Exploring the integration of shared e-mopeds at mobility hubs

A case study on shared e-mopeds and public transport in Rotterdam, the Netherlands

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Abstract

Shared mobility is a rapidly expanding innovation in the field of transportation, with the potential to increase access over ownership and improve first and last-mile connectivity (Alonso Raposo et al., 2019; Oeschger et al., 2020). This study concentrates on shared e-mopeds in the city of Rotterdam, the Netherlands and analyses its current spatio-temporal usage patterns based on a month of travel data. Additionally, the results of a user and non-user survey (N = 431) are used to find out how physical and digital integration affects the use of shared e-mopeds at mobility hubs. Currently, shared e-mopeds are regularly used by only a small share of respondents, using the e-mopeds primarily to commute or for social trips. Users do integrate a portion of their trips with public transit, making multimodal trips in combination with the metro or train most often. These users share the same profile as provided by literature; being primarily male, young, digitally skilled and owning a driver's licence. This also reveals potential barriers for non-users when they do not own a driver's licence or do not have the required skills to digitally plan and pay for a shared e-moped trip. Using ordinal logistic regression analysis, it was found that the intention to use shared e-mopeds at mobility hubs and in combination with public transit, is explained by user characteristics (digital skills and educational level), social influence and factors on the supply of the shared e-moped itself, describing its accessibility and ease of use. The intention to use a shared e-moped is also related to the possibility of making an easy transfer from the shared e-moped to public transit or other shared modes. The intention to use a shared e-moped in combination with the tram, metro or train is related to almost the same variables. Current shared e-moped users were also observed to have a higher intention to use shared e-mopeds in the future, albeit not significant. The results of this study suggest, among other things, that shared e-mopeds are currently partly integrated with public transportation. Improving the possibilities of easy transferring between modes at the hub while keeping the e-mopeds quickly accessible from the trip origin, could increase the number of multimodal trips via mobility hubs.

Keywords – Shared mobility, mobility hubs, shared e-mopeds, micromobility, spatial analysis, user survey

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). Greenhouse gas emissions from road transportation account for 80% of total transportation emissions, with urban transportation accounting for 40% of emissions (Sims et al., 2014). To reduce this increase, 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 and find their way to the mode choice set of users (Schröder et al., 2014; Ton et al., 2020).

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). The first developments of shared micromobility at these hubs were docking bike-share programmes, where travellers could receive a bike after their public transit trip to egress their final destination. However, 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).

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With the rapid development of micromobility and its integration with other modes of transport, studies on this topic are relatively new. Nevertheless, 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 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). However, their integration with mobility hubs and public transportation is unknown. Furthermore, the e-moped providers in the Netherlands primarily use a free-floating system, which might have a different impact on the integration with public transport than the docked bike-sharing systems that have been studied often. Therefore, this research will focus on shared e-mopeds, their travel patterns, and their integration with mobility hubs.

This research aims to fill a knowledge gap on the current use of shared e-mopeds as well as the motivation and users' intention of using a shared e-moped at a mobility hub for their future trips. By combining both these factors, this research aims to provide a full picture of the current state of shared e-mopeds in the whole transportation network as well as their future potential. With this aim, the study contributes to both the practical work field – for instance, the public transport operator RET or the municipality of Rotterdam – as well as the scientific field, such as the *SmartHubs* project to which this study is related (SmartHubs, 2021). The goal of this research is summarized as follows: '*To analyse the spatio-temporal usage patterns and explain how physical/digital integration affects the (potential) use of free-floating shared e-mopeds at mobility hubs'*. This research goal is two-folded, intending to find out how e-mopeds are currently used in practice and how people assess their (potential) use in relation to mobility hubs.

Fulfilling the research goal will result in information on current spatiotemporal travel patterns and quantification of the most important factors regarding physical and digital integration that influence potential use of e-mopeds in relation to mobility hubs. These results provide the PT operators in Rotterdam with information on the integration between e-mopeds and their transportation systems and provide the *SmartHubs* project with information on the most important digital and physical integration factors.

This research focuses on shared e-moped trips and their (non-) users within the city of Rotterdam, the Netherlands. The city of Rotterdam hosts a dense public transit network, and a large number of shared e-moped trips is available to analyse, with over 340 thousand trips in September 2021[1]. First, related literature is reviewed to provide context and offer input to the conceptual framework. Secondly, the research questions, data sources and methodology of this study are explained. Then, the results of both the spatial analysis as well as the survey are presented. Discussion and conclusion of the results complete this research.

2. Literature review

2.1. Shared micromobility

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).

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

[1] Usage of shared e-mopeds has been fluctuating throughout 2020-2021 due to nationwide restrictions in response to the COVID-19 pandemic.

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).

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 prohibited in the Netherlands.

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] The same user profile seems to hold in the Netherlands as well: users of shared micromobility in Rotterdam were primarily male (65%) and in the age group of 26-35 years old. In Amsterdam, just 29% of users are female, 74% is highly educated and 75% of users is younger than 35 years old (Municipality of Amsterdam, 2021; Municipality of Rotterdam, 2021a).

Bike-sharing systems, for instance, are mostly concentrated in dense urban centres, around public transportation hubs, neglecting suburban areas outside the city centre. Ricci (2015) sees this as the main explanatory variable to the socio-economic user profile of bike-sharing systems. Housing is expensive in those areas, business districts house high-income jobs and people of higher education, which is in line with the previously described user profile (Howe, 2018). It seems that having shared micromobility options in the proximity of a users' home contributes most to the possibility to use it; implying that accessibility is one of the greatest barriers for using shared micromobility (Ricci, 2015). Another factor partly explaining the user profile is digital inequality since most shared mobility providers use digital platforms (e.g., mobile applications) and digital payment methods (e.g., *iDeal* or *PayPal*) only (Durand et al., 2021; Horjus, 2021). In addition, the price of the systems can be a reason not to use the shared micro-vehicle too; 21% of Spanish e-moped users stated that competitive pricing was the main motive (not) to adopt the system (Aguilera-García et al., 2020). So, to conclude, the geographical location, lack of digital skills and high pricing are barriers for people not to use shared modes, which helps describe the group of non-users: these potential users are older, living in suburban areas, further away from public transport stops, in neighbourhoods with relatively lower income and education level (Böcker et al., 2020).

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[3], 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 *SmartHubs* project mentions specific integration levels of mobility hubs, which are discussed in Section 3.

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). Parking nuisance can be prevented by using a hybrid free-floating system where specific areas in the city are 'geofenced', where strict geofencing is also referred to as using 'digital docking stations'. In this way, providers and municipalities can indicate areas where parking micro-vehicles is undesirable (Municipality of Rotterdam, 2021b). 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). In addition, parking facilities seem to be a crucial aspect of a hub, raising the question whether completely

[3] Different aspects are considered in literature such as multimodality, inclusion of new micromobility modes, digital services and social integration (Coenegrachts et al., 2021; CoMoUK, 2019; Geurs et al., 2022).

free-floating systems can have the same impact as docked services models that are integrated within the mobility hub (Oeschger et al., 2020).

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). However, the effect of micromobility sharing programmes highly depends on built environment characteristics. BSSs in larger North American cities took riders off crowded buses, while BSS in low-density areas improved access-egress trips of bus lines which indicates that the effect of mobility hubs can go both ways (Shaheen & Chan, 2016). Nevertheless, most of the time, bike-sharing users were already public transport or active transport users before the introduction of the system, again limiting the impact on mode shifts. However, 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. Mode choice factors

Mode choice is inherently a difficult process that is affected by multiple different (categories of) characteristics that influence the choices of users. To understand how (potential) users of shared mobility and mobility hubs determine if and how they are going to make an intermodal trip, mode choice determinants are studied by many scholars, but De Witte et al. (2013) derived a multi-disciplinary definition. Mode or modal choice is defined as "*the decision process to choose between different transport alternatives"* (de Witte et al., 2013, p.331). The transport alternatives refer to a set of mode choice options that can include single modes or multiple modes for one trip. This set of mode choice options remains mostly constant over time, meaning that individuals do not easily include new modes in their mode choice set (de Witte et al., 2013; Ton et al., 2020). Based on an extensive literature review, De Witte et al (2013) provide a framework to distinguish different mode choice factors, namely (i) journey characteristic (i.e., trip) factors, (ii) socio-demographic factors and (iii) spatial factors. This is similar to an earlier study of Cervero (2002) who categorized mode choice factors as (i) generalized trip costs, (ii) socio-economic characteristics (e.g., income) and (iii) built environment factors (Cervero, 2002). Besides these three categories of factors, socio-psychological indicators determine how the user acts on the factors of the other categories.

Trip factors are based on the trip that will be made by the user. *Travel distance* is an important determinant since travellers prefer faster modes of transport – which is most of the time their private car – for longer trips (Franken, 2021). Also, *travel costs* are an important factor. When costs for public transportation increase, people are more willing to use their private vehicles (Cervero, 2002). Nevertheless, (perceived) *travel time*, including waiting time, is often considered the most important trip factor as higher travel times reduce mode choice probability. For considering PT trips, however, accessibility – both physical and digital – of the transit systems is considered more important than travel time (de Witte et al., 2013; Ewing & Cervero, 2010; Tilahun et al., 2016). **Socio-demographic factors** focus on the individual situation and interactions of the user (de Witte et al., 2013). As seen earlier, *age*, *gender*, *education* and *income* all seemed to have a determining role in the mode choice of shared micromobility. Travellers of higher income and education levels had a significantly increased chance of using shared micro-vehicles (Böcker et al., 2020). However, when focusing on mode choice in general, there is no real consensus on this effect since higher income groups also have higher *access to private cars* and use less shared or public transport (de Witte et al., 2013; Ton et al., 2020). **Spatial factors** characterize the built environment where the trip and thus the mode choice takes place (de Witte et al., 2013). Higher *densities* are correlated with lower travel distances and improved *public transport frequency* and *proximity*, positively influencing the odds of choosing PT as mode (de Witte et al., 2013; Tilahun et al., 2016). The presence of *parking space* also influences the mode choice (de Witte et al., 2013). Furthermore, *social safety* in the built environment plays an important role in increasing active and public transportation. When neighbourhoods are green, vibrant, and see low crime numbers, acceptable access-egress distances will increase (Tilahun et al., 2016).

2.4. Intention to use shared mobility & mobility hubs

Besides factors that influence mode choice, there are some generalized theories that are used to explain reasoning behind the acceptance of new technologies and people's intention to use them. These theories are discussed and used to construct the conceptual model of this research since shared micromobility, and mobility hubs can be considered fairly new technologies. A popular model that is widely used is the **Technology Acceptance Model** (TAM), that tries to explain the reasons behind the acceptance of new technologies (Davis, 1989). In the case of transportation innovations, the model can be used to estimate which factors influence the intention of travellers to use these systems (Jahanshahi et al., 2020). TAM incorporates *perceived usefulness* and *perceived ease of use* as determinants of behaviour intention, both influenced by external factors. The usefulness states if the new technology helps users to perform better while ease of use considers how easy it is to use the system. 'Perceived' means that it is not about the real usefulness or ease but on people's beliefs and perceptions (Davis, 1989). Furthermore, *intentional behaviour* is eventually an important determinant of the actual behaviour (Venkatesh et al., 2003). When translating this to the field of mobility hubs, this means that the usefulness of the hub to reach a destination and the ease of using and accessing this hub could influence its potential use by travellers.

Eventually, the TAM was extended to incorporate determinants from multiple acceptance theory models. The most common unification of acceptance theories is the **Unified Theory of Acceptance and Use of Technology** (UTAUT). UTAUT includes four constructs that influence a person's behavioural intention. Firstly, there is *performance expectancy*, which is related to the perceived usefulness of Davis (1989). A study by Jahanshahi et al. (2020) on BSSs, included factors such as 'reaching the destination more quickly' or 'achieving important things'. Secondly, the UTAUT model contains *effort expectancy*, which is the degree of ease associated with using the system, i.e., whether the system is clear and easy to learn (Venkatesh et al., 2003). Thirdly, *social influence* is the extent to which users perceive to be influenced by others, like friends, family or other authority figures (Jahanshahi et al., 2020; Venkatesh et al., 2012). Lastly, the UTAUT includes *facilitating conditions* that refer to the user's perceptions of support to perform better. The addition of the two latter factors makes the UTAUT to be somewhat in line with the Theory of Planned Behaviour (TPB)'s (which is a more general theory on human behaviour) *subjective norm* and *perceived behavioural control* (Rahman et al., 2017).

Studies have applied different models to find out travellers' intention in the mobility field (Rahman et al., 2017). As stated before, Janhanshahi et al (2020) used an extended UTAUT to model the acceptance of a BSS in Iran and found that facilitating conditions (e.g., 'compatibility with other modes') had the strongest effect on the intention to use BBS but it should be noted that this can be different in another (cultural) context (Jahanshahi et al., 2020). On the topic of Mobility as a Service, Ye et al. (2020) also used the UTAUT model to find that performance and effort expectations had a strong link with intention, where convenience was valued more important than time and costs (Ye et al., 2020). In a more European context, Van Veldhoven et al. (2022) used the TPB model to investigate the intention to use shared mobility in Belgium, finding that subjective norms (e.g., perceived compatibility and time safe) and behavioural control (e.g., digital skills) mostly explained travellers' intention to use shared mobility (van Veldhoven et al., 2022).

2.5. Research gap

It is clear that micromobility has a high potential as an access-egress mode for public transport. However, the amount of literature on e-mopeds and their integration with mobility hubs is scarce and the role of e-mopeds in the transportation system is unclear. As 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). Other studies have focused on the role of BSS or e-scooter systems, but the e-mopeds schemes show different characteristics (e.g., longer travel distances and free-floating service models) endorsing the need for more insights into their role. Consequently, this study will analyse the role of the e-moped in the transport system and see if e-mopeds trips are integrated with mobility hubs / PT stops as part of a multimodal trip.

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 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. Conceptual model

As stated in Section 2.5, this research partly focuses on factors that potentially influence the intention of people to use a shared e-moped at a mobility hub. In line with the UTAUT model, intentional behaviour is an important determinant of eventual actual behaviour, so it is possible to analyse factors that influence travellers' intention to use e-mopeds at mobility hubs (Venkatesh et al., 2003). Thus, the theory of the UTAUT serves as a framework for the conceptual framework used in this research (see Figure 2), which includes factors that are expected to influence this intention.

3.1. User characteristics

The *socio-economic factors* are generally used in the UTAUT models as moderator and explain the individual traveller's situation (de Witte et al., 2013; Venkatesh et al., 2003). *Social influence* is an important factor in the UTAUT model and is represented by the 'opinion of others', which was found to be a highly explanatory factor in the study of Van Veldhoven et al. (2022) on shared mobility.

Travel behaviour and the current set of mode options is also an important determinant of mode choice, determining attitude and dependency on certain modes (Ton et al., 2020). Furthermore, adding travel behaviour explains the relation with current mode use. Lastly, two control variables are added: *possession of a driver's licence* and *digital skills*, that control the boundary conditions for using shared micromobility services. Driver's licence possession replaces the car ownership, since owning a licence better reflects potential use. When a person has a low level of digital skills this becomes a barrier for using these types of transportation (Durand et al., 2021; Horjus, 2021), see Section 4.4 for an explanation of the different digital skills levels, based on Horjus (2021).

