Location Optimization for a Vehicle Sharing Service

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Why Car-sharing?

- Social and Environmental costs of personal cars
  - Time lost in traffic congestions
  - CO_2 emissions
- Infrastructure costs
  - Build more roads
  - More parking facilities
- Affordability
  - Sharing maintenance, parking and insurance costs
  - Short length of usage daily
  - Flexibility of vehicle choice

How Car-sharing can help

- Costs of car ownership ignored when individuals decide to drive for a trip (focus only on variable costs)
- Hassle of pre-booking likely to cut down on spur-of-the-moment trips
- In the long term, alternative modes – biking, public transportation etc. – will become more accepted

Car-sharing History

- First car sharing attempt in Switzerland (1948)
  - “Sefage” - Selbstfahrergemeinschaft
  - More attempts in Amsterdam and Montpellier (early 1970s)
  - Driven by economics of car ownership
- StattAuto (Germany) and Mobility (Switzerland), commenced services in late 1980s, are more successful
- Service expanded to Asian cities in 2000s
  - Singapore, possibly most successful

Research Problem

- Most studies show that a large number of car-sharing customers pick up the vehicle by walking down to the station
- Thus it is imperative for the success of the service to locate stations as close to the consumers as possible
- However, there exists a trade-off
  - Too close $\Rightarrow$ cannibalization (too many choices for the customer)
  - Too far $\Rightarrow$ usage reduced (sorry, I take my own car)

Literature

- Shaheen et al. (1998, 2003, 2006): Business of car sharing and social influence
- Ciari et al. (2008): Simulation to evaluate the “true” benefits
- Efthymiou at al. (2012): Drivers of demand
- Uesugi et al. (2007) / Correia and Antunes (2012): One-way car sharing – uncertainties and inventory of vehicles
- Fan et al. (2008) / Nair (2011): Optimal fleet sizes at stations

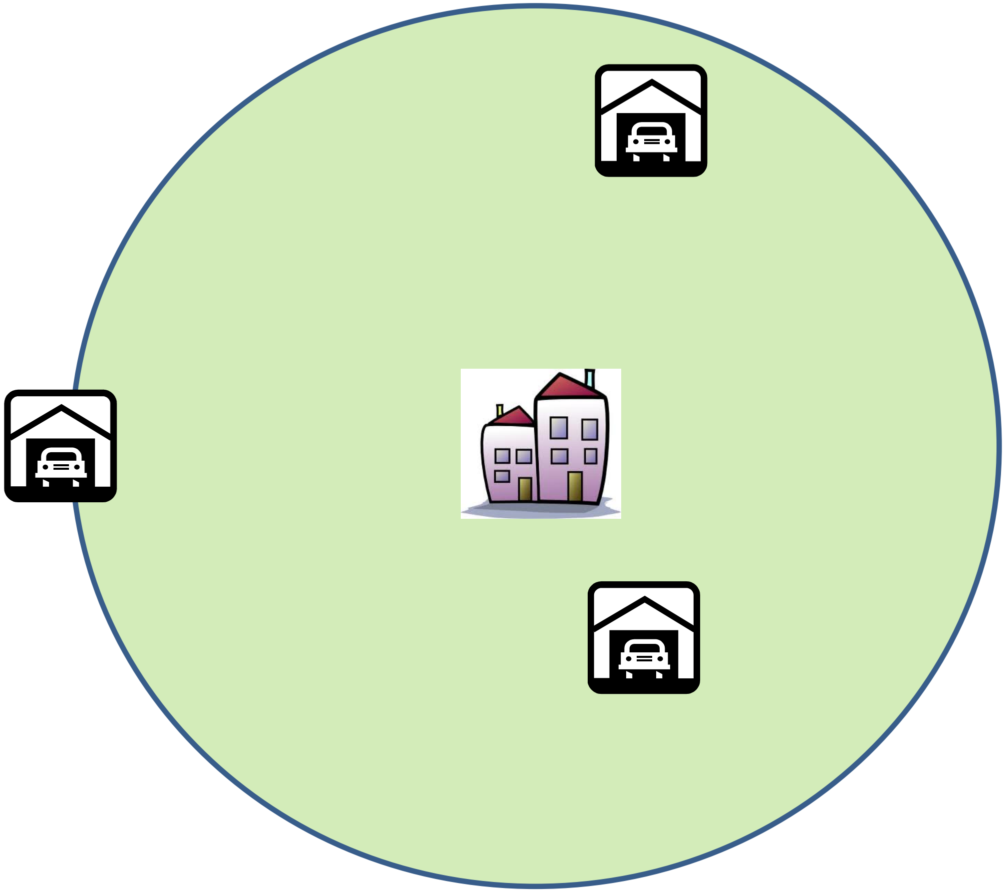
Motivation

- Research so far on drivers of demand and using these drivers to identify "attractive" locations in the target area
- Qualification on attractiveness of a locality, but no pareto studies to show the diminishing returns of placing too many stations
- While optimization of fleet sizes at the stations is studied, optimization of locating the stations has been ignored in the literature
  - Can the problem of locating stations be solved using the algorithms for classical "optimal facility location" problem? Unfortunately, no

