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Intersection based innovations and cyclists' route choice decisions in urban areas

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ABSTRACT

This paper presents the background, setup, and results of a stated choice experiment investigating the influence of three different intersection based innovations on cyclists' route choice decisions. Next to commonly used route attributes, the following three intersection based innovations were investigated: 'Flo', a bicycle speed advice tool; 'Schwung', a bicycle - traffic light communication tool; and 'BikeScout', an intersection flashing system. The generated stated choice experiment was included in an online questionnaire that was filled out by 608 respondents who evaluated in total 3648 choice tasks. The evaluations were analyzed using a Multinomial Mixed Logit model. The model estimation results show that the commonly used route attributes (travel time, type of bicycle path facility, pavement quality level, motorized traffic speed, bicycle crowdedness, and number of traffic light intersections) have the highest influence on cyclists' route choice decisions. The impact of intersection based innovations on cyclists' route choice decisions is limited.

1. Introduction

Despite the fact that cycling is already a popular means of transport in the Netherlands, authorities are still looking for improvements in cycling infrastructure (Verrips and Hilbers, 2020). The need for improvements is (negatively) supported by the increase of bicycle causalities in the Netherlands (SWOV, 2022, 2023). While cycling in urban areas, cyclists experience various opportunities and challenges related to safety, comfort, and circulation (Van der Waerden et al., 2011; Snizek et al., 2013; Gamble et al., 2017; Kazemzadeh et al., 2020; Gadsby et al., 2021; Pearson et al., 2023). These opportunities and challenges can encourage but also discourage the use of the bicycle in general, or the use of certain bicycle routes or facilities in particular (Hull and O'Holleran, 2014; Krenn et al., 2014; Sanders, 2015; Hopkins and Mandic, 2017; Misra and Watkins, 2017; Vedel et al., 2017; Useche et al., 2019; Gadsby et al., 2021; Pearson et al., 2023). Besides focusing on road segments with separate bicycle lanes and paths, a lot of attention is paid to the opinion of cyclists regarding intersections as sources of conflicts with other transportation modes and delay for cyclists (Heinen et al., 2010; Casello et al., 2017). The study of Pearson et al. (2023) showed that one of the main barriers to cycle is the concern about collision with a motorized vehicle which is strongly related to intersections. In addition, Milakis and Athanasopoulos (2014) looked at prioritization of cycling infrastructure investments based on end users preferences. They found that the end users considered junction density as one of the most important criteria (together with ride difficulty), showing the attention cyclists pay to the intersections they use. More recently, the study of Bialkova et al. (2022) showed that the absence of intersections has a positive impact on cyclists' safety perception.

The attention for intersections focuses on both infrastructural and organizational measures. Examples of the first group of measures are bike boxes, raised crossings, and combined traffic lanes (Buehler and Dill, 2016). The second group of measures deals with various ways in which bicycles are supported while crossing an intersection, for example implementation of separate bicycle signals (or extra green phases), bicycle 'green' wave/route, and countdown timers (De Lange, 2019; De Angelis et al., 2019; Nygardhs, 2021). Previous studies mainly focus on warning systems for dangerous and risky situations and do not pay much attention to optimize the flow and circulation speed of bicyclists (Kapousizis et al., 2022). The urge for not only paying attention to dangerous and risky situations (especially car-bicycle crashes) but also to flow and circulation is supported by an increase of behavioral adaptation and risk compensation of (e−)cyclists due to an increase of waiting time at signalized crossings in combination with a lower level of

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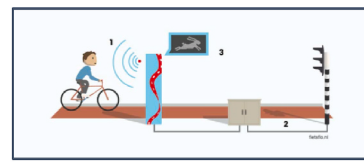
patience. This all results into an increase in red light running and in addition, higher risk on accidents at crossings (Ma et al., 2019; Schröter et al., in press).

In the Netherlands, three different intersection related innovations are currently implemented and tested in practice: Flo, a bicycle speed advice tool; Schwung, a bicycle - traffic light communication tool; and BikeScout, an intersection flashing tool (Table 1). The first two innovations can be considered 'cyclists oriented' to reduce the delay at intersections and in addition, reduce travel time and improve traffic flow. The third innovation is more 'car driver oriented' and focuses on traffic safety. At the moment, the three innovations are mainly evaluated at the level of individual intersections and bicycle crossings (Van Wilgenburg et al., 2017; Mooren et al., 2018; Van Mierlo et al., 2020; Kemming and Van der Sande, 2021). There is no structured evaluation available in the context of bicyclists' route choices with the main question 'Does the presence of one or more innovations on a route trigger bicyclists to choose the route that is equipped with the innovation(s)'? The aim of this study is to provide more insights into the contribution of intersection based innovations to bicyclists' route choice decisions in urban areas. The effects of the three different intersection based innovations mentioned above are investigated in more detail using a stated choice approach. The generated insights can help planners and developers to optimize the design of bicycle routes with newly developed features and communicate the effectiveness with potential users (Dell'Era et al., 2018; De Angelis et al., 2019). The effectiveness can be expressed in terms of changes in use of the newly designed route and the existing alternative routes: how many bicyclists are attracted to the new route and from what routes do the come. Several studies show that bicyclists often deviate from the shortest route in favor of more safe and convenient routes (Krenn et al., 2014; Dessing et al., 2016; Misra and Watkins, 2017). Insights in changes in use can also help to prioritize and evaluate investments in bicycle infrastructure (Hong et al., 2020;

Table 1
Explanation of the selected intersection based innovations (Gebhard, 2020).