3.2. Multimodal trip characteristics

It becomes clear from the literature review that integration between e-mopeds and mobility hubs is key to increase users' intention to make a multimodal trip. Therefore, factors relating to physical and digital integration (see Geurs et al., 2022)[4] are applied to the performance and effort expectancy items. **Physical integration** relates to integrating multiple (shared and public) modes of transport at an easily accessible location, taking away transfer barriers between the modes to stimulate use (Jorritsma et al., 2021). Hubs should supply safe, barrier-free access to all facilities by focusing on uniform design and visibility (Bell, 2019). **Digital integration** corresponds with the concept of MaaS, to make sure that users can access information on one user-centric digital platform using a standard format to book a multimodal trip (Jittrapirom et al., 2017). To make the 'digital' mobility hub more accessible for everyone, systems should be designed following universal design principles with easy to understand, intuitive design for every user group (Geurs et al., 2022).

For performance expectancy, *distance* to the shared e-moped from home and PT, *availability*, easy *wayfinding* and fast *transfer* are added as physical integration factors (Bell, 2019; Geurs et al., 2022; Tilahun et al., 2016). Travel time and travel costs are considered as well since these are crucial factors for bike and e-scooter trips. The e-moped shows different characteristics on these points (see Table 1) but has a similar usage pattern, making it interesting to see if these factors have a different impact. Also, the ease of finding *parking facilities*, as found by Oeschger et al. (2020) to have an impact on hub use, is considered to see if this has an effect, especially in a city currently using an almost free-floating service model. Furthermore, the added value of physical payment methods (e.g., at a service point) is added, since this potentially increases the usefulness of the mobility hub (Geurs et al., 2022). For effort expectancy, digital factors of *multimodal planning* and *payment* (both related to MaaS) are added as well as *easiness to use* and *learn* both the e-moped itself and the multimodal system (Geurs et al., 2022; Jittrapirom et al., 2017).

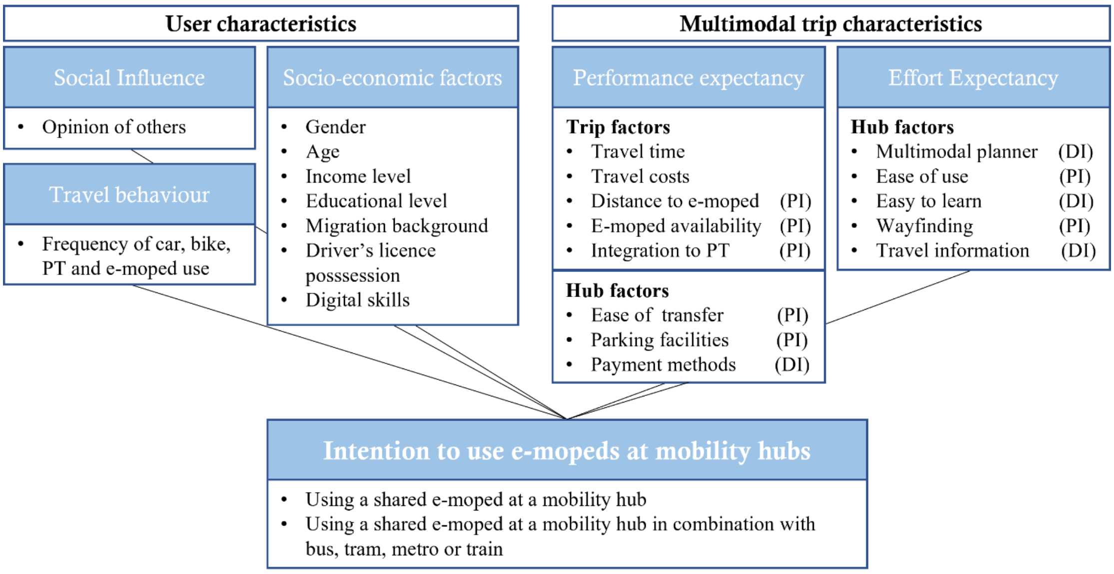


Figure 2. **Conceptual model used in this research.** [PI] = Physical Integration and [DI] = Digital Integration, both related to the *SmartHubs* integration ladder (Geurs et al., 2022).

[4] Geurs et al. (2022) also define a third level of integration, namely *Democratic integration*, meaning that different stakeholders (e.g., users/mobility providers) should be represented and engaged in the development of a mobility hub, integrating different fields of knowledge (Geurs et al., 2022). This type of integration is outside the scope of this research and more information can be found in Geurs et al. (2022).

3.3. Behavioural intention

The behavioural intention focuses on the intention to use an e-moped at mobility hubs. A distinction is then made between using an e-moped in combination with bus, tram, metro or train, to see if there is a difference between making multimodal trips considering these PT combinations, as was suggested by Böcker et al. (2020). Following from the UTAUT model, intentional behaviour is an important determinant of the eventual actual behaviour of people, i.e., factors that are found to be related to intention are expected to be related to future actual behaviour as well (Venkatesh et al., 2003).

4. Methodology

4.1. Research questions

To fulfil the research goal, a number of research questions will be addressed. The first two questions (RQ1 and RQ2) are related to current use of shared e-mopeds to find out if and how shared e-moped services substitute or complement existing mobility options, which is similar to studies focussing at different shared micromobility modes (e.g., Arias-Molinares et al., 2021; Jiao & Bai, 2020; Yan et al., 2021). Furthermore, there is also a focus on locations of potential mobility hubs, referring to locations that have the potential to become mobility hubs, but currently do not comply with the definition in Section 2.2. The second questions (RQ3 and RQ4) relate to these locations, to find out which factors influence people's intention to travel via a mobility hub using a shared e-moped, to see how potential use of shared e-mopeds might evolve. These questions are similar to studies that also focus on intention to use mobility hubs or multimodal transport systems (e.g., Horjus, 2021; van Veldhoven et al., 2022). The questions are formulated as follows:

RQ1. Are current spatio-temporal usage patterns of e-mopeds correlated with the location of potential mobility hubs?
RQ2. Which modes are substituted/complemented by e-moped use?
RQ3. To what quantitative extent do the physical/digital integration factors influence potential users' intention to use e-mopeds at mobility hubs?
RQ4. How can different user groups be defined based on their intention to use e-mopeds at mobility hubs and user characteristics?

4.2. Study area & dataset

Rotterdam is the second-largest city of the Netherlands (~652.000 inhabitants), located in the *Randstad* region. The largest seaport of Europe is located in Rotterdam, and the *Nieuwe Maas* river that connects the port with the rest of the country splits the city into two. 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 were first introduced in Rotterdam in 2016, with currently 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[5] (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).

To better understand the shared e-moped trips in Rotterdam a dataset containing shared e-moped and shared bike trips and parking events from September 2021 is gathered (Fietsberaad CROW, 2022) The unfiltered dataset contains approximately four hundred thousand trips, provided in csv format with the following attributes:

- *System id:* the mobility provider. This data will be dropped to make anonymise single providers.
- *Bike id:* unique identifier of the e-moped. Will be substituted by a new identifier leaving out the provider.
- *Latitude & Longitude start:* coordinates of the start location of the trip.
- *Latitude & Longitude end:* coordinates of the end location of the trip.
- *Start & end time:* start and end time of the trip.
- *Location in zone*: indicating if the start/end of the trip is within the study area.

[5] These averages are based on raw data from the dashboard shared mobility in the period May 2021 until April 2022. Please note that during a number of months in this period, different COVID-19 restrictions were still in place, which influences the number of trips.

4.3. Spatial analysis

The workflow of the spatial analysis included data cleaning, transforming, describing and analysing. Since times and locations of the trips were provided, duration and Euclidean distance between the start and end point of the trip could be determined. These metrics are then used to filter non-realistic values from the dataset using the following rules: (i) only e-moped trips starting in Rotterdam, (ii) duration should be shorter than 1 day and (iii) distance should be more than 0 kilometre and shorter than 100 kilometres, resulting in 376 thousand trips. Secondly, outliers are removed based on the interquartile range of both duration and distance (based on Arias-Molinares et al. (2021)), resulting in 347,942 shared e-moped trips included in the analysis, used to answer RQ1 in particular.

Regarding the temporal dimension, the start/end hour and weekday variables are determined to evaluate usage patterns. Trips per day in September 2021 are compared with weather and event reports to make sure high/small numbers are not caused by for instance large events or severe weather conditions. On the spatial dimension, the start/end locations of trips are aggregated in 200m-sided hexagons, because 200 metres showed to be 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. First, a global statistical tool (Global Moran's I) will be used to analyse the spatial autocorrelation of both the origins and destinations of the trips (Arias-Molinares et al., 2021). However, only considering global statistics suggests that the shared e-moped trips are stationary divided over space, which might not always be the case (Unwin, 1996). Therefore, Local Indicators of Spatial Association (LISA) will be used in addition. *Local Moran's I* (Anselin, 1995) will be used to identify statistically significant hotspots. Clusters (high-high or low-low) and outliers (high-low, low-high) are identified using this technique (Arias-Molinares et al., 2021). The distance measure will be based on contiguity on the edges only because that corresponds with all hexagons neighbouring the analysed hexagon.

When analysing the correlation to public transport stops, a distance measure is needed to relate the start or end of trips with public transit stops. In literature, it can be found that people, once they decided to walk, are willing to walk approximately 400 metres to bus stops and up to 800 metres for train. However, these distances are dependent on multiple individual and built environment characteristics and are expected to be lower in cities with a dense public transit network (Daniels & Mulley, 2013; van Soest et al., 2020). Moreover, walking from the shared e-moped to a stop is a different phenomenon since walking is combined with e-moped use. Therefore, a Dutch study on acceptable walking distances from a parked bike to a destination is used, which shows that people are willing to walk a maximum of 200 metres from a parked bike (CROW, 2021). This distance is used to decide what kind of trip the e-moped trip is: (i) both trip start/end near PT stop, (ii) one trip start or end near a PT stop or (iii) the trip start, and end are not related to a PT stop (Yan et al., 2021).

Finally, a Geographically Weighted Regression (GWR) model is used to study the effect of a number of independent variables on a local scale. The GWR model will be run in ArcGIS software (ArcGIS Desktop 10.8) and runs a local linear regression model with numeric explanatory variables. The model gives a unique regression coefficient per input cell or TAZ. The density of shared e-moped starts is used as the dependent variable. To make sure the GWR model is specified correctly and has sufficient predicting power, scatterplots of variables and an Ordinary Least Squares (OLS) regression model is used to find as many explanatory variables as possible (Caspi et al., 2020; Hosseinzadeh et al., 2021).

4.4. Survey

A survey among both users and non-users of shared e-mopeds was used to gather data, especially needed for answering RQ2 – RQ4. The content of the survey is based on a review of questionnaires from other studies, public bodies and shared mobility literature (e.g., 6t-bureau de recherche, 2019; Chopdar et al., 2022; Guo & Zhang, 2021; Horjus, 2021; Kopplin et al., 2021; Lime, 2018; PBOT, 2019; van Marsbergen et al., 2022), and consists of three parts:

- *A.* Travel behaviour & mode substitution
- *B.* Intention to use shared e-moped at mobility hubs and explanatory factors
- *C.* Sociodemographic information

Part A includes questions on the travel behaviour of respondents, related to shared e-mopeds and shared (e-)bikes. The questions are related to travel behaviour in general, the travel motive and specific mode substitutes and complements. For e-moped mode substitution, most studies used retrospective counterfactual questions, meaning the questions recall past travel behaviour and hold an if-statement. Focussing on this specific trip (referred to as the *last trip*) removes social desirability and other response biases (Wang et al., 2022). Questions on trip purpose and motivation need to be included in relation with mode substitution questions, because these can be explanatory reasons for substituting other modes for the specific trip (Guo & Zhang, 2021). Appendix A provides more context to the survey and the purpose of the questions.

Part B includes a scenario where the respondents need to consider making a regular trip of theirs using a shared e-moped via a mobility hub. The explanation of the mobility hub and its physical and digital integration is in line with *Level 2* on the *SmartHubs* integration ladder (Geurs et al., 2022). The description is neutral in a way, that no specific company or location is mentioned but the respondents are asked to suppose that the hub is located at a PT stop near to their home address, to make it easier to visualise the scenario. The behavioural intention statements are followed by statements that relate to the explanatory factors as mentioned in the conceptual model. A Likert-scale ranging from strongly disagree to strongly agree is used in answering these statements (Chopdar et al., 2022; Kopplin et al., 2021).

The final part of the survey holds questions on user characteristics. The sociodemographic information can be used in two ways. They are part of the conceptual model and could therefore explain the behavioural intention of respondents. Secondly, these characteristics are used to compare the sample population to the general population to check the representativeness of the sample. Furthermore, a selection of questions is added to represent the digital skill categories used by Horjus (2021), who found that higher digital skills explain a higher intention to use shared transport (Horjus, 2021). The categories are as follows: (0) No access to a mobile phone, (1) Access to a mobile phone, (2) Access to a mobile phone and using the phone to plan trips, (3) Access to a mobile phone and using the phone to plan trips and pay for them.

The survey targets both users and non-users of shared micromobility and is distributed to three different groups: (i) the RET customer panel (N = 204, response rate = 38.6%); (ii) RET social media (N = 184) and (iii) distribution of flyers in the area surrounding the PT stops of Rotterdam Central Station, Zuidplein and Kralingse Zoom (N = 43, response rate = 3.9%). The flyer is depicted in Appendix C. All versions of the survey were directed to a digital questionnaire using Crowdtech software. The digital survey was open from the 26th of April until the 22nd of May. The flyers were distributed during a period of two weeks, starting on the 11th of May. Of the respondents that received a flyer, 83% (N = 25) said that they received the flyer at Kralingse Zoom or the Erasmus University, which is located nearby. Rotterdam Central Station and Zuidplein were both only indicated once as the location where the respondent received the flyer.

4.5. Data analysis

The survey resulted in N = 431 (93.9% of total) responses after removing responses that did not answer the first two questions on their current shared e-moped or e-bike travel behaviour (resulting in N = 28 removed responses), with N = 348 (80.7%) respondents completely finishing the whole survey. The results include N = 98 (22.7% of valid) responses of people that have (more than) once used a shared e-moped during last year, and N = 87 (20.2%) users of shared (e-)bikes. These responses (Part A) are used to analyse trip motivation and mode substitution and complementation, related to RQ2. The N = 401 (93.0%) responses to the questions in Part B are analysed using an ordinal logistic regression model to determine the influence of the independent variables on the categorical dependent variables. The variables used in the model are shown in Table 2 and are based on the conceptual model (Figure 2). When questions on the importance of the independent variables were answered with *'I do not know'*, these answers were categorized as *neutral*. Furthermore, the answers are transferred to a 3-point Likert-scale (i.e., *disagree-neutral-agree*) because of low counts in cells when using the 5-point Likert-scale (see Appendix I for frequencies of answer categories), increasing the number of responses per category thus improving the model.

