A mathematical model of complex mobility patterns for big traffic generators competition and sustainability

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i-SUP 2008

22-25 April

The problem

To support decisions about the following:

Simulate and measure the environmental impact of BTG:

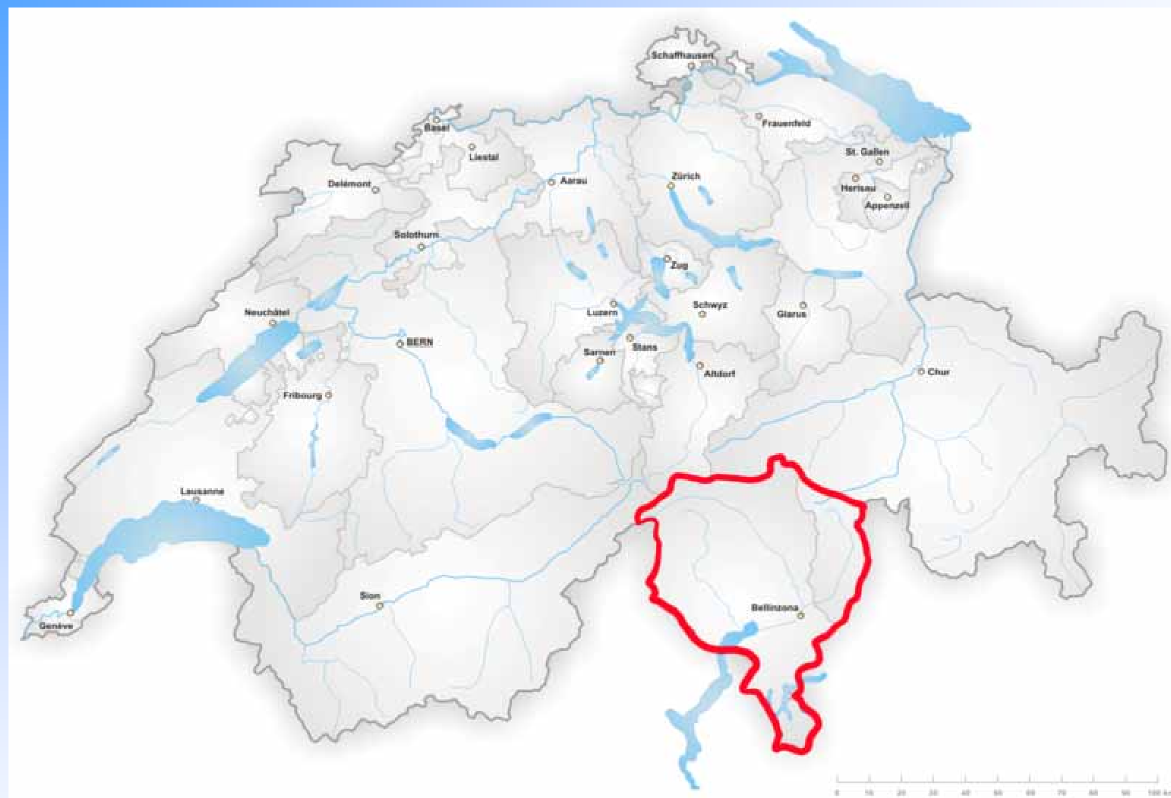
1. to use a mathematical model of BTG to define what is a BTG in a normative sense;

2. what zones of Ticino are suited for hosting new BTG

3. what thresholds should be applied for limiting the amount of BTG in each zone

Find the best placement for a BTG from the economical point of view

General data about the model



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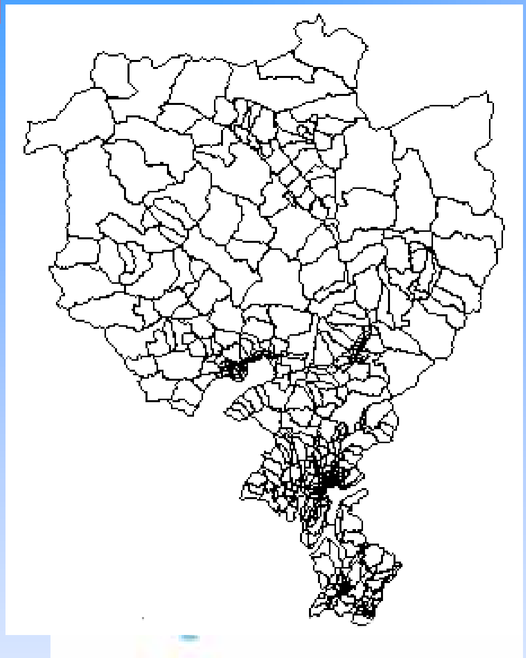