Innovation	Description	Illustration
Flo, speed advice	Flo is a pole which can be placed along a cycle path roughly 100 m before a traffic light, which gives cyclists speed adjustment advice in order to reach the traffic light during a green light. The pole measures a cyclist's speed as they approach and shows a different image based on if the cyclist should: speed up (hare), maintain speed (thumbs up), slow down (tortoise), or if you can't get a green light (cow).	 Source: bikeflo.com
Schwung, traffic light communication	Schwung is a smartphone application for cyclists developed by Vialis and Moop Mobility which communicates with smart traffic lights to request a green light for approaching cyclists.	 Source: bicycledutch.wordpress.com
BikeScout, intersection flashing tool	The BikeScout light system, developed by Heijmans Infra, warns car drivers about oncoming cyclists in order to improve traffic safety at crossings where a bike path has priority. BikeScout detects oncoming cyclists, measures their speed, and illuminates a row of LED lights in the road surface when a cyclist/scooter is 5 s from crossing the intersection.	 Source: heijmans.nl

Meng, 2022).

The remainder of the paper is organized as follows. First, some attention is paid to cyclists' route choice decisions and the role intersection related attributes play in these decisions. Next the adopted research approach is outlined. This section is followed by a brief description of the data collection and the composition of the sample. Next, some attention is paid to the impact of the explanatory videos on respondents' awareness regarding three innovations and respondents expectations regarding the included innovations. The following section presents the results of the model analyses. The paper ends with the conclusions and recommendations.

2. Cyclists' route choice decisions

In general, cyclists' route choice decisions include aspects related to travel time, comfort, and safety (Van der Waerden et al., 2011; Snizek et al., 2013; Gamble et al., 2017; Gadsby et al., 2021). In this context, the number and design of intersections on routes play an important role as both regulated (traffic lights or priority) and unregulated intersections often create dangerous conflicts and delays for cyclists (Pearson et al., 2023). On the other hand, intersections give the opportunity to regulate priority for cyclists and offer the opportunity to change routes. Various studies investigated the role of intersections in cyclists' route choice decisions using revealed preference/count data (Van der Waerden et al., 2011; Snizek et al., 2013; Bernardi et al., 2018; Gamble et al., 2017; Gadsby et al., 2021), stated preference data (Sener et al., 2009; Caulfield et al., 2012; Van Overdijk et al., 2017; Vedel et al., 2017) or GPS tracking data (Menghini et al., 2010; Broach et al., 2012; Pereira Segadilha and Da Penha Sanches, 2014; Ton et al., 2017; Dessing et al., 2016). Some studies found that the presence of intersections in a route decreases the attractiveness of route. For example, Sener et al. (2009) found that the number of stop signs, red lights, and cross streets has a high impact on bicyclists' route choice decision. Cyclists prefer a low number of stop signs, red lights, and cross streets on their route. Menghini et al. (2010) found that cyclists avoid signal controlled intersections but that this issue was not the most important one for choosing a route. Caulfield et al. (2012) showed that the more intersections are included in the route, the lower the attractiveness of the route is. In their study, the number of intersections was the second most important route attribute, after travel time. Van Overdijk et al. (2017) found that the more non-priority and traffic light intersections are present in a route, the lower the attractiveness of the route is. In addition, Vedel et al. (2017) found that cyclists are willing to cycle 1.3 km longer to avoid routes with many stops, such as intersections. Ton et al. (2017) included the number of intersections per kilometer as network attribute in their route choice model and found a significant effect indicating that a higher number of intersections results into a lower utility of a route alternative. Moreover, Broach et al. (2012) found that the presence of traffic signals and stop signs decreases the utility of a route because of delay. However, they also concluded that in the case of high conflicting traffic volumes the negative influence changes into a positive influence. This finding is supported by Buehler and Dill (2016) who conducted an extensive literature review and found that intersections have negative effects on cycling experience, but also that certain features (e.g. high traffic volumes) can offset this.

Other studies showed that the presence of traffic light regulated intersections positively affected the choice for a certain route or a longer route compared to the shortest route between origin and destination. For example, Dessing et al. (2016) found that the presence of traffic lights is positively associated with route choice of children cycling to school. They noticed that the actually cycled routes differed from the shortest in having more traffic lights and more intersections. More recently, Bernardi et al. (2018) found that the presence of traffic lights positively affected the choice for a longer route compared to the shortest route alternative.

Another group of studies focuses on the level of importance of route related attributes. One example of studies that focus on importance scores is the study of Pereira Segadilha and Da Penha Sanches (2014) who found that the intersection related attributes have an importance score of above average (between 3.45 and 3.62 on a 5-points scale) but are considered as less important than road related characteristics including number of trucks/buses (score 4.59), traffic volume (score 4.59), and traffic speed (4.52).

The brief overview of previous studies shows that the presence of intersections plays a varied role (major versus minor; encouraging versus discouraging) in the cyclists' route choice decision process. Methodologically, the way intersections are included in most studies is very straightforward: number of intersections and/or number of (non-)priority or traffic light regulated intersections. No studies were found that investigate special regulations or features for cyclists at intersections like the ones presented in the first section of this paper. As more of these intersection related innovations are put into practice to stimulate cycling flow and safety, it is valuable to investigate their impact on cyclists' route choice behavior. By doing this, it might become clear if cyclists are attracted to bicycle routes that are equipped with special features making investments worthwhile.

3. Research approach

To get insight into the contribution of intersection based innovations on cyclists' route choice behavior, a stated choice experiment is set up (Hensher et al., 2005). This kind of experiment offers the opportunity to investigate new or relatively new innovations in a controlled environment with a preselected set of attributes that vary independently. Stated choice experiments also provide the possibility to show multiple choice situations to one respondent which reduces the need for respondents. The innovations introduced in section 1 are combined with seven attributes that are considered as most relevant in the context of cyclists' route choice decisions (Sener et al., 2009; Menghini et al., 2010; Broach et al., 2012; Caulfield et al., 2012; Pereira Segadilha and Da Penha Sanches, 2014; Majumdar and Mitra, 2017; Misra and Watkins, 2017; Ton et al., 2017; Van Overdijk et al., 2017; Vedel et al., 2017; Bernardi et al., 2018). To support the planners and developers of bicycle routes as much as possible, the attributes cover a variety of topics identified as relevant in previous studies covering the cyclist's trip (travel time), surrounding traffic (speed, crowdedness), applicable regulation (priority), and available infrastructure (type of path facility, pavement, traffic lights). An overview of the attributes and their corresponding levels is presented in Table 2.