Table 2. Variables included in the ordinal logistic regression model. The variables captured in the components are highlighted with * or +.

Independent variables		**Dependent variables**
Frequency of shared e-moped use	Travel time	Intention to use shared e-moped at mobility hub
Frequency of shared bike use	Travel costs	
Frequency of car use		
Frequency of PT use	PI – distance to shared e-moped*	Intention to use shared e-moped at mobility hub in combination with:
	PI – availability of shared e-moped*	
Gender	PI – integration shared & PT*	• Bus
Age	PI – ease of using shared e-moped*	• Tram
Income level	PI – wayfinding at hub+	• Metro
Educational level	PI – ease of transfer between modes	• Train
Migration background	PI – parking facilities at hub+	
Driver's licence	DI – travel information at hub+	
Digital skills	DI – payment methods at hub+	
	DI – multimodal planner	
Social influence of others	DI – easy to learn application	

Kendall's thau-b correlation test is used to check to what extent the independent variables are correlated (Statistics Solutions, 2022). From Appendix E, it can be seen that multiple variables show a correlation above 0.35, which is considered high (SPSS Tutorials, 2022). So, income level will be omitted since it has a high correlation with education level (τ = 0.383, $p < 0.001$) and a high number of missing values. Education level will be used to address income level as well. Furthermore, car use is correlated with having a driver's license (τ = 0.431, $p < 0.001$), which leads to removing driver's licence from the model because of a higher N for car use. In addition, most multimodal trip characteristics correlated strongly with one another (e.g., strongest correlation being 0.721 ($p < 0.001$)), so a Principal Component

Analysis (PCA) was performed to reduce the number of variables included in the final regression model (see Appendix G). Finally, two components were found based on the focus of the questions (e-moped or hub-related variables). The variables for ease of transfer to PT and ease of transfer to shared mobility (τ = 0.513, $p < 0.001$), and multimodal planner app and ease of using the app (τ = 0.617, $p < 0.001$), did not fit into one of the components and are therefore treated solely with omitting one of the two variables because of high correlation. Finally, frequency of mode use is recoded into binary variables and PT use is not included in the model since only 3.3% of respondents never use PT modes. Frequency of shared moped and bike use are combined to shared mobility use to increase the group that has experience with shared micromobility.

Other assumptions of the logistic regression are assessed using SPSS software. The proportionality of odds is evaluated using the test of parallel lines, and multicollinearity is checked using VIF values, where a value above 4.0 indicates a problem of multicollinearity (Garson, 2014). Appendix H shows the VIF collinearity statistics with a maximum value of 2.56, showing no problem with multicollinearity in all logistic regression models.

5. Analysis and results

This section consecutively discusses the executed analyses and results of both the spatial analysis of the shared e-moped trip data (Section 5.1) as well as the output of the survey, with Section 5.2 discussing the representativeness of the sample. Section 5.3 focusses on the mode substitution and complementation of the shared e-moped. Section 5.4 on the intention to use the shared e-moped at a mobility hub in the future and Section 5.5 the intention to combine the moped with PT. Section 5.6 discusses the differences between user groups for their behavioural intention. Section 5.7 completes this section by combining the analyses' results.

5.1. Current spatio-temporal use of shared e-mopeds in Rotterdam

Table 3 shows descriptive statistics of the analysed trips that start within the city of Rotterdam. 73% of trips take place on weekdays (i.e., working days) and 27% on weekends. This is in line with the research of Arias-Molinares et al. (2021), who concluded that this could imply that e-mopeds are not only used for social/recreational trips but also for commuting. Furthermore, working day trips are generally shorter in duration than weekend trips, averaging around 13:35 min and 14:18 min, respectively, endorsing the possibility that more recreational trips are undertaken during weekends. The travel duration of shared e-mopeds is somewhat longer than generally found for e-scooters (Caspi et al., 2020; Jiao & Bai, 2020).

Table 3. Descriptive statistics of all trips and split between weekday and weekend trips

	All trips	***Weekday trips***	***Weekend trips***
Trips	347,942	250,326	91,936
Trips percentage	100%	73%	27%
Average trips per day	11,409	11,378	11,492
Average duration (seconds)	827	815	858
Average Euclidean distance (km)	1.76	1.73	1.83
Average trips per moped	4.87	4.86	4.91

When exploring hourly patterns, Figure 3 shows the average trip starts per day of the week per fifteen minutes. During working days, two peaks are noticed: one in the morning between 8:00 and 9:00 and one in the afternoon between 16:00 and 18:00. On Friday and Saturday, the busiest days for shared e-mopeds, an extra peak can be noticed around 22:00 and 23:00. Over weekends, the typical morning rush peak is not visible and there is only one, flatter peak during the afternoon. Interesting on weekends (and Friday, following on Thursday night, which is a typical student night-life evening) are the trips made between 0:00 and 02:00, implying that people use the shared e-moped to travel to or from night-life activities. In relation to the regular morning rush, the shared e-moped trips peak at 8:45. This peak during the morning rush is in line with e-moped trips in cities across Spain as investigated by Arias-Molinares et al. (2021). The morning peak also has a clear and fast ending, which is different from the afternoon peak.

Figure 4a shows the number of trip destinations per hexagon in September 2021 from trips that started in the city of Rotterdam. It becomes clear that most trips end in downtown Rotterdam, with high densities around the train/metro stations *Rotterdam Centraal* and *Blaak*, metro junction *Beurs*, and streets such as *Coolsingel* and *Oostplein*. In general, 60% of all trips start and end within the city centre, with 43% of all trips never leaving this area at all. Most trips start or end in the *Rotterdam Centrum*[6] district (38%), with 18% of all trips taking place within the respective district itself. From trips that start within the city neighbourhoods or suburbs of Rotterdam, on average 50% move towards the city centre as well.[7] In

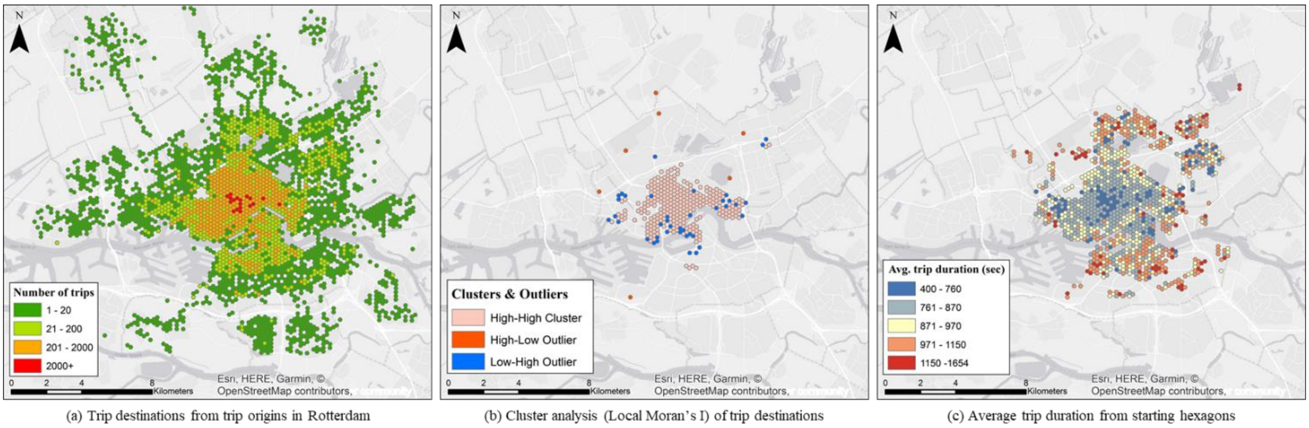
[6] *Rotterdam Centrum* is a specific PC4 district within the city centre.

[7] City centre is defined as a 0 – 2000m buffer, City neighbourhoods as 2000 – 4000 m buffer and suburbs as 4000 – 10000 m buffer. The *Lijnbaan, Cool* is used as the centre point of these buffer zones. See Appendix A for a complete analysis of those specified areas.

general, it holds for nearly all districts that most trips starting in a particular district either end in the *Rotterdam Centrum* area or stay within the district itself. This pattern can also be seen in Figure 4.c, showing that the further the trip starts from the central area of Rotterdam, the longer the trip takes. Average trip duration in the South of Rotterdam is on average the highest but might be caused by the lack of geofenced locations to leave the shared e-moped, i.e., it takes generally longer to travel towards a suitable place where ending the trip is allowed.

Figure 3. **Average shared e-moped trips starting in Rotterdam per day of the week per 15-minutes.** The dark grey bars show the regular rush hours (morning rush between 7:00 and 9:00; afternoon rush between 16:00 and 18:00).

The Global Moran's I global autocorrelation index confirms that trips are clustered. Both origins and destinations of trips are significantly spatially clustered, endorsed by a Global Moran's I index of 0.58 ($p < 0.01$) and 0.62 ($p < 0.01$), respectively, both with positive z-scores. Local Moran's I has been used to visualize local spatial clustering (see Figure 4.b). Significant high-high clusters mean that the feature is surrounded by other high values. Outliers are encircled by lower values (i.e., high-low outlier) or higher values (low-high outlier) (Jiao & Bai, 2020). It can be seen that the main service area of the shared e-mopeds is one large, significant high-high cluster, which might be caused by the fact that also hexagons with a small number of counts were included. It also seems that the high-low outliers are located in places that do not show a particularly high number of trips, see Figure 4.a. After checking these high-low outliers in the surrounding of Rotterdam by hand, most outliers can be explained by having locally high scores for the area where they are in, while having a neglectable number of trips for the overall analysis (the maximum count being 63 trips during the whole month).



(a) Trip destinations from trip origins in Rotterdam (b) Cluster analysis (Local Moran's I) of trip destinations (c) Average trip duration from starting hexagons

Figure 4. **Spatial patterns of shared e-moped trips in Rotterdam** (September 2021). Figure 4.b. only includes hexagons that belong to one of the depicted categories, other hexagons showed non-significant relations. Figure 4.c. only includes hexagons with a trip count above five.

These outliers might be caused by geofenced parking locations, limiting the possibility of parking the e-moped near the outlier-hexagon and thus causing a high-low outlier. Some other interesting locations, outside the major high-high clusters, are (i) *Zuidplein* (high-high cluster), (ii) *Rotterdam Alexander* (high-high cluster) and (iii) *Marconiplein* (high-high cluster). The *Rotterdam Alexander* district is also an interesting location when considering Figure 4.c, where trips are generally shorter in duration, which might indicate that shared e-mopeds are predominantly used within the neighbourhood itself, maybe to travel towards the train/metro station. Secondly, there is the *Marconiplein* area with a cluster of shorter trip durations, indicating that people use the shared e-moped from the metro station towards popular destinations in the vicinity (e.g., shopping centres, educational facilities or hospitals). Both these cluster (Figure 4.b) and duration (Figure 4.c) patterns are in line with the study of Arias-Molinares et al. (2021) and show that the shared e-moped trips cluster at the city centre or, to a lower degree, at local centres, like educational locations or PT stops.

Of all trips, 23.5% start and 23.4% end near a metro/train stop. To see if the location of e-moped trips' origins and destinations are correlated with the location of PT stops, the e-moped trips are classified based on the classification of Yan et al. (2021). Figure 5 shows the classification of trips. The classification tells if a trip starts and/or ends within the service area of a PT stop. Two factors are taken into account, namely the size of the service area (e.g., 100m or 200m Euclidean distance radius) or the type of PT mode (e.g., bus (B), tram (T), metro (M) and train (T)). The following types of trips are considered: **Type 1**, going from a PT stop towards a PT stop, so the trip could have been made by transit, making the e-moped a substitute. However, it should not immediately be judged as such since the considerations of the user are unknown. For instance, it might be the case that the e-moped was picked-up close to PT, because of geofencing (Oeschger et al., 2020; Yan et al., 2021); **Type 2**, starting (**a**) or ending (**b**) at a PT stop, so used as first-last mile access or egress mode of transit, which can be classified as a complement to the PT network; **Type 3**, not related to PT locations and therefore potentially filling a need within the user's mode choice set, which can be seen as a complement to PT. However, it should be noted that Type 3 trips could also substitute other modes of transportation, such as biking or walking, which might not be desired by policymakers (Municipality of Rotterdam, 2021a).

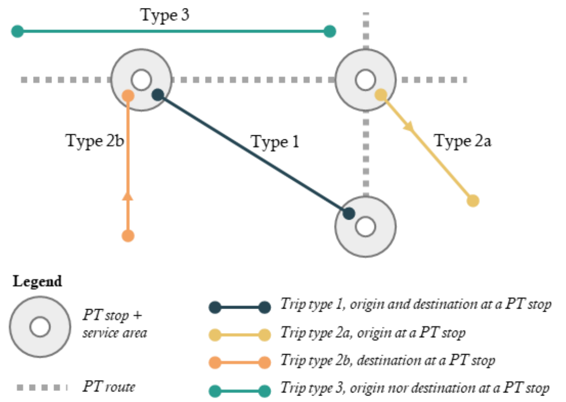


Figure 5. Classification of trip types. Based on Yan et al. (2021)

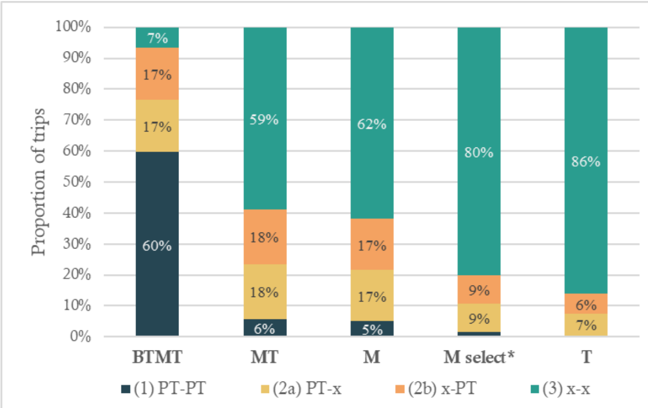


Figure 6. Proportion of trips divided over the trip types for different PT modes. Note: *M select* considers a selection of metro stations[8].

