Comparison of Homogeneous and Heterogeneous Motorised Traffic at Signalised and Two-way Stop control Single lane Intersection

Puspita Deo[1], Heather J. Ruskin[1]

[1] School of Computing, Dublin City University, Dublin, Dublin 9, Ireland
{dpuspita, hruskin}@computing.dcu.ie

Abstract. Results of a microscopic model of mixed motorised traffic consisting of short vehicles, (e.g. cars), and long vehicles, (taken to be double the length of the short vehicles), for an urban two-way single lane intersection are presented here. We model the intersection using both signalised and un-signalised stop control rules. The model allows for the detection of bottleneck activity in both homogenous and heterogeneous traffic conditions, and was validated by means of field data collected in Dublin, Ireland. The validated model was used to study the impact of inclusion of long vehicles on traffic performance in an urban environment. Traffic mix is, however, taken to be dominated by short vehicles overall, in argument with observed live data collected.

1 Introduction

Homogeneous traffic flow has attracted much attention, not only for exclusively single lane roads but also for more complex configurations [1]. We focus here however on factor that contributes to heterogeneous traffic flow inability for a single lane. A major issue is clearly that of bottlenecks. Bottleneck conditions are crucial for single lane flow when right turning (RT) and long vehicle (LV) proportions increase. The focus of the research community on homogeneous, ignores many important features of real heterogeneous traffic and it is clear that more experimental work on heterogeneity is needed.

Heterogeneous motorised traffic flow characteristics for single lane roads are essential to understanding urban traffic problems. Such models would be of significant help to traffic planners, in making key decisions. Simulation modelling is an increasingly popular and effective tool for analysing a wide variety of dynamic problems, which are not amenable to study by other means [2] and there are many examples of their use in modelling traffic.

Unfortunately, the literature shows that limited studies only have concentrated on heterogeneous traffic movements for single-lane situations in Western European countries. Yet many European cities have a wide range of road capacity within the city environment and relay on single lane connection to major arterial routes. Different heterogeneous urban traffic models have already been reported in some cases, these include:

A stochastic traffic-flow simulation model [3] for urban highways looked specifically at collection and extraction of headway data. The model is also capable of simulating traffic movements at curbside bus stops and bus bays; microscopic simulation model [2] of mixed motorised and no motorised traffic over an urban arterial mid block section, the passenger car unit (PCU) technique [4] for estimating the influence of heavy vehicles to modify the gap acceptance parameters for drivers of heavy vehicles and drivers who accept a gap just ahead of a heavy vehicle; first-order second moment method [5] used to estimate the saturation flow and the delay caused to traffic at signalised intersections under heterogeneous traffic conditions; a model for depicting road traffic behaviour (MORTAB) [6] under mixed traffic conditions and heterogeneous traffic flow on roads where vehicles move without lane discipline [7]. These have in most cases, discussed validation of the proposed model and their outcomes, these studies, though intended for simulating heterogeneous flows are moving of vehicles on any available part of road space without lane discipline.

In multi class traffic flow models, the focus is mainly on using macroscopic conditions for highway multi class flows [8]. Vehicle interactions, such as over taking and lane changing are also taken into account.

In comparing the homogeneous original LWR model (i.e. Lighthill, Whitham, and Richards macroscopic first-order continuum model) to a heterogeneous version [9]. The authors divided the heterogeneous traffic population into homogeneous classes, so that the original LWR model describes vehicles of each particular class if and only if the road is free of other vehicles. This permits deviation of a fundamental diagram for each class separately. The characteristic properties of each class is described by its fundamental diagram

The impact, of mixed traffic conditions on delay due to vehicle interaction, persons and vehicle stopping rules at a signalised intersection are described in [10]. The author's note that the most important limitation, inherent to all analytical delay models for signalised intersections, is their inability to predict delay for traffic conditions that are different from those assumed in the models. In particular, because they were designed to evaluate flow patterns from a macroscopic point of view, (that is, by considering only hourly flows and average traffic behaviour), these models cannot be used to analyse the delay incurred by individual vehicles.

