Université du Québec
École de technologie supérieure

The Selection of Harvest Areas and Wood Allocation Problem

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Value Chain Optimization
NSERC Strategic Network
optimizing the forest bioeconomy

Ressources naturelles Québec

FPInnovations

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IFORS The Art of Modeling BARCELONA 2014

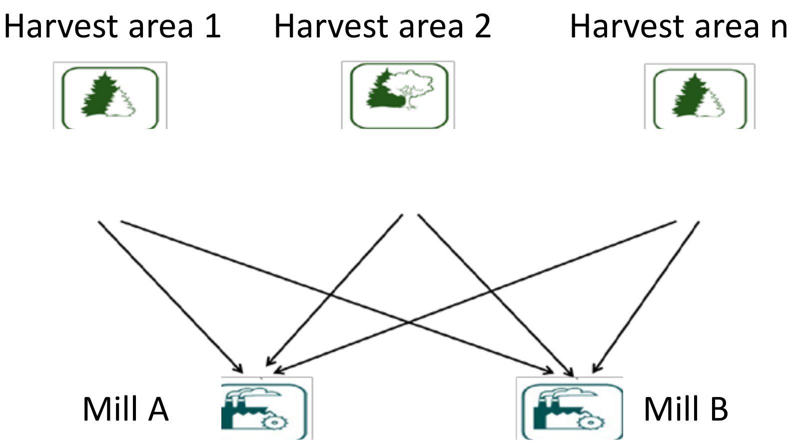
Context

Strategic forest management planning
(Coutry,province, or province level)

Tactical, mid-term planning
(forest management unit or regional level)

Operational, short-term level
(forest management or harvest area level)

Realt-ime, execution level
(harvest area level)



Context…

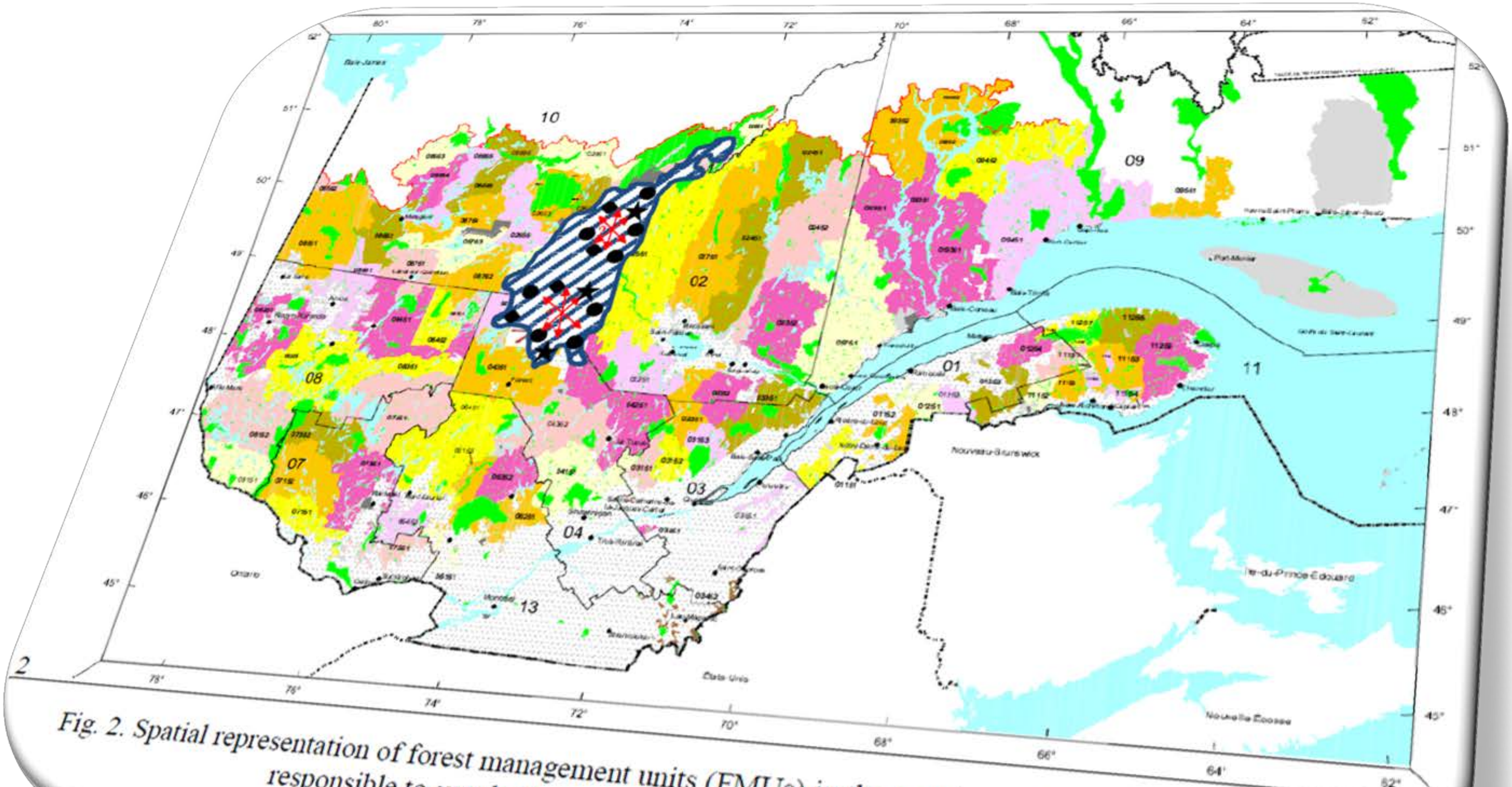


Fig. 2. Spatial representation of forest management units (FMUs) in the province of Québec. Each FMU is responsible to supply the mills within its territory. Source: MRN.

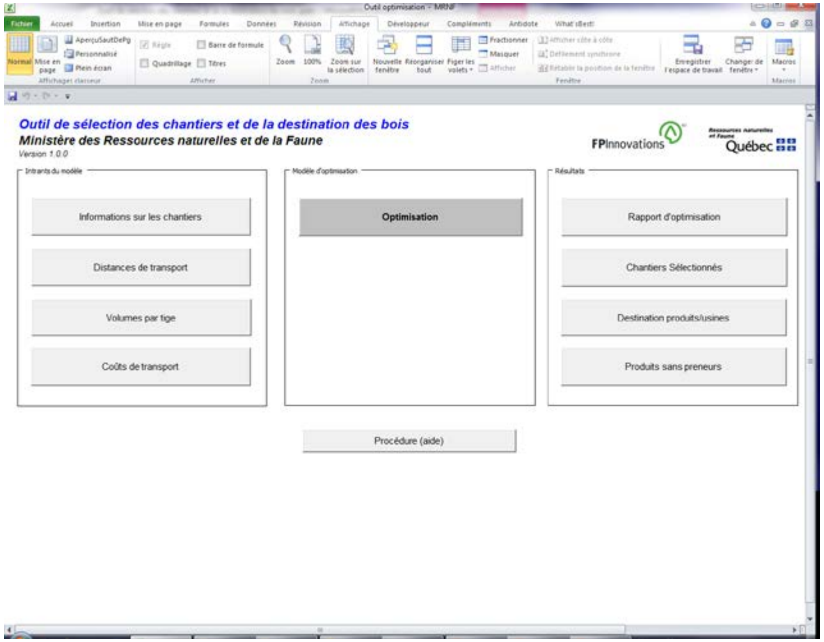
The needs - Problem Description

- Develop an optimization tool capable to support the decision maker to:
  - Select the harvesting areas for year 1 while balance specific criteria over the 5 years planning horizon (year 1 and years 2-5),
  - Define the wood allocation for year 1 to fulfill the mills' demands and minimize the total costs.

- Provide an easy tool to use with a friendly GUI
- Test and validate the tool using real data (FMU data)
- Train the staff (end users) of the MRN (Québec)

Approach

- Formulate the problem as a MIP with multiobjective function;
- Use ***What's Best as solver*** *(*Lindo*)*,
- Easy to implement the model using the tool (embeded in Excel);
- Why to adopt such approach/solution:
  - Short time to prototype and develop the tool;
  - Easy to use (Excel spreadsheet);
  - Licenses fees very low (500$/license);
  - No annual fees (licenses).



Mathematical Formulation

Sets and Indexes

- $m \in M$: Set of mills,
- $a \in A$: Set of harvest areas,
- $p \in P$: Set of wood assortments (raw material),
- $t \in T$: Set of periods (planning horizon),
- $cr \in CR$: Set of criteria to consider in the multiobjective function (procurement, transportation distance and cost, winter access, volume per stem, budget for sylvicultural prescriptions, percentage of certification).

Mathematical Formulation

Decision Variables:

- X_{ampt}: Total flow from harvest area a to mill m for raw material p (m^3) in period t.
- Y_{at}: Binary variable$=1$ if harvest area a is selected to be harvested in period t, 0 otherwise.
- $Slack_{up}{}^{cr}, Slack_{down}{}^{cr}$: Slack variables (up and down) for the optimization criteria (difference between target and actual value).

Mathematical Formulation

Objective Function

- $\sum_{cr \in CR} \boldsymbol{Slack_{up}}^{cr} + \boldsymbol{Slack_{down}}^{cr}$

The multi-objective function aims to minimize the summation over the difference between the target value and the real value for each optimization criterion for the selected harvest area.

Mathematical Formulation

Constraints:

- $\sum_{m \in M} X_{ampt} = v_{ap} * Y_{a,t}, \quad \forall a, p, t$
- $\sum_{t} Y_{a,t} \leq 1, \forall a$

This constraint ensures that raw materials are harvested from selected harvest area does not exceed the total volume available to cut in that area.

- $\sum_{a} X_{ampt} \leq md_{pm}{}^{max}, \ \forall m, p, t = 1$
- $\sum_{a} X_{ampt} \leq 4 * md_{pm}{}^{max}, \forall m, p, t = 2$
- $md_{pm}{}^{min} \leq \sum_{a} X_{ampt}, \forall m \ p, t = 1$
- $4 * md_{pm}{}^{min} \leq \sum_{a} X_{ampt}, \forall m, p, t = 2$

This constraint expresses minimum and maximum demand per raw material required by mills.

Mathematical Formulation

Constraints:

- $\sum_{a \in A} \boldsymbol{cutB_a} * \boldsymbol{Y_{at}} \leq \boldsymbol{totB_t}, \forall \boldsymbol{t} \in \boldsymbol{T}$

  This is the budget constraint preventing the total cost of the selected areas to exceed the available budget.

- $\sum_{a \in A} val_a{}^{cr} * Y_{at} - tar^{cr} * \sum_{a \in A} Y_{at} + \left(Slack_{up}{}^{cr} - Slack_{down}{}^{cr} \right) = \mathbf{0}, \forall \boldsymbol{t}, \boldsymbol{cr}$

  A set of constraints that expresses the difference between the target value and real value for each optimization criterion

Optimization tool

- Two main decisions
  - Select the harvesting areas (year 1)
  - Allocate the wood to the mills (year 1)

- The harvesting area is at the forest management unit (FMU) and not stand level.

