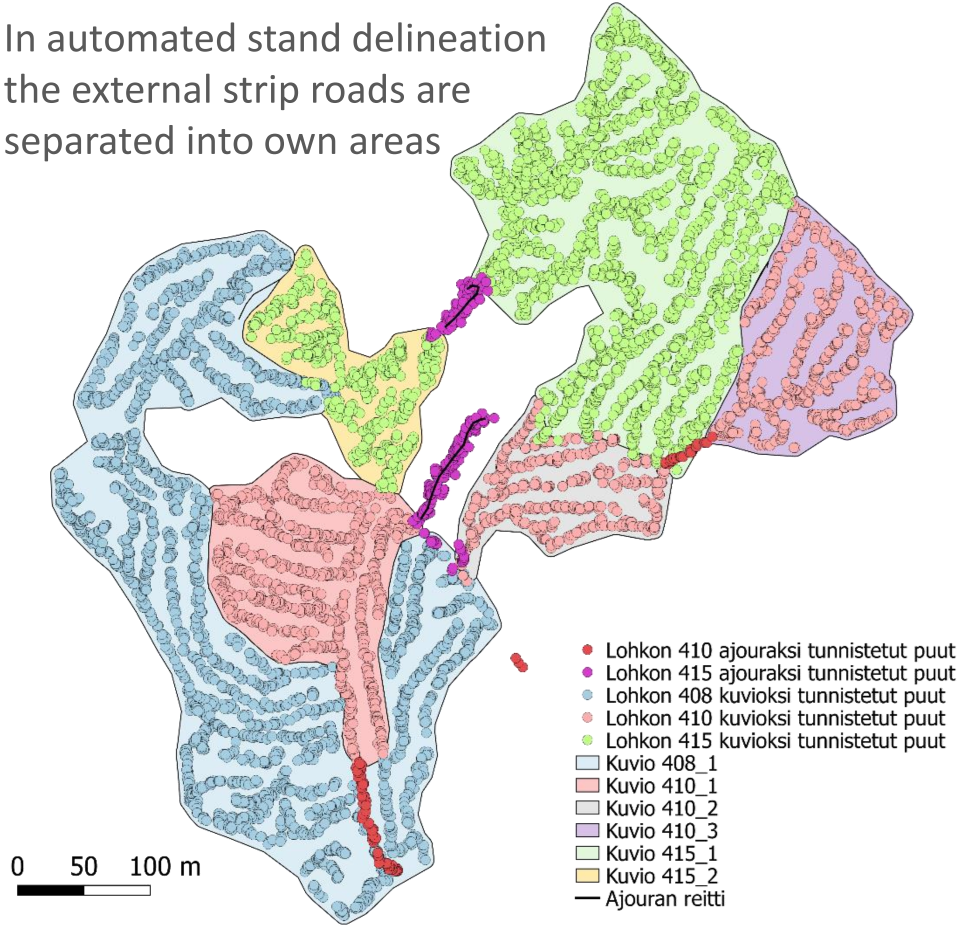
- If the method is applied to update forest inventory data, all the external strip roads will be located within some other stand. In that case it is possible to update the grid-level forest inventory data with the delineations of strip roads.

