BEHAVIOURAL ANALYSIS OF VEHICLE-PEDESTRIAN INTERACTIONS: THE CASE OF STREET DESIGNS WITH ELEMENTS OF SHARED SPACE

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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 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. Segregation has been deemed by some detrimental for urban environments due to its perception as resulting in "the domination of vehicular traffic and associated noise and air pollution alongside street clutter and ugly surroundings" (2). Instead, street design has shifted gradually towards the concept of "shared space" 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.

Elaborating more on the term "shared space", and conversely to popular belief, this 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. These may range from the removal of guardrails and the introduction of "informal" (uncontrolled) pedestrian crossing facilities in a traditional "kerbed" street layout, through to radically-engineered layouts with a single surface and little or no delineation between pedestrian and vehicle areas (3-7). Recent guidance published by the UK Department for Transport defines shared space 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” (8). 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 (9-10); and the “Complete Streets” initiative in the USA (11).

Despite the fact that certain road user groups (mostly the elderly and disabled) have expressed their discomfort towards the idea of shared space because they perceive it as less safe (7, 12), it has been 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 (4). From a traffic engineering perspective this 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 (13-14), 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 (15) and conceptualised by Svensson and Hydén (16) 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 (17), interactions are further classified in a three-dimensional 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 (18), 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).

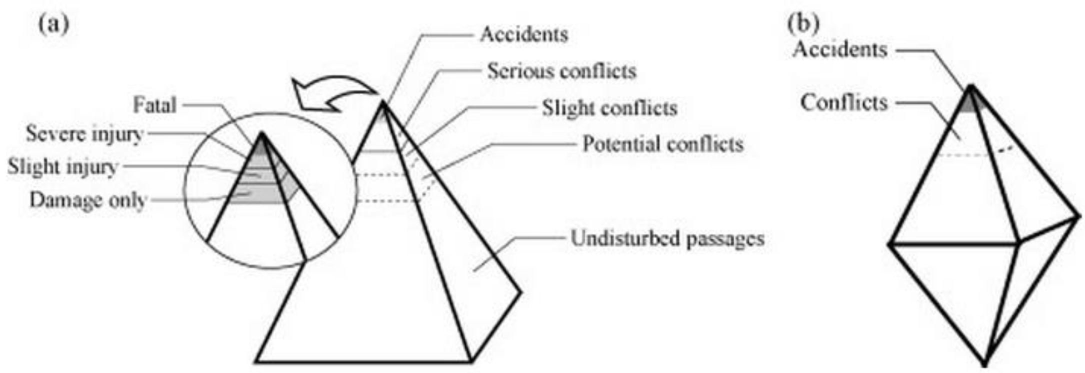

FIGURE 1: Conceptual framework of vehicle-pedestrian interactions (18): (a) pyramid hierarchy (15), and (b) diamond representation (17)

The aim of this paper 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, and to demonstrate its application on a redeveloped street layout in a before- and after-context. 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 application, which includes the description of the test site and the data collection, and a summary of the results. Section 5, 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 (15), applied by Svensson (17) and Chen et al (19) to vehicle-pedestrian conflicts; the "US Department of Transportation Conflict Technique" (USDTCT) from the Federal Highway Administration in the US (20), used by Lord (21) 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 (22), adapted by Kaparias et al (13-14) and by Salamati et al (23) to consider the movement of pedestrians. Further techniques have also been developed for the purposes of their respective studies: Cynecki (24) 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 (25) 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 (26-27) 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 (28-29), 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 (30), and an early 21st century road users' monitoring exercise in Sweden's Skvallertorget (Gossip Square) (31).

The first case study, as reported by Muhlrad (30), 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 (31) 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 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. The method consists of two steps: 1) The categorisation of vehicle-pedestrian interaction events, and 2) the grading according to their severity. 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): This type of interaction occurs in situations where vehicles appear to be static or travelling at a very low speed (less than the pedestrians' walking speed) and pedestrians are also in the road space. This occurs most commonly in three separate circumstances:
  (1) When a traffic signal has changed vehicles begin to pull away but there are still some pedestrians in the road space that have not yet completed their crossing
  (2) When a vehicle travels around a sharp corner at the same time as a pedestrian is crossing the road
  (3) When there is a slow moving queue of vehicles and pedestrians choose 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. 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.

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

Criterion II: Change in direction

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

Criterion III: Acceleration

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

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. 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.

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 interaction point, 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.

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).

(a)

(b)

(c)

(d)

Source: Royal Borough of Kensington and Chelsea

FIGURE 2: Exhibition Road before (left) and after redevelopment (right)

The project was implemented over three 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 re-development, 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. Unravelling of a one-way system (Figure 2b and 2c): 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 redevelopment, 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.
3. Re-design of pedestrian crossing facilities (Figure 2d): 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 redevelopment 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. The scheme also included the removal of pedestrian guardrails and other street clutter to further facilitate pedestrian movement.