- The tool is flexible and can be used at:
  - Forest management unit level
  - Regional level (aggregate FMUs) – transportation synergies

Criteria and parameters - inputs

- The optimization takes into account the following criteria (economic, sylvicultural treatments, etc.):

  - Procurement cost($\$/m$^3),
  - Average transportation distance (km)
  - Transportation cost ($\$/m$^3),
  - Winter accessibility (%),
  - Volume per stem($m^3/stem$),
  - Certified surface (m^3).
  - …

Criteria and parameters - inputs

The tool is flexible and can be configured for different needs – regional basis

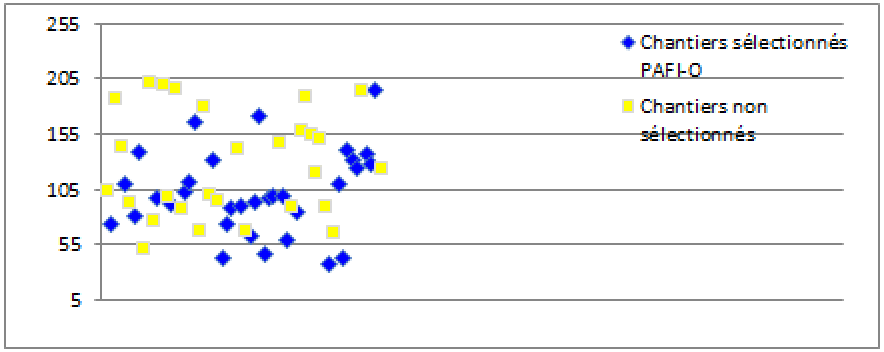
Active	Criteria to consider into the optimizatio	Type	Impact	
	1. Volume en garantie d'approvisionnement	***Required***	*Sélec./Desti.*	Constraints
1	**2. Coûts d'approvisionnement (sans le transport)**	*Optional*	*Selection*	Target value
1	**3. Distance moyenne de transport**	*Optional*	*Selection*	Target value
1	**4. Volume par tige moyen**	*Optional*	*Selection*	Target value
1	**5. Volume par ha moyen**	*Optional*	*Selection*	Target value
1	**6. Volume par km moyen**	*Optional*	*Selection*	Target value
1	**7. Budget coupes partielles**	*Optional*	*Selection*	Constraints
1	**8. % de récolte hiver**	*Optional*	*Selection*	Target value
1	**9. % de CMO dans coupe de régénération (CR)**	*Optional*	*Selection*	Target value
1	**10. Volumes sans preneurs**	*Optional*	*Selection*	Minimiser
1	**11. Stratégie d'aménagement**	*Optional*	*Selection*	Valeurs cibles
1	**12. Distance de transport chantiers/usines**	*Optional*	*Destination*	Minimiser
	13. Coûts d'approvisionnement aux usines	*Optional*	*Destination*	Constraints
	14. Distances de transport chantiers/usines	*Optional*	*Destination*	Constraints
	15. Volume par tige par usine	*Optional*	*Destination*	Constraints
	16. % récolte bois hiver	*Optional*	*Destination*	Constraints
	17. % résineux moins désirable	*Optional*	*Destination*	Constraints
	18. % feuillus moins désirable	*Optional*	*Destination*	Constraints

Decisions and results- outputs

1. Select harvesting areas for period 1
   - Within the set of the harvesting area (upcoming 5 years), we need to select the area for year 1 while balancing with the upcoming periods (2-5 years) for different criteria and targets
   - Example target : transportation distance

3. Distance moyenne de transport

Chantiers sélectionnés PAFI-O	102	km	Activé	
Chantiers non sélectionnés	149	km	*Valeur cible:*	*120*
Total soumis	121	km	*Écart cible:*	*15.16%*



ID	Harvesting area	Selected	Non selected
1	ANCRE	0	1
2	BAKER	1	0
3	BANANE	0	1
4	BAZINET	0	1
5	BEAUDRY	1	0
6	BEAUREGARD	0	1
7	BLEUET	1	0
8	BOTTINE	1	0
9	BOULEAU	0	1
10	CABASTA_EST	0	1
11	CANARD	0	1
12	CERISE	1	0
13	CHAHOON	0	1
14	CHARLIE_PROFOND_SUD	0	1
15	CINDY	1	0
16	CLOUD	0	1
17	COLLEEN	0	1
18	CORNEY	1	0
19	COTE_JAUNE_EST	1	0
20	CULOTTE	1	0
21	DELAFERME	0	1
22	DOROTHY_NORD	0	1
23	DOUAIRE	0	1
24	DUBE	1	0
25	FELICIA	0	1
...	...	...	...

Decisions and results- outputs

2. Determine the destination (where to deliver the wood)
   - Define the assignments between the harvesting areas (selected in year 1) and the mills for each products,
   - Calculate some key indicators for each mill and harvesting area

Allocation for SPF Product

Harvesting area \ mill	Bois K.M.S. (GMI) (L'Annonciation)	Coop forestière Hautes-Laurentides	Forex Inc. (Ferme-Neuve)	Forex Inc. (Rivière-Rouge)	Groupe Crête St-Faustin
ANCRE					
BAKER				7 877	
BANANE					
BAZINET					
BEAUDRY			6 558		
BEAUREGARD					
BLEUET					45 464
BOTTINE	3 200				9 823
BOULEAU					
CABASTA_EST					
CANARD					
CERISE			5 949		
...					

			Transportation distance	Procurement	Average volume per stem	% of seasonal harvesting
Destination	Products	Allocation	km	$	m³/stem	%
Bois K.M.S. (GMI) (L'Annonciation)	SPF	3 200	137	67.55	0.17	1.00
Coop forestière Hautes-Laurentides		500	25	50.76	0.16	1.00
Forex Inc. (Ferme-Neuve)		323 600	103	56.46	0.15	0.50
Forex Inc. (Rivière-Rouge)		84 800	106	52.94	0.15	0.36
Groupe Crête St-Faustin		91 000	136	58.85	0.16	0.16
Null		0	0	0.00	0.00	0.00
Null		0	0	0.00	0.00	0.00
Null		0	0	0.00	0.00	0.00
Null		0	0	0.00	0.00	0.00

Why such opimization tool ? (FPAlloc)

- Speed up the planning process of the selection and allocation of harvesting area to the mills ***(3-4 weeks of workload reduced to 1-2 days for more than 50 end-users)***
- Allow to simulate different allocation scenario and assess the economics of such decisions
- Support the interaction between the governments and industry – support tool
- Tradeoff between different optimization criteria (multiobjective planning)
  - Economic,
  - Sylvicultural,
  - Forest management practices.

Ongoing work and next steps

- Include more spatial issues in the allocation and harvesting area

Min

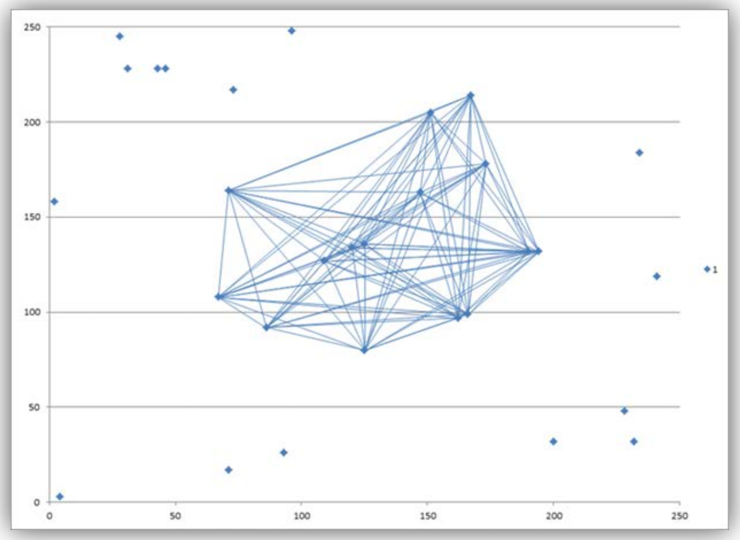
$$disp = \sum_I \sum_{I/j \neq i} d_{ij}.W_{ij}$$

S.T

$$W_{ij} \leq Y_i \qquad \forall i \in I ; \forall j \in I$$

$$W_{ij} \leq Y_j \qquad \forall i \in I ; \forall j \in I$$

$$W_{ij} \geq Y_i + Y_j - 1 \qquad \forall i \in I ; \forall j \in I$$



W_{ij} : Linearization parameter that take the value 1 if both areas i and j are selected, 0 otherwise.

Ongoing work and next steps

- Include more spatial issues in the allocation and harvest

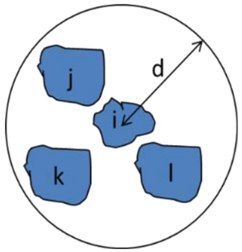


Fig. 3. Spatial representation of neighbor's definition as the number of areas within a predefined scope of radius *d* centered on harvest area *i*.

Objective function

$$disp = \sum_{a \in A} \sum_{b \in A}^{a \neq b} \frac{{d_{ab}}^2}{n_{ab}} . W_{ab}$$

d_{ab} : Distance between the harvest areas a and b
n_{ab} : Neighborhood parameter defined as the product of the harvest areas a and b neighbors value $n_{ab}=n_a*n_b$

- Two main modifications to better fit the spatial dispersion :
  - Introduce a ***neighborhood factor*** to promote the selection of dense clusters of harvest areas.
  - Consider ***squared distance*** to balance its impact with the neighborhood factor and promote the selection of a maximum amount of areas in a same cluster before moving to another one.

Some results….

