LandSpaCES*: A Spatial Planning Tool for Land Consolidation

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(LandSpaCES* = Land Spatial Consolidation Expert System)

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Contents

1. Land consolidation concepts
2. LACONISS
3. LandSpaCES
4. Design module
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6. Conclusions
Land fragmentation
Land consolidation
Land consolidation = 

Land reallocation + Infrastructure

The problem: “How to optimally rearrange the existing land tenure structure in a certain rural area so as to fulfill the aims of a particular land consolidation project?”

It is the most important and complex process of land consolidation

Land redistribution + Land partitioning
Land redistribution

- **Design problem : decision making**
  - Which landowners will take property in the new plan and which not?
  - What is the total area and value of the property which will receive each landowner in the new plan?
  - How many parcels will receive each landowner in the new plan?
  - What is the area and value of each new parcel?
  - What is the approximate location of the new parcel(s) will take each landowner?

- **Evaluation problem**
  - Once we have a set of alternative solutions which one is the best?
LACONISS

LAAnd CONsolidation
Integrated Support System for planning and decision making
The operational framework of LACONISS

LACONISS (Land Consolidation Integrated Support System for planning and decision making)

LandFragmentS (Land Fragmentation System)

LandSpaCES (Land Spatial Consolidation Expert System)

LandParcelS (Land Parcelling System)

Intelligence phase
Land Fragmentation module (GIS+MADM)

Design phase I
Land redistribution design module (GIS+ES)

Choice phase I
Land redistribution evaluation module (GIS+MADM)

Alternative land redistribution plans

Best land redistribution plan

Final land reallocation plan

Design II & Choice II
Land partitioning module (GIS+GAs+MODM)
The scope of the system

- automate the process of land redistribution
- be used as a decision support tool
- structure the process in a systematic and transparent way
- considerably diminish the time needed to carry out the process
- be capable of evaluating a set of alternative land redistributions
LandSpaCES integration tools

GIS

MCDM

Solutions

ES

Design module

Evaluation module

Best solution
Expert systems (ES)

“IF this condition (or premise or antecedent) occurs THEN some action (or results or conclusion, or consequence) will or should occur”.
4. Design module

Interface

4. Design module

Input Case Study’s GIS data
- Before Land Consolidation
  1. Input shapefiles
  2. Input Database Tables
- After Land Consolidation
  1. Input shapefiles
  2. Input Database Tables

Input Facts
1. What is the min parcel area limit (in sqm) for this land consolidation area (as set by Legislation)?
2. What is the min property area limit (in sqm) for a landowner to receive a parcel (as set by the LCCommittee)?
3. What is the min property land value limit (in C$Pounds) for a landowner to receive a parcel (as set by the LCCommittee)?
4. Define the small-medium-large holdings size (in sqm) ranges:
   - Small holding
   - Medium holding
   - Large holding

Run Land Distribution Model
1. Define the weights for the PPI calculation
   - Select the weight for the Area
   - Select the weight for the Value
2. Define the min area limit for the creation of a new parcel for those landowners may receive more than one:

Display Outputs / Decisions
- Output Database Tables
  1. Display the NewParcelsLS table
  2. Display the NewOwnershipLS table
- Output Map
  1. Display in full extent the land distribution map and label OwnerID/ParcelID
  2. Display the attribute table of the output map

System Evaluation
Calculate System Validation parameters
- Calculate
- Exit
Input data: GIS layers

4. Design module

Cadastral plan

Roads and streams
Inputs data: cadastral databases

4. Design module
Facts: decision variables

- **F1** The minimum parcel area limit (in m²) for this land consolidation area as set by legislation
- **F2** The minimum holding’s size limit (in m²) for a landowner to receive a parcel in the new plan as set by the Committee
- **F3** The minimum holding’s land value limit (in CyP) for a landowner to receive a parcel in the new plan as set by the Committee
- **F4** The lower limit (in m²) of a “small” holding size
- **F5** The upper limit (in m²) of a “small” holding size
- **F6** The lower limit (in m²) of a “medium” holding size
- **F7** The upper limit (in m²) of a “medium” holding size
- **F8** The lower limit (in m²) of a “large” holding size
- **F9** The weight for parcel area for the calculation of the PPI (Parcel Priority Index)
- **F10** The weight for parcel land value for the calculation of the PPI (Parcel Priority Index)
- **F11** The minimum residual area limit (in m²) for the creation of a new parcel for those landowners may receive more than one parcel

