RECCOMENDATIONS FOR CYCLE INFRASTRUCTURE SOLUTIONS ON HILLS BASED ON CYCLISTS' PREFERENCES

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1. INTRODUCTION

Important factors that influence cycling behaviour in slopes includes the steepness and whether it is up- or downhill. Different types of cyclists also have different preferences. Because of this, there is no single *correct* cycle infrastructure solution (Minnesota State Department of Transportation, 2007). In the following, a study examining cyclists' preferences to cycle infrastructure solutions on up- and downhills and for different gradients will be described.

According to the Norwegian Ministry of Transport and Communications, it is a political objective in Norway that all future growth at passenger transport in large cities should be accommodated by public transport modes, walking and bicycling (Samferdselsdepartementet, 2013). Research show that to facilitate increased bicycle traffic, it is important to establish bicycle infrastructure that feels safe and effective for cyclists (Pucher et al., 2010). In Norway, cyclists are allowed to cycle in many different infrastructure solutions: sidewalks, separate bicycle- and walking paths, bicycle lanes, and cycling in mixed traffic.

In order to encourage cyclists to choose established bicycle infrastructure solutions, cyclists need to find the infrastructure attractive. Norwegian topography and associated slopes of roads are in many places challenging for cyclists. In particular increased differences in altitude reduces the share of bicycle traffic significantly (Hjortol et al., 2014). Consequently, to increase the share of travels taken by cycling, facilitating for cycling on hills is important.

The literature study leading up to this analysis revealed no previous research exploring cyclists' preferences considering cycle infrastructure solutions on up- and downhills. Previous research is limited to cyclists' preferences, where gradients are not taken into account.

Generally, cyclists prefer infrastructure solutions dedicated to cyclists rather than no dedicated solution. Among these dedicated solutions, which is the most preferred solution, varies in different studies. A common finding is that many cyclists perceive both the cycle lane and cycle path as attractive solutions. Several studies explore cyclists' preferences on the subject of solutions. These all base their conclusions, however, on data from flat terrain. It is uncertain if the same conclusions can be made for cyclists on hills (Broach et al., 2012, Carter et al., 2013, Hunt and Abraham, 2007, Antonakos, 1994).

Cyclists' behaviour vary at different gradients. While going uphill, the cyclists' speed will be reduced, and some cyclists may need to stand while cycling. This makes it difficult for cyclists to keep a steady position without wobbling (Ribeiro et al., 2014, Minnesota State Department of Transportation, 2007). Therefore, to maintain the balance on uphills, cyclists need more space (Department for Transport et al., 2008). The cyclists' speed will vary depending on the steepness of the slope, whether the slope is up- or downhill, and according to individual differences among cyclists. The results from a Norwegian master thesis showed correlation between the cyclists speed and the gradient. The collected data showed a tendency to a reduction of speed increase and decrease at high gradients on up- and downhills. Uphill, the maximum cycle speed will be limited by the cyclists' endurance. The minimum cycle speed uphill will be limited by a certain speed that is necessary to maintain the balance. Downhill, the cyclists seem to in greater extent choose their own speed. However, there is a maximum limit to speed downhill as well as uphill. This might be due to the cyclists' uncertainty and unwillingness to expose themselves to risks (Grønlund and Overå, 2014).

In a study by Parkin and Rotheram (2010), a model suggesting a linear relation between the gradient and cycle speed was estimated. The mean cycle speed on flat terrain is found to be 21.6 km/h. For each additional 1% of negative gradient, the mean speed is increased by 0.86 km/h. Similar, the mean speed decreases by 1.44 km/h for each additional 1% of positive gradient. Recommendations to cycle infrastructure solutions on hills and requirements to maximum gradients on cycle paths differs from country to country.

In this paper, the following research question will be addressed:

- What are the preferences of cyclists regarding different cycle infrastructure solutions and possible placements on hills?
- Do these preferences change depending on whether the cyclists are going up- or downhill or at different gradients?

Recommendations of infrastructure solutions for cyclists on hills will also be identified.

2. METHODOLOGY AND SURVEY DESIGN

The study was divided into three parts. The first part is a literature review regarding cycle speed on hills and cyclists preferences in general. By conducting the literature review, gaps were identified concerning cyclists' preferences to cycle infrastructure solutions on hills.

Secondly, a small sample of focused interviews were conducted. The aim of the focused interviews was to get inputs to the content and design of a stated preference-interviews. In total, eight focused interviews were done. A convenience sample was chosen, and different ages for both genders were represented. They were asked questions concerning to cycling on hills, like how they experience to cycle on hills or how they behave when cycling on hills. They were also asked which factors had influence for their choice of positioning in different cycle infrastructure solution. The focused interviews lasted between 15 and 35 minutes and were carried out during spring 2015 according to the proceedings outlined by Yin (2002).

Thirdly, 105 stated preference interviews were conducted. Cyclists were interviewed on the street on uphills with varying gradients. In this paper, the hills with the given gradients will be denoted as in the following table:

Table 1: Denotations of hills with different gradients

Gradient	Denotation
3.7 %	Gentle hill
5.4 %	Medium steep hill
8.0 %	Steep hill

These findings will be exemplifies through recommendations to cycle infrastructure solutions for the medium steep hill after the findings section.