Following a fractional factorial design, the 9 attributes and corresponding levels were combined in 27 bicycle route alternatives (Hensher et al., 2005). The generated design guarantees that the correlations between the main effects of the attributes are zero. The 27 alternatives were randomly placed into choice sets consisting of two specified alternatives (route 1 and route 2) and one extra option (neither) for those who did not want to make a choice (Fig. 1). Two versions of the choice tasks were constructed: one with Flo and BikeScout presented in Fig. 1, and one with Schwung and BikeScout. This is done to prevent confusion regarding the presence of the two traffic light related innovations (Flo and Schwung) at the same time. Each respondent evaluated three choice tasks with Flo/BikeScout and three choice tasks with Schwung/BikeScout.

4. Data collection

The experiment was included in an online survey using the package LimeSurvey (LimeSurvey.org). To introduce the included attributes with corresponding levels, several explanatory texts and illustrations were presented to the respondents before the evaluation of the tasks started. One example of these illustrations is shown below in Fig. 2 with at the top a calm traffic situation, in the middle a medium traffic situation, and at the bottom a busy traffic situation.

Table 2
Overview selected attributes and corresponding levels.

Attribute	Description	Levels
Travel time	Travel time of the bicycle trip excluding potential waiting times at intersections (Free flow condition)	19 min 17 min 15 min
Bicycle path facility	Type of facility for majority of bike infrastructure, illustrated with three example photos per level	No bicycle facilities Bicycle lane Separate bicycle path
Pavement quality	Road surface quality of bike facility, illustrated with three example photos per level	High Medium Low
Traffic speed	Speed limit of adjacent motorized traffic	30 km/h 50 km/h 60 km/h
Crowdedness	Traffic intensity on bike facility, illustrated with three example photos per level (see Fig. 2)	Calm Medium Busy
Traffic light intersection	Number of intersections along the route with traffic lights	3 traffic lights 2 traffic lights 1 traffic light
Flo/Schwung	Presence of innovation at all intersections along the route	Present Not present
Bicycle priority crossings	Number of intersections along the route where bicycles have priority	1 priority crossing 3 priority crossings 5 priority crossings
BikeScout	Presence of light signal at all intersections along the route	Present Not present

The three intersection related innovations were explained in the first part of the online questionnaire by text and short videos. In addition, respondents were asked to answer some questions regarding their familiarity with the innovations and their understanding of the included exploratory videos. The questionnaire also included several questions regarding the respondent's experiences with cycling and some personal characteristics.

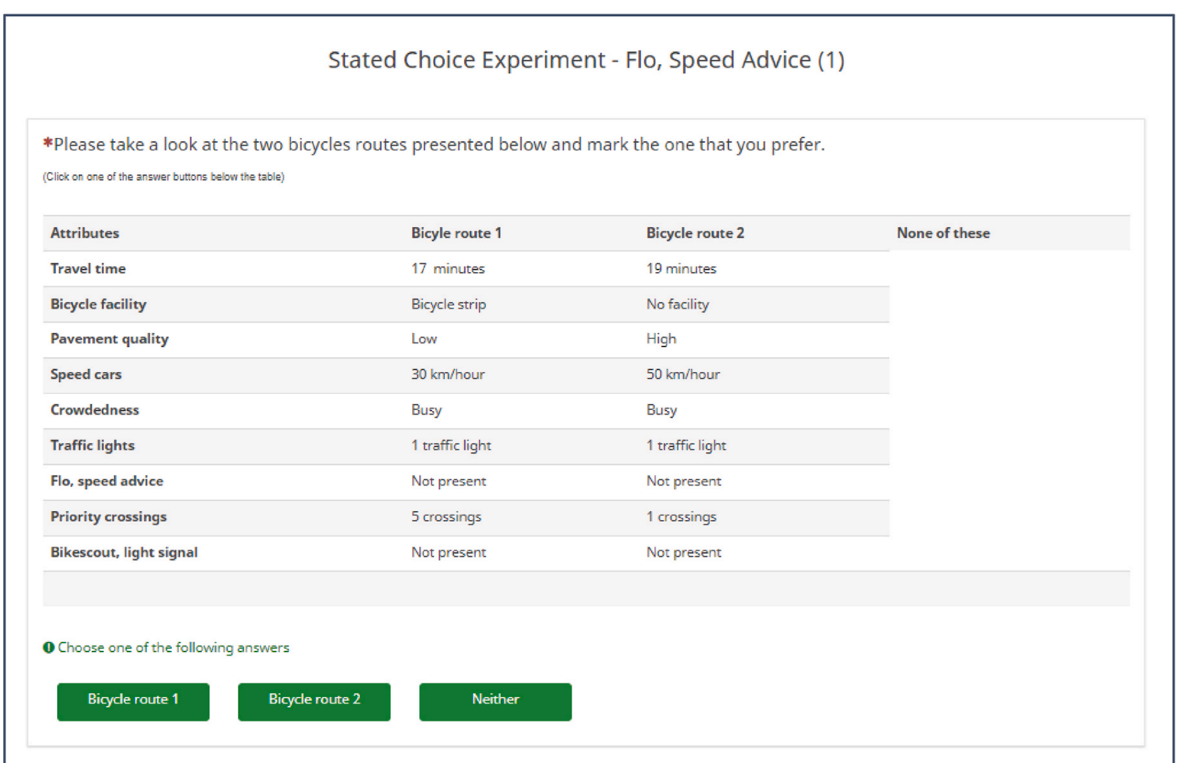
The invitations for the online questionnaire were distributed among members of an online marketing panel of PanelClix (PanelClix.nl). All invited members indicated to be interested in mobility related surveys. In total, 608 members of the panel fully completed the questionnaire. Some details of the respondents are presented in Table 3. It appears that the respondents are very well divided among the separated characteristic levels and that each level is well represented. The table also shows that at the national level the sample follows the distribution of the Dutch cyclists.

