Matching analysis for peer-to-peer car-sharing using synthetic populations in France

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Short summary

Peer-to-peer (P2P) car-sharing enables privately owned vehicles to be temporarily shared through digital platforms, yet its realistic urban potential remains insufficiently understood. This study applies synthetic populations to assess P2P car-sharing potential. Daily activity–travel patterns are analyzed to extract demand and supply. A two-step assignment process identifies spatially and temporally feasible matches and determines compatible assignments under operational constraints. The framework is applied to French cities, Dunkirk, Nantes, and Paris, representing diverse urban contexts. Results show that walking distance strongly influences matching levels, while temporal patterns are consistent across cities. A significant share of individuals have no feasible match, revealing spatial and temporal imbalances, while a small subset accounts for most interactions. Findings indicate that P2P car-sharing shows the potential to reduce car ownership and parking demand, and support public transport in low-access areas. The framework provides a scalable tool for assessing operational feasibility at the urban scale.
Keywords: Peer-to-Peer Car-Sharing; Accessibility; Shared Mobility Solution; Synthetic Population

1 Introduction

Urban transportation systems face increasing pressure, creating a need for innovative solutions to improve efficiency and sustainability Alisoltani et al. (2022, 2021). Shared mobility systems have gained attention due to their ability to improve accessibility and resource utilization. Car-sharing enables users to access vehicles when needed, without owning a private car, typically through a distributed fleet available at multiple locations across a city S. Shaheen et al. (2001). Previous studies have identified several benefits of car-sharing systems. In particular, they expand mobility options in areas with low accessibility, especially where public transportation (PT) services are limited Leroy et al. (2023); Guilluy (2024), and can complement public transportation networks Namazu & Dowlatabadi (2015). By providing access to vehicles across urban areas, car-sharing can contribute to reduced parking demand Wang et al. (2020), lower car ownership levels, and fewer vehicle kilometers traveled Namazu et al. (2018). It can also improve accessibility in low-accessibility areas by complementing public transportation Schaefers (2013); Baptista et al. (2014), and contribute to lower emissions Curtale et al. (2021); Long & Axsen (2022).

Car-sharing services are commonly provided through professional operator systems, in which centrally managed fleets offer predictable availability and operational control. While such systems benefit from high reliability, they require substantial investment in vehicles and infrastructure Nourinejad et al. (2015). More recently, peer-to-peer (P2P) services have emerged within shared mobility systems Alisoltani et al. (2024). This service relies on private vehicle owners making their vehicles available to other users Hörl et al. (2023). This model has been implemented in Europe and North America Münzel et al. (2020), motivated by its potential to reduce operating costs and extend spatial coverage to areas where professional services are limited or absent. Despite these advantages, P2P car-sharing systems are subject to specific constraints. Their operation depends directly on the temporal and spatial availability of privately owned vehicles, which can result in mismatches between supply and demand Chang et al. (2022); S. A. Shaheen et al. (2012); Turoń (2023). As a result, the practical potential of P2P car-sharing at the urban scale remains uncertain.

Existing approaches are limited in their ability to capture interactions between demand (travelers) and supply (privately owned vehicles) at the urban scale. To address this need, this study proposes a simulation-based approach to assess the potential of P2P car-sharing using agent-based transportation modeling.
The goal of this study is to provide analytical insights that support decision-making related to P2P car-sharing and to identify potential opportunities for its implementation. The analysis does not evaluate perceived advantages or disadvantages of P2P car-sharing from the users' perspective, nor does it aim to provide universal recommendations applicable to all city types. Instead, the proposed framework is intended as a decision-support tool for policymakers and transportation authorities, helping to identify where, when, and under which conditions P2P car-sharing policies may be most relevant, given local urban and mobility characteristics.

