AGILE: GIScience Series, 6, 49, 2025. https://doi.org/10.5194/agile-giss-6-49-2025
Proceedings of the 28th AGILE Conference on Geographic Information Science, 10–13 June 2025.
Eds.: Auriol Degbelo, Serena Coetzee, Carsten Keßler, Monika Sester, Sabine Timpf, Lars Bernard
This contribution underwent peer review based on a full paper submission.

Estimating the Ride-Sharing Potential for Universities in Hanover: An Integer Programming Approach

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Abstract. This study explores the potential of ride-sharing as a sustainable transportation option for universities in Hanover, Germany, by using an integer programming optimization model. Based on data from a detailed survey of university members, the simulation aims to match participants while respecting constraints such as vehicle seating limits and acceptable detour distances. The model is applied to two scenarios, demonstrating that even with a limited number of participants, it is possible to achieve meaningful reductions in vehicle usage, travel distance, and emissions by improving vehicle occupancy. Notably, higher tolerances for detours enable the inclusion of individuals without access to a vehicle. While the model offers an optimistic perspective, it highlights the substantial potential of organized ride-sharing to ease traffic congestion and lessen environmental impact.

Submission Type. analysis

BoK Concepts. [GC2-4] Equation-based models, [AM12-3] Integer programming, [TA11-3] Users in infrastructure & transport

Keywords. car pooling, ride-sharing, commute, sustainable mobility

1 Introduction and Overview

In 2022, the average occupancy rate of cars in Germany was just 1.4 persons per vehicle (Umweltbundesamt, 2022). This rate is believed to be even lower for daily commutes, indicating substantial inefficiency in personal vehicle use. Such low occupancy rates contribute to a range of sustainability and traffic-related issues, including increased congestion and higher emissions. To address these issues, ride-sharing systems for organized car-pooling offer significant potential to reduce both traffic volume and environmental impacts (Agatz et al., 2012).

As part of a research project, we plan to implement a dynamic ride-sharing system tailored for four collaborating higher education institutions in Hanover, Germany. This system will include an application that automatically arranges car pools by matching drivers and passengers. Although ride-sharing has many benefits, several factors influence its uptake. General, factors affecting the willingness to ride-sharing are demographic factors (age, income, etc.), psychological factors (e.g., saving money or time, comfort, socializing, trust), interventions (e.g., parking availability, guaranteed ride) as well as situational factors (fixed/regular work schedule, commute distance, fuel costs) (Julagasigorn et al., 2021).

Various studies address these challenges by proposing methods to optimize different components of ride-sharing systems. For example, Furuhata et al. (2013) provide a comprehensive overview of state-of-the-art models and future directions, emphasizing the importance of dynamic matching algorithms, user trust, and route optimization. Further approaches focus on alleviating certain factors, e.g., the selection of optimal meeting points (Czioska et al., 2019), as well as optimizing the matchmaking (Agatz et al., 2012).

Unlike public ride-hailing platforms, our approach focuses on a closed user group: only members of the partner institutions can participate. Such an exclusive setup is expected to foster a higher level of trust, as users share a common affiliation and likely similar objectives. This choice aligns with findings in previous studies (e.g. Olsson et al. (2019)), which suggest that shared community identity can enhance the effectiveness and adoption of ride-sharing services. Interestingly, also social networks can have a similar effect (Mirisaee et al., 2013).

As an initial step in the related project, a comprehensive mobility survey was conducted among university members, including students and employees. While responses indicate that carpooling is currently rare (about 1 %), they also reveal a strong interest in ride-sharing and a desire for additional incentives to boost the system's appeal and acceptance. This survey data forms the foundation for an initial analysis of the potential, presented in this work. It aims to find out, what is the saving potential if ride-sharing would be practiced. It explores two major parameters in their impact, namely (1) different occupancy limits and (2) detours required to pick up passengers.

The analysis addresses the following research questions:

1. Can enough passengers be found in the neighborhood of the drivers to increase the vehicle occupancy, even with the limited university population?
2. Is it possible to save on the total emissions despite detours to collect additional people?
3. Does the system offer the capacity to carry additional people without a car in order to expand their mobility options?

This preliminary estimation of ride-sharing potential does not capture the full range of features typically found in commercial platforms. Commercial ride-sharing services often try to optimize routes and matches on demand, to provide maximum flexibility with pick-up or drop-off along the route. Further, they integrate other travel modes and consider different time schedules of the participants. In contrast, this analysis focuses primarily on the basic feasibility of ride-sharing in a university context. Nevertheless, this analysis of the potential is a critical step in evaluating both the effectiveness and scalability of a university-based ride-sharing solution. Our future work will build on these initial findings, incorporating more advanced elements to produce a more robust and realistic assessment of ride-sharing efficiency and user acceptance.