	Data		Resolution time		
	Problem size	v_{ap}	**SCIP**	**CBC**	**CPLEX**
Test 1	150 Areas	Constant	157 sec	730 sec	42 sec
Test 2	100 Areas	Variable	2 011 s sec	512 sec	213 sec

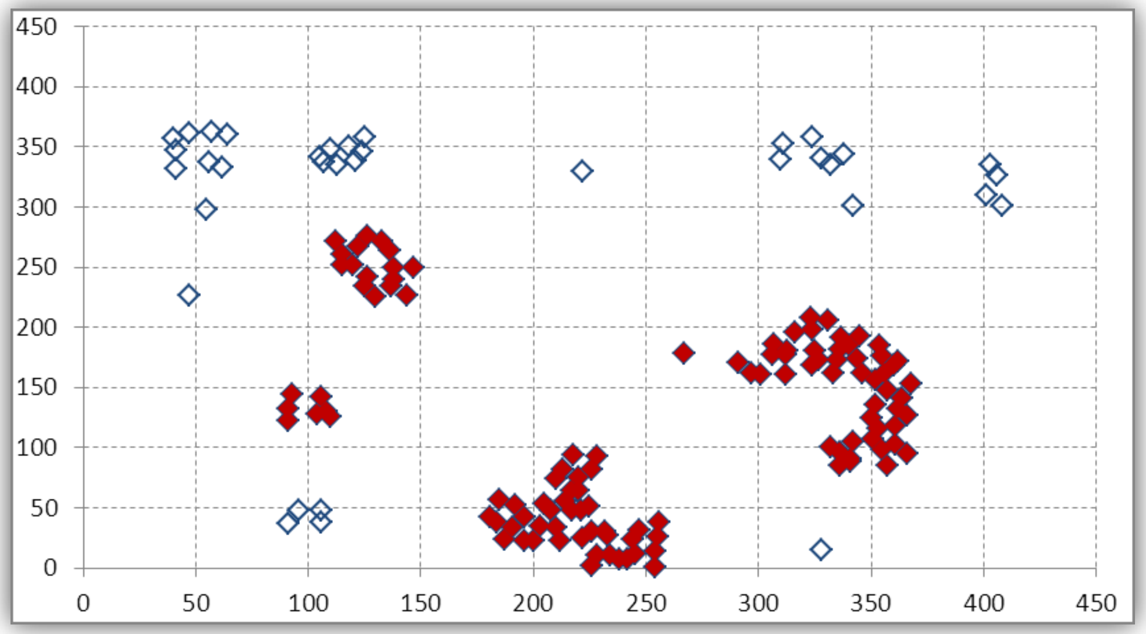


Fig. 3. Spatial representation of the selected harvest areas (red filled diamond) vs. non selected harvest area (open diamond) for Test 2.

Some results….

Tests		SCIP	CBC	CPLEX	GUROBI
1	**Disp + ADist**	60 min	153 min	16 min	7 min
2	**Disp + Stem + ADist**	26 min	60 min	8 min	6 min

ADist : Average transportation distance between harvest area a and mills
Stem : Average volume per stem

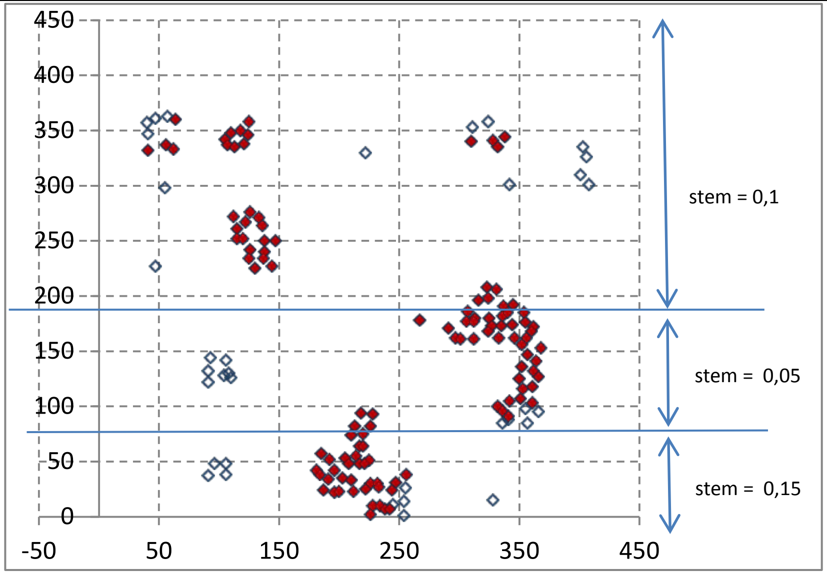


Fig. 4. Spatial representation of the selected harvest areas (red filled diamond) vs. non selected harvest area (open diamond) for Test 2.

Some results….

Tests	Criteria	Resolution time
1	dispersion	GUROBI : 49 sec
2	dispersion + Stem + ADist	GUROBI : 2h46 min
3	dispersion + ADist	CPLEX : 14 min
4	dispersion + ADist + detailed mills demand of raw material	CPLEX : Out of memory GAP 49% GUROBI : 15 min
5	dispersion + Stem + ADist + detailed mills demand of raw	CPLEX : Out of memory GAP 70% GUROBI : 19 min

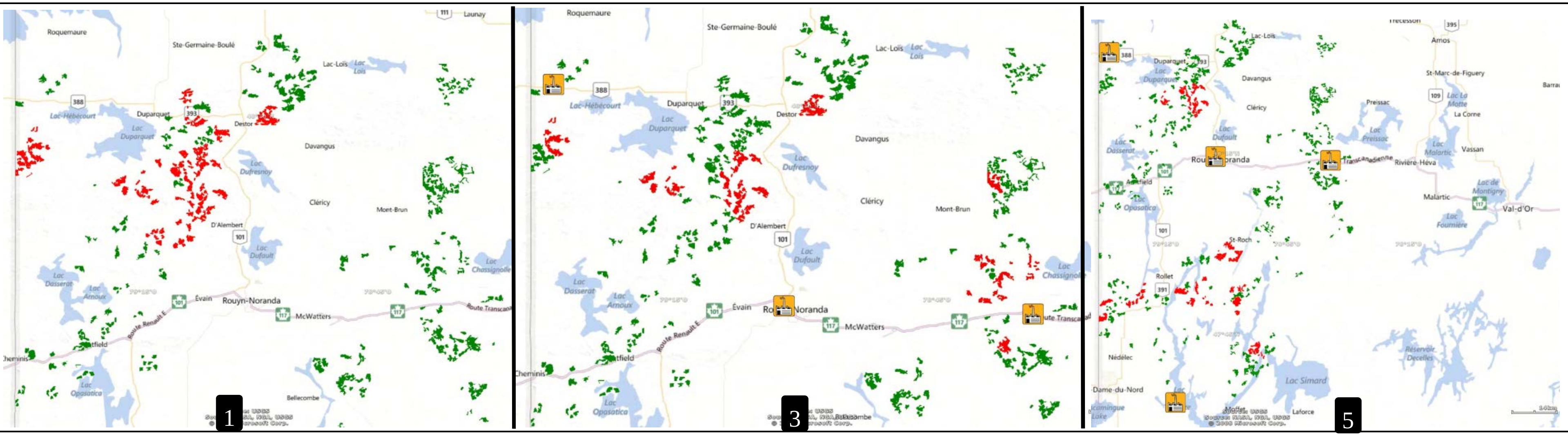


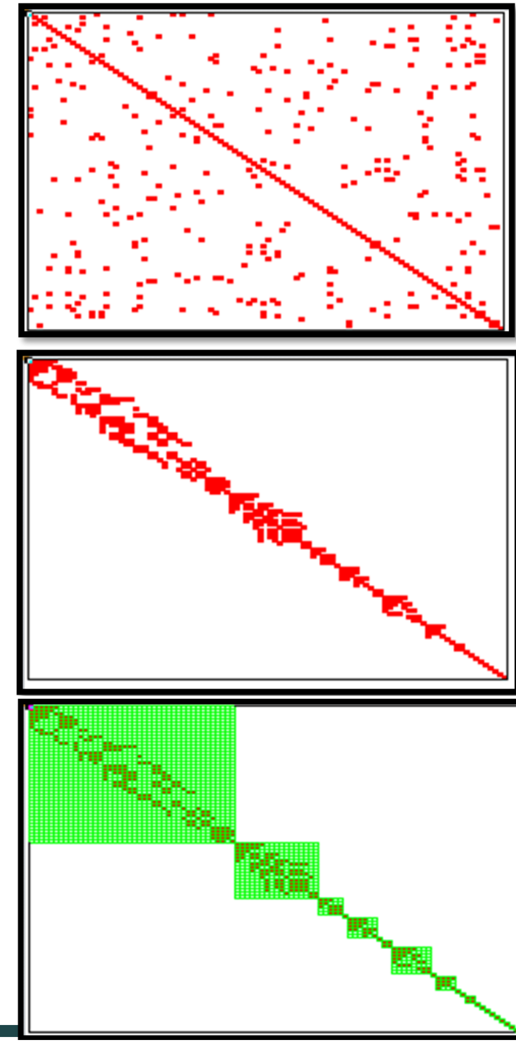
Fig. 5. Spatial representation of the selected harvest areas (red) vs. non selected harvest area for Test 1, 2, and 3.

Rank-Order Clustering Algorithm (King's algorithm)

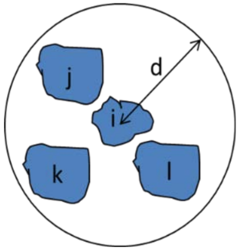
- Step 1: Assign binary weight and determine decimal weight for each row and column say "Wi" and "Wj"

$$W_i = \sum_{p=1}^{p=m} b_{ip} 2^{m-p}$$

  - m is the total number of columns
  - i is the number of row
  - bip is either 0 or 1 depending upon the matrix.
- Step 2: Rearrange the rows to make "Wi" fall in descending order.
- Step 3: Repeat steps 1 and 2 for each column, then go to step 1 again.
- Step 4: Repeat above steps until there is no further change in position of each element in each row and column.



Rank-Order Clustering Algorithm - ROC (King's algorithm)

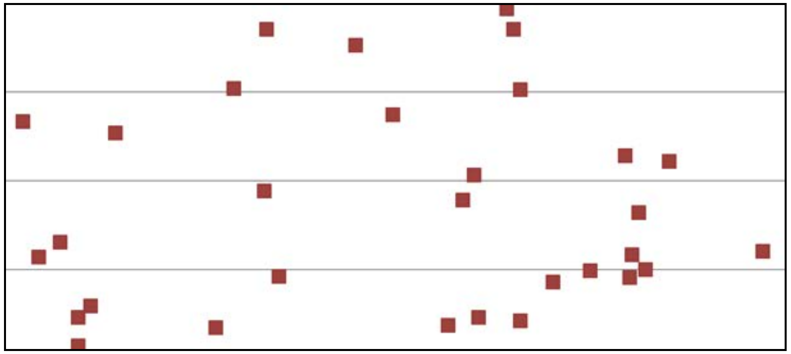


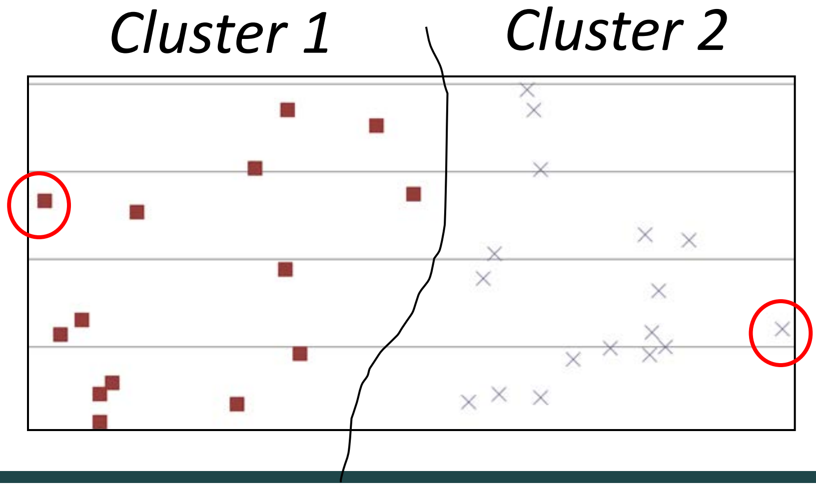
- Define a radius where all harvest area within the radius are included in the cluster;
- Transform the matrix distance into 0/1 variables to apply the ROC algorithm:
  - If the distance d_{ij} between harvest area i and j $\leq d$ then 1
  - If the distance d_{ij} between harvest area i and j $\geq d$ then 0

