Analysis of cyclist-pedestrian interactions at a floating bus stop site in Edinburgh, United Kingdom

Report by Monika Grigorova and Professor Tom Rye

Edinburgh Napier University

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1. Introduction

1. Background and objectives

The City of Edinburgh Council commissioned the Transport Research Institute (TRI) of Edinburgh Napier University to undertake an assessment of the interactions occurring between pedestrians and cyclists at the newly built floating bus stops on Leith Walk, Edinburgh. The Council supplied the TRI with video recordings of several sites of which one was selected for analysis due to the better positioning of the cameras and thus better visibility of the interactions. The layout of the floating bus stop at the site chosen for analysis is illustrated on Image 1.

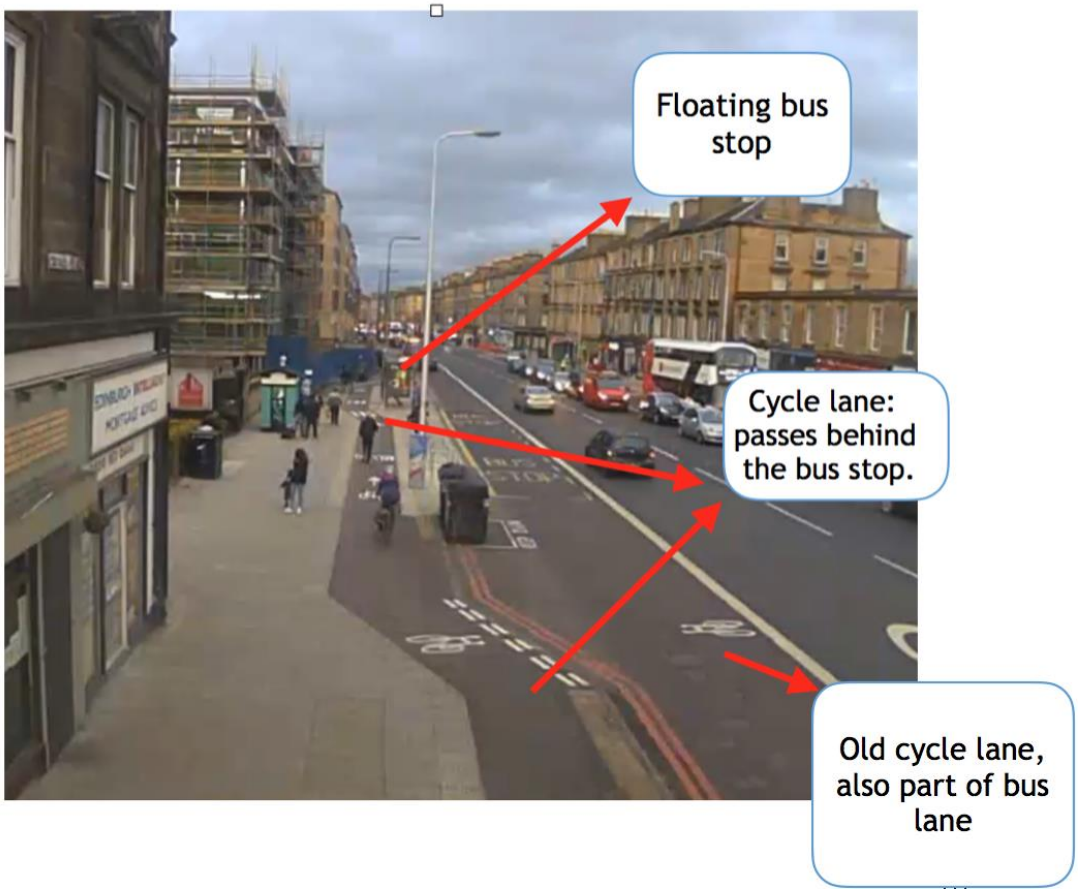

Image 1. The floating bus stop and cycle lane at the analysed location.

The conflicts occurring between pedestrians and cyclists are analysed by the means of interaction analysis which characterises interaction events on a scale from 1(least severe) to 5 (most severe). This approach will help identify the most severe conflicts and evaluate the factors and patterns of behaviour associated with them.