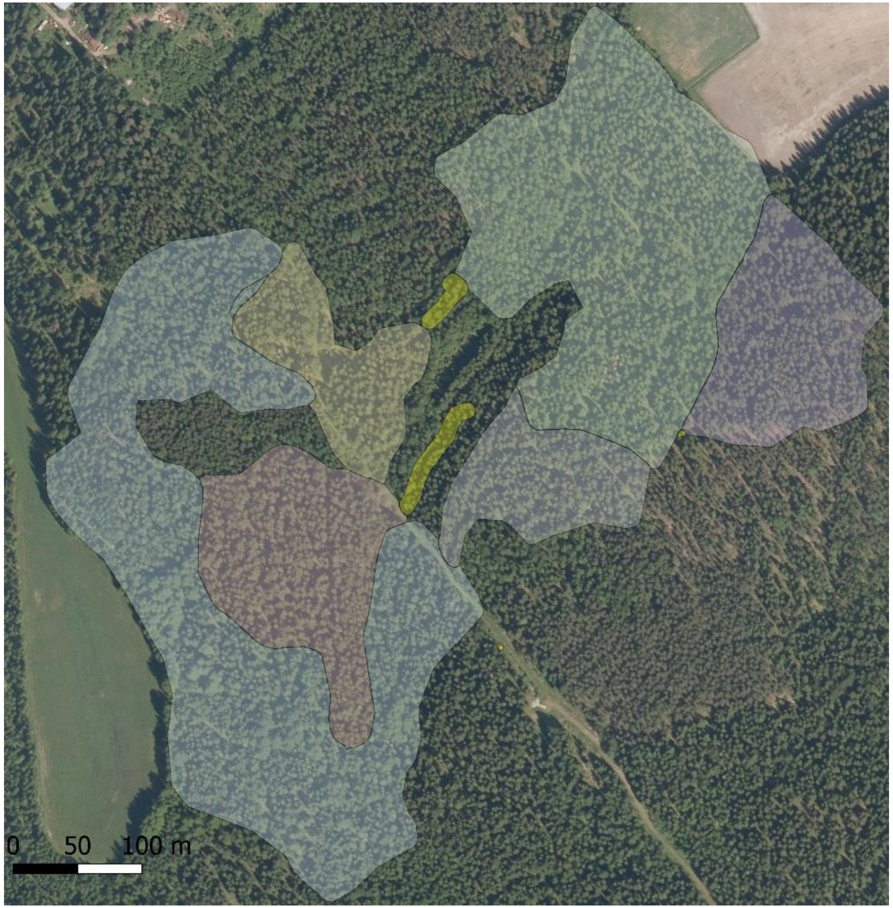




Example of automated stand delineation

In automated stand delineation the external strip roads are separated into own areas





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Results of automated stand delineation

Results of the automatic algorithm were compared to the semiautomatic algorithm at the object, stand and strip road level. The average size of the area, the minimum and maximum values and standard deviation were calculated based on an automatic and semiautomatic method.

The semiautomatic method was published in Metsäteho´s result report 5/2017: Melkas, T. & Riekki, K. 2017. Hakkuualueen rajan muodostus hakkuukoneen sijaintitietoon perustuen (in Finnish) - Stand delineation based on harvester location data.

- A method is based also on Delaunay-triangulation, buffering and different kind of parameters and it produces the stand delineation based on operative data collected by harvesters
- The method includes manual adjustment of the stand delineations for both stands and strip roads. Also the intersections were handeld with different way in semiautomatic method.

Results of automated stand delineation

	Automatic			Semiautomatic		
	Object	**Stand**	**Strip road polygons**	**Object**	**Stand**	**Strip road polygons**
Number of objects or stands, $N_{objects\ or\ stands}$	433	572 (585)	722	429	638	69
Area, hectares						
average	2,5	1,8	0,01	2,7	1,8	0,18
minimum	0,0	0,0	0,00	0,0	0,0	0,01
maximum	20,1	12,3	0,34	20,5	12,7	1,95
standard deviation	2,6	1,9	0,02	2,7	2,0	0,30
Number of harvested stems, N_{stems}	622498	592585	10655	618973	612173	6121

