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► To cite this version:

Dylan Moinse, Alain L'Hostis. Optimizing intermodal commuting by way of detours and breaks: Evidence of micromobility users in France. 2023. halshs-04160573v1

HAL Id: halshs-04160573

<https://shs.hal.science/halshs-04160573v1>

Preprint submitted on 12 Jul 2023 (v1), last revised 6 Mar 2024 (v2)

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Optimizing intermodal commuting by way of detours and breaks: Evidence of micromobility users in France

Dylan Moïnse (corresponding author)^a, Alain L'Hostis^a

^aUniv Gustave Eiffel, Ecole des Ponts, LVMT, F-77454, Marne-la-Vallée, France

Abstract

The intermodal use of micromobility alternatives in combination with the transit network significantly expands station catchment areas. However, the determination of station neighborhood sizes often reveals a subset of users surpassing the measured distance threshold, prompting the question of why these intermodal passengers travel longer distances. This scientific article aims to gain a comprehensive understanding of the distances covered and itinerary choices made by micromobility users, in order to provide relevant urban planning recommendations. This research builds upon emerging scientific literature that emphasizes the adoption of detours and breaks by intermodal passengers to optimize their journeys, thereby reversing the negative perception associated with longer distances and waiting times. Given the complexity of intermodal travel, this investigation examines the interrelationships among detours, breaks, and spatial and temporal optimization strategies. Detours are classified based on typology and geometric forms, termed as "Escaping Transit Voronoi Station" (E-TVS), while breaks, indicated by waiting times, are analyzed in terms of activities conducted during the modal chain. The investigation employs both objective approaches, utilizing a questionnaire for geocoding trips, and perception-based approaches, through go-along interviews to capture individuals' perspectives. The key findings from the geostatistical analysis reveal that micromobility users are willing to travel an additional two kilometers or ten minutes during access or egress to avoid transfers, thereby extending the catchment area to 6 kilometers, representing a 125% larger coverage compared to trips without detours. The implementation of detours by micromobility, which are 6 to 8 times longer, allows for considerable average time savings of 19% and kilometeric distance savings of 3%, primarily made to avoid public transport transfers. Furthermore, breaks during the intermodal journey provide an opportunity for daily shopping activities in station neighborhoods, optimizing the overall modal chain. Remarkably, 95% of the analyzed intermodal trips exhibit temporal and/or spatial optimization. These findings underscore the potential of designing a public transportation system that combines efficiency with well-spaced stops and local accessibility, reconciling the performance-adherence dilemma and fostering transit-oriented development areas.

Keywords: Breaks, Detours, Distances, Intermodality, Micromobility, Optimization, TOD

1. Introduction

The promotion of transit-based urban development containing unregulated urban sprawl and creating a pedestrian-friendly urban environment, to reduce vehicular traffic congestion and to design more sustainable regions, is conceptualized as Transit-Oriented Development (TOD) (Calthorpe 1993, pp. 16, 40). Internationally formulated, this urban model has the potential to fundamentally rethink about multiscale communities (Dittmar and Ohland 2012) by supporting coordination between urban planning and mobility. TOD's fundamental principles are based on the formulation of the "6Ds" including Density, Diversity, Design, Demand management, Destination accessibility and Distance to transit (Cervero and Kockelman 1997; Ewing and Cervero 2010, pp. 200, 273).

1.1. Integrating micromobility ridership patterns into a re-examined TOD

Being a critical dimension in the TOD equation, the "Distance to transit" variable is very crucial to measure the accessibility of a public transport station. In fact, this parameter needs

to be more widely discussed, as the half-mile distance has become the norm to size a train station neighborhood in the United States (Guerra, Cervero, and Tischler 2012, p. 102), leading to a TOD standard in urban planning. Facing this artificial rule (Guerra, Cervero, and Tischler 2012, p. 105), a variety of studies have shown the increased reach of walk-and-ride around high frequency hubs surrounded by attractive facilities (Hasiak 2019; Ker and Ginn 2003; L'Hostis 2016, pp. 30, 79, 7), in connection with the "bursting of the bubble" concept (Canepa 2007, p. 33). In contrast, the academic body on the role of cycling feeding modes in the TOD areas' extension is less developed (Martens 2004; Moïnse et al. 2022, pp. 283, 3).

Regarding the first and last mile (FLM) connections, the combination of bicycle and transit leads to the Bicycle-based TOD (B-TOD) concept (Lee, Choi, and Leem 2016, p. 979) by significantly widening the stations' catchment area and enhancing public transport ridership. The B-TOD, driven by the revival of the bicycle (Héran 2015, p. 27), is expected to be complemented by emerging new micromobility solutions resulting in the development of a Micromobility-based TOD. The consid-

erations associated with these TOD models depend largely on the expansion of station neighborhoods fostered by micromobility feeders. In this respect, cycling service areas, particularly for railway catchment areas, tend to converge between three and four kilometers (Moïnse 2022a, p. 15). This paper focuses on micromobility devices, which refer to lightweight and compact vehicles such as (electric) bikes, folding (electric) bikes, (electric) scooters, (electric) skateboards, unicycles, onewheels, hoverboards or segways. Micromobility can be found in owned vehicles or shared fleets and is considered as a convenient, environmental and cost-effective alternative to private cars.

However, the range of cycling connections over three kilometers suggests that a significant part of intermodal behavior exceeds this threshold. How can it be explained that passengers travelling by light vehicles to or from a station can cover more than this distance threshold, given that each metro stop is rarely further than a kilometer away, or up to five kilometers away for train stations? This paper addresses this issue by considering that a share of intermodal users would bypass closer transit points by intentionally making detours, for the purpose of reducing perceived costs related to time, distance, or stress.

1.2. Detours, breaks and optimization

All detours observed in mobility patterns are the result of a search for time-distance based-optimization, making it appear as a positive value (L'Hostis 2017, p. 459). Detours can be analyzed with the indicator of circuitry (Barrington-Leigh and Millard-Ball 2020, p. 1949), found in graph theory (Kansky 1963). Circuitry expresses the level of detours from a location, comparing the length of minimum trips to the straight-line Euclidean distance. In literature, circuitry is almost always seen as undesired. As opposed to this view, we want to understand circuitry why this choice was made, and seen circuitry as a positive pattern. The most advanced form of detour involves starting a route in the opposite direction to the final destination to reach a higher efficiency mode of travel, and is defined as "space inversion" (Tobler 1961; Bunge 1966, p. 106). In this respect, this spatial pattern has hardly been examined from the optimization perspective, except for a high-speed train and air connection study at Charles de Gaulle airport linked to Lille's stations (L'Hostis 2014, pp. 144, 161), or for the strategic location of the secondary train station Lesquin allowing improved intermodal accessibility by skipping metro detours (L'Hostis and Conesa 2010, pp. 14–17).

Beside detours, L'Hostis (2017, p. 447) analysis highlights the role of breaks in the optimization of trips. Breaks, defined as periods of immobility during a journey and during which a secondary activity may be conducted, serve the purpose of reloading the movement, as in the cases of a hotel night to allow a long journey, of the refueling of a vehicle, or of resting on a bench midway of an urban walk. These breaks are all necessary to generate optimized trips, and, similarly to detour, they counter-intuitively contribute to the optimization process of movement and hence distances. Recognizing the role of break can lead to reformulate the mathematical definition of geographical distance (Kloeckner 2023, p. 12). Waiting for a train in a station

is also a form of break in movement, made necessary to change the transport mode, from a temporally and spatially continuously accessible individual transport mode deployed in public space such as walking, or micromobility, to an access point and timetable-based transport mode such as rail. In this regard, the choice of a transit stop for accessing the transit system, and the strategies deployed to avoid a negatively perceived connection between trains, can be seen as a task consisting in determining the temporal and spatial distribution of breaks in trips, by organizing detours. In this view, detours and breaks are connected to each other in a dialectic relationship in the formation of trips and distances through a broader optimization process. This is the framework we propose to apply in this paper.