2 Methodology

This study evaluates the potential of peer-to-peer (P2P) car-sharing. Daily activity–travel patterns are generated using a synthetic population generation pipeline that allows producing households, individuals, and their daily mobility patterns for French territories based entirely on open data Hörl & Balac (2021). The pipeline is applied to three French cities, Dunkirk, Nantes, and Paris, at 1% household sampling rate to reduce computational complexity while preserving behavioral realism. It provides detailed trip records (departure and arrival times, locations, and modes), which are ordered by individual and trip sequence to ensure temporal consistency before being used in the car-sharing potential assessment. From simulation outputs, individual trip chains are reconstructed to identify the demand side (users seeking access to a vehicle) and the supply side (private vehicles that are temporarily not in use).
User Slots User slots represent time windows during which an individual performs one or several consecutive trips that start and end within a predefined spatial radius, such that the origin and return destination location can be assumed to be effectively the same. Within such a window, all trips are made either by private car, as a car passenger (e.g., taxi or ride-hailing services), or by short walking segments that connect car-based trips. The time interval between the departure time of the first trip and the arrival time of the corresponding return trip is defined as a user slot.
Owner Slots Owner slots represent spatio-temporal windows during which privately owned vehicles are not in use and could potentially be made available for sharing. For each vehicle owner, all car-based trips are sorted chronologically. Owner slots are identified as the time intervals between two consecutive car trips. This condition ensures that the vehicle remains parked at a fixed location and is continuously available throughout the entire slot (Figure 1).

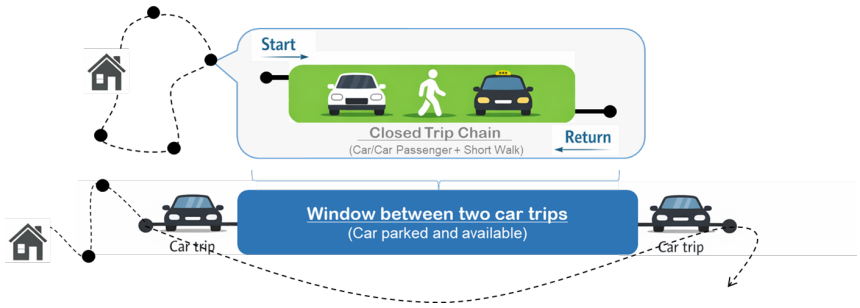


Figure 1: User and owner slot schematic

After constructing the user and owner slot datasets, the next step is to evaluate potential shared-mobility interactions arising from these availability windows. The analysis focuses on user–owner interactions that represent peer-to-peer (P2P) car-sharing opportunities. User and owner slots belonging to the same individual are not matched, so only true P2P interactions are considered.

Upper-bound: Feasibility match In the first step of the assignment model, feasibility matching is performed by constructing, for each user slot, the set of owner slots that satisfy the defined spatial and temporal feasibility constraints. User and owner slots belonging to the same individual are excluded from this process to ensure that only genuine peer-to-peer interactions are considered. No exclusivity or conflict constraints are imposed at this step, allowing multiple feasible associations between user and owner slots. The resulting set of feasible user–owner pairs constitutes the

upper-bound feasibility match, representing the theoretical maximum P2P car-sharing potential.

Lower-bound: Compatibility Assignment In the second step, we perform a compatibility user–owner assignment based on the previously identified compatible pairs. The objective is to construct a conflict-free set of matches in which each user slot is assigned at most once, while each owner can serve multiple users, provided that sharing time intervals do not overlap.
The assignment is implemented using a greedy, priority-based method, in which feasible matches are selected sequentially based on predefined priorities. Duration-based prioritization favors longer assignments to maximize utilization while preserving computational efficiency in large-scale scenarios. For each selected user slot, the owner slot with the earliest available start time is chosen. When a match is accepted, the user slot is removed from further consideration. On the owner's side, the accepted rental interval is deducted from the owner's availability window, and the owner's slot is split into the remaining free sub-intervals before and after the rental (if any). These remaining sub-intervals can then be matched with other user slots.
Compatibility Assignment is subject to the same feasibility rules seen earlier. A minimum time buffer is enforced between consecutive assignments to account for operational constraints. This procedure produces a set of non-overlapping assignments, while allowing sequential use of the same owner slot across multiple users when sufficient remaining availability time exists. The resulting set of assignments provides an operationally compatible estimate of achievable P2P car-sharing interactions.
To evaluate the robustness of the proposed methodology, the analysis considers three French cities (Dunkirk, Nantes, and Paris) and two spatial configurations to assess the impact diverse urban contexts and accessibility assumptions. The scenarios differ by the walking-distance threshold, which also defines the spatial tolerance for trip-chain matching. Two configurations are considered, 200 m (Scenario A) and 400 m (Scenario B). In both cases, identical temporal parameters are applied, including a buffer time of 10 minutes and minimum duration thresholds of 60 minutes for users and 120 minutes for owners.

