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Modelling and Simulation of Mixed Traffic

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Abstract

Traffic simulation is one of the most effective tools for the testing of new road design solutions, however the simulation of Asian traffic with potentially the most rapidly changing traffic conditions, and requiring new infrastructures and improvement solutions, is still at an early stage. In that purpose, we developed a new mixed flow model for the micro simulator of Aimsun. The model aims at providing a detailed and robust behavioural model to simulate Asian traffic conditions. This paper provides a description of the model, followed by a short sensitivity analysis focussed on capacity and jam density and an application to a busy junction in the city of Thane, India.

1. Introduction

Recent developments in the modelling of two-wheeled vehicles include the adaptation of a number of existing behavioural models such as Car-following and Lane-changing models, Cellular Automata models (Nagel K. & Schreckenberg M., 1992) and Social Force models (Helbing D. & Molnar P., 1995). The Car-following model can account for each pair of vehicle types present in the heterogeneous flow (Mathew T.V. & Ravishankar K.V.R. 2011) and may include Lateral discomfort caused by lateral friction between vehicles (Gunnay B., 2007). The problem of dealing with non lane-based lateral movements can be treated either in a discrete form, splitting the lanes into narrow strips where vehicles can occupy several strips at a time and applying some sort of lane changing from strip to strip (Mathew et al. 2013), or in a continuous way by introducing a veering angle, and a path selection process to update the lateral position and lateral speed (Lee T.C. 2008). Similarly to the strip approach, an extension of the cellular automata model with smaller cells and where vehicles can occupy several cells at a time has been proposed by different authors (e.g. Yao et al. 2009, Vasic and Ruskin 2012). Social Force models including different forces for each vehicle type pairs (Li et al. 2011) and additional contact and friction forces (Jiang et al. 2012) have also been proposed. Although a number of specific models have been proposed to simulate the behaviour of two-wheeled vehicles, the vast majority of them have not been properly validated due to the lack of relevant empirical data.

Like most traffic simulators, Aimsun was originally developed to simulate European traffic. Involving little vehicle heterogeneity, its microscopic behavioural model is based on driving rules using lane based discipline, priorities, stops, give-ways and cooperation. Those concepts do not hold in Asian traffic. With an aim of simulating significant portions of the Asian road network we developed a new behavioural model involving both decision taking and movement completion.

The model is based on the observation that drivers only seem to be concerned by what is ahead and that they try to keep moving forward at all costs. The model also considers the widely heterogeneous range of vehicles characteristics co-existing on the road network. Special attention has been given to the computational speed and the robustness of the method as the purpose of this model is to simulate large areas and a wide variety of networks and traffic conditions. Based on a deterministic rule-based path selection model that does not require any spatial discretization, this new model is fully integrated in the micro simulator and compatible with other Aimsun features and can be run with multi-threads. It can be activated only locally on a few sections and only for one or more vehicle types if required, or for all vehicle types and sections.

2. Mixed Flow Model

We have introduced the modeling of lateral non-lane based movements in the Aimsun micro-simulator. The possibility to activate non-lane based movements by vehicle type and section makes it very flexible and able to simulate situations ranging from the specific behavior of motorcycles in lane based flows (for e.g. in European cities such as Barcelona) to fully non-lane based traffic including vehicle types with a wide range of characteristics such as those in Indian traffic. In this section we present the additional parameters required, the modifications made to the car-following model to include multiple leaders, the effects of potential swerving maneuvers and lateral friction; and the path selection model used to compute the intended lateral position of the vehicle.

2.1 New model parameters

The non-lane based model requires new parameters that constrain the lateral spacing and movements of the vehicles. We introduced the lateral clearance and maximum lateral speed. The minimum lateral spacing between two vehicles is the sum of the lateral clearances of both vehicles. Although some observation seem to suggest that the lateral clearance has some correlation with the speed of the vehicles (e.g. Mallikarjuna et al. 2013), we only include vehicle to vehicle variations coming from distributions defined by vehicle type. The reason for this is that the vehicle-vehicle dispersion is quite large and the speed trend can be considered as a second order approximation. When moving laterally, the vehicles use their maximum lateral speed as no lateral acceleration model has been implemented so far.