5. Descriptive analysis

The intersection based innovations are also in the Netherlands relative new. Therefore, the first part of the questionnaire consisted of detailed explanation of the three innovations, both by text (see Table 1) and a 30-s video. After presenting this, the respondents were asked to answer some questions regarding their familiarity with the innovation and the understanding of the videos. It appears that in advance most of the respondents are not familiar with the included innovations (26 percent knows BikeScout and 12 percent knows Flo/Schwung). After reading the exploratory text and watching the videos, most respondents indicated that they understand the meaning/working of the presented innovations (Fig. 3).

After explaining each intersection based innovation in detail, the respondents were invited to shed a light on their expectations regarding the innovation. The expectations covered 5 different topics: safety, comfort, visibility, cycling speed, and desirability. For each topic and each intersection based innovation, a thesis was phrased as follows: 'I do expect (or do not expect) that the innovation contributes to my (topic) while cycling'. The respondent could use a 5-points scale to express their opinion ranging from disagree to agree.

Fig. 4 shows the distributions of the topic specific evaluation scores for the three investigated intersection based innovations. It appears that


Stated Choice Experiment - Flo, Speed Advice (1)

*Please take a look at the two bicycles routes presented below and mark the one that you prefer.
(Click on one of the answer buttons below the table)

Attributes	Bicyle route 1	Bicyle route 2	None of these
Travel time	17 minutes	19 minutes	
Bicycle facility	Bicycle strip	No facility	
Pavement quality	Low	High	
Speed cars	30 km/hour	50 km/hour	
Crowdedness	Busy	Busy	
Traffic lights	1 traffic light	1 traffic light	
Flo, speed advice	Not present	Not present	
Priority crossings	5 crossings	1 crossings	
Bikescout, light signal	Not present	Not present	

Choose one of the following answers

Bicycle route 1 Bicycle route 2 Neither

Fig. 1. Example of stated choice task in LimeSurvey.

Fig. 2. Illustrations of Crowdedness used in questionnaire (Gebhard, 2020).

Table 3
Personal characteristics of the respondents (N = 608).

Characteristics	Levels	Sample		National[a]
		Frequency	Percentage	Percentage
Gender	Female	296	48.7	51.9
	Male	312	51.3	48.1
Age	35 years or younger	196	32.3	29.5
	36–50 years	160	26.3	23.1
	51–65 years	166	27.3	26.6
	66 years or older	86	14.1	20.8
Education	Low	98	16.1	20.2
	Medium	272	44.7	35.0
	High	238	39.2	44.8
Household composition	Single	123	20.2	23.7
	Without children	271	44.6	33.9
	With children	214	35.2	42.5
Home location	Very high urban	146	24.0	28.1
	High urban	159	26.2	30.6
	Average urban	132	21.7	15.9
	Low urban	171	28.1	25.4

[a] Based on cyclists of 18 years and older included in the 2020 Dutch National Travel Survey (CBS, 2020).

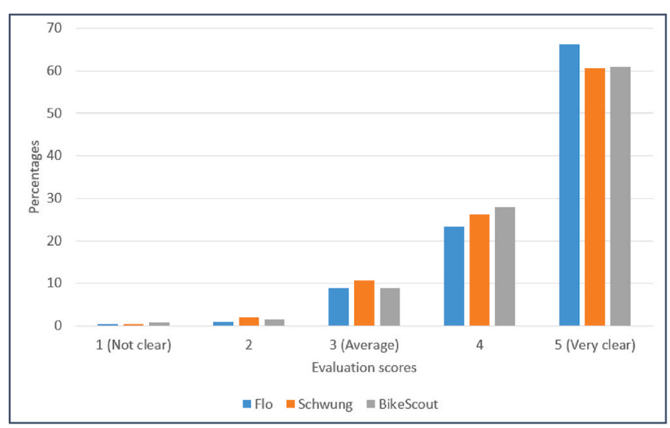


Fig. 3. Evaluation scores of exploratory value of videos (N = 608).

the expectations regarding Flo and Schwung are more or less similar: respondents are strongly divided about the contribution of the innovations to the included topics. In the case of BikeScout, a different result can be noticed: respondents expect a substantial contribution of the innovation when looking at the included topics especially when it concerns safety and visibility.