3 Results and discussion

For all case studies, the analysis is conducted at the regional scale, covering 1,937 agents in Dunkirk, 13,345 in Nantes, and 107,340 in Paris. Based on simulated trips, individuals generating valid trip chains are identified. The share of individuals with at least one user slot is 73%, 74%, and 47%, while owner slot shares are 79%, 59%, and 40% in Dunkirk, Nantes, and Paris, respectively.
Differences across cities reflect variations in travel behavior and urban context. Higher user shares in Nantes and Dunkirk suggest more regular round-trip patterns, while higher owner shares in Dunkirk indicate greater car availability, likely linked to lower public transport accessibility and more dispersed urban form. These patterns provide context for interpreting performance indicators, including population coverage, match and assignment rates, and temporal distributions.

Upper-bound results (Feasibility match)

Table 1 summarizes the feasibility results for Dunkirk, Nantes, and Paris under two spatial configurations. In all cities, increasing the acceptable walking distance leads to a strong increase in the number of feasible matches. At the same time, the number of users changes marginally between scenarios. This indicates that the walking-distance threshold mainly affects matching opportunities rather than the size of the participating population.
Clear differences between cities are observed. In Scenario A, Dunkirk and Nantes show similar feasibility levels, while Paris performs better. In Scenario B, Nantes exhibits the lowest feasibility outcomes, whereas Dunkirk and Paris benefit more strongly from the larger walking distance. Paris consistently shows the highest feasibility across both scenarios.

Table 1: Upper-bound feasibility match results across all cities and scenarios

City	Dunkirk		Nantes		Paris	
Scenario	A	B	A	B	A	B
Users with at least one match (%)	27.6%	47.1%	24.7%	35.6%	39.5%	54.7%
Owners with at least one match (%)	5.9%	13.1%	6.0%	11.5%	10.2%	19.8%
Match rate per 1% of population	2.3	8.6	2.2	7.1	3.9	14.9

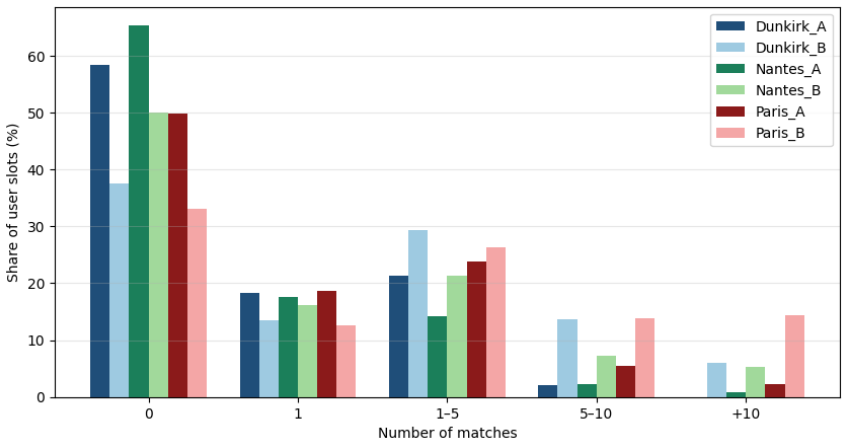


Figure 2: Distribution of feasibility matches per user slot

Figures 2 and 3 show the distribution of feasibility matches per user and owner slots. In all cities, a large share of slots remains unmatched, especially under the restrictive configuration (Scenario A), where about 50–65% of user slots and 55–71% of owner slots have no feasible matches, with higher shares in Dunkirk and Nantes.
Increasing the walking-distance threshold (Scenario B) reduces unmatched slots and increases the number of slots with multiple matches, particularly in the 1–5 and 5–10 categories.