Methodology

- Assumption
  - Given a super-set of locations
  - Linear relationship between the drivers and station performance
- Objective
  - Pick *n*-best locations
- Constraints
  - Logical, political or business
  - Example, only k stations from a certain region, at least k stations from a region, etc.
- Modeled as MILP and solved? No

Circle of influence of mobility attractor



Mathematical Model

- Unfortunately, performance of a station depends on the presence of other stations in the vicinity
- This interaction effect with the same mobility attractor makes problem non-linear

$$Max \sum_{k=1}^{K} z_k Exp(Y_k) \qquad \text{... (1)}$$

subject to:

$$\sum_{k=1}^{K} z_k = n \qquad \text{... (2)}$$

$$Exp(Y_k) = \beta_0 + \sum_f \beta_f X_{f,k} \qquad \forall\, k \qquad \text{... (3)}$$

$$X_{f,k} = \sum_{s \in s_k} \left(\frac{r_{f,s}}{\sum_{k \in k_s} z_k} \right) \qquad \forall\, f, k \qquad \text{... (4)}$$

Solution Algorithm

- Even though the problem formulation is non-linear, the problem can be solved easily to produce "*reasonably good*" solution using a greedy heuristic
  - Fix a set of n variables, $z_k = 1$ for which $\beta_f \, r_{f,s}$ is maximum
  - Recompute X-variables based on the impact of circle of influence
  - Fix the new set of n variables, $z_k = 1$
  - Continue the above steps till the solution does not improve any further
- Is this procedure guaranteed to converge?