OBS. Results do not include the cutting of hold-over trees

Results of automated stand delineation

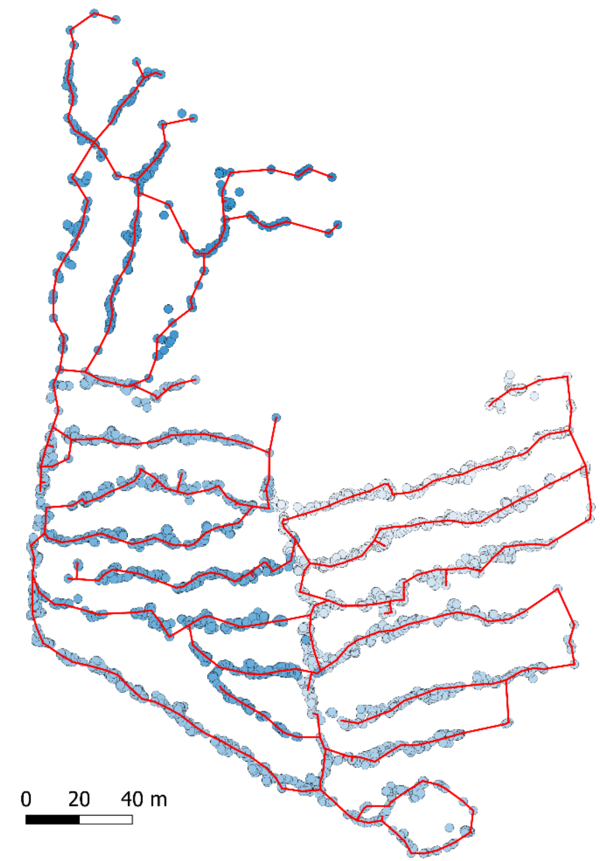
- The method produced automated stand delineations for thinnings and final fellings (n_{object}=433).
- For cuttings of hold-over trees (n_{object}=22), the formation of stand boundaries is not reasonable from the harvester data. Instead, in further work (ecs. in updating) it is adequate to state the locations of the cutted trees.
- The success of the automated stand delineation depends on the quality of the input data. The results presented here are valid for the current dataset.
- Based on the delineated stand results (n_{stands}=585):
  - 97,8 % of the stands were produced without problems,
  - 0,5 % (n=3) had erroneous locations recorded by harvester (GNSS –receiver had recorded one single coordinate value for significant part of the object),
  - 0,3 % (n=2) was found that geoprocessing did not occur as it should have, and this cannot be detected automatically (not explicitly invalid geometry),
  - 0,2 % (n=1) had invalid geometry preventing the correct stand delineation, despite several automated cleanings, and
  - 1,2 % (n=7) of the cases can be solved in further work by additional logical rules relating to cutting type.
- Based on the objects included in this study (n_{object}=433):
  - External strip roads leading to stands were found in 70,2 % of objects.
  - Roughly 4,6 % of total amount of stems were felled from the external strip roads.

Strip roads - from tree group to strip road network

- The starting point is the stand-wise tree groups from finalized stands (no external strip roads)
- The trees are split into ”working parts” by felling order and distance
- Strip road lines are produced for the working parts, taking into account that harvester fells trees in mixed order when going back and forth
  - The order of the trees alone does not result unambiguous strip road lines
- The strip road lines are merged together

→ The strip road network is obtained

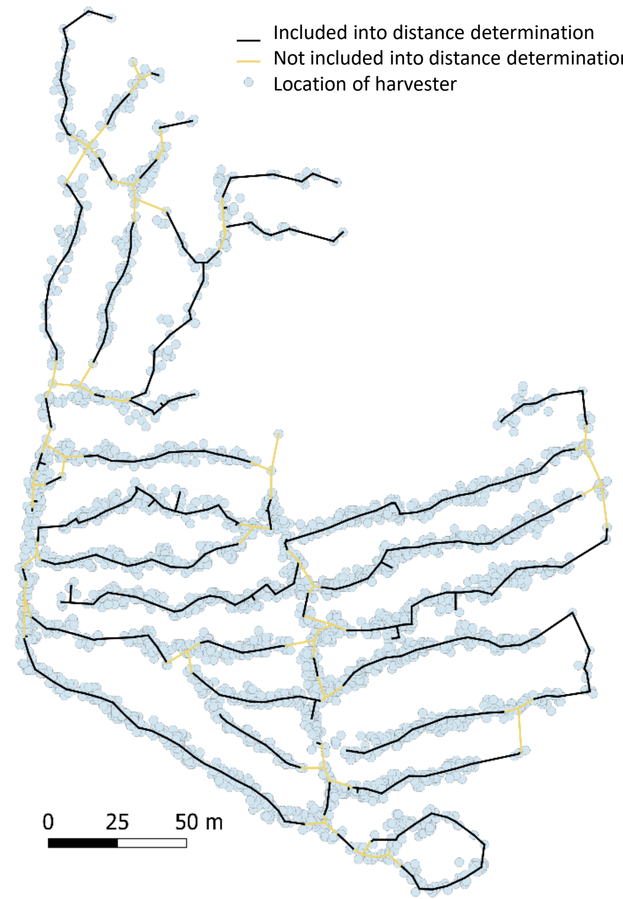
- The area is calculated by assuming a constant width of 4.5m