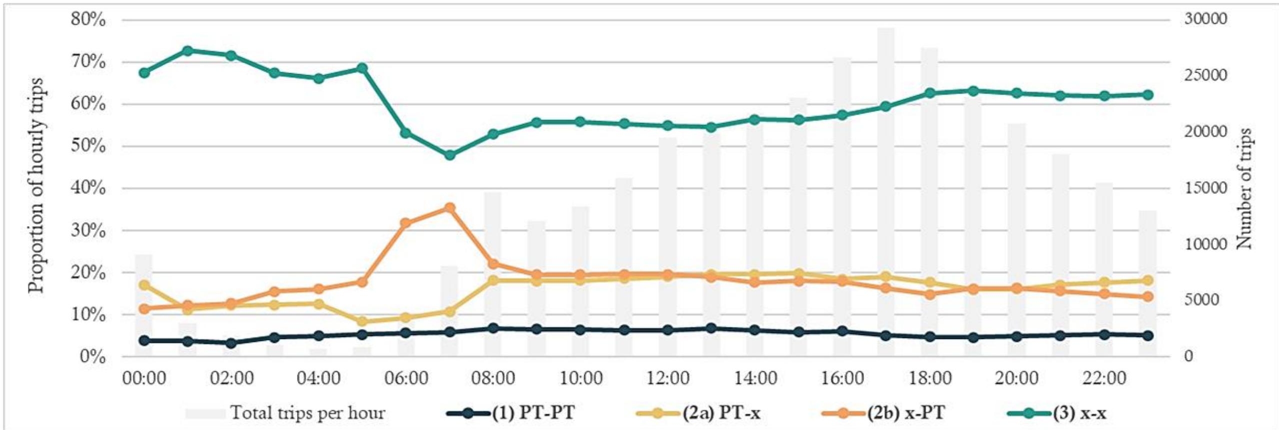


Figure 7. Proportion of trips divided over trip types per hourly trip starts. PT modes: metro & train; Service area: 200m (*MT 200*).

When considering all PT modes and a service area[9] of 200m (*BTMT 200* in Figure 6), 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 will be inefficient due to required transfers. However, a great percentage of these trips could actually be a Type 3 trip, due to the high density of the public transit network in

[8] In Figure 6, *M-select* considers a selection of metro stations, excluding the larger stations with highly visited points-of-interest in their vicinity. Excluded stations: *Dijkzicht, Coolhaven, Kralingse Zoom, Beurs, Blaak, Rotterdam CS, Rotterdam Alexander* and *Schiedam*.

[9] A service area of 100m was deemed to small and is therefore not discussed nor depicted in Figure 6-7. Considering a service area of 100m for BTMT instead of 200m resulted in: 18% trips of Type 1, 23% trips of Type 2a and 2b and 36% of Type 3. For MT100, over 76% of trips is of Type 3.

Rotterdam, i.e., there is a high probability that a trip falls within a PT service area whether the e-moped user uses the PT modes or not (Yan et al., 2021). When considering metro and train (*MT 200* in Figure 6), only 6% of trips substitute PT trips and 36% of trips are a first or last-mile journey. Trips starting or ending in the city centre[7] have a higher probability to be related to PT, while trips in the city neighbourhoods or suburbs[7] have a relatively higher chance to be of Type 3. Furthermore, analysing solely metro stops shows almost the same result as metro and train together, because most train stations also have a metro station present. When analysing train stops only (*T200*), 13% of trips are of Type 2 and 0.5% of Type 1, showing that over 13% of shared e-moped's origins or destinations are related to a train stop. The much larger percentage when including metro stops is primarily caused by the largest metro stops with a lot of other types of destinations in their vicinity (such as shopping or educational locations). When these larger stops are excluded from the analysis, the percentage of trips related to metro stops drops to 19% (Type 1 and Type 2 combined, see Figure 6 *MT select*[8]). So, it seems that a large share of bus or tram trips could be replaced by shared e-mopeds, while the e-moped is partly a complement for metro and train trips.

Figure 7 is based on metro and train stops (*MT200*), and reveals the distribution of trip types over an average day based on the proportion of trip types per hour. It shows that aside from a few exceptions during the rush hours, the general patterns stay roughly the same throughout the day (this holds for both week and weekend days). During the morning, trips of Type 2b are higher at the expense of Type 2a and Type 3, which implies that the shared e-mopeds are used to access PT at these hours. However, it is important to take caution with these conclusions, since the number of trips (grey columns in Figure 7b) is still relatively low. In the afternoon rush at the hours of 17:00 and 18:00, the proportion of Type 2a trips increases at the expense of Type 2b, showing more trips from PT locations towards other areas, where the shared e-moped might be used as a last-mile solution. This phenomenon corresponds with the commuting pattern as perceived in Figure 3.

To quantify the relation between PT locations and shared e-moped trips, a global unweighted OLS model was used to determine significant factors that influence the dependent variable: the logarithmic start of trip density was used to make sure the variable was normally distributed. The results of the OLS model can be seen in Table 4 and fully in Appendix B. The OLS global model can predict 52.4% of the dependent variable variation, based on the adjusted R-squared. From the OLS model, four factors are positively related to the number of trip starts. No variables are omitted because of large VIF values (above 7.5), revealing global multicollinearity (Hosseinzadeh et al., 2021). However, based on the *Jarque-Bera statistic*, the residuals are not normally distributed (and spatially clustered as shown by a Global Moran's I index of 0.026, $p < 0.05$), making the results not reliable. Most probably, one or more important explanatory variables are not included in the OLS model.

Table 4. Partly results of global OLS regression model. Input independent variables with non-significant p-values are omitted.

	Dependent variable: log (start of trips density)		
Independent variable	**Coefficient**	**p-value**	**VIF**
Population density	0.00016	0.002	2.28
Percentage 15-24 years old	0.127	0.013	1.65
Percentage 25-44 years old	0.101	0.048	6.16
Public transit density	0.066	0.005	1.17

Still, based on the significant variables of the OLS model, a GWR model is fitted. The GWR model results in an adjusted R-squared of 52.3% with a lower AIC index than the OLS model, which is in line with literature (Caspi et al., 2020; Hosseinzadeh et al., 2021). From both models, it can be concluded that, although the models are not completely reliable, population density, percentage of people below the age of 44 and the public transit density are positively related to the number of shared e-moped trips that start in a neighbourhood. So, based on the trip data it can be stated that shared e-moped trips are partly correlated with the locations with a high density of PT, which can be seen as potential mobility hubs.

Overall, the spatial analysis of shared e-moped trips suggests that the e-mopeds are (partly) used to commute, based on a clear two-peak pattern. Origins of trips are clustered around PT stops or other points of interest (e.g., educational locations), while destinations are more dispersed throughout the city and its residential neighbourhoods. Trips starting further away from the city centre show a longer trip duration, suggesting e-mopeds are being used as a substitution for other modes to travel towards the centre of Rotterdam. However, trip purpose and geofencing of the service area play a crucial role in the actual motivation of the trip. The outcome of the survey is needed to explain the correlation between shared e-moped trips and public transportation. The survey results are used to verify the hypotheses that follow from the spatial analysis and existing literature: (i) *Considering trips related to PT locations, shared e-mopeds primarily substitute bus and tram trips and complement metro and train in a multimodal trip*, and (ii) *Shared e-moped trips are correlated with PT locations*. The survey results are used to confirm mode substitution and complementation, to provide a user's profile and to explore factors explaining the correlation with PT locations. Section 5.7 synthesises both spatial analysis and survey results.

5.2. Representativeness and descriptive statistics of the sample

As mentioned in Section 4.4, a survey was introduced in addition to the trip data to receive more information on users and non-users of shared micromobility. Firstly, the socio-demographic characteristics of the survey respondents are compared to characteristics of the full population of Rotterdam to check to representativeness of the survey sample. Table 5 provides this comparison for both the full group of respondents as well as the three sub-groups, based on the distribution method.

Males are overrepresented in the survey compared to the general population of Rotterdam (64.3% compared to 49.4%, respectively)[10]. A bias towards higher age groups can also be noticed in the survey sample, due to less people of age group 25-34 (14.9% compared to 21.6%) and relatively more people above the age of 55 included in the survey sample (39.9% to 33.6%). This is mostly caused by the high average age of the RET panel sample, with 54.1% of respondents above the age of 55. Furthermore, people with a Dutch background are strongly overrepresented compared to the average population of Rotterdam (93.9% and 47.1%, respectively) and the sample also contains more people with a high educational level (53.6% compared to 30.3%). Overall, the survey sample shows a bias toward males, older age groups, high educational levels and a Dutch background. This bias is not unexpected and can partly be explained by the fact that the RET panel consists primarily of men of older age. In addition, the messages towards the panel and on social media were in Dutch, making it more difficult for people speaking a different language to participate.

Table 5. Comparison of socio-demographic characteristics of survey respondents and population of Rotterdam. Data for the population of Rotterdam is based on CBS data for different reference years, which are mentioned per variable (CBS Statline, 2021).

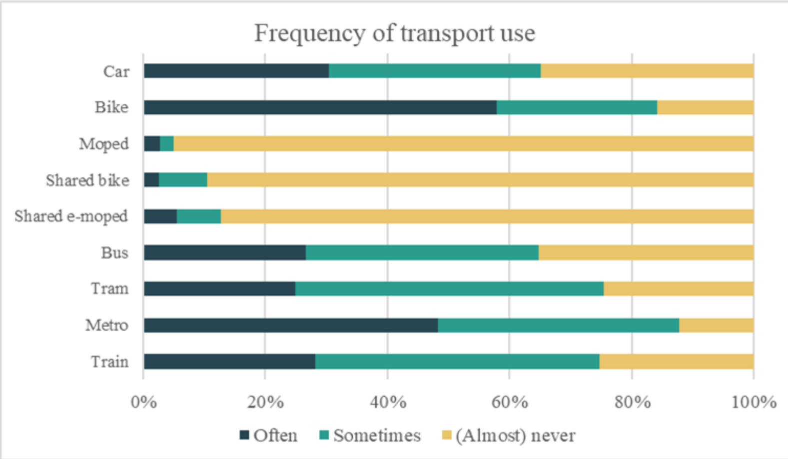
Variable	Population of Rotterdam	Sample full survey	*Sample RET panel*	*Sample social media*	*Sample flyer locations*
Gender (2021)		*N = 353*	*N = 184*	*N = 137*	*N = 32*
Male	49.4%	64.3%	66.8%	63.5%	53.1%
Female	50.6%	34.6%	32.6%	35.0%	43.8%
Other	0.0%	1.1%	0.5%	1.5%	3.1%
Migration background (2020)		*N = 328*	*N = 170*	*N = 127*	*N = 31*
Dutch background	47.1%	93.9%	92.9%	93.7%	100.0%
Western migration background	13.6%	2.4%	2.9%	2.4%	0.0%
Non-western migration background	39.3%	3.7%	4.1%	3.9%	0.0%
Age (2021)		*N = 348*	*N = 181*	*N = 136*	*N = 31*
18-24 years	12.8%	12.4%	5.0%	11.0%	61.3%
25-34 years	21.6%	14.9%	10.5%	19.9%	19.4%
35-44 years	16.4%	16.7%	15.5%	20.6%	6.5%
45-54 years	15.6%	16.1%	14.9%	19.9%	6.5%
55-64 years	14.4%	24.1%	29.3%	22.8%	0.0%
65-74 years	10.8%	15.5%	24.9%	5.9%	3.2%
> 75 years	8.3%	0.3%	0.0%	0.0%	3.2%
Educational level (2019)		*N = 347*	*N = 182*	*N = 133*	*N = 32*
Low	32.0%	10.7%	16.5%	4.5%	3.1%
Medium	37.7%	35.7%	39.6%	27.8%	46.9%
High	30.3%	53.6%	44.0%	67.7%	50.0%
Income level (2018*)		*N = 254*	*N = 119*	*N = 106*	*N = 29*
< €30.000	52.9% *	27.2%	31.1%	16.0%	51.7%
€30.000 - €50.000	33.2% *	37.0%	43.7%	34.9%	17.2%
> €50.000	13.9% *	35.8%	25.2%	49.1%	31.0%

Note: * Income levels for full population are based on standardized household income levels, where the categorizations do not correspond with the category breaks as used in the survey making a comparison difficult (CBS & OBI, 2018).

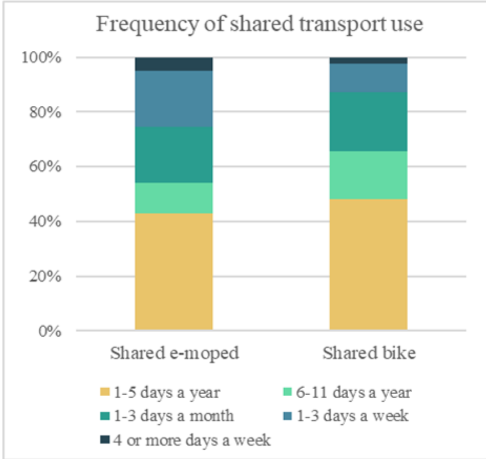
Figure 8.a shows the frequency of transport use of the respondents. When compared to Dutch travel research (*ODiN 2019*) for the region Rotterdam, it can be stated that car users are underrepresented in the sample (30.5% of respondents often use a car, compared to 54.7% of the population of Rotterdam), and PT users are overrepresented (67.3% of respondents qualifies as using any form of PT often, while 35.3% and 15.9% of the Rotterdam population indicate to often use BTM (bus, tram or metro) and train, respectively). In addition, 34.9% of respondents indicate that they (almost) never use a car, compared to 25.3% in the *ODiN* sample (CBS, 2020). The most frequently used modes of the respondents are the personal bike or the metro, indicating the leading role of the metro within the PT network of Rotterdam, with only 12.2% of respondents not using the metro. For the shared moped and bike, 5.5% and 2.5% of respondents state they often use them, which is in line with the study of Horjus (2021) in The Hague, where 87.5% did not use one of them during the past year (Horjus, 2021). People that have used the shared e-moped or bike during the past year, mostly used it only 1-5 days during the previous year (42.9% and 48.3%, respectively), which is depicted in Figure 8.b. This finding is in line with a user study by the municipality of Rotterdam which showed that people scarcely use the e-mopeds on a daily basis (Municipality of

[10] 68% of respondents provided their postcode to verify their home address. 60% of those respondents have a postcode directly in the municipality of Rotterdam and 85% of respondents live in Rotterdam or its surrounding municipalities.

Rotterdam, 2021a). Over a quarter of shared e-moped users use the moped multiple times per week, compared to 13% of shared bike users, indicating that shared e-mopeds are more frequently used than shared bikes. Of the 67.3% of the respondents that qualify as using any form of PT often (96.7% uses PT often or sometimes), 2.9% is both a frequent PT and shared e-moped user (frequency =*often*). From regular shared e-moped users, 52% use a bus, tram, metro or train often.



(a) Frequencies (%) of the use of different transportation modes on average. Shared e-moped (N=454) and shared bike (N=436) frequencies are based on aggregated responses to a slightly different question with more possible frequencies (see Figure b). For all other modes: N=361.



(b) Frequencies (%) of shared micromobility use in the past year. The option *'Never'* has been neglected here.

Figure 8. Frequency of transportation use (%) for (a) different modes of transport and (b) shared modes of transport during last year. In Figure 8.a., using a shared bike or e-moped *1-5 days a year* is categorized as *(almost) never*.