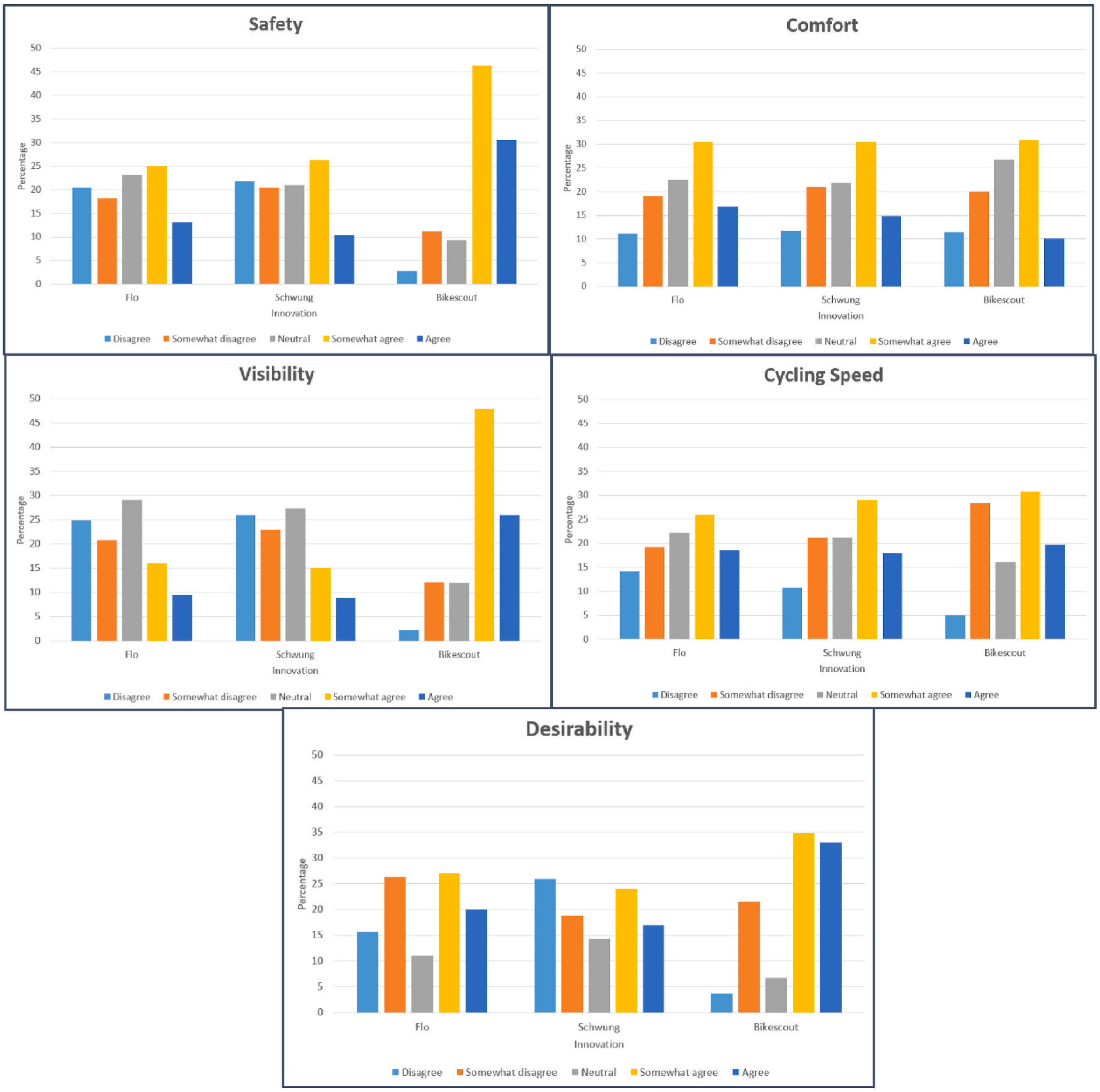


Fig. 4. Topic specific evaluation scores of innovations(N = 608).

6. Model analysis

In total, the 608 respondents evaluated 3648 evaluated choice tasks. The evaluations are analyzed using a Multinomial Mixed Logit (MML) model that allows for investigating random taste variation in the population of decision makers by estimating mean and standard deviation parameters. Random taste variation across decision makers gives a more accurate representation of real world behavior than assuming the same taste for all decision makers like assumed in Multinomial Logit (MNL) models that estimate only mean parameters (e.g. Train, 2003; Hess and Polak, 2009). In addition, MML is able to include panel effects representing repeated choices made by each respondent. Several examples show that MML models perform better than MNL models (e.g. Bhat et al., 2008; Hess and Polak, 2009; Borgers et al., 2010).

The MML models involve the integration of the standard MNL equation over the distribution of unobserved random parameters (e.g., Train, 2003; Bhat et al., 2008):

$$P_{qi}(\theta) = \int_{-\infty}^{+\infty} P_{qi}(\beta) f(\beta|\theta) d(\beta)$$

Where,

$$P_{qi}(\beta) = \frac{e^{\sum_k \beta_k \cdot x_{qik}}}{\sum_j e^{\sum_k \beta_k \cdot x_{qik}}}$$

where,

P_{qi} is the probability that individual q chooses alternative i;

x_{qik} represents for each individual q the value of each attribute k of alternative i,;

β_k represents parameters of attribute k which are random realizations from a density function $f(\beta)$;

θ is a vector of underlying moment parameters characterizing $f(.)$.

The density $f(\beta)$ is a function of parameters θ that represents, for example, the mean and (co)variance of the β's in the population. In previous applications $f(\beta)$ has been specified to be normal or lognormal: $\beta \sim N(b, \sigma)$ or ln $\beta \sim N(b, \sigma)$ with parameters b and σ that are estimated. For a large selection of parameters the normal distribution is a valid choice. The lognormal distribution is useful when the parameter is known to have the same sign for every decision maker, such as a price parameter that is known to be negative for everyone (Train, 2003).

The estimated MML model can be tested against a model with all parameters equal to zero (null-model) using the Log-likelihood Ratio Statistic (LRS). In addition, McFadden's pseudo R-Square can be calculated to determine how well the model predicts the observed choice (Hensher et al., 2005). Basically, the value of McFadden's pseudo R^2 varies between 0 (no fit) and 1 (perfect fit). Values between 0.2 and 0.4 are considered to be indicative of 'extremely' good model fits (Louviere et al., 2000; page 54). According to Hensher et al. (2005; page 338), a pseudo R^2 of 0.3 or higher represents a 'decent' fit for a discrete choice model.