	1	2	3	4
1	*1*		*1*	*1*
2		*1*		
3	*1*		*1*	*1*
4	*1*		*1*	*1*

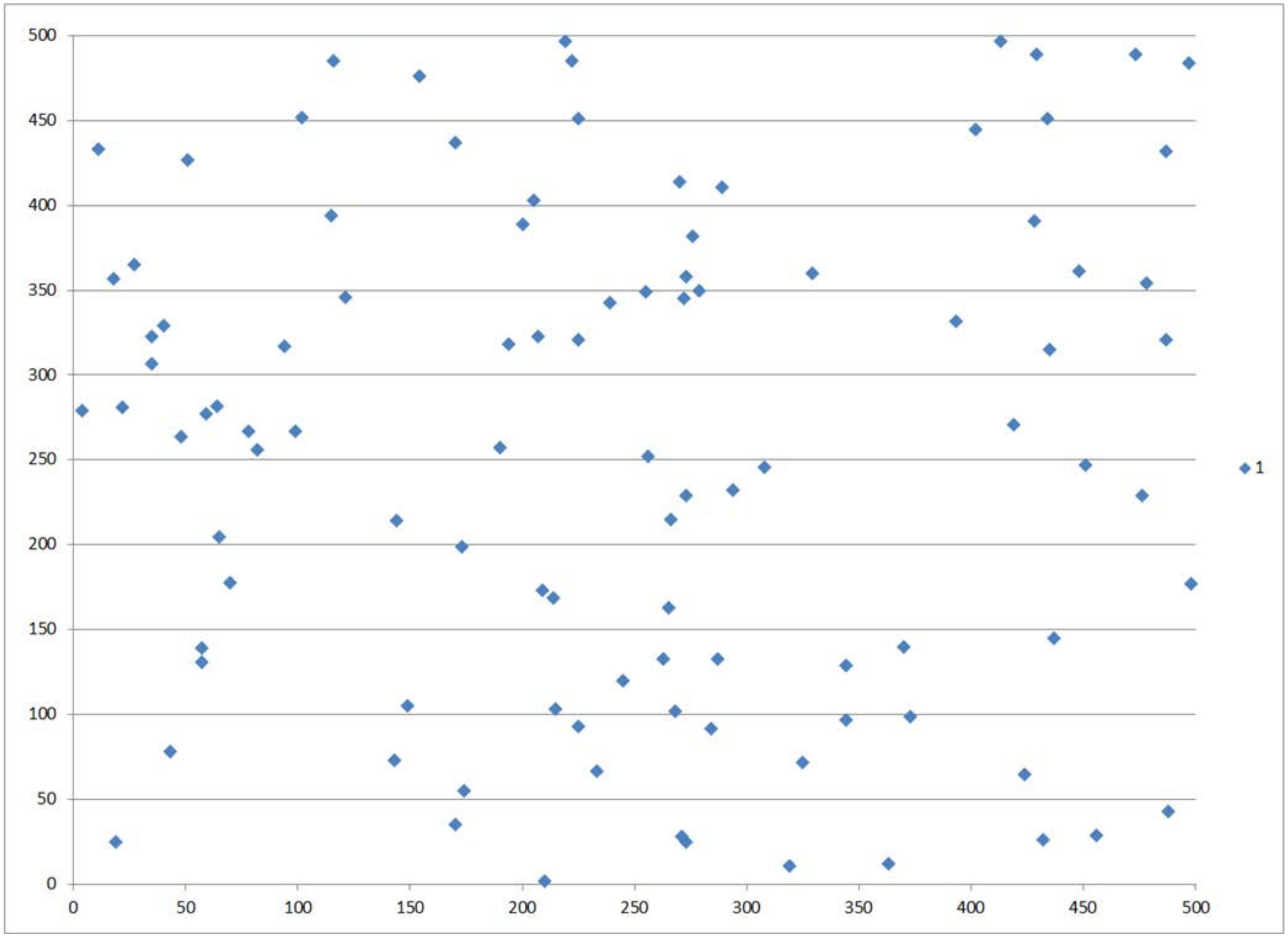
Clustering based on the cardinal points (the two most distant points)

- For each cluster (previous algorithm) perform the following clustering:
- Find the two far distant points (extreme points);
- Divide this cluster into two clusters based on the distance (each harvest area is associated to the closest extreme point);
- Iterate the last two steps until there is no cluster with more than two harvest areas.
- *Minimizing dispersion, is equivalent to minimizing the number of clusters open at each layer (harvest area within the cluster is open)*

