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Working Paper

Linking microsimulators of bus stops and traffic operations: The case of PASSION and BusSIGSIM

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Abstract

The aim of this article is to explore the linkage of two microsimulators developed at the University College London. At present, these models deal independently with buses at either bus stops or traffic networks. First, both microsimulators are described in some detail. The generic way in which both models can be connected is then proposed. As a result of this analysis, the main issues for a comprehensive introduction of public transport vehicles (buses) into microscopic traffic simulators are highlighted. One practical outcome of this study is that the improvement in the representation of buses in microscopic traffic simulators will allow the engineers to take into account traffic management measures that otherwise will not be assessed.

1. Introduction

During the past years, the object oriented modelling has been used to simulate the traffic system, as its components can be represented as entities interacting each other. The main entities in a traffic network are vehicles, road segments, junctions and traffic signals, which can be modelled as agents. These agents have the ability to perceive changes in their environment and, as a result, modify their behaviour for a given objective. For example, the reaction of a driver to a given stimulus ahead can be to speed up to reduce his/her travel time. This is an old idea that had lead to the car-following models since the 1950s (TRB, 1997). Nowadays, however, this idea has been translated into computer code to produce powerful microscopic traffic simulation models ("traffic microsimulators" hereinafter). An analysis of many of these traffic microsimulators can be found in reports of the European SMARTEST (Simulation Modelling Applied to Road Transport European Scheme Tests) project, which analysed the characteristics of 32 traffic microsimulators (Fox, 2000). A complete report of the SMARTEST project can be found in its website (www.its.leeds.ac.uk/projects/smartest).

The thrust of this article can be summarised in the following sentence taken from the introduction of the SMARTEST project: *'Public transport vehicles behave in a different way to other vehicles but are often not modelled in sufficient detail to reflect these differences.'* (www.its.leeds.ac.uk/projects/smartest/intro.html: Areas requiring improvements). As a result, this article, after a brief review about how public transport is being considered in microscopic traffic simulation models, examines in some detail two microsimulators developed at the Centre for Transport Studies, University College London (UCL). These microsimulators were developed independently to deal with buses at either bus stops (PASSION) or traffic networks (BusSIGSIM). Then, we propose a way for linking both microsimulators in order to generate a traffic microsimulator capable of a comprehensive representation of the interactions between traffic, buses and passengers at arterial roads or traffic networks. In the development of this proposal we point out the key issues that need to be taken into account for a proper consideration of public transport vehicles in traffic microsimulators.

2. Examination of microscopic simulators

2.1. How public transport is included in traffic microsimulators

At present, the traffic microsimulators are being used for planning and managing urban and rural traffic, as well as for evaluating Intelligent Transport Systems or ITS (see for instance Boxill and Yu, 2000; Fox, 2000). However, with few exceptions, they are car-oriented tools (e.g. Liu et al, 2000). In addition, when buses or other public transport vehicles are considered, the models have been used to evaluate signal control strategies or exclusive lanes for maintaining regular headways (e.g. Abdulhai et al, 2002; Lindau, 1983). This implies a number of simplifying assumptions about bus characteristics and behaviour, which has led to consider buses as “long cars” that stop between junctions down a fixed route.

In most traffic microsimulation, a bus at a bus stop causes the same reaction in the following vehicle as an unexpected stopping car. In real life, however, drivers in a road with buses know the possibility of bus stop blockage, so they avoid the kerbside lane or they are prepared to overtake a bus as soon as they can. This behaviour is more notorious when buses make an important proportion of the traffic flow on a road (say 10% or more), which leads to what Gibson et al (1989) called *de facto* bus priority; i.e. buses take the kerbside lane for their (almost) exclusive use.

On the other hand, Silva (2001), in a thorough review, argues that bus stops are poorly represented in most traffic microsimulators. In fact, the models assume that a bus stop is a place located near the middle point of two junctions in the kerbside lane. At that point, a bus stops during a fixed (or random) time for boarding and alighting passengers. Normally, the stopping time is not related to the passenger demand, passenger characteristics or its variation during the simulation period. Silva (1997 and 2001) also offers a good discussion on the representation of buses in traffic microsimulators.

