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Effectiveness of traffic signs to prevent fly parking

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ABSTRACT

As bicycle use increases, so does the need for formal parking spaces to safely store them while performing other activities at a destination. In the Netherlands, several municipalities have created indoor and outdoor formal parking spaces, which remain underutilised. Instead, many cyclists choose to 'fly park', i.e. informally lock their bicycle to objects on the street. This can cause dangerous situations or inconvenience, for example by blocking sidewalks. The discrepancy between the use of formal and informal parking spaces may be attributed to a lack of information provided to cyclists about the available formal parking options. This study investigated the effectiveness of different traffic sign designs in encouraging the use of formal parking spaces. The designs were developed within this research with the intention of capturing different communication strategies, namely hazardous, neutral educative and negative educative. A stated preference choice experiment was then performed to allow the comparison of the effectiveness of the different designs, and thus communication strategies. The responses were analysed using discrete choice modelling. According to the results, traffic signs alerting users to the fact that controls are performed (hazardous communication) are the most effective in the fly parking prevention, especially for frequent bicycle users.

1. Introduction

Bicycle use is increasing worldwide, as it is being promoted by governments all over the world (Pucher and Buehler, 2017), and that increase creates the need to provide attractive bicycle parking facilities with sufficient capacity. This need stems from the fact that bicycles remain parked for most of the day. Private owners and companies typically create these facilities within the surroundings of their own house and their company respectively. In city centres, the municipality is responsible for attractive facilities with sufficient capacity to accommodate the bicycles of visitors of the city centre, while keeping the city centre attractive and liveable. In the Netherlands, several municipalities have created indoor and outdoor parking facilities, which are henceforth referred to as 'formal' parking spaces. These facilities, however, are found to be underutilised. Instead, many cyclists choose to 'fly park', which is informal parking where bicycles are locked to objects on the street citepgamman2004. This implies that bicycles are often haphazardly parked in city centres, causing for example inconvenience by blocking sidewalks (Van der Spek and Scheltema, 2015). More background on these parking options can be found in Section 2.1.

The discrepancy between the use of formal and informal parking spaces may be reduced when information is provided to cyclists about the available formal parking options (Gamman et al., 2004). To encourage the use of formal parking spaces, an effective way of communicating about the presence of these options should to be implemented. Traffic signs placed along the street are the most common form of communication in traffic. The visual design and message displayed on the signs requires further exploration, so that the most effective one can be identified.

A contribution of this research is the design of new traffic signs that communicate information about the parking facilities. This research further focuses on investigating the effectiveness of the proposed traffic sign designs to reduce fly parking and to encourage the use of formal parking spaces. This is done by means of a stated preference experiment and the development of discrete choice models.

The paper is structured as follows. Section 2 provides background information on the bicycle parking options and choice factors, as well as on types of communication. Section 3 describes the methodology used to perform this research. In Section 4 the results of the data collection and processing are presented. Finally, in Section 5 conclusions are drawn and recommendations for future research are made.

2. Background

In this section, literature is reviewed to provide background information on the different bicycle parking options and causes of fly parking (Section 2.1). Moreover, factors affecting the parking behaviour of cyclists are identified to guide the selection of factors to be included in

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(a) Outdoor parking on racks (Van Andel 2022).

(b) Outdoor parking within a designated area without racks (Van Andel 2022).

(c) Indoor parking with and without racks (Biesieklette Holding B.V. 2024).

Fig. 1. Formal parking examples (Van Andel, 2022; Biesieklette Holding B.V., 2024).

(a) Bicycles locked on bridge railing.

(b) Bicycles locked on trees.

(c) Bicycles parked on sidewalk.

Fig. 2. Fly parking examples (Van Andel, 2022).

this research (Section 2.2). In Section 2.3, the aspects of information are discussed to set the foundations for the traffic sign design.

2.1. Bicycle parking options

In city centres, municipalities are implementing different types of formal bicycle parking facilities. Some examples of types appearing in the Netherlands are illustrated in Fig. 1, while the reader is redirected to the work of Gamman et al. (2004) for examples in other countries. In the figures different types of racks can be seen, but also a designated area without racks where bicycles can be parked with a chain- or bike-lock.