The scientific literature dealing with the relationship between bicycle detours and route optimization is very limited and based on Dutch empirical studies, and is coupled with a knowledge gap regarding emerging micromobility alternatives. It has been shown that passengers combining cycling and rail favor the most convenient train stations that offer fast and more frequent connections, rather than the nearest ones (Krizek and Stonebraker 2010, p. 2144). Jonkeren and Kager (2021, p. 468) have found that bicycle-train travelers infrequently use suburban stations in the Netherlands, preferring to cycle further to avoid transfers or to access a station providing better services linked to frequency, comfort, and facilities. By conducting an on-board transit revealed preference survey in The Hague, similar results were obtained for bicycle-tram users, the main motive reported being transfer dodging (Rijsman et al. 2019, p. 3). According to Nieves (2018, p. 51) who carried out a survey in the Amsterdam Metropolitan Area, the majority of bicycle-train passengers are willing to cycle an additional five minutes to reach a station to reduce the number of transfers, and half of them are even willing to cycle an extra ten minutes. This insight supports a choice model indicating that one train transfer (€0.60 per avoided transfer) is equal to a disutility of six minutes bicycle time (€0.11 per minute less) in the Netherlands (Mil et al. 2020, p. 665). In addition, the same phenomenon associated with the detours undertaken by intermodal cyclists can also be observed for buses with higher speed and frequency in the Amstelland-Meerlanden region (Brand et al. 2017, p. 750).

1.3. Research aim

This study aims to gain a better understanding of the itinerary choices and distances covered by intermodal passengers using mass transit and micromobility alternatives, as well as optimization-based strategies undertaken by cycling riders in France. Our objective is to determine and classify the emergence of such intermodal practices, supported by the introduction of e-scooters, and to define a regional Micromobility-based TOD. This geographical approach is intended to highlight planning issues in order to provide guidance for stakeholders (i) and to encourage the development of these intermodal solutions within auto-oriented communities (ii), where walking combined to public transport seems to lack competitiveness. The main contribution proposed in this field is a better understanding of extended micromobility connections, characterized

by detours, and aimed at maximizing intermodal journeys to shorten time or distance spent.

To meet this research objective, the paper is organized as follows. In [section 2](#), the methodology applied is described, namely objective and perception-based mixed approaches. Next, in [section 3](#), the findings are outlined and discussed, reflecting catchment area sizes by the different micromobility option. By measuring the station area extension, this more comprehensive insight allows to further study detours and breaks by micromobility and to cluster these mobility practices. Then, [section 4](#) summarizes the key insights and perspectives for future research associated with this research field.

2. Materials and Methods

This paper takes advantage of the articulation of objective and perception-oriented approaches to provide a two-sided analysis of the considered issue. In order to understand these mobility behaviors, we developed a "customized" investigation (Paugam 2012, p. 208) dedicated to the intermodal travelers' subgroup. Our mixed-method conceptual framework is designed on the basis of an exploratory and qualitative approach in view of setting up a quantitative study, later validated by the qualitative assessment (Paugam 2012, p. 215). Accordingly, this research work adopts the questionnaire and go-alongs interviews to achieve a complementarity purpose (Greene, Caracelli, and Graham 1989, p. 258). It should be noted that both methods have been conformed to Data General Protection Regulation (GDPR) and validated by University Data Protection Officer (DPO) departments before being implemented.

We combined geostatistical and perception-based analysis in four steps: measurement of the kilometer and time distances by generating itineraries (i), determination of the influence of angle patterns in the selection of cycling routes (ii), classification of optimization strategies by identifying detours – by means of a Voronoi polygon approach – and stated breaks (iii), and optimization clustering analysis by using spatio-temporal indexes (iv).

2.1. Online questionnaire

This study focuses on characterizing detour routes experienced by intermodal commuters. A survey using an online questionnaire was conducted to capture the experience of intermodal travelers using micromobility solutions. This questionnaire was designed for riders combining transit and micromobility usage and included closed-ended questions associated with the respondents' intermodal travel patterns, urban environment, and sociodemographic variables. The self-administered questionnaire was carried out on [©LimeSurvey](#)¹ from April 2022 to January 2023. The first stage of the campaign consisted in the distribution of flyers on the platforms of nine train stations located in the Hauts-de-France region, during two days at peak hours

¹[©LimeSurvey](#) is an advanced and open source online statistical survey web to create survey forms (LimeSurvey 2023).

for each site, with the authorization from the regional direction of the station manager, SNCF Gares & Connexions. This chosen geographic perimeter is justified by the dense and connected rail network of the region, coupled with the emergence of intermodal practices by e-scooters in the main stations as well as in secondary ones (Moinse 2022b, p. 7). A second step was undertaken to distribute the survey across online social networks and research and association communities. During this period, the questionnaire's scope was widened to cover not only France, but also Europe.

A total of 217 complete and screened responses were collected from the questionnaire after data cleaning, among which 119 occurred in the Hauts-de-France and 40 in the Île-de-France region. Only 7 respondents reported completing an intermodal journey abroad. To build subsamples addressing detours and breaks (see [figure 1](#)), the sampling process captured full responses (1 & 2) that comprised the last intermodal journey (3), provided checked location coordinates (4), with access and/or egress characterized by an identified detour or a stated break (5), and with a work- or educational-related purpose (6). In our approach, a detour means the use of a railway station different from the closest to the origins and destination of the trip. The user will exploit the potential of his micromobility option to travel a longer distance than what walking permits, and reach a train station further away in order to obtain benefits on his overall journey. In our view, reaching a station further away represents a detour when compared to accessing the railway through the closest railway or metro station. The selected detour-based sample includes 129 trips, while the break-based sample size is 110 responses. The introduction of this questionnaire was coupled with an exploration of these individual mobility experiences by conducting mobile interviews, to deepen the knowledge of this subject (Bergeron, Paquette, and Poullaouec-Gonidec 2014, p. 120). This approach, named go-along and recommended by Pages, Lammoglia, and Josselin (2021, p. 19) regarding the emergence of e-scooters in particular, is suited to gain a better understanding of how such intermodal strategies could optimize the way people commute. The spatial identification of intermodal journeys with detours resulted in a sample size of 129 stated rides, and more specifically a list with 170 access or egress legs involving a detour.

2.2. Go-along interviews

By capturing mobility experiences and particularly the relationship between trips and built environment, the go-along interview is an innovative method, where the researcher and participant visit a predetermined location in order to obtain contextualized perspectives. This mobile interview allows generating micro-geographies of meaning (Büscher and Urry 2009; Bergeron, Paquette, and Poullaouec-Gonidec 2014, pp. 110, 116) providing evidence about personal motivational meanings, hardly accessible by way of survey (Desprès, Lord, and Negron-Poblete 2019, p. 3). This research method, based on a follow-up exercise, examines the perceptions of participants by drawing on the strengths of the participatory observation and on-site interviews. Depending on the mode investigated, the go-

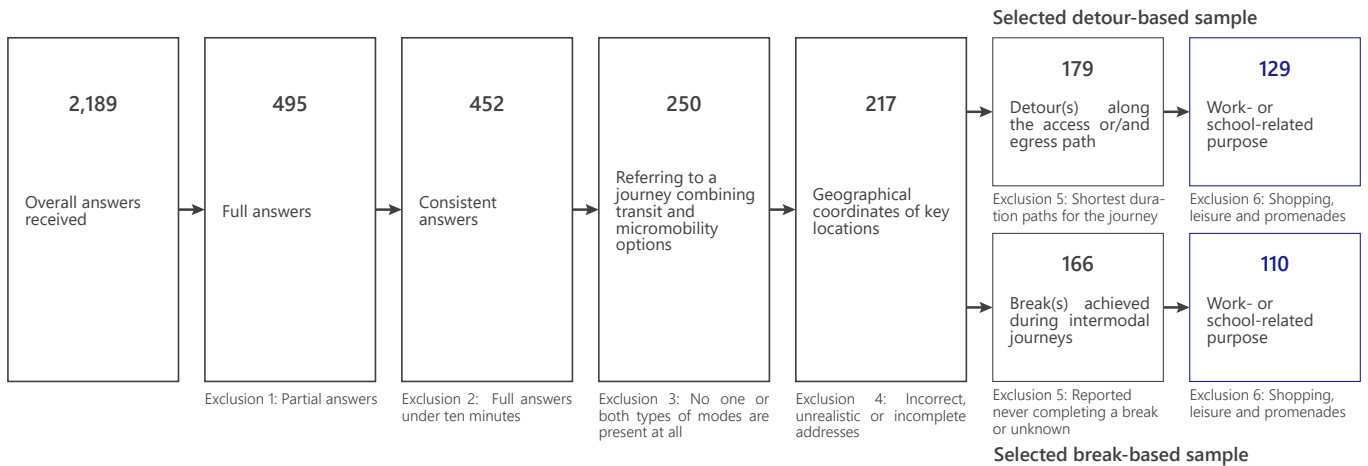


Figure 1: Survey sampling process based on identified detours and stated breaks

Source: Moïnse, 2023

Table 1: Intermodal go-along and participant characteristics

Characteristics	Participant 1 (PCTE1)	Participant 2 (PCTE2)
Modal combination	E-scooter + regional train + e-scooter	E-scooter + metro + e-scooter
Optimization strategy	Avoiding metro network and break time	Metro station choice
Ride-along date	11 April 2022 (7:00)	25 March 2022 (8:30)
Country (region)	France (Hauts-de-France)	France (Hauts-de-France)
Transit line	K60 (train): Lille - Maubeuge	Line 1 (metro): CHU Eurasanté - 4 Cantons
Origin station	Lille Flandres (Lille)	République - Beaux-Arts (Lille)
Destination station	Maubeuge (Maubeuge)	Cité Scientifique Pr. Gabillard (Villeneuve d'Ascq)
Kilometers	97.3 (1.4 + 94.4 + 1.5)	11.4 (1.3 + 7.9 + 0.5 + 1.7)
Time (minutes)	84 (6 + 72 + 6)	30 (4 + 15 + 2 + 9)
Trip frequency	1 time per week	2 times per week
Trip purpose	Working	Educational
Intermodal experience	6 months	1 year
Age	23	26
Gender	Female	Male

along is distinguished by two forms (Wegerif 2019, p. 7): the walk-along which usually prevails, and the ride-along which relates to vehicles and is introduced in this paper.