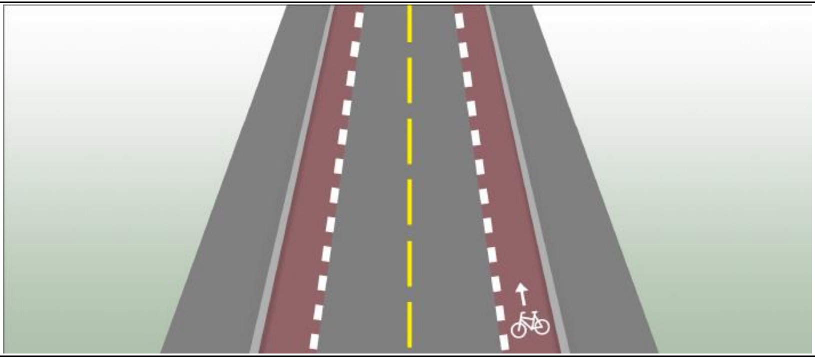
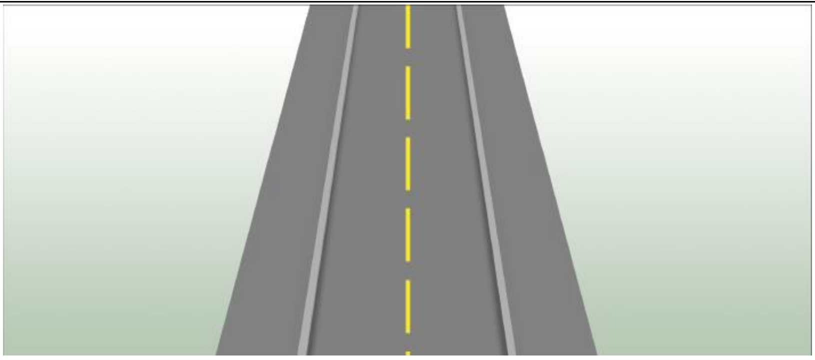
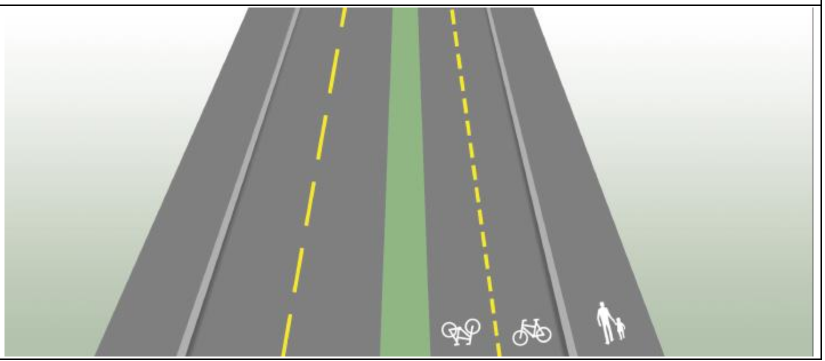
During the stated preference interviews, three different scenarios were presented, which the cyclists were supposed to give statements about. The interviews were conducted “in-situ” so the experience of cycling on hills was fresh and it became easier to imagine how the scenarios would be. All the passing cyclists were asked to participate, as long as the interviewer was free. This was found to be the most effective way to get a representative sample. Both interviews for up- and downhills were done while cyclists were going uphill because of the slow speeds. That made it easier to get in touch with the cyclists. Each scenario described a hypothetic situation, and the cyclists were supposed to imagine that the different scenarios were established on the hill they were cycling in. While showing printed pictures of the three scenarios, the respondents were asked questions such as:

- If you were supposed to cycle this hill once more, under the same circumstances, how would you rank the possible placements for positioning if the road were designed like this scenario?
- If you should recommend to the road administration which infrastructure solution to choose in a hill like this, how would you rank these three different solutions?

The first question was repeated for the three scenarios. The alternatives could be placements like left and right sidewalk, the road lane, the cycle lane and the segregated cycle path. In the end, the cyclists were asked to answer the same questions, just for downhills. Age, gender, use of helmets, use of bicycle outfit and the purpose of the journey were also registered. The stated preference interviews lasted between two and five minutes, and took place during spring 2015.

Since the interviews took place along both a two-lane road and a four-lane road, two sets of illustrations were produced for each scenario to reflect the actual conditions. Table 2 show the two-lane road scenarios.

Table 2: The three different scenarios

Scenario 1 - Cycle lane	
Scenario 2 - No dedicated solution for cyclists	
Scenario 3 - Cycle path	

A pilot study was carried out, containing 10 - 20 interviews. Experiences from the pilot showed the importance of being clear about whether it was a question about up- or downhills. It also showed that the number of questions should be kept to a minimum to avoid time-consuming interviews. The pilot was followed by 105 successfully completed interviews.

Mean scores and standard deviations were calculated to measure the different possible placements' and solutions' attractiveness. To calculate the mean scores and standard deviations, the different scenarios and possible placements in each scenario were given scores, depending on how the respondents ranked the different possible placements and scenarios. The possible scenarios were given points from 0 to 4. 4 points were given to the highest ranked possible placements, and 0 points were given if the placements were not considered as an option for the cyclists. The different scenarios were given points from 1 to 3. If the respondents were not sure or able to rank some of the possible placements or scenarios, the same score were given. The mean scores and standard deviations were calculated based on these scorings. In addition, the share of respondents who ranked the possible placements highest and the share of respondents who did not regard any of the possible placements to be an opinion was calculated.

To determine whether the different possible placements and scenarios were ranked significantly different in various slopes, chi-square tests were conducted.

Regression- and correlation analyses were conducted to determine what kind of cyclists who were more likely to rank the different possible placements and scenarios high. The analyses also show whether the cyclists rank any of the possible placements or scenarios high at certain gradients.

Analysis of variance, based on the mean scores of the possible placements and scenarios, divided into each the cyclists' purpose of the trip were conducted. This was done to determine whether there were significant differences between how the cyclists with various purposes of the trip ranked the different possible placements and scenarios.

