

# A mathematical modelling process for geomatics platform & management in health-care policy:

Geography of spatial utilization of the  
health services: A Newtonian modelling  
of hospital catchment areas

## Problem

How does recourse to health care services depend on geography and distance to a hospital?

Can we identify one or more factors governing the spatial utilization of a hospital?

## Hypothesis

There is a link between recourse to health-care and distance in km or in time (road network)

→ Law of « the principle of least effort » is expected for:

**The peripheral hospitals (non-university hospitals).**

If the hypothesis is true → we can use a **gravity model**, referring to Newton's law

## Ours aims are

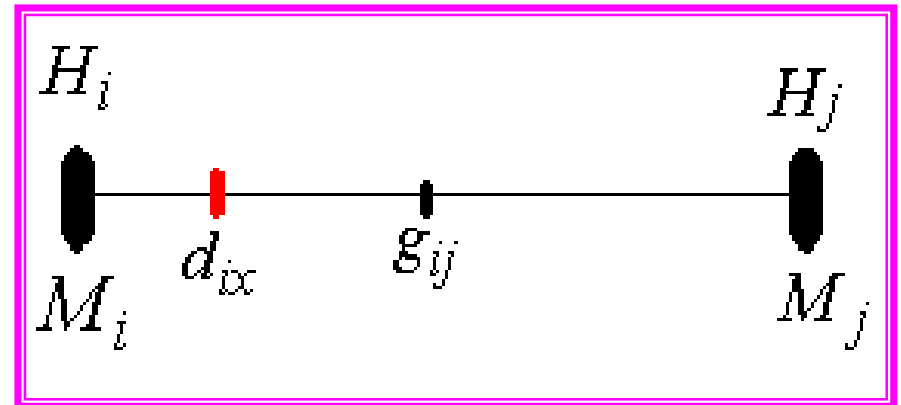
To validate our gravity model

\*Model → goal → simulate hospital attraction by specialty and hospital places

To develop a potential health-care planning tool adapted to needs and real-life health districts.

# Reilly's formula

$$d_{ix} = \frac{d_{ij}}{\left(1 + \sqrt{\frac{M_j}{M_i}}\right)}$$



where

- $d_{ix}$  = “balance point” also called “equal attraction point” between two hospitals.

# *Enhanced Reilly model*

$$d(i, b_{o(i,j)}) = \frac{d(i,j)}{1 + \sqrt{\frac{M_j * P_{oj}}{M_i * P_{oi}}}}$$

$$d(i, b_{e(i,j)}) = \frac{d(i,j)}{1 + \sqrt{\frac{M_j * P_{ej}}{M_i * P_{ei}}}}$$

**1- Observed balance point : based on geographical data (in blue)**

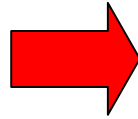
**2- Estimated balance point : based on mathematical calculation (in yellow)**

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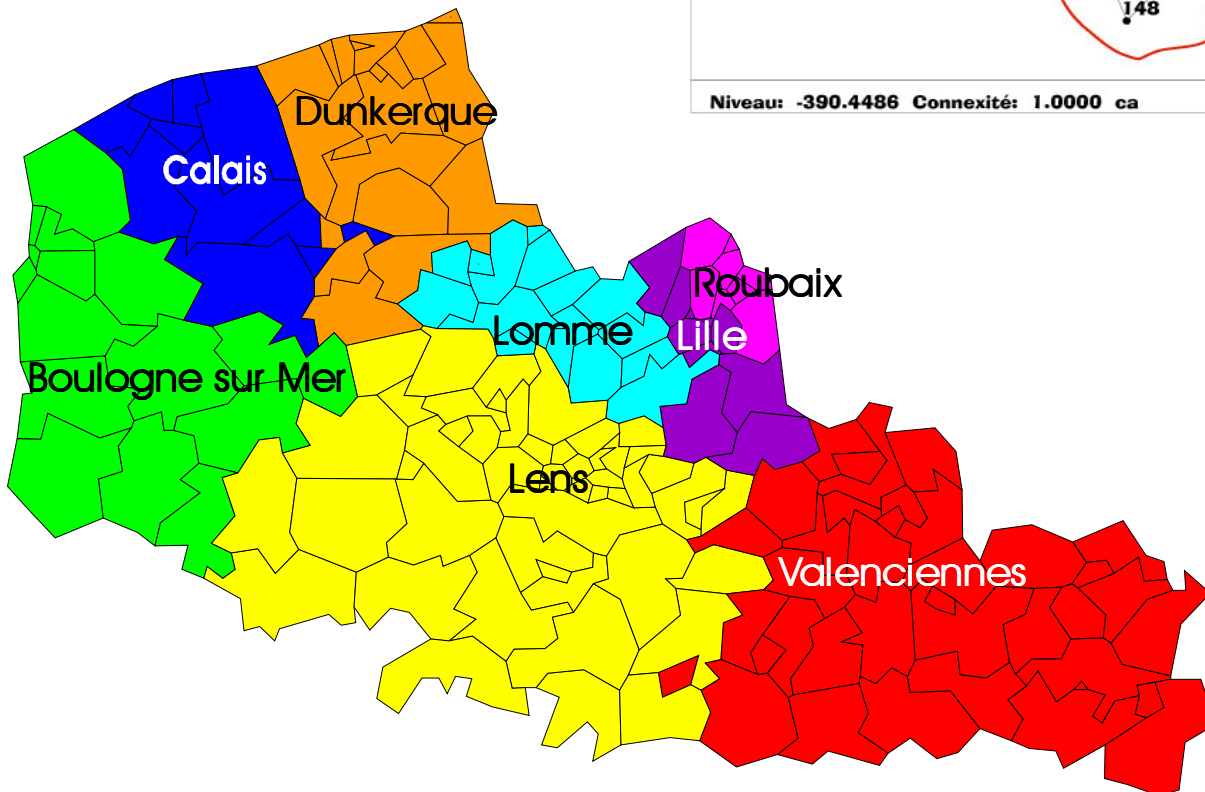
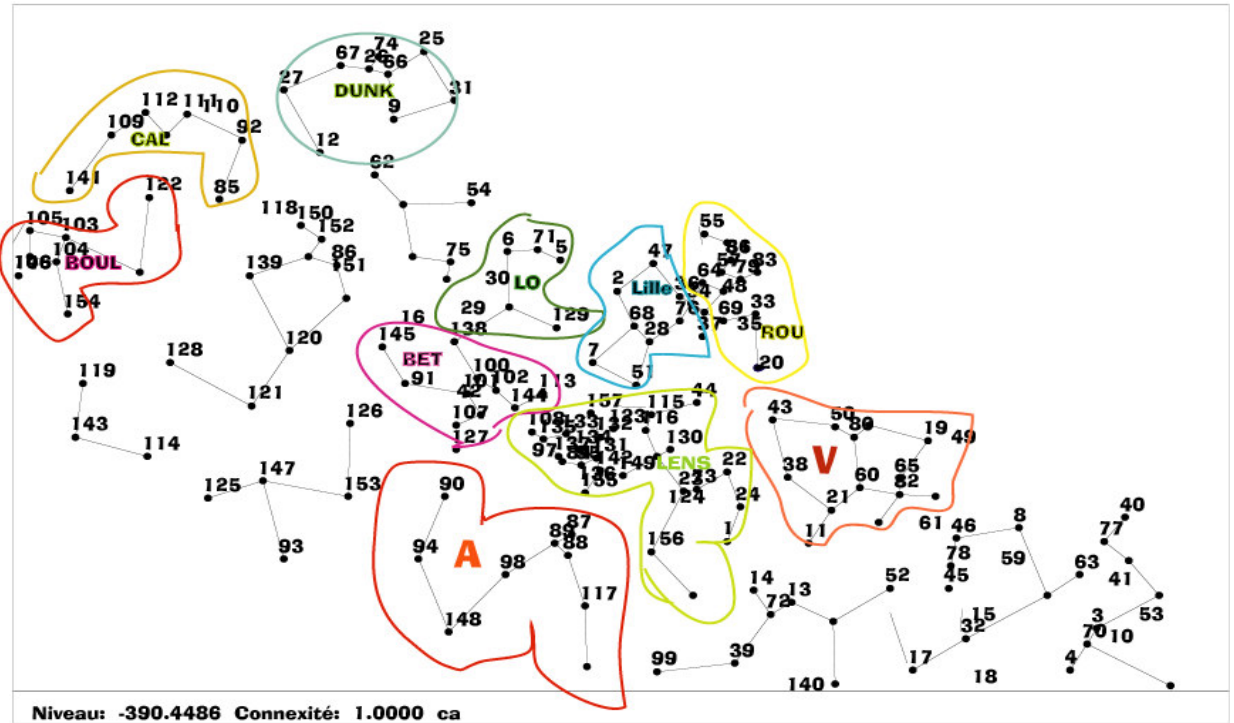
## *What is novel*

- Model by specialty .. Base map (onco-heamatology, total hip prosthesis surgery etc.)
- Ability to simulate opening, closing of units for management.
- Drawing Models are computed and automated.