2 Matching Approach

In a ride-sharing system, participants are typically assigned to vehicles based on their starting points and destinations, with the option of picking up additional passengers along the route if travel paths overlap. In this initial study, however, we adopt a simplified approach: we do not account for picking up or dropping off passengers along the route. Instead, we focus only on shared trips among participants with broadly similar origins and destinations. Given the small number of distinct destinations, participants are grouped by their target university campus. Within each group, drivers (i.e., participants with access to a car) collect the nearest passengers. Furthermore, in the absence of detailed scheduling data, we assume that all participants travel at compatible times. This simplification reduces the analysis to an optimization problem, which is described in the following.

In this ride-sharing scenario, let

$$P = \{p_1, p_2, \dots, p_n\} = P_{\text{no car}} \cup P_{\text{has car}} \tag{1}$$

be a set of n people with interest in car-pooling and commuting to the same institution/campus. Some have access to a car ($P_{\text{has car}}$) with a maximum seating capacity s, others not ($P_{\text{no car}}$). Each person p_i has a target location and needs to be assigned as driver of its own car or passenger with another, such that the total cost (linear travel distances) is minimized. While ensuring that no vehicle exceeds its seating capacity and avoiding unrealistic detours, car owners can drive alone, if necessary, but those without own car might not be matched.

These simplifications allow the modeling to be guided by capacitated facility location problems. Solving this type of problem exactly is NP-hard (Megiddo and Tamir, 1982), which is why approximate solutions become necessary and with increasing size larger solution gaps have to be accepted. The aim is to assign a demand (in this case people willing to travel) to the distance-optimized, capacity-limited facilities (in this case vehicles).

There is a binary model variable x_{pd} for representing the relationships between the persons, in the form of whether p rides with d or the driver rides with himself. As vehicles are clearly linked to their drivers, they can be represented in combination. The usual variable for selected facilities in FLP is therefore not required and is formulated via self-assignments (x_{dd}).

$$x_{pd} \in \{0, 1\} \quad \text{with } p, d \in P \tag{2}$$

Although in practice, depending on the situation, passengers are picked up at home, meet the driver at a meeting point or walk/ride to the driver independently, as a rough estimate, only simple (air) distances between the drivers and passengers are assumed in this analysis. The costs to be optimized are approximated by the total linear (air) distances of the passengers to the drivers (d_{pd}) and drivers' (x_{dd}) commuting distances (d_d), supplemented by the commuting distances (d_p) of unmatched persons as a penalty term to avoid those:

$$\min \sum_{p \in P} \sum_{d \in P} d_{pd} \cdot x_{pd} + \sum_{d \in P} d_d \cdot x_{dd} + \sum_{p \in P} d_p \cdot (1 - \sum_{d \in P} x_{pd}) \tag{3}$$

Furthermore, additional constraints arise from the problem definition and performance optimization. For example, each person can be assigned to only one driver, and only individuals with a car can serve as drivers. Moreover, car owners must also be designated as passengers – even if they are effectively riding with themselves.

$$\sum_{d \in P} x_{pd} \leq 1 \quad \text{with } p \in P \tag{4}$$

$$\sum_{p \in P} x_{pd} = 0 \quad \text{with } d \in P_{\text{no car}} \tag{5}$$

$$\sum_{d \in P} x_{pd} = 1 \quad \text{with } p \in P_{\text{has car}} \tag{6}$$

Not only the capacity of cars (s) is restricted (count including driver), but also the additional detours for drivers should be considered for realistic matches. For this purpose, the distances to their passengers must not exceed a certain proportion (a) of their commute.

$$\sum_{p \in P} x_{pd} \leq s \cdot x_{dd} \quad \text{with } d \in P \tag{7}$$

$$\sum_{p \in P} d_{pd} \cdot x_{pd} \leq a \cdot d_d \quad \text{with } d \in P_{\text{has car}} \tag{8}$$

Two further conditions are added to directly exclude pairs with too large or too small distances to the destination. This also ensures a better performance.

$$x_{pd} = 0 \quad \text{with } p \in P, d \in P_{\text{has car}} : d_{pd} > a \cdot d_d \tag{9}$$

$$x_{pd} = 0 \quad \text{with } d \in P_{\text{has car}} : d_{pd} > d_p \tag{10}$$

3 Analysis of the ride-sharing potential

To analyze possible effects of introducing a ride-sharing system, the information from a mobility survey is processed to create a synthetic population and use it as input for the optimization model described above. Two different scenarios ((A) only current car users interested in ride-sharing and (B) all interested people), each with various limits for detours and seats, are simulated.

