City Research Online

City, University of London Institutional Repository

Citation: Kaparias, I., Bell, M. G. H., Biagioli, T., Bellezza, L. & Mount, B. (2015). Behavioural analysis of interactions between pedestrians and vehicles in street designs with elements of shared space. Transportation Research Part F: Traffic Psychology and Behaviour, 30, pp. 115-127. doi: 10.1016/j.trf.2015.02.009

This is the accepted version of the paper.

This version of the publication may differ from the final published version.

Permanent repository link: https://openaccess.city.ac.uk/id/eprint/6942/

Link to published version: https://doi.org/10.1016/j.trf.2015.02.009

Copyright: City Research Online aims to make research outputs of City, University of London available to a wider audience. Copyright and Moral Rights remain with the author(s) and/or copyright holders. URLs from City Research Online may be freely distributed and linked to.

Reuse: Copies of full items can be used for personal research or study, educational, or not-for-profit purposes without prior permission or charge. Provided that the authors, title and full bibliographic details are credited, a hyperlink and/or URL is given for the original metadata page and the content is not changed in any way.

City Research Online: http://openaccess.city.ac.uk/ publications@city.ac.uk

BEHAVIOURAL ANALYSIS OF INTERACTIONS BETWEEN PEDESTRIANS AND VEHICLES IN STREET DESIGNS WITH ELEMENTS OF SHARED SPACE

I. Kaparias[1], M.G.H. Bell[2], T. Biagioli[3], L. Bellezza[1], B. Mount[3]

1 Collaborative Transport Hub, City University London, UK

2 Institute of Transport and Logistics Studies, University of Sydney, Australia

3 Centre for Transport Studies, Imperial College London, UK

ABSTRACT

This paper describes the development and implementation of qualitative behavioural criteria in order to analyse the conduct of pedestrians and vehicles when they are required to interact with each other, with particular interest to street designs with elements of shared space. The new behavioural analysis technique is developed by identifying the fundamental principles that underpin existing traffic analyses, such as traffic conflicts techniques, and adapting those to a qualitative framework that describes the mindset and rationale of road users. The technique is then applied to a case study in London, using video data from periods before and after the redevelopment of the Exhibition Road site from a conventional dual carriageway to a modern design with some elements of shared space. With the main goals being to assess the pedestrians' confidence and the vehicles' tolerance/patience when forced to interact with each other, behavioural trends are related to instantaneous characteristics of the vehicle flow (vehicle approach speed and traffic density). The data produced are used to develop and validate qualitative behavioural relationships for pedestrian-vehicle interactions, as well as location-specific conclusions for the Exhibition Road site.

1 INTRODUCTION

Urban street design has traditionally been very closely tied with road safety. The latter has been a concern since the introduction of motorised vehicles, and became paramount with mass motorisation from the 1950s onwards. Of particular importance was the protection of pedestrians, who, being more vulnerable, faced greater risk of suffering injury or death. This was pursued by means of their segregation from vehicular traffic, which, dating back at least to the work of Le Corbusier in the 1930's, relied upon the design and implementation of structures including pedestrian subways and bridges, as well as guardrails and walls separating pedestrian pathways from the road, which in turn was reserved for vehicles. The concept is set out most lucidly in Buchanan's 'Traffic in Towns" report (1) of 1963, which served as a street design manual in the UK for many decades.

In recent years, however, there has been a trend away from traffic segregation, driven by developments in architecture and urban planning. Instead, street design and traffic engineering have seen a shift in focus from vehicles to pedestrians as a means of creating a better public realm, mainly by asserting the function of streets as places rather than arteries and designing more to a scale aimed at easier pedestrian movement and lower vehicle speeds. Examples of this approach include: the removal of segregating features such as street furniture, signage and kerbs; the introduction of more "informal" (uncontrolled) pedestrian crossing facilities; or the re-engineering of layouts with a single surface and little or no delineation between pedestrian and vehicle areas (2-6).

As part of the trend away from traffic segregation, the concept of "shared space" has emerged in recent years. Shared space is defined by the UK Department for Transport as "a street or place designed to improve pedestrian movement and comfort by reducing the dominance of motor vehicles and enabling all users to share the space rather than follow the clearly defined rules implied by more conventional designs" (7). As such, and conversely to popular belief, the term "shared space" is not used to characterise entire streets and places as "shared" or "not shared", particularly given that streetscape design cannot be standardised and needs to be context-sensitive. Instead, shared space is used as an "umbrella" term to collectively refer to a range of streetscape treatments, aiming at creating a more pedestrian-friendly environment. Examples of streets with varying extents of shared space elements can be found around the world and include: the concept of "woonerf" and "home zone" in residential areas in the Netherlands and UK respectively; the "Manual for Streets" approach in the UK (8-9); and the "Complete Streets" initiative in the USA (10).

The shared space concept has been met with mixed reactions from different road user groups. Opponents of the concept (such as some elderly and disabled road users) have expressed their discomfort towards the idea because they perceive it as less safe (6, 11). Proponents, on the other hand, have suggested that shared space actually contributes to the improvement of road safety, mainly due to the introduction of ambiguity, which makes both drivers and pedestrians more vigilant (3). From a traffic engineering perspective, the latter view is a paradox, since shared space introduces a greater degree of vehicle-pedestrian interaction. This highlights the need to analyse the interactions between vehicles and pedestrians from a behavioural perspective. It should be clarified here, though, that this is different from traffic conflicts analysis, a method of which has recently been developed and applied (12-13), as it does not focus on the mechanics of the interaction (i.e. speed, direction etc.), but on the qualitative behaviour of the road users which may or may not lead to a conflict (or accident) situation.

More specifically, the framework defined by Hydén (14) and conceptualised by Svensson and Hydén

(15) is followed here, according to which the range of interactions is represented by a pyramid, the height and width of which denote the severity (from “undisturbed passages” to “fatal accidents”) and occurrence frequency of interaction events respectively. In an extension of the framework (16), interactions are further classified in a diamond, as it is argued that the occurrence of the least severe events is rare when road users are undisturbed by other road users. The framework is illustrated in Figure 1, as fully presented by Laureshyn et al. (17), and the present work focuses on what is defined as “encounters of medium severity”, which comprise the majority of road user interactions. In the graphical representation, these cover roughly the “potential conflicts” and the top half part of the “undisturbed passages” slices of the pyramid (Figure 1a), and the central portion of the diamond (Figure 1b).

[Figure 1 here]

The present paper has two key objectives. The first objective is to present a new qualitative behavioural analysis technique for the vehicle-pedestrian interaction events defined, for use in both conventional and shared space environments. This is expected to complement the work of Laureshyn et al. (17) by providing a means of conducting behavioural observations in the public realm in a systematic way. The second objective is then to apply the new method on a redeveloped street layout in a before- and after-context and to draw conclusions as to changes in the behaviour of drivers and pedestrians following the redevelopment. The work has been carried out as part of a traffic monitoring programme of the Exhibition Road project, comprising the conversion of the layout of the Exhibition Road site in London’s South Kensington area from a conventional dual carriageway to a single surface, featuring a number of elements of shared space.

The paper is structured as follows: Section 2 presents the background of the study through a review of traffic conflicts and behavioural analysis methods. Section 3 describes the new qualitative behavioural analysis method developed for vehicle-pedestrian interactions, while Section 4 deals with its implementation, which includes the description of the test site and the data collection. Section 5 provides a summary of the results obtained, and. Section 6, finally, concludes the paper and identifies areas of future research.