**Hierarchical clustering,  
agglomerated and  
sequential**



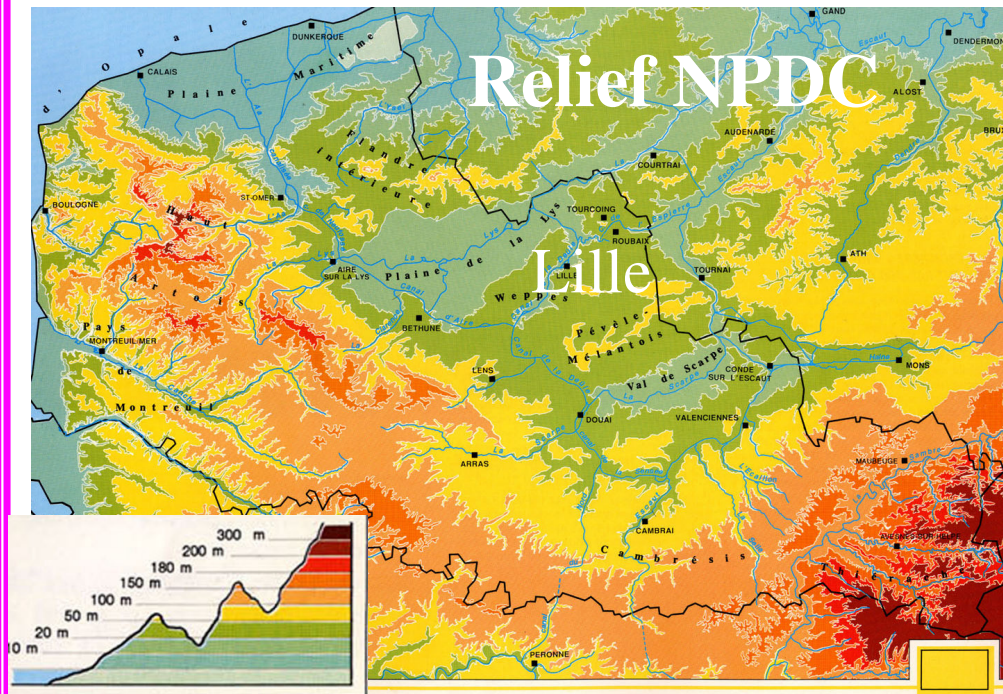
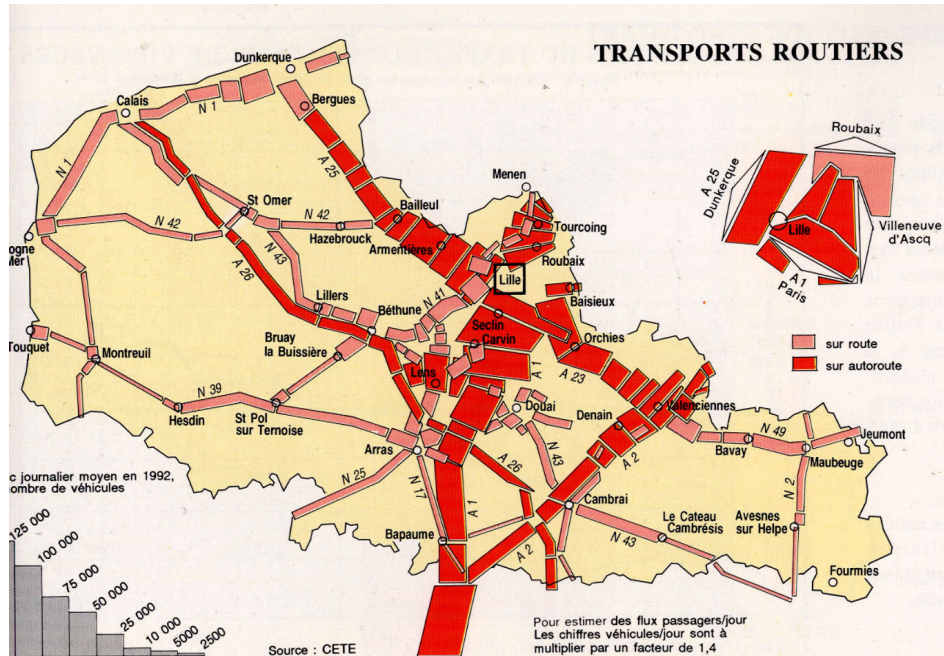
**Example of grouping by  
Relative Neighbourhood  
Graph  
(NRG)**



**Non-hierarchical  
clustering:  
Example of grouping  
by **K-Means****

# Geography of the Nord-Pas-de-Calais region

- Capital city : Lille ‘Metropolis’
- Surface area → 12414 Km<sup>2</sup>
- Inhabitants. → 4 million
- Density of population → 323 inhab./km<sup>2</sup>
- Relief: plain 0-50 m (north)  
plateau 120-200m (south)
- Agriculture → (71 %)
- Forest → (8%)
- Artificial background → (13 %)
- Urban zone → 3rd rank after the PACA and Paris regions (82.6%)



# Modeling process in 4 parts

## 1-Onco-heamatology (adult)

→ complex, costly pathology groups: less frequent

**6 hospital places** (Public sector) for 7 existing units

**Mapping** : ward districts ‘157’

## 2- Trauma orthopaedics (total Hip Prosthesis)

→ complex, costly pathology groups : more frequent

**18 hospital places** (public sector) for 19 existing units

**Mapping** : post office PMSI districts ‘ 387’

**PMSI Databases = american DRGs  
1996 and 1999**

**Automation of models – MATLAB**

**Phase 1** : descriptive regional geographic study from the observed catchment areas.

**Phase 2** : implementation of geographical and mathematical models,

**Phase 3** : compararisons between:  
1° observed attraction and observed refined model.  
2° both observed and estimated refined models.

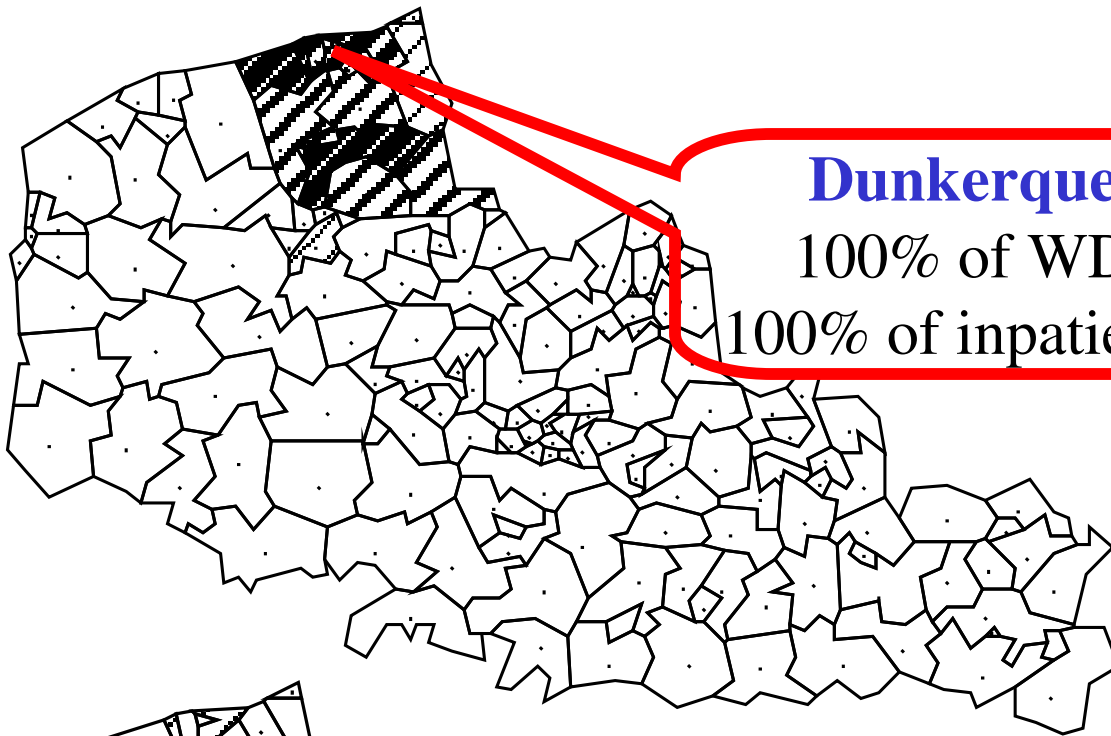
**Phase 4** : spatial prediction of the attraction → simulation model by specialty for reorganization, opening or closing of units.