This study explores two participants' discourses who had volunteered for a ride-along after completing the questionnaire. These participants were selected among the 46 volunteers after setting multiple conditions: inclusion of optimization strategies based on detours and breaks (i), representative distances travelled (ii), within the study area (iii), and a diversity of public transport modes (iv). It is worth noting that the two participants recorded were contacted at the end of the questionnaire pilot phase from February to March 2022, and that this qualitative approach is likely to be further reinforced with future ride-alongs. The two mobile interviews were applied using an e-scooter, the researcher being equipped with an embedded sports camera² and the interviewee with a microphone. The simultaneous visual and audio recording of the followed sub-

²The handheld camera used for recording video aboard the vehicles is a *Go-Pro*, fitted on the researcher's e-scooter and kept by hand in the public transport.

ject, who gave their consent earlier, contributed to the multi-criteria analysis of the gathered data (Bergeron, Paquette, and Poullaouec-Gonidec 2014, p. 120).

The first trip took place on 11 April 2022 and implied a participant travelling between two northern French cities by regional train (TER) and personal e-scooter. This 23-year-old woman's commutes usually once a week for the past six months. During her feeding trip by e-scooter, her modal choices referred mainly to the willingness to cut out a detour made by metro and to the appropriation of the waiting time at the train station to maximize the utility of the trip. As for the second run that occurred on 25 March 2022 with a man heading to the Lille's campus for one year by metro and e-scooter, similar transfer avoidance was mentioned along the access and egress trips (see table 1).

2.3. Voronoi diagram

Assuming that micromobility users, especially for active modes, seek to perform the shortest trip (Héran 2009, p. 116), an intermodal traveler makes at least one detour from the moment the departure stop closest to the origin or the arrival stop

nearest the destination is not used. Once the questionnaire responses were cleaned up, a spatial analysis using geographical information system (GIS) tools was applied to sample the commuting journeys made with one or multiple detours. For this purpose, we generated the tessellation visualization available in the QGIS geometry package. The existing rail network such as train, metro, and tramway lines and stations were partitioned by the standard Voronoi diagram (Mota, Takano, and Taco 2014, p. 479): Voronoi polygons divide the plane into cells with a common closest site in Euclidean metrics, independently of network hierarchy (Lebedeva, Kripak, and Gozbenko 2018, p. 429). This type of cartographic representation produced a simplified Transit Voronoi diagram (T-VD), conceptualized by B. Y. Chen et al. (2022, p. 5), intended to allocate the theoretically closest stop to each origin and destination (see figure 2). By entering the 217 validated geographic coordinates associated with the origin and destination places connected to the departure and arrival stations, a total of 129 intermodal trips were revealed having one or both stations not matching the closest station to the points, including 83 located in the Hauts-de-France region. We called this type of detour, based on mobility practices, an "Escaping Transit Voronoi Station" (E-TVS).

2.4. Kilometer and time distance estimation

Following the spatial approach leading to the detection of detours by micromobility, a characterization of these intermodal practices was implemented, considering kilometer distance and time. To measure these two variables, the kilometer and time estimations were based on the network-based minimum distance feasible with the indicated micromobility option. Regarding the principle of least effort (Zipf 1949, p. 348), there is evidence that cyclists attempt to access their destination with the minimum number of detours (Qiu et al. 2022, p. 7), even though they are constrained by both physical and psychological urban barriers, as measured by the detour index (Héran 2009,

p. 115). The preference for the network-based minimum distance is further supported by the questionnaire results: when asked "Did you choose the shortest ways to get to and from the stations?", 84% agreed. The itineraries were then mapped out with the online routing ©Graphhopper API³, with the web interface *GraphHopper Maps*. The geocoding process gathered the kilometer distance, travel time and slope for each leg, from the utilitarian bicycle system calculated with an average speed of 16 km/h.

2.5. Optimization ratios

Two different types of routes were projected on QGIS by importing the paths provided by the route planner. The first one is the effective journey (*eff*) that corresponds to the network-based minimum distance actually made by the respondent and that incorporates an E-TVS. While the second one represents an alternative journey (*alt*) scenario where the individual is

³©GraphHopper 0.13, released 2019, is an open source routing engine for roads and public transit and uses ©OpenStreetMap (OSM), Shuttle Radar Topography Mission and open access GTFS data (GraphHopper 2017).

expected to cancel the detour and to access and egress the nearest rail station with the least kilometer distance. Effective itineraries are measured by effective distance (km_{eff}) (Cauvin-Reymond 1984, p. 34), which reflects the balance of the objective (Briggs 1976) and cognitive, subjective and perceived (Carter 1977; Bailly 1977; Sadalla and Magel 1980) kilometer distances (Deutsch and Isard 1961; Mittelstaedt et al. 1974), and by effective time values (t_{eff}), either objective – as measured by an external observer – (t_{effo}) or perceived (t_{effp}). Similarly, the alternative journey is described by alternative distance (km_{alt}) and time weight parameters (t_{altp} and t_{altp}), as shown in the following equation 1:

$$\begin{aligned}
km_{alt} &= km_{access(alt)} + km_{PT(alt)} + km_{egress(alt)} \\
km_{eff} &= km_{access(eff)} + km_{PT(eff)} + km_{egress(eff)} \\
t_{alt_o} &= t_{access(alt_o)} + t_{PT(alt_o)} + t_{egress(alt_o)} \\
t_{eff_o} &= t_{access(eff_o)} + t_{PT(eff_o)} + t_{egress(eff_o)} \\
t_{alt_p} &= 1.8 * t_{access(alt_p)} + 2.8 * t_{waiting(alt_p)} + 1 * t_{PT(alt_p)} + 1.8 * t_{egress(alt_p)} \\
t_{eff_p} &= 1.8 * t_{access(eff_p)} + 2.8 * t_{waiting(eff_p)} + 1 * t_{PT(eff_p)} + 1.8 * t_{egress(eff_p)}
\end{aligned} \tag{1}$$

where $t_{eff(p)}$ and $t_{alt(p)}$ are measured by segment-specific weights, the feeding trips (access and egress) and the interchange time (waiting) having respectively an expected perceived time value 1.8 times (Wardman 2001; Gleave 1997, p. 110) and 2.8 times (Hörl and Balac 2021; Wardman 2001, p. 110) higher relative to the time onboard the main transit mode (in-vehicle). This multiplicative time brings in a more realistic

way waiting, access and egress time into the perceived time formula. The time required to wait for a public transport mode is estimated on the basis of commuting peak hours and varies depending on the type of mode: a 15 minutes value is assumed for high-speed rail (TGV) and Intercités (Pagliara, Vassallo, and Román 2012, p. 12), 10 minutes for regional trains (TER and Transilien) (Ingvardson et al. 2018, p. 300), and 5 minutes for

Legend

Built environment

- Railway station
- Subway station
- ◇ Tramway station

Boundaries

- Voronoi diagram
- Municipality boundaries

Surveyed micromobility-and-ride

- To or from Lille Flandres
(station: regional and high-speed trains)
- To or from Lille Europe
(station: high-speed trains)
- To or from Lille CHR
(stop: regional trains)