2 BACKGROUND

Most of the research that has been carried out with the objective of monitoring vehicle-pedestrian interactions so far has been concerned with traffic conflicts analysis. A wide range of traffic conflicts techniques have been developed, many of which are based on well-established vehicle-vehicle methods and adapted so as to account for pedestrian movement. Notable examples include: the “Swedish

Traffic Conflicts Technique" (STCT) from Lund University in Sweden (14), applied by Svensson (16) and Chen et al. (18) to vehicle-pedestrian conflicts; the "US Department of Transportation Conflict Technique" (USDTCT) from the Federal Highway Administration in the US (19), used by Lord (20) in a vehicle-pedestrian conflicts context; and the "Institute of Highways and Transportation Conflicts Technique" (IHTCT) from the Transport and Road Research Laboratory in the UK (21), adapted by Kaparias et al. (12-13) and by Salamati et al. (22) to consider the movement of pedestrians. Further techniques have also been developed for the purposes of their respective studies: Cynecki (23) derived a method categorising vehicle-pedestrian conflicts at crossings into one of 13 types with a view of identifying potential safety hazards; Malkhamah et al. (24) used vehicle-pedestrian conflicts along with traffic characteristics data to perform automated assessment of the safety of Pelican crossings in the UK; and Ismail et al. (25-26) developed an automated video analysis system to classify road users as vehicles or pedestrians, identify conflict situations between them and categorise them according to their severity.

When it comes to behavioural analysis, however, the situation is much fuzzier, as no generic behavioural criteria that can be used to examine lower severity interactions in different traffic situations have been developed. In fact, previously conducted behavioural observations studies used methods designed according to the particular objectives targeted (such as the work of Lobjois and Cavallo (27-28), who looked at the gap acceptance of crossing pedestrians of different ages) and have usually been complemented by additional data from questionnaires, accident records and traffic conflicts analyses. Individual example studies worth mentioning here include: a 1980s drivers' behaviour monitoring study in the Philippines (29), and an early 21st century road users' monitoring exercise in Sweden's Skvallertorget (Gossip Square) (30).

The first case study, as reported by Muhlrad (29), aimed at observing and monitoring the behaviour of drivers in the Philippines, and used data from three different sources: demographical data from questionnaires distributed to the population, accident data from regional authorities, and traffic conflicts data from moving observer vehicles on a number of test routes around the country. Two key aspects of driver behaviour were singled out from the monitoring for further investigation: the observance of no-overtaking markings and the behaviour at junctions with a "Stop" sign. The results indicated a fairly high rate of non-compliance with no-overtaking markings in urban areas and a very high percentage of non-compliance with "Stop" signs. Despite obtaining generalised relationships for drivers' behaviour in particular traffic situations, however, more detailed conclusions were difficult to obtain due to the lack of a more concrete data collection and analysis framework.

A more comprehensive behavioural analysis technique was used in the second case study, which aimed at monitoring the behaviour of drivers and pedestrians in Sweden's Skvallertorget (Gossip

Square), a square on which a shared space design was implemented, substituting the previous signalised intersection layout. Investigations into the performance of the new layout were carried out for the three-year period following the redevelopment (30) and the road users' behaviour was analysed with respect to vehicle speed and flow volumes in order to get an insight into their mindset. The analysis was also carried out in conjunction with resident questionnaires. The results showed that in the majority of the vehicle-pedestrian interactions observed the pedestrian's trajectory characteristics (speed, direction) remained unchanged. As opposed to that, in the vast majority of the cases where the driver's trajectory remained unchanged after interacting with a pedestrian, the vehicle's speed was low, generally less than 30 km/h and in most cases even less than 20 km/h. Nevertheless, no before-study was conducted, and as such it was not possible to draw conclusions on the effect of the layout on the users' behaviour.

The fact that behavioural analysis methods are generally developed when they are required means that it is difficult to compare results from different techniques. Therefore, the development of a qualitative behavioural analysis method, based on fundamental principles, that can be applied to a variety of interaction situations would not only allow comparisons between different investigations but would also mean that generic conclusions could be drawn about the nature of vehicle-pedestrian interactions. The behavioural analysis method developed and used in this study utilises the key points from other forms of traffic analyses but applies them to the context of vehicle-pedestrian interactions.

3 METHODOLOGY

The basis of the new behavioural analysis method is video observation, whereby vehicle-pedestrian interaction events are recorded and evaluated according to a number of criteria with respect to their nature and severity as a function of the instantaneous traffic flow characteristics. A description of how these interactions events are defined and identified is comprehensively presented by Laureshyn et al. (17), and is therefore omitted here. The method introduced consists of three steps: 1) The categorisation of vehicle-pedestrian interaction events; 2) the grading according to their severity; and 3) the presentation of the results in relevant tables and/or figures, enabling the assessment of the vehicle-pedestrian interactions in a site, in a similar way as accident or traffic conflicts analysis. These are described next.

3.1 Categorisation of interactions

The first step of the behavioural analysis method is to classify events observed in the public realm as vehicle-pedestrian interactions and to categorise them according to their type. From preliminary observation of the traffic situation in a number of sites, the following two types of vehicle-pedestrian interactions are identified:

- Steady Car – Pedestrian (SC-P): The vehicle involved in the interaction is a four-wheeler (i.e. car, van etc. – generalised as 'Car' for convenience) and is already travelling at a steady pace at the time of interaction with a pedestrian. This means that the vehicle's movement is perceived to be independent rather than a result of a reaction to a previous interaction event.
- Effective Shared Space (ESS): Vehicles appear to be static or travelling at a very low speed (less than the pedestrians' walking speed) and pedestrians are also present in the road space. Examples of this include: pedestrians clearing a crossing immediately after the change of a traffic signal; a vehicle travelling around a sharp corner at the same time with a crossing pedestrian; or a slow moving queue of vehicles with pedestrians choosing to walk between them to cross the road.

It should be noted here that additional interaction types can be defined if further road users and vehicle types (e.g. cycles, buses, motorcycles, etc.) are taken into account and specified separately. However, this extends beyond the scope of the study.

3.2 Criteria and grading

Following the categorisation of an interaction, its severity is established by assessing a number of criteria. Similarly to conflicts analysis, the key traits that describe the nature of an interaction are pace (driving or walking for vehicles and pedestrians respectively) and direction changes, as they are a practical basis for an observation-based study since they can be recorded instantaneously by a single observer without the need for specialised equipment. The criteria used in the new behavioural analysis method are hence defined based on pace and direction change observations, bearing in mind though that different grades should be used for vehicles and pedestrians, as their general conduct on the road is likely to be different.

For both pace and direction change observations a number of aspects need to be considered when carrying out a behavioural analysis. Namely, the extent to which a pedestrian alters his/her walking pace as a result of an interaction with a vehicle provides an insight into his/her confidence on the road. On the other hand, the extent to which a driver alters his/her driving pace (speed) as a result of an interaction with a pedestrian gives an indication on his/her willingness to share space with pedestrians; besides, this is also likely to have a significant effect on pedestrian behaviour. In addition, the willingness to share space is also explored from grading the extent to which a driver accelerates back to his/her desired speed following an interaction with a pedestrian (subsequent acceleration). With respect to direction, grading the extent to which pedestrians alter their path across the carriageway indicates their confidence in sharing the space with vehicles. For vehicles, on the other hand, grading the extent to which drivers alter their path shows their willingness to compromise with pedestrians crossing the road; this includes both the extent of the directional change and how early the change occurs.

With the above considerations in mind, three criteria are defined in order to evaluate the nature and severity of vehicle-pedestrian interactions:

I. Change in pace (for both vehicles and pedestrians)
II. Change in direction (for both vehicles and pedestrians)
III. Subsequent acceleration (for vehicles only)

The grades used for each criterion are shown in Table 1. It should be noted that the criteria could also be applied to vehicle-vehicle interactions by applying the vehicle-specific grading to both parties. In that case the grades would represent the tolerance/willingness of each driver to share the road space with other motorists.