Ticino, Switzerland, about 150’000 inhabitants

517 **zones**

Economical activities subdivided in 45 categories:

- retailer of foods, drinks
- retailer of furniture
- retailer of do it yourself tools
- banks
- retailer of electronic devices
- retailer of clothing
- …

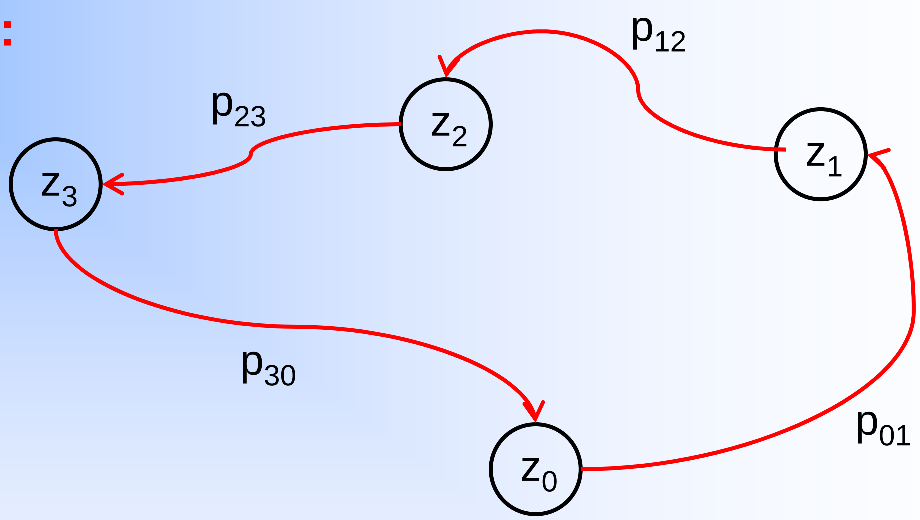
Three time windows:

- Average working day
- Saturday
- Sunday

Complex mobility patterns 1/2

One of the problems in the modeling of BTG related dynamics is that individuals follow "**complex mobility patterns**", i.e. movements that are not only origin-destination, but can include more than one destination for more than one goal

Kernel:



Goals: $g = (g_1, g_2, \ldots, g_s)$

-To buy necessaries
- to buy complements
- to do shopping
- to spend time for fittness
- to buy furnitures
- …

Complex mobility patterns 2/2

Characteristics of movement: $c = (c_1, c_2, \ldots, c_p)$

a family of parameters defining boundary conditions under which the movement takes place:
- the preferred time window to start the movement
- the relative importance of goals
- fuzzy constraints over the average time and money to be spent for each goal

The pair $(g\ ,\ c)$ is called **type of movement**

Example of complex mobility pattern:

- to buy necessaries (g_1) in z_1 and complements (g_2) in z_2 starting from home z_0, using the paths p_{01}, p_{12} and p_{20}
- on the weekend (c_1)
- with necessaries much more important than complements (c_2)
- using average time and money for necessaries and not so much time and money for complements (c_3)

The modeling framework: Interaction Spaces

The system has been modelled as an **Interaction Space** (IS), a new type of mathematical structure aiming to define complex systems made by several interacting entities

IS generalize both multiagents systems and cellular automata and can be seen as a good interpolation between AI based methods and Physics' methods

In an IS one can use:

- continuous or qualitative state variables
- populations of agents instead of single agents
- there is a clear mathematical definition of cause-effect relation between interactions
- differential equations for extensive variables and their probability distributions (general theorem not a starting point)
- synchronous (discrete time) or asynchronous (continuous time) dynamics