Strip road spacings

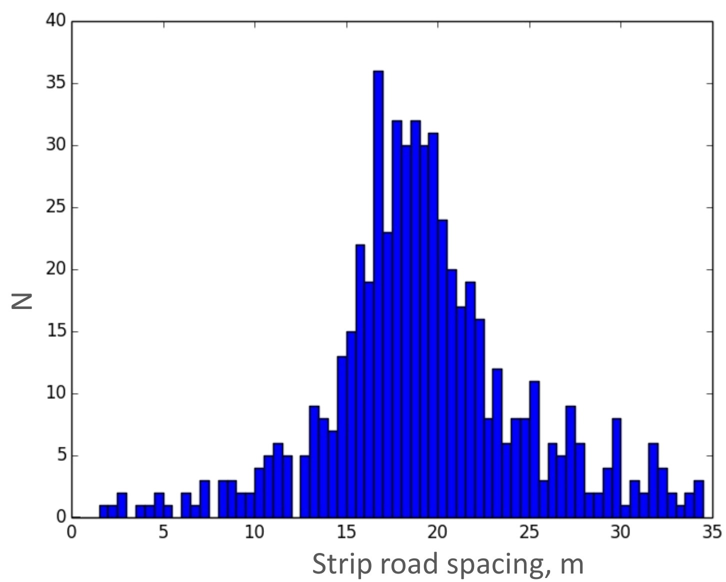
- The spacings of strip roads were determined from network line segments
  - Provides a lot of sampling points per stand (roughly N = 100 for 2ha)
  - The crossings were excluded

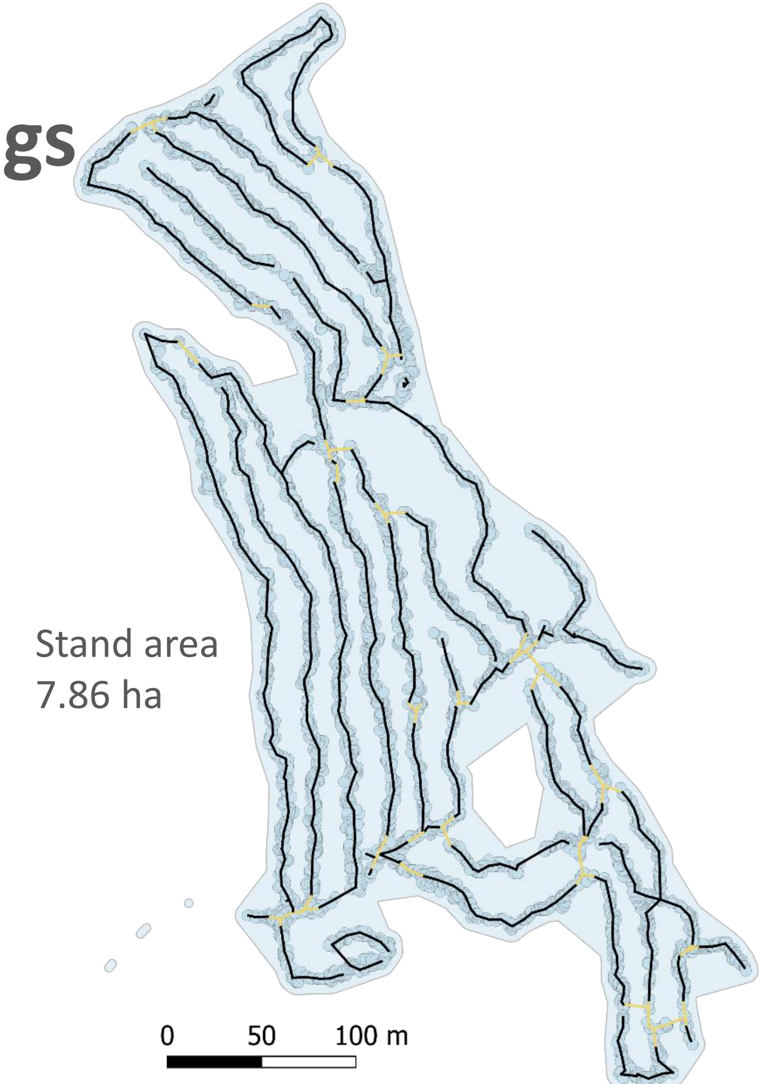
→ Average strip road spacing and its standard deviation are obtained