In the following, we discuss two microsimulators developed as part of our research at UCL. One is BusSIGSIM, a traffic microsimulator developed for studying the interactions between buses and cars in networks (Silva, 2001; Tyler et al, 2003). The other is PASSION, a microsimulator of interactions between buses, passengers and traffic restraints at bus stops (Fernández, 2001a, 2001b, 2002).

2.2. BusSIGSIM

BusSIGSIM is based on modifications made to the microsimulator SIGSIM for a better representation of the interactions between buses and other traffic either in networks or arterial roads. Some of the features of SIGSIM, taken form Silva (2001), are summarised next.

SIGSIM was designed to evaluate real-time signal optimisation. It was first developed to model traffic at a single junction. Afterwards, a version was developed to model networks (Silcock, 1993). The model continued its development as a parallel computing version. Thus, the work made by Silva (2001) was based on version 3.0 of parallel SIGSIM (Crosta, 1999).

SIGSIM is a mix between fixed-time and event-based simulation built on Gipps' car-following and lane-changing algorithms (Gipps, 1981 and 1986). Each type of vehicle entering the network (cars, heavy and light good vehicles, buses and motorcycles) is assigned to a route (a set of consecutive one-way links connecting nodes) for which the traffic flow and traffic composition is defined. The generation of a vehicle is an event that produces an object with characteristics taken from a table of means and distributions. The kinematics of a vehicle is then updated every ⅔ seconds. Vehicles can be generated either at fixed or random intervals.

Buses in SIGSIM have additional characteristics to the rest of the traffic: number of passengers on board, capacity of vehicles (88 passengers), and total boarding and alighting times at bus stops as a function of the number of passenger at bus stops. The model calculates the dwell time at a bus stop as the maximum of the total boarding or alighting time plus 4 seconds of dead time (typical characteristics of London's two-door, double-decker buses). SIGSIM assumes that during the dwell time a bus produces a temporary obstruction of the kerbside lane. In addition, *'The internal delay is a result of vehicular interactions, simulated by the car-following and lane changing models with no specific provision to represent bus stop operations.'* (Silva, 2001: 79).

Passengers are produced in SIGSIM from an origin-destination matrix between bus stops; they are randomly generated from a distribution around average cells values in the matrix. In principle, all the passengers represented in SIGSIM start and end their journeys within the simulated network; however, the use of dummy bus stops outside the network can allow the user to overcome this limitation. Finally, for each passenger generated SIGSIM assigns his/her origin and destination stop and the marginal boarding time, which is taken from another distribution.

In order to focus the analysis, it was decided that *'As BusSIGSIM is concerned with the simulation of vehicular interactions in traffic, the factors affecting the total and marginal passenger service times are not modelled further than in the original SIGSIM.'* (Silva, 2001: 93). An additional feature of the model with respect to bus stops is the following: *'In order to allow the model to work properly, users are advised to design the network in such a way that bus stops are positioned sufficiently far away from the junction boundaries, so that the relevant sight distances are entirely covered within one junction. This is a limitation in BusSIGSIM, imposed by the architecture of the parallel version of SIGSIM.'* (Silva, 2001: 100)

As a result, of all the potential interactions between buses and traffic that take place around bus stops, BusSIGSIM considers three elements: stopping buses at bus stops, vehicles trying to overtake stopping buses, and vehicles travelling in adjacent lanes. The aim was to understand how the operation of bus stops could affect general traffic. Thus, BusSIGSIM is able to calculate the lateral positions of buses operating in a wide range of stop types to replicate the real entering and leaving paths, as well as the actual gap between the stopped bus and the kerb (Figure 1). This releases the traditional assumption made in most traffic microsimulators in the sense that, with the exception of bus bays, a bus at a bus stop is an unavoidable obstruction for the upstream traffic. On the contrary, field observations and simulation experiments made with BusSIGSIM showed that traffic *squeeze* in the vicinity of a stopping bus. Tyler et al (2003: 127) define this behaviour as follows: *"Squeeze is the use of temporary* de facto *lanes, narrower than the existing ones, in order to accommodate the traffic stream in the available street width and avoid stopping behind an obstacle (e.g. a stopped bus)."* This is shown in Figure 2. Therefore, the expected delays for cars are less than those calculated with most computational tools for traffic analysis. For example, comparing SIGSIM and BusSIGSIM outputs in a single carriageway road, Tyler et al (2003) reported an average 5.5-s/veh drop in car delays and an average 2.6-s/veh increase in bus delays.