Binomial analyses were also conducted. The objective of this analysis was to determine whether there were any significant difference between the two most recommended scenarios, regarding the number of cyclists that ranked these scenarios highest.

In order to determine whether there were any significant difference between the mean scores given up- and downhill, the two most recommended scenarios' mean scores up- and downhill were compared by using paired t-tests.

The results were analysed using the software SPSS.

3. RESULTS

First, the results regarding how the cyclists ranked the possible placements will be elaborated. These results showed that most of the cyclists will probably position themselves in the infrastructure solutions, as long as there is a dedicated solution for cyclists. In general, it is more likely that the cyclists will position themselves on the sidewalk while going uphill than downhill. It is also more likely that they will position themselves in the road lane downhill compared to uphill.

Secondly, the results regarding how the cyclists ranked the different scenarios will be described. The rankings were based on recommendations to the scenarios. These results showed that cyclists generally recommend cycle infrastructure solutions above no dedicated solution for cyclists. The results also show that a cycle path is more preferred rather than a cycle lane uphill, and a cycle lane is more preferred than cycle path downhill.

The analyses are based on 105 conducted SP-interviews. Some characteristics of the sample are summarised in the following:

- 54 % were men, 46 % were women.
- The mean age of the sample is 38,5 years old, with a standard deviation of 14,8 years. The respondents' age range from 14 to 75 years old.

- 53 % were commuting to or from work, 13 % were commuting to or from school, 20 % were on their way to or home from visit or leisure activities, 6 % to or from shopping or service, and 8 % were exercising.
- 79 % wore a helmet and 47 % wore a cycle outfit.

3.1 RANKINGS OF THE POSSIBLE PLACEMENTS

Share of respondents who ranked the placements as their first choice, mean scores, standard deviations and share of respondents who did not considered the placements as an option

Share of respondents who ranked the placements as their first choice, mean scores, accompanying standard deviations and share of respondents who did not consider the possible placements as an option have been calculated. These are shown for each possible placement in table 3, 4 and 5, respectively for each of the three scenarios.

Table 3: Scenario 1 – cycle lane
Share of respondents who stated the possible placement as their first choice (FC), mean score, standard deviation (SD) and share of the respondents who did not consider the possible placement as an option (NA)

		Uphill				Downhill			
Positioning	**Gradient**	**FC**	**Mean**	**SD**	**NA**	**FC**	**Mean**	**SD**	**NA**
Cycle lane	**3.7 %**	82.9 %	2.85	0.35	0.0 %	91.4 %	2.94	0.21	0.0 %
	5.4 %	77.1 %	2.81	0.38	0.0 %	85.7 %	2.83	0.55	2.9 %
	8.0 %	88.6 %	2.92	0.24	0.0 %	85.7 %	2.89	0.27	0.0 %
	Total	82.9 %	2.86	0.33	0.0 %	87.6 %	2.89	0.37	1.0 %
Left sidewalk	**3.7 %**	2.9 %	1.09	0.82	28.6 %	0.0 %	0.82	0.82	34.3 %
	5.4 %	22.9 %	1.87	0.92	11.4 %	0.0 %	0.37	0.99	74.3 %
	8.0 %	0.0 %	0.92	0.66	25.7 %	0.0 %	0.43	0.89	60.0 %
	Total	8.6 %	1.29	0.90	21.9 %	0.0 %	0.54	0.93	56.2 %
Right sidewalk	**3.7 %**	17.1 %	2.08	0.77	8.6 %	5.7 %	1.69	0.74	14.3 %
	5.4 %	5.7 %	1.67	0.89	17.1 %	2.9 %	1.12	0.69	40.0 %
	8.0 %	14.3 %	2.27	0.39	0.0 %	5.7 %	1.33	0.58	25.7 %
	Total	12.4 %	2.01	0.75	8.6 %	4.8 %	1.38	0.70	26.7 %
Road lane	**3.7 %**	0.0 %	0.82	0.83	37.1 %	8.6 %	1.50	0.96	17.1 %
	5.4 %	2.9 %	0.30	0.71	80.0 %	14.3 %	1.93	0.91	14.3 %
	8.0 %	0.0 %	1.01	0.79	31.4 %	8.6 %	1.91	0.84	11.4 %
	Total	1.0 %	0.71	0.82	49.5 %	10.5 %	1.78	0.92	14.3 %

Table 4: Scenario 2 – no dedicated solution for cyclists
Share of respondents who stated the possible placement as their first choice (FC), mean score, standard deviation (SD) and share of the respondents who did not consider the possible placement as an option (NA)

Positioning	Gradient	Uphill				Downhill			
		FC	Mean	SD	NA	FC	Mean	SD	NA
Left sidewalk	3.7 %	11.4 %	1.53	0.99	25.7 %	5.7 %	1.18	1.00	31.4 %
	5.4 %	57.1 %	1.92	0.68	5.7 %	5.7 %	0.46	0.84	65.7 %
	8.0 %	2.9 %	0.96	0.69	25.7 %	2.9 %	0.59	0.91	48.6 %
	Total	23.8 %	1.37	0.82	18.1 %	4.8 %	0.66	0.86	46.7 %
Right sidewalk	3.7 %	74.3 %	2.15	0.51	2.9 %	42.9 %	1.71	0.73	14.3 %
	5.4 %	40.0 %	1.55	0.93	22.9 %	17.1 %	1.33	0.73	25.7 %
	8.0 %	82.9 %	2.26	0.31	0.0 %	34.3 %	1.51	0.68	22.9 %
	Total	65.7 %	1.99	0.63	8.6 %	31.4 %	1.52	0.74	21.0 %
Road lane	3.7 %	22.9 %	1.14	0.85	20.0 %	54.3 %	1.65	0.93	14.3 %
	5.4 %	5.7 %	0.34	0.71	77.1 %	82.9 %	2.08	0.78	11.4 %
	8.0 %	17.1 %	1.26	0.78	17.1 %	62.9 %	1.92	0.76	8.6 %
	Total	15.2 %	0.91	0.88	38.1 %	66.7 %	1.88	0.84	11.4 %

