Smart hubs in Rotterdam:
een studie naar deelmobiliteit in combinatie met OV

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Samenvatting

Deelmobiliteit, zoals deelfietsen en deelscooters, worden meer en meer ingezet, voornamelijk in grote steden met de potentie om autobezit te verlagen en de bereikbaarheid van openbaar vervoer te verbeteren. Echter, in Nederlandse steden waar actief en openbaar vervoer vaak al veel gebruikt wordt, zouden deelscooters en deelfietsen juist ook concurreren met deze ritten. De vraag is daarom of deze vormen van deelmobiliteit een aanvulling zijn op het OV-netwerk of juist concurreren met het stedelijk OV? Daarnaast wordt gekeken naar de potentie van zogenaamde mobiliteitshubs, waar openbaar vervoer geïntegreerd wordt aangeboden met deelvervoer. Wat als de deelscooters zouden worden aangeboden op deze goed geïntegreerde hubs, worden de scooters dan meer gebruikt in multimodale trips? En welke integratie factoren spelen hierbij een belangrijke rol?

In deze studie wordt, aan de hand van een trip data analyse en een enquête, gekeken naar de huidige rol van deelvervoer in Rotterdam en de integratie met het OV. Op dit moment worden deelscooters en deelfietsen maar door een klein deel van de Rotterdammers gebruikt, vooral voor woon-werkverkeer of om te reizen naar sociale activiteiten. Een deel van deze reizen wordt gemaakt in combinatie met het OV, maar de meeste deelscooter en deelfiets ritten zijn op zichzelf staande ritten, onafhankelijk van OV. De ritten die als aanvulling op het OV netwerk worden gemaakt zijn meestal in combinatie met de metro of de trein. Hier zijn de deelscooter en deelfiets een goede aanvulling op het vervoerssysteem van de stad, waar ze kunnen bijdrage aan betere bereikbaarheid van OV. Er wordt hiervoor echter wel een prijs betaald, uit de data analyse én de enquête blijkt dat vooral de deelscooter ook concurrentie is met het stedelijk OV-netwerk.

Met behulp van een regressie model is vervolgens gekeken naar de potentie van mobiliteitshubs en de integratie van deelscooters op zulke locaties. Hieruit blijkt dat de intentie om een deelscooter te gebruiken op een hub, voornamelijk wordt verklaard door enkele gebruikerskarakteristieken (zoals digitale vaardigheden en sociale invloeden) en factoren op het gebied van deelscooter aanbod. Potentieel gebruik is hoger wanneer veel aandacht wordt besteed aan de bereikbaarheid en het gebruiksgemak van de deelscooter, net zoals de overstap mogelijkheden op de hub. Zolang deelmobiliteit makkelijk en snel te bereiken is voor gebruikers, kunnen mobiliteitshubs de integratie met OV verhogen.

1. Introduction

Shifting from the private car to more sustainable ways of transportation is needed to overcome the rising problems of urbanisation and global warming (Ma et al., 2020). Active and public transportation are generally seen as promising solutions, and governments worldwide are working on increasing the attractiveness of these sustainable modes but are not always successful (Bachand-Marleau et al., 2011). One issue that users of public transportation (PT) have to overcome, is the so-called first and last-mile of their trip. Since public transport is bound to certain stations and a timetable, it cannot take users exactly to their destination at all times, which makes travelling more difficult (Grosshuesch, 2020). To become a suitable alternative, PT needs to integrate with other forms of transportation that help users to access or egress the public transit system more easily, enabling multimodal mobility behaviour (Miramontes et al., 2019). In this light, innovative shared micromobility options, such as bikes, scooters and e-mopeds, might improve the connectivity within these intermodal trips (Schröder et al., 2014).

Shared micromobility has developed rapidly over the past years. Limited space in urban areas and a graduate paradigm shift towards less consumerism and less ownership create a good environment for the introduction of shared modes of transport (Alonso Raposo et al., 2019; Miramontes et al., 2019). Using micromobility options, users are expected to overcome first and last-mile transportation issues when properly integrated with other modes of transport (Oeschger et al., 2020). Mobility hubs facilitate this integration of different shared and public transportation options by ideally offering an effortless transfer and reducing parking nuisance (Gössling, 2020). New micromobility options might change the role of the mobility hub as a docking station, since many providers also offer free-floating systems for bikes, scooters and e-mopeds (Grosshuesch, 2020). While this evolution positively affects the first and last-mile problem, it also brings uncertainty to the effortless transfer at mobility hubs because clear integration with shared or public transport modes is missing (Oeschger et al., 2020).

Many studies have been focusing on bike-sharing and car-sharing, and the impact of mobility hubs on mode choice (Arias-Molinares et al., 2021). Shared e-scooters (standing scooters, in Dutch: elektrische step) are also being studied increasingly, due to them being implemented in cities all across the globe (Liao & Correia, 2019). However, the amount of scientific research on e-mopeds and their relationship with mobility hubs is scarce. E-mopeds (electrically powered, seated two-wheelers) are relatively new, but are expanding rapidly across the Netherlands, with e-mopeds being offered in over twenty cities (GoSharing, 2022). Since the Dutch Ministry of Infrastructure and Water Management does not allow the majority of (shared) e-scooters on its public roads, shared bikes and e-mopeds are the main form of micromobility that is offered in major Dutch cities, making the Dutch shared mobility situation interesting to study. However, their integration with mobility hubs and public transportation is unknown.

Therefore, this research will focus on shared e-mopeds and shared bikes, their travel patterns and integration with public transportation, and their similarities and differences. It is aimed to provide a full picture of the current integration of these shared vehicles and public transportation as well as their future potential, when integrating them at mobility hubs.