The paper presented here, describes the development of a traffic-flow model using a two component cellular automata for urban single-lane intersection with heterogeneous motorised traffic. The advantages of cellular automata models are that they are computationally simple and flexible and can encapsulate the complexity of real world traffic behaviour through detailed specification. Such models are capable of producing clear physical patterns that are similar to those we see in everyday life. Where as mathematical models have a closed form solution, which describes properties of the traffic flow in general. The model attempts to simulate the presence of both short and long vehicle interaction at the urban intersection and the impact of this mix on intersection performance. This is constructed based on previous work on homogeneous flows at an intersection [11], which was designed to describe stochastic interaction between individual vehicles and independent of headway distribution.

2 Two Component Cellular Automata Model

The model proposed in this article simulates single lane two-way signalised and un-signalised intersections. For the cellular automaton (CA) model, the road is considered as divided into cells of length 7.5m. Each cell is occupied by one particle per cell corresponding to a standard car of length less then or equal to 7.5metres. Long vehicles (LV) are taken for simplicity, to be double the length of a standard car, i.e. two cells are considered occupied by one LV. In our model a car is thus a short vehicle (SV) of length 1 and a LV is of length 2. Both the SV and LV will move exactly one cell in one time step if the cell in front is vacant. The state of each cell at the next time step is determined from the state of the cell itself and of its nearest neighbouring cell in the direction of movement at the current time.

2.1 Vehicle Manoeuvre at a Two-way Stop (TWSC) Control Intersection

A two component one-dimensional Cellular automata is used to simulate the interaction between the vehicles, in which a vehicle will move only one cell in a given time step. Minor-road vehicles will move on to the junction only when the required numbers of empty cells are available. In the CA model described, the states of all cells update simultaneously. Figure 1 represents the current situation for available spaces and, to follow through on the movement, we consider the situation at the next time-step. We assume that all driver behaviour is rational and that, for our CA model, the space required in terms of different number of vacant cells in the opposing directions of flow road for SV and LV is an extension of that specified in [11] for rational and conservative driver checks.

Fig. 1 indicates the conditions for RT vehicle (SV or LV) driver to enter the intersection from a minor road. A SV and LV need to check 8 and 11 marked cells respectively. Marked cells are denoted as 0, L, nR, sR. A "0" means that the cell needs to be vacant," L" means that the cell needs to be either vacant or occupied by vehicle that will turn left, “nR” means that the cell must not be occupied by right-turning vehicle, “sR” means the cell needs to be either occupied by a right turning short vehicle or vacant.

A vehicle from the opposing minor road at a two way stop control intersection (TWSC), which intends to move straight-ahead or turn left (LT), has priority over a RT vehicle from the given minor-road according to rule of the road. However, priorities between minor-road vehicles might not be distinct [12]. They indicated that drivers were observer to enter the intersection on a first come, first-served basis.

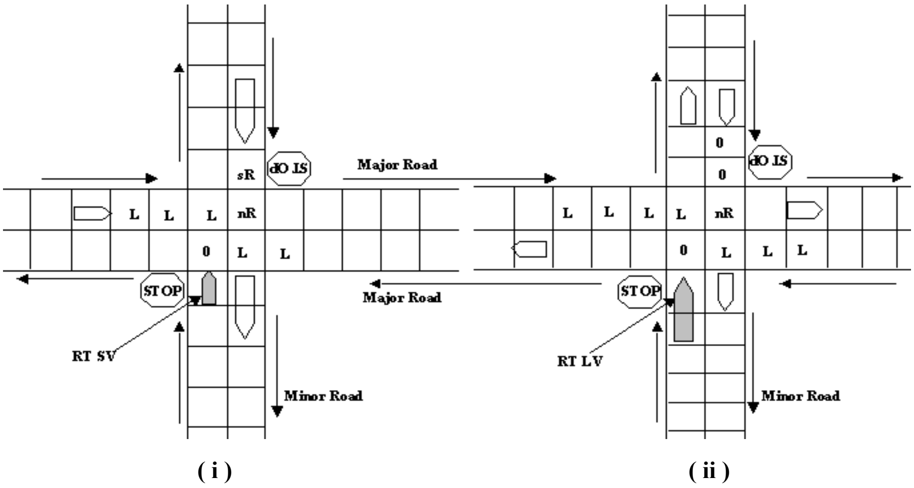
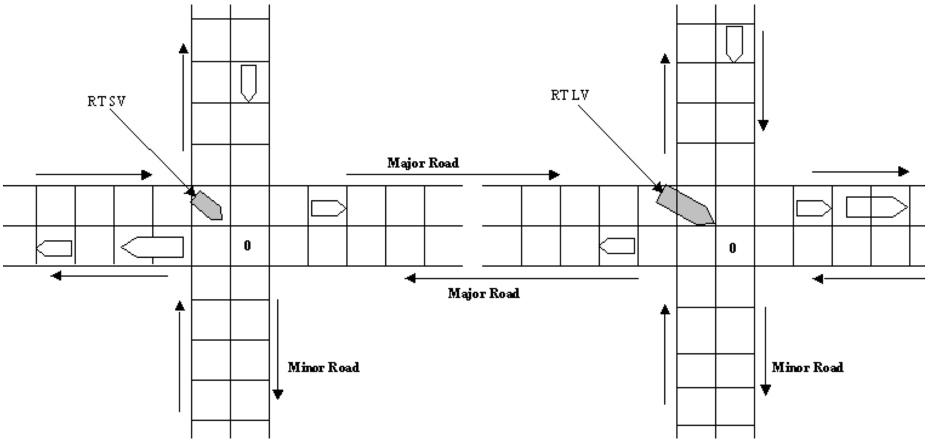