The specific aims of the current investigation are:

- To extract the interactions occurring between pedestrians and cyclists from the video recordings provided;
- To characterise the interactions according to a pre-defined severity scale;
- To extract the patterns of interaction and the factors which contribute to conflict;
- To make recommendations for improvement.

2. Literature review

2.1. Interaction analysis

The interaction analysis used in the current study categorises the observed interactions between cyclists and pedestrians into five categories of increasing severity. This methodology was introduced by the MVA consultancy (2010) who applied it to assess the levels of conflict between motorised vehicles, cyclists and pedestrians before and after the change of signage at two sites in London. This method has been subsequently used in the context of driver – pedestrian interaction. Sterling et al. (2009) assessed the severity of conflict interactions associated with re-timing of the "green man" signal at 9 signal controlled junctions in London. More recently, Sustrans RMU (2016) applied interaction analysis to the study of pedestrian – cyclist interactions at 2 floating bus stops in Cambridge. Thus, the methodology in question has already been directly applied to sites and road-users similar to those of the current study. Furthermore, the 5-level interaction analysis provides more detail and better sensitivity to less severe conflicts than employing analyses with fewer levels of interaction such as the encounter – conflict – collision categorisation used by Walker et al. (2005) in studying pedestrian – vehicle conflicts at Puffin and Pelican crossings. Therefore, the 5-level interaction methodology was chosen for the purposes of the current study. The 5 levels are shown and explained in Table 1.

2.2. Cyclist – pedestrian interactions at bus stops

Two studies of pedestrian – cyclist interactions at bus stops were identified from the literature. Afghari et al. (2014) characterised the interaction between cyclists and pedestrians when the latter need to cross a cycle path in order to reach a bus stop. Their conflict severity assessment was based on extracted by computer vision movement trajectories and speed. Although relevant to the current investigation of how bus stop – cycle lane proximity affects interactions between pedestrians and cyclists, the focus of Afghari et al. (2014)'s study was on the development of a methodology for automatic collection and analysis of interaction data. The second study identified was the above mentioned Sustrans RMU (2016) investigation of pedestrian - cyclist conflicts at floating bus stops through interaction analysis. This study showed that the majority of observed interactions were within the scope of safe and normal behaviour and precautionary action was taken by the pedestrian and/or cyclist with ample time for manoeuvre. They also found that within their data sample pedestrians were more likely to take evasive actions than cyclists. The current study extends these findings through a case study of a floating bus stop on Edinburgh's Leith Walk.

2. Methodology

2.1. Site characteristics and data collection

Leith Walk is one of the main arterial routes connecting the area of Leith in the North of Edinburgh to the City Centre. Heavy pedestrian flow is observed during rush hours, the busiest time being between 16:00 and 19:00 in the evening.

Image 1 illustrates the camera view used for analysing the interactions occurring at the bus stop area. The Wondershare Filmora Video Editor software was used for viewing of the videos. Five weekdays (Monday to Friday, 1st to 7th of November, 2017) were selected for analysis. Data reduction was carried out on the recorded hours between 07:30 in the morning and 19:00 in the evening. This captured both the morning and evening rush hours as well as the calmer periods in between. Thus, the total length of video analysed was 62.5 hours.

2.1. Interaction analysis

For each observed interaction a score 1 – 5 was assigned according to how well the interaction fitted the criteria described in Table 1. The distinction between Precautionary Action and Controlled Action was subtle. 1 was generally assigned to interactions when the pedestrian or cyclist took the required precautionary action well in advance of the encounter. A 2 was assigned when the evasive action took place closer to the point of hypothetical collision which also made the evasive action riskier, faster and put the road users in closer proximity to each other. The best judgement of the scorer was used at instances which were ambiguous and a detailed description of the encounter was provided in order to illustrate what the decision was based on. Additionally, for each interaction it was noted whether the pedestrian and cyclist were facing each other. It was also noted whether or not there was a bus at the bus stop and whether the pedestrian was headed towards the bus or was leaving the bus stop area after alighting from a bus. The quality of the video material did not allow the exploration of additional variables such as gender, age and the speed of the cyclists and how these relate to the frequency and severity of the interactions.