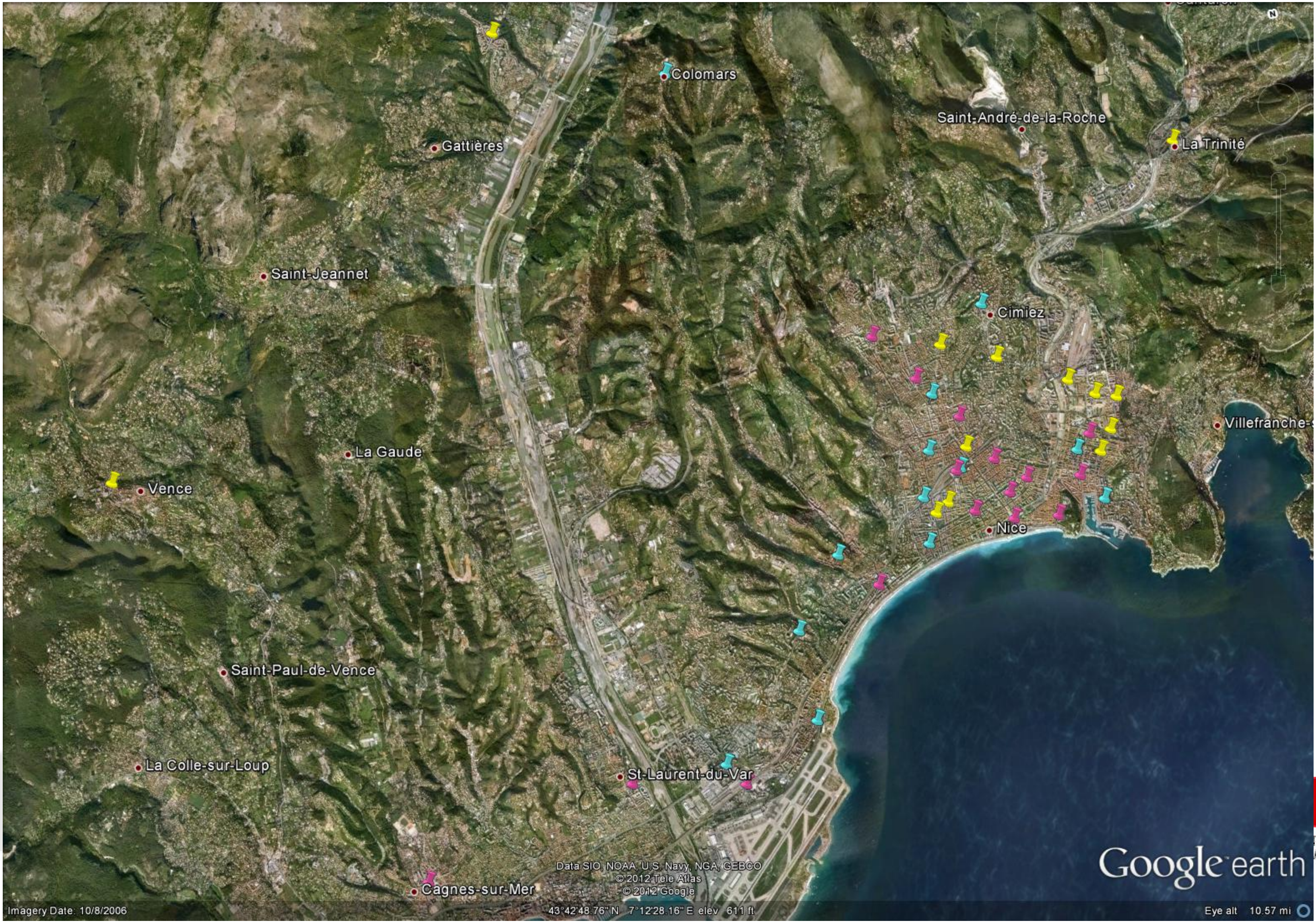
Case Study: Autobleue

- Autobleue is the electric-car sharing facility operationalized in the city of Nice and its suburbs in April 2011
- Nice is one of the few cities in world that boasts of a full electric car sharing system
- Plan to locate 70 stations around the city, but the question is where
- Mountainous terrain adds to the complexity

Case Study

- Objectives
  - Understand and analyze the performance of existing Autobleue stations
  - Use this analysis to predict areas for locating additional stations
- Collaborative project between Veolia and EPFL
  - Study from Jan 2012 to Mar 2012
- Available data
  - Autobleue data (until Dec 2011)
  - IRIS data from NCA
  - EMD data

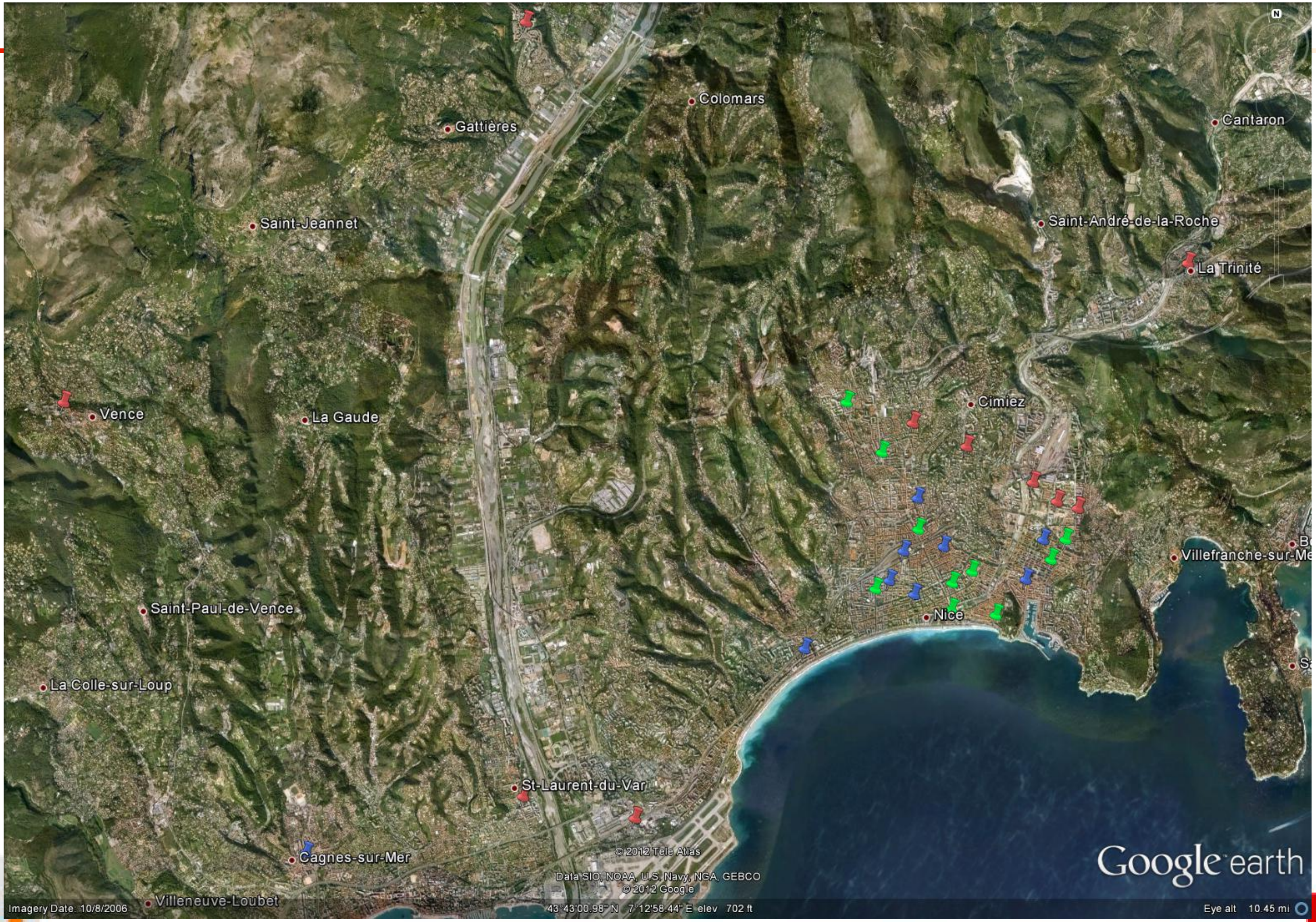
Autobleue Growth Map



Proposed Autobleue Growth (Phase 2.3+)