Fig. 1 A right turning vehicle from minor road TWSC Intersection **(i)** SV **(ii)** LV

The movement of the RT SV and LV vehicle from a minor road does not need to consider opposing vehicles if one of the conditions is met: (a) for SV vehicle first cell in the opposing minor road is vacant and for LV two cells opposing minor road should be vacant, (b) RT vehicle is the first vehicle in the opposing minor-road, (c) The first vehicle in the opposing minor-road arrives at a stop-line in less than stop time delay time.

2.2 Right Turning Vehicle Manoeuvre at a Traffic Light Controlled (TLC) Intersection

In Fig. 2 show the requirements in terms of cells free for a right turning vehicle from both the major and minor road at a controlled intersection are shown. If a designated cell is not vacant, than the entering vehicle has to wait before manoeuvring. An SV vehicle needs one time step to crossing a given cell, while LV needs two time steps.



(i) **(ii)**

Fig. 2 A right turning (RT) vehicle from major road **(i)** SV **(ii)** LV

2.3 Control Rule: Signalised and TWSC Intersection

In the signalised intersection, the traffic flow is controlled by a set of traffic lights, which are operated in a fixed cycle manner, (constant period of time T). A cycle is divided into three phases; green, yellow and red, all with fixed periods which sum to T. In our model we consider two main stages for control. In Stage-1, the traffic light is green for major roads and simultaneously red for minor roads. At the second part, the lights change colour to yellow for the major roads and simultaneously change to red for minor roads. In the stage-2 the same cycle is repeated in reverse, i.e. minor roads become green and yellow and major roads become red. In the case of a TWSC intersection, a minor road vehicle has to wait for 2-time steps to prior entering the intersection in before checking available of the space.

3 Real traffic data of the local intersection

Dublin City Council collects detailed traffic in a variety of ways. A particular forms is local single lane two-way intersection (Single as that for Rathgar Road/ Frankfort Avenue used here). The checks on data are collected manually over a 10-hour period at 15-minute intervals. In this instance, the weather is recorded as fair. The composition of traffic and turning percentage at the study location is shown in Tables 1 and 2.

Table 1. Turning Percentage (%) and flow (Total vehicles in10 hours)

Characteristic	(Road-1)*		(Road-2)*		(Road-3)*		(Road-4)*	
	Flow	%	Flow	%	Flow	%	Flow	%
Left turning traffic	532	10	387	16	140	3	481	23
Straight through traffic	4160	85	1569	65	4427	90	1526	71
Right turning traffic	245	5	472	19	374	7	131	6
Totals for 10 hours	**4937**	**100**	**2428**	**100**	**4941**	**100**	**2138**	**100**
Averages per hour	**494**		**243**		**494**		**214**	

* Road-1 and Road-3 are major roads and Road-2 and Road-4 are minor roads.