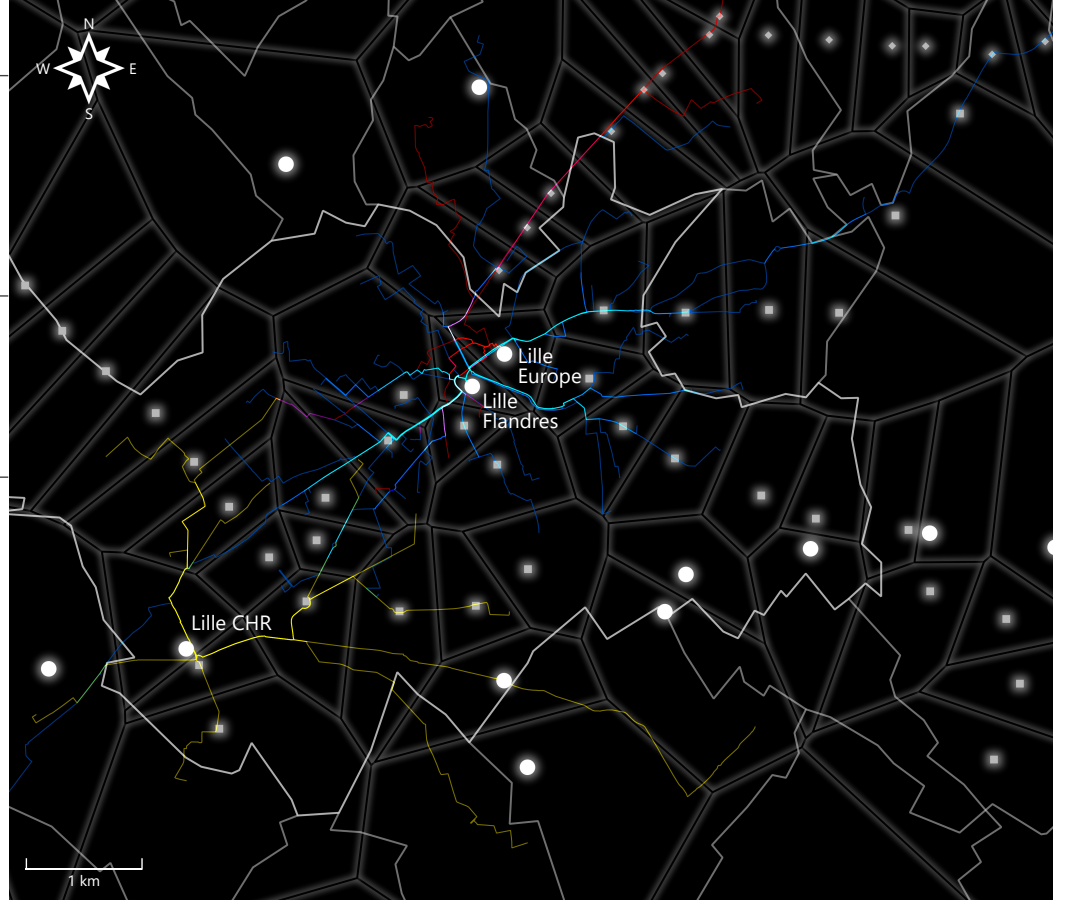


Figure 2: Map showing respondents' itineraries originating or terminating beyond the defined Voronoi polygon, in Lille (France)

Source: Moïnse, 2023

suburban trains (RER), metro and tramway networks (Hua et al. 2018; Ingvardson et al. 2018, p. 300).

The completion of this database was used to determine the level of detour, measured from the ratio of a chosen route to its Euclidean or network-based shortest route distance. This ratio is known in literature as the Route Directness Index (RDI) and is robust to measure the connectivity with a straight route reference (Park and Akar 2019, p. 193), or the Geographical Route Directness Index (GRDI) between the observed and the network shortest path (Ciscal-Terry et al. 2016, p. 126). In the context of our research hypothesis on detours as a way of optimizing movement, the indicator originally planned to compute the circuitry rate was inverted to capture the kilometer benefits resulting from detours. As a result, the revisited GRDI, named optimization ratio (R), is defined as a kilometer optimization ratio (R_{km}), an objective time (R_{t_o}) and perceived time ratio (R_{t_p}), expressed by the equation 2. By computing both R indicators, a more comprehensive examination of optimization tactics using detours can be conducted by clustering individual patterns in the light of crossed space-time criteria. When the sample is queried in relation to the determined ratios, several classes of strategies can be outlined depending on the time and kilometer savings observed.

$$R_{km} = \frac{km_{alt}}{km_{eff}}$$

$$R_{t_o} = \frac{t_{alto}}{t_{effo}} \quad (2)$$

$$R_{t_p} = \frac{t_{altp}}{t_{effp}}$$

2.6. Angles and space inversion of detour routes

To calculate the angle of point B located between point A and point C using the obtained geographic coordinates, we can employ the concepts of spherical trigonometry. Spherical trigonometry is a branch of trigonometry that applies to objects situated on a sphere, such as the Earth. It is important to note that this calculation assumes that points A, B, and C are located on an idealized sphere, like the Earth, and that the geographic coordinates are precise. In reality, approximations and additional corrections may be necessary depending on the cartographic projection used and the characteristics of the Earth's surface. The steps to determine the angle are as follows: Determining the geographic coordinates of points A, B, and C (i); converting the geographic coordinates to Cartesian coordinates

(x, y, z) (ii); calculating the vectors AB and BC (iii); calculating the scalar product of AB and BC (iv); and calculating the norm of AB and BC (v); measuring the angle in radians and converting it to degrees (vi).

Once we have obtained the geographic coordinates of each point A, B, and C, expressed in latitude and longitude using the WGS84 reference system, we can convert them to Cartesian coordinates (x, y, z) using the conversion formulas for a sphere (see [equation 3](#)):

$$\begin{aligned} x_{(A,B,C)} &= R * \cos(\text{latitude}) * \cos(\text{longitude}) \\ y_{(A,B,C)} &= R * \cos(\text{latitude}) * \sin(\text{longitude}) \\ z_{(A,B,C)} &= R * \sin(\text{latitude}) \end{aligned} \quad (3)$$

where R is the radius of the Earth.

Using the measured Cartesian coordinates, we then calculated the vectors AB and BC by subtracting the Cartesian coordinates of points A and B, and then B and C (see [equation 4](#)).

$$\begin{aligned} AB &= (x_B - x_A, y_B - y_A, z_B - z_A) \\ BC &= (x_C - x_B, y_C - y_B, z_C - z_B) \end{aligned} \quad (4)$$

From the obtained vectors AB and BC, we calculated respectively their scalar product ($AB \bullet BC$) and norm ($\|AB\|$ and $\|BC\|$) (see [equations 5](#) and [6](#)).

$$AB \bullet BC = (x_{AB} * x_{BC}) + (y_{AB} * y_{BC}) + (z_{AB} * z_{BC}) \quad (5)$$

where x_{AB} , y_{AB} , and z_{AB} are the components of vector AB, and x_{BC} , y_{BC} , and z_{BC} are the components of vector BC.

$$\begin{aligned} \|AB\| &= \sqrt{(x_{AB}^2 + y_{AB}^2 + z_{AB}^2)} \\ \|BC\| &= \sqrt{(x_{BC}^2 + y_{BC}^2 + z_{BC}^2)} \end{aligned} \quad (6)$$

Lastly, it was possible to obtain the angle between vectors AB and BC, in radians (α in radians and δ in degrees) (see [equations 7](#) and [8](#)).

$$\alpha = \frac{AB \bullet BC}{\|AB\| * \|BC\|} \quad (7)$$

where \arccos represents the arccosine function.

$$\delta = \alpha * \left(\frac{180}{\pi}\right) \quad (8)$$

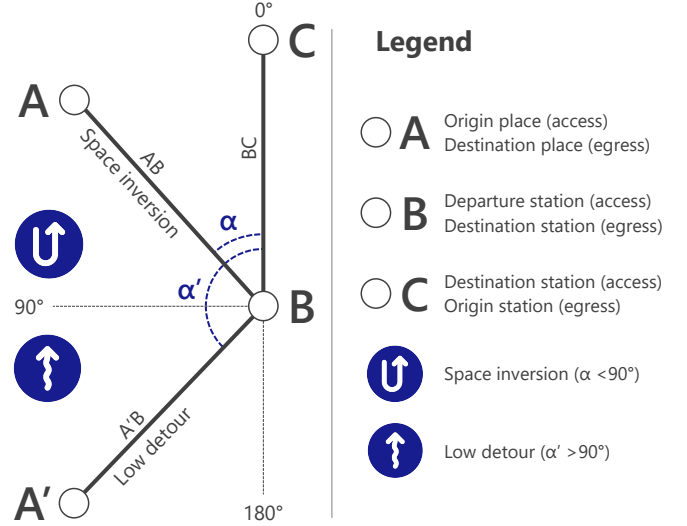


Figure 3: Angle patterns and space inversion

Source: Moïnse, 2023

Once the angles were calculated, we generated an analysis grid to categorize the angles of the determined E-TVS routes. We identify the extreme detour shapes as space inversions, which occur when the angle falls within the range of 0° to 90° . These angles correspond to micromobility trips that originate (point A) from the opposite direction of the destination (point C). Conversely, a detour is not classified as a space inversion when the angle ranges from 90° to 180° , indicating a linear path towards the destination (see [figure 3](#)).