3.1 Preparation of Input Data

The analysis is based on a mobility survey conducted at the four organizations (Leibniz University Hannover, Hannover Medical School, University of Applied Sciences and Arts, Leibniz Information Centre for Science and Technology and University Library) among students and employees in summer 2024. Although the survey achieved a good feedback, we need to upsample the survey dataset to a synthetic university population of real size and balance.

3.1.1 Mobility Survey

The mobility study was prepared and carried out as part of the research project DiNaMo under the leadership of project partners, who also processed the feedback. It was sent to all (in total about 51,629) students and employees at the participating institutions as an online survey by email in summer 2024. After cleaning, 3,978 questionnaires were evaluated, with the participation rate varying between the institutions and in particular between employees (13.1-34.8 %) and students (2.1-4.5 %). The survey includes questions about status group at the university, work place, presence times, mobility equipment (e.g., car, bike), mobility choice at good/bad weather and business trips, aspects of decision and motivation for mobility modes, and personal aspects like home, income and kids. After removing obvious duplicates and inconclusive information, the dataset was pseudonymized to protect the participants.

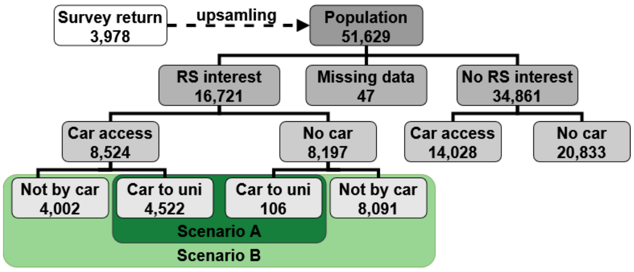

Figure 1. Upsampled population split by interest in ride-sharing, car access, and whether they currently commute by car. The two scenario populations used in the analysis are highlighted.

For this study, the responses were extrapolated to the whole population in the following way: the entries are first weighted inversely according to the response rate of the respective group (students and employees) and institution and then sampled up to the total number of mailing lists.

From the population, 43.8 % have access to a car, but depending on the weather only 13.1-16.6 % commute primarily by individual motorized vehicles (9.0-9.9 % by foot, 29.2-43.4% by bicycle and similar, 31.7-43.3 % by public transport). Here, the majority of students with very low car access reduce the higher prevalence among employees, which is still well below the general Hanover Region average of 47 % (van Zadel, 2018). About 1 % of the participants state that they already use ride-sharing. In addition, respondents were asked which factors would motivate them to use ride-sharing (e.g. flexible use, meeting point directly at home/work, reliable return trip, the option to share costs, but also that nothing could motivate them). Accordingly, 32.4 % would be open to ride-sharing in principle. The others were considered as refusers and thus formed a share of 67.6 %, and were excluded in the following analysis. The median distance between home and university is 6.0 km, with many people living in the immediate vicinity and a few very far away. A comparison based on attitudes towards ride-sharing shows that those who are interested live in a median distance of 10.0 km, which is further away than those who refuse (5.6 km).

Figure 1 gives an overview of the upsampled population. From those interested in ride-sharing, 8,524 people own a car, but do not necessarily use it for their daily commuting; only 4,512 of them are using it. 8,197 people have stated interest in ride-sharing, but do not own a car.

3.1.2 Preparation of Synthetic Population

The basis for a realistic assessment is the information on the home locations as zip codes and the target campus. In order to synthesize a realistic distribution, this information is mapped to the zip code areas (from OpenStreetMap contributors (2025)) and then, in turn is intersected with the 100 m cells of the German census in order to sample a point, weighted according to their population size. In this way, the rough distribution of people is disaggregated based on the distribution of the total population.

With the corresponding information from the survey on commuting destinations and car availability, a geographically extrapolated demand is prepared.

3.2 Simulation study

We use the model introduced in section 2 to simulate two different sets of people resulting in two scenarios to analyze. Based on the data of the survey, refusers of ride-sharing are excluded from the calculation, as they would not participate at all.

