ETH zürich

D BAUG

D-BAUG Lighthouse Project: E-Bike City Subproject E

Spatial optimization of large-scale street network redistribution under flow, accessibility and exposure constraints

Nina Wiedemann, Henry Martin, Martin Raubal
Mobility Information Engineering (MIE) Lab, Chair of Geoinformation Engineering, ETH Zürich

1 Introduction

The optimization of street networks has been a key part of GIS and transportation literature for a long time [1]. However, the allocation of bike lanes has mainly been regarded as an iterative process, where a low number of new lanes is added to an existing network [2]. A major redistribution of urban space, such as considered in the *E-bike City Project*, offers new opportunities to optimize bike and car lane allocation according to complex spatial constraints.

2 Problem setting

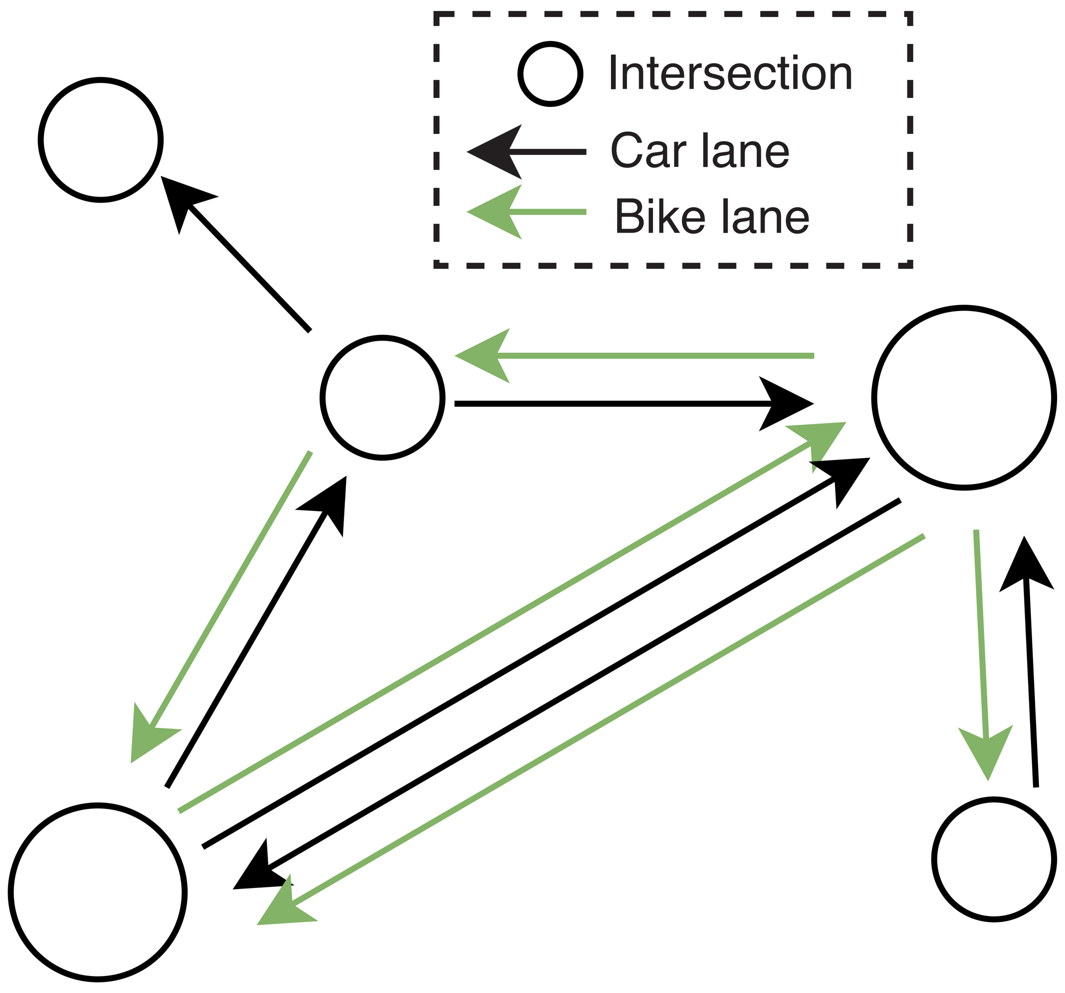


Fig. 1 Optimizing street network allocation

The current street network is extracted from Open Street Maps (subproject C) and represented as a graph with intersections as nodes and edges as lanes. The conversion of up to 50% of the space to bike lanes can therefore be modelled as a graph optimization problem (Fig. 1) with the following targets and constraints:

Targets

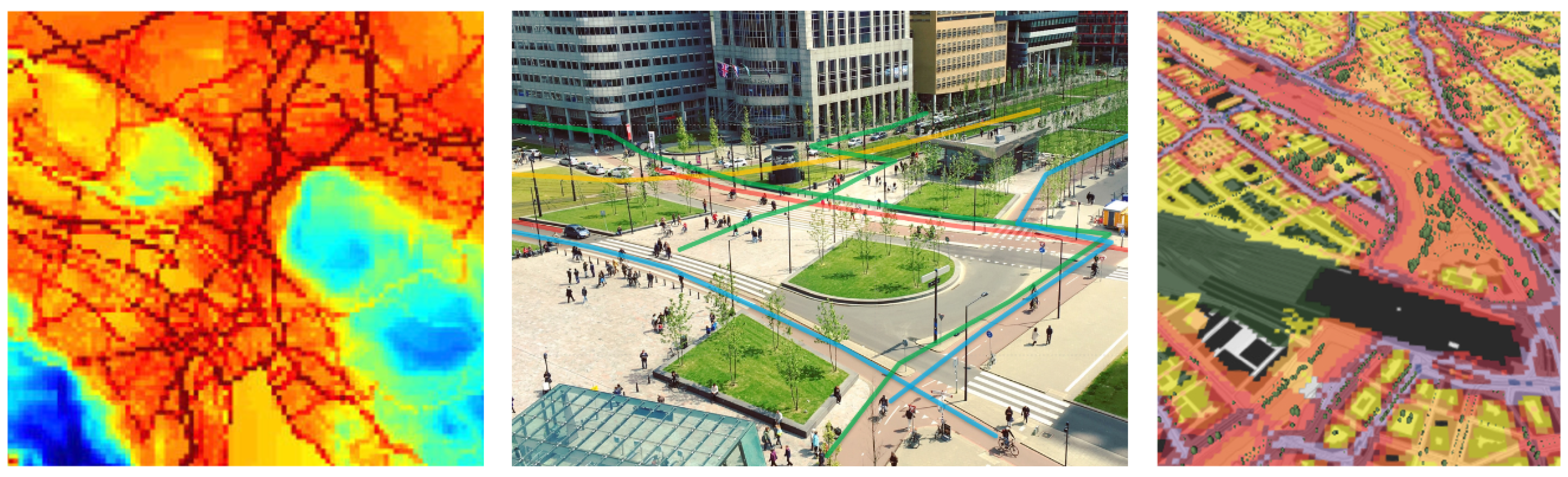
1. Maximize connectivity (flow) of car lane subgraph
2. Maximize connectivity (flow) of bike lane subgraph
3. (Multi-modal) accessibility of key points
4. Minimize risk exposure on bike lanes

Constraints

1. Reallocation constraint (around 50% should be bike lanes)
2. Infrastructure constraints (maximum lane capacity)
3. Public transport constraints, e.g. fixed bus lanes

The basic formulation of this problem, namely a discrete assignment of edges to either the car or the bike lane network (Fig. 1), is a mixed-integer problem and is therefore NP-hard. However, iterative schemes [4] or approximations can yield applicable solutions.

3 Methods



a) Air quality (Opensense) b) Mutli-modal accessibility c) Noise levels (BAFU)

Fig. 2 Spatial constraints for optimizing street network layout

This research aims at 1) the identification of suitable criteria and their efficient computation from spatial data, and 2) the optimization of the network according to these criteria. We proceed in the following steps:

- **GIS analysis:** In the first step, we will develop a GIS-based tool for evaluating a street network according to spatial constraints. As shown in Fig. 2, this includes the calculation of the level of exposure to heat, noise and air quality. Furthermore, different accessibility measures for uni- and multi-modal chains will be developed, consdering insights from previous studies [3].
- **Baseline:** A baseline approach is a simple minimum spanning tree of the street graph, fulfilling only connectivity constraints.
- **Spatial optimization** Last, the bike network layout will be optimized with respect to quality measures from the developed GIS tools. This could, for example, be achieved with a relaxed multi-commodity flow formulation.

4 Outlook

The solutions from this subproject will lead to street network alternatives that are optimized according to different spatial criteria. This significantly enriches the analysis of the e-bike city project, as the variance of downstream analysis results (e.g. safety, costs, and emissions) dependent on the new network layout can be assessed. Furthermore, our work aims to provide a computational tool for decision-makers to propose targeted redesign solutions and to compute spatial measures such as accessibility efficiently.

5 References

[1] Guo-Ling Jia, Rong-Guo Ma, and Zhi-Hua Hu. “Review of urban transportation network design problems based on CiteSpace”. In: *Mathematical Problems in Engineering* 2019 (2019).

[2] Luis Guillermo Natera Orozco et al. “Data-driven strategies for optimal bicycle network growth”. In: *Royal Society open science* 7.12 (2020), p. 201130.

[3] Daniel J Reck, Henry Martin, and Kay W Axhausen. “Mode choice, substitution patterns and environmental impacts of shared and personal micro-mobility”. In: *Transportation Research Part D: Transport and Environment* 102 (2022), p. 103134.

[4] Christoph Steinacker et al. “Demand-driven design of bicycle infrastructure networks for improved urban bikeability”. In: *Nature Computational Science* (2022), pp. 1–10.

MIE lab

geoinformation engineering ikg eth zurich