[Table 1 here]

3.3 Presentation of the evaluation results

The evaluation of each interaction event by assigning grades to the three criteria is further complemented by vehicle approach speed and vehicle density measurements, so as to be able to relate the interaction characteristics with the instantaneous traffic flow characteristics and draw conclusions on the behaviour. Vehicle approach speed is measured by establishing a suitable known length on the road in the footage and measuring the time it takes for a vehicle to cover it. Vehicle density, on the other hand, expresses the number of vehicles in the road section extending 10 m behind and 10 m in front of the position of the pedestrian, travelling in the direction of the vehicle involved (i.e. on the same side of the road that the interaction takes place) and at the point in time when the first reaction, of either the pedestrian or vehicle, takes place.

It should be noted here, that the behaviour of drivers in ESS interactions is not recorded, as the short distances covered mean that it is difficult to distinguish their behavioural response.

Classified interaction events are then aggregated by user (vehicle/pedestrian) and severity, and optionally by location and time period, and are presented in relevant tables, in relation to the measured traffic characteristics. This allows for a global assessment of the behaviour of the road users, which can be site-specific, or even at the network level. For instance, using the method in a before-after context of a streetscape scheme, it is possible to draw conclusions with respect to any changes in behaviour (e.g. “drivers give way to pedestrians more frequently after the implementation of the scheme”).

The presentation of the results can also be complemented by appropriate visualisation in order to highlight any findings.

4 IMPLEMENTATION

The new vehicle-pedestrian interactions behavioural analysis method is implemented on the Exhibition Road site in London's South Kensington area using video data. This section presents the implementation setup and procedure, including a description of the implementation site and data collection, followed by a summary of the results obtained.

4.1 Site description

Exhibition Road is an 800 m long road located in West London and is home to a number of London's most popular museums (Natural History, Science, V&A). The surrounding area of South Kensington is well-known as a cultural centre, including venues such as the Royal Albert Hall and many academic institutions, including Imperial College London. As the previous conventional dual-carriageway-layout of Exhibition Road was crowded (a problem exacerbated by numerous pedestrian barriers) and dominated by high traffic flows and parked vehicles, the local authority (Royal Borough of Kensington and Chelsea) undertook an engineering scheme, the 'Exhibition Road Project', which included its redevelopment featuring a number of elements of shared space (Figure 2).

The project was implemented over four years from mid 2008 to completion in late 2011. More specifically, the following three main streetscape treatments were carried out:

1. <u>Re-allocation of street space</u> (Figure 2a): The previous layout of the 24-metre wide Exhibition Road consisted of a 16-metre wide dual carriageway, accommodating one lane of traffic in each direction as well as excess width allocated to parked vehicles, and of two 4-metre wide footpaths on either side of the carriageway, accommodating pedestrians. As a result of the redevelopment, traffic was shifted to the eastern side of the road to occupy a single carriageway of 8 metres width (termed the "traffic zone"), with the former western side of the dual carriageway becoming a so-called "transition zone", accommodating primarily pedestrians, but also parking, cycles and coaches alighting to drop-off or pick-up passengers. The two 4-metre footpaths remained in place and formed the so-called "pedestrian zone". The space also saw the removal of the kerbs and the implementation of an end-to-end single surface.
2. <u>Re-design of pedestrian crossing facilities</u> (Figure 2b): At the intersection of Exhibition Road with Cromwell Road, the original design included a staggered north-south pedestrian crossing

on the western side of the site, which, however was not following the desire-lines and required pedestrians to cross in two stages, thus resulting in a high number of jaywalkers. The re-development removed the staggered crossing and replaced it with a wide (12-metre) straight-across crossing, allowing pedestrians to complete their crossing in a single phase.

3. Unravelling of a one-way system (Figure 2c and 2d): In the original layout, a one-way system was in place around the South Kensington Station area, whereby the southbound traffic was led along the southern tip of Exhibition Road and along Thurloe Street, while the northbound traffic was guided along Thurloe Place. As a result of the re-development, Thurloe Place was converted to a two-way street, accommodating both the northbound and the southbound traffic, while Thurloe Street was converted to an access-only street.

[Figure 2 here]

4.2 Implementation setup

Video footage has been collected through non-conspicuous (visible, but not revealing the purpose of the study) high-mast cameras for periods before and after the implementation of the Exhibition Road scheme as part of recent studies analysing traffic conflicts in the area (13-14). This has also been complemented by vehicle traffic and pedestrian crossing counts, in order to relate to changes in the traffic conditions around the site. In this study, the data collected is used to assess the impact of the new design of Exhibition Road on road users' behaviour using the new method for analysing behavioural interactions. In the before-case, the data refers to August 2008, prior to the start of the redevelopment works, and has been collected from a number of critical locations in terms of vehicle-pedestrian interaction occurrences. For the after-situation, the video footage comes from the same locations for periods between October and December 2011, following the completion of the scheme. The locations are shown in Figure 3, with street-level views shown in Figure 2:

- L1: Exhibition Road main body (Before: Cameras A & B – After: Cameras 4, 5, 6 & 7):
  In the original layout (Figure 2a, left), pedestrians wishing to cross Exhibition Road at this location (entrances of V&A, Natural History and Science museums) needed to detour by more than 100 m to reach the closest formal pedestrian crossing; as a result, they chose to cross freely. The new layout (Figure 2a, right) facilitates those crossing movements through the described re-allocation of road space and the implementation of the single surface.
- L2: Cromwell Road junction (Before: Cameras C & D – After: Cameras E, F, G & H):
  In the original layout (Figure 2b, left), the facilities provided to pedestrians wishing to cross Cromwell Road to continue walking on either the eastern or the western kerbsides of Exhibition Road were two staggered pelican crossings, which required a detour and often long waiting times for a green man signal. As a result, the vast majority of the pedestrians used

"shortcuts" by-passing the staggered crossings and jaywalking, thus coming into conflict with right-turning southbound traffic from Exhibition Road in the case of the western crossing, or with left-turning southbound traffic in the case of the eastern crossing. Both crossings have now been replaced by a wide straight-across crossing in the new layout (Figure 2b, right).

- L3: Thurloe Street (Before: Camera F – After: Cameras 1 & 2):
  Pedestrians using this location in the original layout (Figure 2c, left) were faced with two problems: the non-provision of adequate pedestrian crossing facilities, and the insufficient space for pedestrians on the southern kerbside of the road, such that footpath overcrowding resulted in a large number of free crossings. Coupled with high vehicle speeds and poor visibility for both vehicles and pedestrians, this location presented a well-known safety hazard. In the new layout (Figure 2c, right), this location has been redesigned as "access-only", giving much more space to pedestrians.

As analysing the complete duration of the video data would take up a significant amount of time and provided that peak and off-peak periods exist in vehicle-pedestrian interactions as a result of peak and off-peak traffic and pedestrian flows, five hours of analysis for each location for the before- and after-case have been selected, with a mix of week and weekend days chosen depending on the location and the availability of video data. These are:

- Weekdays: **08:00 – 09:00** (morning rush hour, offering an insight of the local residents' and workers' use of the road), **12:00 – 13:00** (midday, when a large number of tourists enter and exit the museums) and **17:00 – 18:00** (evening rush hour, with tourists and workers leaving the area, and locals returning)
- Weekends: **12:00 – 13:00** and **17:00 – 18:00** (again midday and evening rush hour)

The video footage is analysed using the new method and behavioural occurrences and their severity are identified, drawing comparisons between the before- and after-situation.