LOCALITIES	NB STATIONS AS SPECIFIED INITIALLY	COMPLETED PHASE 1	COMPLETED PHASE 2.1	COMPLETED PHASE 2.2	TO BE DEFINED PHASE 2.3 / 2.4 / 2.5	ESTIMATED TOTAL
Nice	58	14	10	12	21	57
Cagnes-sur-Mer	4	1	0	0	3	4
Saint Laurent du Var	2	1	0	0	1	2
Beaulieu-sur-Mer	1	0	0	0	1	1
Carros	1	0	1	0	0	1
La Trinité	1	0	1	0	0	1
Vence	1	0	1	0	0	1
Villefranche-sur-Mer	1	0	0	0	1	1
St Martin du Var	1	0	0	0	1	1
Colomars	0	0	0	1	0	1
Total :	70	16	13	13	28	70

Autobleue Performance Map



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Autobleue Performance Drivers

- It is obvious that Autobleue performance is not uniform across geographies and there must be some drivers, which are impacting the station demand and performance
- Thus, the objective of this study is to:
  - Understand and analyze the various drivers of demand for Auto Bleue service from the rich data that is made available to us from the different sources,
  - Build a mathematical model to represent the performance of Auto Bleue station through these drivers, and
  - Use the mathematical model to optimize the location of future stations.