2. Shared mobility in the existing literature

2.1 Shared micromobility across the globe

Research on shared e-mopeds and their relationship with mobility hubs is limited. However, shared bikes and e-scooters are more widely implemented and therefore studied more often, and can thus provide a base to determine the conceptual framework for the relation between e-mopeds and mobility hubs (Caspi et al., 2020). In general, shared mobility offers transportation services in which the vehicles might be accessed by multiple users for different trip purposes (Murphy & Sharon, 2016, p.5). At the beginning of the shared mobility era, most implemented systems focused on car or bike-sharing. However, implementations of shared mobility initiatives are increasing rapidly across the globe. A relatively new and constantly developing concept is shared micromobility modes (see Figure 1), which are especially utilized in denser urban areas (Liao & Correia, 2019). Studies on the effect of shared micromobility schemes are scarce (except for bike-sharing schemes (BSS)) and this will therefore be the focus point of the research (Gössling, 2020).

Figure 1. Shared micromobility modes discussed in this study. E-moped on the left is from provider *Felyx*, the (e-)bike in the middle is from *Vaimoo*. Both are active in Rotterdam, the Netherlands. On the right, a (standing) e-scooter from provider *Lime* can be seen. This type of e-scooter is widely implemented across the globe but is currently prohibited in the Netherlands.

Micromobility consists of using light vehicles (below 350 kg) that are designed for short distances (< 15 km), have a low maximum speed (< 45 km/h) and includes both human-powered and electric-powered vehicles. Bikes, scooters, mopeds but also hoverboards, gyro boards and other self-balancing vehicles are categorized as micromobility (ITF, 2020; Liao & Correia, 2019). **Bicycle sharing** already started in the 1960s and has developed a lot since then. Currently, most systems use modern technologies (such as e-bikes) and easily accessible docking stations, also called bike-sharing stations, which are strategically positioned in urban areas so users can easily get a bike for a short trip from station to station (Martin & Shaheen, 2014; Ricci, 2015). **E-scooter sharing** is one of the newest inventions in the micromobility field, using electric-powered micro-vehicles, sometimes referred to as electric kick scooters or standing electric scooters, which are lightweight and have a maximum speed of around 20 km/h. Most e-scooter providers use a free-floating scheme, where the vehicles can be parked anywhere within the (digital) boundaries of the predetermined area (Gössling, 2020; ITF, 2020; Liao & Correia, 2019). **E-moped sharing** is implemented in 88 cities worldwide, especially in European cities. The systems use vehicles that are heavier in comparison to e-scooters and have a maximum speed of 25-45 km/h, based on national regulations (Howe, 2018; ITF, 2020).

The impact of shared micromobility is debated among scholars. Focusing on bicycle sharing, De Chardon (2019) found that cities implement bike-sharing systems mostly to promote equity and sustainability but in reality, many systems are technology-driven solutions without a clear benefit to the city. Moreover, studies indicate that bicycle-sharing systems substitute walking trips instead of car trips, reducing the bike-sharing scheme's (BSS) effect on beneficial mode shifts (Böcker et al., 2020). However, Li et al. (2018) found that the introduction of a BSS improved the access-egress of public transit and therefore saw an increase in both bike and public transit users. De Kruijf et al. (2018) showed that specifically targeting the use of shared e-bikes reduced car use, illustrating the potential of shared bikes. In addition, Liao and Correia (2019) summarize studies that investigated the mode substitution of e-scooters: some studies showed that the introduction of e-scooters substituted 34% of car trips whereas others showed that e-scooters replaced 37% of walking trips or 5-41% of trips previously completed by bike, illustrating the discussion on sustainability benefits. The same holds for shared e-mopeds; a German based study found that almost a quarter of shared e-moped trips was longer than 6 km, emphasizing that it is not only a first-last mile solution, substituting active trips, but also creates new trips (Degele et al., 2018). However, an Amsterdam-based survey showed that only 22% of users would otherwise have used a car or taxi for their e-moped trip. A similar survey in the city of Rotterdam found this percentage to be 23%, with the rest of the trips substituting active and public transport (Municipality of Amsterdam, 2021; Municipality of Rotterdam, 2021a). The characteristics of different shared micromobility schemes are presented in Table 1.

Table 1. Characteristics of different shared micromobility schemes *

	(e-) Bikes	E-scooters	E-mopeds
Trip length	1 – 3.5 kilometre [LC19] Maximum: 4.6 km [S18]	2-3 kilometre [SS18] 1.8 kilometre [S19]	4-5 kilometre [H18] 1-3 kilometre [AM21] 5.3 kilometre [D18]
Trip duration	10-16 minutes [S18]	13.86 minutes [SS18]	15-20 minutes [SS18]
Usage pattern	Peak usage on weekdays in morning, afternoon and evening. [LC19] High weekend usage [R15]	Both during weekdays and weekends, peak usage in afternoon commute. [LC19]	Peak usage in morning and evening commute. [AM21] At weekends during the evening. [LC19]

* *References*: [AM21]: Arias-Molinares et al., 2021; [D18]: Degele et al., 2018; [H18]: Howe, 2018; [LC19]: Liao & Correia, 2019; [R15]: Ricci, 2015; [SS18]: Smith & Schwieterman, 2018; [S18]: Sokoloff, 2018; [S19]: Statista, 2019.