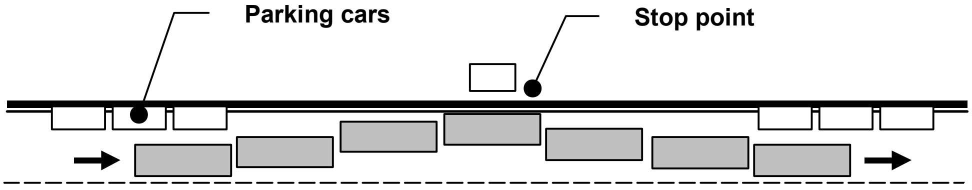

Figure 1: Replication of a stopping bus path in BusSIGSIM

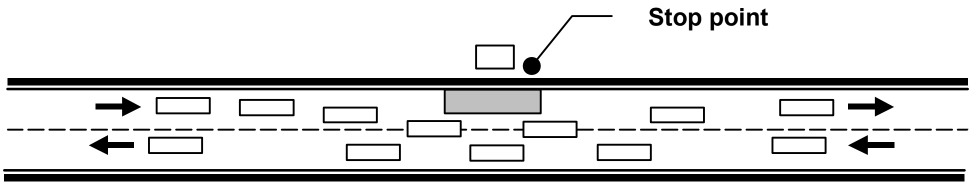

Figure 2: Traffic squeezing at a bus stop as represented in BusSIGSIM

This new way of representing the behaviour near bus stops requires a modification of the car-following model. Details of the new behavioural model can be found in Silva (2000 and 2001).

2.3. PASSION

The model developed for representing bus stops operations is called PASSION, for PArallel Stop SimulatION. The expression "parallel" in the name of the program does not mean a particular computing architecture at present. However, at the early stages of our research the complexity of the problem required a parallel design to represent all the various concurrent processes at the bus stops. Once this was understood, it was possible to represent the problem in a serial code. As a result, a PC-based microsimulator was written. Figure 3 shows the modular components of PASSION. These are:

- *Bus Module:* it generates the characteristics of buses, such as route, arrival times at the bus stop, number of alighting passengers, average alighting time of passengers, spare bus capacity, and blocking times to leave the berth.
- *Passenger Module:* it generates the characteristics of the passengers, such as desired route, arrival time at the platform, and boarding time of each passenger.
- *Main Interaction Module:* it manages the relationships between the bus and the passenger modules, and considers the conditions of the bus stop design and the bus operation system.
- *Performance Module:* it summarises the results of the interactions and allows the evaluation of the changes made in the inputs.

Other inputs for the model are:

- The bus stop design, which is related to the type of bus stops (e.g. on/off-line)
- The bus operation system, which is related to the type of buses (e.g. one/two doors, ticketing system, boarding and alighting facilities)

The model was developed as a virtual laboratory to experiment with the system under study (see Figure 4); that is, a one-berth stop area, its adjacent platform, and its immediate traffic restraints. The aim is to reproduce the behaviour of the system under different cases of bus and passenger characteristic, bus stop design and bus operation. To provide flexibility to the simulation, the bus and passenger modules are able to produce any arrival pattern of buses and passengers, from constant to actual inter-arrivals (e.g. from video recordings).

The outputs enabled to us the discovery of the influence of diverse factors on the performance of bus stops. This knowledge can then be used to derive rules to improve bus operations. Further details of the model can be found in Fernández (2001) or Fernández and Planzer (2002). However, the two main internal models are the calculation of passenger service times (PST) and bus stop capacity. These are described hereafter.