The results of the model estimation are presented in Table 4. The model is estimated using NLogit 6.0 (Econometric Software Inc, 2016). The final estimation is based on 1000 random 'Halton' draws which gave similar results as an estimation with 500 draws in accordance with findings of Hensher et al. (2005) and Borgers et al. (2010). For the estimation, the data of the two versions of the choice experiment are combined where the attribute values of one version are set to zero (having no influence on the choice) when the choice of the other version are considered vice versa. This makes that most attributes are considered in all choice sets and that the Schwung and Flo related attributes are only considered in the case the choice set includes the innovation.

At the bottom of the table, some details of the model's goodness-of-fit are presented. The LRS value in combination with the Chi-square test value shows that the model outperforms the null model in representing the observed choices. In addition, the values of the (adjusted) McFadden's pseudo R^2 show that the model is very well able to predict the observed choices that the respondents made.

Table 4
Parameter estimates of the Mixed Logit model.

Attributes	Levels	Mean	Standard dev.
Constant	Bicycle route 1/2	**4.6786***	**3.1251**
Travel time	19 min	**−0.3884**	**0.5672**
	17 min	0.0343	0.0651
	15 min	*0.3541*	
Type of bicycle path facility	No bicycle facilities	**−0.9144**	**0.7127**
	Bicycle lane	**0.1124**	0.2484
	Separate bicycle path	*0.8020*	
Pavement quality level	High	**0.5778**	**0.6016**
	Medium	**0.1308**	**0.2867**
	Low	*−0.7086*	
Motorized traffic speed	30 km/h	**0.3291**	**0.3596**
	50 km/h	−0.0314	0.0432
	60 km/h	−0.2977	
Bicycle crowdedness	Calm	**0.5146**	**0.4670**
	Medium	0.0620	**0.3832**
	Busy	*−0.5766*	
Number of traffic light intersections	1 traffic light	**0.3811**	0.1181
	2 traffic lights	*−0.1815*	
	3 traffic lights	**−0.1996**	0.0463
Presence of Flo	Present	0.0318	0.0295
	Not present	*−0.0318*	
Presence of Schwung	Present	0.0791	0.2328
	Not present	*−0.0791*	
Number of bicycle priority crossings	1 priority crossing	0.0356	0.2488
	3 priority crossings	*0.0256*	
	5 priority crossings	−0.0612	0.0283
Presence of BikeScout	Present	**0.1161**	0.1496
	Not present	*−0.1161*	
Model Goodness-of-Fit			
Log-likelihood null model		−4007.738	
Log-likelihood final model		−2582.310	
Log-likelihood Ratio Statistic		2850.855	
Chi-square test value for 36°-of-freedom (95%)		50.998	
McFadden pseudo R-squared		0.356	
Adjusted McFadden pseudo R-squared		0.353	

* **Bold** - > significant at confidence level of 90 percent or higher; ** *Italic* - > Reference level.

The table also shows the parameter estimates and corresponding part-worth utilities based on effect coding of attribute values (see below). The MML provided two sets of parameters: one for the means and one for the standard deviation of each mean. The effects of all significant parameters are as expected based on findings in the literature (see literature section). A positive parameter shows that the presence of the attribute level makes a route more attractive, while a negative parameter shows that the presence of the attribute level decreases the attractiveness of a route. The positive parameter of the constant shows that in advance (without looking at additional attributes) bicyclists attach a higher utility to the detailed route alternative compared to the option 'Neither'. For the attributes, this means that the attractiveness of a bicycle route can be increased by shortening the travel time, implementing bicycle lanes and paths, offering medium or high quality pavement, decreasing speed of adjacent motorized traffic, decreasing the crowdedness level on the bicycle facility, removing traffic light on the route, and implementing the BikeScout system at crossings. A significant parameter of standard deviation expresses that taste variation between respondents exists. This is valid for the attributes 'Travel time', 'Bicycle path facility', 'Pavement quality', 'Motorized traffic speed', 'Bicycle crowdedness', and 'number of priority crossings'. The literature does not provide expectations regarding this result which makes future research on heterogeneity necessary.

With the estimated mean parameters, part-worth utilities can be calculated by using the estimated parameters and the effect coded attribute values (X_1*MeanParameter$_1$ + X_2*MeanParameter$_2$). The coding for the first attribute level is $X_1 = 1$ and $X_2 = 0$; for the second attribute level: $X_1 = 0$ and $X_2 = 1$; and for the third/reference level: $X_1 = -1$ and $X_2 = -1$. For the calculation all parameters are used, where non-significant parameters are considered as best guesses-values (Figs. 5 and 6). In general, all figures show expected contributions of the attribute levels on the utility of route alternatives: more preferred routes include short travel time, separate bicycle paths, high pavement quality, low motorized travel speed, low crowdedness level, small number of traffic lights, and presence of BikeScout. Based on the range attributes cover (difference between lowest and highest point in the graph), it can be concluded that the attributes 'Bicycle path facility' and 'Pavement quality' have the biggest contribution. The importance of Bicycle path facilities is in line with findings of several other studies (Sener et al., 2009; Menghini et al., 2010; Broach et al., 2012; Caulfield et al., 2012; Ton et al., 2017; Van Overdijk et al., 2017; Vedel et al., 2017; Bernardi et al., 2018). The conclusion regarding bicycle paths is also supported by Pearson et al. (2023) who found that riding on the road with motor vehicle traffic and concern about injured through collision with a motor cycle are the most deterring elements when considering the use of a bicycle. The conclusion regarding the quality of pavement is supported by findings of Pereira Segadilha and Da Penha Sanches (2014) and Van Overdijk et al. (2017) that show the high importance of pavement quality in the context of bicyclists route choice decisions. Compared to the contributions of the other attributes, the absence/presence of the innovations has a limited contribution to the total utility of a route alternative.

