A Decision Support System to plan bike mobility interventions

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Main goal of cycling planning

Facilitate the development of cycling for different types of trips (systematic, occasional, touristic ...) through interventions that encourage the use of bicycles

Recurring problems:

- BUDGET OF ADMINISTRATIONS OFTEN LIMITED
- UNCERTAINTY IN THE CHOICE OF THE MOST APPROPRIATE TYPE OF INTERVENTIONS
- DIFFICULTY IN LOCATING PRIORITY INTERVENTIONS
Goal of the project:

Implementation of a DSS (Decision Support System) aimed at supporting the administrations in the selection of infrastructure projects to be carried out under conditions of limited resources.

- Characterization of network elements via a Bike Quality Index BQI
- Definition of interventions and admissible final configurations
- Models for the calculation of cycle paths at minimum generalized cost
- Decision-making model and algorithms to determine the optimal set of interventions
A Decision Support System to plan bike mobility interventions

- Interventions and final configurations
- Characterization of network elements using BQI index
- Evaluation of interventions by means of BQI index
- Demand of cycling movements
- Models for the routes calculation and flows assignment
- Generalized cost of all users
- Optimization model for the selection of interventions
- Available budget or other constraints
- Set of interventions to be implemented
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Characterization of the network by means of a Bike Quality Index

Construction of an index that represents a Bicycle Level of Service:
• for each link (road sections)
• for each node (intersections)

The index is mainly determined by the perception of safety and comfort of the cyclists

The index is built starting from the most significant characteristics of a road section or of an intersection valued by the cyclists
Development of 3 submodels

Distinct formulations relating to alternative conditions of march

\[ y_j = c_j + \sum_i \beta_{ij} \cdot x_{ij} \]
Tuning of the 3 submodels:

Survey: Evaluation of movies

Physical and functional characteristics of elements reproduced by movies

average ratings [Y]
1 2 3 4 5 6
A B C D E F

Redefinition of the explanatory variables [X']

METODOLOGY:
Selection of significant variables [X] by backward elimination based on the t-test on the parameters and on cross-validation:
- Prevent over-parameterization (overfitting)
- Ensure statistical goodness of the least-squares linear regression

estimated parameters [C, β]

Final Model
Overall formulation of Bike Quality Index:

\[
BQI = \begin{cases} 
4.375 - 0.168 \cdot L_e + 0.794 \cdot \frac{F_1 + 0.15 \cdot F_2}{1000} + 0.220 \cdot \ln(V - 29) + 0.789 \cdot f_{parc} - 0.805 \cdot F_{cicl} + 0.876 \cdot F_{pavn} \\
4.609 - 0.892 \cdot L_c + 0.605 \cdot f_{parc} - 0.605 \cdot F_{col} + 1.089 \cdot F_{dip} \\
3.718 + 0.309 \cdot \frac{F_{tot}}{1000} + 1.147 \cdot f_{confr} - 1.012 \cdot f_{cicl} - 0.283 \cdot F_{L} + 0.820 \cdot F_{pavn}
\end{cases}
\]

(MAC) (MAP) (MN)
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BQI_{MAC} = 4,375 - 0,168 \cdot L_e + 0,794 \cdot \frac{F_1 + 0,15 \cdot F_2}{1000} + 0,220 \cdot \ln(V - 29) + 0,789 \cdot f_{parc} - 0,805 \cdot F_{cicl} + 0,876 \cdot F_{pav}

Le = \textbf{width} of the outside lane of traffic [m]
F_1 = \textbf{flow} of motorized traffic in the outside lane (adjacent to the cyclist) [veic/h]
F_2 = \text{flow of motorized traffic in the opposite direction [veic/h]}
V = \text{average speed of motorized traffic [km/h]}
f_{parc} = \textbf{parking} on the road: % occupancy [0 \div 1]
F_{cicl} = \text{presence of bike lane bordered only by horizontal strip [0|1]}
F_{pav} = \textbf{pavement}: presence of pav. class 3 (cobbles) [0|1]
**A Decision Support System to plan bike mobility interventions**

\[
\text{BQI}_{\text{MAP}} = 4,609 - 0,892 \cdot L_c + 0,605 \cdot f_{\text{parc}} - 0,605 \cdot F_{\text{col}} \\
\quad + 1,089 \cdot F_{\text{dip}}
\]