Table 2. Traffic Composition (Total vehicles in10 hours)

Vehicle Types	(Road-1)		(Road-2)		(Road-3)		(Road-4)	
	Flow	%	Flow	%	Flow	%	Flow	%
Short vehicle (Car)	4703	95	2391	98	4678	95	2111	99
Long vehicle (bus or lorry)	234	5	31	2	263	5	27	1
Total for 10 hours	**4937**	**100**	**2428**	**100**	**4941**	**100**	**2138**	**100**
Averages per hour	**494**		**243**		**494**		**214**	

4 Result from Computer Simulations

Our simulations were carried out for 36000 seconds, equivalent to 10 hours for a all length of each entrance road=100 cells. For turning rate and traffic composition, the real traffic data (references Section 3) is used to specify initial values, unless other wise specified. This is a baseline, we would be expected to vary, the baseline values in a sensibility analysis to determine how robust this model is to different assumptions and values.

Table 3. Comparison: Overall Throughput of Homogeneous and Heterogeneous Traffic (TWSC and TLC Intersections)

AR(1,2,3&4)		Throughput (vph)		
		SV	SV+LV	LV
0.05	TLC	866	871	52
	TWSC	863	872	415
0.1	TLC	1593	1481	17
	TWSC	1568	998	99
0.15	TLC	2303	1221	10
	TWSC	1773	747	95
0.2	TLC	3020	807	5
	TWSC	1859	664	61
0.25	TLC	3559	424	5
	TWSC	1944	339	18
0.3	TLC	4039	343	5
	TWSC	2147	250	17
0.35	TLC	4330	248	4
	TWSC	2293	175	13
0.4	TLC	4683	139	4
	TWSC	2429	121	12

Table 3 show results for a series of simulations with arrival rates of four roads equal ($AR1=AR_2=AR_3=AR_4$) and which varied from 0.05 to 0.4 (equivalent to 180 vph to 1440 vph). For turning rate and traffic composition for all approaches Table 1 and 2 values were used. We found that throughput of homogeneous traffic (i.e. 100 percent passenger cars or a SVs in our model) increases linearly as arrival rate of all approaches increase simultaneously. It is also clear that the throughput of 100 percent SV in TLC intersection is higher than that of TWSC intersection. In this case arrival rates were not high enough to produce the saturation but were designed to assess impact of vehicle mix on the flow.

In the case of heterogeneous traffic (i.e. SV+LV), when the arrival rate of all approaches increases throughput increases up to certain extent and than minimal at AR =0.2 both in TWSC and TLC intersection. The throughput of the heterogeneous traffic in TLC intersection is higher again than that of the TWSC intersection.

When the traffic is 100 per cent long vehicles the throughput obtained in TLC intersection is nearly zero as compare with the 100 percent short vehicle traffic. In the case of TWSC intersection throughput increases up to maximum at AR=0.05 then falls to minimal throughput at AR=0.2. Homogeneous long vehicle traffic clearly does better at a TWSC intersection, but in reality no city traffic is 100 per cent long vehicles. Clearly, while conditions are extreme and therefore artificial in these test. Our model can be used to predict the impact of traffic mix on intersection performance.

4.2 Comparison of Entry Capacity of the major road: (TLC and TWSC Intersections)

Right-turning vehicles from a major road where RT, ST and LT vehicles share road space, can block ST and LT vehicles behind and in the same road in single lane found. RT rates (RTR) of the major roads thus have great impact on major-road capacity. In order to examine this for road entry, we varied right turning rate (RTR) of the roads from 0.01 to 0.1. Arrival rate was fixed at AR_1=AR_2=AR_3=AR_4=0.15, (equivalent to 540 vph) for this test case.