7. Conclusions

The research presented in this paper focuses on the contribution of intersection based innovations to bicycle route choice decisions. Beside seven regularly investigated route attributes (travel time, bicycle path facility, pavement quality, motorized traffic speed, bicycle crowdedness, number of traffic light intersections, and number of priority crossings), the influence of three different innovations was investigated: Flo', bicycle speed advice; 'Schwung', bicycle - traffic light communication; and 'BikeScout', intersection illumination. All attributes are included in a stated choice experiment that was implemented in an extensive online questionnaire. The questionnaire was distributed among selected

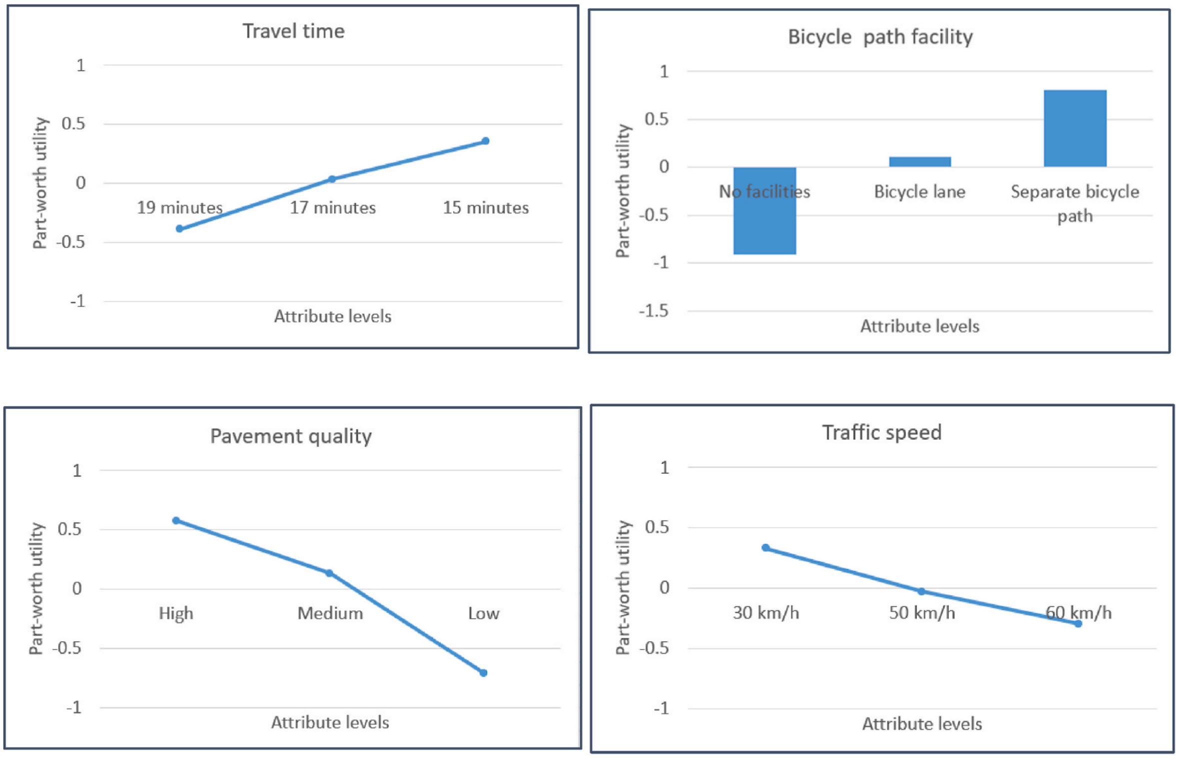


Fig. 5. Part-worth utilities of Travel time, Bicycle path facility, Pavement quality, and Motorized traffic speed.

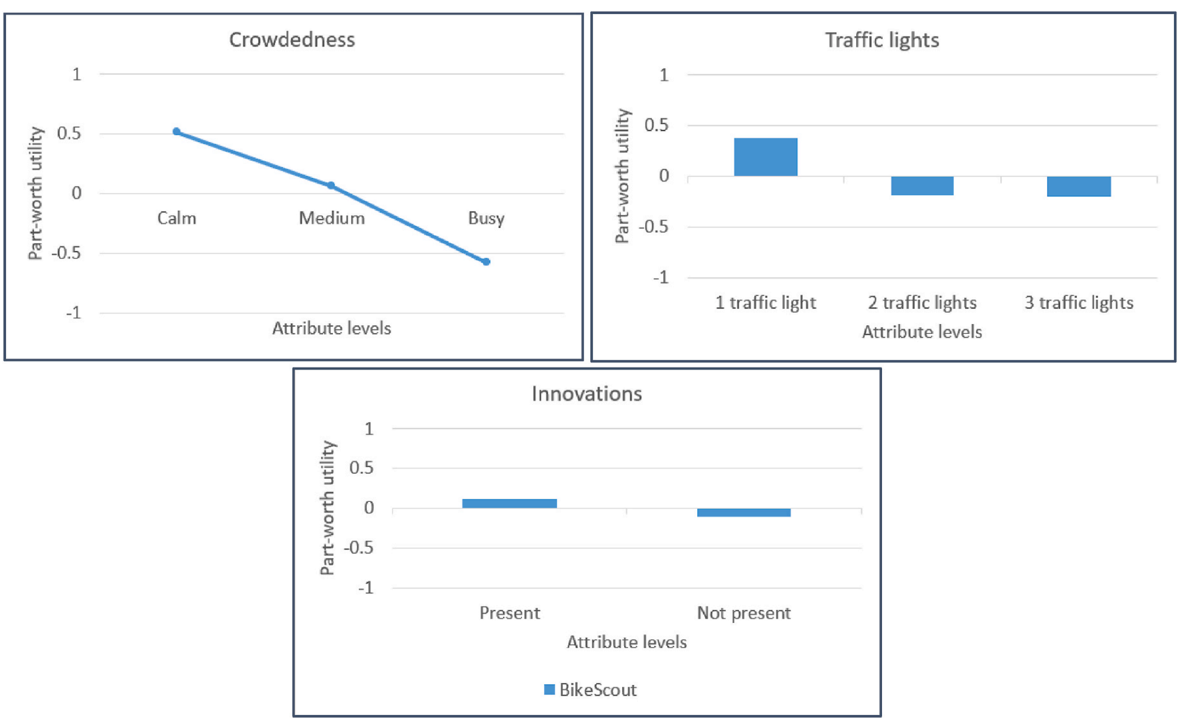


Fig. 6. Part-worth utilities of Bicycle crowdedness, Number of traffic lights, and Innovations.