When the provided options are not at the location that users would consider ideal (i.e. optimum proximity to their destination), they choose to fly park instead (Gamman et al., 2004). Another term encountered in literature for this phenomenon is 'wild parking' (Van der Spek and Scheltema, 2015). Some examples of fly parking are depicted in Fig. 2. As can be seen in the pictures, in some cases bicycles are secured to street furniture not intended for that purpose and in other cases they are just left on the sidewalk with a chain- or bike-lock. The latter is also referred to as a 'locking-light' extension of fly parking, which is convenient for short trips to further reduce the required time for the trip (Larsen, 2017).

The location of a formal parking facility is not the only reason found in literature that keeps the facilities underutilised. Another reason is the ability of the facility to provide security through guards or surveillance (Gamman et al., 2004). Moreover, it is found that once fly parking is prevalent, it becomes the norm (Fujii et al., 2002; Abou-Zeid et al., 2013). Last but not least, fly parking occurs when the demand for parking is higher than the provided capacity at the formal parking options (Nakamura and Abe, 2014).

2.2. Bicycle parking choice factors

Previous studies have investigated the factors that influence bicycle parking behaviour. The findings indicate that this behaviour is affected by characteristics of the facility, of the trip and of the users.

Starting with the facility, its location should be within 50 m from the destination to be effectively used (Department of the Environment, Transport and the Regions, 1997), but cyclists are willing to walk a bit further to reach a facility of higher quality (Molin and Maat, 2014). Next to quality, cyclists also value cost (Van der Spek and Scheltema, 2015) and have a preference for free storage (Molin and Maat, 2014; Fournier et al., 2023). A reason that was already mentioned as a cause for fly parking is the lack of sufficient security. Cyclists have a preference for facilities where surveillance is present and the type of surveillance might play a role as well (Molin and Maat, 2014; Arbis et al., 2016; Yuan et al., 2017). Moreover, cyclists appreciate sheltered facilities (Yuan et al., 2017) that are organised and where availability of an empty space is easy to identify (Van der Spek and Scheltema, 2015; Yuan et al., 2017).

Regarding the trip characteristics, the purpose and length of the trip are important (Heinen and Buehler, 2019). Another influencing factor is the duration of stay (Rietveld and Daniel, 2004; Majumdar and Mitra, 2015). If people are planning to keep the bicycle parked for a longer period of time, they are often willing to walk a bit further from the parking facility to their destination, provided that they can park in a safer, or higher quality facility.

With respect to the user characteristics, it has been found that women place a greater emphasis on feeling safe when choosing a parking space compared to men and take less risks (Rietveld and Daniel, 2004; Majumdar and Mitra, 2015). Age is another factor that can influence behaviour. On the one hand, younger people tend to make a higher proportion of trips by bicycle compared to other age groups, possibly because they have less access to alternative modes of transportation and are therefore dependent on their bicycles (Rietveld

and Daniel, 2004). On the other hand, younger people may also be more likely to engage in unlawful behaviour, such as illegally parking their bicycles (Kaplan et al., 2018). In addition to that, older people may have more routine behaviour and a greater need for clarity, which could make it harder for them to change their behaviour (Rietveld and Daniel, 2004). The type, and more implicitly the cost of the bicycle, also plays a role, as research has indicated that people may treat the parking of these more expensive bicycles differently (Van der Spek and Scheltema, 2015; Larsen, 2017; Heinen and Buehler, 2019; Egan et al., 2022). Last but not least, the frequency of parking is also a contributing factor (Heinen and Buehler, 2019). Frequent users could have more of a routine in parking behaviour, which is harder to change, but at the same time they might also be more dependent on their bicycle, making them more careful in their parking choices.

2.3. Aspects of information

According to Van Erp (2007) there are three aspects of information: semantics (i.e. the content), syntax (i.e. the way it is expressed) and pragmatics (i.e. its effect on the receiver's behaviour). Within our research, traffic signs have already been determined as the syntax. The pragmatics is what our research aims to investigate. What remains to be identified is the semantics. Van Erp (2007) has identified three categories of semantics in relation to the enforcement of policies:

1. Educative Communication: Explanation of current or new regulations while letting people make their own decisions. The information should be presented to people who can change the behaviour in response to these regulations (Magat and Viscusi, 1992). The expected behavioural change should be easy and not interfere with people's daily routines (Goldenbeld and Wisman, 2004). Van Erp (2007) concluded that educative communication can make people reconsider their position, but if a negative attitude towards the policy already exists, just presenting information will probably not make people change their behaviour.
2. Hazardous or Threatening Communication: Threatening with legal action such as sanctions or fines, or making people fear the consequences for themselves. Utilisation of fear-inducing communication strategies is often employed in situations where potential health concerns are present and research suggests that this application of the communication method is ineffective (Peters et al., 2014). Contrary to that, threatening with sanctions is found to be effective, especially when people feel the chances of getting caught for an offence are higher (Klepper and Nagin, 1989). This can be achieved by indicating that checks will be held. Of course, some checks should also actually be held, otherwise the effect will disappear over time (Van Erp, 2007).
3. Normative Communication: Making people aware of social norms and the legitimacy of regulations. Many individuals comply with rules and regulations not solely due to the threat of punishment, but also due to certain norms and values. Social norms involve people relating their behaviour to what others, who they consider equals, would do. Research shows that making people aware of the behaviour of the majority can make them more likely to follow rules as well (Peters et al., 2013).

Another category that is encountered in literature is 'persuasive communication', which according to Van Erp (2007) is a combination of hazardous and normative communication. All these identified categories will henceforth be referred to as 'communication strategies'.

Over the past years, municipalities have attempted to communicate the presence of new parking facilities by means of posters or traffic signs. Some examples are illustrated in Fig. 3. These signs make use of the educative communication strategy, providing route guidance to the facility and, if possible, real-time information on the availability of spaces within the facility. As previous research has shown that persuasive communication strategies are more effective than educative communication strategies (Delaney et al., 2004), it is worthwhile to investigate more designs that adopt different communication strategies.

3. Method

The method used to perform this research consists of three consecutive steps. In the first step, the different designs of traffic signs need to be created, as they form the basis for the remainder of the research. Next, a data collection procedure is set up to gain insights into the understanding and preferences of potential users for the proposed designs. The last step is to process the collected data in a way that the results can be extrapolated and generalised. Each of these steps is further explained in the corresponding subsection of this section.

3.1. Traffic sign designs

As already explained, new traffic sign designs had to be created for this research that should communicate information about parking facilities. This is done based on existing traffic signs to ensure familiarity, which in turn leads to higher effectiveness (Ng and Chan, 2008; Ou and Liu, 2012; Zhang and Chan, 2013). Moreover, different strategies to convey information have been selected for testing in Section 2.3.

The goal of this research is to investigate how people could be moved away from fly parking towards the formal options through communication. So, all traffic sign designs should either encourage the use of the formal parking options or discourage the use of fly parking.

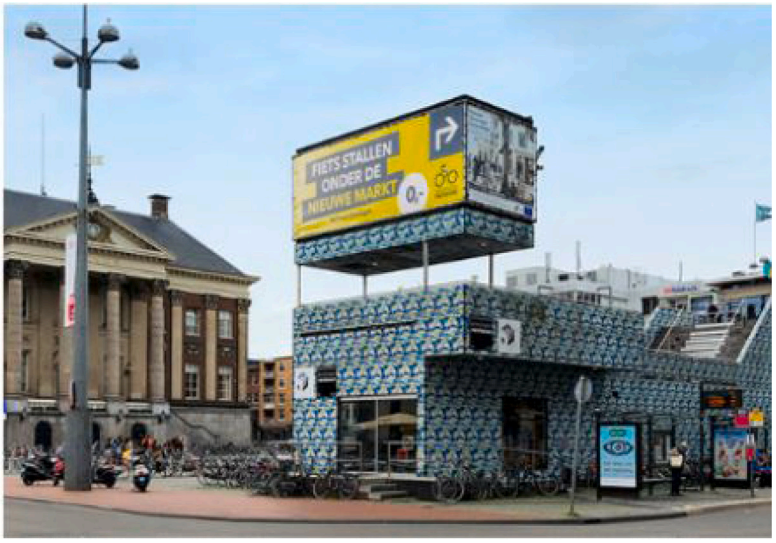
Based on the educative strategy, two designs are proposed. One represents a 'neutral' educative sign that simply informs participants of possible parking options, directing them to formal indoor and outdoor parking spaces, and the other represents a 'negative' educative sign that informs cyclists about the fact that fly parking is forbidden.

When designing the neutral educative sign, the information that should be communicated is (i) the fact that there is a parking facility, which is typically done with the letter 'P'; (ii) the mode for which the facility is suited, which can be indicated by using a bicycle image; (iii) the direction towards which the parking can be found using an arrow; (iv) the distance between the sign and the facility, and lastly; (v) the type of parking, which for indoor facilities is denoted with a roof over the bicycle and in case of outdoor spaces is indicated with a bicycle rack. An example for the resulting design for indoor and outdoor facilities is depicted in Figs. 4(a) and 4(b), respectively.