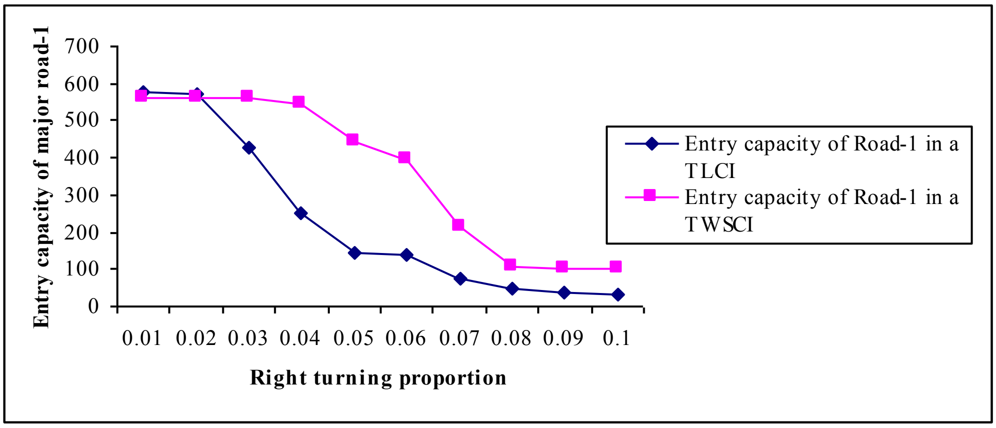


Fig. 3 Entry Capacity of major road1 Vs Right turning rate

Fig. 3 shows, unsurprisingly, that the entry capacity of the major road intersection declines with RTR increase. We conclude that the capacity for mix traffic of the major road declines when the percentage of RTR increases for both TLC and TWSC intersections. TLC entry capacity curve is lower than that for the TWSC intersection, since the TWSC intersection free flow traffic.

4. 3 Proportion of vehicles at a TLC Intersection

Table 4 Overall Throughput for different SV: LV mix. All arrival rates (AR) taken to be the same for all roads

$AR_{(1,2,3,4)}$	SV: LV					
	1:0	**0.9:0.1**	**0.8:0.2**	**0.7:0.3**	**0.6:0.4**	**0.5:0.5**
0.05	8657	1675	1260	875	767	691
0.1	16021	3274	931	746	668	482
0.15	23911	1242	716	472	377	464
0.2	30362	1152	503	300	250	186
0.25	35697	940	406	191	119	99

Table 4 illustrates effects of different SV: LV proportions on overall throughputs. In each scenario, the turning rates of all approaches are based on the field data (Table 1). The arrival rate of the two major roads and minor roads are taken to be equal and vary from 0.05 to 0.25 (equivalent to 180 vph to 900 vph). It is found that the throughput of the intersection increases when the traffic is homogeneous (100 percent SV) even if the arrival rate is increased. In contrast the heterogeneous traffic throughput decreases with increased arrival rates and proportion of LV in the traffic mix.

4. 4 Model validation

Our model has been validated, by simulating heterogeneous traffic on a single lane road using field data collected by Dublin City Council (ref. Tables 1 and 2). The model was run 50 runs of ten hours and the average result is presented in Tables 5 and 6. The data on Tables 5 and 6 were used and the graph obtained is presented in Fig. 4 and Fig. 5.

Table 5. Comparison of real data of Table1 with simulated Data

Road Number	Turning Rate								
	LTR			STR			RTR		
	*Obs	*Sim	% Error	*Obs	*Sim	% Error	*Obs	*Sim	% Error
Road-1	**532**	500	-6.01	**4160**	4243	+1.99	**245**	251	+2.53
Road-2	**387**	403	+4.13	**1569**	1626	+3.63	**472**	474	+0.42
Road-3	**140**	156	+11.42	**4427**	4662	+5.30	**374**	171	-54.27
Road-4	**481**	515	+7.06	**1526**	1593	+4.39	**131**	50	-61.83