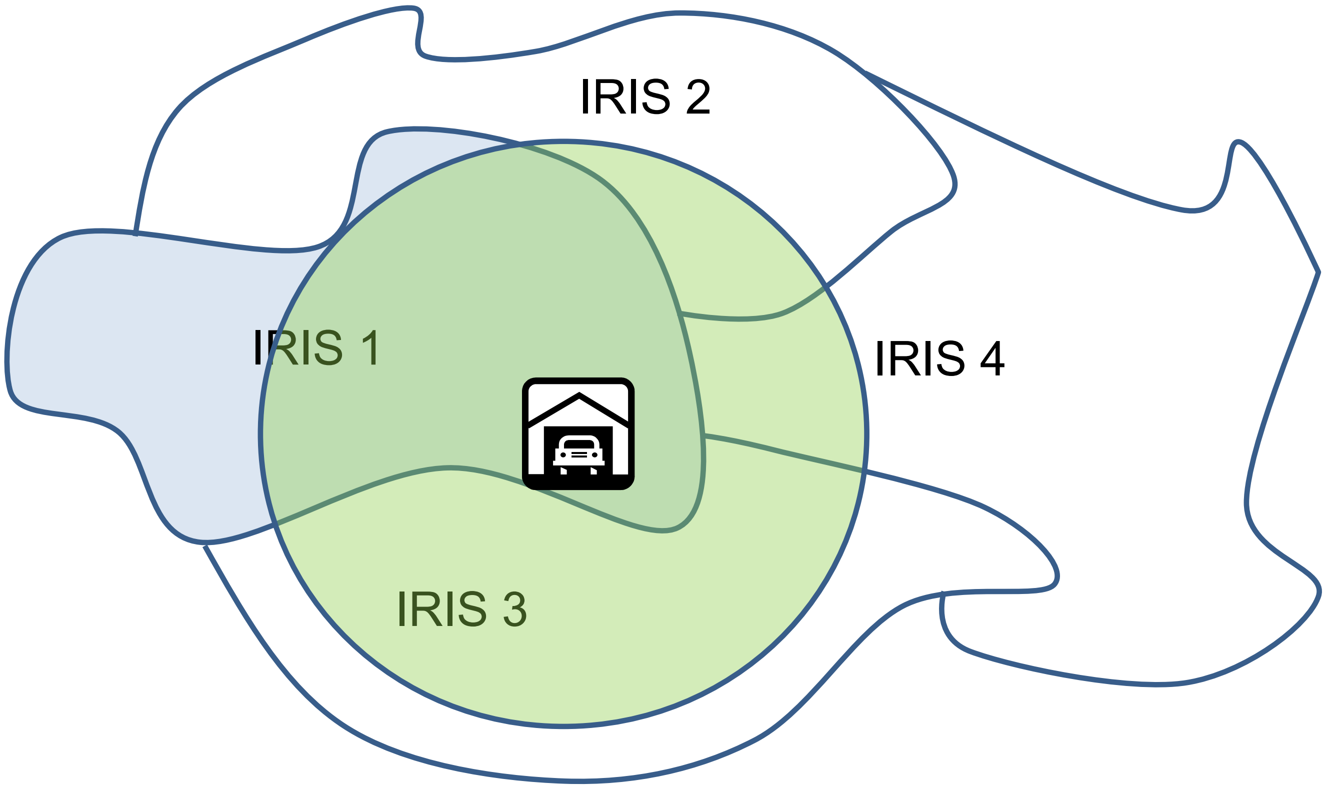
Independent variables

- The following independent variables are considered for modeling as many of these variables show a reasonable correlation with Auto Bleue performance:
  - Velobleue performance indicator
  - Public transport rides
  - Share of residents using their personal cars for transport to office
  - Share of residents using two-wheeler or public transport to reach workplace
  - Share of residents that are entrepreuners / craftsmen
  - Share of residents that are Managers / Professionals
  - Share of residents that are employees and associate professionals
  - Share of residents that are workers

Independent variables (contd.)

- The list of independent variables (continued):
  - Population density
  - Share of males in the population
  - Share of 25-54 age group persons in the locality
  - Special variable for Gare Thiers
  - Number of other Autobleue stations with 500 m
  - Mobility attractors, such as college lycee, commercial complex, temporary accommodation / hotels, student housing, hospitals, etc.

Sphere of Influence of an Autobleue Station



- From an Autobleue station, we draw a circle of 500 m radius and weight the share of the parameter by the area covered for each IRIS commune

Key results of the regression model

- The following factors impact the number of avg Autobleue bookings per day at each station (under assumption of linearity):
  - Share of managers and experts (+)
  - Share of car users driving to workplace (-)
  - Public Transport rides (+)
  - Population density (+)
  - Hotels (+)
  - Commercial center (+)
  - College Lycee (+)
  - Distance to another Autobleue station (-)

Optimization Model

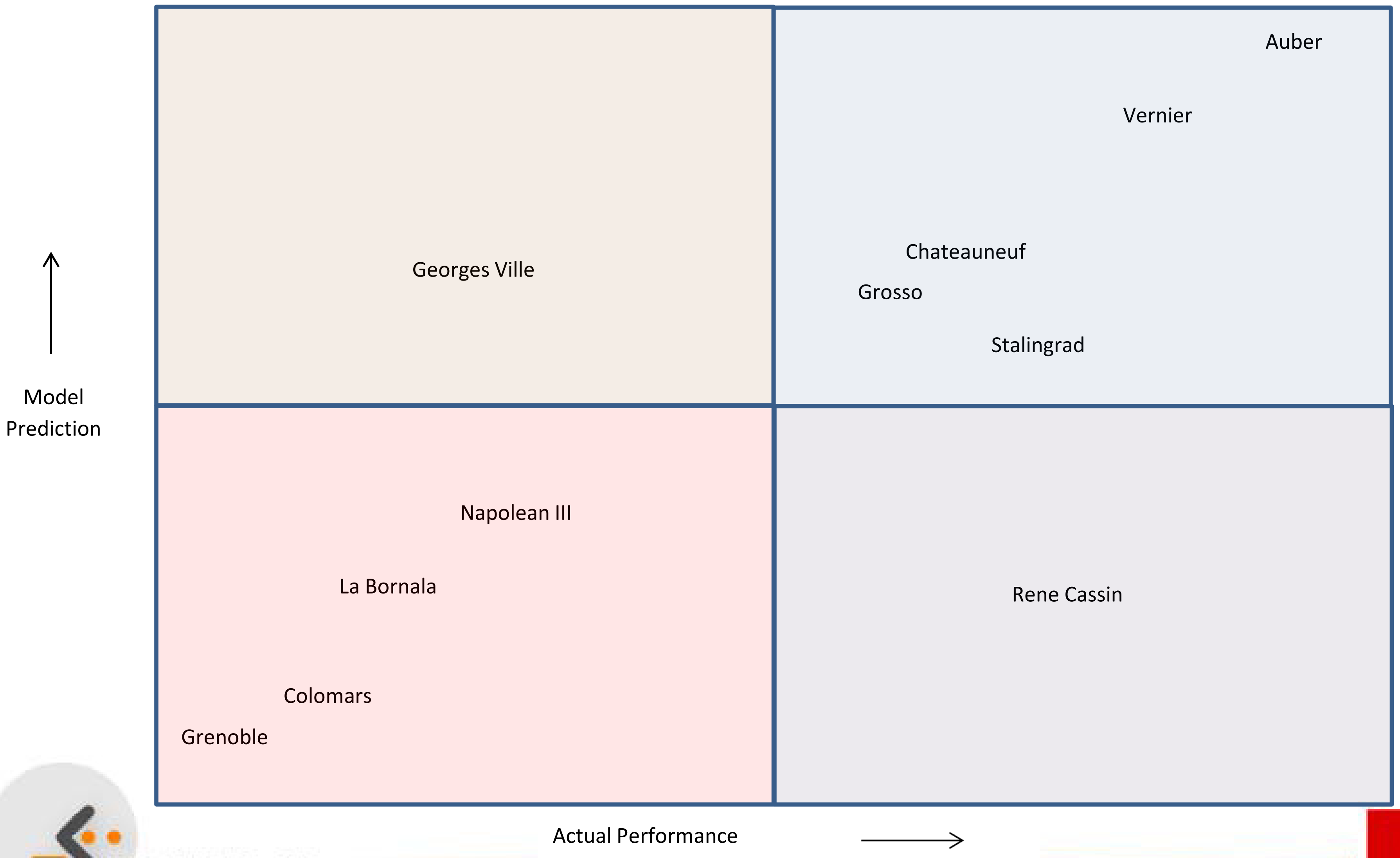
- Let the expected performance of Auto Bleue at a locality be represented as $Exp(Y_k)$, where