Table 5: Scenario 3 – cycle path
Share of respondents who stated the possible placement as their first choice (FC), mean score, standard deviation (SD) and share of the respondents who did not consider the possible placement as an option (NA)

Positioning	Gradient	Uphill				Downhill			
		FC	Mean	SD	NA	FC	Mean	SD	NA
Cycle path	3.7 %	97.1 %	2.79	0.51	2.9 %	88.6 %	2.89	0.32	0.0 %
	5.4 %	97.1 %	2.98	0.13	0.0 %	91.4 %	2.94	0.21	0.0 %
	8.0 %	100.0 %	3.00	0.00	0.0 %	88.6 %	2.92	0.24	0.0 %
	Total	98.1 %	2.97	0.30	1.0 %	89.5 %	2.92	0.26	0.0 %
Left sidewalk	3.7 %	0.0 %	1.24	0.86	28.6 %	0.0 %	0.86	0.82	37.1 %
	5.4 %	2.9 %	1.48	0.88	22.9 %	0.0 %	0.39	0.95	77.1 %
	8.0 %	0.0 %	0.94	0.66	25.7 %	0.0 %	0.64	0.89	51.4 %
	Total	1.0 %	1.22	0.83	25.7 %	0.0 %	0.63	0.92	55.2 %
Right sidewalk	3.7 %	2.9 %	1.80	0.82	14.3 %	2.9 %	1.74	0.75	17.1 %
	5.4 %	0.0 %	1.42	1.01	31.4 %	0.0 %	1.20	0.76	34.3 %
	8.0 %	2.9 %	2.08	0.52	2.9 %	0.0 %	1.22	0.80	31.4 %
	Total	1.9 %	1.77	0.84	16.2 %	1.0 %	1.39	0.79	27.6 %
Road lane	3.7 %	0.0 %	0.73	0.78	40.0 %	8.6 %	1.39	1.00	20.0 %
	5.4 %	2.9 %	0.26	0.73	85.7 %	8.6 %	1.69	1.00	22.9 %
	8.0 %	0.0 %	0.99	0.76	28.6 %	14.3 %	1.91	0.82	8.6 %
	Total	1.0 %	0.65	0.81	51.4 %	10.5 %	1.67	0.96	17.1 %

Table 3, and 5 show that when there was a cycle lane or a cycle path available, these two placements got the highest mean scores. This applies to all gradients, and both up- and downhill. In these two scenarios, the right sidewalk got the second best mean score uphill. Downhill, the road lane got the second best mean score. Table 4 shows that when there is no dedicated solution available, the right sidewalk is given the highest mean score uphill. Downhill, the road lane is given the highest mean score.

Table 3, 4 and 5, shows that generally, the right sidewalk is given a higher mean score compared to the left sidewalk, except from the medium steep uphill. Some respondents commented that it felt unnatural to cycle against the driving direction on the left sidewalk, and the right sidewalk was therefore preferred to the left sidewalk. On the medium steep uphill, the results may be due to poor quality on the right sidewalk. In this case, the left sidewalk is given a higher mean score than the right sidewalk. The tables also show that positioning on the sidewalk is more attractive uphill than downhill and positioning on the road lane is more preferred downhill compared to uphill. According to the cyclists' statements, this is because of the low speeds uphill, and high speeds downhill. However, several cyclists do not consider the road lane to be a solution. This applies especially uphill. During the interviews, some cyclists said that they did not want to position themselves in the road lane uphill because it does not feels safe and they might hinder the motorized traffic. The tables also show that to many cyclists, none of the sidewalks were considered as an option. Especially not the left sidewalk. Some of the cyclists explained that with high speeds downhill, and a desire to avoid conflicts with pedestrians. The left sidewalk was for many cyclists not considered an option because it felt unnatural. Some of the respondents also thought it was illegal to cycle on the left sidewalk.

Table 3, 4 and 5 show no clear pattern between the gradients and the possible placements' mean score, share of respondents who stated the possible placements as their first choice or share of respondents who did not consider the possible placements as an option.

Chi-square tests

For both scenario 1 and 3, were cycle lane and cycle path were possible placements, the chi-square tests showed no significant difference between the number of respondents who stated the different placements as their first choice at different gradients. This applies to both up- and downhills. This means that the gradient does not affect cyclists' placements.

In scenario 2 - no dedicated solutions for cyclists, the chi-square test gave no significant differences uphill. Downhill, results from the test gave significant difference on a 3.4%-significance level. This means that there is a correlation between the number of respondents who stated the different placements as their first choice and the gradients. On downhills, a higher number of cyclists ranked the road lane as the best possible placement on the medium steep hill compared to the gentle and steep hill.

Regression and correlation analyses

In the following, general trends among cyclists' preferences will be described. The trends differ depending on which scenario that is analysed. The findings from the analyses will therefore be described separately for each scenario. First significant results uphill will be described. Secondly significant results downhill will be described. The results for scenario 1, 2 and 3 are given in table 6, 7 and 8 respectively. The tables show what type of cyclists the various placements higher compared to other cyclists. The tables also show at which gradients the different placements have been ranked higher. Even though some kind of cyclists have ranked a possible placement higher compared to other cyclists, it does not necessarily mean that this kind of cyclists rank the current possible placement highest. In the following tables, the accompanying p-values are given in the parentheses for p-values below 0.10. For the correlation analyses, the Pearson Correlation coefficient is also given in the parentheses, before the p-value.