Shared micromobility attracts a particular user profile in terms of socio-economic and demographic attributes. Most of these studies concentrate on BSSs or e-scooters and show similar results: users are primarily male, Caucasian, young (under 40) and highly educated (Adnan et al., 2019; Böcker et al., 2020; Martin & Shaheen, 2014; Ricci, 2015). On the topic of equity, research shows that most shared mobility systems (including bikes, scooters and cars) benefit privileged demographics (De Chardon, 2019), meaning that users are generally young males with higher education and income levels, and already frequent public transport and bike users (Liao & Correia, 2019), endorsing the previously mentioned studies. To summarise these user characteristics, Howe (2018) describes shared mobility users (to be more specific: e-moped users) as "*young urban professionals"* (Howe, 2018, p.21).

2.2 Integration of shared micromobility and public transportation

The popularity of shared micromobility derives from its potential to increase the accessibility of public transport and to decrease car ownership, especially in cities where people prefer other modes over cars (Alonso Raposo et al., 2019). To reach this potential, shared micro-vehicles should be integrated with public transportation, so that they can be treated as one individual, sustainable transportation mode, benefiting both systems (Oeschger et al., 2020). Ji et al. (2018) found that when shared micromobility is offered in proximity to public transportation, PT trips will see an increase, because the efficiency of the complete intermodal systems is improved. Nevertheless, sharing systems were not only complementary to PT: when the bus network around metro stations was dense, people tended to shift from bike-sharing to using the bus for their access-egress trips, meaning that bus and shared bikes substitute each other (Ji et al., 2018). That integration between the micromobility and PT increases intermodal trips was shown in a study by Coenegrachts et al. (2021), indicating that physical and digital integration of shared mobility services with public transport is a challenge in reaching the potential that shared mobility services can offer. In other words, a seemingly effortless transfer between the shared micro-vehicles and public transportation is needed, to stimulate intermodal trips. This transfer can happen at so-called mobility hubs.

A mobility hub is a location where travellers change between different shared or public transport modes, but it can also become a location for other purposes and services, emphasising the broad possible implementations of a mobility hub (Bell, 2019). There are many different definitions in both the academic world and planning practice, focussing on different aspects of the hub, but the definition used in this research is based on the work of the *SmartHubs* project that combines the work of multiple scholars: *"A mobility hub is a physical location where different shared transport options are offered at permanent, dedicated and well-visible locations and public or collective transport is available at walking distance"* (Geurs et al., 2022, p.10). This lastly mentioned walking distance reveals that integration between different modes is key at mobility hubs since it helps to increase the number of multimodal trips. The distance or proximity of shared micromobility and public transportation is thus an important factor (Böcker et al., 2020; Ji et al., 2018), i.e., the transport modes offered at a hub should be easily accessible for all (CoMoUK, 2019). And accessibility is considered broader than *physical* accessibility; mobility hubs and shared micromobility services should also offer *digital* accessibility, where people without access to or knowledge of those systems are at a disadvantage, increasing exclusion among those groups (Durand et al., 2021).

The integration of shared micromobility services and public transportation, and thus travel behaviour, also depends on the service model providers use. Systems that use docking stations constrain users in making effective short trips since long walking distances towards these stations can take up a great amount of time (Li et al., 2018). Free-floating systems allow a vehicle to be returned anywhere in the public area, except for restricted areas. Vehicles are tracked by GPS and borders of the area are defined in collaboration with municipalities (Li et al., 2018; Municipality of Rotterdam, 2021a). This freedom comes with a price; the systems are usually more expensive, cause more nuisance in public space, and increase digital inequality since a mobile phone is needed to start a ride (Gu et al., 2019). However, docked systems' integration with public transportation is generally better and could therefore be a better choice to attract micromobility as access-egress mode (Gu et al., 2019).

When shared micromobility and public transportation are properly integrated at mobility hubs, the mobility hubs could potentially overcome, amongst other things, gaps in the public transportation network, improve safety and accessibility, change parking needs and improve the public realm (CoMoUK, 2019). Miramontes et al. (2019) found that users of mobility stations increase their public transport use. A different study quantifies the effect of integration of bike-sharing and public transport, which in Montreal has led to a 10% increase in rail usage (Martin & Shaheen, 2014). These effects are also observed in the Netherlands: a recent study found that under the conditions of a perfectly integrated system, shared modes have the potential to be interesting egress alternatives for metro trips in Rotterdam (Montes Rojas, 2021). Thereby, multimodal integration with the current transportation system also further increases the utility of shared mobility, indicating that the integration benefits both ways (Coenegrachts et al., 2021). Increasing the catchment area of public transportation might improve the accessibility of people that did not have access before, potentially increasing transport equity as well (Liao & Correia, 2019).

2.3 Research gap

It is clear that micromobility has a high potential as an access-egress mode for public transport. However, different shared modes might have a different integration with public transportation. For instance, bicycle sharing is considered to be complementary to train with bicycle-train combination being a competitive alternative to motorized transport modes (Kager et al., 2016). Although, there are fundamental differences between different PT and bicycle sharing stations in terms of trips they attract, therefore more research is needed to understand the role of sharing services in urban transportation (Hyland et al., 2018). For the shared e-moped, Liao & Correia (2020) state: are shared e-mopeds complementary to the PT network, or competitive? An important question, because the ability of shared e-mopeds to complement urban transport will determine if it is beneficial for urban sustainability and liveability (Aguilera-García et al., 2020).