# **Onco-Heamatology results**

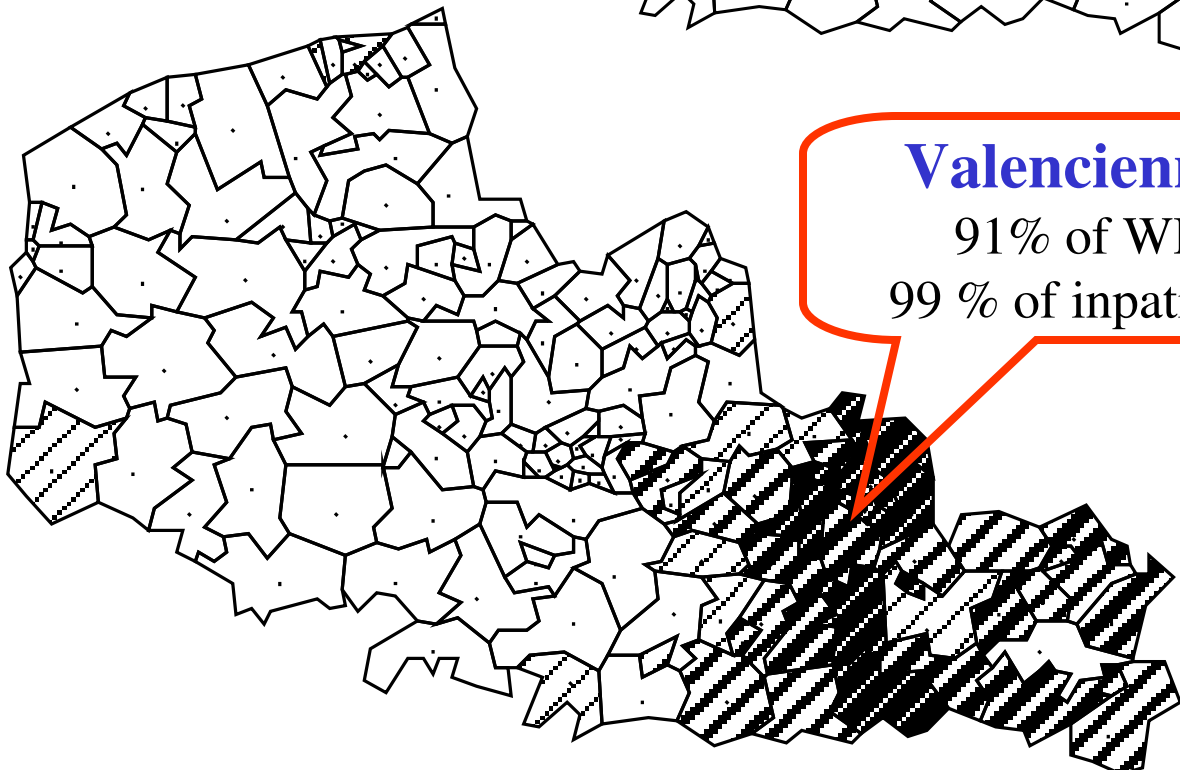
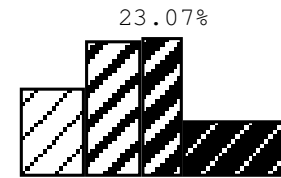
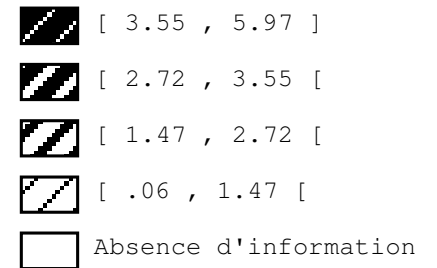
## **PHASE 1 : OBSERVATION**

**Mapping : observed attraction  
areas**

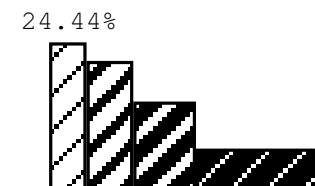
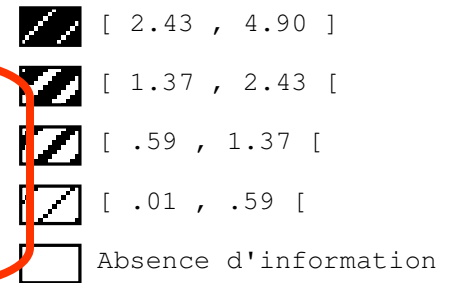