Table 6: Scenario 1 – cycle lane
Results from regressions and correlation analyses given for the four possible placements

		Uphill		Downhill	
Positioning	**Factor**	**Regression**	**Correlation**	**Regression**	**Correlation**
Cycle lane	**Gradient**				
	Gender				
	Age				
	Helmet	With (0.027)	With (0.304/0.002)		
	Cycle outfit		With (0.189/0.054)		
Left sidewalk	**Gradient**			Less (0.002)	Less (-0.228/0.020)
	Gender		Women (-0.181/0.065)		Women (-0.222/0.023)
	Age	Younger (0.094)	Younger (-0.171/0.084)		
	Helmet	With (0.089)		With (0.014)	
	Cycle outfit			Without (0.023)	Without (-0.186/0.057)
Right sidewalk	**Gradient**			Less (0.046)	Less (-0.162/0.100)
	Gender			Women (0.051)	Women (-0.246/0.012)
	Age				
	Helmet				
	Cycle outfit			Without (0.005)	Without (-0.296/0.002)
Road lane	**Gradient**			Higher (0.032)	Higher (0.182/0.064)
	Gender			Men (0.006)	Men (0.279/0.004)
	Age				
	Helmet				
	Cycle outfit				

Scenario 1 – cycle lane

Uphill:

- Cyclists wearing helmets and cycle outfit generally rank the cycle lane high compared to other cyclists.
- Women, cyclists with decreasing age and cyclists wearing helmets tends to rank the left sidewalk higher than other cyclists.

Downhill:

- Women and cyclists wearing helmets and cycle outfit generally rank the left sidewalk high compared to other cyclists.
- Cyclists also tend to rank both the left and right sidewalk higher at low gradients.
- In the right sidewalk, women and cyclists without cycle outfit rank the placement higher than men and cyclists without cycle outfit.
- The road lane is generally ranked higher at high gradients, and is often ranked higher by men than by women.

Table 7: Scenario 2 – no dedicated solution for cyclists
Results from regressions and correlation analyses given for the three possible placements

Positioning	Factor	Uphill		Downhill	
		Regression	Correlation	Regression	Correlation
Left sidewalk	Gradient	Less (0.069)		Less (0.004)	Less (-0.191/0.054)
	Gender		Women (-0.166/0.091)		
	Age	Younger (0.088)	Younger (-0.183/0.064)	Younger (0.016)	Younger (-0.227/0.022)
	Helmet			With (0.002)	
	Cycle outfit			Without (0.013)	Without (-0.204/0.039)
Right sidewalk	Gradient				
	Gender			Women (0.031)	Women (-0.269/0.006)
	Age				Younger (-0.180/0.068)
	Helmet				
	Cycle outfit				Without (-0.194/0.047)
Road lane	Gradient			Higher (0.060)	
	Gender		Men (0.190/0.052)	Men (0.049)	Men (0.255/0.009)
	Age				
	Helmet				
	Cycle outfit			With (0.035)	With (0.215/0.028)

Scenario 2 – no dedicated solution

Uphill:

- Women and cyclists with decreasing age generally rank the left sidewalk high compared to other cyclists.
- The left sidewalk is ranked higher on hills with low gradients.
- Men generally rank the road lane higher compared to women.

Downhill:

- Cyclist are more willing to cycle on the left sidewalk when the gradient is low.
- Cyclists with decreasing age, cyclists wearing helmets and cyclists without cycle outfit rank the left sidewalk higher, compared to other cyclists.
- Women, cyclists with decreasing age and cyclists without cycle outfit generally rank the right sidewalk higher than other cyclists.
- Men and cyclists wearing cycle outfit tend to rank the road lane higher compared to women and cyclists without cycle outfit.
- No dedicated solution for cyclists is more attractive when there is high gradients compared to low gradients.

Table 8: Scenario 3 – cycle path
Results from regressions and correlation analyses given for the four possible placements

		Uphill		Downhill	
Positioning	**Factor**	**Regression**	**Correlation**	**Regression**	**Correlation**
Cycle path	**Gradient**				
	Gender			Women (0.044)	Women (-0.247/0.011)
	Age	Younger (0.010)	Younger (-0.172/0.082)		
	Helmet	With (0.060)			
	Cycle outfit			Without (0.064)	Without (-0.187/0.056)
Left sidewalk	**Gradient**	Less (0.039)		Less (0.062)	
	Gender	Women (0.011)	Women (-0.316/0.001)		
	Age	Younger (0.001)	Younger (-0.322/0.001)	Younger (0.006)	Younger (-0.275/0.005)
	Helmet			With (0.009)	
	Cycle outfit			Without (0.018)	Without (-0.225/0.22)
Right sidewalk	**Gradient**			Less (0.019)	Less (-0.232/0.018)
	Gender			Women (0.031)	Women (-0.244/0.12)
	Age				
	Helmet				With (-0.164/0.097)
	Cycle outfit			Without (0.099)	Without (-0.229/0.019)
Road lane	**Gradient**			Higher (0.015)	Higher (0.220/0.024)
	Gender		Men (0.172/0.080)		
	Age				
	Helmet	Without (0.052)			
	Cycle outfit			With (0.014)	With (0.199/0.042)

Scenario 3

Uphill:

- Cyclists with decreasing age and cyclists wearing helmet are more likely to rank the cycle path higher compared to other cyclists.
- Women and cyclists with decreasing age tends to the rank left sidewalk higher compared to men and cyclists with increasing age.
- Left sidewalk is a more attractive placement at hills with low gradients.
- Men and cyclists without helmets tend to rank the road lane higher than other cyclists.