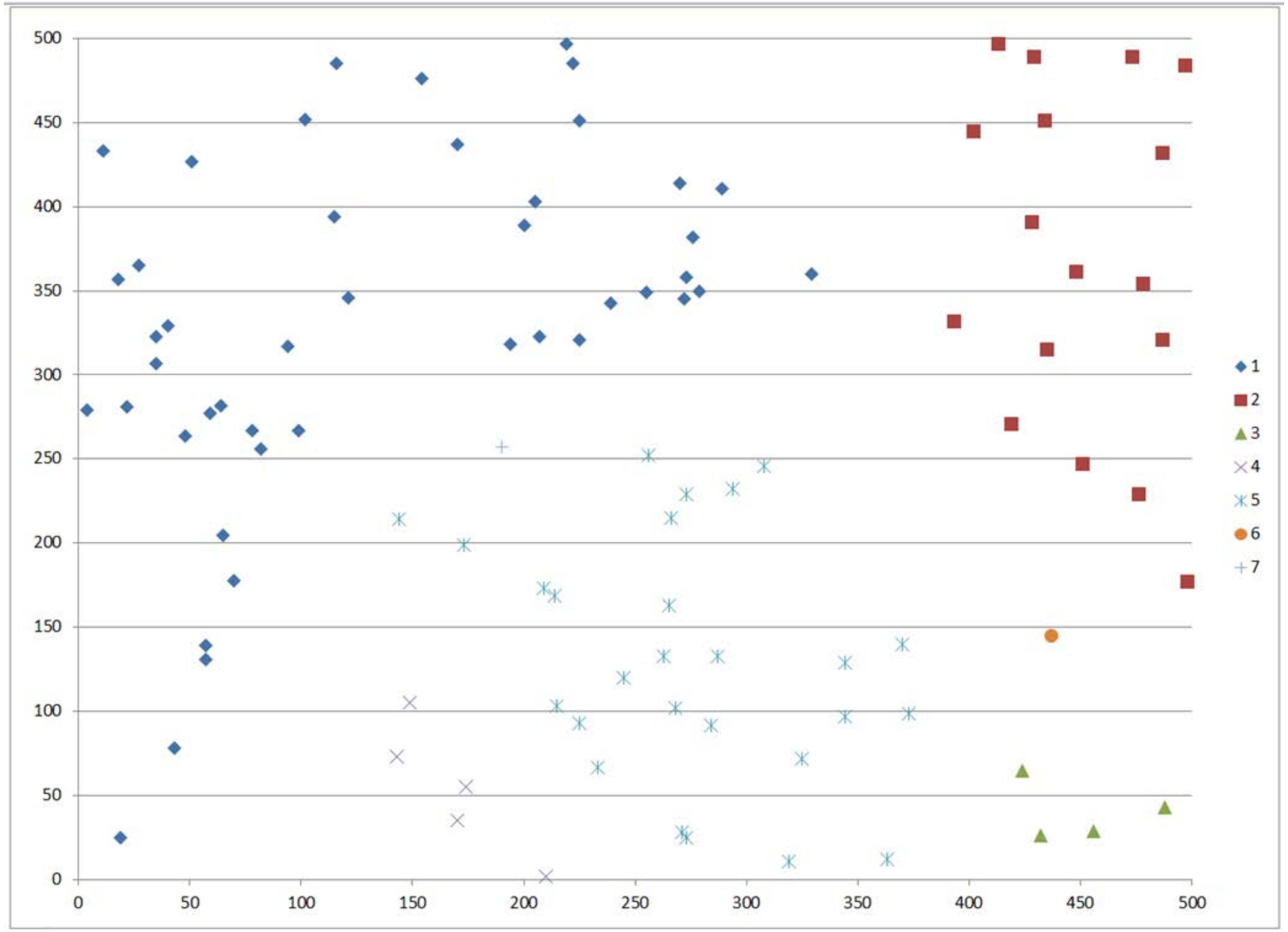




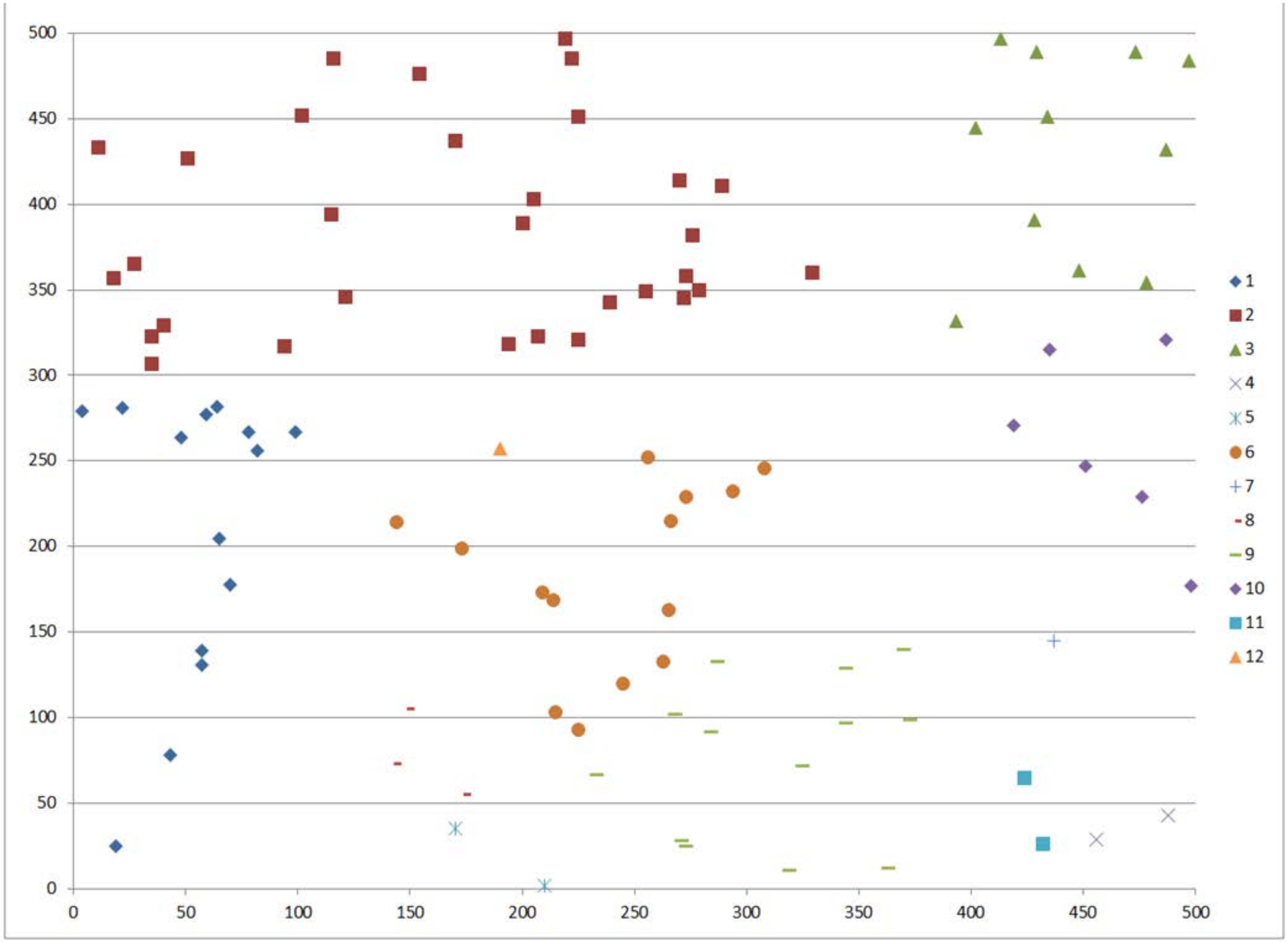
Clustering based on the cardinal points (the two most distant points)



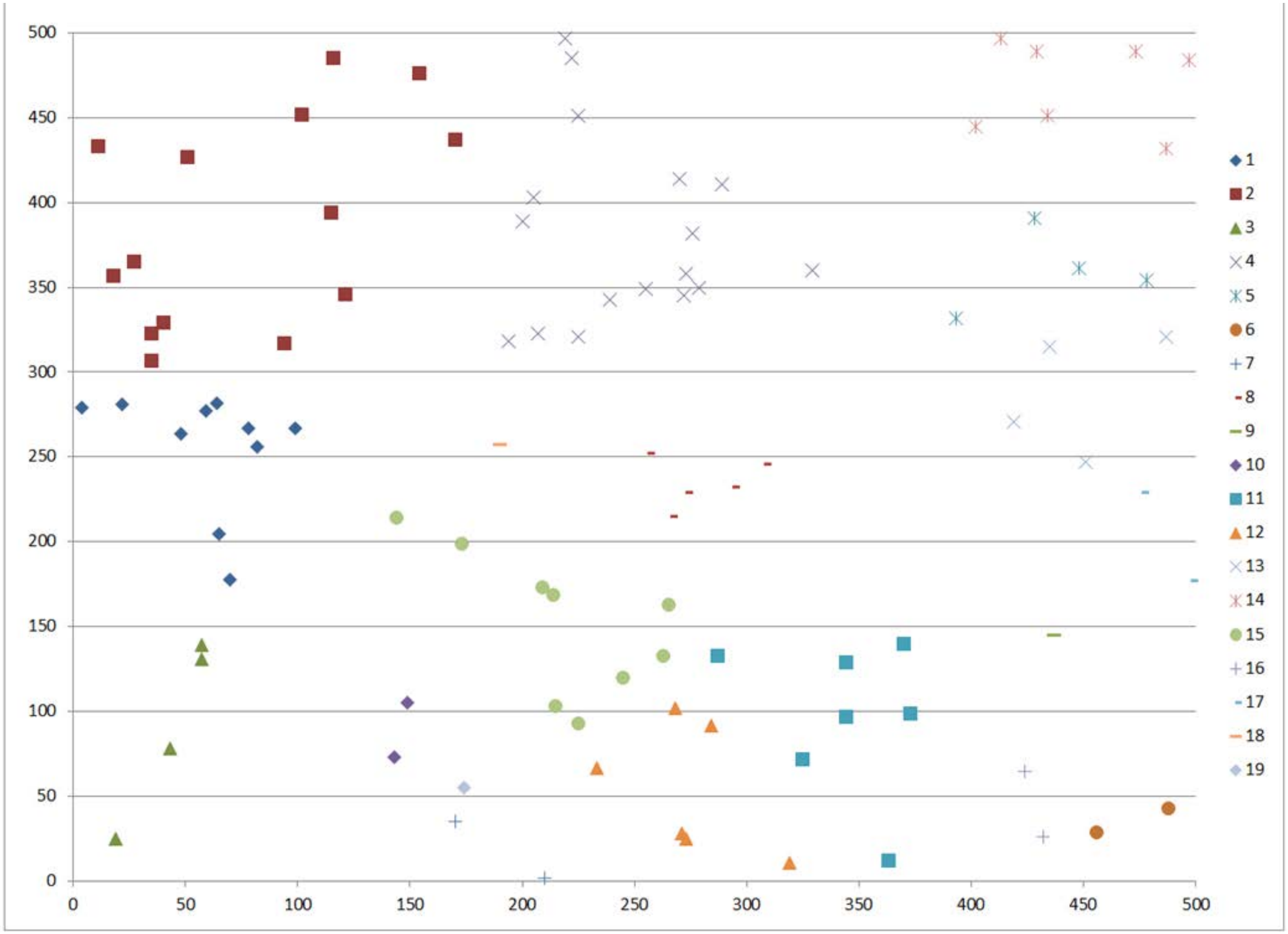
Clustering based on the cardinal points (the two most distant points) – Layer 1



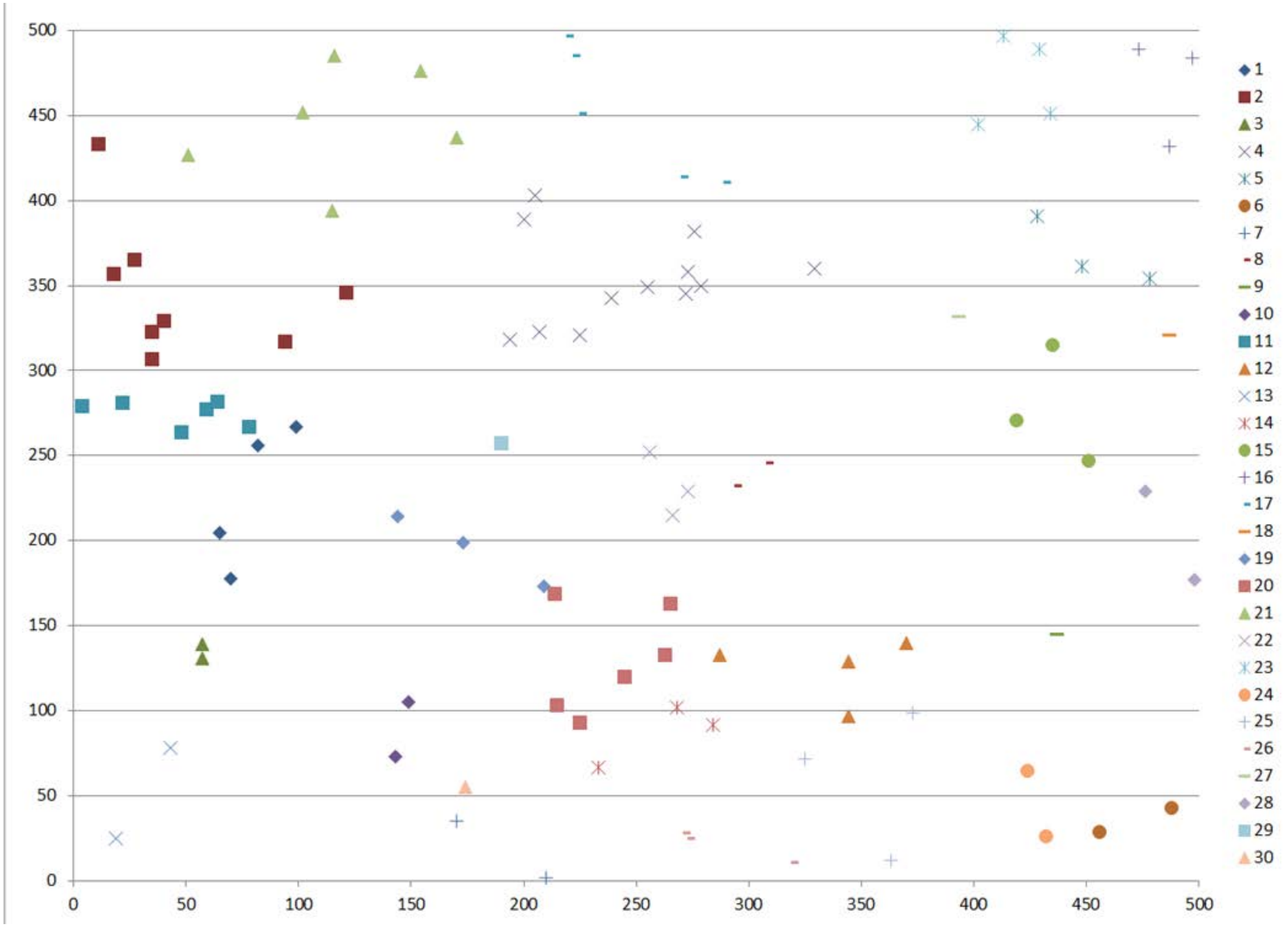
Clustering based on the cardinal points (the two most distant points) – Layer 2