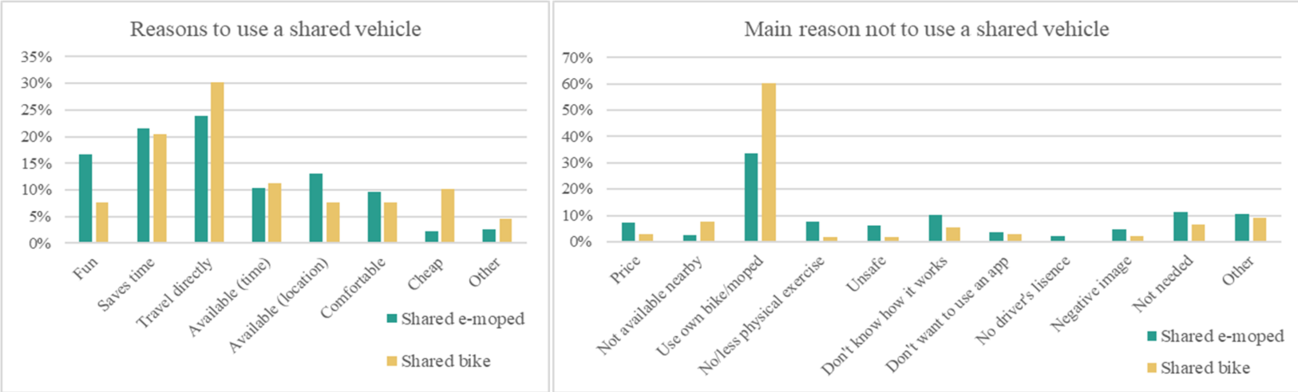
5.3. Role of the shared e-moped in the mode choice set

To get an understanding of the role of the shared e-moped in the complete mode choice set of the user, users of shared e-mopeds answered questions about travelling by shared e-moped in general as well as their last shared e-moped trip (N = 98). Users of shared e-mopeds are primarily men (76%, compared to 64.3% for the whole sample), highly educated (62.3% compared to 53.6%) and relatively young (54% of users are below the age of 35, compared to 27.3%). Based on a Pearson's Chi-square test of independence (Appendix D), a significant difference between users and non-users of shared e-mopeds was found in gender, age, owning a driver's license and digital skill level. Being a user or non-user is therefore associated with those factors. The digital skill level is also significantly positively correlated with shared e-moped use (τ = 0.364, p < 0.001). This user profile is in line with research on shared mobility users (e.g., Böcker et al., 2020; Howe, 2018; see also Section 2.1) and previous research on shared mobility users in Rotterdam (Municipality of Rotterdam, 2021a). To summarize, men of a lower age group, who own a driver's licence and have a higher digital skill level are more likely to be a shared e-moped user. 46.9% of these users use the shared e-moped to travel from/to social activities like sports or going out at night (as observed in Figure 3), while 28.7% of trips commute from/to work or school/university (N = 92).

Figure 9.a depicts the reasons why users of both shared e-mopeds and shared (e-)bikes use the vehicle[11]. The main reason to use any form of micromobility in Rotterdam seems to be the possibility to travel directly to the destination of the trip, which was mentioned by 24% of shared e-moped users. Saving time came in second, with 22% of users mentioning this reason. Striking for the shared e-moped is also the large shared of the reason *'it is fun'*, mentioned by 17% of users while only 8% of bike-sharing users stated this. Availability at every instant as well as the availability of the e-moped close to home is almost equally important, with the latter being slightly more important for shared e-moped users (10% compared to 13%). Interesting is the fact that the location of the vehicle is less important for shared bike users, which might be caused by the fact that bike-sharing providers use docking stations (e.g., the PT-bike) more often than shared e-moped providers.

Figure 9.b shows the main reason non-users of both shared e-mopeds (N = 349) and shared bikes (N = 346) to not use them. For the bike, 60.1% of non-users state they prefer to use their own bike or moped. Reasons for non-users of shared e-mopeds are more divided, with 33.5% favouring using their own bike or moped. Research based in Spain for e-mopeds showed price to be the main drawback of the system (21%), which is however not the case in Rotterdam with only 7.2% mentioning price (Aguilera-García et al., 2020). Other frequently mentioned motives for not using a shared e-moped in Rotterdam are people not needing it to travel (11.2%), not knowing how the system works (10.3%), having less physical exercise (7.7%) and an overall negative attitude towards shared e-mopeds (4.9%). Considering the latter, non-users especially mention the free-floating aspects and the parking nuisance that follows from it, which is also seen as a drawback of the free-floating system, indicating the potential of systems using docking zones (Gu et al., 2019)

[11] Although this study's main focus is on shared e-mopeds, results on the shared (e-)bike are also (partially) included to present differences or similarities.



(a) Reasons to use a shared e-moped (sum = 269) or shared bike (sum = 195). Respondents could provide multiple reasons.

(b) Main reason not to use a shared e-moped (N = 349) or shared bike (N = 346). *Negative image* is a summary of multiple open responses discussing different forms of nuisance.

Figure 9. **Reasons to (a) use a shared e-moped (N = 98) or shared bike (N = 87)** and **(b) reasons do not use a shared e-moped or shared (e-) bike.** Figure 9.b. only includes respondents that have never used a shared bike during the previous year.

Respondents that used the shared e-moped during the past year were asked to provide more details on their last trip (N = 96). First of all, 24% indicated 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 the shared bike in The Hague uses drop zones making the system a less suitable first/last mile solution compared to the mainly free-floating e-mopeds in Rotterdam (Bachand-Marleau et al., 2011; van Marsbergen et al., 2022). In contrast, 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 PT-bike (*OV-fiets*), this suggests that the integration of the bike at the train station is an important factor explaining the use.

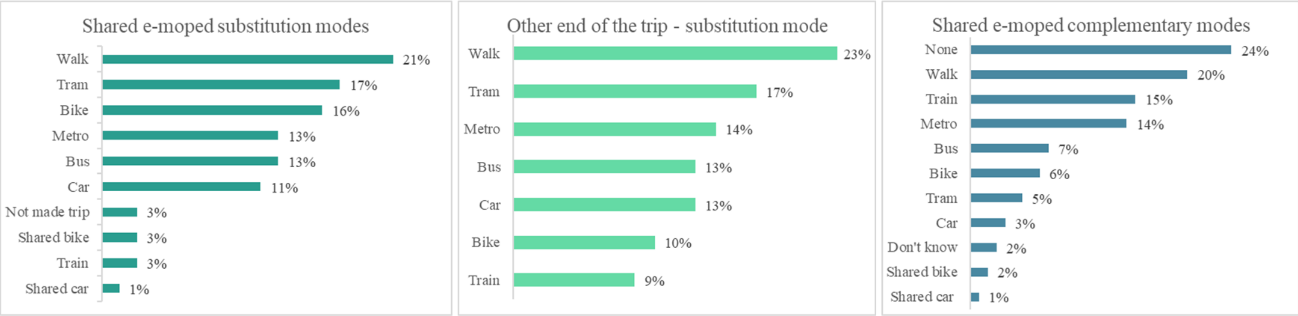
When comparing different groups of PT users, the share of shared e-moped users is the largest among people that almost never use the bus, tram or metro (N = 361) relative to more frequent users of these PT modes. This is differently for the train, showing the largest share of shared e-moped users among frequent users of the train: 28% of people often using the train used a shared e-moped once or more during the past year, while this percentage is at maximum 21% for bus, tram and metro[12]. So, the group of non-users of bus, tram and metro use the shared e-moped more than frequent users. On the other hand, the group of frequent train users does use the shared e-moped more than less frequent users, indicating that the shared e-moped might be mostly used complementary to the train compared to the other PT modes.

In addition, Figure 10.a shows which modes people would have used if the shared e-moped was not available during their last trip. 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. Almost the same substitution pattern is found for two-way trips where the shared e-moped was just used at one leg of the trip (55.6% of trips, N = 50), for which the results are shown in Figure 10.b. In 54% of those cases, PT was used for the other leg of the trip, which is in line with research for e-scooters in Paris (with 44% of trips being one-way and 57% of trips the other way using PT) (6t-bureau de recherche, 2019).

37% of trips replace active forms of transportation, namely biking and walking, which is comparable with results for e-scooter sharing schemes, revealing that up to 41% of walking or bike trips could be substituted by e-scooters (Liao & Correia, 2019). 11.5% of trips would otherwise be made by car, which is a lower share than the previously found 23% by the municipality of Rotterdam (Municipality of Rotterdam, 2021a). This difference cannot be derived from the survey results but might be caused by the large share of frequent PT users / low share of car users in the survey sample. Lastly, only 2.5% would not have made the trip when the e-moped was not available, showing that the number of new trips generated by shared e-mopeds is marginal. These substitution numbers are comparable to those of shared bike users, who indicate that the shared bike primarily replaces active transport or local public transport[13]. Only 3% of shared e-moped users and 2% of shared bike users indicate that the respective micro vehicle substitutes the other, indicating that the vehicles are used for different purposes or by different groups of users.

[12] Only 12.2% of respondents never uses the metro, i.e., metro users are overrepresented, making results of the metro users less reliable.

[13] 51 out of 87 shared bike-users answered questions on their last trip due to the routing decisions within the survey (see Appendix C).



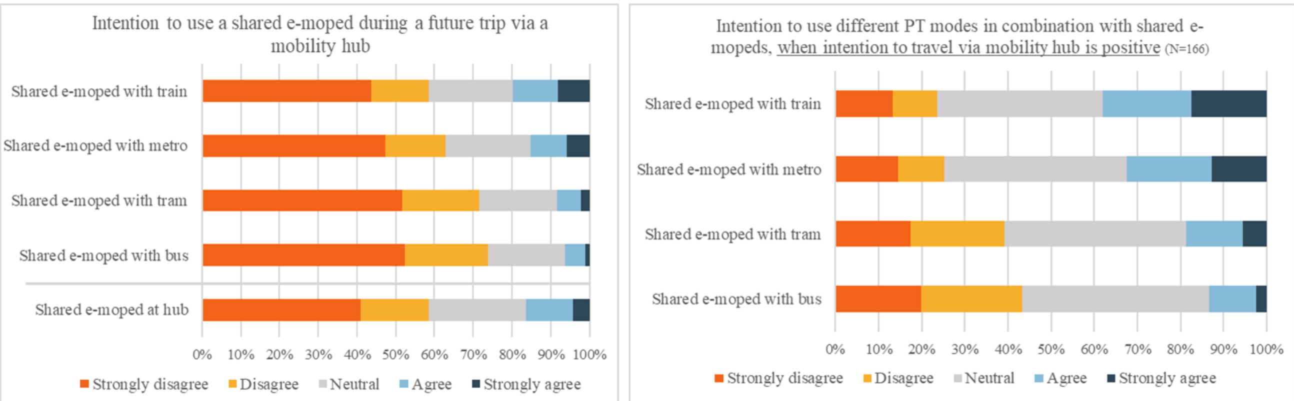
(a) Transportation modes potentially used by respondents if the shared e-moped would not have been available during their last trip (N=92). (b) Transportation modes used by respondents during the other leg of the trip / on their way back, instead of the shared e-moped (N=50). (c) Transportation modes used by respondents during the same trip in addition to the shared e-moped (N=91).

Figure 10. Transportation modes used as substitute of or complementary to the shared e-moped. Multiple response options were possible at all questions related to all three sub-figures. The options *shared vehicle* and *taxi* are omitted in Figure b since both showed 0%.

Transportation modes that are used during the same trip in addition to the shared e-moped are shown in Figure 10.c. 24% of users did not use a different mode of transportation during the trip (presumably walking towards the moped is neglected by these respondents) and 20% of users walked towards or from their moped. Of the respondents that walked towards the moped, 75% did not use another mode during the trip. Combining these findings suggests that in total 39% of shared e-moped trips are not combined with a different mode of transportation except walking towards the vehicle. In contrast to substitution modes, 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 here, 7.2% and 4.8% respectively. This is in line with the findings from the spatial analysis (see Section 5.1), showing that the shared e-mopeds are used as access and egress modes to public transit but mainly for the train and metro.

5.4. Factors influencing the intention to use a shared e-moped at a mobility hub

From the results of the previous sections, it can be learnt that a large part of shared e-moped trips is used in a multimodal trip with public transportation. In this section, it will be investigated which factors influence the intention, of both users and non-users, to travel via a mobility hub using a shared e-moped and the intention to combine the e-moped with PT. Figure 11 illustrates the responses to the intentional behaviour questions in the survey, 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 (Figure 11.a '*shared e-moped at hub*'). 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 19.7% intend to combine the e-moped with the train. 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 11.b, N = 166), 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).



(a) Response to statements: *I expect to use a shared e-moped at a mobility hub in the future* (N=400) and *I expect to combine the shared e-moped with ... (PT mode)* (N=369), in the context of having a mobility hub close to home in the future. (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 positive (neutral, agree or strongly agree) (N=166).

Figure 11. Intention to use a shared e-moped via a mobility hub in general and in combination with different modes of public transit.

The impact of the explanatory factors on this behavioural intention is presented based on the results of an ordinal logistic regression analysis, first for the dependent variable 'intention to use shared e-moped at a mobility hub' and the 14 independent variables. As discussed in Section 4.5, the multimodal trip characteristics regarding the shared e-moped itself and the physical and digital integration at the mobility hub show strong correlations. Using a principal component analysis, the variables are fit into two components: (i) *the importance of shared e-moped supply factors* and (ii) *the importance of mobility hub facilities*, grouping them based on their role within the conceptual model, resulting in a component correlation coefficient of 0.364, explaining 68.4% of the total variance. The components are included in the model as covariate, regression factors. The model fit of the regression model is checked based on deviance and Pearson statistics (see Appendix J), giving conflicting results for the significance with $p = 1.000$ and $p = 0.024$, respectively. However, with a large number of cells with zero frequencies, a significant Chi-square ($p < 0.001$), and the assumptions of proportional odds being met ($p > 0.05$), it can be concluded that the model can predict the variance in the independent variable properly. Table 6 shows a section of the complete parameter estimates for the logistic regression model with only the independent variables that have significant parameter estimates ($p < 0.05$). Some variables show only one category to be significant, however, based on the Wald statistic for the complete variable, it can be concluded that these whole variables can be considered to have a significant effect on the independent variable (see Table J.17 in Appendix J). Based on these results, it shows that *shared e-moped supply factors*, *transfer to PT at Hub*, *social influence*, the *educational level* and the *digital skills level* significantly affect the behavioural intention to use a shared e-moped at a mobility hub.

The importance of shared e-moped supply factors is associated with an increase in the odds of considering using a shared e-moped at a mobility hub, with an odds ratio of 1.810, indicating that respondents who agree with the importance of shared e-moped supply factors are more willing to use a shared e-moped in the future. The variable describes a combined effect of the importance of *the availability of the e-moped*, *the ease of using the e-moped*, *availability of the e-moped near PT* and *distance to the shared e-moped*. The latter two variables show the strongest correlation and odds ratio with the intention to use a shared e-moped (see Appendix G), emphasizing the importance of easy access and convenient usage (as found by Ye et al., 2020). In addition, the importance of transferring to PT at the mobility hub (which is also used to state the importance to transfer to shared mobility) shows an odds ratio for disagreeing of 0.271, implying that respondents who do not value an easy transfer to PT are 3.69 (1/0.271) times less likely to use a shared e-moped at a mobility hub. The same applies to the neutral category which also decreases the possibility of intending to use a shared e-moped, with an odds ratio of 0.410, underlining the importance of fast and easy transit system accessibility (de Witte et al., 2013).