Downhill:

- Women and cyclists without helmets generally rank the cycle path higher compared to men and cyclists wearing helmets.
- The left sidewalk is ranked higher at hills with low gradients. It seems like especially cyclists with decreasing age, cyclists wearing helmets and cyclists without cycle outfits rank the left sidewalk higher than other cyclists.
- Women, cyclists wearing helmets and cyclists without cycle outfits tend to rank right sidewalk higher compared to other cylists.
- The right sidewalk is generally ranked higher at low gradients.
- At higher gradients, the road land is ranked higher.
- Cyclists wearing cycle outfit are more likely to position themselves in the road lane.

Analyses of variance

The focus of the analyses of variance were points given to the different placements depending of the respondents' purpose of the trip. An analysis of variance conducted for scenario 1 – cycle lane, showed significant differences uphill. The differences is significant on a 5.1 % level. Significant differences were also identified for scenario 3 – cycle path uphill. These differences are significant on a 6.0 % level. The significant differences for both scenario 1 and 3 relate to the left sidewalk. It seems like cyclists with exercising as the main purpose, generally ranked this scenario lower than other cyclists. Especially compared to the cyclists with shopping and service as their main purpose.

The analysis of variance for scenario 3 – cycle path, show no significant differences downhill. Uphill, the analysis of variance show some significant differences. The significant differences relates to the left sidewalk and the road lane. It seems like cyclists with exercising as their main purpose, generally ranked the road lane higher, and the left sidewalk lower compared to other cyclists. The differences related to the left sidewalk is significant on a 6.0% - level. The differences related to the road lane is significant on a 7.8% - level.

For the rest of the cases, the analyses gave no significant differences. In these cases, the given mean scores among the cyclists with different purposes are quite similar.

3.2 RANKINGS OF THE DIFFERENT SCENARIOS

Share of respondents who ranked the scenarios as their first choice, mean scores and standard deviations

The respondents were asked to rank the different scenario from most to least recommended scenario. Mean scores and accompanying standard deviations for the different scenarios are given in table 9. Maximum and minimum score is respectively 3 and 1 point.

Table 9: Share of respondents who state the scenario as their first choice (FC), mean score and standard deviation (SD) for the scenarios

		Uphill			Downhill		
Scenario	**Gradient**	**FC**	**Mean**	**SD**	**FC**	**Mean**	**SD**
Scenario 1 - Cycle lane	**3.7 %**	48.6 %	2.49	0.51	62.9 %	2.63	0.49
	5.4 %	37.1 %	2.37	0.49	40.0 %	2.40	0.50
	8.0 %	54.3 %	2.51	0.56	57.1 %	2.57	0.50
	Total	46.7 %	2.46	0.52	53.3 %	2.53	0.50
Scenario 2 - No solution	**3.7 %**	0.0 %	1.03	0.17	11.4 %	1.34	0.68
	5.4 %	5.7 %	1.14	0.49	5.7 %	1.14	0.49
	8.0 %	5.7 %	1.17	0.51	5.7 %	1.26	0.56
	Total	3.8 %	1.11	0.42	7.6 %	1.25	0.59
Scenario 3 - Cycle path	**3.7 %**	54.3 %	2.51	0.56	34.3 %	2.17	0.71
	5.4 %	68.6 %	2.69	0.47	65.7 %	2.60	0.60
	8.0 %	48.6 %	2.43	0.61	40.0 %	2.20	0.76
	Total	57.1 %	2.54	0.56	46.7 %	2.32	0.71

Table 9 shows that scenario 1 - cycle lane and scenario 3 - cycle path are the two most preferred scenarios in all gradients both up- and downhill. Besides this, there is no clear pattern between the different scenarios' score and gradient. In total, scenario 1 - cycle lane has a little higher score compared to scenario 3 - cycle path uphill. Downhill, it is opposite. Low scores are given to scenario 2 - no dedicated solution for cyclists both up- and downhill. However, it seems like scenario 2 - no dedicated solution for cyclists are more attractive downhill compared to uphill.

When comparing which solutions the respondents ranked as the most preferred solution up- and downhill, 72% of the respondents ranked the same solution highest up- and downhill.

Chi-square tests

The chi-square tests showed that there were no significant differences between the different scenarios. This applies to both up- and downhills. This means that the cyclists do not tend to rank any scenario higher at certain gradients.

Regression and correlation analyses

Table 10 shows what kind of cyclists that are more willing to rank the various scenarios higher compared to other cyclists, and at which gradients the different scenarios have been rank higher. The accompanying p-values are given in the parentheses for p-values below 0.1. For the correlation analyses, the Pearson Correlation coefficients are also given in the parentheses, before the p-value.

Table 10: Results from regressions and correlation analyses given for the three scenarios

Scenario	Factor	Uphill		Downhill	
		Regression	Correlation	Regression	Correlation
Scenario 1 Cycle lane	Gradient				
	Gender	Women (0.016)		Women (0.016)	Women (-0.167/0.086)
	Age	Older (0.085)	Older (0.202/0.039)		
	Helmet		With (0.166/0.091)		
	Cycle outfit	With (0.033)	With (0.244/0.012)		
Scenario 2 No solution	Gradient				
	Gender				
	Age				
	Helmet				
	Cycle outfit	With (0.051)	With (0.245/0.012)	With (0.010)	With (0.291/0.003)
Scenario 3 Cycle path	Gradient				
	Gender	Men (0.042)			
	Age	Younger (0.018)	Younger (-0.260/0.008)	Younger (0.092)	Younger (-0.173/0.078)
	Helmet				
	Cycle outfit	Without (0.063)	Without (-0.228/0.019)		

Uphill:

- Women, cyclists with increasing age and cyclists wearing helmet and cycle outfit generally rank scenario 1 - cycle lane higher compared to other cyclists.
- Cyclists wearing cycle outfit rank scenario 2 – no dedicated solution higher than other cyclists.
- Scenario 3 - cycle path is a solution generally ranked higher by men, cyclists with decreasing age and cyclists without cycle outfit.