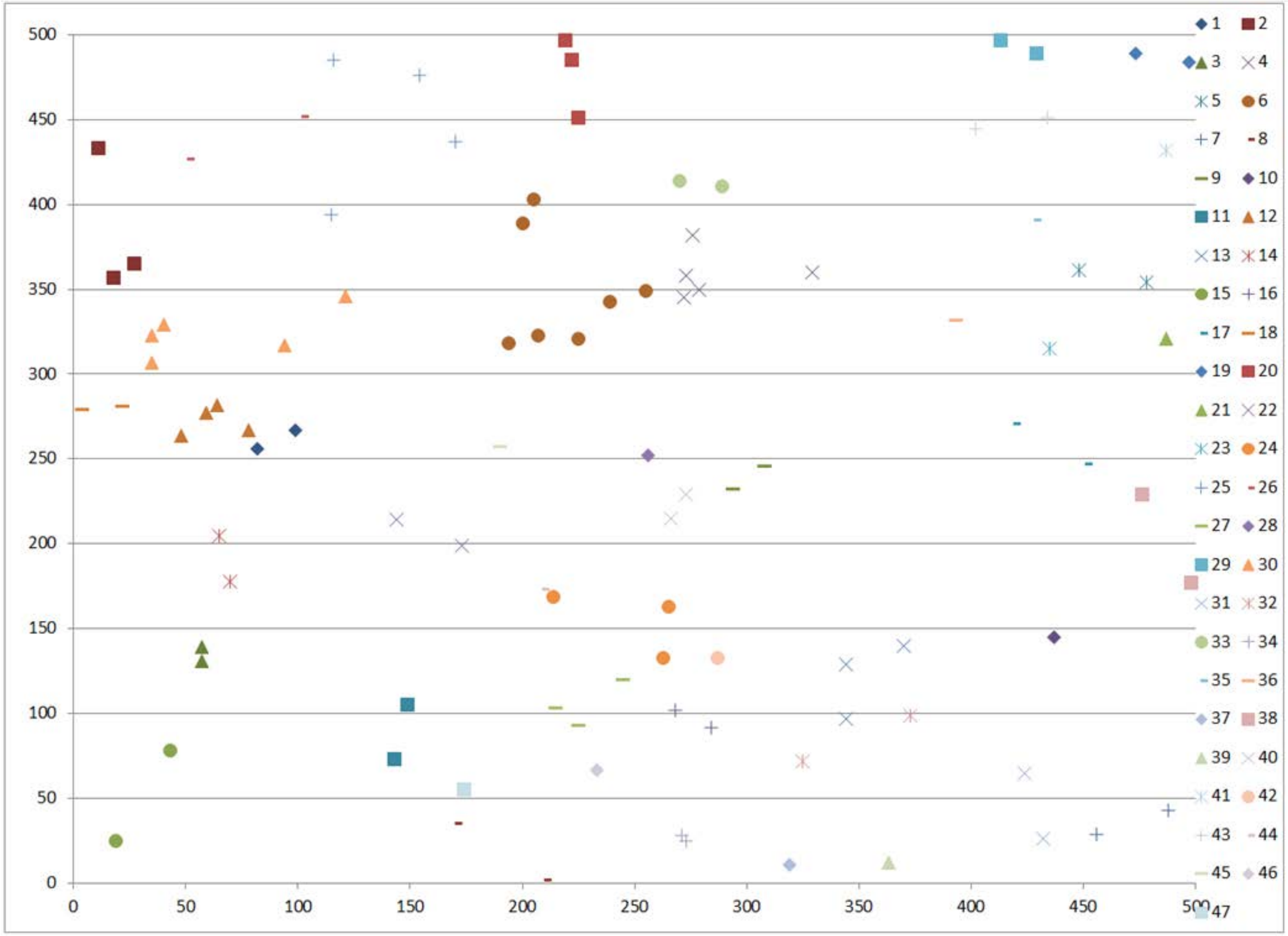
Clustering based on the cardinal points (the two most distant points) – Layer 3



Clustering based on the cardinal points (the two most distant points) – Layer 4



Clustering based on the cardinal points (the two most distant points) – Layer 5



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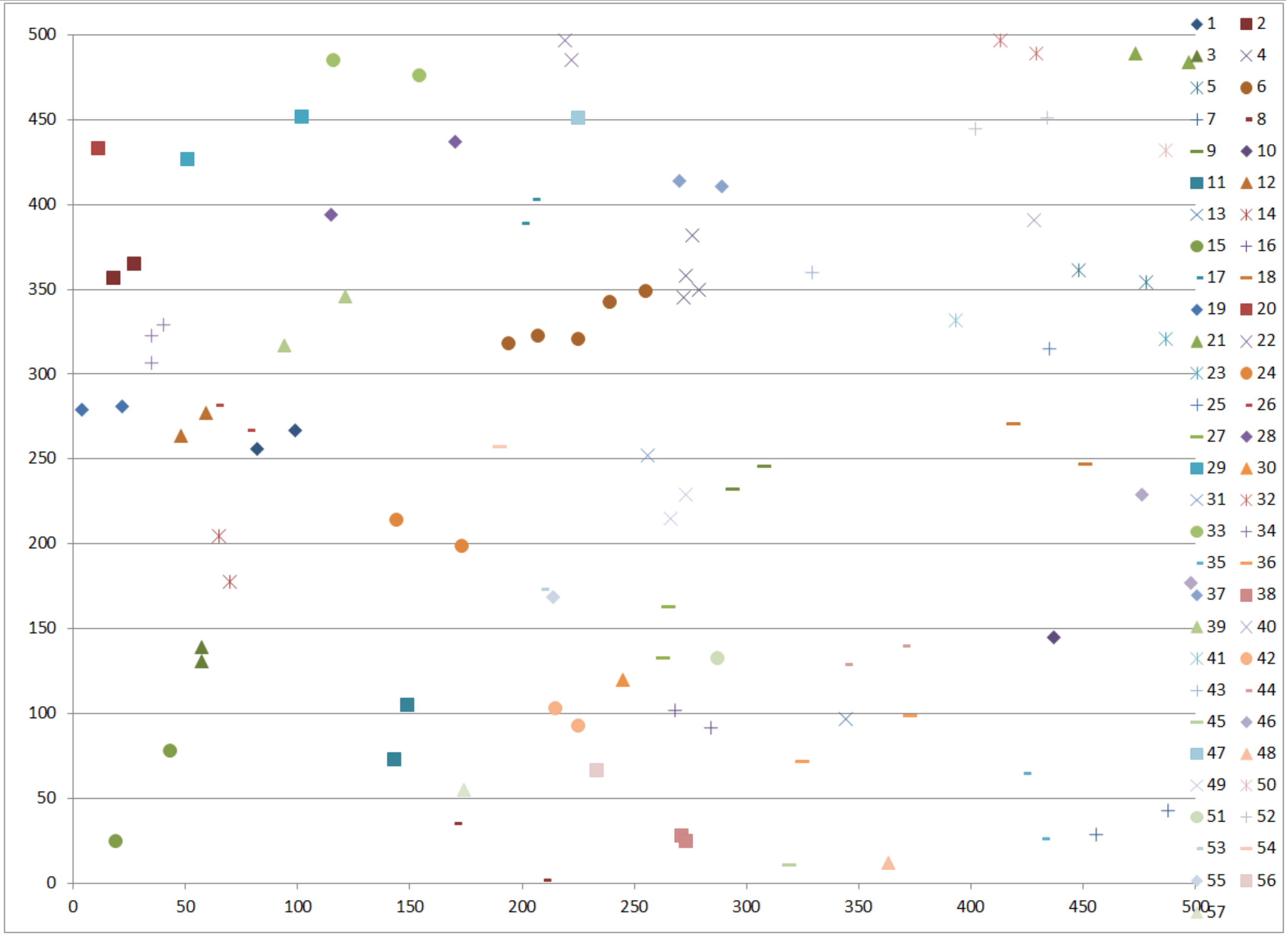
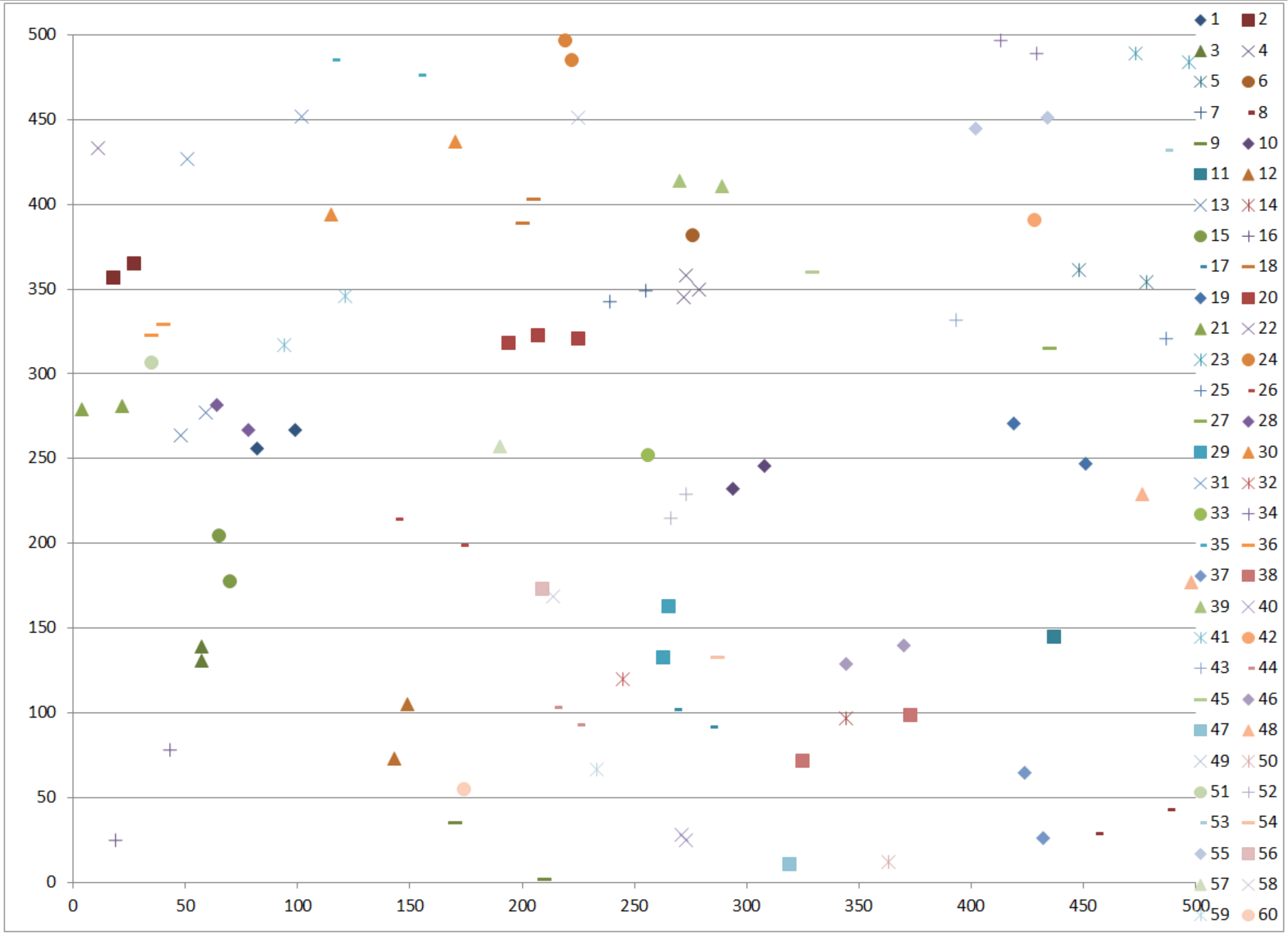
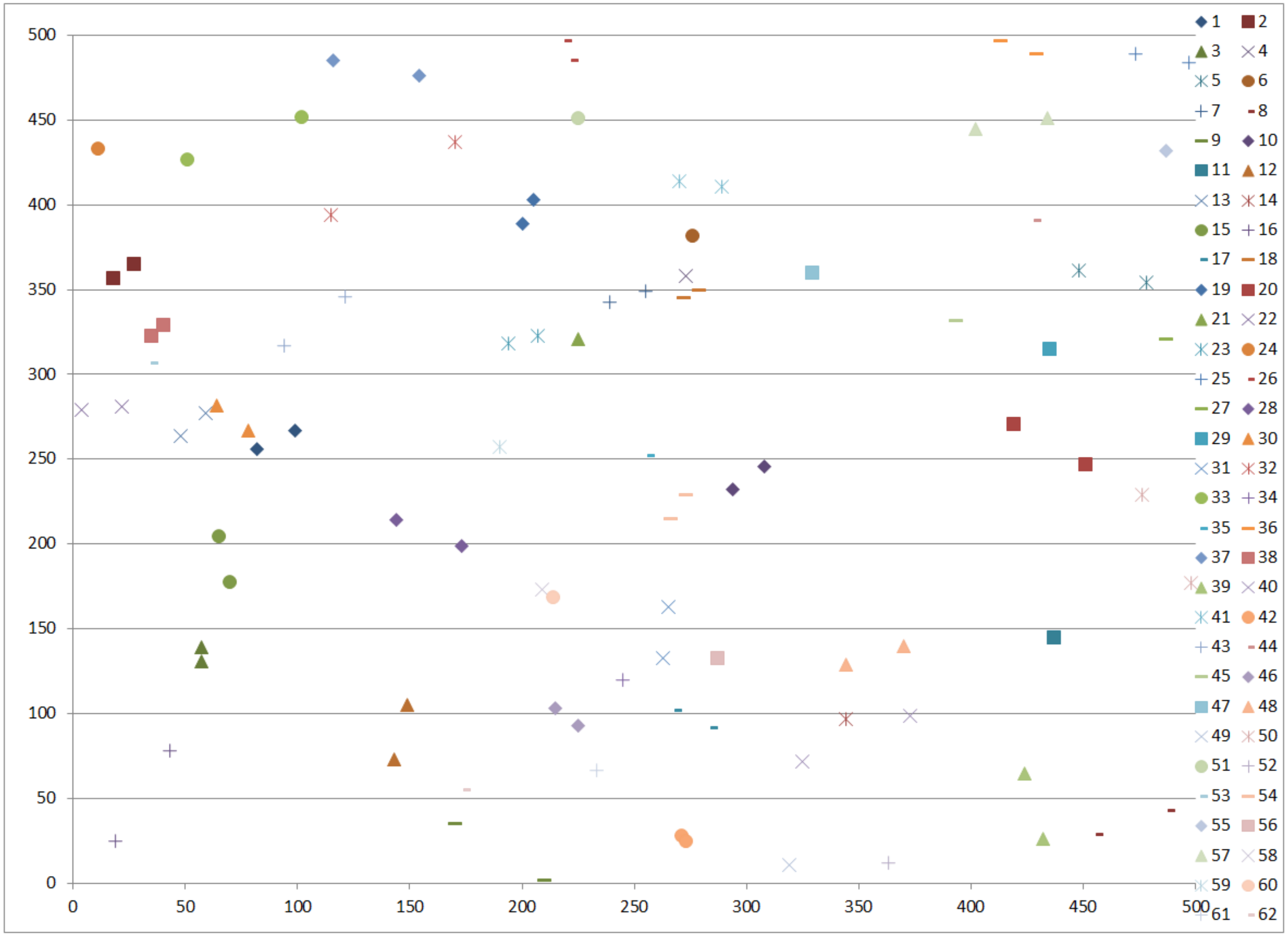
Clustering based on the cardinal points (the two most distant points) – Layer 6