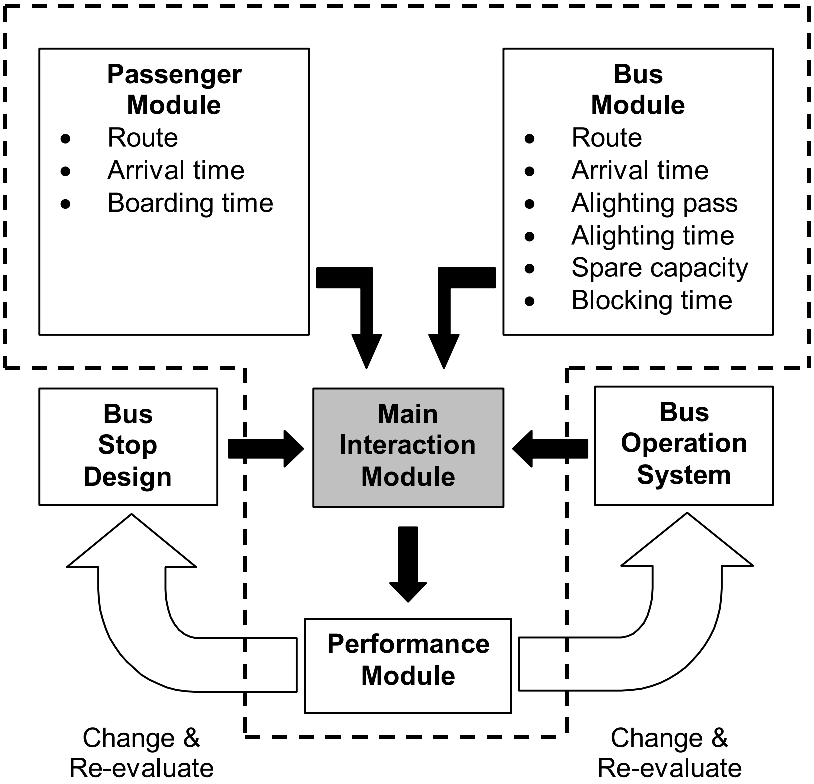

Figure 3: Components of the PASSION simulator

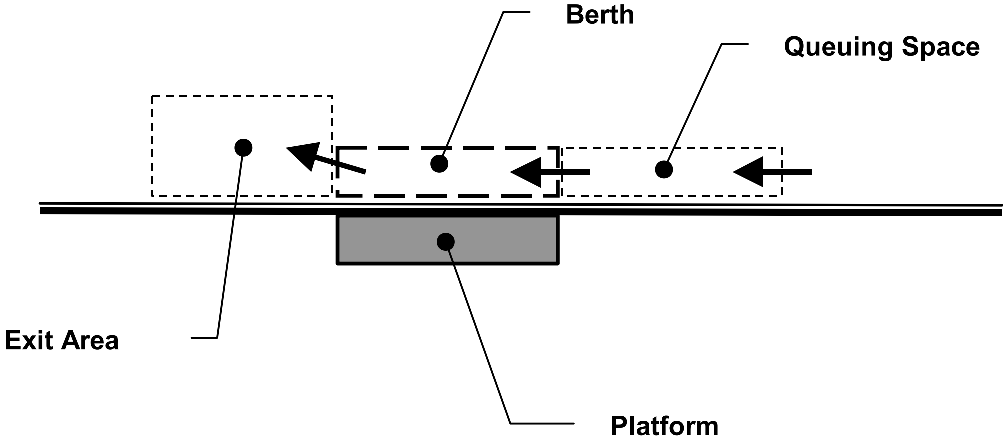

Figure 4: The scope of the PASSION microsimulator

The interactions between buses and passengers at a bus stop are represented by the passenger service time (PST); i.e. the time that a bus takes for boarding and alighting operations. This is calculated in PASSION with the following model.