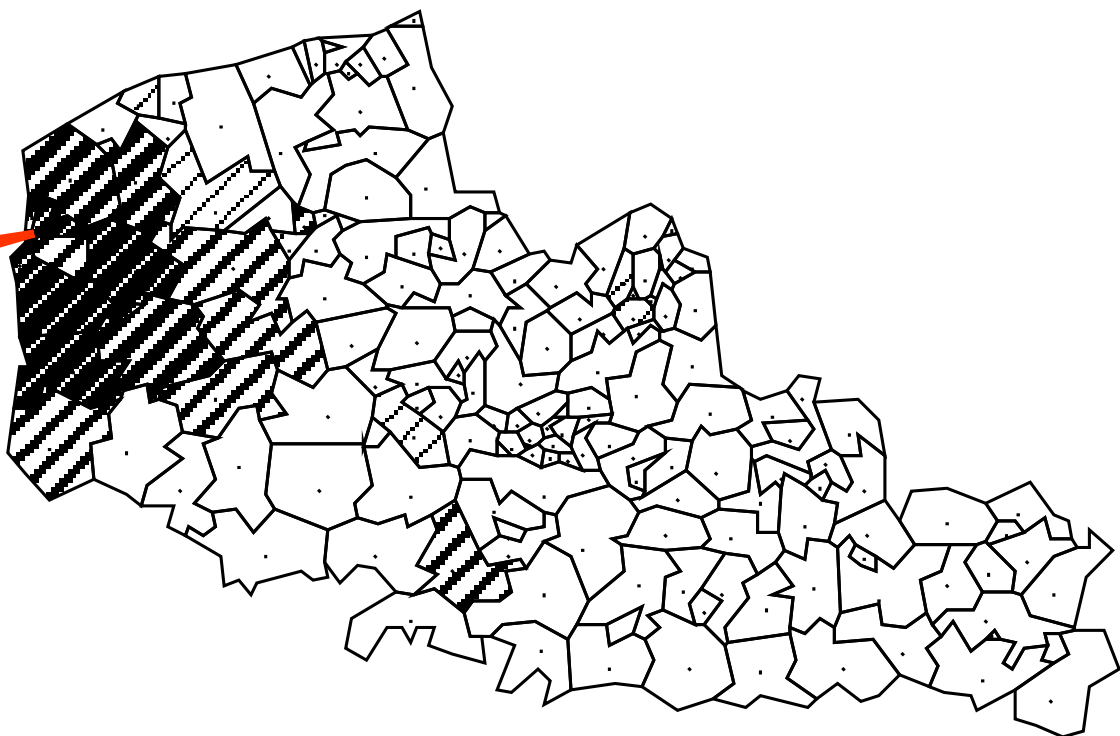
IF Dunkerque



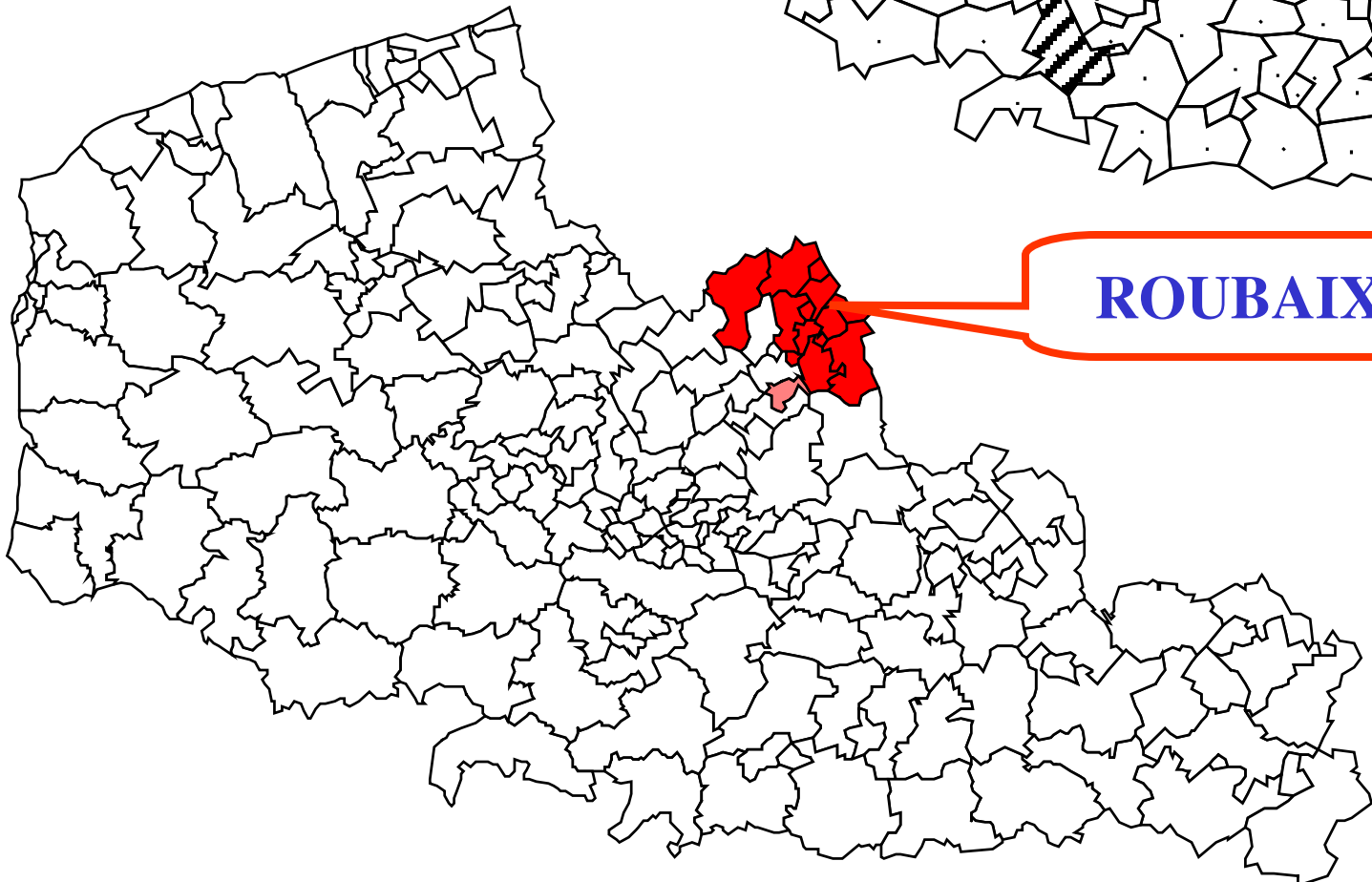
IF Valenciennes

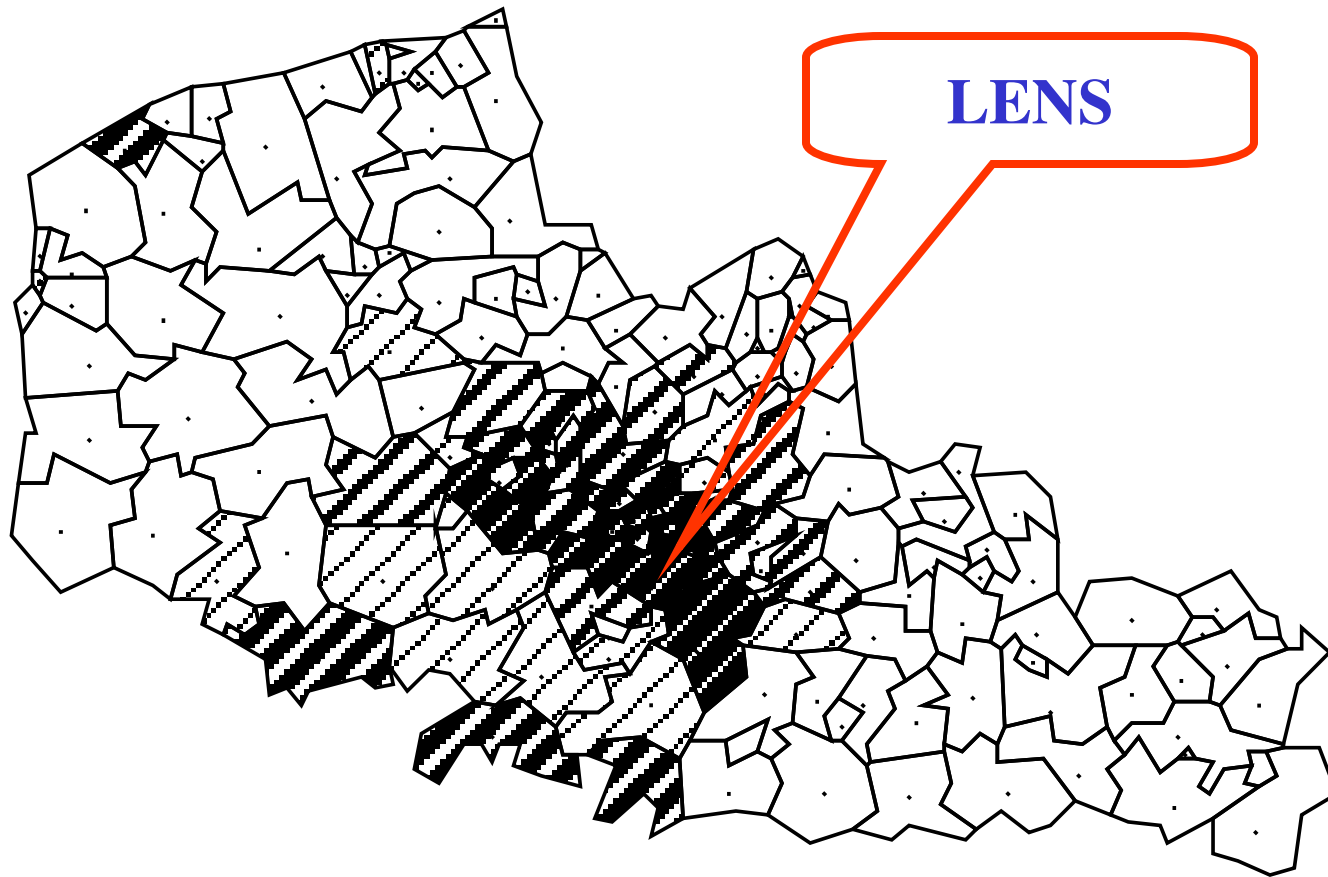


**Boulogne/Mer**




**ROUBAIX**





IF LENS

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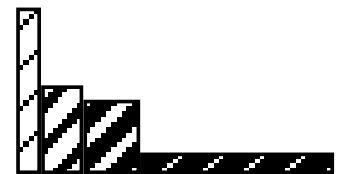
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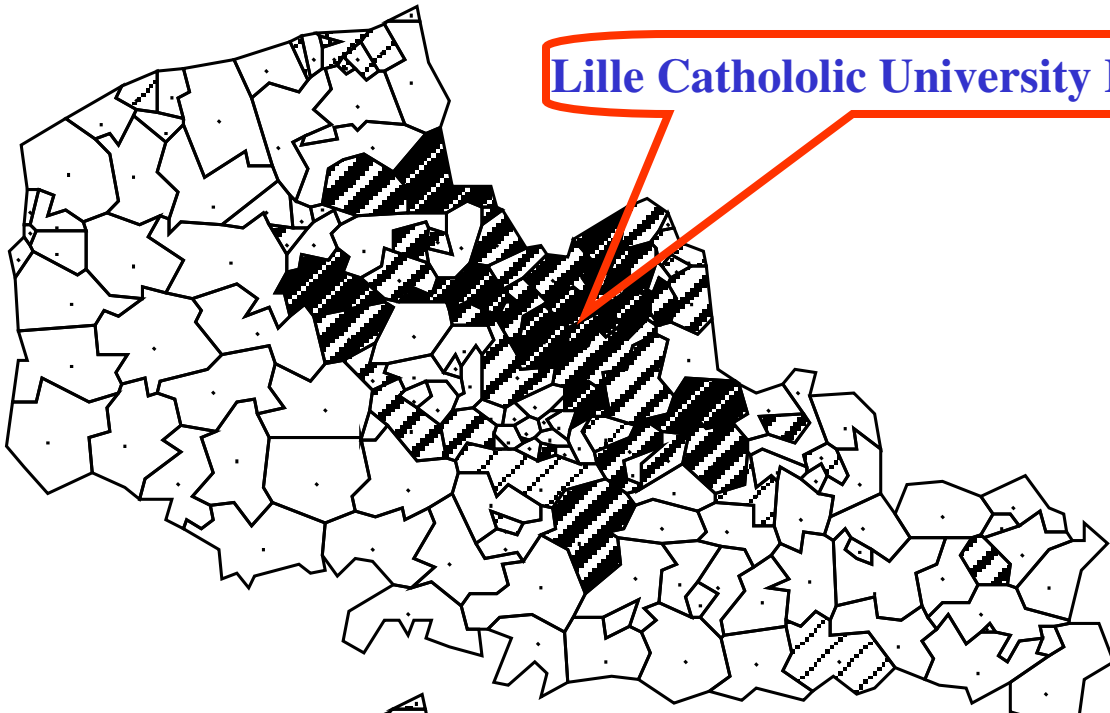
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25.92%