Example of strip road spacings

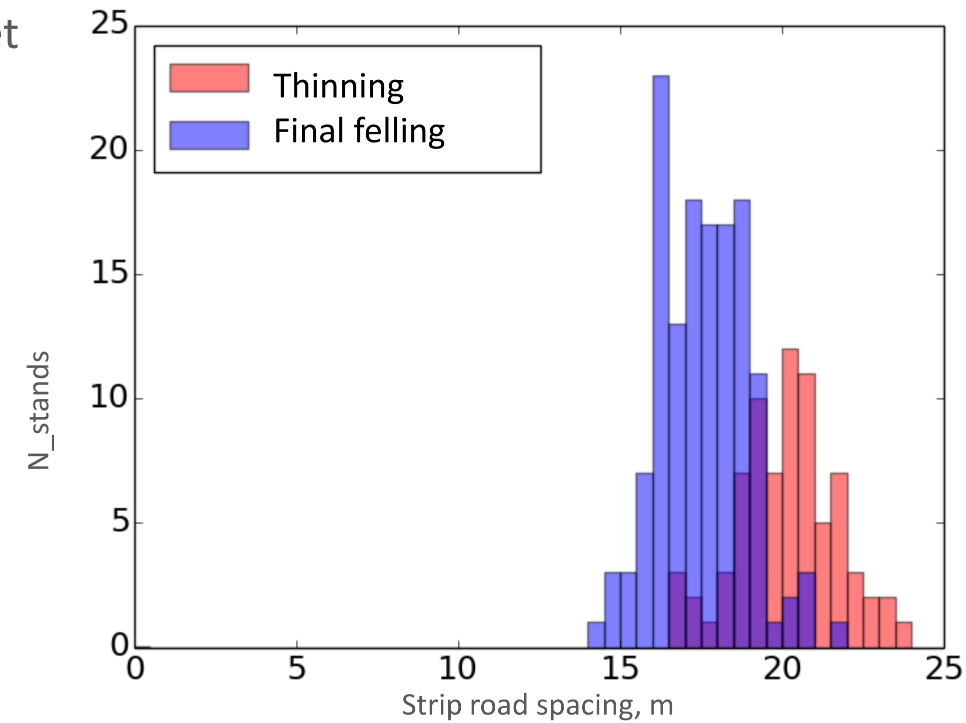
First thinning:
- Strip road length 570m/ha (4.45km)
- Strip road area 25% of stand (1.97 ha)
- Average spacing 19.3m, standard deviation 5.5m
- Sampling points N = 577





Strip road spacing results

- Thinnings have typically a different average strip road spacing than final fellings in the current dataset
  - For stands which had sampling point amount *N* > 100
  - Thinnings: 76 stands
  - Final fellings: 138 stands



Conclusions

- The method can be used to delineate operated stands, to separate external strip roads leading to stands, and to recognize non-harvested areas over certain size that are within the stands.
- The method can be used to update stand delineations into forest database and handle the intersections with neighbouring stands, resulting in solid stand boundaries after update for both existing and new stands.
- The accuracy of the GNSS –receivers affects stand delineation. What newer GNSS –receivers we have, that better the accuracy is.
- Using this method in update to forest inventory data requires masking of the resulting stands with field, water and road masks.
- The method can be used also to produce quality information of the strip road network (total length, area and average spacing of the strip roads).

Further work

- Fine-tuning of parameter values
- Refining the handling of intersecting stand boundaries (algorithm III)
  - Adding more logical rules for complex cases of intersecting stand geometries
  - Management of invalid geometries

- Comparison study: how well automatically delineated stands correspond with reference stands obtained from aerial images/field recordings/semiautomatic stand delineation
- Comparison study: how well automatically produced strip road networks correspond with reference strip road networks from field recordings.

This study has been conducted in co-operation with shareholders of Metsäteho and Finnish forest centre. The study is part of research program **Forest information and digital services** of the Ministry of Agriculture and Forestry in Finland, aiming to enhance the use of forest information, improve the quality and mobility of the information and develop digital services.

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