member of an online panel. In total 608 completed the questionnaire and evaluated 3648 choice tasks. The evaluations are analyzed using a Mixed Multinomial Logit model. The estimation process resulted into a decent model fit and many significant mean parameters and standard deviations. The current study shows that the most contributing attributes to the total utility of a route are 'bicycle path facility', 'pavement quality', and 'bicycle crowdedness'. At some distance these attributes were followed by the attributes 'travel time', 'motorized traffic speed', and 'number of traffic light intersections'. All findings are in line with findings from previous studies (Sener et al., 2009; Menghini et al., 2010; Broach et al., 2012; Caulfield et al., 2012; Pereira Segadilha and Da Penha Sanches, 2014; Majumdar and Mitra, 2017; Misra and Watkins, 2017; Ton et al., 2017; Van Overdijk et al., 2017; Vedel et al.., 2017; Bernardi et al., 2018). The contribution of the presence of BikeScout to the total utility of a route alternative is statistically significant but moderate in size. This finding is in line with the findings from the descriptive analyses showing that respondents have serious expectations regarding BikeScout especially when looking at safety and visibility. No significant contribution was found for the attributes 'number of priority crossings', 'presence of Schwung, traffic light communication', and 'presence of Flo, speed advice'. The limited effect of the first attribute might be caused by the fact that respondents feel safe and experience no delay when passing/approaching a priority or signalized crossing. The absence of an effect of Schwung and Flo might be caused by the fact that respondents consider the provided information and the way it is provided as too vague. This latter effect is in line with the varying expectations that respondents have about the two innovations. It should also be mentioned that the expected gain in travel time due to these innovations might be limited compared to the total travel time. In addition, it appears that for several attributes heterogeneity exists between the respondents. This is valid for the attributes 'travel time', 'type of bicycle path facility', 'pavement quality level', 'motorized traffic speed', 'bicycle crowdedness', and 'number of priority crossings'.

For practice, it is clear to keep a focus on traditional attributes of bicycle routes. It is also good to notice that some intersection related innovations contribute significantly to the utility (and therefore safeness and attractiveness) of bicycle routes (Kapousizis et al., 2022). This means that the attractiveness of a bicycle route can be increased by shortening the travel time (e.g. making short cuts, allowing two way movements in one way streets, removing traffic lights, and shortening the delays at traffic lights), realizing bicycle lanes and separate bicycle paths, offering medium or high quality pavement (asphalt instead of tiles), decreasing speed of adjacent motorized traffic (speed limit), decreasing the crowdedness level on the bicycle facility (distribute bicyclists by separating destination traffic from through traffic), removing traffic light on the route, and implementing the BikeScout system at crossings. It is also interesting to know that some investigated effects are homogeneous among cyclists. Especially, the effect of BikeScout can be of interest because BikeScout is another way of making cyclists visible to car drivers. Wood et al. (2009) investigated the relationship between cyclist visibility and crash involvement: the use of visibility aids (fluorescent/reflective vest/strips, flashing lights, and bicycle lights) was advocated by cyclists, but they tend not to wear/use it. With BikeScout practitioners are less dependent on cyclists' willingness to wear suitable clothing and/or add suitable equipment at their bicycle.

To make the study possible, some assumptions had to be made regarding the focus, composition, and explanation of the stated choice experiment. First, the investigated innovations only deal with perpendicular movements of bicyclists and conflicting traffic flows. It might be interesting to look at turning movements at intersections. For example, Thorslund and Lindström (2020) identified the situation of right-turning vehicles and crossing cyclists as dangerous situation at intersections. In addition, Casello et al. (2017) emphasize the challenges that cyclists left-turns include. Second, in this study no distinction is made between regular bicycles and electrical bicycles, which might be interesting to investigate in more detail. For example, Ma et al. (2019) found that red light running seems to be one of the main risky riding behaviors seen with e-bikes (related to patience when waiting for a red light). Third, to reduce the respondents' burden, a choice had to be made regarding the number of attributes and the content of selected attributes. Literature suggested some other attributes that might be relevant to include in future research such as slope/gradient (Menghini et al., 2010; Broach et al., 2012; Van Overdijk et al., 2017), motorized traffic volume (Sener et al., 2009; Caulfield et al., 2012; Pereira Segadilha and Da Penha Sanches, 2014; Majumdar and Mitra, 2017; Misra and Watkins, 2017), and presence of on-street parking (Sener et al., 2009; Majumdar and Mitra, 2017).

At the moment, the investigated innovations are only implemented at a few locations in the Netherlands. It is expected that more intersections will be equipped with one or more innovations, making more and more cyclists familiar with intersection related innovations (e.g. Zhang and Blokpoel, 2018). In due time, it will be very interesting to see if the adoption of intersection related innovations really increases the (perceived) safety of cyclists and if this increased perceived safety results in more cyclists and/or changes in cyclists' route choice.

Authors' statement

The authors confirm contribution to the paper as follows: study conception and design: P. van der Waerden, S. Gebhard, and J. van der Waerden; data collection: S. Gebhard and P. van der Waerden; analysis and interpretation of results: P. van der Waerden; draft manuscript preparation: P. van der Waerden and J. van der Waerden. All authors reviewed the results and approved the final version of the manuscript.

Data availability

Data will be made available on request.

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