In addition, previous studies have shown that to be able to overcome the first and last-mile of a trip, shared mobility should be integrated properly with public transport. Many of those studies focus on the impact of mobility hubs on the transportation system, considering external factors that influence people's mode choice. Within the *SmartHubs* project, an integration ladder was constructed based on this literature. It is hypothesized that higher levels of integration, i.e., "smarter" mobility hubs, cause an increase in the use of PT and the use of shared mobility, and create more user value (Geurs et al., 2022). Hence, this study will also focus on the effect of different integration factors, to see if physical and digital integration of free-floating e-mopeds and mobility hubs has an effect on the (potential) use of e-mopeds as an access-egress mode at mobility hubs, thus combining the current use and integration of e-mopeds with the potential integration in the future.

3. Shared mobility and PT – current integration in Rotterdam

3.1 Study area: Rotterdam, the Netherlands

Rotterdam is the second-largest city of the Netherlands (~652.000 inhabitants), located in the *Randstad* region. Interesting about Rotterdam is its large share of inhabitants with a migration background (52%), of which 36% have a non-western background (CBS Statline, 2021). When focusing on mobility, a survey showed that trips to the centre of Rotterdam can be divided into car (42%), public transport (29%) and bike (29%) trips. However, the municipality of Rotterdam aims to lower the share of car trips to 28% by 2040 (Municipality of Rotterdam, 2020). To make this happen, the municipality relies on the public transport network of Rotterdam, which is operated by the *RET*. The RET operates the bus, ferry, tram and metro lines, of which the latter transports ~450,000 passengers per day (before the COVID-19 pandemic) (RET, 2020).

Shared micromobility vehicles in Rotterdam are currently operated by six different providers offering e-mopeds and (e-)bikes, mostly using free-floating systems (Municipality of Rotterdam, 2021b). On average, 2305 e-mopeds were available last year and were used to make ~269,000 trips per month (Fietsberaad CROW, 2022). The origins and destinations of trips are not evenly spread throughout the city of Rotterdam, partly because some e-moped providers were preserved in offering e-mopeds in southern Rotterdam due to lower willingness to pay and vandalism (Municipality of Rotterdam, 2021a, 2021b). In terms of use, earlier research showed that 23% of shared e-moped users would otherwise have used a private car for the same trip, while most users switched from active (33%) or public transportation (27%) (Municipality of Rotterdam, 2021a).

3.2 Dataset & analyses

Shared e-moped and shared bike trips have been analysed using a trip dataset for September 2021, consisting of start and ending coordinates of the trips as well as the duration. After data cleaning and outlier removal, the dataset contained ~347,000 shared e-moped trips and ~14,800 shared bike trips. The general characteristics of the trips within the dataset can be found in Table 2, showing that the shared e-mopeds and bikes are used to travel comparable distances, only with a much shorter average duration for the mopeds. Furthermore, the shared e-mopeds are more frequently used than the shared bikes, based on daily average trips and trips per available vehicle. Lastly, the Global Moran's I spatial autocorrelation test has identified a clustered pattern or both service types.

Table 2. Characteristics of shared micromobility trips in Rotterdam. September 2021.

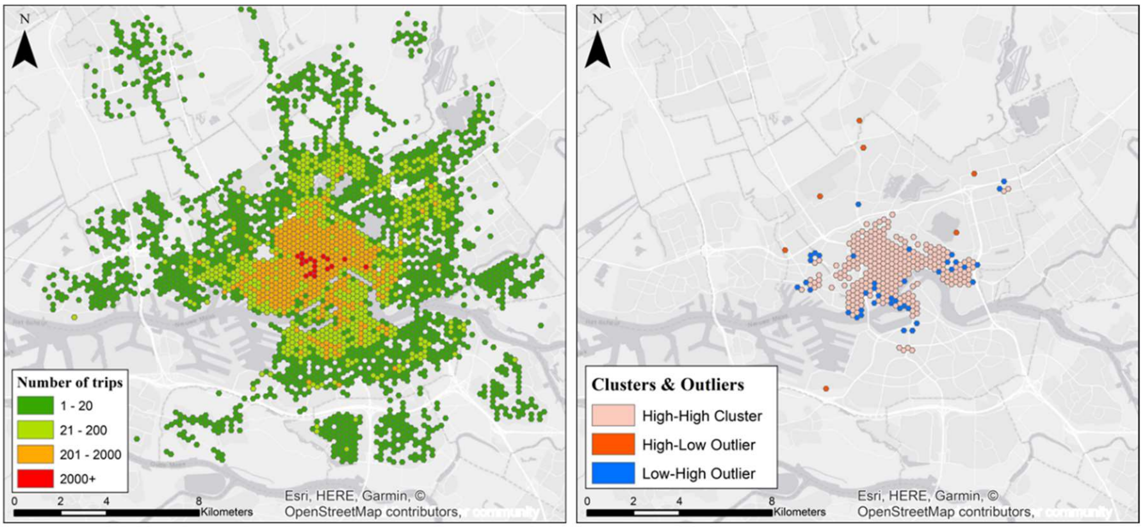
	Shared e-moped trips	**Shared bike trips**
Trips	347,942	14,790
Average trips per day	11,598	493
Average duration (seconds)	827	1200
Average Euclidean distance (km)	1.76	1.58
Average trips per vehicle	4.87 per day	0.54 per day
Global Moran's I cluster score (origins)	*0.58 ($p < 0.01$)*	*0.12 ($p < 0.01$)*

The start/end locations of trips are then aggregated in 200m-sided hexagons, an acceptable walking distance toward a shared micro vehicle (Arias-Molinares et al., 2021; Liao & Correia, 2019). These hexagonal grids are also used to perform spatial analyses, such as *Local Moran's I* (Anselin, 1995) which will be used to identify statistically significant locations where starts or ends of trips cluster (Arias-Molinares et al., 2021). Furthermore, all trips are divided into four categories based on the closeness of their origins or destinations to PT stops: (i) both trip start and end is near PT stop (*PT-PT*), these trips are marked as **competitive**. (ii) only trip start (*PT-x*) or end (*x-PT*) near a PT stop, which are considered to be involved in a first/last mile trip and therefore **complementary**. Lastly, (iii) the trip start, and end are unrelated to a PT stop (*x-x*) (Yan et al., 2021). This categorisation of trips can be seen in Figure 4.a.