The negative educative design should convey the information that the parking action on street furniture is forbidden. A sign prohibiting parking exists for car traffic, as well as in a variant that specifically addresses bicycles and scooters when they should not be parked in a certain area. In the new design, the focus should be on fly parking and not in the area as a whole. This is done by adding a tree and lamppost with a bike placed against it (Fig. 5). These two types of street furniture were chosen as they should be identifiable, even from a distance, and cover most of the fly parking options in the city centre. When the traffic sign conveys information that fly parking is prohibited in the entire city centre (and not only where the sign is placed), the word 'zone' is added under the designed sign. This is in line with the sign convention in the Netherlands, which uses the word 'zone' to indicate that a certain policy applies to an entire area. To indicate that the traffic signs no longer apply to a certain area, the same sign is displayed in grey tones with stripes through it, denoting the end of the zone. The latter is not incorporated in this study, as only areas where fly parking is prohibited are of interest.

The hazardous communication strategy should go a step beyond simply informing that fly parking is prohibited, by involving threats of legal actions or sanctions that will be deployed. As basis for the design of this traffic sign, an existing sign is used that warns cars will be removed if they are parked such that a driveway is blocked. This

(a) Parking tip by municipality of Groningen, guiding cyclists to two closed parking facilities (Bulder 2022).



(b) Bicycle parking facility promotion in Groningen, showing the facility is to the right under the New Market square and free of charge (Bulder 2022).

(c) Dynamic parking availability signs piloted by the municipality of Utrecht (Municipality of Utrecht 2018).

(d) Static route signs guiding to a parking facility in the municipality of Utrecht (Municipality of Utrecht 2018).

Fig. 3. Existing bicycle parking sign examples (Bulder, 2022; Municipality of Utrecht, 2018).

(a) Sign for an indoor facility 50 m away from the sign after making a right turn.

(b) Sign for an outdoor facility 100 m downstream from the sign and on the same road as the sign.

Fig. 4. Proposed traffic sign design based on neutral educative communication strategy for formal parking facilities.

Fig. 5. Proposed traffic sign design based on negative educative communication strategy.

Fig. 6. Proposed traffic sign design based on hazardous communication strategy.

existing sign includes a forbidden to park sign, which for this research is replaced by the negative educative communication design. The sign should also alert people about the fact that checks are conducted and incorrectly parked bicycles are removed, indicated with the Dutch word 'Controle'. The removal is communicated by replacing the car that is being towed away in the original sign with a bicycle being towed away in case of violation of the prohibition. The final design is depicted in Fig. 6.

The third communication strategy is normative communication, which should make cyclists aware of how the majority of other cyclists park their bicycles. For this strategy to work, there are two conditions: (i) the regulations should feel legitimate, which means that enough formal bicycle parking spaces should be provided when fly parking is made illegal, and (ii) the majority of cyclists makes use of these formal spaces. A sign based on this strategy would need to communicate the norm of how others behave when parking their bicycles, while not being overruled by the actual situation at the bicycle parking. A study on bicycle parking around stations found that an individual's choice of parking strongly depends on the decisions made by others before them (Fujii, 2005), which means that observing the situation will give more information than a sign with historical data on how users generally behave. One design concept to capture this communication strategy can be found in Fig. 7. This design will not be investigated further, as its feasibility is hard to guarantee for two reasons. The first reason is that sensors would have to be developed and installed to map the shares of formally and informally parked bicycles, and then update in real-time the share of the red and the green in the pie chart. The second reason is that such information could backfire, as a higher share of informally parked bicycles would suggest to new users that this is the right behaviour to follow.

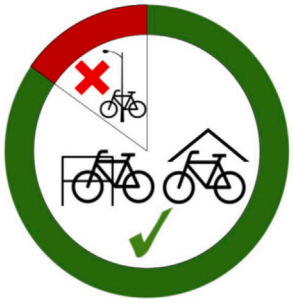


Fig. 7. Proposed traffic sign design based on normative communication strategy.