Clustering based on the cardinal points (the two most distant points) – Layer 7



Clustering based on the cardinal points (the two most distant points) – Layer 8



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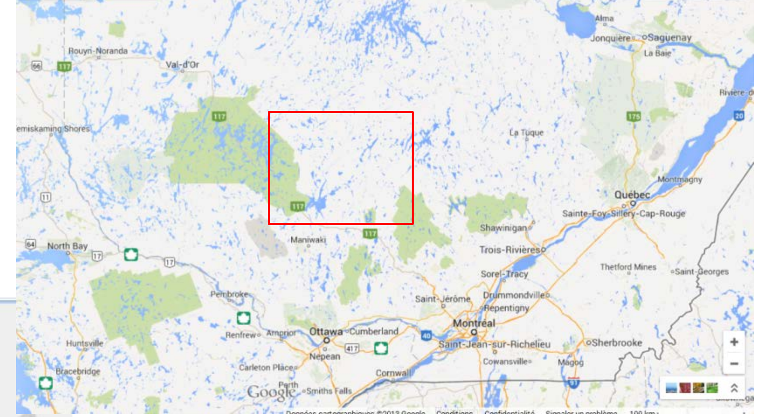
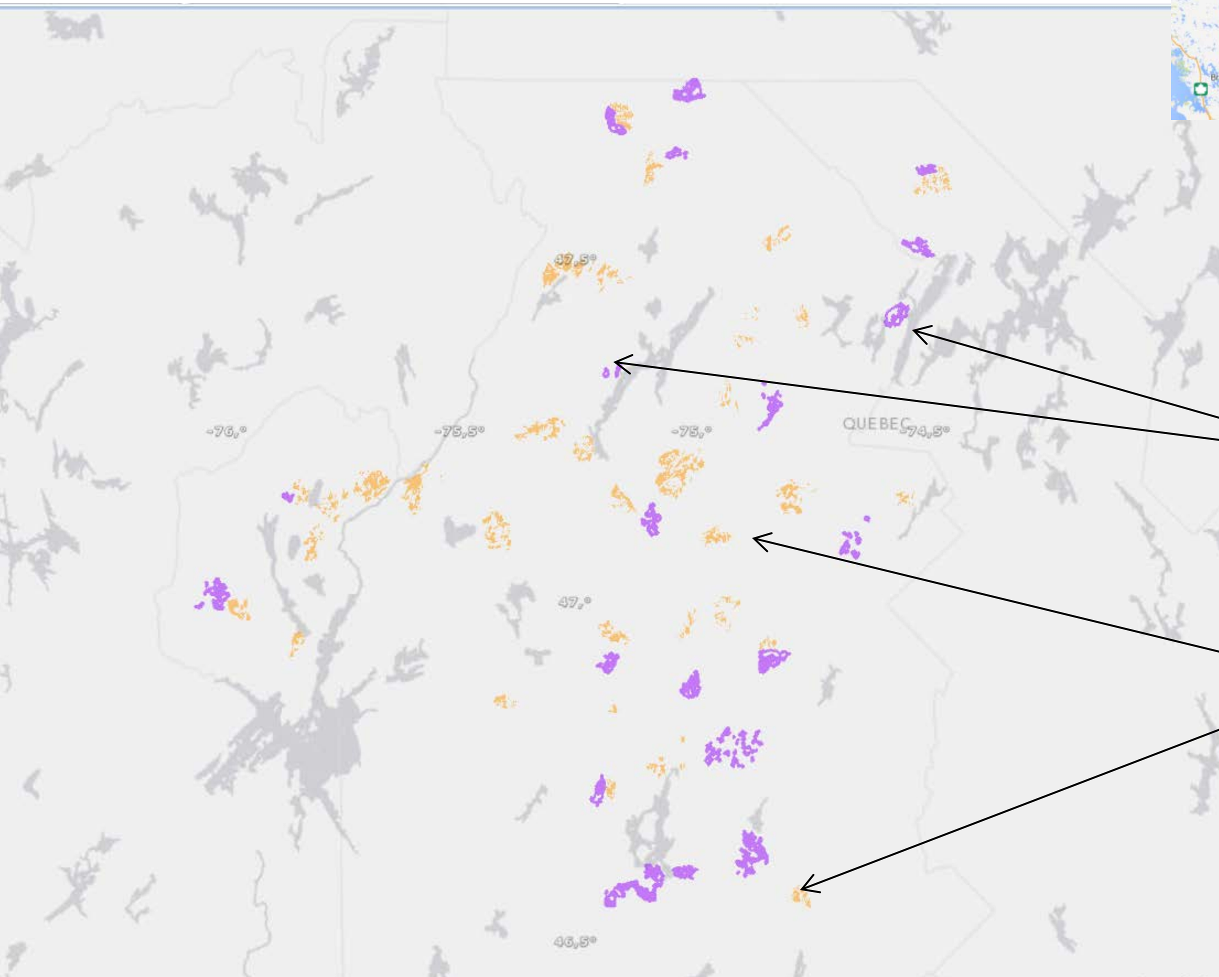
Application to real case
Spatial dispersion is not minimized





Harvest areas to allocate in year 1 (22 areas)