Spatial patterns

<u>Shared e-moped</u>

It becomes clear from Figure 2.a. that most trips end in downtown Rotterdam, with high densities around the train/metro stations *Rotterdam Centraal* and *Blaak* and metro junction *Beurs*. In general, 60% of all trips start and end within the city centre. 50% of trips starting outside the city centre move toward there as well. Figure 2.b. shows that the main service area of the shared e-mopeds is one large, significant cluster, emphasizing that shared e-moped cluster at the centre and at local centres like educational locations or PT stops.



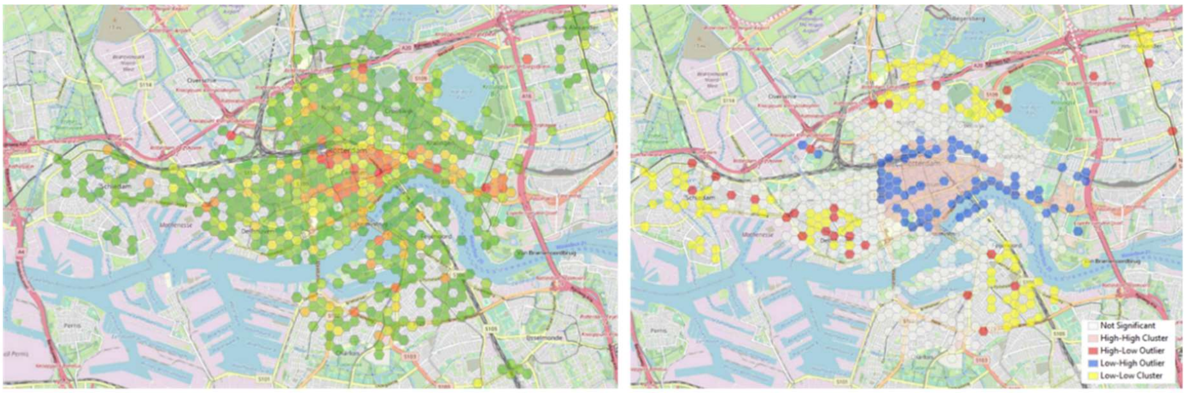
(a) Shared e-moped trip destinations heatmap (only trips that start within Rotterdam)

(b) Shared e-moped trip destinations clusters & outliers (non-significant relations are not depicted)

Figure 2. Spatial patterns of shared e-moped trips in Rotterdam. September 2021.

<u>Shared bike</u>

The highest demand for the shared bike service is observed (Figure 3.a.) in the central district of the city, specifically near stations *Rotterdam Centraal*, *Beurs*, *Blaak* and *Oostplein* as well as on campus of the *Erasmus University*, situated in the East of the city. The spatial clustering tool highlights, besides from the high-high cluster in the city centre, locations in non-central districts (high-low outliers) where bikes are picked up or left most often, which are primarily metro or train stations (e.g. *Rotterdam Noord, Delftshaven, Schiedam*) or recreational areas (e.g. *Kralingse Bos, Diergaarde Blijdorp*).

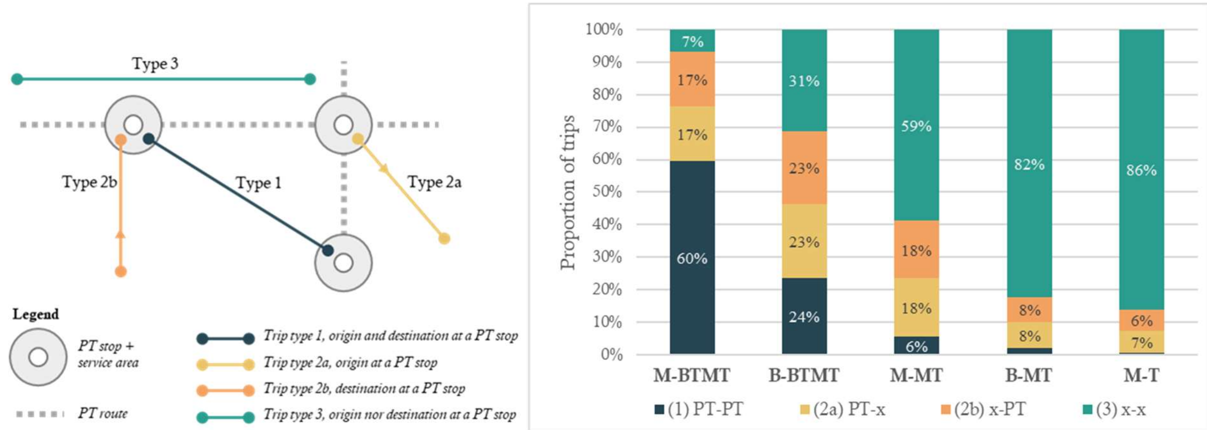


(a) Shared bike origin/destination heatmap (b) Shared bike origin/destination spatial clusters

Figure 3. Spatial patterns of shared bike trips in Rotterdam. September 2021.