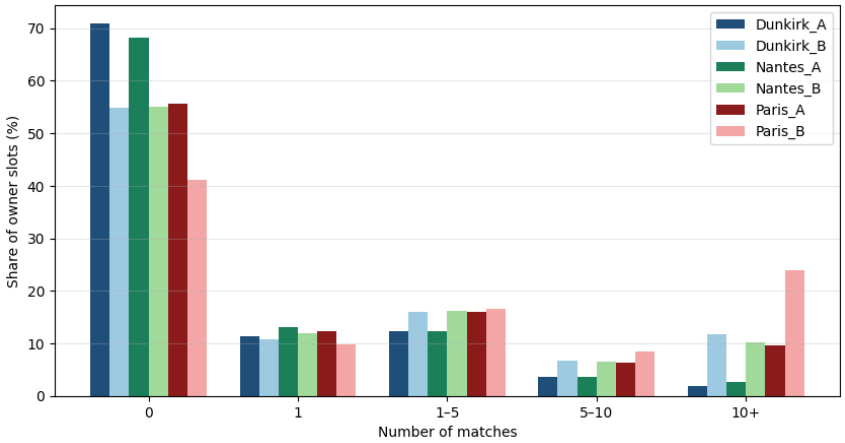


Figure 3: Distribution of feasibility matches per owner slot

Figure 4 shows the distribution of upper-bound feasibility matches by hour of day. Although the trends are not stable, they display a similar temporal pattern across all cities and scenarios. The number of potential matches is very low during the night and early morning, increases rapidly from around 06:00 AM, and reaches a first peak between 08:00 and 09:00 AM. After a short decline, a second peak occurs around midday (11:00–13:00), followed by a gradual decrease during the afternoon and evening.
This pattern is similar across cities and remains stable between Scenarios A and B. Paris and Nantes show the strongest midday peak, with feasibility matches peaking around noon. In contrast, Dunkirk exhibits its strongest peak in the morning, which may be related to work-oriented travel patterns typical of an industrial city.

Lower-bound results (Compatibility assignment)

Table 2 summarizes the compatibility assignment results. Compared to the upper-bound feasibility step, the number of realized interactions is substantially lower, reflecting the application of additional constraints and assignment objectives.
Across all cities and scenarios, a considerable share of users remains without any assignment. This indicates that spatial and temporal mismatches persist also under compatible conditions. Moving from Scenario A to Scenario B increases the number of assignments in all cities, although the

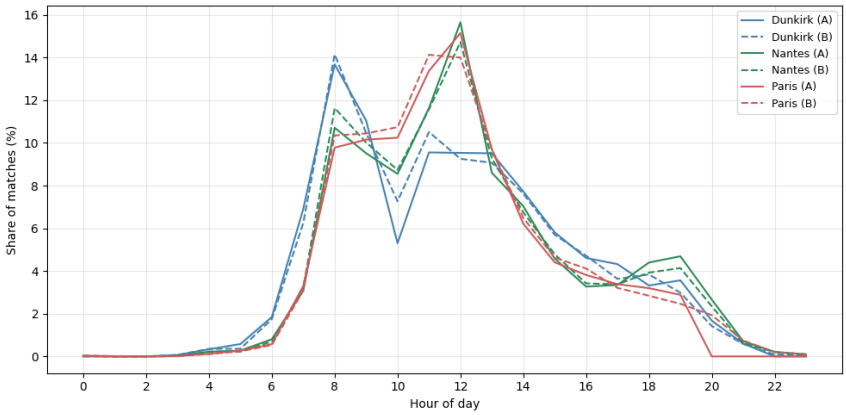


Figure 4: Distribution of matches per hour of day for feasibility matches

Table 2: Lower-bound compatibility assignment results across all cities and scenarios

City	Dunkirk		Nantes		Paris	
Scenario	A	B	A	B	A	B
Number of assignments	1087	1688	6350	9145	50749	66400
Users with assignments	52.9%	62.8%	43.0%	50.4%	53.1%	56.3%
Owners with assignments	48.3%	57.4%	61.4%	67.1%	79.5%	82.6%
Match rate per 1% of population	0.6	0.9	0.5	0.7	0.5	0.6

overall differences between cities are smaller than those observed in the feasibility step.