$$PST_i = \begin{cases} \beta_o + \max\left\{ \sum_{j=1}^{p_{bi}} \beta_{bj} ; \beta_{ai} p_{ai} \right\}, \text{for parallel operations} \\ \beta_o + \left\{ \sum_{j=1}^{p_{bi}} \beta_{bj} + \beta_{ai} p_{ai} \right\}, \text{for sequential operations} \end{cases} \tag{1}$$

where

PST_i : passenger service time of the bus i (s)
β_o : average dead time per stop (s)
β_{bj} : marginal boarding time of passenger j (s)
p_{bi} : boarding passengers to the bus i
β_{ai} : marginal alighting time from the bus i (s/pass)
p_{ai} : alighting passengers from the bus i

As can be seen, this model considers the possibility of parallel or sequential operations for boarding and alighting. This is because it is postulated that buses have either two doors – one for boarding and one for alighting – or just one door that allows passengers to alight and then board. In the model, two sources of variability in the boarding time are introduced: (a) characteristics of passengers, and (b) characteristics of buses. The former can be included in the input file generating a boarding time for each arriving passenger from any given distribution (e.g., uniform). The second source of variability can be incorporated through the bus route, assuming the same type of vehicle for each route. Other ways of providing the β_{bj} values could also be used, such as an average boarding time for all passengers. The alighting time, on the other hand, supports only one source of variation: type of bus. This is because the model does not consider individual alighting passengers, but the bulk of them. The variation in the alighting time can be done in the input file through the bus route, using the same value for each bus of the same route. As the alighting operation is simpler than the boarding one, this assumption infers that all the difficulty rests in the alighting facilities of buses. An average value for all buses can be assumed as well.

Other times generated by the bus-bus and bus-traffic interactions are added to the PST to compute the occupancy time or dwell time; i.e. the total time spent by a bus at the berth. The dwell time is made of a user-defined clearance time of the berth, the PST, and an exit delay based on the state of the exit of the stop area. That is, the time during which a bus, having completed its transfer operation, cannot leave the berth because of restrictions imposed by other traffic. This can be deterministic or stochastic depending on the type of phenomenon that controls the exit (e.g. a traffic signal or gaps in the adjacent lane)

Once the interactions between buses, passengers, and traffic are computed, the program calculates some statistics from the simulation. These are:

- average, maximum and standard deviation of waiting time of passengers;
- mean and maximum number of passengers on the platform;
- mean, maximum and standard deviation of delay to buses;
- capacity and degree of saturation of the bus stop; and
- mean and maximum queue length of buses.

PASSION calculates the capacity of the bus stop in the following way.

$$Q_b = \frac{3600}{\frac{1}{N_b}\sum_{i=1}^{N_b}\left(t_c + PST_i + t_{ei}\right)} \qquad (2)$$

where

Q_b : capacity of the bus stop (bus/h)

N_b : number of simulated buses

PST_i : passenger service time of the bus i (s)

t_{ei} : exit delay for the bus i (s)

t_c : constant clearance time (s)

The calculation of the capacity and other statistics indicate how busy a bus stop is and they are used to design bus stops; i.e. determining the number of stop points and queuing space required for any combination of bus flow and passenger demand.

3. Linking PASSION and BusSIGSIM

From the previous sections the reader can realise that we have cover the simulation of bus operations with two models. One of these deals properly with the traffic interactions *around* bus stops (BusSIGSIM); the other describes in detail the interactions between buses, passenger and traffic restrains *within* bus stops (PASSION). Therefore, it seems convenient, for a more comprehensive analysis, to find a way of linking both approaches. This is discussed further on.

As stated above, one of the flaws of most traffic microsimulators when they include public transport vehicles, rest in the way in which they deal with operations at bus stops. Therefore, the introduction of the capabilities of PASSION as a bus stop simulator in a traffic microsimulator as BusSIGSIM seems a sensible initial strategy.

There is a practical problem though. This lies in the different platforms in which both models have been developed. Despite some detractors, PASSION was coded in a general-purpose language (C^{++}) and at present a Visual C^{++} Windows® version is in progress for providing a user-friendly interface. On the other hand, as mentioned by Silva (2001: 203), '*The portability of BusSIGSIM is another issue that must be mentioned…SIGSIM's parallel version is implemented in a Unix-operated Sun® workstation that hosts a set of transputers, configured in the TPCC (Transport Parallel Computing Centre)… BusSIGSIM kept the same architecture as its platform, so a user also needs to connect to the TPCC to run it. This arrangement may be sufficient for an application "aimed at universities"…, but is inadequate for use by others (e.g. consultants, local authorities etc). A version of BusSIGSIM for PC (personal computer) would certainly be the most portable, but the capacity of this environment to support the software's characteristics is an issue that requires further investigation.'* As this is a computing problem, which could be solved by a computer scientist, we will discuss hereafter in theory how both models can work together.