Note: the number in brackets represents the area in donums (1 donum=1338 m²)

- **Parcel priority index (PPI) defines:**
  - the priority of a landowner-parcel pair in terms of allocating a parcel in a certain location or not
  - the location preferences for the landowner’s new parcels
Outputs: GIS layers

4. Design module
Outputs: database tables

4. Design module
System Vs Human experts

System performance based on nine validation criteria

- C1: 98.04%
- C2: 99.63%
- C3: 89.42%
- C4: 86.56%
- C5: 99.63%
- C6: 89.42%
- C7: 78.65%
- C8: 62.55%
- C9: 62.55%

4. Design module
System Vs Human Experts

- A human expert needs about 30 working days to prepare the case study’s land redistribution problem
  - Study area: 200 hectares
  - Number of parcels/shares: 480
  - Number of landowners: 253
- LandSpaCES needs only 6 minutes
Evaluation module interface

5. Evaluation module
Multi-attribute decision methods (MADM)

(Sharifi et al., 2004)
Set of alternative options

4. Design module
Set of evaluation criteria

- size of new parcels (C1)
- parcel concentration coefficient-PCC (C2) New!
- number of landowners (C3)
- landowner satisfaction rate-LSR (C4) New!
- ownerships ‘completed’ (C5)

### PCC calculation

If \( \text{DoP}_b = \text{DoP}_a \) then \( \text{PCC} = 0 \)

\[
\text{DoP} = \sqrt{\frac{\sum_{i=1}^{n} (x_i - x_{\text{hmc}})^2 + \sum_{i=1}^{n} (y_i - y_{\text{hmc}})^2}{n}}
\]

If \( \text{DoP}_b > \text{DoP}_a \)

\[
\text{PCC} = \frac{\text{DoP}_b - \text{DoP}_a}{\text{DoP}_b} \cdot \frac{n'}{n'}
\]

If \( \text{DoP}_b < \text{DoP}_a \)

\[
\text{PCC} = -\left(1 - \frac{\text{DoP}_a - \text{DoP}_b}{\text{DoP}_a}\right) \cdot \frac{n}{n'}
\]

### LSR calculation

\[
m_i = n - RO_i + 1
\]

\[
\text{Maxm}_i = n - n' + 1
\]

\[
P = \frac{100}{n - n' + 1}
\]

\[
\text{PSR}_i = \frac{100(n - RO_i + 1)}{n - n' + 1}
\]

\[
\text{LSR} = \frac{\sum_{i=1}^{n} \text{PSR}_i}{n'}
\]
Impact table

5. Evaluation module
Standardisation process: Value functions

5. Evaluation module

a. C1: Mean percentage change of size of parcels

b. C2: Mean PCC

c. C3: Percentage change of number of landowners

d. C4: Percentage of ownerships completed

e. C5: Mean LSR
### Decision table

#### 5. Evaluation module

<table>
<thead>
<tr>
<th>OID</th>
<th>Criteria</th>
<th>Weights</th>
<th>Alt-1</th>
<th>Alt-2</th>
<th>Alt-3</th>
<th>Alt-4</th>
<th>Alt-5</th>
<th>Alt-6</th>
<th>Alt-7</th>
<th>Alt-8</th>
<th>Alt-9</th>
<th>Alt-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Criterion-1</td>
<td>0.2</td>
<td>0.562558</td>
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<td>0.582522</td>
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<td>0.678889</td>
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<td>0.633477</td>
<td>0.566872</td>
<td>0.579117</td>
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<td>0.745327</td>
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<tr>
<td>2</td>
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<tr>
<td>3</td>
<td>Criterion-4</td>
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<td>4</td>
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<td>0.915405</td>
<td>0.897421</td>
<td>0.889006</td>
<td>0.811491</td>
</tr>
</tbody>
</table>
### Assign weights to criteria: Qualitative rating method

<table>
<thead>
<tr>
<th>Rank order</th>
<th>Scale of importance</th>
<th>Score</th>
<th>Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Extremely high</td>
<td>100</td>
<td>Upper</td>
</tr>
<tr>
<td>2</td>
<td>Very high</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>High</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Intermediate</td>
<td>40</td>
<td>Middle</td>
</tr>
<tr>
<td>5</td>
<td>Moderate</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Low</td>
<td>20</td>
<td>Lower</td>
</tr>
<tr>
<td>7</td>
<td>Very low</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

\[
\sum_{i=1}^{N} w_i = 1
\]