3. Results and discussion

This section will describe and comment extensively on the findings from the applied method. The remaining part of the third section proceeds as follows: firstly, the paper will focus on the range of feeding modes, when considering E-TVS trips, in order to measure the size of station areas (i); on the overall kilometer- and time-savings due to detours (ii); the classification of the optimization strategies based on detours and breaks (iii); and lastly on the clustering of intermodal journeys in relation to optimization ratios (iv).

3.1. Extended station catchment areas

Before considering detours, it is crucial to determine the distances covered by micromobility users, for both access and egress, to gauge the relevant station catchment areas with regard to intermodal practices. Distances were calculated from geographical coordinates collected from the requested exact addresses and the interactive maps integrated in the questionnaire. To assess the social acceptability distance of micromobility-and-ride respondents, the 85th percentile value of the commuting cumulative distribution was applied (Lee, Choi, and Leem 2016, p. 982), except for walk-and-ride set at the 75th percentile (O'Sullivan and Morrall 1996, p. 23).

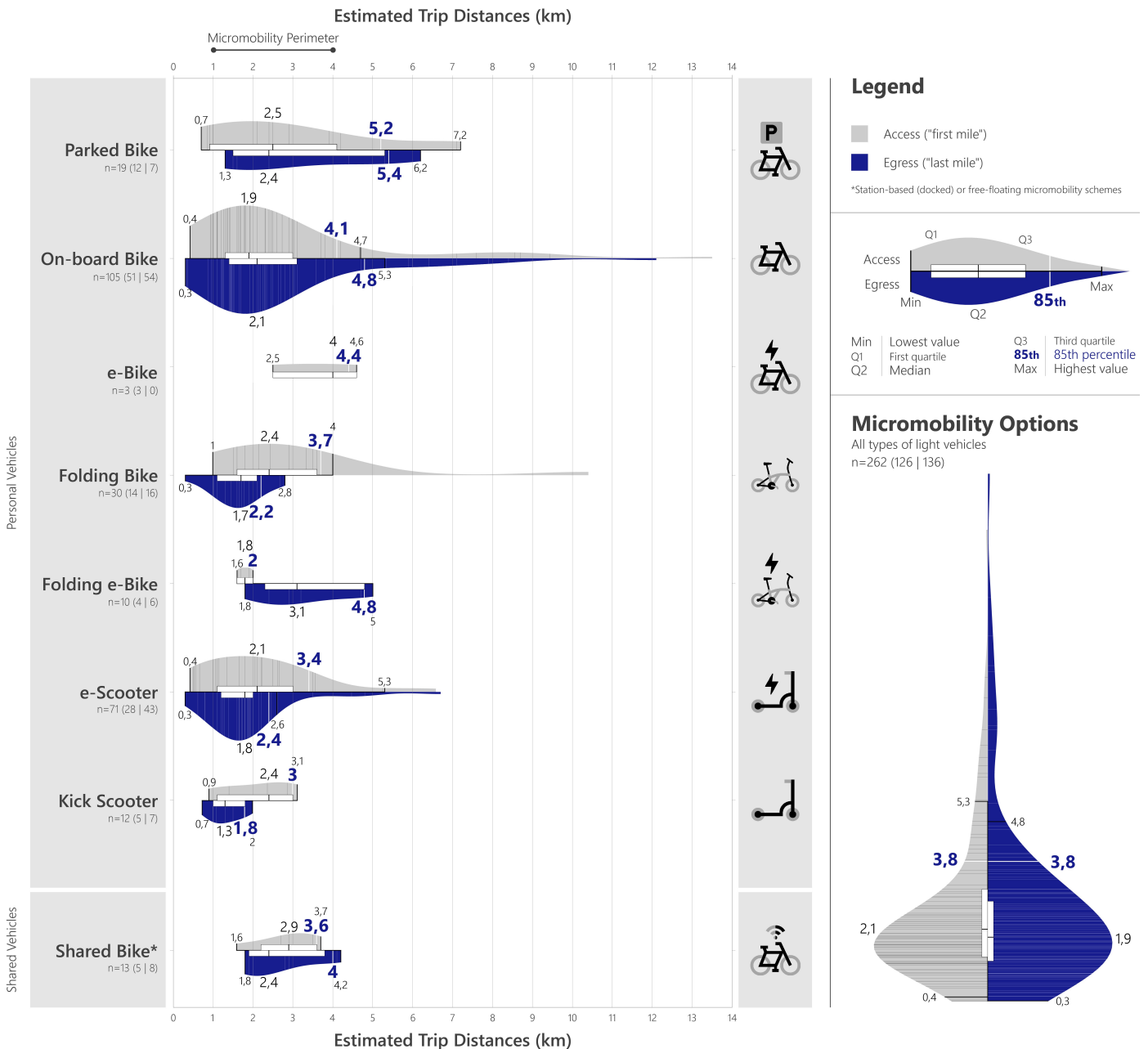


Figure 4: Violin plot of access and egress distances travelled by surveyed commuters, combining transit and micromobility

Source: Moïnse, 2023

As illustrated in figure 4, when looking at the full geocoded sample of intermodal journeys, the impact area of the stations is approximately 3.8 km in both directions overall (n=262). However, the size of the extended station areas reveals disparities in relation to the micromobility solutions surveyed. The conventional bicycle, whether parked at station or taken on-board, covers an acceptable distance of about 4 to 5 km (n=124), 4 km for the station-based or free-floating micromobility (n=13), from 2 to 4 km for the folding bicycle (n=30), and from 2 to 3 km for the e-scooter (n=71). Among the other travel modes used by respondents with transit and micromobility options, walk-and-ride reaches 1.3 km in the 75th percentile (n=49), with access

to 1.7 km (n=18) and egress to 1.2 km (n=31). The range is higher in terms of car usage, with the driver's car being within a tolerable radius of 8.2 km (n=14), and kiss-and-ride up to 5.5 km (n=9), both exclusively for the access link.

Generally speaking, the distance distribution suggests a pedestrian station radius of 1 km and a relevant cycling catchment area between 3 and 4 km. The average access and egress distances of micromobility options are in line with the metro catchment areas measured by Li, Liu, and Ma (2022, p. 9) in Nanjing, who found a 2.47-km coverage by private bicycle and a 2.42-km access and 2.97 km egress by docked bike-sharing, while the car range is 8.85 km and 10.61 km at the 85th percentile.

This intermodal cycling accessibility radius is also consistent with studies showing that 25% (75th percentile) of e-scooter users ride more than 3 km towards medium-sized rail stations in France (Moïnse et al. 2022, p. 21), 20% (80th percentile) of bike-and-bus users cycle more than 4 km in Germany, the Netherlands, and England (Martens 2004, p. 282), or 3.1 km by 10% (90th percentile) of cyclists with BRT in Amsterdam (Brand et al. 2017, p. 5). The in-depth analysis of distances by mode types of our empirical material, considering the development of personal mobility devices (PMD), also highlights the mid-range position of the private e-scooter, positioned between walking and the bicycle. This finding confirms earlier observations by Richer (2021) indicating that PMD’s 85th percentile service area is 2.36 km against 2.71 km for public bike sharing and 3.59 km for the personal bicycle, when combined with mass transit in France.

3.2. Spatio-temporal optimization

A focus on the 129 E-TVS trips subsample, more precisely on the 171 E-TVS access or egress trips by micromobility, was carried out in parallel to this statistical analysis. The estimated kilometer for such trips with detours is higher, with an access range of 6.1 km, with a 2.7 km median, and an egress range of 5.2 km, with a 2.3 km median, for all types of micromobility (n=89). Among the various vehicles belonging to the micromobility category is the classic bicycle reaching a 6.7 km radius and 2.5 km median (n=78), shared micromobility with 4.4 and 2.9 km, (n=17), the folding bike with 6.5 and 2.4 km (n=18), and the e-scooter with 5.7 and 2.5 km (n=36). As compared to the alternative kilometer distances, E-TVS trips with detours include larger distances when accessing the transit network, especially by e-scooter (6.7 km) and bike (7 km). Through a comparison of the distances covered by E-TVS itineraries and detour-free paths, the analysis reveals a statistically significant additional distance of 2 kilometers, equivalent to a 10-minute increase, in the E-TVS routes.