Scale 0 -5	Category name	Criteria
0	No interaction	No response required by cyclist or pedestrian
1	Precautionary action	Anticipatory braking/ slowing down, risk of collision is minimal
2	Controlled action	Controlled braking, slowing down or stepping aside to avoid collision (ample time for manoeuvre)
3	Near miss	Rapid deceleration, stopping or quickly moving aside to avoid collision, resulting in a near miss situation
4	Very near miss	Emergency braking, violent swerve or movement to avoid collision, resulting in a near miss situation.
5	Collision	Emergency action followed by collision

Table 1. Levels of interaction within the interaction analysis methodology (MVA, 2010).

3. Results

1. Overview of all interactions

A total of 101 pedestrian-cyclist interactions were observed. 24 of these were given a severity rating of 2 and 3 were given a severity rating of 3. As expected, and similarly to Sustrans (2016)'s study, no interactions at more severe levels were observed. The full table with interactions ranging 1 to 3 can be found in the Appendix.

Table 2 shows the frequency and severity of interactions according to the time of day. More interactions occurred in the afternoon hours. This is likely to be the case due to the higher number of people and cyclists observed to use and pass by the floating bus stop in the afternoon. Table 3 shows the percentage frequency and severity of interactions according to where the cyclists and pedestrians are facing during the interaction. The table suggests that there are more interactions when cyclists and pedestrians are not facing each other. The interactions in this case are also of higher severity: 20% of the interactions were above score 1 when the pedestrians are not facing each other as compared to 5% of interactions above score 1 when they are. Table 4 shows the percentage frequency and severity of interaction according to whether the pedestrians' movements were related to the bus stop, and whether or not there was a bus at the bus stop at the time of interaction. Visual inspection of the frequency of interaction when pedestrians' movements are related to the bus stop and when they are not, shows that there are more interactions of lower severity (n = 45) when movements are not related to the bus stop than when they are (n=31). At severity levels above 1 the frequency of interaction for the related (n = 11) is slightly lower than the unrelated (n=16) to the bus stop movements.

Table 5 suggests that the most common cause of interaction is pedestrians treating the cycle lane as an extension of the pavement by walking on it (75%). This cause is followed by pedestrians crossing the cycle lane (16%) and the least number of conflicts is caused by pedestrians waiting or standing on the cycle lane (10%).

score	Monday			Tuesday			Wednesday			Thursday			Friday		
-	am	pm all	pm dark	am	pm all	pm dark	am	pm all	pm dark	am	pm all	pm dark	am	pm all	pm dark
1	9	13	8	2	13	9	3	9	4	3	13	4	3	10	3
2	2	4	3	2	4	4	0	1	1	0	3	1	2	4	2
3	0	1	0	0	1	1	0	0	0	0	0	0	1	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2. The frequency of interaction with severity scores 1 - 5 spread across the different days of the week and times of day. It should be noted that in November sunset occurs at approximately 16:25 and the column “pm dark” indicates the number of interactions occurring after this time.

Score	Ped. & Cyclist facing each other	Ped. & Cyclist not facing each other	Total frequency
1	30%	45%	76
2	4%	17%	22
3	1%	3%	7
4	0%	0%	0
5	0%	0%	0

Table 3. The frequency of interactions of different severity according to where the pedestrians and cyclists are facing. Total frequency in this table is different from the total number of interactions because for some interactions there were pedestrians facing both towards and away from the cyclist.

Score	Ped. headed towards bus stop	Ped. walking away from bus stop	Ped. waiting for bus on cycle lane	Total bus-stop-related interactions	Non-bus-stop-related interactions	Bus at bus stop	Bus not at bus stop	Total interactions
1	26%	38%	10%	31	45	35%	43%	76
2	10%	12%	2%	10	14	8%	11%	24
3	2%	0%	0%	1	2	1%	2%	3
4	0%	0%	0%	0	0	0%	0%	0
5	0%	0%	0%	0	0	0%	0%	0

Table 4. Percentage interactions resulting from pedestrians walking towards, away from bus stop or waiting for a bus on the cycle lane (calculated from the total number of bus-stop-related interactions); total number of non-bus-stop-related interactions; percentage interactions during which the bus was or was not at the bus stop (calculated from the total number of interactions).