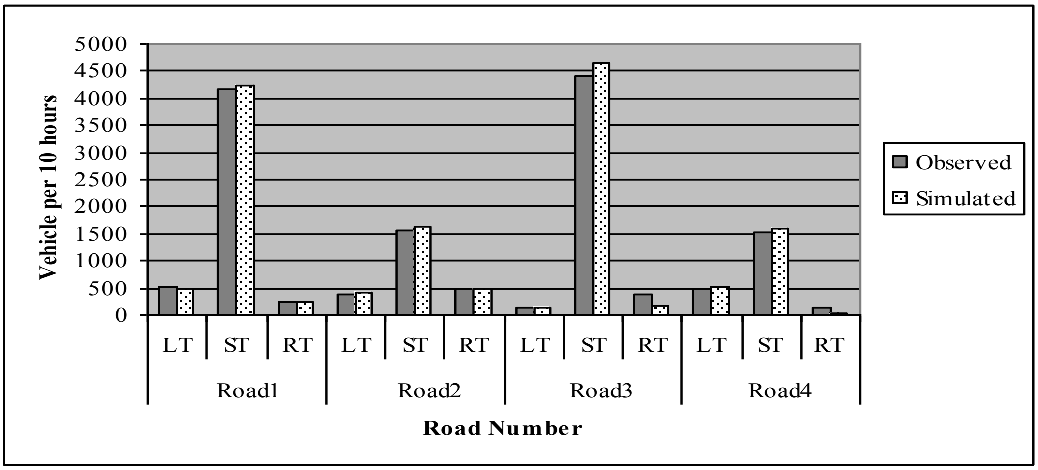


Fig. 4 Model validation (Comparison of Observed and simulated turning data)

It can be shown in Fig. 4 that the simulated data of different turning rates match corresponding observed values well except for the right turning rate (RTR) of roads 3 and 4. The reason is that, in our model we have 2 flow cycle phases i.e., in the first phase roads 1 and 3 have a green light and roads 2 and 4 become red. In the second phase, the lights change colour and movement is allowed for road-2 and road-4 sequentially. So, road-1 and road-2 right turning traffic always takes higher priority than road-2 and road-4 traffic.

* Obs= Observed and *Sim=Simulated data

Table 6. Comparison of real data of Table2 with simulated Data

Road Number	Traffic composition					
	SV			LV		
	*Obs	*Sim	% Error	*Obs	*Sim	% Error
Road-1	**4703**	4777	+1.57	**234**	217	-7.26
Road-2	**2391**	2456	+2.71	**31**	47	+51.61
Road-3	**4678**	4771	+1.98	**263**	218	-17.11
Road-4	**2111**	2137	+1.23	**27**	20	-25.9

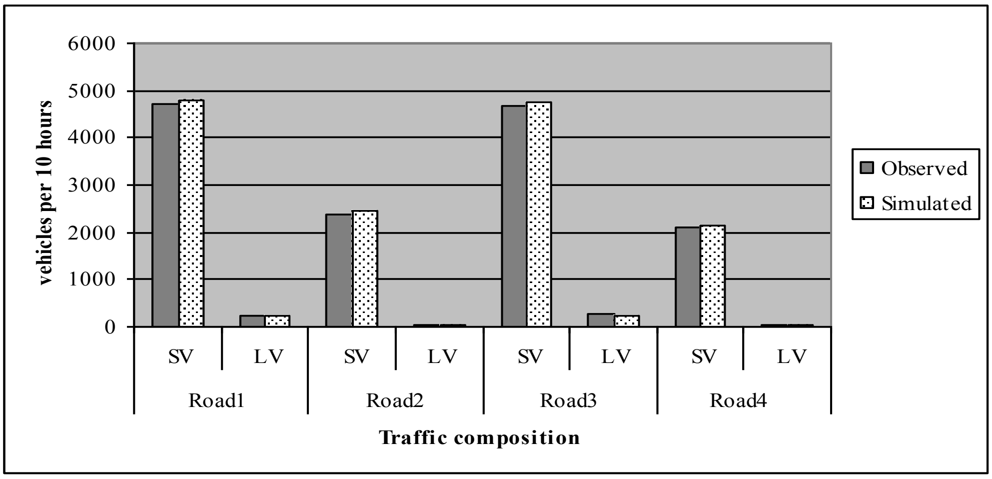


Fig. 5 Model validation (Comparison of Observed and simulated traffic composition data)

As shown in Fig. 5 and Table 6 the simulated value of long vehicle and short vehicle traffic is in reasonable agreement with real traffic data except for road-2 and road-4 long vehicle traffic. Possible reason may be that result is averaged over 50 runs but the real data was collected in just one 10-hour period.