By crossing the observed kilometer distances (km_{eff}) with alternative kilometer distances, labelled (km_{alt}), we can measure the global circuitry coefficient of the 129 commutes. It appears that the average detour rate is 0.97, with a median of 0.98 (see table 2). Statistically, this ratio shows a standard deviation of 0.07 from a minimum value of 0.7 and a maximum of 1.21. In general, E-TVS journeys tend to exhibit relatively shorter kilometer-distance than routes using the rail stations closest to the origin-destination points. Moreover, the average ratio between observed and alternative kilometer distances is 5.75 (n=89) and 7.73 (n=81) regarding access and egress trips. This extent of detouring shows that micromobility users prefer to make average detours 6 to 8 times longer in order to save overall kilometers during the intermodal journey.

This result is supported by the duration analysis of E-TVS commutes. While average total objective time (t_o) saved is 18.82% and perceived time (t_p) is 17.56%, t_{access} and t_{egress} are respectively 3.12 and 3.59 times longer than the alternative shortest trips. *A contrario*, t_{PT} and $t_{waiting}$ are 54.83% and 79.58% less

important thanks to these detours. To the knowledge of the authors, no study has focused on the statistical analysis of such detours using the detour index. Nevertheless, some authors have been interested in the cycling detour rate based on the Euclidean distance, showing a value of 1.14 in Columbus (Park and Akar 2019, p. 195), and between 1.2 and 1.4 for feeding modes to the metro network in Nanjing (Li, Liu, and Ma 2022, p. 10).

3.3. space inversion as a driver for space-time optimization

Starting from the angles (δ) measured for every leg containing a detour (see section 2.6), we examined the question if completing a route in the opposite direction to the destination truly entails time and distance penalties. For this purpose, we have considered, on one side, the access angles of the departure station (B) linking to the origin (A) and to the destination (C), and on the other side, the egress angles of the arrival station (B) connecting the destination (A) and the departure station (C). A simplified analysis framework is applied to assess the resulting angles: space inversion occurs when δ between vectors AB and BC is less than 90° , reflecting a relatively inverted direction with respect to the destination.

Matching the angle of the E-TVS trip (δ_{eff}) with the alternative trip (δ_{alt}), it is found that effective trips involving a detour generally assume an inversion of 76.7° , unlike alternative trips, which are at 110.5° . However, these figures conceal disparities between the access and egress trips. The space inversion of δ_{eff} is on average higher for access (70.74°) than for egress (83.29°). However, comparing them with δ_{alt} demonstrates a greater propensity for space inversion in egress rather than in access: while the difference is only 22.18% between δ_{eff} and δ_{alt} for access; cyclists would be willing to change direction to the extent of 64.51% for egress.

By utilizing the spatio-temporal optimization ratios calculated in the section 3.2, we can determine whether E-TVS routes taking the form of a space inversion actually result in a time loss or, at least, reduced time savings compared to a detour in the same direction as the destination. To address this question, we cross-referenced the angle analysis with the objective time (R_{t_o}) and the distance-based (R_{km}) optimization ratios to determine if there is a relationship between these two variables. The results reveal that R_{t_o} is twice as significant for E-TVS trips using space inversion, at a rate of 25.30% compared to 12.30% for more direct detour shape. In more detail, there is no significant difference between access and egress, with respective percentages of 23.51% versus 14.06% and 27.43% versus 10.59%. Regarding R_{km} , space inversion seems to have a less pronounced impact as detours in the opposite direction result in saving 4.07% of kilometer distance compared to 2.79% for more linear angle patterns. However, significant differences are observed in access segments, with kilometer savings of 5.16% compared to 1.33%. Conversely, egress legs involving space inversion result in fewer kilometers saved compared to an egress without a detour. As demonstrated by figure 6, a positive correlation has been modeled based on angles and R_{t_o} , showing that the more E-TVS trips occur in the opposite direction, the greater the objective time savings.

Table 2: Circuity rate of commuting journeys with at least one detour

Trip	Ratio	Standard Deviation	Minimum value	Maximum value	Sample
E-TVS detour rate (km_{eff}/km_{alt})	0.97	0.07	0.7	1.21	129
E-TVS detour rate (access)	5.75	7.3	1.05	46.73	89
E-TVS detour rate (egress)	7.73	14.23	1.09	115.22	81
E-TVS detour rate (in-vehicle)	0.9	0.12	0.45	1.15	129

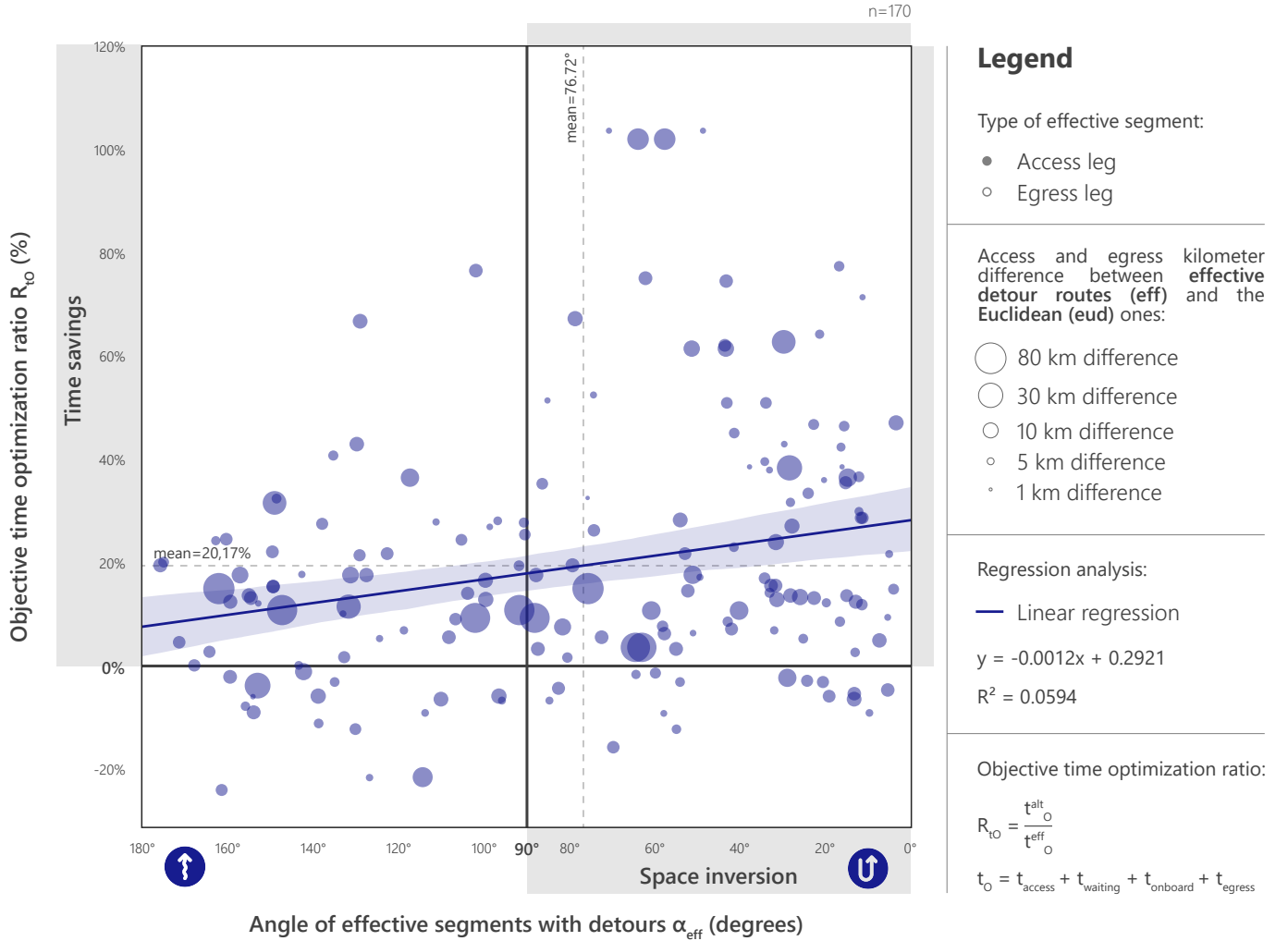


Figure 5: Linear regression between route detour shape and time savings for each intermodal trip

Source: Moïnse, 2023

3.4. Classification of optimization strategies

The statistical analysis of the surveyed E-TVS commutes was supplemented by a spatial analysis of the itineraries, which resulted in the identification of different types of optimization detour-based strategies. We realized a classification of three main forms of detours depending on the context in which the search for network optimization appears: as shown in figure 6, the first mobility practice is named “avoiding transfers” (i), the second “attractive station” (ii), and the last “reduced time on board PT” (iii).