Score	Walk on cycle lane	Cross cycle lane	Wait on cycle lane	Interaction caused by 2 or more people	Interaction caused by 1 person	Total interactions
1	60%	9%	8%	21%	54%	76
2	14%	6%	1%	9%	12%	24
3	1%	1%	1%	1%	2%	3
4	0%	0%	0%	0%	0%	0
5	0%	0%	0%	0%	0%	0

Table 5. Percentage interactions of different severity according to whether pedestrians were walking, crossing or waiting on the cycle lane, and whether the interaction was caused by more than one pedestrian or only one pedestrian.

2. Focus on the most severe conflicts

The focus of this section is on interactions which scored 2 or 3 on the severity scale. Examples from different types of scenarios are chosen.

2.1. Interactions between a pedestrian and cyclist not facing each other

Conflict A

This conflict received a score of 2 because of the late and fast evasive action taken by the cyclist which resulted in a short passing distance between him and the pedestrian.

No	Time	Description	Scale	Pedestrian(s) facing	Cyclist facing	Bus stop activity
4	11:35:27	Elderly ped. walks onto the centre of the cycle lane while a cyclist is approaching, the cyclist takes the evasive action and swerves to the right side and onto the pavement relatively late which results in a riskier interaction.	2	away (from camera)	away (from camera)	Bus is not at stop. Ped. is not walking towards bus stop.

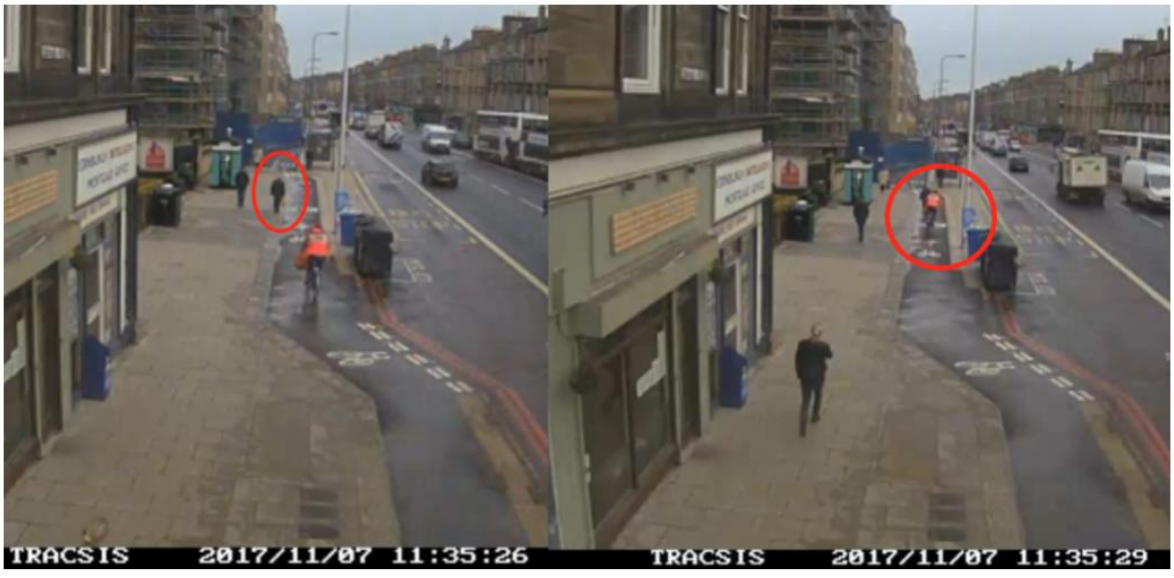

Image 2. Conflict A

2.2. Interactions where a pedestrian crosses the cycle lane, unrelated to bus stop

Conflict B

This pedestrian in this conflict became aware of the cyclist in time and took action. There was no immediate danger for either of them but it received a score of 2 because of the urgency of the response of the pedestrian who moved back to the pavement quickly and in a relatively uncontrolled manner.