[Figure 3 here]

5 RESULTS

The results of the application of the new behavioural analysis method on the Exhibition Road site are reported next. First, the broad results in terms of the frequency and type of vehicle-pedestrian interaction events are presented, and then the severity of the various interaction events is analysed in relation to the characteristics of each location. Finally, a number of general remarks relating to the results are made.

5.1 Vehicle-pedestrian interaction frequency and type

The vehicle-pedestrian interactions recorded during the two observation periods (before and after re-development) grouped by type and location are summarised in Table 2a. It can be immediately seen that SC-P interaction events are more frequent, with 3/4 and 2/3 of the occurrences across all locations being categorised as such in the before- and after-case respectively. Location-wise, the highest levels of interaction between vehicles and pedestrians are observed at the junction of Exhibition Road with Cromwell Road (L2), in both the before- and after-periods, followed by slightly lower levels at the main body of Exhibition Road (L1). A notable feature is the low concentration of ESS interactions in the before-case of L1 and L3, which can be explained by the fact that vehicles do generally not stop there, as there is no junction or traffic light. On the other hand, the very low number of both ESS and SC-P occurrences in the after-case of L3 can be safely attributed to the conversion to an access-only street.

Comparing the before- and after-situation, it is found that the total number of interaction events across the site is lower in the after-case, with a reduction of the order of 30%; this finding is made up of a significant reduction in SC-P occurrences, coupled with relatively constant levels of ESS interactions. Noteworthy findings include: the shift of SC-P interactions to ESS ones at the main body of Exhibition Road (L1), thus resulting in a small increase in total interaction events at that location; the slight decrease of both SC-P and ESS occurrences at the junction with Cromwell Road (L2); and the elimination of almost all pedestrian-vehicle interaction at Thurloe Street (L3).

In order to draw more meaningful comparisons, however, the interaction occurrence numbers should be viewed in relation to the prevailing traffic conditions. Namely, as the redevelopment has brought about a number of traffic management changes giving more priority to pedestrians, pedestrian crossings and vehicle traffic flows have changed. The vehicle and pedestrian traffic flows are shown in Table 2b. As can be seen, there is a significant increase in pedestrian crossings across the site, which is concentrated at Thurloe Street (L3) (pedestrian volume has almost doubled), coupled with moderate increases at L1 and L2. This is accompanied by greatly reduced traffic flows at L1 and L3, and by relatively constant flows on the intersecting Cromwell Road (L2).

Normalising the interaction occurrences with pedestrian crossing flows to draw more meaningful conclusions, it can be seen in Table 2c that the redevelopment scheme has brought about a significant reduction in terms of behavioural interaction occurrences per 1000 pedestrians across the site, which is, again, mainly attributed to the significant drop in SC-P interactions and a corresponding small decrease in ESS interactions. This means that a pedestrian visiting the site is now much less likely to be involved in either an SC-P or an ESS interaction at Thurloe Street, which is expected given the conversion of the layout to access-only. Conversely, at the main body of Exhibition Road (L1) he/she is now more likely to encounter an ESS situation, and less likely to experience an SC-P event; given the implementation of the single surface and the narrower carriageway at that location, which encourages pedestrian crossings and lower vehicle speeds, this finding is also expected.

Looking at the normalised interaction events with vehicle flows, Table 2d shows similar interaction occurrence rates per 1000 vehicles across the site before and after redevelopment, but the figures vary between interaction type and location. Namely, a vehicle at Thurloe Street (L3) is much less likely to encounter an SC-P interaction post-redevelopment, but much more likely to be involved in an ESS interaction; this is expected, given the conversion of the location to access-only, meaning that vehicles visit it only occasionally and always at a low speed. On the other hand, the conversion of the layout to encourage pedestrian activity at the main body of Exhibition Road (L1), and the corresponding decrease in traffic flow mean that a vehicle visiting that location is now much more likely to encounter an interaction event, either SC-P or ESS.

[Table 2 here]

5.2 Vehicle-pedestrian interaction severity

Considering the nature and severity of the interactions by expressing the pedestrians' and drivers' reactions as a function of the instantaneous traffic flow characteristics (speed and density), the results from the three locations of the site are given in Table 3. Again, both pure occurrence numbers and normalised ones are provided.

Starting from the main body of Exhibition Road (L1) in Table 3a, and considering the pedestrians' reactions in the before-case, generally low average vehicle speeds in SC-P interactions appear to give confidence to the pedestrians, as these are likely to enter the road space and negotiate as direct a path as possible across the carriageway, irrespective of the actual speed-density combination. This confidence appears to be higher at ESS interactions, where vehicle density is also higher, despite the small sample of observations. With respect to the drivers' behaviour, these appear to be travelling at low average speeds, though only a few actually slow down to allow pedestrians to traverse the carriageway and, subsequently, assess the road space more thoroughly before accelerating. Also, drivers' behaviour seems to be affected by how congested the road space is, with high vehicle density tending to result in hastier acceleration (as drivers may feel confined and more eager to leave the area). Another remark is that there are few observations of vehicles diverting from their path to give way to pedestrians; these all occur at low speeds.

Looking at the after-case, a change of behaviour can be observed from pedestrians. Namely, even though traffic speeds are at similar low levels (average 16.7 km/h and 16.1 km/h after), the proportion of pedestrians continuing at the same pace and course at SC-P interactions is smaller, with more pedestrians now giving way to oncoming vehicles. This is an unexpected finding, considering the behaviour displayed in the before-case; a possible explanation may lie in the lower vehicle density values, which may result in pedestrians opting to wait for a few more seconds for a single vehicle to pass, rather than forcing their way across to avoid a longer waiting time in the case of an oncoming vehicle platoon. Similarly to the before-case, however, the pedestrians' confidence seems to grow at ESS interactions, where they usually maintain their pace and direction, as anticipated; this behaviour is more evident than in the before-case. As concerns drivers, their behaviour appears relatively unchanged to the before-situation despite the layout redevelopment, with the exception of the fact that less drivers now slow down and, subsequently, wait for pedestrians to clear; this may be in part interpreted as a consequence of the pedestrians' behaviour.

Considering the interactions at the junction of Exhibition Road with Cromwell Road (L2) in the before-case, it can be observed that the vast majority of pedestrians in SC-P interactions attempt to avoid traffic and traverse it as quickly as possible (Table 3b). A similar trend is observed at ESS interactions, where despite the fact that vehicles are stopped or moving very slowly, the most frequent pedestrian reaction is to accelerate. A reason could be the fact that pedestrians may be aware that the vehicles have absolute priority at that location, and therefore aim to get out of the highway as soon as possible – hence the high number of pedestrians that choose to accelerate in a straight line once the traffic begins to move. The behaviour of vehicle drivers seems to be in line with the pedestrians. Namely, due to the fundamental design characteristics of Cromwell Road (high traffic speeds and volumes), drivers appear to show little tolerance towards pedestrians at that location. With very few exceptions, the approach speed and direction of vehicles remains unchanged in the vast majority of the interactions.

In the after-case the behavioural features observed broadly resemble the before-situation. This is expected and may be attributed to the fact that many of the elements of the original design have been retained post-redevelopment (e.g. traffic lights, staggered crossing on the eastern side). As such, pedestrians again generally opt to clear the junction as quickly and as directly as possible when faced with an SC-P interaction situation. Drivers' behaviour also remains relatively unchanged. A noteworthy observation, however, is the reduction of the proportion of pedestrians accelerating at ESS interactions. This may suggest that the new more "open" layout, and particularly the absence of guardrails and other street clutter, gives some confidence to pedestrians at a location where, by definition, it is implied that vehicles have priority.