- The strategy relating to the transfer avoidance is based on the willingness to bypass a transit line in order to ac-

cess a more distant station, allowing to save one or several connections (see figure 6), and their associated, negatively perceived waiting times. Thus, the passenger accesses line C directly without going through line A. This optimization strategy was identified in 152 of the 171 E-TVS access and egress segments. In half of the cases, these detours are embodied by the avoidance of a subway line.

- The strategy based on the attractiveness of further stations privileges a station with a better level of service than the nearest one on the same line as, making it possible to benefit from better frequency and express trains (see figure 6). In our example, the passenger reaches the largest station

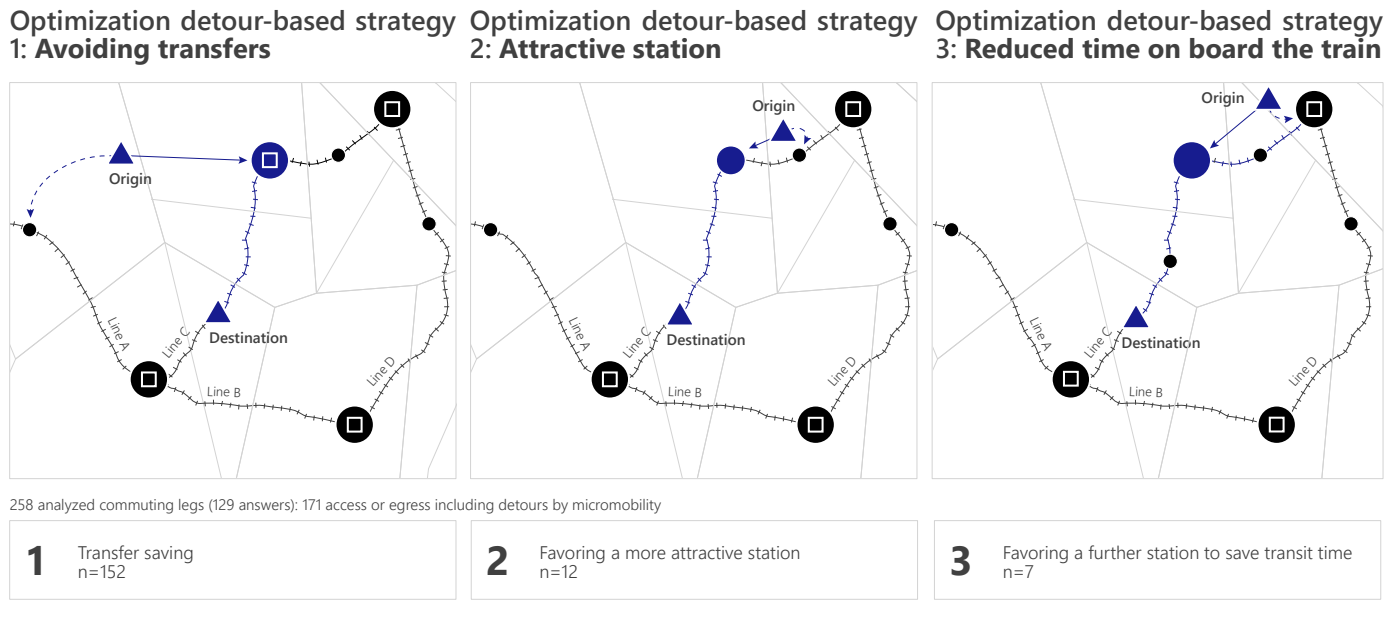


Figure 6: Classification of optimization strategies integrating detours on intermodal journeys, from survey respondents

Source: Moïnse, 2023

on the line C rather than the station with fewer services. This strategy was identified in 12 E-TVS access and egress trips.

- The third strategy aimed at decreasing the time spent on board a transit mode refers to access to a more distant but with an equivalent quality service station as the nearest station in order to reduce time spent on public transport (see figure 6). Only 7 trips were classified in this strategy.

The first optimization strategy, involving the avoidance of connections, was investigated in detail through the two go-alongs. The first participant (PCTE1) justifies why this detour is happening by stating that she lives near “a metro station ten minutes away on foot [...] [but that she has] to take the opposite route”. She adds that she feels it is a “waste of time” and that is why she prefers to “go directly to the station with my own e-scooter”. A similar argument is voiced by the second interviewee (PCTE2), who indicates that he chose to “take an extra five minutes by e-scooter” to reach a metro station located on his destination’s line. This longer route then enables him to avoid to “take two different metro lines with a very painful connection” while “avoiding less comfortable routes” if he had reached the nearest metro station.

This classification of detours made by intermodal travelers extends previous contributions by Rijsman et al. (2019, p. 3) who determine that the motives for choosing a stop further away are mostly related with the quality and comfort of the transit service, where avoiding a transfer is the most cited option. Additionally, Jonkeren, Kager, et al. (2021) and Krizek and Stone-

braker (2010, pp. 468, 2144) highlight the role of more convenient stations. Our analysis also reveals an additional access and egress objective measured time of 9 min for the first optimization strategy, in concordance with the preference for an extra cycling time of 5 to 10 min to reduce the number of transfers (Mil et al. 2020, p. 665).

Another character of optimization strategy lies in the break that necessarily occurs when changing travel mode, notably when accessing a station. This intermediate time related to waiting transit can be analyzed as an opportunity to optimize the trip chain, but also as an opportunity to conduct additional activities during the trip. The 110 respondents, who reported having performed an activity during the waiting stage of their intermodal journey, were asked to specify the activity type(s). This question shows that a majority of breaks were used as an opportune shopping time, while one-quarter of respondents report taking advantage of the break to develop social-related interactions or business activities (see table 3). The very possibility to conduct these activities depends on the existence of a break time and of activity sites and services located in or near the railway station. This analysis highlights the positive role of break in intermodal journeys, and underlines the contribution of urban amenities in forming optimal distances and hence trips, keeping in mind the broader aim to support the alternatives to the car for mobility at the scale of urban regions. This connection between transport and urban development issues calls for a renewed attention by urban and transport actors on the design of railway stations and their surroundings, and on the distribution of services. In this context, the first go-along interview (PCTE1) provides more in-

Table 3: Reasons given for the 110 reported breaks (total number greater than 100% due to multi-choice answers)

Break reason	Sample	Share
Shopping-related break(s)	82	74.5%
Social meeting-related break(s)	30	27.3%
Business-related break(s)	27	24.5%
Leisure-related break(s)	23	20.9%
Administrative-related break(s)	17	15.5%
Visiting-related break(s)	16	14.5%

formation about the advantages of the break, since the interviewee explains that “I can stop at the station because there is a bakery. [...] I save time, clearly, I would not have had the same motivation to shop at local stores near my home or the train station if I had made the same journey by car”. This is in line with Jonkeren and Kager (2021, p. 468)’s study showing that visiting supermarkets and other shops are the most popular activities for trip chaining on the bicycle access leg.

3.5. Clustering of intermodal journeys

By estimating the different optimization ratios (R), this study conducted a clustering of the analyzed commutes. For this, we confronted the kilometer optimization ratio (R_{km}) and the perceived time ratio (R_{tp}) to distribute the routes according to these two variables. On one hand, the spatial optimization ratio helps to compare the kilometer gains saved by the effective kilometer (km_{eff}) and the alternative kilometer (km_{alt}). On the other hand, the temporal optimization ratio represents the time gains saved by the effective perceived time (t_{effp}) as opposed to the alternative perceived time (t_{altp}). Depending on R_{km} and R_{tp} obtained, this statistical assessment sets the analyzed E-TVS commutes in relation to the kilometer- and time-saving or wasting. This analysis consists in a bubble chart that plots the relationship between R_{km} (X-axis) and R_{tp} (Y-axis), with a third variable (Z values) based on the feeding kilometer difference between km_{eff} and km_{alt} , and a categorical variable related to the type of detour (see figure 7).

The clustering analysis of E-TVS trips based on the generated optimization ratios highlights four distinct spatio-temporal optimization profiles. Profile A is characterized by time savings but an unfavorable kilometric ratio, whereas Profile B prioritizes kilometric gains at the expense of time. Alongside, Profile C combines both time and kilometric benefits, while Profile D does not show any time or kilometric improvements. The graphical representation highlights a dense clustering of 84 E-TVS trips, accounting for 65%, in Profile C. Furthermore, when grouping Profiles A, B, and C together, it is revealed that 95% of the analyzed itineraries are included. This demonstrates that nearly all investigated detours enable time and/or distance savings compared to alternative routes. In contrast, the distance difference between the actual and alternative routes does not appear to have an impact on the spatio-temporal optimization ratios, suggesting that a detour of a few kilometers is capable of significantly optimizing an intermodal journey.