5 Conclusions

In this paper, we have described a prototype two component cellular automata model which attempts to simulate traffic flow at a TWSC and TLC intersection for both homogeneous and heterogeneous traffic in a single lane two-way road. These studies have shown that the throughput and entry capacity of mixed traffic depends on the arrival rate and right turning rates of vehicles, as well as proportion of LV. For exclusively single lane homogeneous traffic 100 percent SV actually leads to better than found for heterogeneous traffic flow. Turning rates and traffic composition have been validated using field data collected by Dublin City Council (1997). The simulation result show reasonable agreement is found between observed and simulated values, particularly for low proportion of LV.

We developed novel methodology for modelling motorised heterogeneous traffic flow using two-component cellular automata. It has been found that the method of treating vehicles as two different lengths enables replication of the field conditions of mixed traffic flow. Comparison with work of others: we look at heterogeneity for urban traffic features, such as intersection, controlled and uncontrolled and compares with empirical data, as highlighted in the paper, Sections 2.1, 2.2, 2.3 and 4.4. Although

* Obs= Observed and *Sim=Simulated data

limited to date in terms of vehicle type to our knowledge, only linear traffic for a variety of vehicle types has been presented to date [2,3,7] or controlled intersection for a range of vehicle types [5]. Methods used in these examples are not based on detailed consideration of vehicle manoeuvres using cellular automata.

The present CA model has also been used to investigate traffic conditions of both homogeneous (100 percent SV and 100 percent LV) and heterogeneous traffic (SV+ LV) flow at urban intersections. It is clear that investigations of the nature and impact of long vehicles in exclusively single lane traffic are vital to understanding urban flows. The change in proportion of such traffic has *strong impact* on these shared roads, which are bottlenecks and dictate feeder traffic flow to larger arterial routes. Future work will examine alternative mixes and saturation factors. Further potential development can thus incorporate the effects of other motorised and non-motorised vehicles (i.e. trucks, cycles respectively) for similar or alternative roadway geometry.

References

1. Daganzo C.F.: Remarks on Traffic Flow Modelling and its Applications, (available on http://www.ce.berkeley.edu/~daganzo/PAPER.PDF) [accessed on December 1, 2005]
2. Arasan,V.T, Koshy, R.Z.: Modelling Heterogeneous Traffic flow on Urban Roads, Proc-edings of National Conference on Transportation Systems, IIT Delhi (2002), 394-404
3. Koshy, R.Z., Arasan,V.T.: Modelling Stochasticity of Heterogeneous Traffic, Proceedings of the Fourth International Symposium on Uncertainty Modelling and Analysis, ISUMA(2003), IEEE Computer Socity
4. Troutbeck, R. J.: Effect of Heavy Vehicles at Australian Traffic Circles and Unsignalised Intersections, Transportation Research Record 1398 (1993), 54-60
5. Arasan,V.T, Jagadeesh, K.: Effect of Heterogeneity of Traffic on Delay at Signalised Intersections, Journal of Transportation Engineering (1995), 397-404
6. Ramanayya, T. V.: Highway Capacity under mixed traffic conditions, Traffic Engineering and control (1988), 284-287
7. Arsan, V. T. and Koshy, R. Z. "Methodology for Modelling Highly Heterogeneous Traffic Flow" Journal of Transportation Engineering (2005), Vol. 131, No. 7, July 1, 544-551
8. Hoogendoon S.P. and Bovy, P.H.L.: Continuum modelling of Multiclass traffic flow, Transportation Research part B (2000), 34, 123-146
9. Logghe, S.: Dynamic Modelling of Heterogeneous Vehicular Traffic", Ph.D. thesis (2003), Katholi University Leuven, Kasteelpark Arenberg 40, B http://www.kuleuven.ac.be/traffic/
10. Youn-Soo, K.: Delay, Stop and Queue Estimation for Uniform and Random Traffic Arrivals at Fixed-Time Signalised Intersections", PhD thesis (2000), Civil Engineering, Virginia Tech, Virginia, USA.
11. Wang, R., Ruskin, H.J: Modelling Traffic Flow at an Urban Unsignalised Intersection, ICCS (2002), LNCS 2329, 381-390.
12. Tian, Z., Troutbeck, R., Kyte, M., Brilon, W., Vandehey, M., Kittelson, W.: Ribinson, B.M. A further investigation on critical gap and follow-up time, Transportation Research Circular **E-C108**: 4th International Symposium on Highway Capacity (2000), 397-408