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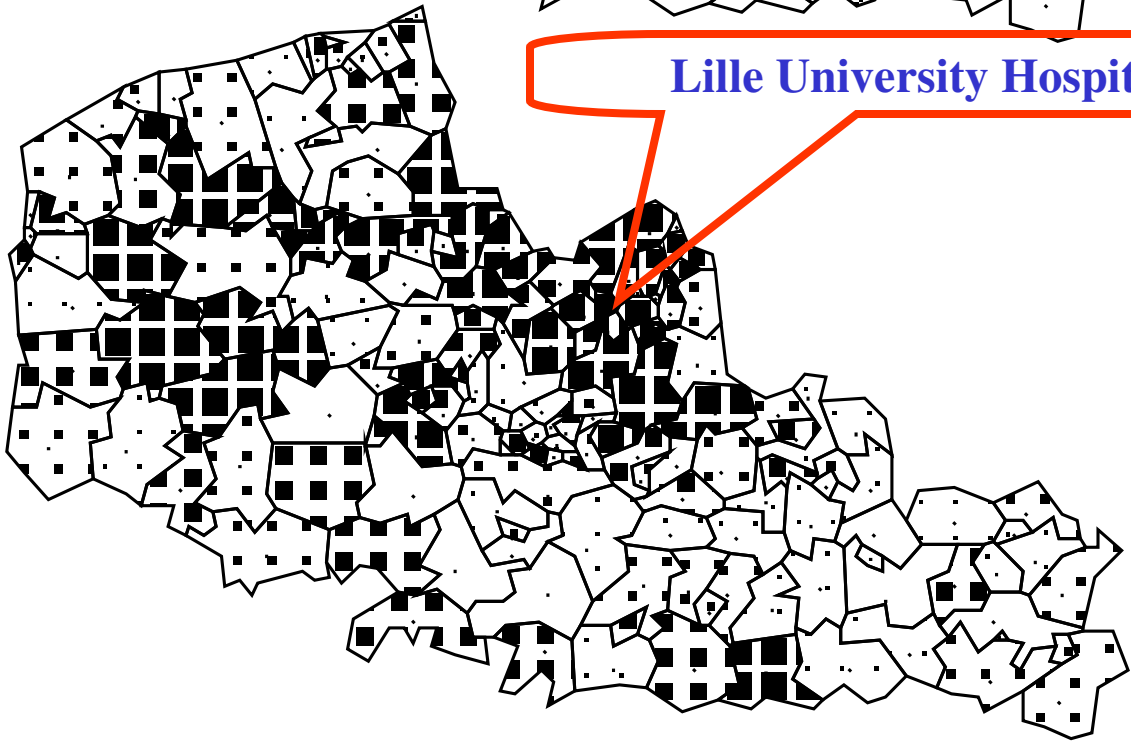
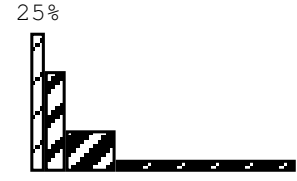
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



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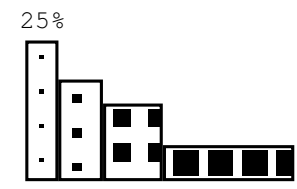
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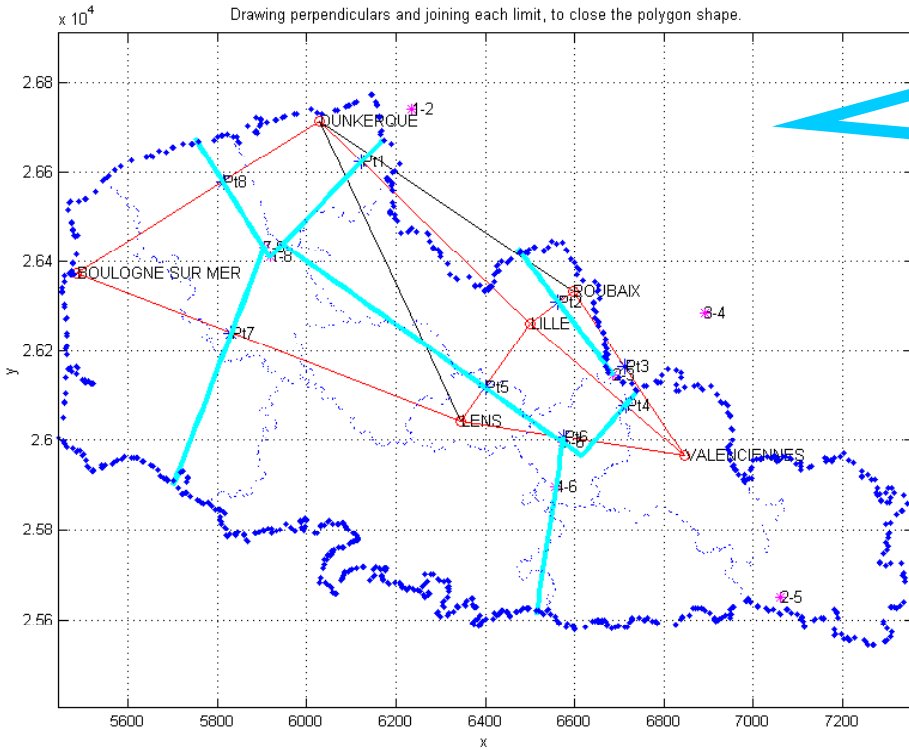
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**PHASE 2 :**