20	18:56:52	Pedestrian starts to cross the cycle path but sees the approaching cyclist and quickly moves back and waits for the bike to pass by before attempting to cross again.	2	To the left	away	No bus at bus stop and pedestrian does not come from a bus.

Image 3. Conflict B

Conflict C

This was one of the most severe interactions observed. It received a score of 3 because of the urgent braking needed from the cyclist and the near miss situation resulting from the pedestrian crossing the cycle lane without assessing it for oncoming cyclists.

No	Time	Description	Scale	Pedestrian(s) facing	Cyclist facing	Bus stop activity
6	11:24:12 Interaction is outside of floating bus stop area.	A pedestrian starts to cross the cycle lane in order to reach a parked vehicle. He does not look around and the approaching cyclist does not take timely evasive action resulting in rapid breaking by the cyclist and a near miss situation.	3	To the right	away (from camera)	Bus is not at bus stop. Pedestrian is not headed towards bus stop.

Image 4. Conflict C

2.3. Interactions involving more than one pedestrian and crowding of the cycle lane

Conflict D

This conflict received a rating of 2 due to the significant and immediate reduction in speed required from the cyclist in order to avoid collision. The pedestrians involved were not aware of the presence of the cyclist as they were walking on the cycle lane with their back to him.

No	Time	Description	Scale	Pedestrian(s) facing	Cyclist facing	Bus stop activity
15	16:15:34	Pedestrian 1 walks on the cycle lane. Pedestrian 2 walks just next to the cycle lane and has an intention to cross it. There is little space between ped. 1 and 2 for the approaching cyclist to negotiate his way and ped. 1 has her back to the cyclist. The cyclist needs to make several zigzagging movements and slow down significantly in order to pass safely by the pedestrians. Ped. 1 makes slight evasive actions once she becomes aware of the cyclist behind her.	2	Ped 1 away (from camera) Ped 2 towards (camera)	away (from camera)	Bus is not not at bus stop. Pedestrians are not headed towards bus stop.

Image 5. Conflict D

Conflict E

This conflict was the most severe observed in the dataset. It involved a pedestrian walking on the cycle lane, pushing a buggy and stopping in the middle of the cycle lane. The approaching cyclist needed to take an evasive action by moving onto the pavement which resulted in a near miss situation with a running pedestrian who was unaware of the approaching cyclist.

No	Time	Description	Scale	Pedestrian(s) facing	Cyclist facing	Bus stop activity
13	17:43:48	Pedestrian 1 with a buggy stops in the middle of the cycle lane. The approaching cyclist swerves to the left in order to go around her, the cyclist goes onto the pavement where pedestrian 2 approaches running and this results in a near miss between the running pedestrian and the cyclist.	3	Ped. 1 towards (camera) Ped. 2 away (from camera)	away	Bus not at bus stop and pedestrian 2 is not running towards the bus stop.

Image 6. Conflict E

Conflict F

This conflict received a score of 2 because of the need for several cyclists to react quickly and reduce their speed in order to avoid collision with a large group of pedestrians, some of which are walking on the cycle lane. This conflict is an example of the cycle lane being occupied by pedestrians due to crowding of the surrounding areas.

No	Time	Description	Scale	Pedestrian(s) facing	Cyclist facing	Bus stop activity
15	18:13:20	A situation of crowding of the cycle lane. Two pedestrians (ped. 1 and 2) walk on the cycle lane while the pavement is occupied as well. Three cyclists approach one after the other and they need to slow down significantly before the cycle lane clears and allows them to pass.	2	Ped 1 away (from camera), ped 2 towards (camera)	away (from camera)	Bus not at bus stop and pedestrians do not originate from or are headed towards the bus stop.

Image 7. Conflict F

Conflict G

This situation received a score of 2 due to the short passing distance between the approaching cyclist and the pedestrians. This was partly due to the cyclist taking the evasive action relatively late.

No	Time	Description	Scale	Pedestrian(s) facing	Cyclist facing	Bus stop activity
17	16:48:24	Two pedestrians are walking on the cycle lane, occupying it entirely. A cyclist approaches from the road with a high speed. The cyclist needs to reduce speed significantly and take evasive action by swerving to the left. One of the pedestrians also takes evasive action by retracting to one side of the cycle lane.	2	towards	away	Bus is not at bus stop. The pedestrians do not originate from the bus stop.

