Multi-Stakeholder Interests in Urban Transport Design: A Bi-Level Optimization Approach for Activity-Based Network Design Problems

Sebastian Brulin
Honda Research Institute Europe,
Offenbach/Main, Germany

Urban transport planning is a complex task due to the multitude of stakeholders involved, including operators, city planners, and transport system users, following their interests and objectives. One of the key challenges in urban network design is the Facility Location Problem (FLP), a multi-objective optimization problem with a diverse range of criteria from the different stakeholders that must be optimized concurrently. This issue has been addressed from various perspectives, recent contributions adopted cooperative approaches for FLP processes [1], [2] and demonstrated how the users could be integrated into the design process. Given that these criteria often represent the objectives of different stakeholders with opposing targets, this paper utilizes a multi-objective bi-level optimization approach to address the FLP. The purpose is to quantify and compare different solutions fullfilling the stakeholder interests, thereby supporting the decision-making process.

Within this study a bi-level optimization framework is utilized to solve the FLP, taking the distribution of Urban Air Mobility (UAM) vertiports as an example. The presented framework involves two interconnected optimization processes that operate alternately. At the outer loop, a Genetic Algorithm (GA) undertakes network optimization, employing a Pareto optimal Non-Dominated Sorting Genetic Algorithm (NSGA-III) to determine the optimal positions for UAM vertiports based on a set of objectives introduced later. The solutions generated at this level are subsequently evaluated at the lower level using an activity-based multi-agent transport simulation (MATSim), as illustrated in Fig. 1. This approach facilitates the exploration of the NDP variant of the Activity-Based Network Design Problem (AB-NDP). It enables the incorporation of recoupling effects on the supply and demand sides of the transport system once a new transportation mode is introduced. Consequently, it considers not only the behavior of agents using the UAM mode but also related factors like network capacity congestion, rush hour traffic, and overall system travel times, integrating these elements in the design process.

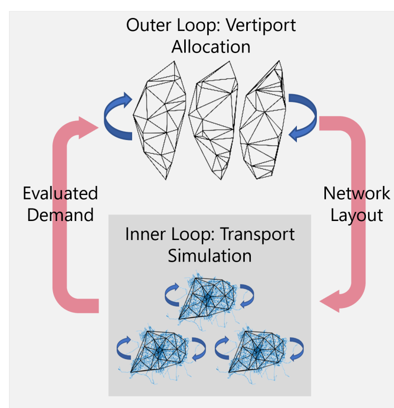

Fig. 1: Proposed bi-level optimization framework: UAM vertiport allocation on the outer loop and transport simulations on the inner loop.

This study presents a framework that derives a set of Pareto optimal solutions for the objectives: (1) profitability, (2) service distribution, and (3) system efficiency, see Fig. 2. These objectives serve to reflect the perspectives of operators, transport system users, and city planners.

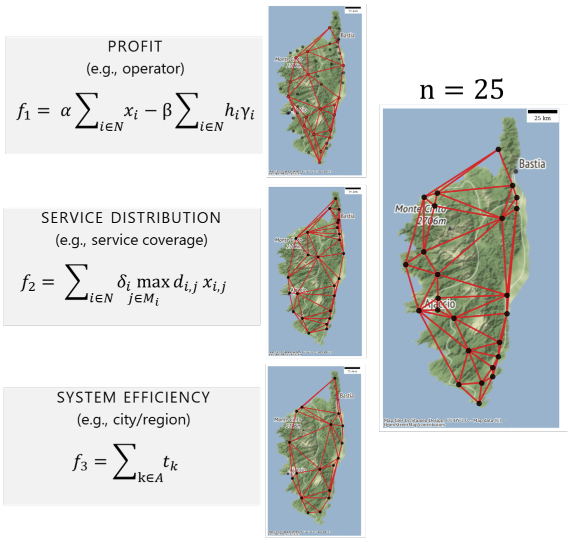

Fig. 2: Objective Formulations and corresponding optimal network design and one found knee point solution from Pareto set.

An open-source simulation of the Corsica [1] region is used [3], [4]. The existing transportation modes are extended through the inclusion of a UAM system via the open-source extension MATSim-UAM [2] [5]. This extension enables the addition of infrastructure and a transportation mode for an aerial mobility service.

Previous studies have shown that solutions obtained from the AB-NDP can surpass static one-level approaches on multiple objectives (e.g., demand and total travel time savings) [6], [7]. In this study, the analysis is expanded to incorporate multiple stakeholders' perspectives and to evaluate the formulation of objectives and their implications on the transport network. A new network design approach is introduced to enhance system efficiency and robustness within a multi-modal transport system. The implications of the non-dominated solutions found on the transportation system are demonstrated.

The proposed framework offers an initial insight into the application of activity-based simulations for solving traditional network design problems, presenting a use case in a multi-stakeholder scenario. The implications of varying network design objectives and their formulations are evaluated and trade off solutions are explored.

[1]https://github.com/eqasim-org/ile-de-france
[2]https://github.com/BauhausLuftfahrt/MATSim-UAM

References

[1] T. Jatschka, T. Rodemann, and G. R. Raidl, "Exploiting similar behavior of users in a cooperative optimization approach for distributing service points in mobility applications," in *5th International Conference on Machine Learning, Optimization, and Data Science.* Springer, 2019, pp. 738–750.

[2] T. Jatschka, G. R. Raidl, and T. Rodemann, "A general cooperative optimization approach for distributing service points in mobility applications," *Algorithms*, vol. 14, no. 8, p. 232, 2021.

[3] K. W. Axhausen, A. Horni, and K. Nagel, *The multi-agent transport simulation MATSim.* Ubiquity Press, 2016.

[4] M. Balac and S. Hörl, "Synthetic population for the state of california based on open-data," in *100th Ann. M. Transp. Res. B.*, 2021.

[5] R. Rothfeld, M. Balac, K. O. Ploetner, and C. Antoniou, "Agent-based simulation of urban air mobility," in *2018 Mod. Sim. Tech. C.*, 2018, p. 3891.

[6] S. Brulin and M. Olhofer, "Bi-level network design for uam vertiport allocation using activity-based transport simulations," in *6th International Electric Vehicle Technology Conference*, 2023.

[7] J. Chow, *Informed Urban transport systems: Classic and emerging mobility methods toward smart cities.* Elsevier, 2018.