**OBSERVED AND ESTIMATED  
MODEL IMPLEMENTATION**

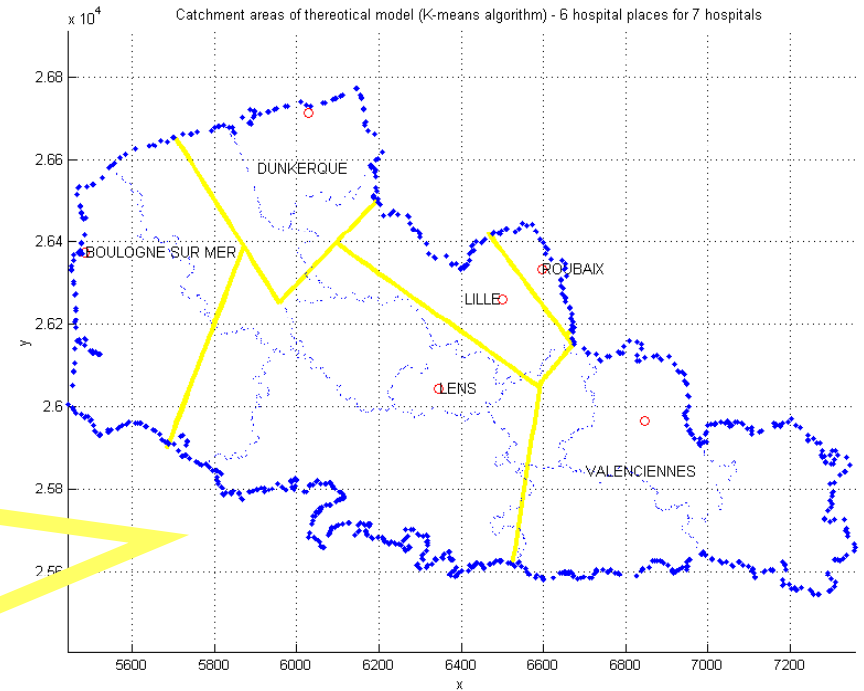


## Observed model

$$d(i, b_{o(i,j)}) = \frac{d(i,j)}{1 + \sqrt{\frac{M_j * P_{oj}}{M_i * P_{oi}}}}$$

## Estimated model

$$d(i, b_{e(i,j)}) = \frac{d(i,j)}{1 + \sqrt{\frac{M_j * P_{ej}}{M_i * P_{ei}}}}$$

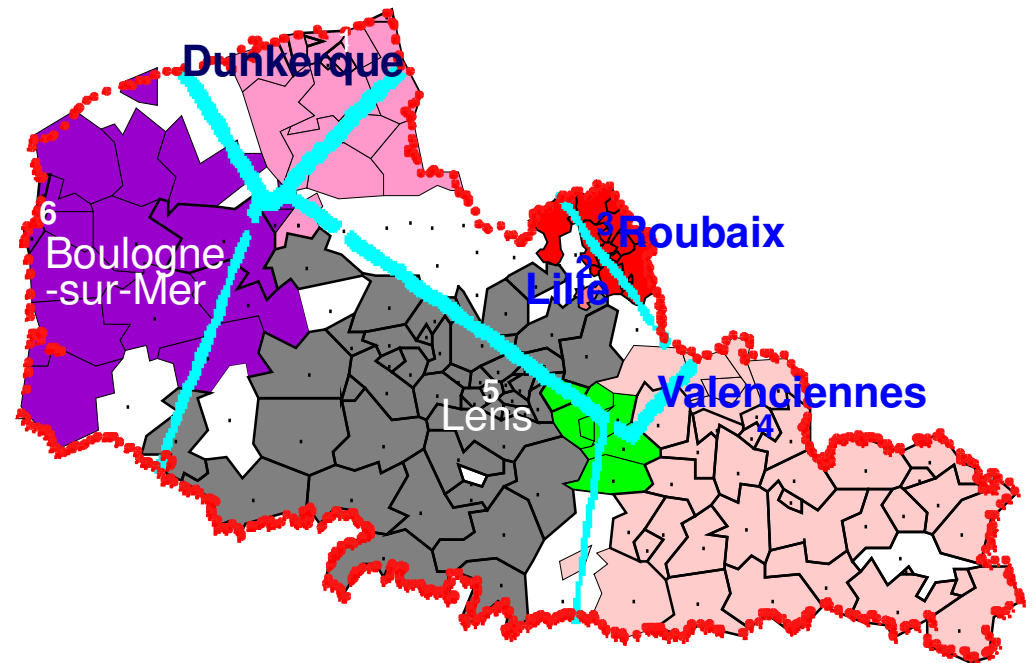


# **PHASE 3 : COMPARISONS**

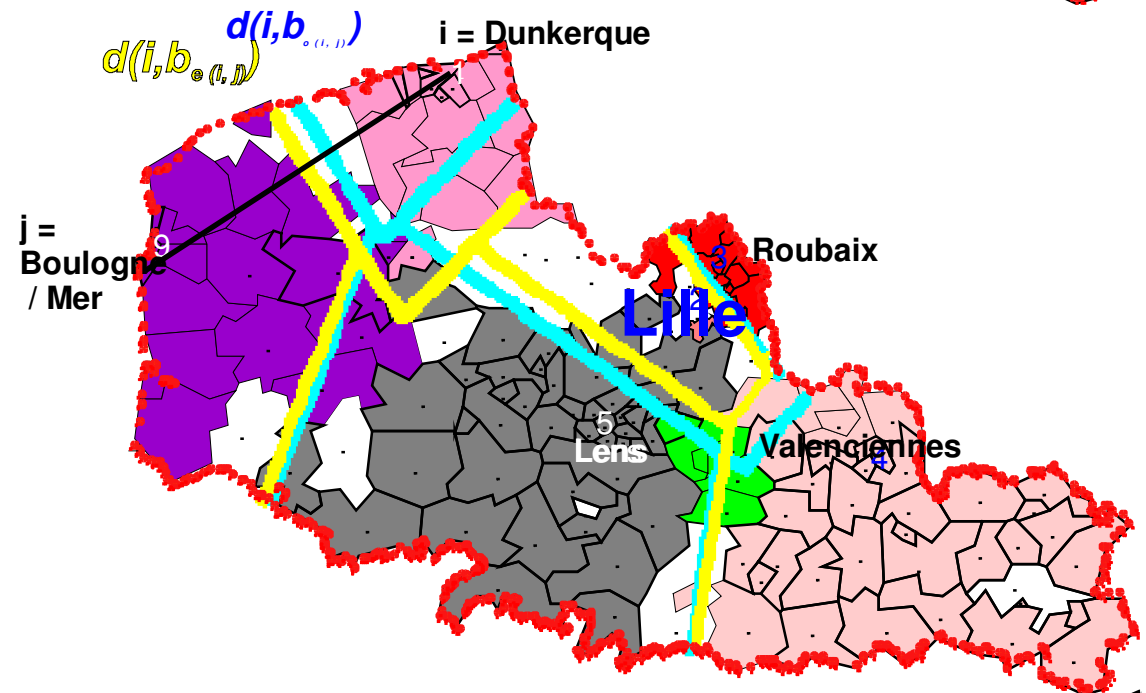
## **between**

- 1) observed map attraction and observed refined model.
- 2) both observed and estimated refined models.

Comparison between observed attraction area of Valenciennes and observed model **blue-plotting**.



This **blue-plotting** from observed balance point  $\mathbf{b}_o(i,j)$  gives us a base for calculation of attraction coefficients with the Estimated model **yellow-plotting**  $\mathbf{b}_e(i,j)$ .