The odds ratio of respondents disagreeing with being influenced by their family and friends to use a shared e-moped is 0.170, implying that people that are not feeling a social influence by their surroundings are 5.88 (1/0.170) times less likely to intend to use a shared e-moped than people that agree to be socially influenced. This demonstrates that when family and friends encourage the respondents to use the shared e-moped, their behavioural intention to use the shared e-moped in the future is significantly increased. A similar effect was found in a study on shared mobility in Belgium, reporting a strong relationship between social influence and intention to use shared mobility as well (van Veldhoven et al., 2022).

Table 6. Parameter estimates of ordinal logistic regression model for intention to use shared e-moped at mobility hub (N = 400). Only independent variables with a significant parameter are shown. Full parameter estimates can be found in Appendix J.

	b	Std. error	Wald	Sig.	Exp(b)	95% confidence interval	
						Lower	Upper
Threshold							
Intention to use a shared e-moped = disagree	-1.884	1.015	3.449	0.063	0.152	0.021	1.110
Intention to use a shared e-moped = neutral	-0.175	1.006	0.030	0.862	0.839	0.117	6.024
Locations							
Shared e-moped supply factors (C1)	0.593	0.217	7.482	0.006*	1.810	1.183	2.768
Mobility hub facilities factors (C2)	0.169	0.179	0.893	0.345	1.184	0.834	1.681
Transfer to PT at Hub = disagree	-1.304	0.571	5.213	0.022*	0.271	0.089	0.831
Transfer to PT at Hub = neutral	-0.892	0.397	5.052	0.025*	0.410	0.188	0.892
Transfer to PT at Hub = agree	0[a]				1		
Social influence = disagree	-1.771	0.576	9.444	0.002*	0.170	0.055	0.527
Social influence = neutral	-1.061	0.655	2.623	0.105	0.346	0.096	1.250
Social influence = agree	0[a]				1		
Educational level = low	1.300	0.484	7.217	0.007*	3.669	1.421	9.471
Educational level = medium	0.425	0.295	2.072	0.150	1.529	0.858	2.726
Educational level = high	0[a]				1		
Digital skills level = Level 0 or Level 1	-1.351	0.518	6.808	0.009*	0.259	0.094	0.714
Digital skills level = Level 2	-0.586	0.336	3.049	0.081	0.557	0.288	1.074
Digital skills level = Level 3	0[a]				1		

Note: [a] This parameter is set to zero because it is redundant; * parameter is significant at (at least) the 0.05 level

For digital skills, the odds ratio of 0.259 for Level 0/Level 1 indicates that respondents with low digital skills are 3.86 (1/0.259) times less likely to agree with the intention to use a shared e-moped at a mobility hub. The parameter estimate for digital skills Level 2 was not significant but based on the overall Wald statistics, respondents of Level 2 show a lower intention than respondents of Level 3. This significant effect is in line with the findings of Horjus (2021) for the intention to use shared transportation, who found odds ratios of 0.203 and 0.415 for Level 0 and Level 1, respectively (Horjus, 2021).

The negative relationship between digital skills and shared mobility use was also found by Van Veldhoven et al. (2022) and corresponds with the statement of Durand et al. (2021) that increasingly digital skills are needed to travel, especially in shared mobility where digital technologies are the only way to access and adopt the system. This effect could be strengthened by the free-floating scheme of the current systems in Rotterdam – where currently 10.3% of non-users indicate that they do not understand the system and therefore do not use it – reinforcing the need for digital applications even more.

Lastly, a low educational level of the respondents significantly affects their intention. A low education level shows a positive coefficient implying that a person with a low educational level has an odds ratio 3.669 times larger than someone with a high educational level to intend to use a shared e-moped. This result is not in line with the previously described user profile of shared e-moped users, where shared micromobility users were described as highly-educated (e.g., Adnan et al., 2019). Therefore, it was tried to find an explanation for this unexpected coefficient. For respondents with a low education level (N = 37), 29.7% of '*neutral*' responses were caused by a recoded *'I do not know*' response, while this is only the case for 8.9% and 7.5% of the respondents for medium and highly educated respondents, respectively, which might cause the difference between the expected results and the actual output showing a negative relation between education level and use.

A number of independent variables are not depicted in Table 6 since they did not significantly predict the independent variable. Interestingly, the importance of mobility hub facilities factors – including *parking, wayfinding, live travel information* and *ticket sale* – did not show a significant impact ($p = 0.345$) on the intention to travel (by shared e-moped) via a mobility hub. It seems that the importance of the shared e-moped itself has more impact than the layout of the mobility hub, i.e., the proper supply of the shared e-moped is a more important determinant to travel using a shared e-moped than the facilities at the hub. Other non-significant multimodal trip variables are *travel time* and *travel costs*, and the importance of the *multimodal planner application*. Furthermore, the socio-demographic variables *car use* and, even more interesting, *shared mobility use* did not show to be significant predictors. This implies that the current use of shared e-mopeds or bikes does not have a significant influence on the behavioural intention. The log-odds ratio suggests that having no experience with shared micromobility decreases the odds of intending to use shared e-mopeds but is not significant ($p = 0.224$). This might be caused by its fairly high significant correlation ($\tau = 0.374$) with digital skills, both factors partially explaining the same effect. Also, gender, migration background and age category do not have a significant effect, which is interesting while considering the described user profile of typical shared micromobility users.

5.5. Factors influencing the intention to use a shared e-moped in combination with public transportation

For the same future trip scenario, respondents were asked if they were intending to use the shared e-moped in combination with the bus, tram, metro or train (see Figure 11). Factors influencing this specific behavioural intention are discussed in this section. However, the ordinal logistic regression model with the dependent variable: 'intention to use the shared e-moped in combination with the bus', does not meet the proportional odds assumption ($-2LL < 0.001$, $\chi^2 = 302.814$, $p < 0.001$) since the log-likelihood is practically zero. This might be caused by the small number of respondents stating they *agree* with using the shared e-moped in combination with the bus, namely N = 25 (6.3%). The model for a trip combination with the bus is added in Appendix K for completeness but will not be discussed in further detail. When the model would have been valid, the variables *mobility hub facilities*, *social influence* (disagree) and *digital skills level* (low) would have had a significant effect on the intention to use a shared e-moped in combination with the bus.

Table 7 shows the parameter estimates for the ordinal regression models of combining the shared e-moped with tram, metro or train. Only the independent variables that have significant parameter estimates ($p < 0.05$) are depicted. For using the shared e-moped in combination with tram, metro or train, some similarities between the parameter estimates are noticeable. Shared e-moped supply factors play an important role in the intention to perform a multimodal trip. For tram, this importance is associated with an odds ratio of 2.116, for metro with 2.417 and for train with an odds ratio of 3.000. These values underline the effect of a proper supply of the shared e-moped on the intention to combine it with other modes of transportation. The variables making up this component relate to the performance of the shared e-moped in a multimodal trip; the shared e-moped should be available close to home and easily accessible from public transportation, relating to a certain performance expectancy on both ends of the shared e-moped trip. These variables facilitate if the shared e-moped is a proper access or egress mode of the public transportation modes, and this is reflected in the outcomes of the ordinal regression models (Bell, 2019; Geurs et al., 2022).

In this light, it is interesting to see that the importance of a good transfer from the shared e-moped to PT (which also reflects the transfer to other shared mobility modes) is a significant predictor for metro and especially for train. For metro, disagreeing with the importance of an easy transfer shows an odds ratio of 0.208, implying that respondents who do not value an effortless transfer are 4.81 (1/0.208) times less likely to use a shared e-moped in combination with the metro[14].

[14] It should be noted that the omnibus Wald chi-square statistic for *transfer to PT at Hub* for the intention to combine with the metro is non-significant for the overall variable (p = 0.106). For the train, the overall significance of the variable is accounted for (p = 0.037).

Table 7. Parameter estimates of ordinal logistic regression model for intention to use shared e-moped in combination with tram, metro or train (N = 369). Only independent variables with a significant parameter for the specific dependent variable are shown. The complete set of parameter estimates can be found in Appendix L (tram), Appendix M (metro) or Appendix N (train).

	b	Std. error	Wald	Sig.	Exp(b)	95% confidence interval	
						Lower	Upper
DV: Intention to use a shared e-moped in combination with the **tram**							
Threshold							
Intention to use a shared e-moped = disagree	0.026	1.149	0.001	0.982	1.026	0.108	9.754
Intention to use a shared e-moped = neutral	1.822	1.151	2.507	0.113	6.183	0.648	58.958
Locations							
Shared e-moped supply factors (C1)	0.748	0.283	6.981	0.008*	2.112	1.213	3.679
Travel time = disagree	1.428	0.682	4.382	0.036*	4.171	1.095	15.886
Travel time = neutral	0.067	0.452	0.022	0.883	1.069	0.441	2.593
Travel time = agree	0[a]				1		
Social influence = disagree	-1.954	0.553	12.494	0.000*	0.142	0.048	0.419
Social influence = neutral	-0.653	0.634	1.062	0.303	0.520	0.150	1.802
Social influence = agree	0[a]				1		
Educational level = low	1.356	0.559	5.874	0.015*	3.879	1.296	11.611
Educational level = medium	0.451	0.338	1.777	0.182	1.570	0.809	3.048
Educational level = high	0[a]				1		
Digital skills level = Level 0 or Level 1	-1.477	0.619	5.694	0.017*	0.228	0.068	0.768
Digital skills level = Level 2	-1.011	0.380	7.088	0.008*	0.364	0.173	0.766
Digital skills level = Level 3	0[a]				1		
DV: Intention to use a shared e-moped in combination with the **metro**							
Threshold							
Intention to use a shared e-moped = disagree	-1.138	1.112	1.047	0.306	0.321	0.036	2.834
Intention to use a shared e-moped = neutral	0.577	1.107	0.272	0.602	1.781	0.203	15.608
Locations							
Shared e-moped supply factors (C1)	0.883	0.262	11.380	0.001*	2.417	1.448	4.037
Transfer to PT at Hub = disagree	-1.569	0.763	4.231	0.040*	0.208	0.047	0.929
Transfer to PT at Hub = neutral	-0.459	0.436	1.110	0.292	0.632	0.269	1.484
Transfer to PT at Hub = agree	0[a]				1		
Social influence = disagree	-2.331	0.619	14.180	0.000*	0.097	0.029	0.327
Social influence = neutral	-1.243	0.700	3.153	0.076	0.289	0.073	1.138
Social influence = agree	0[a]				1		
Digital skills level = Level 0 or Level 1	-1.429	0.555	6.633	0.010*	0.239	0.081	0.711
Digital skills level = Level 2	-1.076	0.360	8.960	0.003*	0.341	0.168	0.690
Digital skills level = Level 3	0[a]				1		
Migration background = Dutch	1.598	0.744	4.610	0.032*	4.941	1.149	21.241
Migration background = non-Dutch	0[a]				1		
DV: Intention to use a shared e-moped in combination with the **train**							
Threshold							
Intention to use a shared e-moped = disagree	-1.004	1.053	0.908	0.341	0.366	0.046	2.889
Intention to use a shared e-moped = neutral	0.598	1.051	0.323	0.570	1.818	0.232	14.266
Locations							
Shared e-moped supply factors (C1)	1.098	0.252	18.947	0.000*	3.000	1.829	4.919
Transfer to PT at Hub = disagree	-1.738	0.689	6.354	0.012*	0.176	0.046	0.679
Transfer to PT at Hub = neutral	-0.503	0.417	1.456	0.227	0.605	0.267	1.369
Transfer to PT at Hub = agree	0[a]				1		
Social influence = disagree	-1.294	0.586	4.866	0.027*	0.274	0.087	0.866
Social influence = neutral	-0.432	0.681	0.402	0.526	0.649	0.171	2.468
Social influence = agree	0[a]				1		
Digital skills level = Level 0 or Level 1	-2.045	0.569	12.905	0.000*	0.129	0.042	0.395
Digital skills level = Level 2	-1.040	0.352	8.725	0.003*	0.353	0.177	0.705
Digital skills level = Level 3	0[a]				1		

Note: [a] This parameter is set to zero because it is redundant; * parameter is significant at (at least) the 0.05 level

For a multimodal trip with the train, respondents not appreciating an easy transfer are 5.68 (1/0.176) times less likely to combine both modes, pointing out the importance of offering effortless transfer possibilities, especially when travelling by metro or train. This emphasizes the importance of physical integration of a mobility hub that, by taking away transfer barriers between modes, should stimulate making multimodal trips (Jorritsma et al., 2021).

Combining the e-moped with the tram does not consider the importance of an effortless transfer as a significant predictor, suggesting that this transfer is less important when using the tram. Another reason might be that tram stops are already easily accessible since a tram stop is generally more accessible by shared e-moped (and in closer proximity due to a higher density of stops) than a metro or train station. Interestingly, *travel time* (disagree) is a significant predictor of the intention to use a tram and shared e-moped. Not valuing travel time is associated with an odds ratio of 4.171, implying that when a respondent does not value travel time as an important aspect of the trip, he or she is more likely to combine the shared e-moped with the tram. The aforementioned suggests that travel time is less important for people willing to travel by tram, which is in line with the tram mostly being used for shorter distance trips where travel time might be of less importance (Bestuurscommissie Vervoersautoriteit, 2022). Additionally, users of both shared e-mopeds and the tram (not particularly in a multimodal trip) have a relatively high share of going out (e.g., nightlife) as trip purpose, where travel time might be of less importance (N = 55).

Furthermore, social influence and digital skills show a similar effect for combining the shared e-moped with tram, metro or train. When respondents disagree with being socially influenced, it reduces their probability of intending to combine the shared e-moped with the tram, metro or train by 7.04 (1/0.142), 10.3 (1/0.097) and 3.7 (1/0.274) times, respectively. Respondents that perceive to be influenced by others (e.g., family and friends) have higher odds of intending to use a shared e-moped in a multimodal trip in the future than respondents that do not perceive this influence.

Digital skills are also seen as a significant predictor in all three models, with odds ratios of 0.228 for tram, 0.236 for metro and 0.129 for train, for Level 0 or Level 1, indicating that lower levels of digital skills are related to lower intention to use a shared e-moped in a multimodal trip. For example, the odds of a respondent of Level 0/Level 1 using a shared e-moped in combination with the train is 7.75 (1/0.129) times smaller than that of a respondent with digital skills Level 3. Digital skills strongly explaining the intention to use shared e-moped is in line with a study by Van Veldhoven et al. (2022) who found this same effect for shared mobility in general, and with the study of Horjus (2021) based in the city of The Hague (Horjus, 2021; van Veldhoven et al., 2022).

Other remarkable significant predictors are low educational level for combining a trip with the tram, and migration background for combining with the metro. Firstly, having a low educational level corresponds with an odds ratio of 3.879, meaning that respondents with a lower education level have a higher intention of combining shared e-moped and tram[15]. The variable migration background is a significant predictor when considering the intention to use shared e-moped in combination with metro, with an odds ratio of 4.941. Respondents with a Dutch migration background would have significantly higher odds of combining the metro with the shared e-moped, however, the group of respondents with a non-Dutch migration background is fairly small (N = 12) making this parameter estimate less reliable.