In the before-case of Thurloe Street (L3), finally, (Table 3c), the road topology significantly reduces the visibility of the pedestrians, confronting them directly with speeding traffic approaching around a 90-degree corner. This is reflected as a negative impact in the behaviour of the pedestrians, as their confidence seems to be reduced. Pedestrians appear to show little desire to dwell in the road space, in the majority of cases preferring to accelerate along the shortest path (towards the pavement) with no deviation when faced with an oncoming vehicle. Vehicle density seems to comfort the pedestrians to a certain extent, as the lack of available road space limits the rate at which vehicles can emerge from around the corner. However when the road becomes more crowded (ESS interactions), pedestrians hurry their crossings. Drivers, on the other hand, seem to exhibit the typical behavioural traits observed in Cromwell Road (L2) in relation to approach speeds and vehicle densities. Speeds are high and most drivers do not seem to react to the presence and actions of the pedestrians and continue at their original speed and course.

The radical redesign of Thurloe Street compared to its original layout (access-only as opposed to one-way) has excluded vehicular through-traffic, thus eliminating most pedestrian-vehicle interactions. It is notable that no SC-P events are recorded post-redevelopment, and that only a small number of ESS interactions are observed. Still, the comparison between the ESS interactions provides some insight into the behavioural changes at that location, in what it becomes clear that the layout has been converted to a predominantly pedestrian area from the previously vehicle-oriented design. Namely, pedestrians now exhibit full confidence and claim their right of way from the occasional single vehicles entering the street for parking and delivery purposes by keeping their pace unchanged and only sometimes deviating from their course.

[Table 3 here]

5.3 Further remarks

With respect to the results obtained, it should be noted additionally that the results may be affected by a number of external factors and effects.

For instance, the before-monitoring period is during the student summer break, while the after-monitoring period is actually immediately after the completion of the scheme (less than one month). This may have a bearing on the results, the former because it may imply lower pedestrian numbers than usual, but most importantly, the latter because it may point to the so-called “settling down” period, and thus not reflecting the long-term behaviour. It would be, hence, useful to further investigate the implications of the timing of the study and to compare the results with a subsequent after-study, when pedestrians and drivers have become more accustomed to the new layout.

There are further aspects that may be affecting the results. One is the possible presence of the so-called “safety-in-numbers” phenomenon, whereby the presence of a larger number of pedestrians alone (irrespective of the street design features) may be impacting the behaviour of individuals with respect to their interaction with vehicles, giving them greater confidence. Another one is the likely change in the surrounding land uses following the redevelopment, such as, for example, a higher proportion of shopping trips than commuting trips to the area due to the presence of more shops than before. A third one is the potential existence of a non-linear relationship between pedestrian volume and interaction occurrences (instead of the currently assumed linear), which would require a different analysis method to the simple ratio comparison that is currently used. These are all effects that need to be acknowledged, and whose actual impact deserves further investigation but extends beyond the scope of this study.

6 CONCLUSIONS

In this paper a new qualitative behavioural analysis method for vehicle-pedestrian interactions has been presented. The method provides for the analysis of video footage and attempts to classify the behaviour of pedestrians and drivers with each other on the basis of their reactions and as a function of fundamental traffic flow characteristics (speed and density). The method has then been applied on the recently redeveloped Exhibition Road in London, where, using video data from a number of critical locations around the site before and after redevelopment, an evaluation in terms of pedestrian-vehicle interactions has been carried out.

In general, the data obtained from the video surveillance, when considered in the context of each specific location, appear to be a genuine reflection of the road-user interactions in the Exhibition Road area. In each location the generalised trends in the data (e.g. vehicle speeds, vehicle density, frequency of pedestrian crossings etc.) can be related to the area being surveyed, based on expert knowledge of the authors. Taking into account all the component data, the results provide useful observations into exactly which factors affect road user confidence and tolerance (pedestrians and drivers respectively) and the extent to which they do so.

In terms of the detail contained in the data, and despite data gaps that can only be filled with further observations (a time-consuming procedure), sufficient information is provided from which to draw non-trivial conclusions and identify trends that could then be related to road user behaviour. For example, a conclusion of the study is that the redevelopment of the Exhibition Road site to a design containing elements of shared space seems to have reduced SC-P interaction events throughout, while keeping ESS events constant, but with notable variations in the effects observed in the three locations monitored. Another conclusion is that the redevelopment appears to have increased the confidence of pedestrians in their interaction with vehicles, but does not seem to have changed the behaviour of drivers. A notable exception is the main body of the street, where it is found that pedestrians seem to now give way to vehicles more than before, and this could be an issue potentially requiring further investigation.

Naturally, the results of the study have implications on policy and practice as concerns the planning and design of successful streetscape schemes with elements of shared space. For example, the finding of greater pedestrian confidence and relatively unchanged driver behaviour following the implementation of the scheme is invaluable information for policy-makers, who wish to conduct an a priori impact assessment of a proposed scheme. Coupled with traffic conflicts analysis, this finding may act as a surrogate safety analysis method, highlighting potential hazards (e.g. speeding) in advance of the implementation, and enabling planners to take them on board at the early stages of the design. Also, together with further findings from different sites, this result could form the beginnings of the calibration stage of an advanced microsimulation model, which would take into account the behaviour of the various road users and would predict their trajectories, thus facilitating the work of practitioners.

Considering the application of the method itself, this can be further improved through the use of more observers in the first instance, but also through the more extensive utilisation of technology. This could include the measurement of speeds and densities by automated means, but also the introduction of machine vision and image processing methods. Such advances can drastically speed-up the analysis, eliminate potential biases, and enable the investigation of more data, such as additional vehicle types. Nevertheless, from the present study it can be concluded that the method is simple to apply, with the assignment of grades to events according to the different descriptions being a fairly straightforward procedure.

Future work includes, at a first instance, the application of the method to other sites, so as to further assess its ability to evaluate generic vehicle-pedestrian interactions. The consideration of more road users, who have not been included here (e.g. cyclists) is an additional point to be covered, along with additional characteristics of road users, such as demographics and perceptions. It would also be helpful to complement behavioural analyses with on-site observations, as these would provide experience of the event and its surroundings, which could throw more light on the potential causes of the interactions. Finally, it would be interesting to explore other aspects of vehicle-pedestrian interactions, such as the behaviour of disabled road users, (e.g. blind and partially-sighted), the effect of weather conditions and the impact on the surrounding area.

ACKNOWLEDGEMENTS

The authors would like to thank the Royal Borough of Kensington and Chelsea for supporting this work by providing data and guidance. Special thanks also go to C. Chan and J. Kennedy for their assistance throughout the conduct of the work.

REFERENCES

(1) Buchanan C, Cooper GHC, MacEwen A, Crompton DH, Crow G, Michell G et al. Traffic in towns, HMSO, 1963.

(2) Hamilton-Baillie, B. A street revolution. Green Places, Vol. June 2004, 2004, pp. 20-23.

(3) Hamilton-Baillie, B. Urban design: Why don't we do it in the road. Journal of Urban Technology, Vol. 11, 2004, pp. 43-62.

(4) Hamilton-Baillie, B and Jones, P. Improving traffic behaviour and safety through urban design. Proceedings of the Institution of Civil Engineers - Civil Engineering, Vol. 158, 2005, pp. 39-47.

(5) Hamilton-Baillie, B. Towards shared space. Urban Design International, Vol. 13, 2008, pp. 130-138.

(6) Hamilton-Baillie, B. Shared space: Reconciling people, places and traffic. Built Environment, Vol. 34, 2008, pp. 161-181.

(7) UK Department for Transport. Local Transport Note 1/11 - Shared space, 2011.

(8) UK Department for Transport. Manual for Streets. 2007.

(9) Chartered Institute of Highways and Transport. Manual for Streets 2 – Wider application of the principles. 2010.