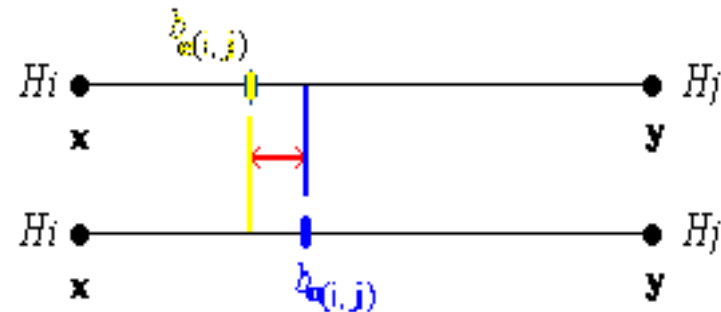




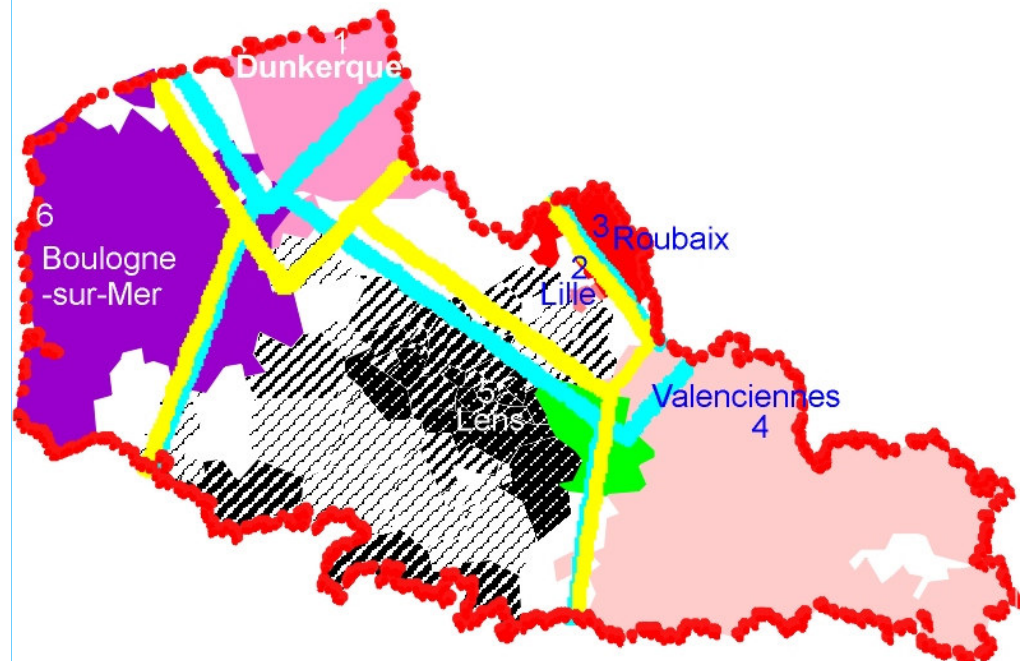
## Ratio of distances from the observed and estimated balance points determines an attraction coefficient '>'; '<' or '=' 1

The interpretation of graphical distance separating the observed and estimated balance points follows an equivalent conception to AC. Three different situations can occur :

- $d(i, bo(i, j)) > d(i, be(i, j))$  observed attraction by i is **higher than in the model**, compared to j.
- $d(i, bo(i, j)) < d(i, be(i, j))$  observed attraction by i is **lower than in the model**, compared to j.
- $d(i, bo(i, j)) = d(i, be(i, j))$  observed attraction by i is **equal to that in the model**, compared to j.



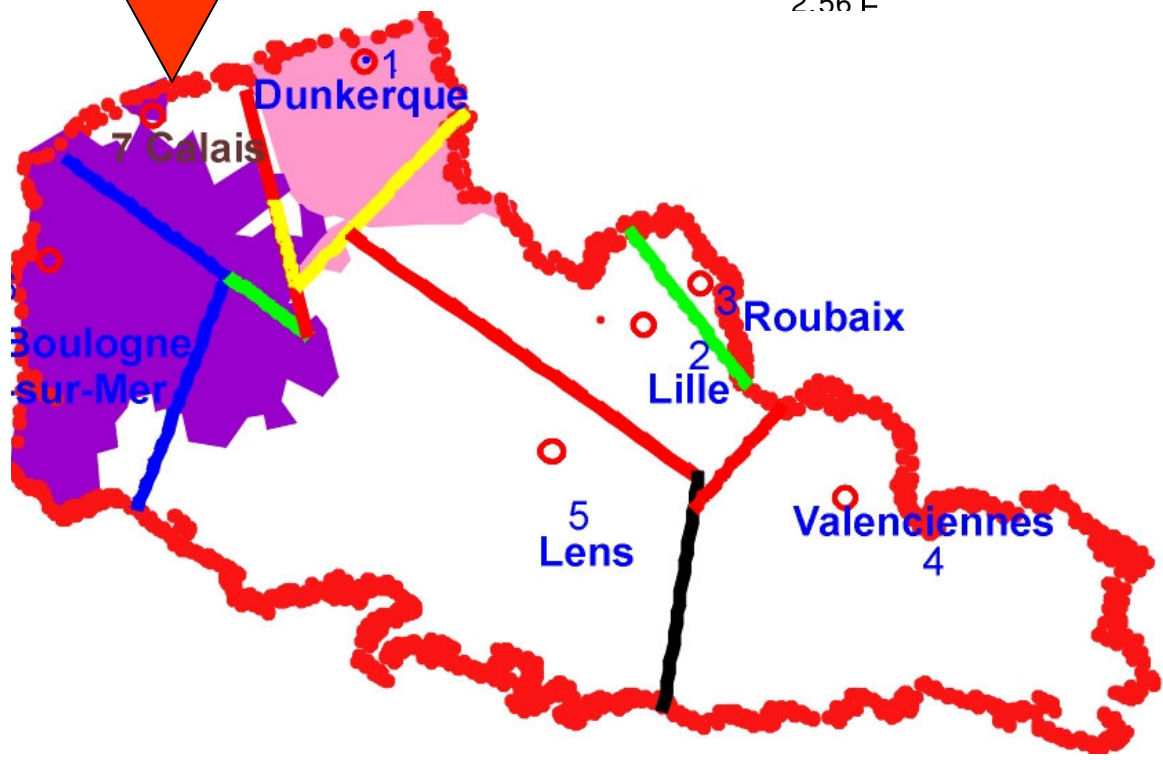
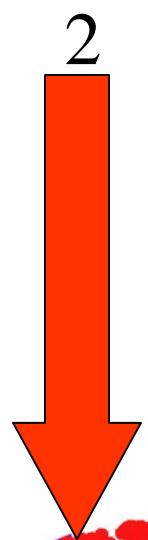
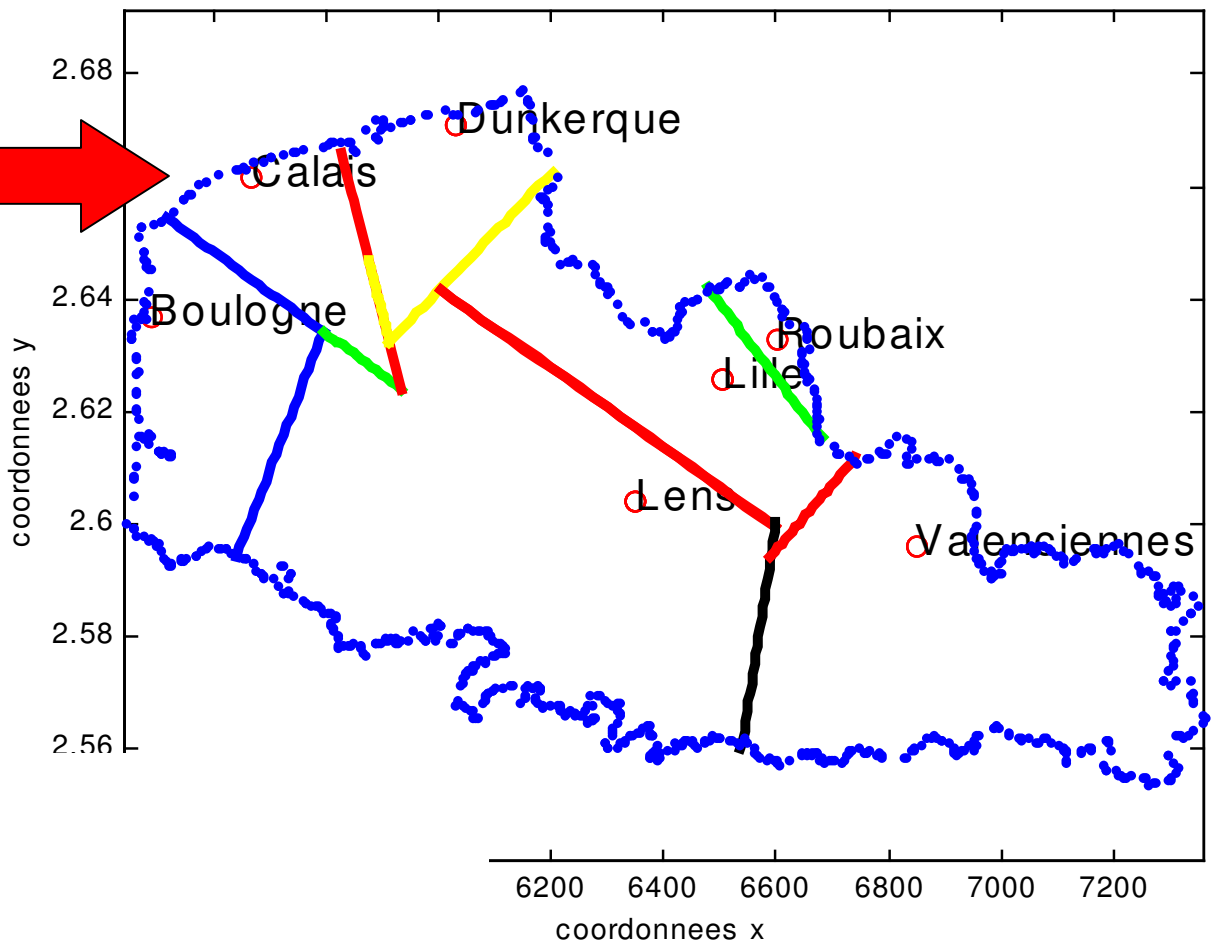
$$AC = \frac{d(i, bo(i, j))}{d(i, be(i, j))} = \frac{38,69}{29,67} = 1.304$$