Axiomatic theory of complex systems

Interacting entities

Commercial surfaces and other BTG

configuration space: amount of commercial, spatial position, number of parking places

Links of the transportation network

configuration space: georeferenced position, speed limit, slope, lanes, a classification into 45 functional categories, maximum capacity

Populations of individuals residing in a given zone

configuration space: spatial coordinates of the zone, statistical data describing the population, for every type of movement: average number of movements, average time spent, average money spent

Complex mobility patterns

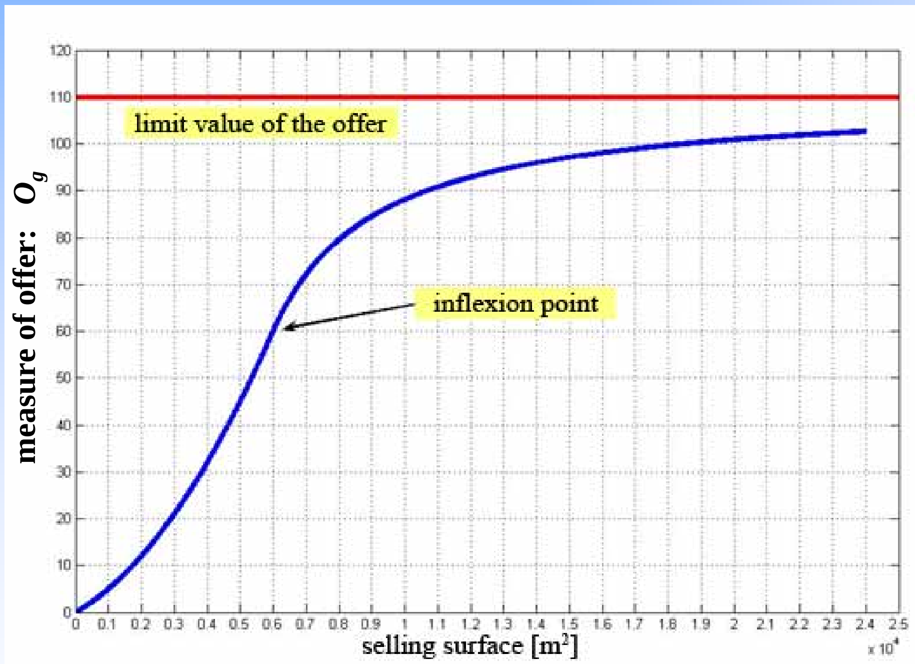
Temporary moving entities: members of a population currently involved in a trip

configuration space: specific residential location, the socio-economical status of the entity, a pointer to a CMP

Attractiveness indicators 1/2

We define an attractiveness indicator for a BTG using **fuzzy logic** methods

The attractiveness depends only on a given **set of goals** $g = (g_1, g_2, \ldots, g_s)$



In the considered BTG there is a selling surface s_i for the goal g_i

The offer $O_{g_i}(s_i)$ of the BTG related to that goal g_i is an increasing function of the selling surface s_i