(10) LaPlante, JN and McCann, B. Complete streets in the United States, 90th Annual Meeting of the Transportation Research Board, Washington, DC, USA, 2011.

(11) Deichman, J, Winterberg, B and Bredmose, A. Shared space - safe space. Ramboll-Nyvig report, 2008.

(12) Kaparias, I, Bell, MGH, Greensted, J, Cheng, S, Miri, A, Taylor, C and Mount, B. Development and implementation of a vehicle-pedestrian conflicts analysis method: Adaptation of a vehicle-vehicle technique. Transportation Research Record, Vol. 2198, 2010, pp. 75-82.

(13) Kaparias, I, Bell, MGH, Dong, W, Sastrawinata, A, Singh, A, Wang, X and Mount, B. Analysis of pedestrian-vehicle traffic conflicts in street designs with elements of shared space. Transportation Research Record, Vol. 2393, 2013, pp. 21-30.

(14) Hydén, C. The development of a method for traffic safety evaluation: The Swedish traffic conflicts technique. Department of Technology and Society, Lund University, 1987.

(15) Svensson, Å, and Hydén, C. Estimating the severity of safety related behaviour. Accident Analysis and Prevention, Vol. 38, 2006, pp. 379-385.

(16) Svensson, Å. A method for analysing the traffic process in a safety perspective, PhD thesis, Lund University, 1998.

(17) Laureshyn, A, Svensson, Å and Hydén, C. Evaluation of traffic safety, based on micro-level behavioural data: Theoretical framework and first implementation, Accident Analysis and Prevention, Vol. 42, 2010, pp. 1637-1646.

(18) Chen, Y, Meng, H and Wang, Z. Safety improvement practice for vulnerable road users in Beijing junctions. 88th Annual Meeting of the Transportation Research Board, Washington, DC, USA, 2009.

(19) Parker, MR Jr and Zegeer, CV. Traffic conflict techniques for safety and operations - Observers manual. FHMA-IP-88-027, Federal Highway Administration, 1989.

(20) Lord, D. Analysis of pedestrian conflicts with left-turning traffic. Transportation Research Record, Vol. 1538, 1996, pp. 61-67.

(21) Swain, J. Highway safety: The traffic conflict technique. Transport and Road Research Laboratory, 1987.

(22) Salamati, K, Schroeder, B, Rouphail, NM, Cunningham, C, Long, R and Barlow, J. Development and implementation of conflict-based assessment of pedestrian safety to evaluate accessibility of complex intersections. Transportation Research Record, Vol. 2264, 2011, pp. 148-155.

(23) Cynecki, MJ. Development of a conflicts analysis technique for pedestrian crossings. Transportation Research Record, Vol. 743, 1980, pp. 12-20.

(24) Malkhamah, S, Tight, M and Montgomery, F. The development of an automatic method of safety monitoring at Pelican crossings. Accident Analysis and Prevention, Vol. 37, 2005, pp. 938-946.

(25) Ismail, K, Sayed, T and Saunier, N. Automated analysis of pedestrian-vehicle conflicts using video data. Transportation Research Record, Vol. 2140, 2009, pp. 44-54.

(26) Ismail, K, Sayed, T and Saunier, N. Automated analysis of pedestrian-vehicle conflicts: Context for before-and-after studies. Transportation Research Record, Vol. 2198, 2010, pp. 52-64.

(27) Lobjois, R and Cavallo, V. Age-related differences in street-crossing decisions: The effects of vehicle speed and time constraints on gap selection in an estimation task. Accident Analysis and Prevention, Vol. 39, 2007, pp. 934-943.

(28) Lobjois, R and Cavallo, V. The effects of aging on street-crossing behavior: From estimation to actual crossing, Accident Analysis and Prevention, Vol. 41, 2009, pp. 259-267.

(29) Muhlrad, N. Traffic conflict techniques and other forms of behavioural analysis: Application to safety diagnoses. Proceedings of the 6th International Co-operation on Theories and Concepts in Traffic Safety (ICTCT) Workshop, 1993.

(30) Jaredson, S. Evaluation of Skvallertorget in Norrköping. PhD thesis, Tekniska Högskolan Linköpings University, 2002.

Table 1: Grades for the three criteria, as a result of an interaction

Criterion I: Change in pace

Grade	Pedestrian's reaction	Vehicle's reaction
1	Continues at the same pace	Continues at full speed
2	Accelerates so as to complete the crossing before the vehicle's arrival	Slows down in advance but does not come to a stop
3	Stops temporarily to let vehicle pass and then continues	Slows down well in advance and stops before reaching the crossing point
4	Returns to pavement immediately	–

Criterion II: Change in direction

Grade	Pedestrian's reaction	Vehicle's reaction
1	Continues along intended path	Continues along intended path
2	Deviates to avoid vehicle	Deviates to avoid pedestrian
3	Returns to pavement	–

Criterion III: Subsequent acceleration

Grade	Vehicle's reaction
1	Accelerates as soon as pedestrians have crossed their path
2	Waits until all pedestrians are well clear before accelerating
3	No change in speed

Table 2: (a) Interaction occurrences by location and type; (b) vehicle traffic flows (veh/h) and pedestrian crossing flows (ped/h); (c) normalised interaction occurrence rates (interaction / 1000-ped); (d) normalised interaction occurrence rates (interaction / 1000-veh)

(a)	Location							
	L1		L2		L3		TOTAL	
	Bef.	After	Bef.	After	Bef.	After	Bef.	After
SC-P	241	196	207	192	231	0	**679**	**388**
ESS	8	75	174	136	24	8	**206**	**219**
TOTAL	**249**	**271**	**381**	**328**	**255**	**8**	**885**	**607**

(b)	Location							
	L1		L2		L3		TOTAL	
	Bef.	After	Bef.	After	Bef.	After	Bef.	After
Veh.	911	472	2186	2108	538	72	3635	2652
Ped.	214	334	1714	1954	807	1610	2735	3898

(c)	Location							
	L1		L2		L3		TOTAL	
	Bef.	After	Bef.	After	Bef.	After	Bef.	After
SC-P	225.23	117.37	24.15	19.65	57.25	0.00	49.65	19.91
ESS	7.48	44.91	20.30	13.92	5.95	0.99	15.06	11.24
TOTAL	**232.71**	**162.28**	**44.46**	**33.57**	**63.20**	**0.99**	**64.72**	**31.14**

(d)	Location							
	L1		L2		L3		TOTAL	
	Bef.	After	Bef.	After	Bef.	After	Bef.	After
SC-P	52.91	83.05	18.94	18.22	85.87	0.00	37.36	29.26
ESS	1.76	31.78	15.92	12.90	8.92	22.22	11.33	16.52
TOTAL	**54.67**	**114.83**	**34.86**	**31.12**	**94.80**	**22.22**	**48.69**	**45.78**

Table 3: (a) Interactions' severity at the main body of Exhibition Road (L1); (b) Interactions' severity at the junction with Cromwell Road (L2); (c) Interactions' severity at Thurloe Street (L3)