Image 8. Conflict G

3.4. Interactions where the pedestrians' movements are related to the bus stop (headed towards bus stop, leaving bus stop, waiting for the bus).

Conflict H

This situation received a score of 2 because the cyclist did not take evasive action. The pedestrian, who is waiting for the bus while standing on the cycle lane, makes the effort in avoiding collision at the last moment.

No	Time	Description	Scale	Pedestrian(s) facing	Cyclist facing	Bus stop activity
28	19:02:06	Pedestrian is pacing the cycle lane and waiting. The approaching cyclist does not take evasive action until the last moment and the pedestrian makes the bigger effort in avoiding collision by stepping forward out of the way of the cyclist at the last moment.	2	To the right	away (from camera)	Bus is not at the bus stop. Pedestrian is waiting for a bus.

Image 9. Conflict H

Conflict I

This conflict received a rating of 2 due to the short passing distance between the cyclist and the pedestrian. This is partly due to the cyclist taking evasive action late and partly due to the pedestrian moving in the direction of the overtaking cyclist.

No	Time	Description	Scale	Pedestrian(s) facing	Cyclist facing	Bus stop activity
18	16:05:20	Pedestrian walks on the cycle lane. The approaching cyclist swerves to the right to pass at safe distance. During the cyclist's manoeuvre the pedestrian starts crossing towards the bus station without being aware of the cyclist. This results in a shorter passing distance between the two.	2	Away (from camera)	away (form camera)	Bus approaches bus stop. The pedestrian is headed towards the bus stop and the bus.

Image 10: Conflict I

Conflict J

This conflicts receives a score of 2 due to the significant response required by the cyclist who needs to brake and almost stop in order to avoid collision with a group of pedestrians.

No	Time	Description	Scale	Pedestrian(s) facing	Cyclist facing	Bus stop activity
17	15:27:04	A big group of pedestrians alights from the bus and starts crossing the cycle lane. The approaching cyclist needs to swerve to the left, reduce speed significantly (almost stop) in order to pass by them safely.	2	Various and not clearly visible	away (from camera)	Bus at bus stop and pedestrians originate from bus.

Image 11. Conflict J

Conflict K

This conflict receives a score of 2 due to the late evasive action taken by the cyclist and the pedestrian being unaware of the presence of the cyclist. These result in short passing distance between the two.

No	Time	Description	Scale	Pedestrian(s) facing	Cyclist facing	Bus stop activity
24	18:08:51	Pedestrian alights from bus and goes onto cycle lane starting to walk on it. Cyclist comes from behind and needs to take evasive action close to the pedestrian in order to avoid collision.	2	away (from camera)	away (from camera)	Bus is at bus stop and the pedestrian originates from the bus.