Harvest areas to allocate in years 2-5

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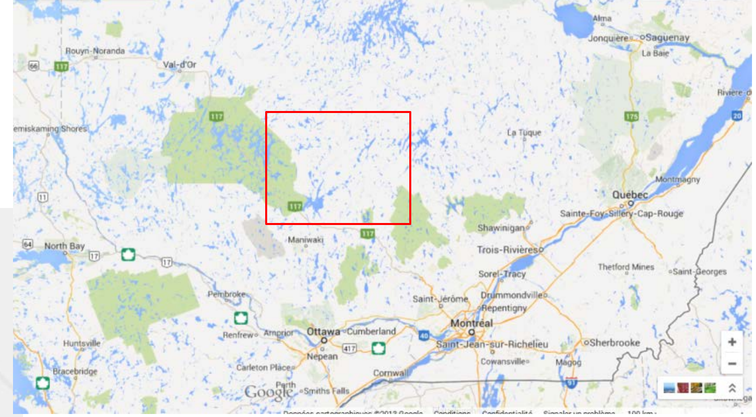
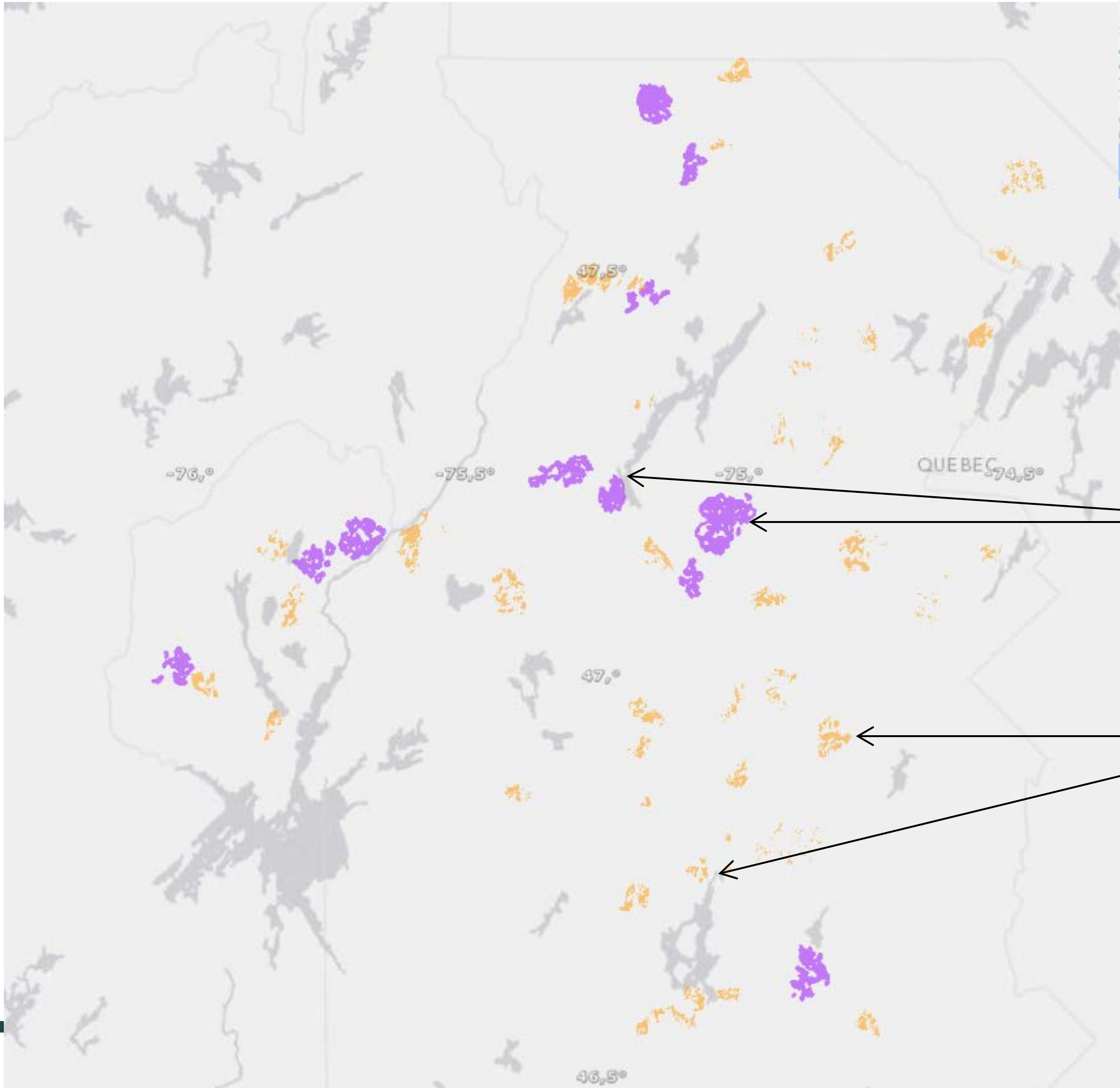
Application to real case
Minimize dispersion



- **Criteria: 2, 3, 4, 5, 6, 10, 12, 13 (13=VIP)**
- **Number of open harvest areas = 12**
- **MST = 220 km**
- **Time = 69 seconds**

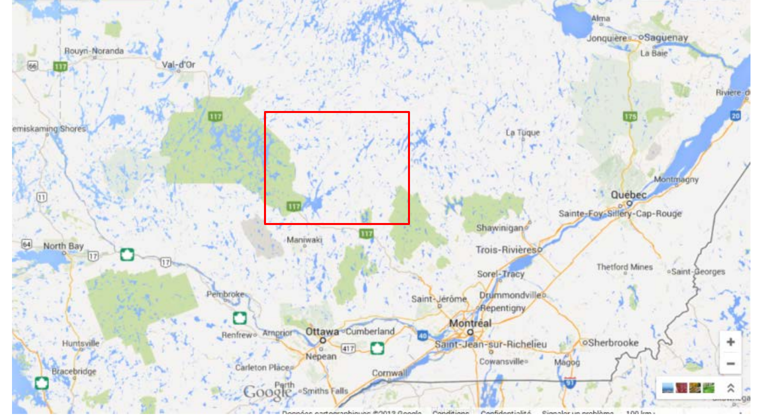
dispersion

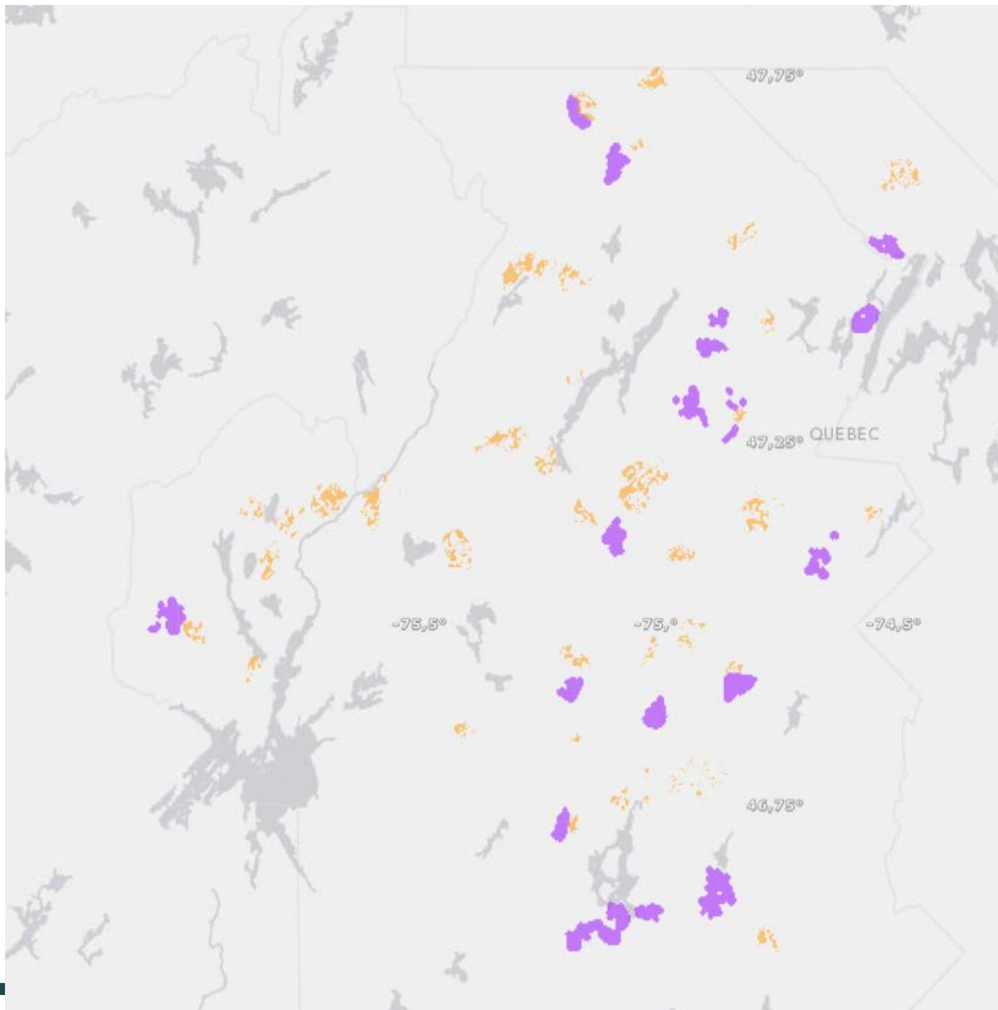


Harvest areas to allocate in year 1 (12 areas)

Harvest areas to allocate in years 2-5

Application to real case
Minimize dispersion

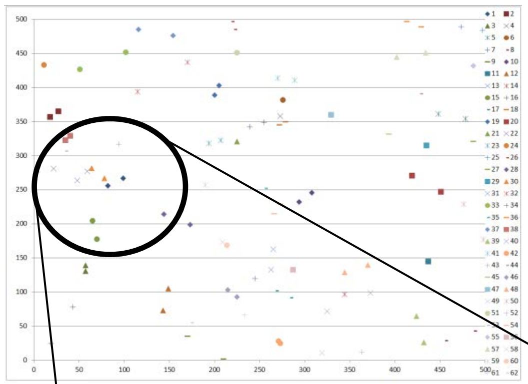




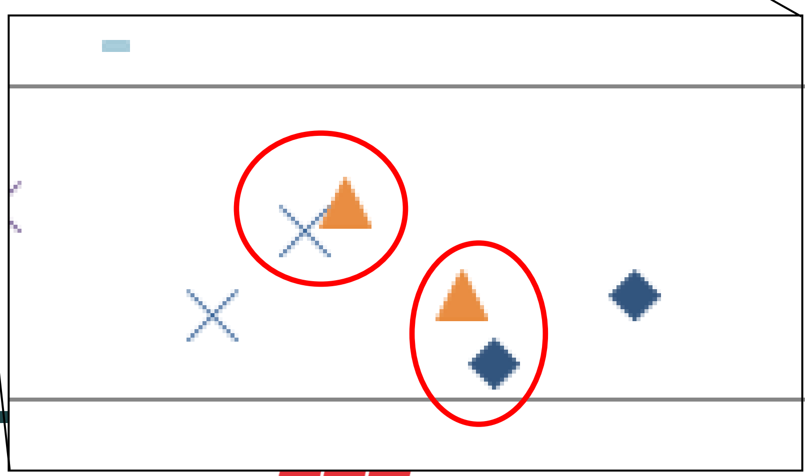
- **Criteria : 2, 3, 4, 5, 6, 10, 12, 13 (13=not important)**
- **Number of open harvest areas = 18**
- **MST = 491 km**
- **Time= 342 seconds**

dispersion

Weakness of the Clustering based on the cardinal points



Layer 8



Weakness: There may be two areas that are very close to each other but aren't in the same cluster.

Concluding remarks and future research

- The optimization tool is widely used at the MRN for planning and wood allocation;
- Key buy-in elements: easy to use (Excel based tool) and the involvement of the end user since the beginning of optimization tool;
- Challenges:
  - Address the spatial dispersion (other clustering algorithms);
  - Explore other methods to normalize the weights of the objective function;
  - Integrate the tool within the entire framework planning at the MRN;
  - Include coordination mechanisms between the mills for more synergies;
  - Include road building into the model (not all harvest areas are connected to the road network);
  - Etc.

Thank you

Merci

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