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Scale of importance</th>
<th>Score</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Extremely high</td>
<td>100</td>
<td>0.294</td>
</tr>
<tr>
<td>C2</td>
<td>Very high</td>
<td>80</td>
<td>0.235</td>
</tr>
<tr>
<td>C3</td>
<td>High</td>
<td>60</td>
<td>0.176</td>
</tr>
<tr>
<td>C4</td>
<td>Intermediate</td>
<td>40</td>
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<tr>
<td>C5</td>
<td>Moderate</td>
<td>30</td>
<td>0.090</td>
</tr>
<tr>
<td>C6</td>
<td>Low</td>
<td>20</td>
<td>0.059</td>
</tr>
<tr>
<td>C7</td>
<td>Very low</td>
<td>10</td>
<td>0.029</td>
</tr>
</tbody>
</table>

\[
\text{Score Classes}\]
Value function approach

\[ V_j = \sum_{i=1}^{N} w_i v_{ij} \]

- \( V_j \) is the overall value i.e. performance score of the \( j^{th} \) alternative (\( j = 1 \) to \( M \))

- \( v_{ij} \) is the standardised value of the score \( \alpha_{ij} \) in the \( j^{th} \) alternative with respect to the \( i^{th} \) criterion (\( i = 1 \) to \( N \)) measured by utilising an appropriate value function

- \( w_i \) is the weight for criterion \( i \)
## Ranking alternative solutions

### Alternatives

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Ranking order</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>1</td>
</tr>
<tr>
<td>A2</td>
<td>2</td>
</tr>
<tr>
<td>A3</td>
<td>3</td>
</tr>
<tr>
<td>A4</td>
<td>4</td>
</tr>
<tr>
<td>A5</td>
<td>5</td>
</tr>
<tr>
<td>A6</td>
<td>6</td>
</tr>
<tr>
<td>A7</td>
<td>7</td>
</tr>
<tr>
<td>A8</td>
<td>8</td>
</tr>
<tr>
<td>A9</td>
<td>9</td>
</tr>
<tr>
<td>A10</td>
<td>10</td>
</tr>
</tbody>
</table>

### 5. Evaluation module
Sensitivity analysis

- SA of weights
  \[ D'_k = \min_{1 \leq i < j \leq M} |\delta'_{k,i,j}| \quad \text{sens}(C_k) = \frac{1}{D'_k} \]

- SA of performance scores
  \[ R = \frac{(P_i - P_k)}{W_k} \times \frac{100}{a_{ij}} \]

5. Evaluation module
## Case study: 10 alternatives

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Experts solution (Irrigated project)</td>
</tr>
<tr>
<td>A2</td>
<td>Medium area and land value minimum limits</td>
</tr>
<tr>
<td>A3</td>
<td>High area and land value minimum limits</td>
</tr>
<tr>
<td>A4</td>
<td>Unequal PPI weights for area and land value</td>
</tr>
<tr>
<td>A5</td>
<td>Low small-medium-large holdings sizes</td>
</tr>
<tr>
<td>A6</td>
<td>High minimum area of new parcels with high area and land value minimum limits</td>
</tr>
<tr>
<td>A7</td>
<td>Low minimum area of new parcels with high area and land value minimum limits</td>
</tr>
<tr>
<td>A8</td>
<td>Low area and land value minimum limits with low small-medium-large holdings sizes</td>
</tr>
<tr>
<td>A9</td>
<td>Inverse unequal PPI weights for area and land value (comparing to alt-4)</td>
</tr>
<tr>
<td>A10</td>
<td>Arid project</td>
</tr>
</tbody>
</table>
Ranking alternative solutions

Alt-1 = Experts solution
Conclusions

- LandSpaCES is a powerful planning tool for land consolidation
- High system performance of the Design module
- Integration of GIS with ES is still valuable for solving complex spatial planning problems
- Evaluation module provides a comprehensive and flexible evaluation of alternative land redistribution plans
- Value functions is an excellent manner to incorporate experts knowledge in the evaluation process
- Potential applicability to other countries
Many thanks for your attention and patience!