3.2.1 Scenario A: Interested car users

This scenario includes only people currently commuting by car and showing interest in ride-sharing (see Figure 1). The advantage is that almost all of the current car commuters have access to a car and therefore 4,522 of the 4,628 people considered are potential drivers. At the same time, there is a lot of potential for saving vehicles. A disadvantage could be the limited group of people and thus the potentially lower spatial density, which restricts accessibility of passengers in the neighborhood and limits matches.

3.2.2 Scenario B: All interested

In the second scenario, we optimistically assume that all people who expressed interest in ride-sharing will potentially participate. Based on the population in Figure 1 additional 4,002 potential drivers and further 8,091 possible passengers are added to the considered pool of persons. Thus, compared to scenario A, 3.6 times more people are considered in this ride-sharing scenario.

3.3 Implementation

We formulate the matching approach described in section 2 as linear integer problem. To be able to solve the problem with the Gurobi solver (Gurobi Optimization, LLC, 2024), we have to introduce a simplifying assumption. We assume that only people with the same destination travel together which allows us to break down the overall problem into independent sub-problems for each destination. This leads to eight target locations for the four institutions; due to the different sizes of the institutions, they vary vastly in number of people. In order to be able to calculate several scenarios with varying parameters, the solution gap (approximated difference to the optimal solution) was set to 2 %. However, due to the partly randomly distributed population, we do not expect advantages from a more optimal solution.

For the two participation scenarios, studies on two parameters were conducted: occupied seat limit and detour limit – related to extra trips necessary to collect the passengers. The number of available seats in the cars is varied from one (only the driver) to five (four passengers). In addition, experiments with different limits for detours are carried out. These constraints are given in terms of the percentage of the drivers' original distance and are evaluated for the values 5, 10, 20 and 50 %.

4 Results and Discussion

For the evaluation, the results from the individual destination sub-problems were combined to provide a complete overview. The main outcome of the optimization is the assignment of passengers to drivers and their respective vehicles. From this, both vehicle occupancy and the number of transported persons can be directly determined. Additionally, the air distances between drivers and passengers origins as well as their destinations were used to estimate emissions. These estimates are based on average CO_2 equivalent values per kilometer for different modes of transportation and vehicle types, as reported in Umweltbundesamt (2022) for Germany. When converting from person-kilometers to vehicle-kilometers using an average occupancy rate of 1.4, the resulting emissions are approximately 236.6 g/km for combustion engines, 169.4 g/km for hybrids, and 110.6 g/km for electric vehicles. Since air distances are used, these estimates are optimistic in absolute terms. However, since comparisons are made on a relative basis, this simplification is acceptable.

4.1 Scenario A: Interested car users

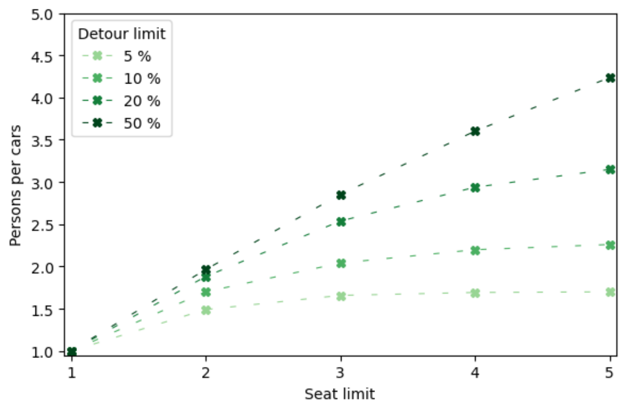

Figure 2. Average car occupancy (persons per car) based on detour and seat limits for scenario A.

First, a look at the minimum scenario A to estimate how the current situation would develop with pooling. As expected, Figure 2 shows that with an increase in the allowed seat count, more people are matched and thus the average vehicle utilization increases. With regard to research question 1, the current number of interested drivers is in general sufficient to find matching partners. There is also an effect of the detour limit, as higher limits have occupancy rates. However, especially with the lower detour limits, it reveals the limitations of the restricted group of people. For example, at 5 % detour, the utilization of the vehicles hardly increases despite increasing the seat limit to over three, since no more passengers are likely to be found in the restricted vicinity of the drivers.