(a)	Crit	Grade	L1																	
			SC-P										ESS							
			Before					After					Before				After			
			Frq	Frq /1000 -ped	Frq /1000 -veh	Veh spd	Veh den	Frq	Frq /1000 -ped	Frq /1000 -veh	Veh spd	Veh den	Frq	Frq /1000 -ped	Frq /1000 -veh	Veh den	Frq	Frq /1000 -ped	Frq /1000 -veh	Veh den
Ped	I	1 – unchanged	103	481	113	15.8	2.1	52	156	110	15.9	1.9	7	33	8	3.1	73	219	155	3.1
		2 – accelerate	54	252	59	16.2	2.3	22	66	47	15.8	2.0	1	5	1	3.0	2	6	4	2.5
		3 – give way	78	364	86	15.6	2.3	110	329	233	15.9	2.1	-	-	-	-	-	-	-	-
		4 – return	6	28	7	18.1	2.6	12	36	25	17.7	1.9	-	-	-	-	-	-	-	-
	II	1 – unchanged	194	907	213	16.0	2.1	147	440	311	16.1	2.0	3	14	3	2.6	50	150	106	3.2
		2 – deviate	41	192	45	14.5	2.3	37	111	78	15.5	2.2	5	23	5	3.1	25	75	53	3.2
		3 – return	6	28	7	17.4	2.4	12	36	25	17.7	2.1	-	-	-	-	-	-	-	-
Veh	I	1 – full speed	207	967	227	15.4	2.1	182	545	386	16.0	1.9	-	-	-	-	-	-	-	-
		2 – slow down	30	140	33	13.0	2.5	13	39	28	12.1	2.3	-	-	-	-	-	-	-	-
		3 – stop	4	19	4	11.0	2.4	1	3	2	9.9	2.0	-	-	-	-	-	-	-	-
	II	1 – unchanged	233	1089	256	17.0	2.2	189	566	400	16.2	2.0	-	-	-	-	-	-	-	-
		2 – deviate	8	37	9	10.3	2.2	7	21	15	11.8	1.4	-	-	-	-	-	-	-	-
	III	1 – acc. immed.	14	65	15	13.5	2.7	14	42	30	13.1	2.2	-	-	-	-	-	-	-	-
		2 – wait to clear	20	93	22	11.5	2.3	1	3	2	10.4	2.0	-	-	-	-	-	-	-	-
		3 – no change	207	967	227	16.2	2.2	181	542	383	16.1	2.0	-	-	-	-	-	-	-	-
						km/h	veh				km/h	veh				veh				veh

(b)	Crit	Grade	L2																	
			SC-P										ESS							
			Before					After					Before				After			
			Frq	Frq /1000 -ped	Frq /1000 -veh	Veh spd	Veh den	Frq	Frq /1000 -ped	Frq /1000 -veh	Veh spd	Veh den	Frq	Frq /1000 -ped	Frq /1000 -veh	Veh den	Frq	Frq /1000 -ped	Frq /1000 -veh	Veh den
Ped	I	1 – unchanged	83	388	91	18.9	2.4	81	243	172	19.0	2.4	68	318	75	3.2	65	195	138	3.3
		2 – accelerate	95	444	104	19.0	2.4	85	254	180	18.8	2.4	95	444	104	2.7	67	201	142	2.4
		3 – give way	16	75	18	19.2	1.8	17	51	36	19.1	2.1	1	5	1	2.0	2	6	4	2.5
		4 – return	13	61	14	19.7	2.3	9	27	19	19.2	2.3	10	47	11	2.8	2	6	4	2.5
	II	1 – unchanged	193	902	212	19.4	2.1	183	548	388	18.9	2.4	157	734	172	3.1	122	365	258	3.2
		2 – deviate	1	5	1	22.8	2.0	-	-	-	-	-	7	33	8	2.3	12	36	25	2.4
		3 – return	13	61	14	20.4	2.3	9	27	19	19.2	2.3	10	47	11	2.8	2	6	4	2.5
Veh	I	1 – full speed	200	935	220	19.3	2.1	188	563	398	19.1	2.3	-	-	-	-	-	-	-	-
		2 – slow down	7	33	8	14.7	2.5	4	12	8	15.0	2.5	-	-	-	-	-	-	-	-
		3 – stop	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	II	1 – unchanged	207	967	227	19.0	2.3	192	575	407	19.0	2.3	-	-	-	-	-	-	-	-
		2 – deviate	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	III	1 – acc. immed.	2	9	2	14.7	2.5	1	3	2	15.0	2.0	-	-	-	-	-	-	-	-
		2 – wait to clear	4	19	4	16.8	1.8	3	9	6	16.2	2.0	-	-	-	-	-	-	-	-
		3 – no change	201	939	221	19.1	2.3	188	563	398	19.1	2.4	-	-	-	-	-	-	-	-
						km/h	veh				km/h	veh				veh				veh

(c)	Crit	Grade	L3																	
			SC-P										ESS							
			Before					After					Before				After			
			Frq	Frq /1000 -ped	Frq /1000 -veh	Veh spd	Veh den	Frq	Frq /1000 -ped	Frq /1000 -veh	Veh spd	Veh den	Frq	Frq /1000 -ped	Frq /1000 -veh	Veh den	Frq	Frq /1000 -ped	Frq /1000 -veh	Veh den
Ped	I	1 – unchanged	74	346	81	23.4	2.4	-	-	-	-	-	12	56	13	2.1	7	21	15	1.0
		2 – accelerate	128	598	141	26.2	2.2	-	-	-	-	-	10	47	11	3.2	-	-	-	-
		3 – give way	12	79	19	26.0	2.3	-	-	-	-	-	2	9	2	1.0	1	3	2	1.0
		4 – return	17	56	13	25.3	2.2	-	-	-	-	-	-	-	-	-	-	-	-	-
	II	1 – unchanged	195	911	214	26.0	2.1	-	-	-	-	-	20	93	22	2.6	4	12	8	1.0
		2 – deviate	22	103	24	24.9	2.3	-	-	-	-	-	4	19	4	1.8	4	12	8	1.0
		3 – return	14	65	15	25.0	2.4	-	-	-	-	-	-	-	-	-	-	-	-	-
Veh	I	1 – full speed	204	953	224	26.0	2.2	-	-	-	-	-	-	-	-	-	-	-	-	-
		2 – slow down	22	103	24	23.1	2.5	-	-	-	-	-	-	-	-	-	-	-	-	-
		3 – stop	5	23	5	19.0	2.4	-	-	-	-	-	-	-	-	-	-	-	-	-
	II	1 – unchanged	223	1042	245	25.8	2.2	-	-	-	-	-	-	-	-	-	-	-	-	-
		2 – deviate	8	37	9	25.2	2.0	-	-	-	-	-	-	-	-	-	-	-	-	-
	III	1 – acc. immed.	18	84	20	22.5	2.7	-	-	-	-	-	-	-	-	-	-	-	-	-
		2 – wait to clear	7	33	8	18.9	2.7	-	-	-	-	-	-	-	-	-	-	-	-	-
		3 – no change	206	963	226	25.8	2.1	-	-	-	-	-	-	-	-	-	-	-	-	-
						km/h	veh				km/h	veh				veh				veh