On the demand side, Dunkirk shows the most favorable outcome in Scenario B, with 62.8% of users assigned. Paris also performs well, with 56.3% of users assigned in Scenario B, and it has the lowest share of unmatched users in Scenario A (46.9%). Nantes shows the most restrictive results, with 43.0% of users assigned in Scenario A, increasing to 50.4% in Scenario B.

On the supply side, Paris consistently exhibits the highest share of owners with at least one assignment, followed by Nantes and Dunkirk. In Scenario A, 79.5% of owners in Paris are assigned, compared to 61.4% in Nantes and 48.3% in Dunkirk. Similar patterns are observed in Scenario B, with assignment shares of 82.6%, 67.1%, and 57.4%, respectively. The lower assignment share in Dunkirk may be related to its higher proportion of owners in the population (79%), compared to Nantes (59%) and Paris (40%), which increases competition among owners for available user demand.

The assignment rate further illustrates these patterns. Higher rates are observed in Scenario B, confirming the sensitivity of achievable P2P car-sharing assignments to walking-distance assumptions. Dunkirk exhibits the highest assignment rates (0.6 in Scenario A and 0.9 in Scenario B). Nantes and Paris show similar rates in Scenario A, while in Scenario B, Nantes performs slightly better.

The higher assignment rate observed in Dunkirk is consistent with its comparatively large share of owner slots (79%) combined with a high proportion of users (84%). This indicates a relatively strong supply base of available vehicles alongside substantial demand represented by round-trip chains. In contrast, lower owner shares in Nantes (59%) and especially Paris (40%) suggest a more constrained supply of vehicles relative to demand, which limits achievable compatibility despite differences in overall population size or density.

Figure 5 illustrates the hourly distribution of lower-bound compatibility assignment. Across all cities and scenarios, a consistent temporal pattern is observed. The number of assignments is very low during the night and early morning hours, then increases rapidly from around 06:00, reaching a first peak at approximately 08:00. After this morning peak, feasibility matches decline, with the sharpest decrease observed in Dunkirk (Scenarios A and B) and in Nantes (Scenario B).

Between 10:00 and 14:00, city-specific differences emerge. In Paris (Scenario A), a second peak occurs around 12:00, followed by a decline. In Paris (Scenario B), the downward trend continues without a pronounced midday peak. Nantes shows an increase toward a second peak at around 12:00, while Dunkirk reaches a second peak slightly later, around 13:00. After the midday period, all cities exhibit a minor increase or a temporary flattening of the declining trend before feasibility matches decrease again to near-zero levels during nighttime hours.

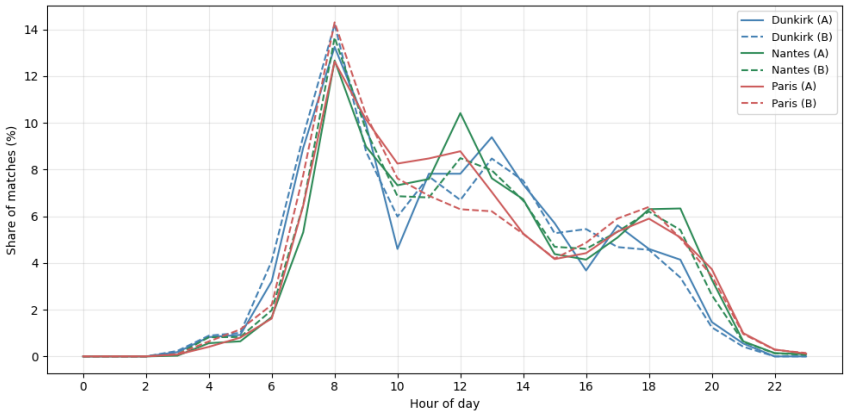


Figure 5: Distribution of assignments per hour of the day for compatibility assignments