4.2 Implementation setup

Video footage has been collected through 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 the following (Figure 3):

- L1: Exhibition Road main body (Before: Cameras A & B – After: Cameras 4, 5, 6 & 7):
  In the original layout, 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 facilitates those crossing movements.
- L2: Cromwell Road junction (Before: Cameras C & D – After: Cameras E, F, G & H):
  In the original layout, 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. The western crossing has been replaced by a wide straight-across crossing in the new layout, while the staggered crossing on the eastern side has been retained but redesigned.
- L3: Thurloe Street (Before: Camera F – After: Cameras 1 & 2):
  Pedestrians using this location in the original layout 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, 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.

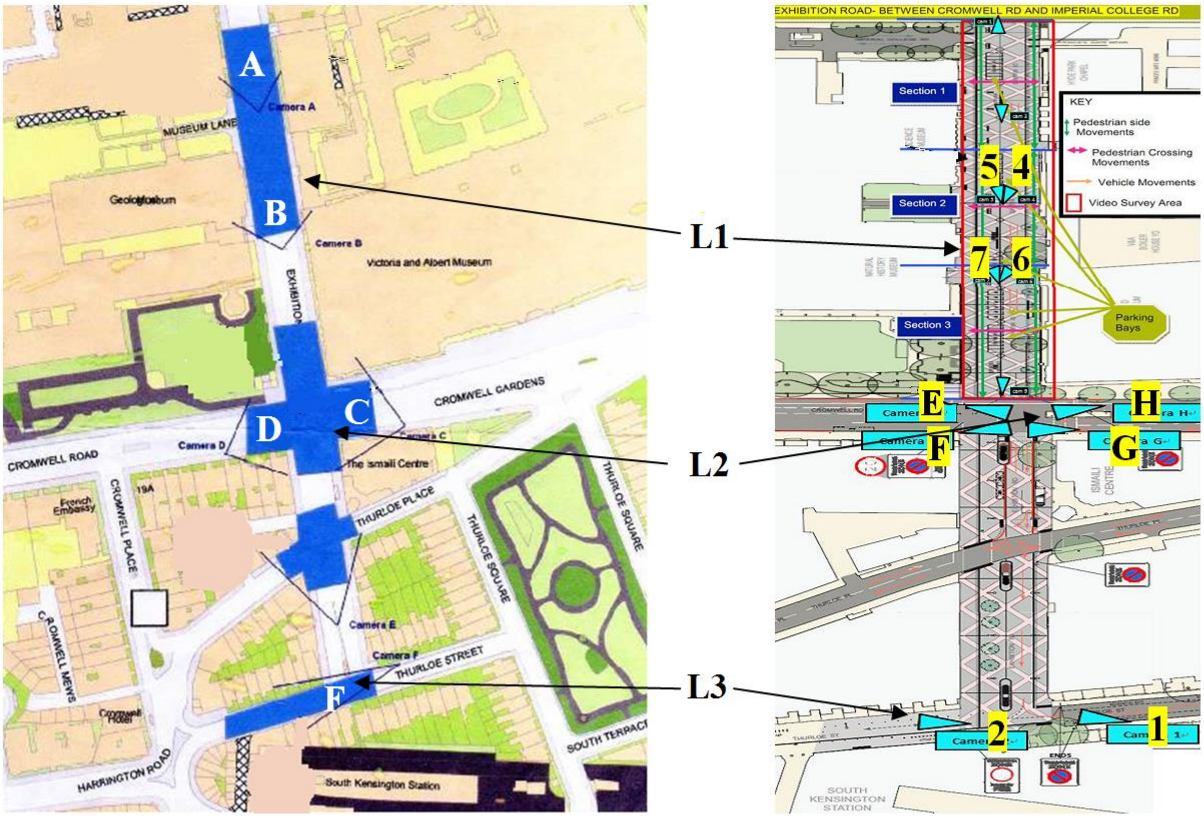

FIGURE 3: Camera locations at the Exhibition Road site in the before- (left) and after-monitoring (right)

4.3 Results

The vehicle-pedestrian interactions recorded during the two observation periods (before and after redevelopment) 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).

Considering the nature 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 Tables 2b-2d.

TABLE 2: (a) Interaction occurrences by location and type; (b) Interactions' severity at the main body of Exhibition Road (L1); (c) Interactions' severity at the junction with Cromwell Road (L2); (d) Interactions' severity at Thurloe Street (L3)