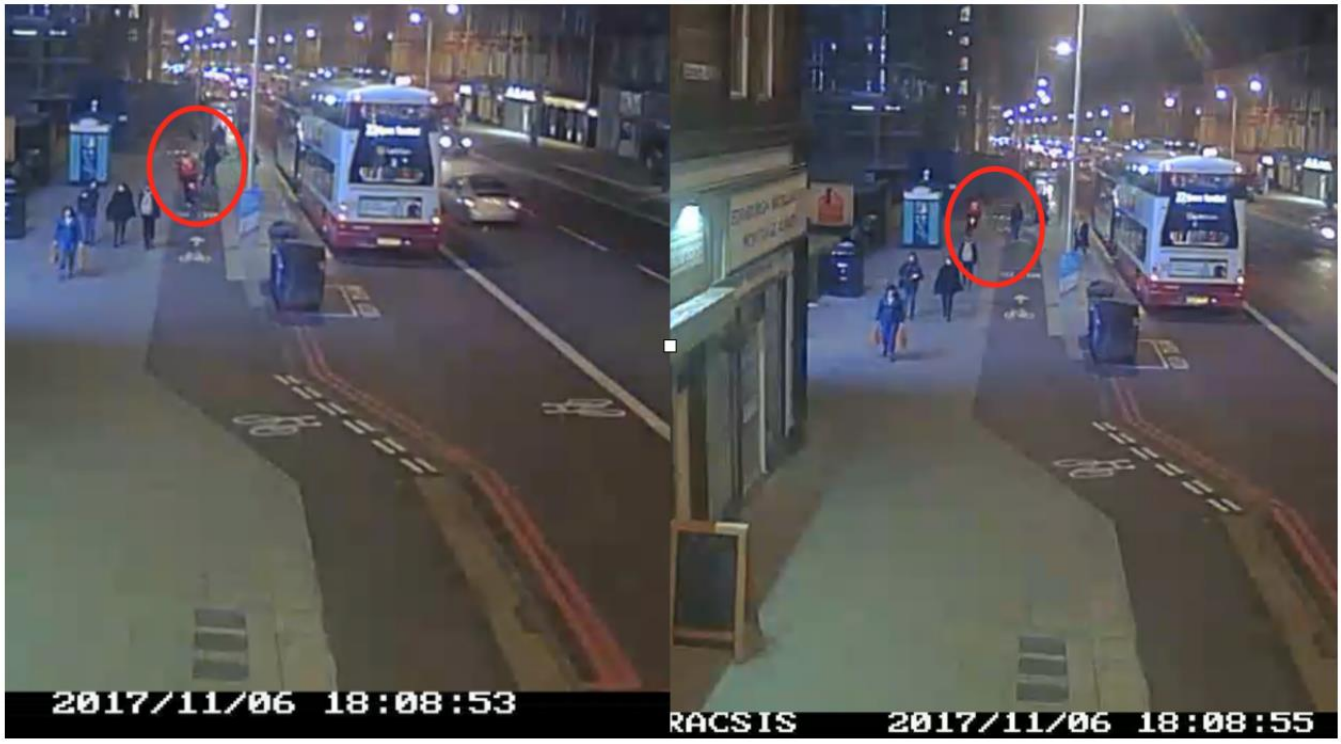

Image 12. Conflict K

4. Emerging patterns of interaction

The cases highlighted in the Results section have illustrated some of the patterns observed in pedestrian - cyclist interactions. The most important factors which contribute to the number and severity of the conflicts will be discussed below.

4.1. Pedestrians walking on the cycle lane, facing or not facing the cyclist

Inspection of the full interaction analysis table in the Appendix shows that the three main causes of pedestrian - cyclist interaction are pedestrians walking on, crossing or waiting on the cycle lane. While pedestrians walked on the cycle lane only a small number of cyclists were observed to violate the direction of movement or to cycle outside of the cycle lane when there was sufficient space on it.

The conflicts which occurred on the pavement (for example conflict E) were caused by the need for the cyclist to swerve around pedestrians who were walking on the cycle lane (in the case of conflict E it was a woman who stopped a buggy in the middle of the cycle lane). Furthermore, Table 5 confirms that it is pedestrians walking and waiting on the cycle lane, rather than those who just attempt to cross it, who cause the majority of conflicts with cyclists. Thus, it can be concluded that walking on the cycle lane is the most common underlying cause of pedestrian - cyclist conflict at the floating bus stop. This is a similar finding to Sustrans (2015)'s report which showed that pedestrians using the cycle lane as an extension of the pavement ware the most common cause of conflict with cyclists.

As illustrated in Table 2, conflicts occurred both when pedestrians and cyclists were facing each other and when they were not. The number and severity of conflicts, however, were higher when they were not facing each other. Conflicts A, I, and K are an illustration of the complications which arise when the cycle lane users are not facing each other. During Conflict A the elderly pedestrian is completely unaware of the approaching cyclist behind him. Thus, the cyclist is the one who needs to take evasive action and leave the cycle lane in order to avoid collision. In all three conflicts mentioned the cyclist takes the evasive action relatively late which results in shorter passing distance. In Conflict I this escalates further because the pedestrian decides to move in the direction of the cyclist while the cyclist is overtaking him. In this way the unaware pedestrian shortens even further the passing distance between himself and the cyclist. Therefore, the problem arising for cyclists from pedestrians walking with their back to them is the unpredictability of the pedestrians' movements which can potentially cause a conflict of higher severity.