In conclusion, three traffic sign designs are proposed and evaluated in this research. Two reflect educative communication and one reflects hazardous communication. Educative communication can be neutral, presenting information about formal parking options (Fig. 4(a) in case of indoor facilities and Fig. 4(b) in case of outdoor facilities), or negative (Fig. 5), indicating that fly parking is forbidden in a specific area. Hazardous communication also indicates that fly parking is forbidden and, more importantly, alerts cyclists that controls are conducted and incorrectly parked bicycles are removed (Fig. 6).

3.2. Data collection set-up

In order to collect data on the preferences of potential users, a stated preference choice experiment is conducted using an online survey. This data collection method is chosen because the research concerns hypothetical traffic situations, as the signs are not yet placed along any cycling route, and because the online survey can reach a wide range and large amount of respondents.

Since the traffic sign designs are new, the first part of the survey addresses whether people notice the signs and whether they correctly interpret their meaning. Respondents have to watch a short video clip, shown from the viewpoint of a cyclist cycling through the city centre. This video clip contains several traffic signs, both existing and new, and respondents are instructed to look for a parking space within the video. After watching the clip, they have to indicate which traffic signs, out of a list, they noticed in the video clip. Moreover, they were asked to interpret the meaning of the new signs. This 'quiz' is followed by a short explanation of the true meaning of the new signs to ensure that all respondents have the same, intended understanding of the signs.

In the next part of the survey, the choice experiment is performed. Participants are presented with images of 12 scenarios (trade-offs), each showing different parking options (formal indoor parking, formal outdoor parking and fly parking) and different traffic signs. An example of such a trade-off is displayed in Fig. 8, where people were asked to select the location where they would park their bike by choosing among A, B, C and D given that their intended destination is at the location of the yellow box.

In some scenarios, a reference case with no traffic signs, and thus no communication, is used. The images are created as realistically as possible avoiding excessive information that could overwhelm the respondents. The scenarios also test several other factors influencing parking behaviour identified from literature. More specifically, the walking distance from the location of the sign to the parking facility is chosen to be communicated to the users, so that the distance itself as well as the appreciation for having it communicated can be assessed. The preference for a sheltered facility is also evaluated, by comparing the indoor (i.e. sheltered) and outdoor parking facilities. The duration of stay is chosen to be investigated, as well as all the user and bicycle characteristics found in literature. Parking at a facility is free of charge and availability is always assumed. Moreover, the trip purpose is fixed as 'leisure' because that is the main reason to go to the city centre of

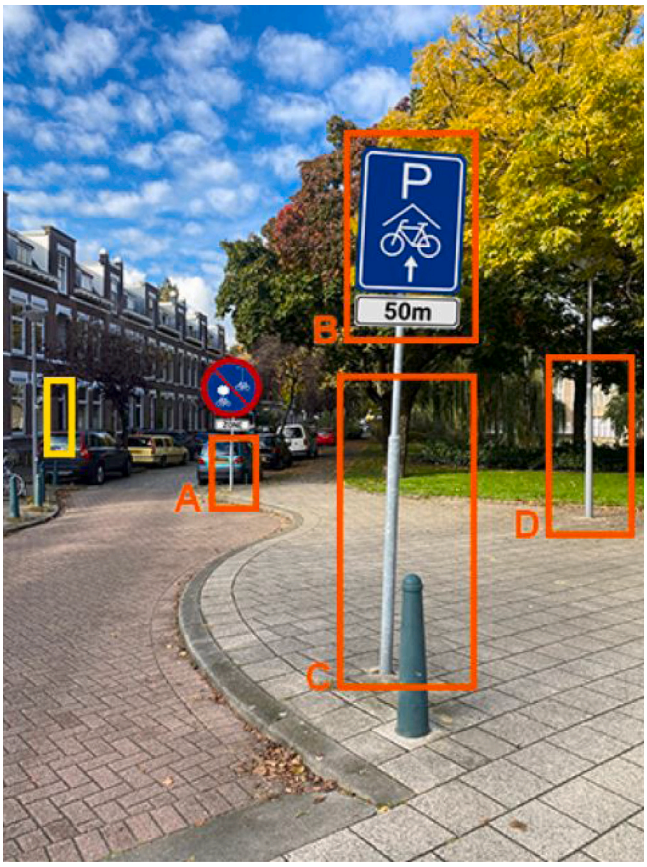


Fig. 8. Example of a trade-off provided in the stated choice experiment.

Table 1
Overview of factor values being investigated.