Relation to PT stops

The categorization as explained in section 3.2 has been used to study the correlation between origins/destinations and PT stops, and results can be seen in Figure 4.b. When considering all PT modes for shared e-mopeds (*M-BTMT 200* in Figure 4.b), the proportion of Type 1 trips is 60%. From this, it can be concluded that a lot of shared e-moped trips could have been made by (a combination of) bus, tram, metro and/or train, although in practice a lot of these trips would be inefficient due to required transfers. When considering metro and train (*M-MT 200* in Figure 4.b), only 6% of trips substitute PT trips and 36% of trips are a first or last-mile journey. For the shared bike (*B-BTMT* and *B-MT* in Figure 4.b), the number of trips related to PT locations is relatively lower, which might be partly caused by the difference in used service area. However, also when using a 100m service area for the shared e-moped, more trips are related to PT than for the shared bike.



(a) Classification of trips based on Yan et al. (2021)

(b) Proportion of shared e-moped (M-) or shared bike (B-) trips divided over the trip types for different PT modes. Note that different services areas are used for the mopeds (200m) as for the bikes (100m) due to differences in service models.

Figure 4. Classification of shared e-moped and shared bike trips.

In general, it seems that a large share of bus or tram trips could be replaced by shared e-mopeds, while metro and train are being partly complemented by e-mopeds. For the shared bike, among the trips that have originated and/or ended near a transit stop, the majority could be categorized as complementary (Type 2). However, for both shared e-moped and bike, most trips were not related to PT locations. Besides that, close to 20% of bicycle trips have originated and ended at the same location with some bicycles being continuously rented out for several days, which indicates that some commuters prefer to use the shared bike for multi-purpose trips over other transport modes. One observation consistent across all cases is a nearly even split between PT-x and x-PT categories. This phenomenon possibly indicates that these trips are made by the same group of users. In other words, commuters who have, for example, used a shared e-moped or bike on their way from home to the transit station are likely to use it again on their way back.

3.3 Survey results: complement or competition to PT?

In addition to the data analysis, a survey was conducted. The survey targets both users and non-users of shared micromobility and is distributed to three different groups: (i) the RET customer panel, (ii) social media and (iii) distribution of flyers around main PT hubs. The survey resulted in N = 431 responses. The results include N = 98 (22.7%) responses of people that have used a shared e-moped during last year and N = 87 (20.2%) users of shared bikes, of which 84% have used OV-fiets. Within the complete survey sample males, people with a higher age, Dutch migration background and higher educational levels were a bit overrepresented in the survey as compared to the general population of Rotterdam.

From shared e-moped users, 24% indicate to often combine the shared e-moped with PT, 31.2% sometimes combines both modes and 44.8% never combines PT and shared e-moped during the same trip. The share of people using the shared e-moped in combination with PT is quite high in comparison to the BSS of the public transit operator in The Hague, for which Van Marsbergen et al. (2022) found that 9% of shared bike users uses the bike in combination with urban transit. This might be caused by the fact that Rotterdam has slightly longer travel distances and faster local transit (metro, train), making combinations with PT work better. This study found that 68% of shared bike users used the bike in combination with PT, primarily complementary to the train. With 84% of shared bike users indicating to have used the OV-fiets, this suggests that the integration of the bike at the train station is an important factor explaining the use.

When looking into modes that are substituted by the shared e-moped (Figure 5.a.), 42.7% of users state that they have used the shared e-moped instead of the bus, tram or metro (i.e., local public transit provided by RET), increasing to 45.2% when including the train, only making up for 3% of e-moped substitutions. These findings are in line with the spatial analysis, illustrating that – when it comes to public transit – the shared e-mopeds are primarily supplementing bus and tram trips, and metro trips to a lower degree. Also interesting to see is that 37% of trips replaces active transportation. The shared bikes (Figure 5.c) primarily substitute bus and walking trips, which are other highly used feeder modes of the train. Interesting to see is that shared bikes do not substitute a high percentage of (private) bikes (only 9.8%).
When focusing on the relation of the shared micro vehicles and public transit during one trip, it can be seen that 15.2% of users use the shared e-moped complementary to the train. Overall, 41.6% of trips complement public transportation, but bus and tram have much lower shares, 7.2% and 4.8% respectively. This is in line with the findings from the spatial analysis, showing that the shared e-mopeds are used as access and egress modes to public transit, mainly for the train and metro. For the bike (as already stated, 84% of users is PT-bike user), it is not surprising to see that the shared bike primarily complements the train. In general, the bikes are highly used complementary to public transportation, which might be caused by their proper integration at docked stations near PT stations.