# **PHASE 4 : SIMULATION**

## **OPENING A MEDICAL DEPARTMENT IN CALAIS CITY**

# Simulation in Calais



**Calais = Fictitious  
Mass of 12 beds  
+ *Pe* (K-Means  
method)**

# Model validation and evolution

**Our gravity model** is **robust, reliable and predictive**. It has been validated for the Nord - Pas-de-Calais region in two specialties thanks to:

- 1) Observed local attraction for hospital places (excepted university places)
- 2) **By** comparison, good fits (adequacy) between both observed and estimated models

**Relevant** : the observed plotting with estimated plotting allows an attraction coefficient ratio calculation (AC).

**What is novel** : Simulation to manage health-care supply, Drawing model by specialty, and computed and automated models

## Evolution to :

- \*Implementation of a hospital reputation threshold. **20**
- \*Apply the modeling process to other territories
- \*Avoid Physical barrier → use other distances in time etc.,  
or continue to use the Euclidean distance and to take off one segment between two hospitals if there is a physical barrier.
- \*K-Means alone represents a model of phase 2, like refined Reilly's model. So a new proposal of proximity model for management of health-care services..  
20

# Conclusion

**Model** allows a best-provision network organization and management of health-care supply and demand linked to human spatial behavior. Health-care planning tool to help planning policy.

**Application fields** : health geography, medical IT, health-care planning and management.

**Best knowledge of** spatial utilization – study of health-care district management – health-care quality improvement–staff management on territory by specialty.

**Computer prototype** –planning tools can be integrated into GIS or geomatics platform— for comparison, following of catchment development etc.; fast processing of information and management, Spatial visualization, analysis. **Scalable eAtlas of health-care services and decision-making. Targets : citizens and professionals.**

# Acknowledgments

I thank the following people for the time and care they took in reading drafts and listening to my first oral English presentation and for the helpful suggestions they offered:

- \***Thumerelle, Pierre Jean.** Lille 1 university, geographic section, Thesis Director
- \***Beuscart, Régis.** Lille 2 university, medical computing I. T. Section, Thesis Director.
- \***Quentin, Julie.** Medical Doctor and my best friend

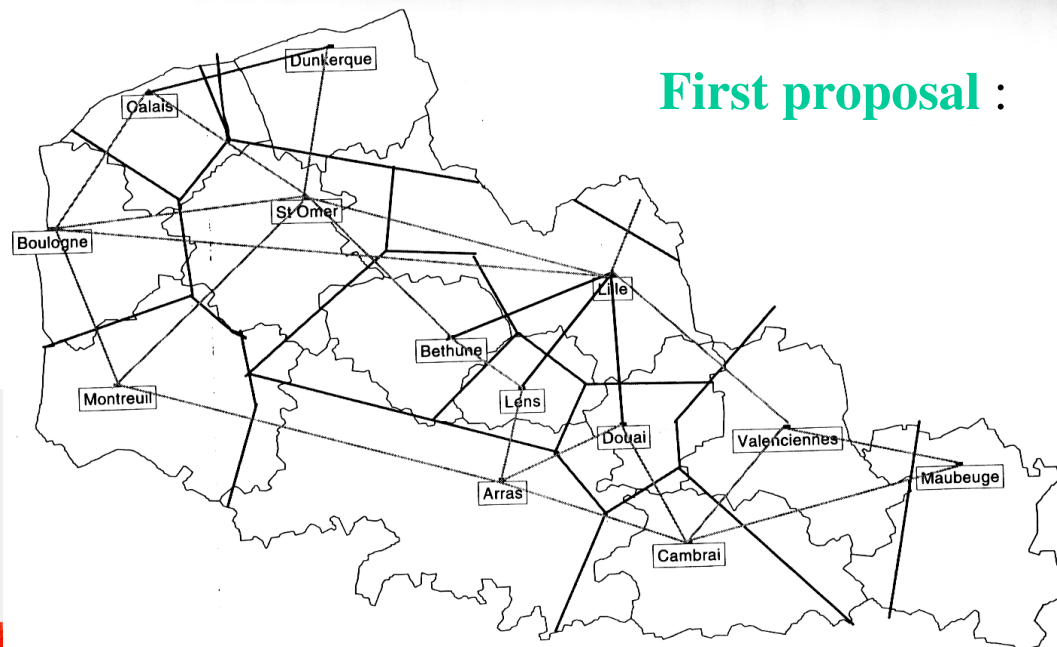
# Background

Gravity model applied in Health : Reilly's model used with real database

## First proposal :

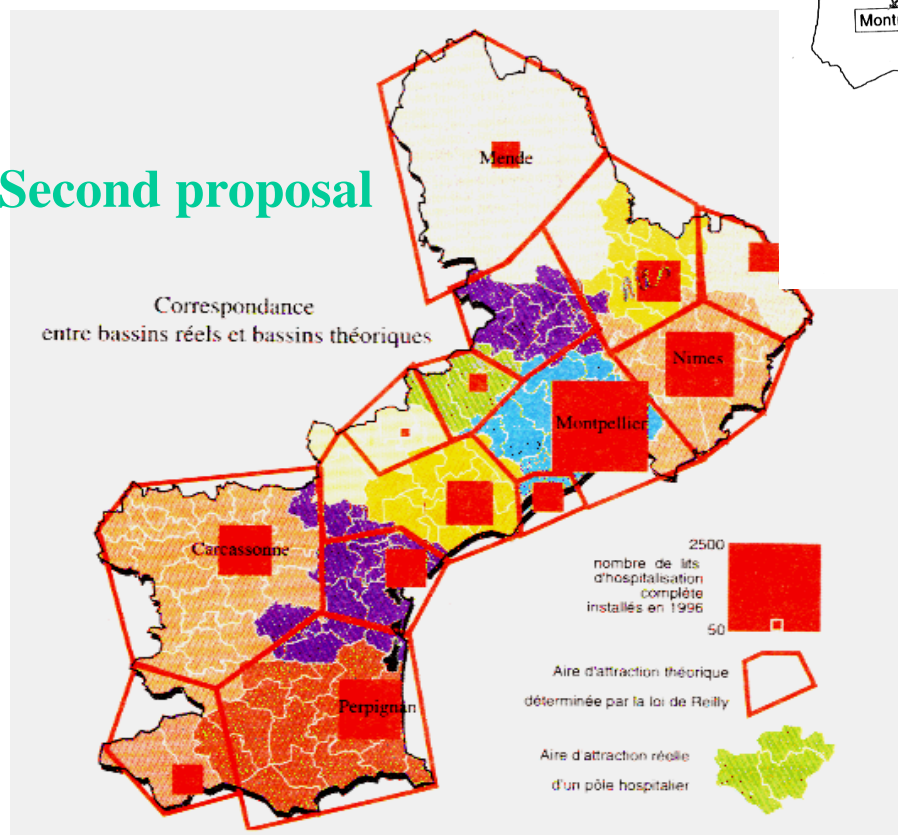
Health-care sectors cut-out figure

: base map of the Nord-Pas-deCalais region. *E. Vigneron Rapport DRASS April 1994.*



## First proposal :

## Second proposal



## Second proposal :

Health basin cut-out figure

: base map of the Languedoc-Roussillon region (*« Géographie de la santé en France » E. Vigneron et F. Tonnellier*) **February 1999.**

# Annex, phase 3: comparisons

Aires d'attraction estimées -DESSIN 3 - 18 Poles - 19 ETS Publics GHM295