\( L_c = \text{width} \) of bike lane [m]

\( f_{\text{parc}} = \text{parking} \): % occupancy of the line adjacent to the cyclist \([0 \div 1]\)

\( F_{\text{dip}} = \text{presence of obstructions or discontinuities} \) \([0 \div 1]\)

\( F_{\text{col}} = \text{coloration} \): presence of background staining of the track \([0 \div 1]\)

Sub-model

Protected bike lane (MAP)

**Figure 14:** Segnale strada ciclabile - Germania

In Olanda, invece, vengono proposte ... - Give cycling a push, 2011

**Figure 15:** Strada ciclabile e sue caratteristiche – Olanda (Presto – Give cycling a push)
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\[ BQI_{MN} = 3.718 + 0.309 \cdot \frac{F_{tot}}{1000} + 1.147 \cdot f_{conf} - 1.012 \cdot f_{cic} - 0.283 \cdot F_L + 0.820 \cdot F_{pav} \]

\( F_{tot} = \) total flow of motorized traffic in input [veic/h]
\( f_{cof} = \) probability of conflict with motorized traffic [0 ÷ 1]
\( f_{cic} = \) factor of presence of cycle lanes [0 ÷ 1]
\( F_L = \) width factor of the branches (>4.5 m) [0 | 1]
\( F_{pav} = \) pavement: presence of pav. class 3 (cobbles) [0 | 1]
Bike Quality Index classes

BQI (1-6) [Diagram]

Bicycle Level of Service (LoS)

- A: Extremely high
- B: Very high
- C: Moderately high
- D: Moderately low
- E: Very low
- F: Extremely low
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Configuration of a network element (link or intersection)

It’s the set of physical and functional characteristics at a given moment.

It’s defined by the values assumed by each of the explanatory variables of the BQI index.

Starting configuration $j_{a, start}^i$

Possible interventions

Cost: $m_{a,i}$
(function of starting and final configuration)

Set of final configurations $j_{a, final}^i$

- Final configuration $j_{a, final}^1 = j_{a, start}^i$
- Final configuration $j_{a, final}^2$
- Final configuration $j_{a, final}^3$
- Final configuration $...$
Admissible final configurations

The set of final configurations of a network element is limited by some constraints and criteria:

- technical constraints that characterize the element itself (e.g. limited overall width of the road section)
- planning, strategic, economic constraints (e.g. funds available only for the creation of protected cycle tracks)
- avoid worsening the bicycle quality index of each element
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Evaluation of interventions through the abacus

Each starting (pre-intervention) and final (post-intervention) configuration can be evaluated by calculating the relative BQI index: \( BQI_{a}^{\text{start}} \) and \( BQI_{a,j}^{\text{final}} \).
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Model for the computation of the minimum generalized cost path

∀ o, d pair:

\[ p_{od}^{c_{min}} = \arg\min_{p \in \text{PATHS}_{od}} \left[ \lambda_1 \cdot \left( \sum_{a \in A_p} BQI_a \cdot l_a + \sum_{n \in N_p} BQI_n \cdot l_n \right) + \lambda_2 \cdot \left( \sum_{a \in A_p} t_a + \sum_{n \in N_p} t_n \right) \right] \]

- \( p_{od}^{c_{MIN}} \) minimum generalized cost path
- \( l_a, l_n \) length of arc \( a \) and node \( n \) (crossing)
- \( t_a, t_n \) travel time of arc \( a \) and node \( n \) (crossing)
- \( A_p, N_p \) sets of all arcs and nodes of path \( p \)
- \( BQI_a, BQI_n \) bike quality index of arc \( a \) and node \( n \)
- \( \text{PATHS}_{od} \) set of all paths between \( o \) and \( d \)

- **Hypothesis:** the user wants to minimize both the travel time and the BQI index
- **Weights** \( \lambda_1, \lambda_2 \) must be tuned in advance
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Cycling O/D matrix and calculation of generalized cost of all users