Match duration statistics further illustrate differences across cities and scenarios under the compatibility assignment. In all cities, average match durations increase when moving from Scenario A to Scenario B, indicating that a larger acceptable walking distance allows longer and more flexible rental opportunities. Overall, these results suggest that more permissive spatial configurations not only increase the number of feasible assignments but also support longer rental durations.
The results show that relaxing spatial thresholds substantially increases matching opportunities, confirming the sensitivity of potential to accessibility conditions. Higher urban density clearly improves matching opportunities. The distribution of matches reveals a pronounced imbalance between supply and demand across space and time. A large share of slots remains unmatched, while a limited number concentrates a substantial proportion of feasible matches indicating strong spatial and temporal heterogeneity within cities. Consequently, locally adapted strategies could be more appropriate than city-wide approaches.
Temporal patterns further clarify these structural dynamics. Most feasible P2P car-sharing opportunities occur during regular daily activity periods, such as commuting to work or education and midday return trips. The similarity of patterns across cities and scenarios suggests that temporal availability is largely driven by common daily travel patterns, whereas spatial constraints primarily affect the scale rather than the timing of feasible matches. This aligns with studies reporting peak activity Ampudia-Renuncio et al. (2020); Abbasi et al. (2021).
The number of realized assignments under the lower-bound configuration indicates a technical potential for substituting trips currently made by private car or taxi with shared vehicle use.

4 Conclusions

Application to Dunkirk, Nantes, and Paris under two walking-distance scenarios shows that spatial accessibility assumptions strongly influence achievable matching levels, while temporal patterns remain broadly stable across cities and scenarios. The results also reveal persistent spatial–temporal imbalances between demand and supply and substantial heterogeneity in matching opportunities within cities. The share of individuals generating valid trip chains for slot construction also differs across cities. These differences reflect distinct travel patterns and car-use behaviors. In particular, Dunkirk shows a high prevalence of owner slots, indicating frequent car use combined with substantial idle periods between trips. Under Scenario B, Dunkirk shows the highest user assignment share (62.8%), followed by Paris (56.3%) and Nantes (50.4%), while owner participation is highest in Paris (82.6%). Assignment rates per population are the highest in Dunkirk, indicating that higher local availability can offset smaller urban scale. Overall, the results highlight the influence of city-specific characteristics. The observed assignment opportunities indicate a non-negligible potential for substituting trips currently made by private car or taxi with P2P car-sharing, which may contribute to reduced car ownership and lower parking demand. Under suitable local conditions, these findings suggest that P2P car-sharing can support broader mobility transitions.
Overall, the proposed framework addresses a key gap in the existing literature by assessing the interactions between travelers and privately owned vehicles. By linking travel behavior, urban form, and operational constraints, it provides a scalable and transferable basis for evaluating P2P car-sharing potential across city contexts. The analysis does not assess perceived advantages or

disadvantages of P2P car-sharing from the users' perspective, nor does it aim to derive universal recommendations applicable to all city types. Instead, it is intended as a scalable, transferable decision-support tool for policymakers, planners, and other stakeholders, helping to identify where, when, and under which conditions P2P car-sharing systems may be most relevant. In doing so, the study supports more evidence-based and sustainable shared-mobility policy design, particularly in contexts where empirical data on emerging transportation services remain limited.

Future work should explore AV-enabled assignments, redistribution strategies, and behavioral factors influencing P2P car-sharing adoption and performance. This study establishes a foundation for future work, in which we aim to implement such systems in real-world urban contexts.

Acknowledgements

This research was supported by the CityFAB program under the "Ex-cellencES sous toutes ses formes" initiative (ANR-21-EXEX-0007), funded by France 2030.

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