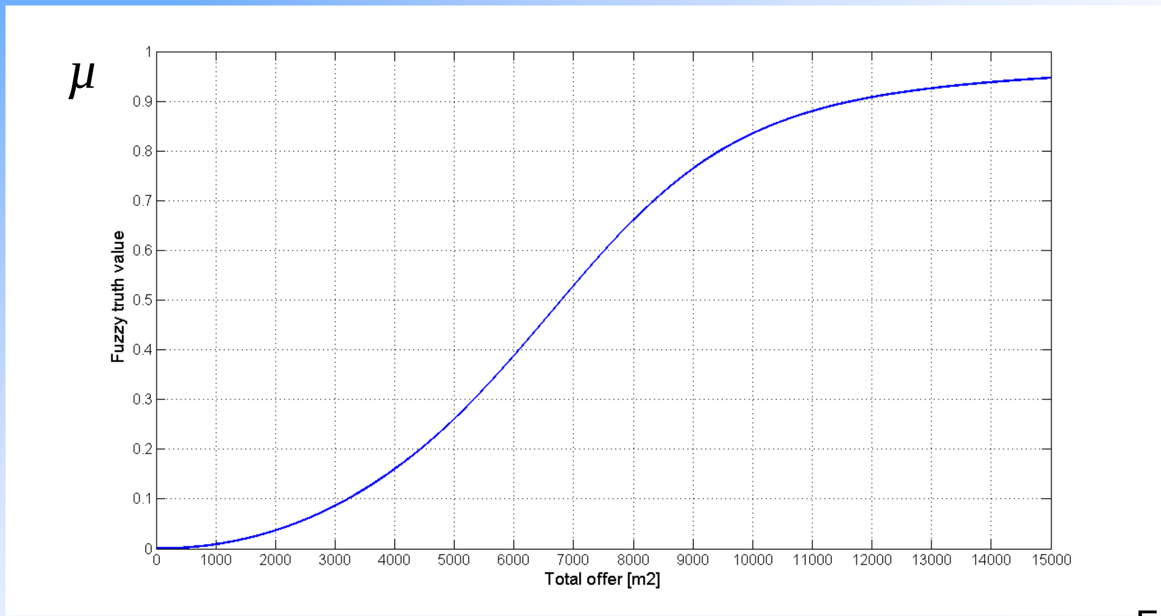
Total offer:

$$O = \sum_{i=1}^{s} O_{g_i}(s_i)$$

Attractiveness indicators 2/2

Now we measure the fuzzy truth of the sentence:

Is it high a value O of total offer?



Fuzzy operator “very”

Attractiveness indicator: $\mu\left(\sum_{i=1}^{s} O_{g_i}(s_i)\right)^{\beta(\text{services})}$

Decreasing function of the selling surface of services

Interactions

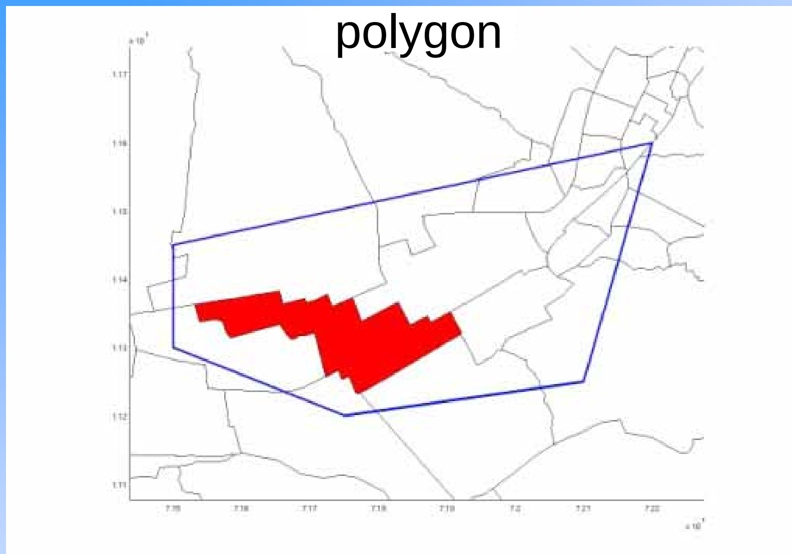
1. Generation of temporary moving entities (TME) and types of movements based on statistical properties of the population

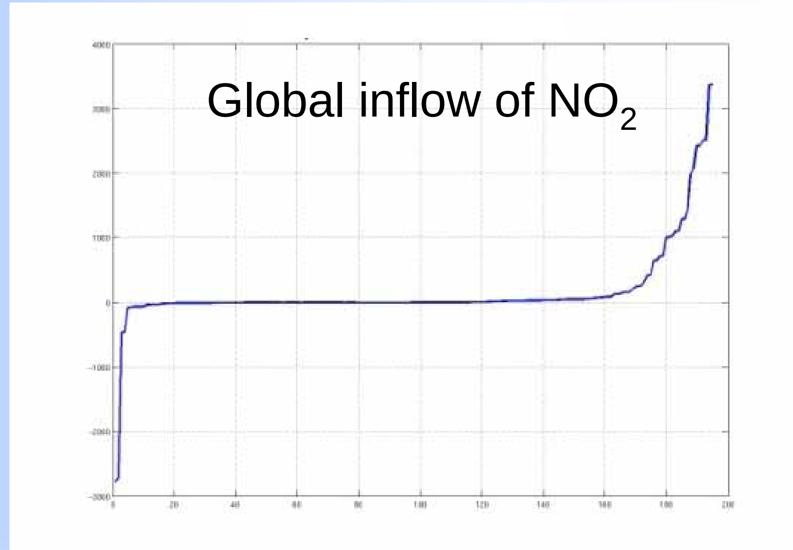
2. Selection of a set of zones by a TME giving higher probability to zones having BTGs with higher attractiveness