(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)	Crit.	Grade	L1									
			SC-P						ESS			
			Before			After			Before		After	
			Frq.	Veh. spd.	Veh. den.	Frq.	Veh. spd.	Veh. den.	Frq.	Veh. den.	Frq.	Veh. den.
Ped.	I	1 – return	6	18.1	2.6	12	17.7	1.9	-	-	-	-
		2 – give way	78	15.6	2.3	110	15.9	2.1	-	-	-	-
		3 – accelerate	54	16.2	2.3	22	15.8	2.0	1	3.0	2	2.5
		4 – unchanged	103	15.8	2.1	52	15.9	1.9	7	3.1	73	3.1
	II	0 – return	6	17.4	2.4	12	17.7	2.1	-	-	-	-
		1 – deviate	41	14.5	2.3	37	15.5	2.2	5	3.1	25	3.2
		2 – unchanged	194	16.0	2.1	147	16.1	2.0	3	2.6	50	3.2
Veh.	I	1 – stop	4	11.0	2.4	1	9.9	2.0	-	-	-	-
		2 – slow down	30	13.0	2.5	13	12.1	2.3	-	-	-	-
		3 – full speed	207	15.4	2.1	182	16.0	1.9	-	-	-	-
	II	1 – deviate	8	10.3	2.2	7	11.8	1.4	-	-	-	-
		2 – unchanged	233	17.0	2.2	189	16.2	2.0	-	-	-	-
	III	0 – no change	207	16.2	2.2	181	16.1	2.0	-	-	-	-
		1 – wait to clear	20	11.5	2.3	1	10.4	2.0	-	-	-	-
		2 – acc. immed.	14	13.5	2.7	14	13.1	2.2	-	-	-	-
				km/h	veh		km/h	veh		veh		veh

TABLE 2 (continued)

(c)	Crit.	Grade	L2									
			SC-P						ESS			
			Before			After			Before		After	
			Frq.	Veh. spd.	Veh. den.	Frq.	Veh. spd.	Veh. den.	Frq.	Veh. den.	Frq.	Veh. den.
Ped.	I	1 – return	13	19.7	2.3	9	19.2	2.3	10	2.8	2	2.5
		2 – give way	16	19.2	1.8	17	19.1	2.1	1	2.0	2	2.5
		3 – accelerate	95	19.0	2.4	85	18.8	2.4	95	2.7	67	2.4
		4 – unchanged	83	18.9	2.4	81	19.0	2.4	68	3.2	65	3.3
	II	0 – return	13	20.4	2.3	9	19.2	2.3	10	2.8	2	2.5
		1 – deviate	1	22.8	2.0	-	-	-	7	2.3	12	2.4
		2 – unchanged	193	19.4	2.1	183	18.9	2.4	157	3.1	122	3.2
Veh.	I	1 – stop	-	-	-	-	-	-	-	-	-	-
		2 – slow down	7	14.7	2.5	4	15.0	2.5	-	-	-	-
		3 – full speed	200	19.3	2.1	188	19.1	2.3	-	-	-	-
	II	1 – deviate	-	-	-	-	-	-	-	-	-	-
		2 – unchanged	207	19.0	2.3	192	19.0	2.3	-	-	-	-
	III	0 – no change	201	19.1	2.3	188	19.1	2.4	-	-	-	-
		1 – wait to clear	4	16.8	1.8	3	16.2	2.0	-	-	-	-
		2 – acc. immed.	2	14.7	2.5	1	15.0	2.0	-	-	-	-
				km/h	veh		km/h	veh		veh		veh

(d)	Crit.	Grade	L3									
			SC-P						ESS			
			Before			After			Before		After	
			Frq.	Veh. spd.	Veh. den.	Frq.	Veh. spd.	Veh. den.	Frq.	Veh. den.	Frq.	Veh. den.
Ped.	I	1 – return	12	25.3	2.2	-	-	-	-	-	-	-
		2 – give way	17	26.0	2.3	-	-	-	2	1.0	1	1.0
		3 – accelerate	128	26.2	2.2	-	-	-	10	3.2	-	-
		4 – unchanged	74	23.4	2.4	-	-	-	12	2.1	7	1.0
	II	0 – return	14	25.0	2.4	-	-	-	-	-	-	-
		1 – deviate	22	24.9	2.3	-	-	-	4	1.8	4	1.0
		2 – unchanged	195	26.0	2.1	-	-	-	20	2.6	4	1.0
Veh.	I	1 – stop	5	19.0	2.4	-	-	-	-	-	-	-
		2 – slow down	22	23.1	2.5	-	-	-	-	-	-	-
		3 – full speed	204	26.0	2.2	-	-	-	-	-	-	-
	II	1 – deviate	8	25.2	2.0	-	-	-	-	-	-	-
		2 – unchanged	223	25.8	2.2	-	-	-	-	-	-	-
	III	0 – no change	206	25.8	2.1	-	-	-	-	-	-	-
		1 – wait to clear	7	18.9	2.7	-	-	-	-	-	-	-
		2 – acc. immed.	18	22.5	2.7	-	-	-	-	-	-	-
				km/h	veh		km/h	veh		veh		veh

Starting from the main body of Exhibition Road (L1) in Table 2b, 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, 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 do not 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 2c). 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 2d), 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.

All in all with respect to the results obtained, it should be noted additionally that 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.

5 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 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.

Considering the application of the method itself, this can be further improved through the measurement of speeds and densities by automated means and through the use of more observers. Such measures 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.

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