4.2. Overcrowding of the pavement

As illustrated in Table 5, 30% of the interactions are caused by more than one pedestrian or a crowd of pedestrians. At higher severity levels the number of interactions caused by more than one person approaches the number of those caused by only one pedestrian. Overcrowding of the cycle lane was observed predominantly in the late afternoon and early

evening hours. The overcrowding was sometimes associated with large groups of pedestrians alighting from the bus stop, as shown in Conflict J. Due to the large number of people present at the same time, some of the pedestrians walking on the cycle lane might not have noticed that they are, in fact, walking on a cycle lane. However, not all instances of crowding were due to the bus stop. Conflicts D and F demonstrate the situation where the (unrelated to the bus stop) flow of pedestrians on the pavement pushed some of the pedestrians to walk on the cycle lane instead. One consequence of this type of scenario is that the cyclists need to significantly reduce their speed and even stop and wait for the cycle lane to clear as they cannot negotiate their way around the pedestrians (as happens in Conflict F). A further complication which arises from overcrowding is when pedestrians are not facing the cyclist who in turn takes the decision to zigzag between the pedestrians rather than stop and wait. This results in short passing distances as illustrated in Conflict D.

4.3. Pedestrians moving away or towards the bus stop

The presence of a bus stop in close proximity to the cycle lane accounts for 42 conflicts compared to 61 conflicts not related to the bus stop. However, at severity level 2 the number of conflicts related to the bus stop (n=10) is close to those not related to it (n = 14), as illustrated in table 4. This demonstrates that the bus stop is one of the causal factors in pedestrian-cyclist interactions. Movement towards or away from the bus stops seems to account for the larger number of conflicts (n = 38% and 50%, respectively), while waiting for the bus on the cycle lane accounts for a much lower number (12%). These interactions are complicated when the pedestrians seem to be looking away from the cyclist during their movements, as happens in Conflict K. The pedestrian there alights from the bus and crosses the cycle lane immediately without looking around. Another such example is Conflict J where a group of pedestrians alights from the bus stop, crowds the cycle lane, and comes into conflict with the cyclists on it. Being part of a larger group could be helping pedestrians feel more visible to cyclists and thus they do not feel the pressure to assess the cycle lane before crossing. As discussed earlier, the pedestrians who alight from the bus as part of a group might also not notice the markings of the cycle lane immediately due to the number of people on and around it. Pedestrians who choose to wait on the cycle lane instead of the bus stop itself do not seem to do so because of crowding of the bus stop. Standing on the cycle lane appeared to be a personal preference (Conflict H). Finally, pedestrians who walk towards the bus stop seem to be focused on reaching the bus stop and this being their immediate goal they forget to watch for cyclists approaching on the cycle lane. This seems to be the case in Conflict I where the pedestrian crosses towards the cycle lane and is unaware of the cyclist behind him.

5. Recommendations for action

The severity of the interactions between pedestrians and cyclists would be improved with an increase in the pedestrians' awareness of the design of the floating bus stop and through

discouraging them from using the cycle lane as an extension of the pavement. Furthermore, increasing the alertness of the cyclists before they enter the bus stop area and encouraging them to lower their speed could potentially lower the severity of the interactions.

Some of these goals could be achieved through a local information campaign which can include a section of the inner and outer sides of the bus stop containing a display of the design of the bus stop and a reminder for pedestrians that there is a cycle lane. This can be presented through an eye-catching image of the bus stop, the participants in interactions at the bus stop, and short sections of explanatory text.

Some infrastructure-related improvements could aim to decrease the cyclists' speed before they enter the area of the floating bus stop. This could be achieved through a specific textured surface which encourages lower speeds, combined with "SLOW" markings on the ground. The tendency of the pedestrians to stand and walk on the cycle lane could be decreased by altering the transition from the pavement to the cycle path through changing the level of the cycle path or the transition surface. Finally, appropriate signage could also be employed to increase the alertness of both cyclists and pedestrians.

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Appendix