Therefore, assuming no limitations in the BusSIGSIM platform, the communication with PASSION can be described as shown in Figure 5. It should be clarified in this representation that a *junction* in BusSIGSIM is made of one *intersection* plus all the links starting and ending at that intersection. This definition is associated with the processing unit that contains that part of the system; i.e. a transputer of the parallel computer. An *intersection*, on the other hand, is the place where traffic links with different directions merge and diverge (Silva, 2001). Therefore, an intersection in BusSIGSIM is what in most network models is called a *node*. In BusSIGSIM it is also possible to define a junction without an intersection, as suggested by Silva (2001) for representing a segment of a bus lane. In this way, a bus stop can be contained in a BusSIGSIM junction, where the node (or intersection) is the bus stop.

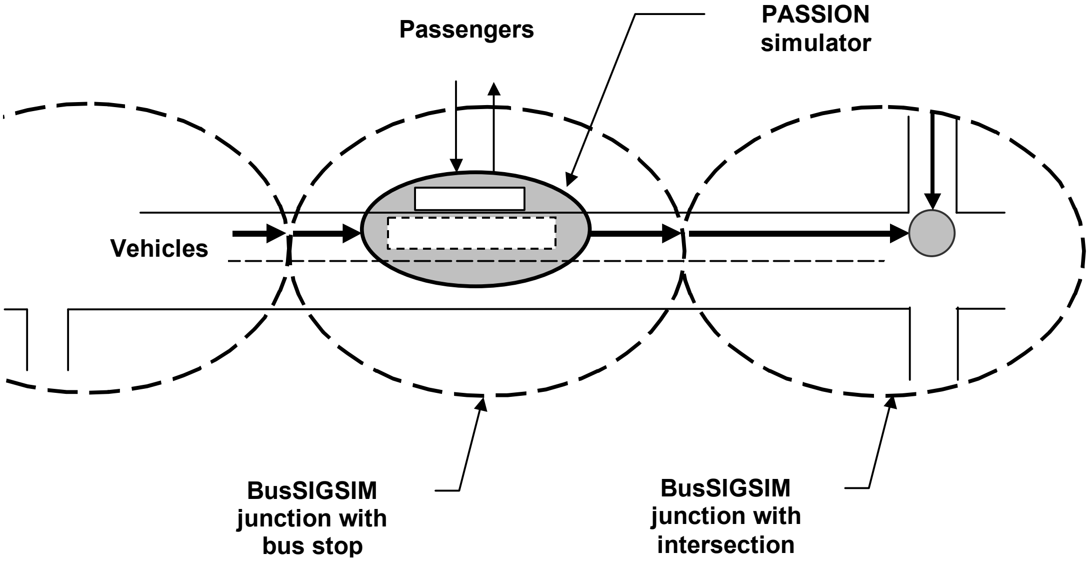

Figure 5: Communication between BusSIGSIM and PASSION microsimulators

The interaction between the microsimulators can be described as follows. BusSIGSIM processes the vehicles through the network until they reach the berth of a bus stop, as described in section 2.2. At that point of the simulation, the bus is delivered to the PASSION model. Then, PASSION deals with the bus and the passengers at the bus stop in the way described in section 2.3. Once the capacity, queues and delays at the bus stop are computed, the bus is returned to BusSIGSIM for replicating its progression along the network.