  $$Exp(Y_k) = \beta_{INTERCEPT} + \beta_{ME} X_{ME,k} + \beta_{PT} X_{PT,k} + \beta_{CR} X_{CR,k} + \beta_{CC} X_{CC,k} + \beta_{Hot} X_{Hot,k} + \beta_{CL} X_{CL,k} + \beta_{PD} X_{PD,k} + \beta_{Dist} X_{Dist,k}$$

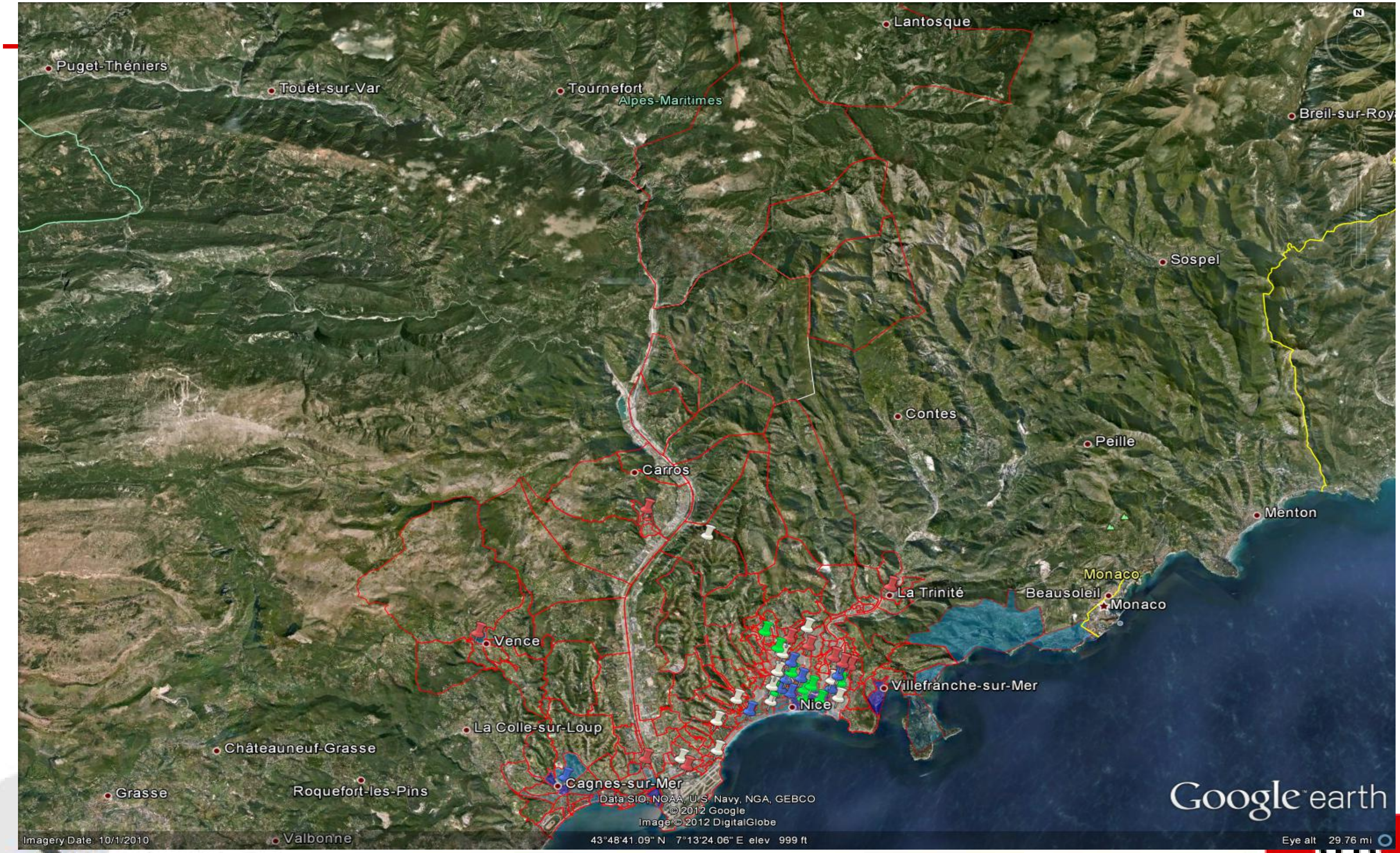
- The basic idea followed by optimization model is to optimize the trade-off between low-potential, but unexplored (untapped) outskirts versus the high-potential, but fast saturating (or already saturated!) center (white versus dark blue areas)