Downhill:

- Women generally rank scenario 1 - cycle lane higher compared to men.
- Cyclists wearing cycle outfit tend to rank scenario 2 - no dedicated solution for cyclists higher than other cyclists.
- Cyclists with decreasing age generally rank the cycle path scenario higher compared to cyclists with increasing age.

Analyses of variance

Mean scores distributed by the cyclists' purposes, show no significant differences uphill. Regarding downhills, an analysis of variance showed significant differences among cyclists with different purposes of the trip. The significant differences relate to scenario 2 - no dedicated solution for cyclists. It seems like the cyclists with exercising as the main purpose, generally ranked scenario 2 – no dedicated solution for cyclists higher compared to other cyclists. This is significant on a 3.8%-level.

Binomial tests and paired t-tests

To see whether there were any significant differences between how many cyclists that had ranked scenario 1 – cycle lane and scenario 3 – cycle path highest, a binomial test were conducted. In addition, the paired t-test was conducted to determine significant differences between the mean scores for scenario 1 – cycle lane and scenario 3 – cycle path. Significant results on p-values below 0.10 from the binomial and paired t-tests are given in table 11. For the binomial tests, the scenario that is ranked highest by most cyclists are also given. For the paired t-test, the scenario with highest mean score are given.

Table 11: Results from the binomial and t-tests

	Uphill		**Downhill**	
Gradient	**Binomial test**	**Paired t-test**	**Binomial test**	**Paired t-test**
3.7 %	-	-	-	Scenario 1 – Cycle lane 0.021
5.4 %	Scenario 3 – Cycle path 0.080	Scenario 3 – Cycle path 0.054	-	-
8.0 %	-	-	-	Scenario 1 – Cycle lane 0.051
Total	-	-	-	Scenario 1 – Cycle lane 0.053

Table 11 shows that scenario 3 - cycle path are ranked significantly higher on uphills, and scenario 1 – cycle lane are ranked significantly higher on downhills. However, the p-values are in most of the cases above 0.05.

4. DISCUSSION

Our research has focused on what the preferences of cyclists regarding different cycle infrastructure solutions and possible placements on hills and if cyclists have different preferences to solutions and possible placements on up- and downhills and at different gradients?

When analysing the recommendations to solution, the analyses showed that the cyclists generally prefer scenario 1 – cycle lane and scenario 3 – cycle path rather than scenario 2 – no dedicated solutions. This correspond to earlier research that applies to cycle infrastructure solutions at flat terrain (Broach et al., 2012, Carter et al., 2013, Hunt and Abraham, 2007, Antonakos, 1994).

No clear patterns emerged between the possible placements or scenarios in any of the cases. This may be explained by local conditions. The interviews were conducted on hills with different traffic volumes. The hills were also of varying lengths. The speed limits were about the same, with small variations. Type of road, type of area and number of junctions and access roads were quite similar on the different hills. These are all factors that might affect the cyclists' preferences to cycle infrastructure solutions. However, some of the results from the binomial tests and t-tests show significant results concerning how the respondents ranked the solutions at different gradients. The results indicate that among the three scenarios, cyclists generally prefer scenario 3 – cycle path uphill, and scenario 1 – cycle lane downhill. The differences are small, and do not apply to all gradients.

The standard deviations to the accompanying mean scores for the different placements are generally high. This applies particularly to the left and right sidewalk and the road lane. High standard deviations indicate a wide range of the given points to the different possible placements. This underlines the variations to cyclists' preferences to possible placements and scenarios.

The variations of mean scores given at different gradients and on up- and downhills, may be caused by individual differences to safety feeling, or various speed preferences among cyclists. Some of the respondents mentioned that they feel it is safer for both themselves and pedestrians when they avoid the sidewalk at high speeds. Others express they avoid the sidewalk to prevent pedestrians that hinder the cyclists. There were also some respondents that preferred the sidewalk above the road lane because of increased safety feeling on the sidewalk.

The sample is not completely representative. The youngest respondent were 14 years old. In total, there were only three respondents under the age of 18. To investigate all type of cyclists' preferences, there should have been conducted more interviews among children. Findings from the focused interviews indicated, however that children prefer separated solutions. Apart from this, the distribution among different age groups, genders, use of helmet, use of cycle outfit and the cyclists' purpose of the trip appears to be good.

There were only 105 conducted SP-interviews. With a higher number of respondents, more results might be significant.

The results did not show any clear pattern regarding how the cyclists position themselves and which scenario they prefer at different gradients. Several respondents expressed, however, that the gradient and whether it was up- or downhill did affect their choice of placement and preferences to solution.

5. APPLICATION

According to the Norwegian Public Road Administration, the speed limit on the current hill is 50 km/h and has an AADT on 11850 (Statens Vegvesen, 2014). It passes maximum 14 busses in an hour (AtB, 2015). Besides this, it passes quite few heavy vehicles. The 1.6 km long road is a 4-lane collector road with sidewalks on both sides, mainly located in a residential area. The cycle volume is quite big, and is mainly consistent of commuters, cycling to or from the city centre. The street section is relatively narrow, with sidewalks on both sides. The road lanes are also narrow. Uphill, most of the cyclists cycle on the left sidewalk. Experiences from the SP-interviews indicate that this might be caused by the right sidewalk's closeness to a rocky wall uphill. Some respondents mentioned that the closeness to the rocky wall might give a claustrophobic feeling. They also mentioned that it is inconvenient to cross the street in the bottom of the hill. In the bottom of the hill, there is a cycle path where pedestrians and cyclists are separated. On the top, there are mixed paths for pedestrians and cyclists on both sides of the road. A photo of the current road are given below.