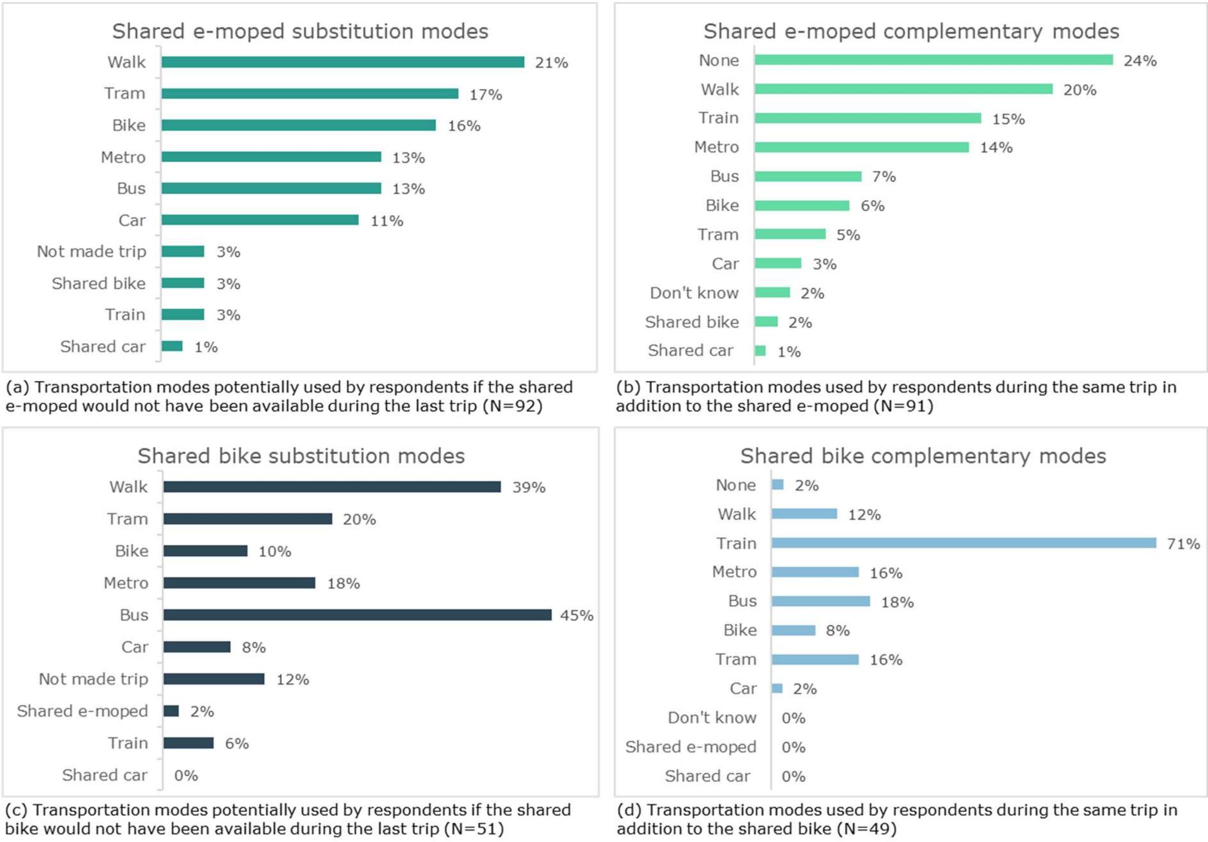


Figure 5. Transportation modes used as substitute of or complementary to the shared e-moped and shared bike.

4. From free-floating to mobility hubs

Based on the current use of shared e-mopeds and bikes, it can be concluded that both fulfil a different use within the transportation system. The shared e-mopeds are mainly used for independent trips, substituting active and local public transportation. The OV-fiets especially complements train trips, as can be expected, while the shared bikes of *Donkey Republic* also function as an independent service. However, both the shared e-moped and shared bike provide a partial solution for first/last mile trips, and better integration at mobility hubs might increase this potential.

4.1 Survey setup

Within the same user and non-user survey (N=431), question were asked on the intention to travel using a shared e-moped integrated at a mobility hub. The respondents were asked to picture their latest trip to work or school, but now including the opportunity to travel via a mobility hub with fairly high physical and digital integration (see Figure 6). After the scenario, respondents were asked to answer questions about the importance of different multimodal trip characteristics (e.g. travel time, shared e-moped accessibility, live travel info at the hub, transfer options, etc.), which can be explanatory factors for the intention to use a shared e-moped at a mobility hub. Hence, these factors are used in a ordinal logistic regression model as independent variables, to see which explain the intention to use a shared e-moped at a mobility hub, i.e. which factors are important to increase use of shared e-mopeds at hubs.

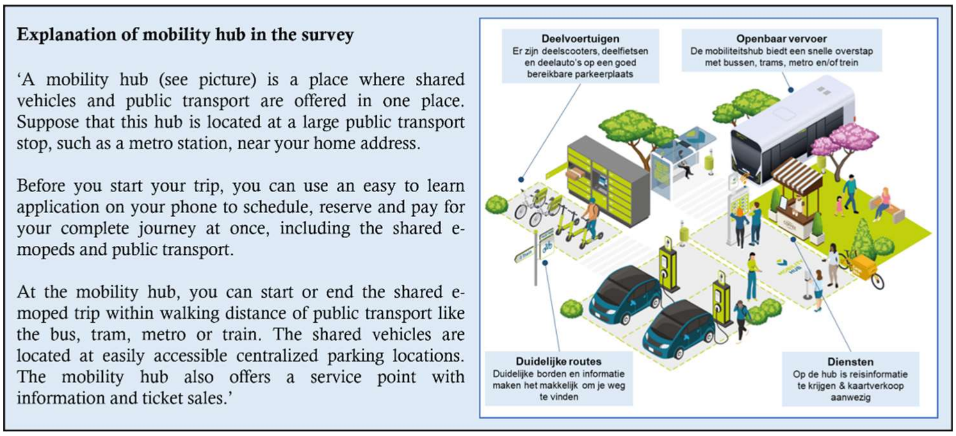
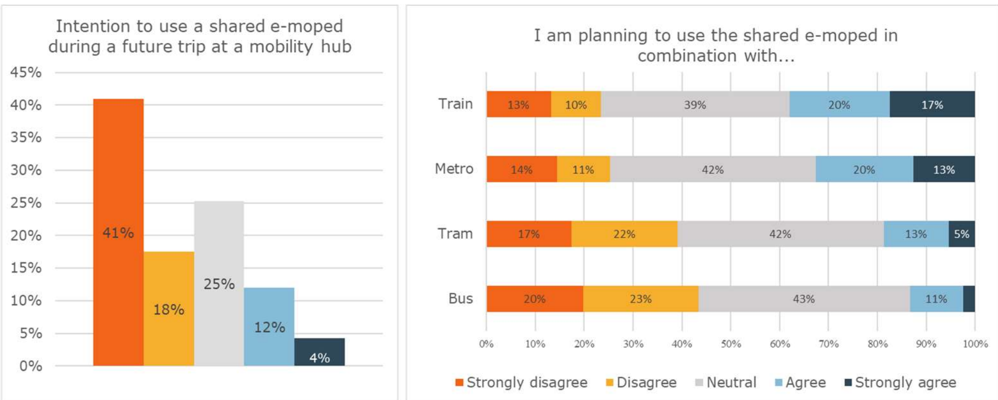