- Model represents the problem mathematically and tries to solve the problem

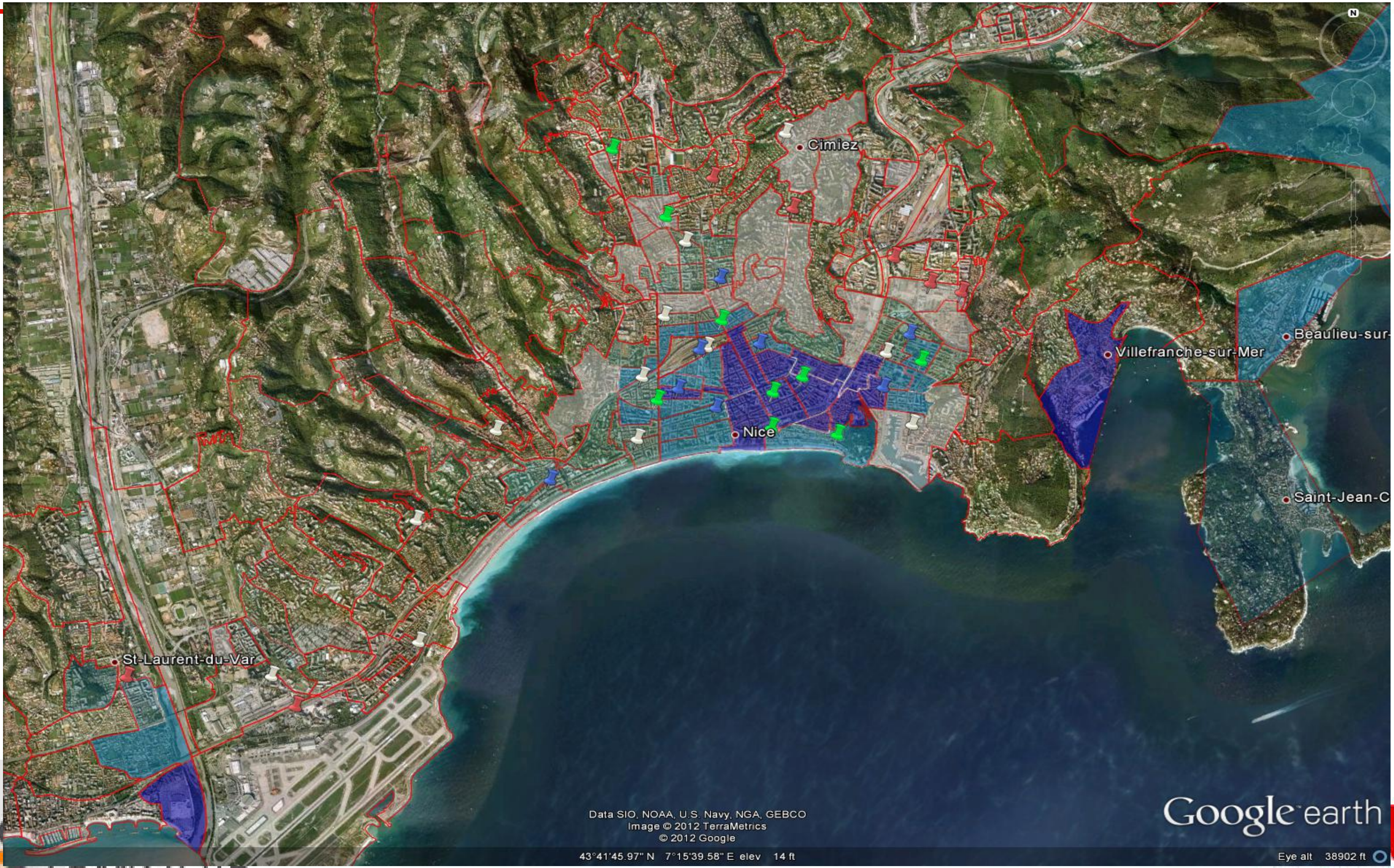
Model Validation



Model Results (over NCA territory only)



Model Results (City of Nice)