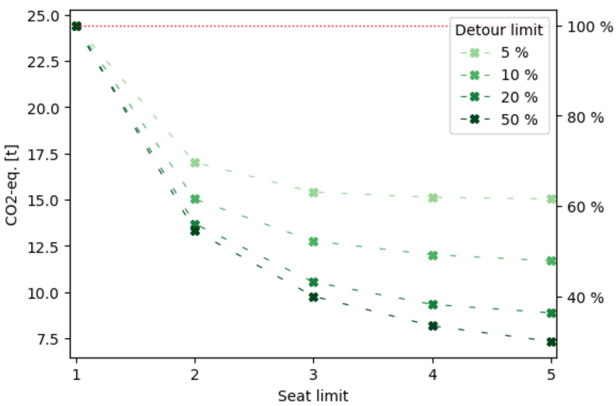

Figure 3. Approximated emissions based on detour and seat limits for scenario A, with current estimation as dashed baseline.

The estimated emissions resulting from travel distances are shown in Figure 3 and follow a similar trend. Inevitably, by pooling, many of the previous solo drivers are now passengers and thus no longer use their car – leading to a strong reduction in CO_2-equivalent – even with a conservative detour limit of 5 %. So research question 2 can be confirmed for this scenario, as emissions are reduced by about 30 % already with the minimal parametrization – with regard to both seat and detour limits.

RQ 3 is skipped in this scenario, as the population is restricted to car-users.

4.1.1 Scenario B: All interested

Compared to the previous scenario, the pool of potential participants is expanded to include all interested persons, including those who do not yet commute by car. In general, the trends are comparable to those in scenario A, but with differences in detail. This also applies to the average vehicle utilization, as shown in Figure 4, which increases with the acceptance of higher detours and passengers. Due to the larger group of people, the saturation already observed in A can be seen here at higher occupation rates (e.g. 2.4 persons/car instead of 1.7 for 5 % detour limit). With detours of up to 50 %, the increase is almost linear and thus almost unlimited. With regard to RQ 1, additional participants are therefore definitely an advantage concerning the utilization.

It should be noted that, compared to A, the extended group of participants not only includes potential passengers, but

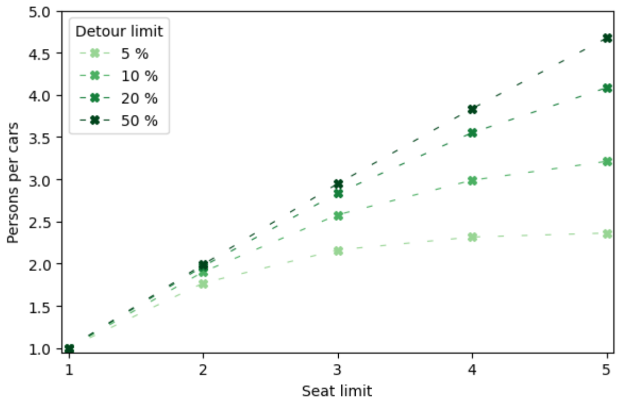

Figure 4. Average car occupancy based on detour and seat limits for scenario B.

also other potential drivers. Especially in the case of a seat limit 1, all 8,524 interested persons with car access initially are forced to drive alone. The baseline drawn in Figure 5 represents the emission balance of the current situation, i.e. the situation specified in the survey, and depicts other specified means of transport in addition to the car. The initial worsening of the CO_2 balance is therefore the result of people initially switching from other means of transport to their own cars, compared to the initial situation. However, it also shows that with the start of pooling from a seat limit of two, the baseline range is reached again directly and falls below it with an increase in the parameter values. Consequently, with regard to RQ 2, a saving is possible with higher accepted limits – despite switching from initially lower-emission modes of transport – thanks to fewer cars with higher occupancy rates.

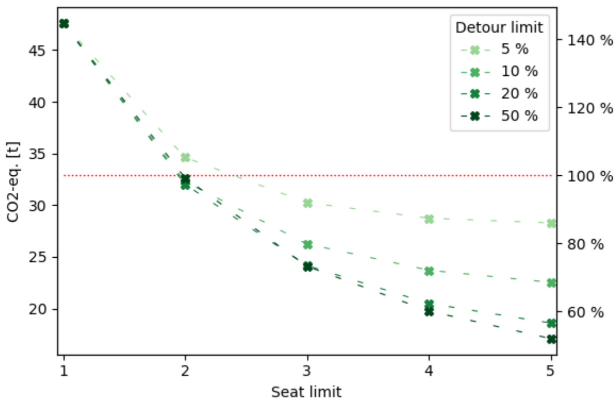

Figure 5. Approximated emissions based on detour and seat limits for scenario B with current estimation as dashed baseline.