Figure 6. Scenario of travelling via a mobility hub within the survey. Only the shared e-moped was considered in this scenario.

4.2 Intention to use a shared e-moped in the future, and factors explaining this

The responses on the intention to use a shared e-moped in the future are provided in Figure 7, showing that 16.3% of respondents agreed or strongly agreed with the statement to travel by shared e-moped via a mobility hub nearby when travelling to work/school in the future, which is higher than the 5.5% of respondents currently using one, revealing a group of potential users. The intention to combine the shared e-moped with a specific PT mode is higher for modes that travel longer distances: only 6.3% of people are willing to combine the e-moped with the bus while 20% intend to combine the e-moped with a train.



(a) Response to statement: *I expect to use a shared e-moped at a mobility hub in the future* (N=400)

(b) Response to statement: *I expect to combine the shared e-moped with ... [PT mode]* when the response to using a shared e-moped at a mobility hub was non-negative, i.e. neutral, agree or strongly agree (N=166)

Figure 7. Intention to use a shared e-moped at a mobility hub & in combination with PT.

If this intention to combine with PT is only considered for people that are not negative about using a shared e-moped in the future (Figure 7.b), these percentages increase to 13.2% and 38% for bus and train, respectively. Nevertheless, the majority of respondents strongly disagree or disagree with using a shared e-moped overall (58.5% for using the shared e-moped at a mobility hub).

When focussing on the variables explaining this intention to use the shared e-moped at a mobility hub, variables related to specific user characteristics as well as physical integration at the mobility hub have a higher influence than digital integration variables. Thus, the intention to use a shared e-moped at a mobility hub is strongly explained by the user's digital skill level, social influence, educational level, the ease of transferring at the hub, and factors describing a convenient and accessible supply of the shared e-moped (see Figure 8). It seems that the mobility hub should above all offer a fast and convenient transfer to other modes of transportation instead of focusing on other facilities at the hub.

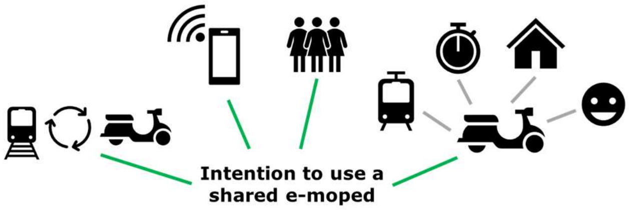


Figure 8. Factors influencing the intention to use a shared e-moped at a hub positively. (f.l.t.r.) Easy transfer at the hub, high digital skills, high social influence, shared e-moped supply factors (e.g. easy access to vehicle at the hub and at origin or ease of using the shared e-moped).

5. The future of smart hubs in Rotterdam

In general, more people are willing to use the shared e-mopeds when offered at a mobility hub if the e-mopeds are still available close to both the origin and destination of the trip. This relates to the importance of hub density as found by Franken (2021), suggesting that a high density of mobility hubs or docking stations is needed to fulfil the needs of the potential users. Lazarus et al. (2020) found the flexibility of a free-floating system to cause more usage in less dense city areas (e.g., suburbs) because docked models were not available. Spatial distribution of the e-mopeds, especially in underserved areas, is valued as an important barrier to equitable access (Meng & Brown, 2021). This is important to consider for policymakers; while docked systems might stimulate integration with PT and can become an instrument to stimulate PT use overall, free-floating systems might increase accessibility for all.

For the transport provider of Rotterdam, the RET, this study shows that current and intended use of shared e-mopeds is the highest in combination with the metro and train, and that shared e-mopeds are most competitive to the bus and tram. The RET could use this to its benefit to overcome gaps in its public transit network and increase its catchment area. The RET, in cooperation with the shared e-moped providers, should target an audience that is young and digitally skilled to increase the number of multimodal trips via their PT network. Improving the public opinion of shared mobility is also important since the social influence of others showed to be an important explanatory factor for future use. Together, the providers should improve the possibilities of easily transferring between PT and shared modes, for instance by decreasing the transfer time or increasing vehicle availability.

To conclude, easy to use and quickly accessible shared e-mopeds, both at the origin of the trip or a transfer location, are the reasons why people currently use and also intend to use a shared e-moped. Increasing the number of multimodal trips via a mobility hub is therefore not determined by its facilities but mainly by the easy access to or from the e-moped. If the free-floating service model changes to a more docked/hub-based model in the future, and the hub allows for a smooth transfer between PT and shared micromobility, this could increase the role of the shared e-moped as access or egress mode. Additionally, improving digital inequality as well as offering physical facilities might encourage current non-users to become interested in the system. However, the free-floating characteristics of the system are currently the main reason the system is used – and will be used in the future – as both a complement as well as a substitute to PT. Consequently, a proper trade-off is needed between physical integration to stimulate multimodal trips as well as keeping the shared e-moped supply widely accessible.

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