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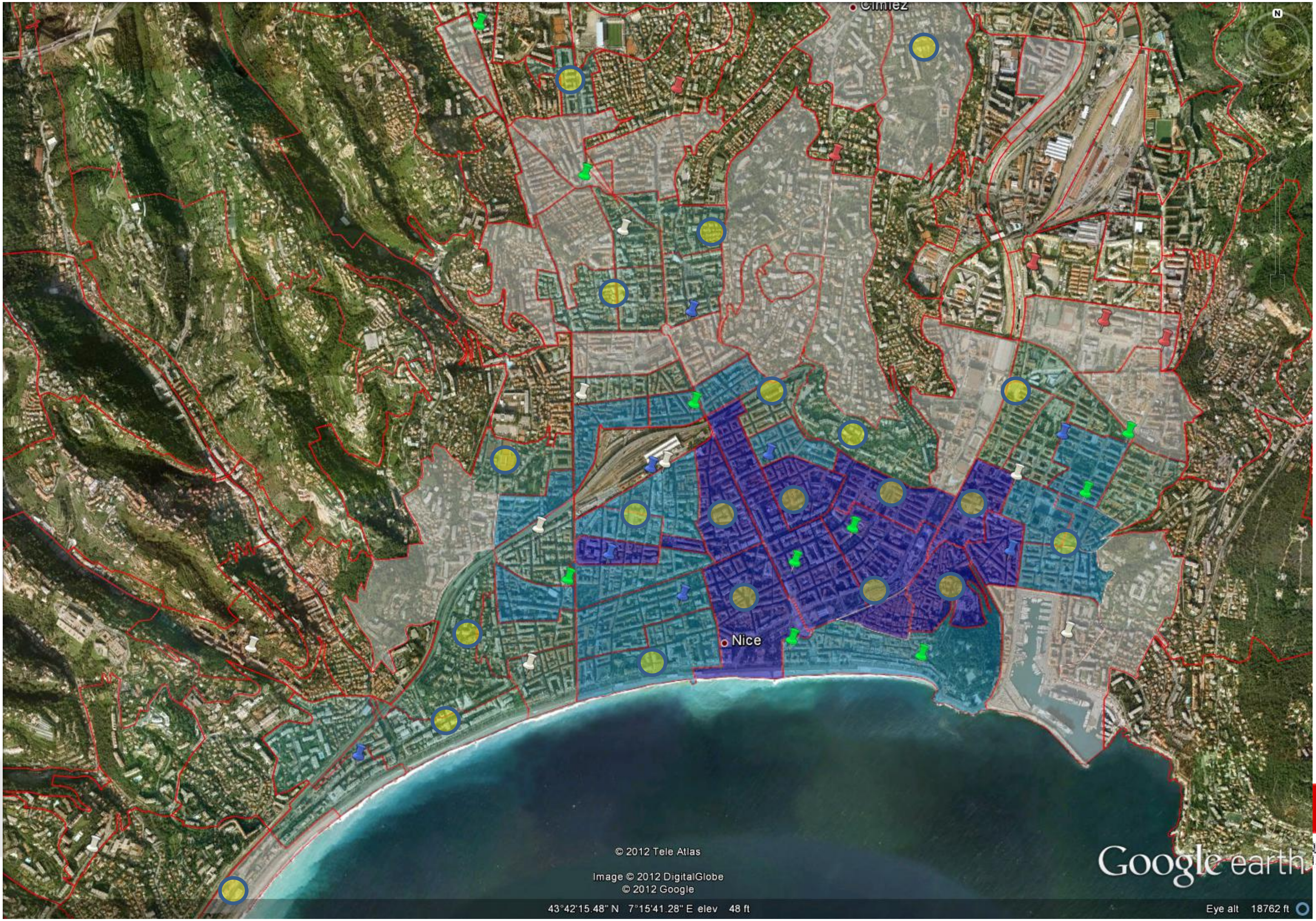
Recommendations for Next Stations within Nice



Concluding Remarks

- One of our major findings is the fact that Auto Bleue service has a strong potential in the heart of the city, but progressively lesser interest as we move outskirts.
- The trade-off for Auto Bleue today is to make a choice between high-performing but saturated heart versus low-interest but untapped outskirts.
- Our study has based the recommendations primarily based on mathematics and science. But locating future stations for Auto Bleue is as much an art and business sense too.
- Impact of the presence of multiple Auto Bleue stations around a target station appears to be underestimated.

Future Research Possibilities

- Linear relationship between variables and car usage
- Time series impact of the station performances
- How to design and operate car sharing sysems to complement public transport? Can one-way system help achieve this goal?
  - If yes, how to redesign and operate a new system so that operational costs are minimized, while augmenting the usage of the system?
  - How to forecast demand better?
  - How to define the pricing strategies (differential pricing?)?
  - How to optimally manage inventory of the vehicles
  - How to resize the system and stations?

Thank You!