Especially for this scenario with many additional people without car availability, the question arises with RQ 3: how much additional capacity does the system offer for them? Figure 6 shows how many people are transported depending on the parameterization. By enabling pooling with an occupancy rate of larger than one, an increase from about 50 % of people (those with car availability) to 70 % and more can be observed. Thus, in addition to the previously discussed savings, more people are transported, up to over 90 % of all interested people at high detour and seat limits.

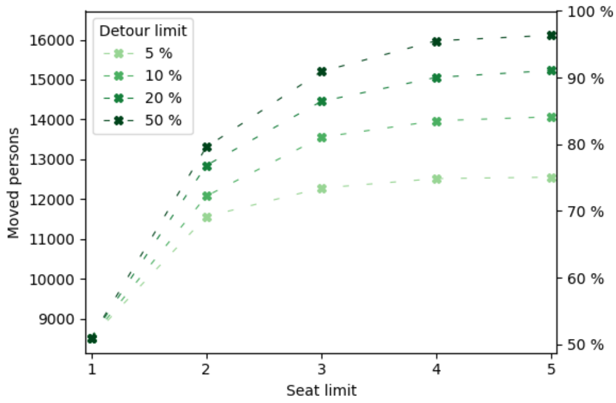

Figure 6. Moved people based on detour and seat limits for scenario B.

5 Summary and Outlook

This admittedly optimistic analysis gives some insights into the potential of a ride-sharing service at universities and shows that the number of people and their geographical distribution is at least theoretically sufficient to share many rides. This makes it possible to increase the vehicle occupancy (RQ 1) and by this reduce the required number of vehicles and traveled distances to drop emissions (RQ 2). Also, the system offers capacities for people without an own car and thus enriches their mobility options (RQ 3).

This study also serves as a basis for the introduction of a real ride-sharing application. The metrics determined in this study can be used to convince potential users of the benefits of such a system. Furthermore, with a real application, data on the usage can be collected and obstacles in real operations identified. The time aspect left out of this study is likely to be quite critical in practice and can lead to difficulties in finding matching partners. Furthermore, effects of certain settings can be studied, e.g. posting of planned trips early could result in higher chances of success than last-minute requests and offers. In general, it can be assumed that there is different demand for central and university-connected residential areas and those in the outskirts of the city or in close vicinity.

Further, a major issue will be the inclusion and investigation of incentives to motivate commuters to use such a service. Among the incentives, elements such as travel time, cost, "green conscience", flexibility, prioritized parking, and reliability can be addressed and exploited to encourage travelers to use such a service.

A general reduction of car usage and preference of alternative mobility should be preferred – not only from a sustainability point of view. It is also beneficial for the general traffic flow, for gained space in public areas and not least on campuses. In addition, the system can be very beneficial in cases where alternatives are not available, e.g. in the outskirts of a city with low service of public transportation. It can be expected that there will always be drivers, who decide to continue using their car: they can provide driving options for others and thus increase efficiency and the environmental footprint of the now joint mobility.

Emission savings could be further leveraged by giving preference to more economical vehicles when matching. In case of doubt, e-car owners could be given preference as drivers and give combustion engine owners a ride. For an overall assessment, this would also have to be placed in the context of alternative forms of mobility, as attractive additional options can always lead to a certain amount of migration and, for example, individuals who are dissatisfied with public transport could switch.

Data and Software Availability

Due to privacy concerns, the survey raw data cannot be published. However, based on the described preprocessing, own (synthetic) input data can be sampled to test the general methodology. The zip code areas used for the rest of the preparation are free data obtained from OpenStreetMap, as is the population grid of the census.

The processing of the data was implemented in Python 3.13 and the packages gurobipy, pyproj, folium, pandas, geopandas, shapely, numpy and pickle. As solver for the integer programming problem the commercial Gurobi (Gurobi Optimization, LLC, 2024) was used with a free academic license. There are (free) alternatives to which the model formulation could be transferred.

Declaration of Generative AI in writing

The authors declare that they have used Generative AI tools in the preparation of this manuscript. Specifically, AI tools were utilized for literature review, language editing and sentence structure, but not for generating scientific content, research data, or substantive conclusions. All intellectual and creative work, including the analysis and interpretation of data, is original and has been conducted by the authors without AI assistance.

Acknowledgements

We would like to thank the project partners and in particular our project colleagues at the Sociology Department of Leibniz University Hannover for the conduction of the survey we used. Further, we thank the university IT services (LUIS) for providing computational cluster access.

This work is funded via the German Federal Ministry of Education and Research (BMBF) under the grant 01UV2301A 'DiNaMo'.

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