One of the issues to be considered in order to improve the representation of bus stop interactions is passenger demand. Passenger demand must be enter into the model in a different way as it is done at present in BusSIGSIM. That is, instead of using an origin-destination matrix with random variations around some cell values, the passenger demand must be specified in the PASSION way (see section 2.3) for each bus stop of the network. This is illustrated in Figure 5 with the two arrows, one entering and the other leaving the "BusSIGSIM junction with bus stop". At least, those bus stops with more and variable demand during the simulation period require this sort of a careful survey. Obviously, this implies to collect more data for the simulation; however, this is the price if real life behaviour wants to be incorporated into the modelling.

In fact, further studies made by Fernández (2003) show the influence of the location of different passenger loads on the performance of buses on an arterial road, despite the priority for buses provided via fixed-plan signal settings. In addition, Fernández and Valenzuela (2003) using an analytical model have confirmed the potential impacts of the stop frequency and stop delays on bus commercial speed – the average journey speed of public transport vehicles between an origin and a destination stop, including any delay arisen in the course of the journey.

4. Concluding remarks

In this paper we have analysed the possibility – even the necessity – of linking traffic and bus stop microsimulators for a better representation of the public transport. The improvement in the incorporation of public transport vehicles, in particular buses, into traffic microsimulators will allow the transport analyst the evaluation of traffic management measures that otherwise will not be considered. One of these measures is an efficient design of bus stops, which includes enter and exit distances, enough queuing space in case of bus bunching, adequate platforms to keep all waiting passengers, facilities for buses to pull out, etc. Most of the time, traffic engineers when dealing with buses forget these issues. Another simple measure is the reallocation of road space in the vicinity of a bus stop to make room for drivers overtaking stopped buses (Tyler et al, 2003). This can be achieved by modifying lane markings to make the squeeze easier. Figure 6 below is the same Figure 2, but now the central line has been moved to allow drivers to overtake buses.

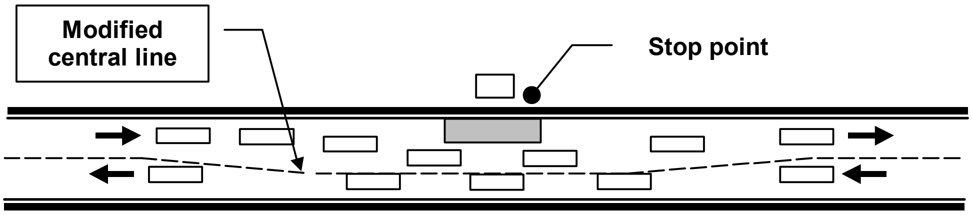

Figure 6: Suggested road markings around a bus stop

The feasibility of connecting bus stop simulators and traffic microsimulators was illustrated herein with the two models developed at UCL for these objectives. This exercise not only showed the viability of linking PASSION and BusSIGSIM, but also, with the appropriate modifications, the possibility of linking PASSION with other traffic microsimulators. The fact that most traffic microsimulators fail in the same aspect that BusSIGSIM – i.e. disregarding the actual interactions between buses and passengers – should make the necessary changes apparent for the modeller.

The above means that all the bus stops to be modelled require the specification of its actual or predicted demand patterns – in the same way as traffic flows joining at nodes are specified in traffic network models. This, in conjunction with the squeezing behaviour explained in this article, is one of the most important factors to be incorporated in traffic microsimulators for dealing with public transport vehicles.

The assumption made in most traffic microsimulators of fixed (or random) stopping times at bus stops is as peculiar as if we consider the same delay at all road junctions in a network. Equally odd would be the fact that these delays at road junctions could be random figures, irrespective of their traffic patterns. As a result, most of the power of the microsimulation is being missing with that assumption about public transport behaviour.

Finally, there is also a further necessity of modelling pedestrian movements around bus stops. This is mainly because there is some empirical evidence that a crowded platform have impact on the increase of the passenger service time (see Fernández, 2001a). However, how exactly pedestrian traffic influences this increase is matter of ongoing research at UCL. For example, How to manage conflicting pedestrian flows on the platform to reduce the passenger service time? Is a single queue the best way of arranging waiting passengers? Is this only an issue for rational road design for pedestrians? As soon as we can understand better the interactions between traffic, public transport vehicles and passengers, the next step is to understand the interactions between people at both platforms and within public transport vehicles.

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