	Formal inside	Formal outside	Informal
Duration [h]	{⟨0.5, ⟩2}	{⟨0.5, ⟩2}	{⟨0.5, ⟩2}
Walking distance [m]	{50, 100, 150}	{0, 50, 100}	{0, 25}
Communication	Neutral	Neutral	Negative, Hazardous

Delft and use the parking facilities of the municipality. An overview of the values of the factors that vary in the different scenarios is shown in Table 1. For more information on the survey questions the reader is redirected to Holster (2023).

3.3. Data processing

In order to process the collected responses, descriptive statistics and modelling are employed. The former is used to gain insights into the characteristics of the sample, and to investigate the understanding of the proposed traffic sign designs. Chi-square tests are performed to check the presence of a relation between the different socio-demographic groups and the parking choices.

Discrete choice models are developed to quantify the magnitude of the different influencing factors based on the choices respondents made in the stated choice experiment. Random utility maximisation is the adopted principle, as it is most often used in transport (Heinen and Buehler, 2019; Ben-Akiva and Bierlaire, 1999) and has also been applied in research on bicycle parking (Gavriilidou et al., 2020). The underlying assumption for this is that travellers exhibit rational behaviour and possess clearly defined preferences. The choice set consists of three alternatives, namely (i) indoor formal parking spaces, (ii) outdoor formal parking spaces and (iii) fly parking.

Table 2
Socio-demographic characteristics of respondents and Dutch population.

	Respondents		Population
	Count	%	%
Gender			
Female	135	50.2	50.3
Male	131	48.7	49.7
Other/not indicated	3	1.1	–
Age (years)			
Under 20	2	0.7	21.1
20–39	183	68.0	25.9
40–64	75	27.9	32.8
65–79	8	3.0	15.3
80 or older	1	0.4	4.9

A base multinomial logit (MNL) model is first estimated, which is further enhanced by interaction terms for the different socio-demographic groups. Using a forward stepwise method, the best fitting MNL model is constructed. The next step is to consider a nested structure (nested logit - NL model), due to the fact that there is a dependence in the formal parking choice alternatives. The last advancement in the model is implemented by correcting for the fact that the same respondent provided several answers that might be linked to each other. This is done by estimating a mixed logit (ML) model that considers panel effects.

4. Results

The survey was distributed in February 2023 and resulted in 269 complete responses. These responses are analysed in this section. First, the sample is introduced, followed by a discussion of the understandability of the designed traffic signs. Finally, the outcome of the best performing model is presented and explained.

4.1. Sample characteristics

The socio-demographic characteristics collected in the survey are presented in Table 2, along with their values in the entire Dutch population gathered through Dutch publicly open population statistics (CBS, 2024).

When comparing the shares in the population with those in the sample, it is found that only the gender is sufficiently captured. The group of individuals in the age group of 20 to 40 years is over-represented, while the older groups and people under 20 are under-represented (less than 10 respondents for ages under 20 and above 65).

To investigate the effect of age in the rest of the research, the categories are regrouped into two categories to have a balanced group size. The ‘young’ group consists of 156 respondents aged under 30 years. The other age group consists of respondents aged 30 years or older.

Next to these socio-demographic characteristics, data were collected on the price of the most frequently used bicycle and frequency of use. These sample characteristics cannot be compared to the entire population, since no data on this is publicly and nationally available.

The price ranges with highest representation were cheap or second hand bicycles for less than €300 (47% of the respondents) and solid or quite new bicycles for €300 to €1500 (24% of the respondents). Two groups are created based on this, cyclists with an ‘expensive’ bicycle for a price higher than €300 or of high emotional value, and cyclists with a ‘cheap’ bicycle that costs less than €300 or could break down any moment. Persons using a rental bicycle are not investigated further, as there were only 11 respondents that selected this option.

Regarding the frequency of bicycle use, three categories are created: (i) infrequent users (17% of the respondents), i.e. bicycle is never used or 1 time per month or less, (ii) frequent users (63% of the respondents), i.e. bicycle is used more than once per week, and (iii) in-between users (20% of the respondents).

Table 3
Estimated parameters for the parking choice model.