Additionally, there are some factors that are not found to be significant predictors. First of all, there are the mobility hub facility factors that are not found to be significant in this research. Also travel time (and travel costs), often considered as one of the most important mode choice factors (Cervero, 2002), are not found to be significant in most models. However, as found in literature, accessibility is often more important when considering PT trips, which is in line with the regression model results, showing a significant effect for e-moped supply factors (including accessibility to the e-moped itself) and easy transferring to PT (de Witte et al., 2013). Current travel behaviour did also not significantly change the odds of the behavioural intention, with current car use (which is also used as a proxy variable for owning a driver's licence) or shared mobility use not significantly predicting the use of the e-moped in combination with tram, metro or train, while Ton et al. (2020) found that the current set of mode choice options plays an important part in the mode choice decision.

5.6. Differences between user groups and their behavioural intention

Potentially, there is a difference between distinct groups in answering the behavioural intention statements. To compare the full survey sample and people who intend to use a shared e-moped (in combination with PT), a Kendall's thau-b correlation test was executed to determine the relationship between several socio-demographic variables and the intention to use a shared e-moped. From the analysis, which can be found in Appendix F, it can be concluded that there is a strong significant correlation between shared mobility usage ($\tau = 0.232$, $p < 0.001$), digital skills ($\tau = 0.264$, $p < 0.001$) and age ($\tau = -0.162$, $p = 0.001$), and the intention to use a shared e-moped at a mobility hub. People who have used a shared vehicle before, have a higher level of digital skills and are generally younger, seem to have a correlation with higher intention to

[15] The omnibus Wald chi-square statistic for education level as a whole, is significant at the 0.05 level ($\chi^2 = 6.418$, p = 0.040).

use a shared e-moped. From a chi-square test of independence for the difference between shared e-moped users and non-users on behavioural intention, it also follows that the variables are not independent, and an association exists between currently using a shared e-moped and intending to use one in the future. Interestingly, age and shared mobility use are not found to be significant predictors in the regression models.

Table 8 compares the characteristics of the full sample with a part of the sample that was positive against the behavioural intention statements. Considering the intention to use a shared e-moped at a mobility hub in general, it can indeed be noted that the sample group showing a positive intention consist of a higher share of men (80.7% compared to 64.3% in the full sample), with a younger age (71% below the age of 45, compared to 44% in the full sample) and a higher level of digital skills (55.7% in Level 3 compared to 25.3%). Moreover, the respondents who intent to use the shared e-moped do own a driver's licence more frequently and are also more regular users of shared mobility.

When considering the *disagree* sample for the intention to use a shared e-moped at a hub, it can be concluded that the group is more comparable to the full survey sample, although the values vary: 38% of respondents are below the age of 45, 63.5% men and 16.8% of respondents in Level 3 of digital skills. Striking is the percentage of non-shared mobility users of 88%, underlining the relation between current shared mobility use and the future intention. Comparing educational level between the three groups (*agree* – *neutral* – *disagree* to use shared e-moped) shows interesting results, with 59%, 34.5% and 60.3% being highly educated in the respective groups (compared to 53.6% in the complete sample), displaying a high percentage of highly educated respondents in both the *agree* and *disagree* sample group.

The sample groups showing a behavioural intention to combine the shared e-moped with tram, metro or train express strong similarities with the sample group with a positive intention of using a shared e-moped at a mobility hub. An exception is the combination with the bus (N = 25), where respondents are generally older (36.4% above the age of 55, compared to 25%, 24.6% and 19.7% for the tram, metro and train, respectively), have a lower educational level and are more frequent car users (40.9% does not use the car frequently, compared to 28.1%, 29.3% and 30.6% for the tram, metro and train, respectively). Still, it should be noted that this group of respondents is low and making a strong conclusion based on these numbers comes with uncertainties.

Table 8. Comparison between the full sample and the five dependent variable classes with a positive behavioural intention.

		Sample *Intention to use a shared e-moped … = agree*				
Variable	**Sample full survey**	**at a mobility hub**	***in combi with* bus**	***in combi with* tram**	***in combi with* metro**	***in combi with* train**
Gender	*N = 353*	*N = 65*	*N = 25*	*N = 33*	*N = 60*	*N = 78*
Male	64.3%	80.7%	81.8%	81.3%	75.9%	77.8%
Female	34.6%	19.4%	18.2%	18.8%	20.7%	20.8%
Other	1.1%	0.0%	0.0%	0.0%	0.0%	0.0%
Migration background	*N = 328*	*N = 65*	*N = 25*	*N = 33*	*N = 60*	*N = 78*
Dutch background	93.9%	95.1%	95.5%	100.0%	98.2%	98.6%
Western migration background	2.4%	0.0%	0.0%	0.0%	0.0%	0.0%
Non-western migration background	3.7%	4.9%	4.6%	0.0%	1.8%	1.5%
Age	*N = 348*	*N = 62*	*N = 22*	*N = 32*	*N = 57*	*N = 71*
18-24 years	12.4%	24.2%	12.5%	18.8%	21.1%	26.8%
25-34 years	14.9%	24.2%	18.2%	28.1%	24.6%	25.4%
35-44 years	16.7%	22.6%	13.6%	15.6%	17.5%	15.5%
45-54 years	16.1%	8.1%	9.1%	12.5%	12.3%	12.7%
55-64 years	24.1%	17.7%	27.3%	18.8%	17.5%	12.7%
65 > years	15.8%	3.2%	9.1%	6.3%	7.0%	7.0%
Educational level	*N = 347*	*N = 61*	*N = 20*	*N = 31*	*N = 55*	*N = 71*
Low	10.7%	6.6%	20.0%	9.7%	7.3%	7.0%
Medium	35.7%	34.4%	35.0%	32.3%	38.2%	31.0%
High	53.6%	59.0%	45.0%	58.1%	54.6%	62.0%
Digital skill level	*N = 356*	*N = 65*	*N = 25*	*N = 33*	*N = 60*	*N = 78*
Level 0 – no phone	3.7%	0.0%	0.0%	0.0%	3.5%	1.4%
Level 1 – phone	12.6%	4.9%	0.0%	3.1%	5.3%	1.4%
Level 2 – phone and plan trips	58.4%	39.3%	45.5%	28.1%	35.1%	41.4%
Level 3 – phone, plan and pay trips	25.3%	55.7%	54.6%	68.8%	56.1%	55.7%
Frequent car use	*N = 361*	*N = 62*	*N = 22*	*N = 32*	*N = 58*	*N = 72*
No	34.9%	32.3%	40.9%	28.1%	29.3%	30.6%
Yes	65.1%	67.7%	59.1%	71.9%	70.7%	69.4%
Frequent shared mobility use	*N = 400*	*N = 65*	*N =25*	*N = 33*	*N = 60*	*N = 78*
No	82.0%	55.4%	52.0%	42.4%	51.7%	48.7%
Yes	18.0%	44.6%	48.0%	57.6%	48.3%	51.3%

For the other three categories, potential multimodal trip users are generally younger (age below 35 is 46.9% for tram, 45.6% for metro and 52.1% for train, compared to 27.3% of the full sample) and more highly educated (58.1% tram, 54.6% metro and 62% train, compared to 53.6% of the full sample). Furthermore, these potential users have a high level of digital skills, are relatively frequent shared mobility users and are also frequent car users. The latter reveals some of the potential that shared mobility has to replace (urban) car trips since current frequent car users are relatively interested in using a shared e-moped in the future. When comparing the PT modes, the current use of shared e-mopeds and bikes has the strongest correlation with the intention to use the e-moped in combination with the metro (τ = 0.249, $p < 0.001$) and the train (τ = 0.330, $p < 0.001$). This phenomenon corresponds with the findings of the spatial analysis (see Section 5.1).

When focussing on the multimodal trip characteristics themselves (see Appendix O), the group of potential users (i.e., having a positive intention to use the shared e-moped) value most characteristics to be more important than the group with a negative intention to use the shared e-moped. For most of these characteristics, a significant difference between those groups is found based on a Pearson's Chi-square test of independence. There are four exceptions to this as the importance of *travel time*, *travel costs*, *live travel information at the hub* and *ticket store at hub* do not differ between those groups. With travel time and travel costs seen as highly important (only 7% and 8% disagree, respectively), it should be acknowledged that although they do not explain the intention to use a shared e-moped, both are still valuable factors.

Additionally, a k-means cluster analysis (see Appendix P) is performed using the two components that describe the importance of the (i) e-scooter supply factors and (ii) the mobility hub facility factors. From the reviewed literature, it became clear that integration between e-mopeds and mobility hubs is key and hubs should offer easily accessible facilities and services (e.g., Bell, 2019; Geurs et al., 2022). However, the ordinal logistic regression models as discussed in Section 5.5 reveal the fact that the shared e-moped supply factors are of higher influence on the intention to use shared e-mopeds at a hub, than the hub factors themselves. The cluster analysis discovered four clusters, with their cluster means varying based on the two components. A number of socio-demographic factors differ significantly between the clusters, namely age, digital skills, car use and shared mobility use. From this analysis, it can be concluded that respondents who strongly value all factors are generally car users and digitally skilled, while respondents valuing mobility hub facilities are relatively older and less used to shared e-mopeds or bikes.

5.7. Synthesis of results

In this section, the results of the different analyses as discussed in the paragraphs above, are combined. The first research question (RQ1): *Are current spatio-temporal usage patterns of e-mopeds correlated with the location of potential mobility hubs?*, is related to the spatial analysis of shared e-moped trips. Based on this analysis, it is concluded that shared e-moped trips are correlated with PT locations and that these trips primarily substitute bus and tram trips and complement the metro and train. These results are substantiated by the results of the survey; where the spatial analysis classified 59% of trips as not related to metro or train, the survey results show 45% of users never combine the shared e-moped with PT and 31% only sometimes. In line with what the results of the spatial analysis suggested, the shared e-moped is used both in multimodal trips in combination with PT, as well as to replace car or bike trips. The relation between PT stops and shared e-moped trips might be explained by the transfer possibilities, which are valued highly by current shared e-moped users. However, with a large share of trips used to travel to social activities, it might be the case that PT-related trips are overrepresented in the spatial analysis, due to these social destinations being close to PT stops and thus being classified as PT-related trips. This makes it possible to answer RQ2: *Which modes are substituted/complemented by e-moped use?*. When the e-moped is used in a multimodal trip, it is especially complementary to the train and, to a smaller extent, the metro. Still, shared e-moped trips primarily substitute active transport modes and urban transit, indicating the debatable role of the shared e-moped in the urban transportation system. Shared e-moped users, who are generally young, highly educated and digitally skilled, mostly use the moped to travel directly to their final destination, not combining the vehicle with modes other than walking.

Figure 12 represents the relation between the factors from the conceptual model and the dependent variables of the OLR models to answer RQ3: *To what quantitative extent do the physical/digital integration factors influence potential users' intention to use e-mopeds at mobility hubs?* 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. 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. However, while the app variables – related to digital integration using MaaS – do not seem significant, digital skills are one of the most important explanatory variables, indicating an existing barrier to the use of shared e-mopeds. Related to the conceptual model and the underlying UTAUT model, a strong effect of social influence is found. All factors regarding both performance and effort expectancy, except for travel time, travel costs and live travel information, show a positive relationship between its perceived usefulness and ease, and the behavioural intention, albeit not all being significant.

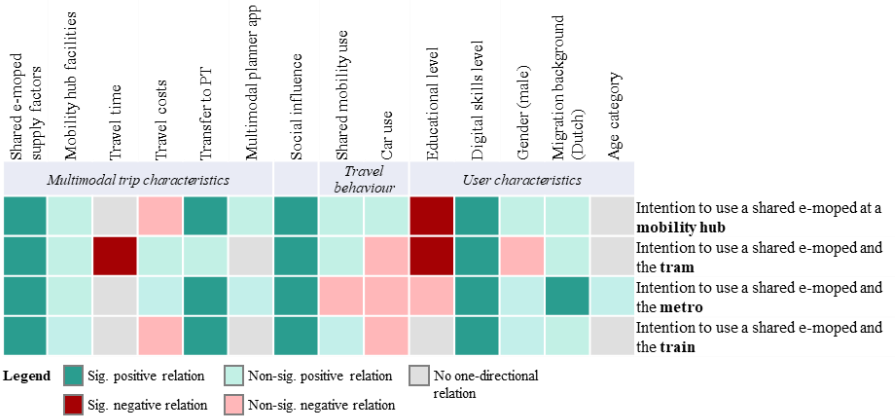


Figure 12. Relation between factors influencing behavioural intention and the intention to use a shared e-moped. The relations are based on the results of the OLR models. Variables and characteristics related to the conceptual model (see Figure 2)

Answering RQ4: *How can different user groups be defined based on their intention to use e-mopeds at mobility hubs and user characteristics?*, it is found that current users of shared micromobility, with relatively younger age and with a higher level of digital skills, are more likely to use a shared e-moped at mobility hubs than people not corresponding with these characteristics. This user profile is the same for people intending to make a multimodal trip including the tram, metro and/or train, while a somewhat different user profile is found for the behavioural intention of combining a trip with the bus. In addition, the potential users are more highly educated, corresponding with the description of Howe (2018) as *young urban professionals*.

When zooming in on the explanatory factors, it is found that the potential users of shared e-mopeds (with positive intention) value the moped's accessibility and availability, while the group with negative behavioural intention – who are generally older and less experienced with shared mobility – are still, relatively, interested in the hub facility factors (see Figure 13). There is especially a large difference in importance of the four variables making up the shared e-moped supply component between the positive and negative intention groups, explaining the explanatory power of this respective component. Furthermore, the importance of travel time, travel costs, having a ticket store and live travel information do not differ significantly between the two groups (positive or negative behavioural intention). This indicates that these variables are valued similarly between the groups. Travel time and travel costs are valued highly for both groups, resulting in being a non-significant predictor of behavioural intention, however, they are both important factors to take into account.