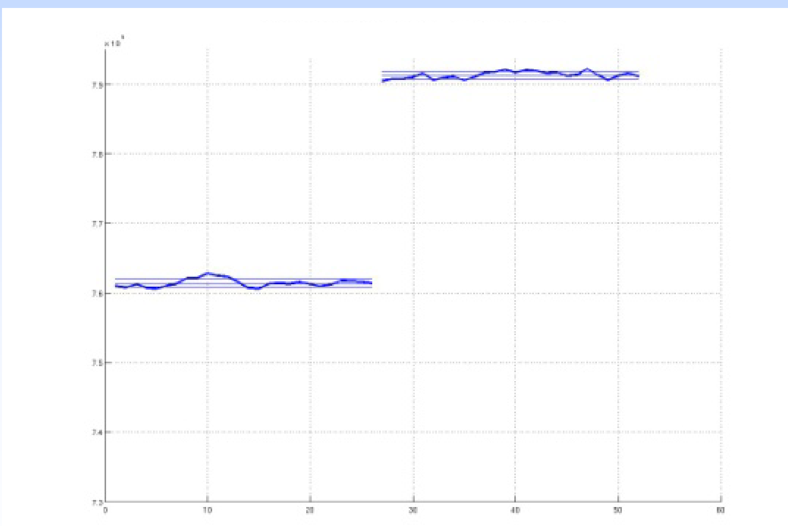
3. Routing: choosing of a path to connect two zones giving greater probability to paths with lower run time (memory about congested roads in the past weeks)