Coefficient name	Coefficient value	Robust standard error	Robust t-test	Robust *p*-value
ASC_{inside}	1.84	0.11	8.05	0.00
$ASC_{outside}$	1.57	0.10	15.67	0.00
$\beta_{hazardous}$	−2.66	0.20	−13.52	0.00
$\beta_{hazardous\ x\ infrequent}$	1.09	0.33	3.32	0.00
$\beta_{negative}$	−1.66	0.22	−7.55	0.00
$\beta_{neutral}$	−2.91	0.24	−11.95	0.00
$\beta_{neutral\ x\ expensive\ x\ outside}$	−0.38	0.17	−2.21	0.03
$\beta_{neutral\ x\ infrequent}$	1.00	0.31	3.19	0.00
$\beta_{neutral\ x\ young\ x\ inside}$	−0.24	0.10	−2.33	0.02
$\beta_{none\ x\ expensive\ x\ fly}$	−0.74	0.22	−3.36	0.00
$\beta_{Long\ x\ inside}$	−3.34	0.29	−11.53	0.00
$\beta_{Long\ x\ fly}$	−2.40	0.26	−9.24	0.00
β_{Rack}	2.49	0.14	17.42	0.00
$\beta_{WD\ x\ outside}$	−0.03	0.00	−10.23	0.00
$\beta_{WD\ x\ fly}$	0.89	0.22	4.08	0.00
$\beta_{young\ x\ inside}$	−0.24	0.10	−2.33	0.02
σ_{panel}	−1.39	0.12	−12.04	0.00

4.2. Understandability of new traffic signs

The analyses pertaining to the video clips showed that respondents generally had a good understanding of the meaning of the new traffic sign designs. This is an encouraging finding for the usability of the proposed designs.

However, only 6.3% of the respondents correctly identified which signs were present in the video clip. This could be attributed to the instructions given to them, which did not raise a need to check the signs, and the lack of anticipation of parking signs along the bicycle path.

4.3. Discrete choice models

The best performing MNL model contains interaction terms between the socio-demographic characteristics and the communication strategies, indicating that the different groups have a different response or sensitivity towards the type of communication being used. This model is further tested for the presence of a nested structure, but the NL model results show that the two formal parking options are seen as independent by the respondents.

The choice set without this nest is thus further used for the estimation of the ML model. In this model, the coefficients of the best performing MNL model are included, along with an extra parameter (σ_{panel}) that corrects the bias of the multiple choice responses collected by the same person. This ML model is overall the best performing model.

The estimated values of the coefficients of this ML model are shown in Table 3, along with their robust statistics. The model consists of 17 parameters.

Based on these coefficient values, the final utility functions for the three parking options are formulated as follows:

$$U_{inside} = 1.84 - 3.34 \cdot (Long) + 2.49 \cdot (Rack) - 0.24 \cdot (Young) + (Neutral) \cdot \left(1.00 \cdot (Infrequent) - 0.24 \cdot (Young) - 2.91\right) + X$$

$$U_{outside} = 1.57 + 2.49 \cdot (Rack) - 0.03 \cdot (WD) + (Neutral) \cdot \left(1.00 \cdot (Infrequent) - 0.38 \cdot (Expensive) - 2.91\right) + X$$

$$U_{fly\ parking} = -2.4 \cdot (Long) + 0.89 \cdot (WD) - 0.74 \cdot \left((None) \cdot (Expensive)\right) - 1.66 \cdot (Negative) + (Hazardous) \cdot \left(1.09 \cdot (Infrequent) - 2.66\right)$$

where X is drawn from a normal distribution $N(0, 1.39^2)$.

The alternative specific constants (ASCs) indicate that the inside and outside parking facilities are preferred over the fly parking, as both coefficient values are positive and fly parking has been taken as the reference parking option in the model development.

Moreover, it is found that all types of communication reduce the attractiveness of parking options addressed by the corresponding communication. Hazardous and negative educative communication only apply in relation to fly parking, and as expected, both show a negative effect ($\beta_{hazardous} = -2.66$ and $\beta_{negative} = -1.66$ respectively). This means that both strategies manage to discourage users from parking at street furniture, with hazardous communication being more effective as it has a higher negative value. Another intuitive finding is that infrequent bicycle users feel less threatened by the hazardous communication, as for them the effect is $1.09 - 2.66 = -1.57$, which is similar to the effect of the negative educative communication.