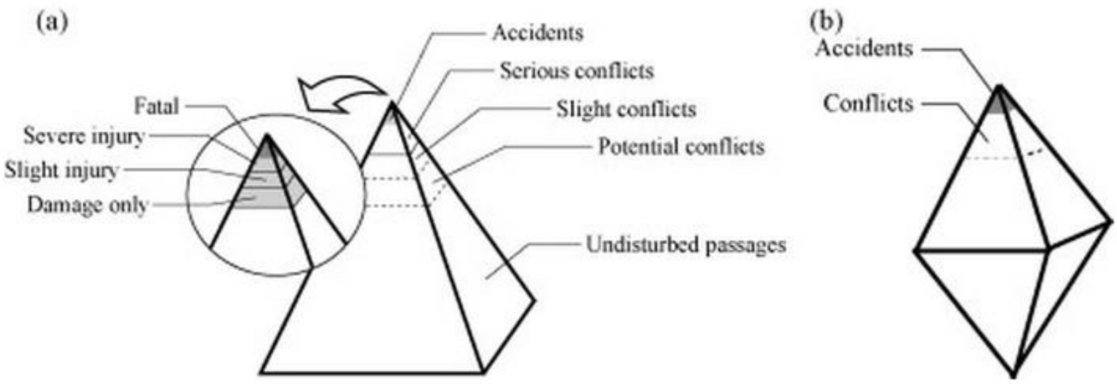
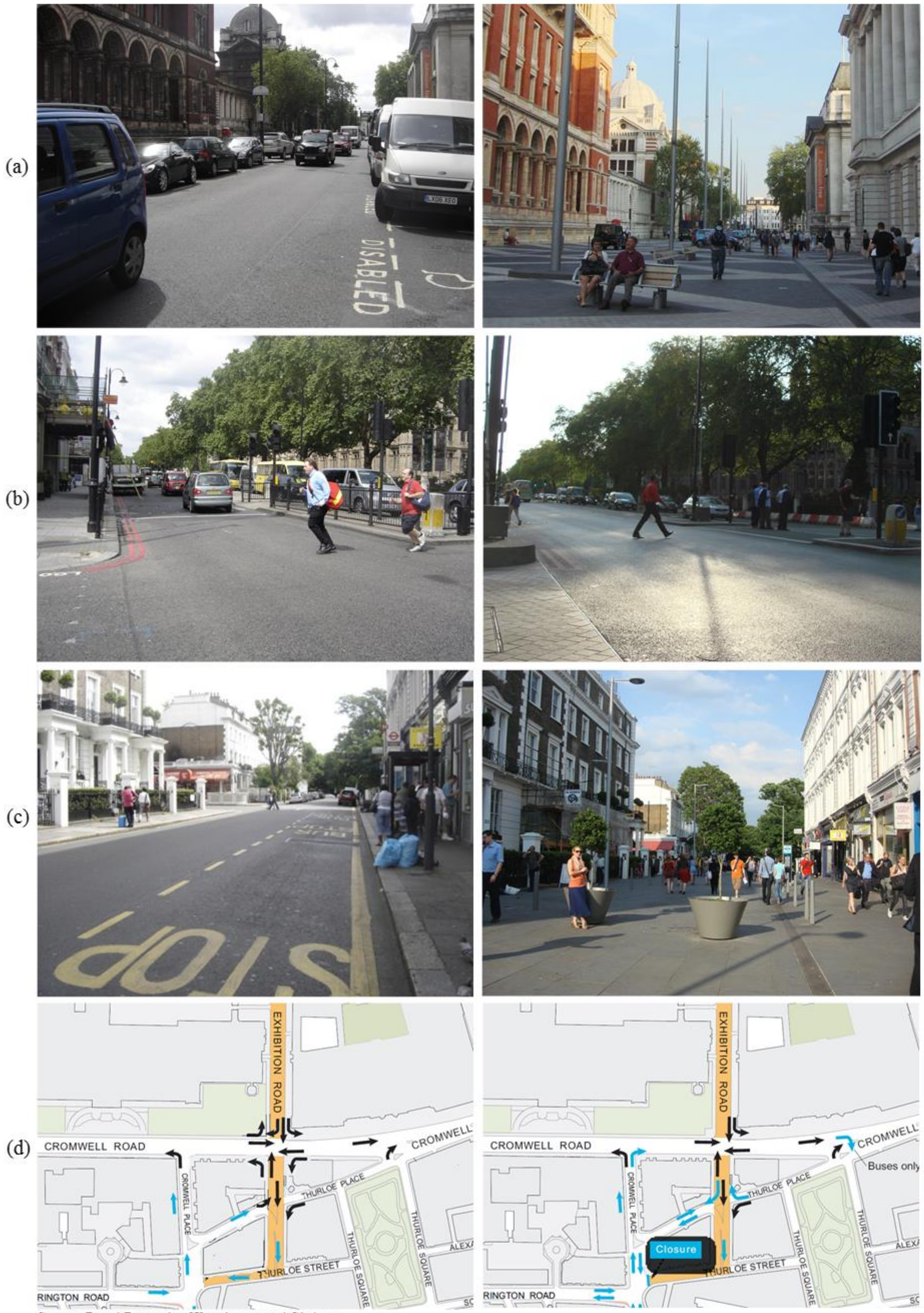


Figure 1: Conceptual framework of vehicle-pedestrian interactions (17): (a) pyramid hierarchy (14), and (b) diamond representation (16)



Source: Royal Borough of Kensington and Chelsea

Figure 2: Exhibition Road before (left) and after redevelopment (right): (a) Exhibition Road main body (L1); (b) Cromwell Road junction (L2); (c) Thurloe Street (L3); (d) traffic management changes (one-way unravelling)

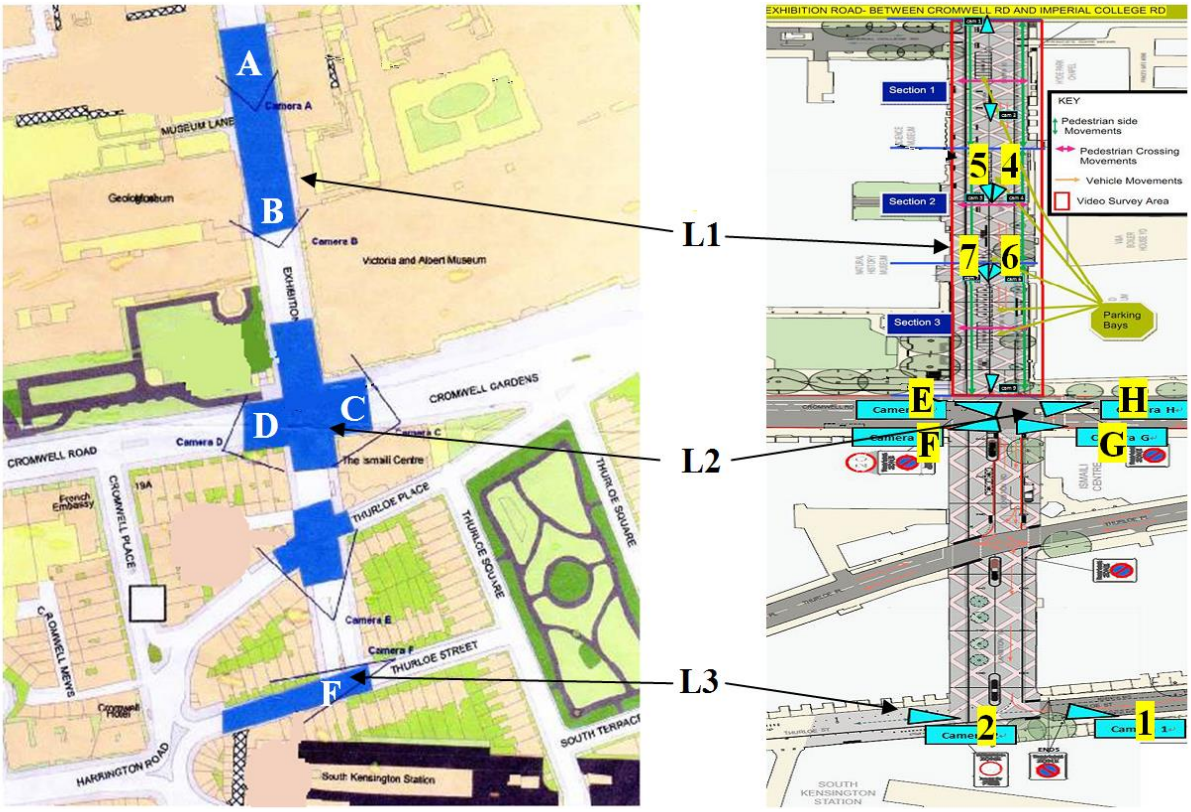


Figure 3: Camera locations at the Exhibition Road site in the before- (left) and after-monitoring (right)