Known for each o/d pair:
- the minimum generalized cost of the travel
- users’ flow (from o/d matrix)

it’s possible to calculate the generalized cost of all the users:

$$C^{GEN\ TOT} = \sum_{o,d \in OD\ pairs} f_{od} \cdot \left[ \lambda_1 \cdot \left( \sum_{a \in A} c_{MIN}^{p_{od}} BQI_a \cdot l_a + \sum_{n \in N} c_{MIN}^{p_{od}} BQI_n \cdot l_n \right) + \right. \left. \lambda_2 \cdot \left( \sum_{a \in A} c_{MIN}^{p_{od}} t_a + \sum_{n \in N} c_{MIN}^{p_{od}} t_n \right) \right]$$

$p_{od}^{c_{MIN}}$ minimum cost path

$OD\ pairs$ set of all od pairs

$f_{od}$ flow between o and d

$N_{p_{od}^{c_{MIN}}}$ set of all nodes of path $p_{od}^{c_{MIN}}$

$A_{p_{od}^{c_{MIN}}}$ set of all arcs of path $p_{od}^{c_{MIN}}$
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Optimization model for the selection of interventions

Goal:

determine the set of interventions on road sections and on intersections that minimizes the overall generalized cost of travels:

\[ \text{minimize } C^{\text{GEN TOT}} \]

subject to a main constraint:

- fixed total budget: \[ \sum_{a \in A, j \in J_{a}^{\text{final}}} m_{a,j} \leq BUDGET \]
- and/or maximun number of interventions: \[ \sum_{a \in A, j \in J_{a}^{\text{final}}} z_{a,j} \leq N_{int} \]
Mathematical Programming formulation

\[ y_{a,j} = \begin{cases} 1 & \text{if intervention } j \text{ on arc } a \text{ is performed} \\ 0 & \text{otherwise} \end{cases} \]

\[ x_{a}^{od} = \begin{cases} 1 & \text{if arc } a \text{ is traveled in the } od \text{ path} \\ 0 & \text{otherwise} \end{cases} \]

\[
\text{minimize} \sum_{od \in ODpairs} f_{od} \cdot \left( \lambda_1 \sum_{a \in \bar{A}} l_a \left( BQI_{a,\text{start}}^{\text{start}} - \sum_{j \in I_{a}^{\text{final}}} \Delta BQI_{a,j} y_{a,j} \right) x_{a}^{od} + \lambda_2 \sum_{a \in \bar{A}} t_a x_{a}^{od} \right) 
\]

subject to: \[ \sum_{j \in I_{a}^{\text{final}}} y_{a,j} \leq 1 \quad \forall a \in \bar{A} \]

subject to budget constraint and path constraints

where intersection are represented as arcs and so: \[ \bar{A} = A \cup N \]
APPLICATION TO A STUDY AREA

Milano (City Centre + “Città Studi”)
BQI index for carriageway and protected bike lanes
Demand: use of BikeMi (bike sharing) O/D
Assignment of cycling trips:
Determining the ranking of the best interventions:

<table>
<thead>
<tr>
<th>type of intervention</th>
<th>link</th>
<th>% improvement of $C_{\text{GEN TOT}}$</th>
<th>increase of cyclists on the arc [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>cycle-pedestrian area creation</td>
<td>via Torino</td>
<td>0,81</td>
<td>63</td>
</tr>
<tr>
<td>cycle-pedestrian area creation</td>
<td>via Mazzini</td>
<td>1,52</td>
<td>64</td>
</tr>
<tr>
<td>cycle-pedestrian area creation</td>
<td>via Rastrelli</td>
<td>2,14</td>
<td>103</td>
</tr>
<tr>
<td>cycle-pedestrian area creation</td>
<td>via Cordusio</td>
<td>2,72</td>
<td>51</td>
</tr>
<tr>
<td>cycle-pedestrian area creation</td>
<td>Largo Cairoli</td>
<td>3,3</td>
<td>41</td>
</tr>
</tbody>
</table>
Determining the ranking of the best interventions only on cycle paths

<table>
<thead>
<tr>
<th>type of intervention</th>
<th>link</th>
<th>% improvement of $C_{GEN \ TOT}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>cycling track continuity restoration</td>
<td>via Molino delle Armi</td>
<td>0,07</td>
</tr>
<tr>
<td>cycling track continuity restoration</td>
<td>via Francesco Sforza</td>
<td>0,12</td>
</tr>
<tr>
<td>cycling track coloring</td>
<td>via Carducci</td>
<td>0,15</td>
</tr>
</tbody>
</table>
Thank you for your attention

For any question luca.studer@polimi.it