For neutral educative communication, the negative effect is in line with literature findings (Van Erp, 2007), and implies that presenting no communication on the parking options works better than presenting neutral educative communication. This result could, however, also be interpreted as follows: it is not the type of communication that has a negative impact, but the information of the distance shown on the sign that people deem too far. This communication type is appreciated by infrequent users ($\beta_{neutral\ x\ infrequent} = +1$), while it is even less valued by users of expensive bicycles when the information leads to outside formal parking facilities ($\beta_{neutral\ x\ expensive\ x\ outside} = -0.38$). Apparently the users do not consider those parking spaces safe and thus disregard the information. The information is also disregarded by young users when leading to inside parking spaces ($\beta_{neutral\ x\ young\ x\ inside} = -0.24$). This age group seems to have a negative perception of inside parking facilities in general ($\beta_{young\ x\ inside} = -0.24$).

When no communication is present, users of expensive bicycles still seem to avoid fly parking ($\beta_{none\ x\ expensive\ x\ fly} = -0.74$), which is an intuitive finding.

Besides the effect of communication types on the parking choices, other factors are also found to be of influence. Firstly, users have a preference for inside parking spaces compared to outside options. An unexpected result is that this trend reverses when the duration of the parking is longer than 2 h. In that case, people are more likely to choose outside formal parking options. One possible explanation for this is that the pictures for the scenarios were different in the short and long stay situations, so the preference for outside parking could be associated with the parking options provided in those pictures.

Another factor that influences the parking choices is the walking distance between the sign and the parking spaces. People are slightly less likely to walk as far for a formal outside parking space compared to a formal inside parking space ($\beta_{WD\ x\ outside} = -0.03$). However, people are willing to walk towards a fly parking space that is a bit further away yet visible in the image ($\beta_{WD\ x\ fly} = +0.89$), which means that this finding only holds for very small walking distance.

5. Conclusions

In this section, the main findings of the research are summarised, leading to recommendations for practice. The assumptions and limitations of the current research are then discussed, followed by recommendations for future research.

5.1. Main findings

Based on the survey results and estimated models, it is concluded that traffic signs using hazardous communication are the most effective in discouraging cyclists from parking at street furniture, and opting for formal parking facilities instead. A sign employing this strategy is depicted in Fig. 6. It alerts cyclists that fly parking is prohibited, controls are performed and fly parked bicycles are towed away.

Simply informing that fly parking is prohibited (negative educative communication strategy) also reduces the phenomenon, but to a lesser extent. Municipalities that are facing issues with bicycles parked outside of the intended parking facilities should place signs that state "fly parking is prohibited", and, if their budget allows, warn and perform controls.

Another finding is that infrequent cyclists are less alarmed by these warnings, which does not need special attention as their infrequent use also implies that their parking behaviour is less frequently encountered. A user group that could benefit from special attention is the group of cyclists younger than 30 years. Contrary to findings in literature and the older age group, younger cyclists are negatively predisposed towards indoor parking facilities. The reasons behind this should be further investigated and, if necessary, corrected by campaigns or education on the value parking at indoor facilities.

Regarding the understandability of the proposed designs, it is concluded that the signs are well understood but poorly noticed on the side of the road. This means that users understand the message intended by the sign, but extra efforts are required to make cyclists aware of these traffic signs along the bicycle path.

5.2. Discussion

Even though the findings are in line with expectations based on previous research, the survey methods might have introduced some bias in the results (i.e. magnitude of estimated parameters). One source of bias is the choice of visuals for the different scenarios. In order to prevent repetition and distraction of the respondents, each scenario was implemented on a different real-world base photo. Any information depicted on these photos and not explicitly included in the model could have influenced the choice of the respondents. One example is that no fly parking was presented in the photos, which prevented a norm to be set and might have led to an underestimation of the extent of fly parking.

Besides that, the use of photos is in itself not ideal for decisions that are taken by a cyclist en route. A different method that allows immersion into a real traffic environment by means of video recordings or virtual reality, for example, could capture this choice behaviour more realistically. Familiarity with the situation is also ignored, while it could have an effect for frequent users. Furthermore, the sampled population creates some bias in the results, as the groups of adolescents and elderly are too small to be separately investigated.

Last but not least, it should be kept in mind that traffic signs are one way of nudging cyclists to the intended parking behaviour, but they are not sufficient on their own. For example, if the sign warns for controls and towing of fly parked bicycles, then controls should actually take place from time to time. Moreover, the formal parking facilities should match the user preferences as indicated by previous research as well as our model results (for instance location of the facility and sheltering of the parked bicycles).

CRediT authorship contribution statement

Alexandra Gavriilidou: Writing – original draft, Methodology, Conceptualization. **Rolien Holster:** Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Winnie Daamen:** Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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