Nevertheless, the observation of a few detours in Profile D indicates that other factors external to spatial or temporal opti-

mization may explain the choice of such detours. Although this research has chosen to focus particularly on distance-related dimensions, it is crucial to integrate essential variables playing a role in FLM route choices, such as characteristics of the urban environment, road infrastructure, and the ambiance and stress levels of the transport networks (Zuo, Wei, and N. Chen 2021, p. 79).

4. Conclusions

The purpose of the present research was to examine detours and breaks made by commuters combining micromobility and public transport network, as a way to optimize intermodal travel. One of the more significant findings to emerge from this study is that making detours allows to save an average 18% of the total perceived time and 3% of the kilometer covered, while breaks are an opportunity to capitalize on this time, especially by shopping. Importantly, our results provide evidence for the positive relationship between detours, breaks, and optimization, since commuters access and egress on average 3 times more time than the shortest route to cut their transit time in half and their waiting time by 80%. The distance distribution analysis reveals a considerably wider station catchment area. The extent of the detour trips using micromobility is 5-6 km, equivalent to 20 min, with the conventional and folding bicycles reaching 7 km and the personal e-scooter 6 km. It has been demonstrated that time savings are greater when detours assume the form of space inversion. This paper also explores the detour characteristics, following a classification process that indicated that a substantial proportion of journeys involve detours to avoid transfer, usually with the metro network. The last key insight from this research consists of a clustering of the surveyed trips, suggesting that 95% of the detour sample saves either time or kilometer, and that 65% of optimization strategies save both.

By revisiting the questions raised, we have demonstrated that the four main research hypotheses underlying this method have been validated, confirming the positive relationship between detour, pause, and intermodal travel optimization strategies:

- What is the size of station areas? Does it evolve taking into account the E-TVS strategies developed by the surveyed riders? The acceptable transit catchment area by micromobility is 4 km, but it extends to 6 km for travelers who take detours. This difference results in 2 km or 10 min (+125%) longer access/egress trips to make a detour.

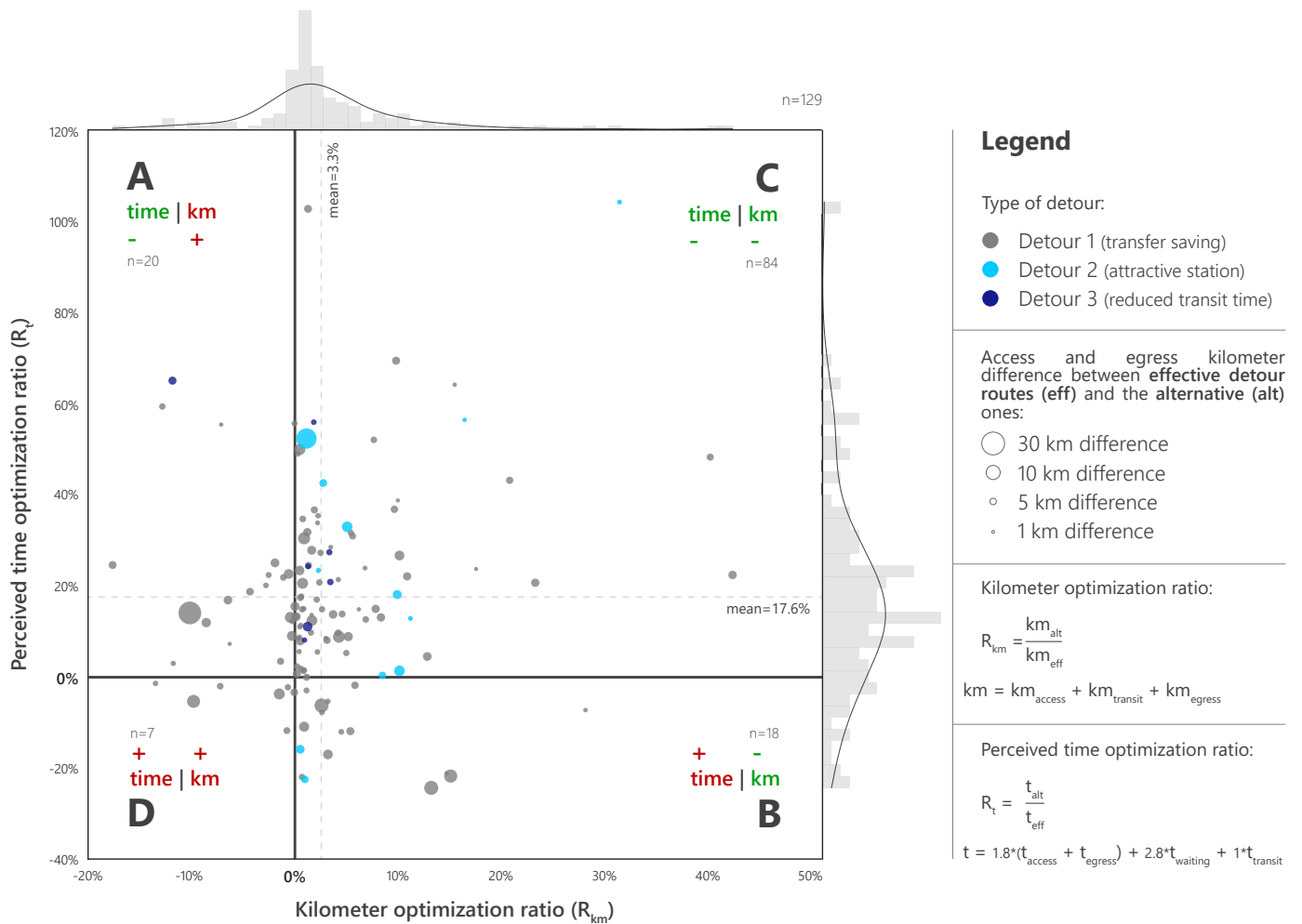


Figure 7: Clustering of intermodal journeys comprising detours across four categories of spatio-temporal optimization

Source: Moïnse, 2023

- Does making E-TVS during an intermodal journey result in increased travel time and kilometer? The detour-based optimization strategy allows for time savings of 19% and kilometer savings of 3%. By categorizing intermodal travel profiles, the majority of strategies enable both time and kilometer reduction.
- Similarly, does the direction have an impact on the performance of intermodal journeys? On the contrary, space inversion (extreme form of detour) is associated with time savings: 25% compared to 12% for detours without space inversion.
- What are the main motivations for making E-TVS or a break in intermodal journeys? The primary motivation behind making E-TVS is often to avoid transfers. Breaks are typically taken to carry out daily shopping tasks.

The extended catchment area, which benefits both from the intermodal use of micromobility and from optimization strategies based on detours and breaks, enhances the Micromobility-based TOD (M-TOD) model by determining a relevance perimeter for micromobility in connection with the stations. Regarding the

TOD model, the “culture of indifference towards public transport” (Tan, Bertolini, and Janssen-Jansen 2014, p. 656) by authorities generates significant barriers. The ambition of this paper is to contribute to a better understanding of transit based mobility, with the aim to inform design and urban development policies. The privileged accessibility to more attractive stations due to their better level of service leads to rethinking the reorganization of mobility systems, considering the dual approach between the efficiency of the mass transit network and territorial connectivity. A part of the dilemma of public transport network design and operation can be captured with the concept of territorial adherence (Conesa 2010, p. 248), where an improved adherence generates a more spatially spread access to the detriment of the overall performance of the system. In fact, the intermodal use of micromobility associated with detours seems to overcome this dialectical issue by promoting the coexistence of direct and fast transit systems to major stations with local accessibility. Future research should consider the potential effects of detours as an individual mobility strategy. In addition, exploring the relationship between these optimization experiences and the built environment might prove an important

area for further investigation. Future research is needed to confirm this novel approach by conducting more robust qualitative methods.

Acknowledgements

The authors are thankful for the help and support provided by the research associates Biao Yin and Tatiana Seregina regarding the measurement of time-related values for intermodal travel. We are also grateful to the participants attending the "Interviewing and representing territories from individual experiences: contributions of perception methods" seminar organized by the Laboratoire Ville Mobilité Transport on the 16th of March 2023 in Paris, who gave useful advice regarding this research project. We would like to acknowledge the respondents to the questionnaire as well as the participants who agreed to participate to go-alongs as part of this research.

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