Figure 1: Photo of the current road

The road is located in a steep terrain, and the ability to increase the cross section of the road is limited. To facilitate better for cyclists, the road lanes and/or the sidewalks need increased widths or a dedicated solution for cyclists should be implemented. To obtain areas, it will probably be at the expense of the numbers of road lanes. With traffic volumes below 12 000, it should in principle be sufficient with a two-lane road. It is therefore suggested to use some of the road lane area, to better facilitate for cyclists. This requires that no large increase in traffic volumes is expected. It also requires that even if the number of road lanes are reduced to a two-lane road, the traffic flow should maintain sufficient. If this is not the case, other, possible routes should be examined and identified.

When asked to consider scenario 3 - cycle path uphill, in total 103 out of 105 would most likely position themselves in the cycle path. Among the respondents on this hill, 34 out of 35 would most likely position themselves in the cycle path. Downhill, the corresponding number is 94 out of 105 in total and 32 out of 35 for this hill. Given scenario 1 – cycle lane, 87 out of 105 in total and 27 out of 35 in this hill will most likely position themselves in the cycle lane uphill. Downhill this is 92 out of 105 in total and 30 out of 35 in this hill. This means that a few more cyclists will make use of the cycle infrastructure solution if a cycle path is implemented, compared to the implementation of a cycle lane.

When the cyclists on this hill were asked to rank the three different scenarios, most of the cyclists ranked cycle path as the most preferred solution both up- and downhill. Based on how the cyclists ranked the different scenarios on this hill, cycle path is the most suitable solution both up- and downhill. Uphill, this is a solution ranked high by cyclists with all kind of purposes. Comparing the mean scores given for scenario 1 – cycle lane and scenario 3 – cycle path in table 9, scenario 3 – cycle path is in total given higher mean score both up- and downhill. Uphill, this applies to all cyclists, except from the cyclists who have exercise as the main purpose of the trip. These cyclists have given the scenario 1 – cycle lane a mean score above scenario 3 – cycle path. Downhill, this applies to cyclists with all kinds of purposes. These are results that applies to the cyclists in the evaluated hill only.

Based on the above – and the analysis of cyclists' preferences – the following recommendation is given: A separated cycle path on the left side of the road uphill is recommended in this case. Left side of the road uphill is recommended because of the rocky wall on the other side of the road, which might feel unpleasant to cycle near. A cycle path on the left side uphill, also gives a continuous cycle infrastructure solution from the stretch before the uphill. To provide a solution for pedestrians and cyclists who are not very likely to position themselves in the cycle path, sidewalk on both sides of the road should also be implemented.

If a cycle lane were to be implemented instead of a cycle path, crossing the road at the bottom of the hill, should be facilitated better.

This is a recommendation that will please many cyclists. On the other hand, there will also be many cyclists that would prefer other cycle infrastructure solutions to be implemented. Compared to the current solution, cycle path is a preferred solution among most of the cyclists. This applies both up- and downhill.

This is a recommendation for one case. On other hills, other facilities might be better. Local conditions must therefore be considered. Surveys to investigate cyclists preferences before implementing solutions, might also be useful.

6. CONCLUSIONS

Introductorily, it was written about how there does not exists a single *correct* cycle infrastructure solution because of the varying preferences among cyclists (Minnesota State Department of Transportation, 2007). Cyclists' preferences to cycle infrastructure solutions on hills seems to vary as well. So do how the cyclists are most likely to position themselves at different scenarios. In addition to personal characteristics and the cyclists' purpose of the trip, whether the hill is up- or downhill also influence cyclists' preferences. Because of this, it is difficult to give a recommendation to cycle infrastructure solutions on hills and at different gradients.

When choosing cycle infrastructure solution, it is important to consider local conditions. If the cyclists' preferences' are uncertain, it might be useful to conduct stated preference-interviews. If the analyses appears to provide no certain results, the contact with the respondents out in field might be valuable.

Even though cyclists are more willing to position themselves in the road lane downhill compared to uphill, cycle infrastructure solutions are preferred above no dedicated solution for cyclists. This applies both up- and downhill. The mean scores estimated from the stated preference-interviews showed that cyclists generally rate scenario 3 – cycle path higher than scenario 1 – cycle lane uphill, and scenario 1 – cycle lane higher than scenario 3 – cycle path downhill. Downhill, this is a statistic significant result. Uphill, it only shows an indication.

According to the results above, a cycle path uphill, and cycle lane downhill should be recommended. However, it is unknown how suitable the combination will be in practice. Traffic safety issues and transitions between other cycle infrastructure solutions on the top and bottom of the hills are problems that might occur. Further research should therefore include examination about how suitable this combination is. Implementations of test stretches with a cycle path uphill and a cycle lane downhill may be appropriate. This study only include preferences to two-way cycle paths. One-way cycle paths uphill might also be an opportunity, and further research should therefore be done in both cases.

It is unknown whether these findings applies to hills generally, or only the hills were the interviews were conducted. To determine this, further work with more interviews in other hills or observational studies on hills need to be conducted. To determine how the volume of pedestrians, traffic volume or the possible placements widths' affects the cyclists' preferences, these are factors that might be included in further research.

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