4. BTG related activities: spent time and money based on constraints given by the origin population

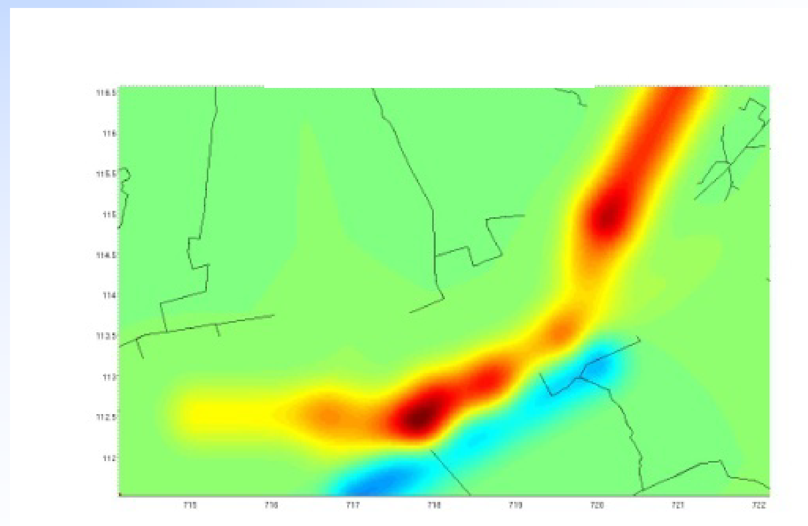
Examples of simulated observables





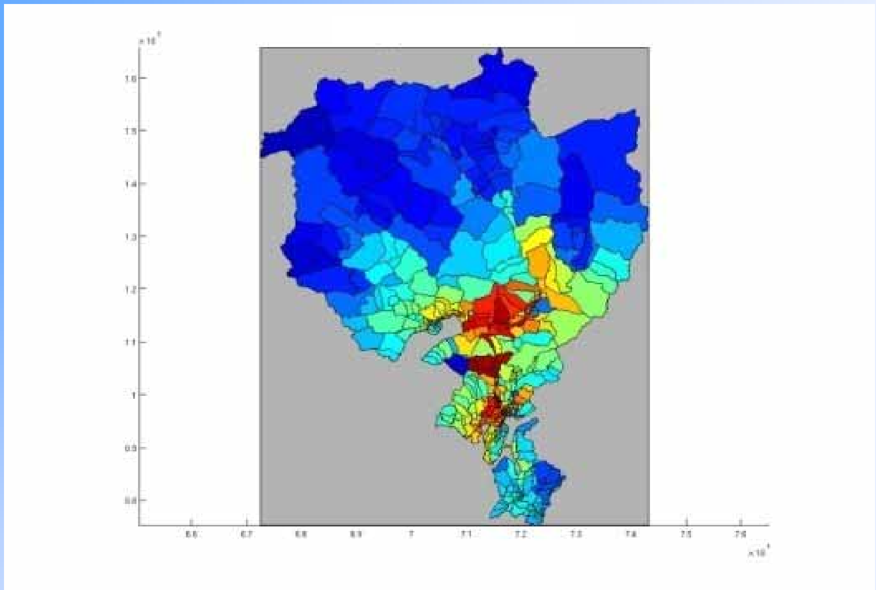


Inflow of NO_2 on a single link

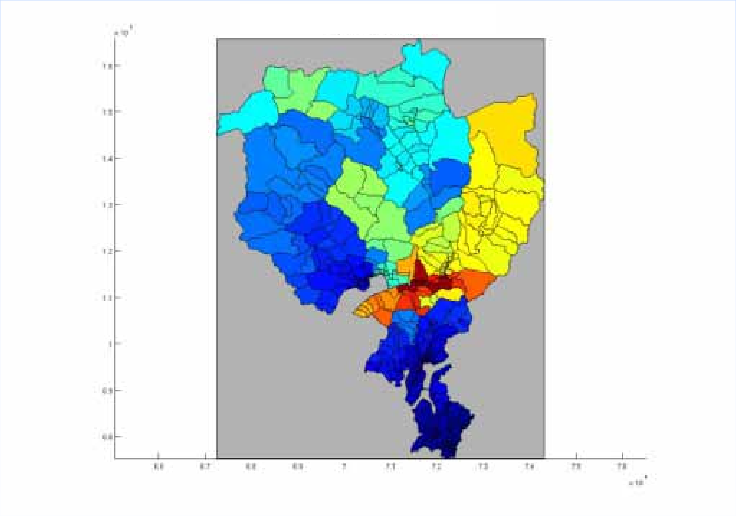


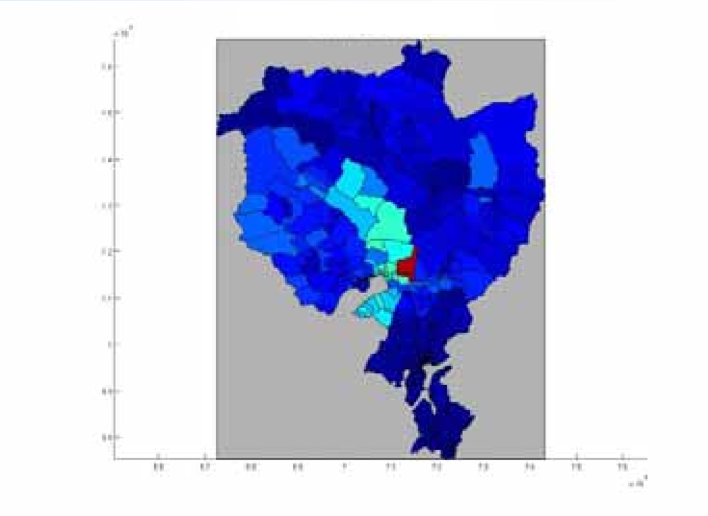
Map of inflow of NO_2

Indicators for BTG placement



Fields of pressure for a new shopping center for a given goal





Catchment areas of new shopping centers

Calibration and validation

Calibration:

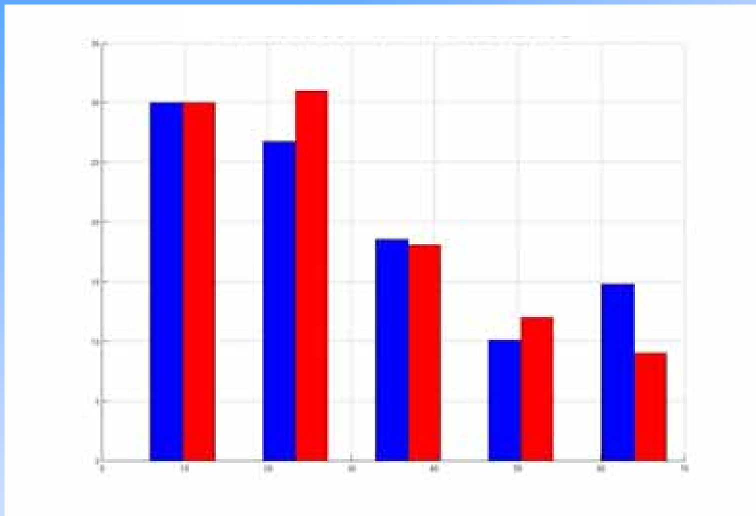
1. We calibrated the parameters of the attractiveness indicator so as to obtain the expected classification of BTGs:

1: Morbio Inferiore (Ghitello)	95
2: SantAntonino (Centri Commerciali)	92
3: Muralto (Stazione)	89
4: Losone (Al Ponte)	86
5: Lugano (Municipio)	84
6: Grancia (Centri Commerciali)	72
7: Biasca (Stazione)	71
8: Bellinzona (Collegiata)	69
9: Canobbio (Piano Trevano)	67
10: Mendrisio	66
11: Chiasso	57
12: Agno (Paese)	54
13: Lugano (V. Brentani)	54
14: Faido	51

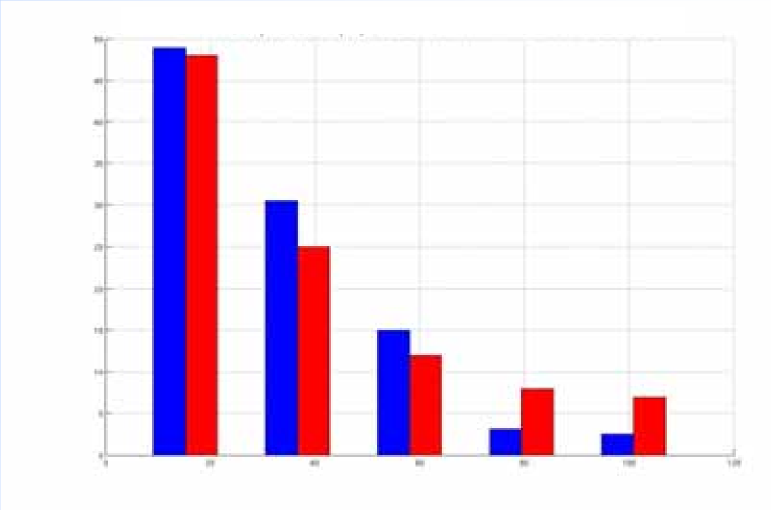
Calibration based on experts' knowledge

Calibration and validation

We calibrated using one survey…



calibration



validation

… and validated using another survey

Further validations about 6 BTGs:

1.15915 visits foreseen by the survey and 21794 by the model (error: 36.7%)

2. 21.4 Km on average to reach one of the 6 BTG, 13.2 Km in the model (-38.3%)

3. order of magnitude of inflows of NO_2 as expected by experts

Future improvements

1. Possibility to choose alternative routes: now there is only the quickest

2. Endogenous dynamics of new BTGs based on the pressure fields
   - searching of the most problematic zones w.r.t. environment
   - searching of the best zones to locate a new BTG

3. Time windows of 1 hour
   - more reliable estimate of vehicles speed
   - comparison with measured counting data

4. Coupling with a urban growth model
   - longer forecasts
   - best estimation of economical risk in the placement of new BTGs

5. Microsimulation dynamics for vehicles movements
   - estimation of maximum levels of pollutions
   - estimation of roads' level of service

Contacts

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