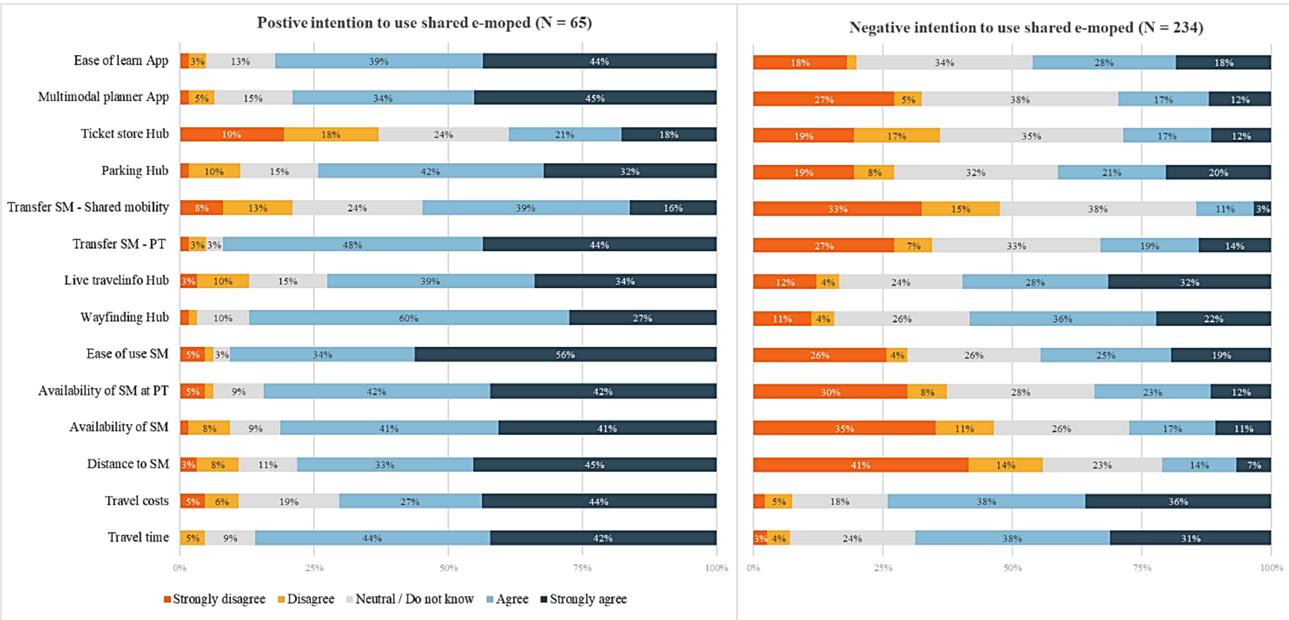


Figure 13. Importance of multimodal trip characteristics for respondents with a positive and negative behavioural intention. The group with *neutral* behavioural intention is not taken into account.

6. Discussion

This section discusses the results that have been presented in the previous sections as well as the limitations and implications of certain methodology decisions. Furthermore, the results will be discussed in light of current ongoing trends in shared mobility policy since the field is changing rapidly, and the research contribution to practice and theory will be discussed.

6.1. Limitations of the study

Trip data quality and implications

As acknowledged by the data quality feed of the CROW, the data offered by the e-moped providers is usable but still needs some improvements (Stichting CROW, 2022), affecting the results of the trip data analysis. For instance, the start and end locations of trips are not always correct (e.g., at the location of a depot) or the duration of trips is aggregated per 30 seconds, which gives discrepancies in the analysis results. Additionally, the trip data does not include the exact travelled distance. Determining the network distance for the complete dataset takes too much computational power, so the Euclidean distance was used as a proxy for the network distance. The Euclidean distance does not correspond with the real distance that has been covered, especially not for north-south movements in Rotterdam, where it is difficult to travel in a straight line due to crossing the river, so a hard conclusion cannot be drawn from this.

Furthermore, only the complete dataset for trips starting or ending in the municipality of Rotterdam was provided. A small selection of surrounding municipalities permitted to use their trip data, resulting in an incomplete overview of all trips going towards or coming from the city of Rotterdam. For most analyses, only trips starting in Rotterdam were taken into account to be able to compare different results. However, a dataset for trips starting in Schiedam was also available, which showed different results: 28% of trips starting at MT200 locations (23.5% for trips starting in Rotterdam). Moreover, almost 51% of trips starting in Schiedam end in the municipality of Rotterdam, suggesting an attraction for trips outside of Rotterdam as well.

Implications of survey sample representativeness

Public transit users are overrepresented in the sample (96.7% use PT at least sometimes), influencing the outcomes of the analyses by presumably overestimating the number of current multimodal trips, the importance of transfers to PT and the behavioural intention of making a future multimodal trip (Ton et al. 2020). The variables gender, age and migration background did also not correspond to the population of Rotterdam. When interpreting the results, one should take caution in generalising the results to the complete population. Where most studies claim age to be a significant predictor of mode choice of shared micromobility, the age category did not show to affect respondents' intention in this study (Böcker et al., 2020; de Witte et al., 2013). It might be possible that the underrepresentation of younger age groups has caused this effect. As presented by De Chardon (2019), shared mobility systems generally benefit privileged groups, making it interesting to see what typical non-users (i.e., older age, lower educated, non-Dutch migration background) think about the potential of the system (de Chardon, 2019). However, the survey sample only partly completes this goal since people with lower education levels and migration backgrounds are underrepresented, limiting the possibility to compare the survey sample to the population of Rotterdam. Between migration background and digital skills, no significant relationship has been found while this relationship is acknowledged in other studies (Durand et al., 2021). This might be caused by the fact that migration background is determined based on country of birth, while it might be better to include the background of the respondent's parents as well (Horjus, 2021). Increasing the number of surveys distributed at PT stations and their surrounding neighbourhoods might improve the survey's representativeness, but currently, the number of responses is too low (N = 43).

Link between spatial analysis and survey

As stated before, the trip data does not include a user profile thus lacking information on user characteristics. On the other hand, the survey's part on behavioural intention does not include questions on travel demand in general, only for currently shared e-moped and bike users. To overcome this discrepancy, the survey being distributed in the city of Rotterdam results in a user profile corresponding to the users within the trip dataset, making it possible to connect the two analyses for the current users of shared e-mopeds. With the current use of shared mobility being correlated with the intention to use it in the future, it can be said that almost 47% of trips of people intending to use a shared e-moped currently go towards social activities and 29% towards work or education locations. The spatio-temporal analysis shows that the largest share of trips goes towards the city centre. Here, many trips are related to PT because of the high density of the public transit network in this area. However, as suggested by the results of the user survey, this might be an overestimation due to the equally high density of social activities destinations in this area. Moreover, shared e-moped users also qualify as frequent PT users (52% of shared e-moped users often use PT), which might influence the overestimation of current PT-related trips in the spatial analysis as well as the future multimodal trip intention.

Additional research might be needed to more intricately link the characteristics of users with actual travel behaviour and trip destinations (Lazarus et al., 2020). Distribution of flyers at the potential mobility hubs would have provided a stronger link between the survey and current use, but the response rate at those locations is too low to ground conclusions on. A real connection between trip data and its users is therefore missing, which can be overcome by working together with shared e-moped providers, for instance by asking the survey questions right after a trip, i.e., combining the trip data with additional information like trip purpose, motivation and user characteristics. This would also allow for a better comparison of current PT locations. Furthermore, built environment characteristics could have been considered in the OLR models, allowing for better inclusion of mode choice factors within the conceptual model.

Generalisability of the study

The survey as well as the trip data, originate from Rotterdam and this study's results need to be seen within this context. Especially Dutch cycling culture as well as the Dutch policy on shared mobility (e.g., excluding e-scooters) differ from other countries (Ma et al., 2020). Further research should focus on the use of shared e-mopeds in other cities with a different, less dense public transportation system and another set of shared mobility options, possibly with other service models to be able to generalise the findings of this study.

Lastly, the dataset used for the analyses originates from September 2021, during the COVID-19 pandemic. The month of September has been selected since the amount of restriction on travel and daily life was the lowest; schools were opening up again, events could take place and social distancing would change from mandatory to strict advice at the end of September (Rijksoverheid, 2021). However, in the aftermath of COVID-19 restrictions, differences in travel behaviour are present due to widely introduced remote work options (Brough et al., 2021) and a lower frequency on the urban PT network of Rotterdam (RET, 2021), possibly increasing the attractiveness of individually shared e-mopeds. This also affects the results of the survey since respondents were asked about their travel behaviour in the past year. Both have an impact on the theoretical and practical implications of the study since actual future behaviour might be different.

6.2. Practical implications

Gu et al. (2019) stated that governments changed from a "*neutral-positive to a neutral-negative*" policy (Gu et al., 2019, p.144) on shared mobility due to the rapid expansion of the new industry, exposing a view that improved regulation of these innovative technologies is on its way to overcome negative side-effects (e.g., parking nuisance). This study shows that, when policies will partially ban the free-floating aspects of the systems, the effects might be two-folded, depending on spatial characteristics (Shaheen & Chan, 2016). On the one hand, offering shared e-mopeds at mobility hubs increases its connectivity with PT, which increases the intention to use the system. This could improve and increase access-egress trips, especially in areas with a low density of PT. On the other hand, docking systems offer less freedom and availability of the shared e-moped from users' origins, potentially decreasing the intention to use the system in multimodal PT trips, with users switching to walking, using a private bike, or back to using the car (van Marsbergen et al., 2022). Therefore, municipalities should investigate the implementation and impact locally, taking into account the built environment and (potential) user characteristics to pinpoint their policies.

In general, more people are willing to use the shared e-mopeds when offered at a mobility hub – behavioural intention percentages are found to be higher than current use – 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 (Lazarus et al., 2020). 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. In line with the findings of Arias-Molinares et al. (2021), it is recommended that PT operators and shared e-moped providers introduce partnerships and work together on better integration of both systems (Arias-Molinares et al., 2021). To make shared mobility available for everyone, people who are older, less educated and less frequent users of shared mobility should be taken into account. This group has dissimilar needs and wishes and a lower intention to use shared e-mopeds in the future. This group seems particularly interested in the facilities at the mobility hub, emphasizing the need for a higher level of physical integration to be able to include and introduce this group to shared micromobility. Additionally, shared e-moped providers should improve digital accessibility if they want to include this group of lower digitally skilled potential users.

6.3. Theoretical contribution

Shared micromobility is one of the main trends in transportation research (Liao & Correia, 2019). In this field, knowledge of the role of the free-floating shared e-moped system, as operated in the Netherlands, is underdeveloped. This research tried to cover this gap by investigating the role of the shared e-moped in the transportation system and its future potential as an urban transportation mode. Regarding the first, this research found that the shared e-moped, compared to shared bikes or e-scooters, is used on relatively longer trips, mostly to travel to social activities or to commute to work or school. Both the spatial analysis as well as the survey results – although the user sample was relatively low – suggested that the free-floating shared e-mopeds compete with buses and trams and are used as access/egress to metro and train, contributing to a better understanding of the shared e-moped's role in the mode choice set.

Existing literature summarized shared mobility users as *young urban professionals* (Howe, 2018, p.21) and this is no different for shared e-moped users in Rotterdam. Additionally, this research found that the current shared e-moped user mostly values the easy access to the e-moped, caused by its free-floating characteristics. Furthermore, potential future use was mainly explained by similar factors, emphasizing that current users adopt the use of the shared e-moped because of the moped itself and not due to the facilities of the mobility hub. The integration of shared mobility with PT is, in line with current literature (e.g., Coenegrachts et al., 2021; Martin & Shaheen, 2014), confirmed to be a key factor for behavioural intention. These insights provide a promising area for future research, as it might be that the mobility hub integration becomes more important when schemes change to docked formats.

Of all significant variables, the social influence of others (related to subjective norms) was found to be the most influencing predictor (β = -1.771, p = 0.002 for the disagree category), which is an interesting result. Van Veldhoven et al. (2022) also found a strong effect of subjective norm, but most studies find a smaller effect size (Kopplin et al., 2021; van Veldhoven et al., 2022). Interestingly, most multimodal trip variables from the conceptual model did not show to be significant predictors of behavioural intention to use the shared e-moped. Especially factors related to physical and digital integration at the mobility hub itself were not found to be significant predictors, while literature agrees that this integration is key to increasing the number of multimodal trips (Geurs et al., 2022).

For current users of both shared mobility and PT – which were overrepresented in this study - digital and physical integration might not be as important as for current non-users, since the current users already know how the systems work and are, assumably, satisfied with the situation. Another explanation is the possibility that the survey setup has skewed the answers on the multimodal trip characteristics since the questions were focused on the importance, influencing the respondents in positively skewing the outcomes (Nemoto & Beglar, 2014). The used UTAUT framework in combination with a survey is mostly used for already existing systems (instead of a future scenario), making the constructs of performance and effort expectancy more applicable for respondents than in this study (Horjus, 2021; Jahanshahi et al., 2020).

6.4. Recommendations for further research

Based on the limitations and implications of this study, recommendations for further research can be made. First of all, a more extensive survey among shared e-moped users, integrated with their trip data, could reveal the actual trip purpose and provide a better estimation of the mode substitution and competition with PT. Future research should also clearly focus on real-life cases including the actual layout and integration at a mobility hub, using pilot studies or a stated choice setup, to obtain a better understanding of actual behaviour and usage. Furthermore, the strong relationship between digital skills and behavioural intention suggests the need for improving digital accessibility and equity for non-users. Further research is needed to find out how the group of current non-users and non-intenders can be reached.

Policymakers, among which the municipality of Rotterdam, are working towards a more regulated docking policy for shared e-mopeds to overcome, for instance, parking nuisance (Municipality of Rotterdam, 2021b). With a change toward more restrictive service models (e.g., docking zones instead of free-floating), it is interesting for future research to study the same city and providers within this new system to see what changes in practice. Future research could also focus more on specific locations within the city, to study travel behaviour on a smaller scale or by linking shared e-moped trips with PT travel departure times to get a better understanding of integration. In this way, spatial factors can be included in the conceptual models more easily, taking into account important built environment characteristics. In addition, focusing on specific locations with socially excluded groups might show different needs and explanatory variables for behavioural intention.

7. Conclusion

This study has investigated the role of the shared e-moped within the transportation system of Rotterdam and the intention to use the shared e-moped at a mobility hub, based on a trip data analysis (~347.000 trips) and survey (N = 431). By combing both the current use of the free-floating shared e-mopeds and its future potential at mobility hubs, this study gives a broad overview of shared e-moped use and fulfils the research goal to *analyse the spatio-temporal usage patterns and explain how physical/digital integration affects the (potential) use of free-floating shared e-mopeds at mobility hubs*.

Currently, shared e-moped use is partly integrated with locations of potential mobility hubs (i.e., locations offering shared mobility as well as public transportation). Sometimes this integration might be caused by providers geofencing the service area but generally, the integration is focused on larger PT stations with high connectivity to the metro and train network. The metro and train are most frequently mentioned as complementary PT modes, while the bus and tram are primarily substituted by the shared e-moped. This might be caused by the fast and direct travel possibilities that the free-floating shared e-mopeds have over the bus and tram. Results from both the spatial analysis and the survey suggest that shared e-mopeds currently have a role as first or last-mile mode, however, they also replace a large share of trips previously performed by active or public modes of transport. This endorses the fact that there is a potential for the shared e-moped to improve the connectivity of the PT network as a whole, especially in areas where bus or tram services are limited because it is appreciated as a faster and more flexible option.

When the integration of shared e-mopeds at mobility hubs would be improved upon, by offering improved physical and digital integration, 16.3% of respondents intend to use the shared e-moped, while currently, only 5.5% of respondents use an e-moped. This study has found that this higher share of behavioural intention is caused by several explanatory factors, with factors regarding the supply of the shared e-moped being one of the most important ones. 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. Mobility hub integration factors themselves not explaining the use of the shared e-moped, might be justified by the fact that a large share of e-moped trips is not related to PT, and thus not to potential mobility hubs, at all. 58% of trips do not start nor end near PT locations and 55% of users stated that they did not use the shared e-moped in a multimodal trip with PT, emphasizing that integration with PT is not necessary for those trips. 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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