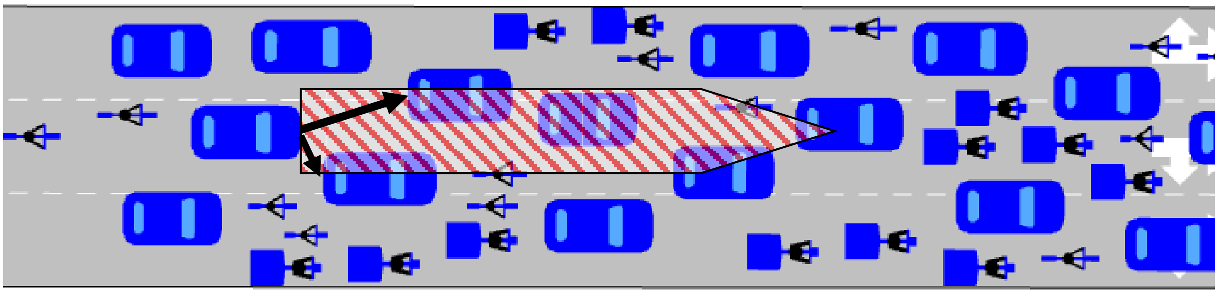
2.2 Modified Car-Following

2.2.1. Handling multiple leaders

The non-lane based approach requires the consideration of multiple leaders. The scan for leaders is bound to a rectangular strip bound laterally by the rightmost and leftmost points the vehicle can reach during the current maneuver, lateral clearance included. If the vehicle has no lateral movement it is simply defined by its width plus lateral clearances. If it is aiming at some lateral position, the strip extends up to the final lateral position taking the width and lateral clearance also into account. Vehicles whose rear is not entirely visible from the follower's point of view are not taken into account as they have an indirect influence as the leaders of the vehicles that are partially occluding them.

Among all the leaders that fulfill these criteria, the most restrictive one is defined as able to reach a halt closest by on the road. This can be calculated by its position plus the distance required to brake and reach a stop. An example is illustrated in Figure 1. Two leaders are identified in the downstream strip. The full car-following model is only applied with respect to the most restrictive leader.

Figure 1: Identification of multiple leaders



2.2.2. Reduced headway due to the possibility of swerving

The possibility for a vehicle to swerve in order to avoid collision instead of braking is taken into account in the longitudinal speed formulation. Formalized in different papers such as Gunnay B. (2007), Lee T.C. (2008) or Mahapatra G. & Maurya A.K. (2013), we propose a simplifyed version here. The width of the leader, lateral clearances of both leader and follower and the maximum lateral speed of the follower define the lateral shift and execution time needed to avoid the leader. When the duration of the swerving manouver is less than the reaction time i.e. for significant amount of lateral shift, the gap can be reduced without risking collision, given that the required space is available next to the leader to complete the swerving manouver. The equation of the Gipps (1981) safety distance becomes:

$$Gap(t) = (x_l(t) - x_n(t) - l_l - s_n) =$$

$$\frac{V_l^2(t)}{2b_l} - \frac{V_n^2(t+\tau_n)}{2b_n} + 0.5V_n(t)\,\tau_n + V_n(t+\tau_n)\ \min(\tau_n; \frac{dlat}{Vlat}) \quad (1)$$

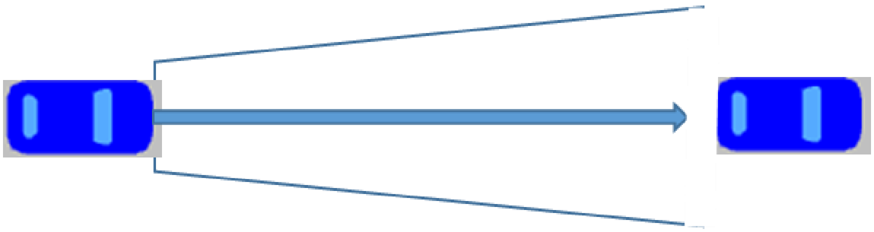
yielding the modified speed equation:

$$V_n(t+\tau_n) = b_n \min(\tau_n; \frac{dlat}{Vlat}) +$$

$$\sqrt{(b_n \min(\tau_n; \frac{dlat}{Vlat}))^2 - b_n\left[2(x_l(t) - x_n(t) - l_l - s_n) - V_n(t)\,\tau_n - \frac{V_{l(t)}^2}{b_l}\right]}$$

where $V_n(t)$ is the speed of the follower at time t; $V_l(t)$ the speed of the leader at time t, b_n the maximum deceleration of the follower, b_l the maximum deceleration of the leader, $x_n(t)$ the front position of the follower, $x_l(t)$ the front position of the leader, l_l the length of the leader, s_n the minimum inter-vehicular distance of the follower, τ_n the reaction time of the follower, dlat the lateral distance to reach the side position, Vlat the maximum lateral speed.

Figure 2: Safety distance as a function of lateral shift including swerving manoeuvre.



2.2.3. Reduced maximum desired speed due to lateral friction

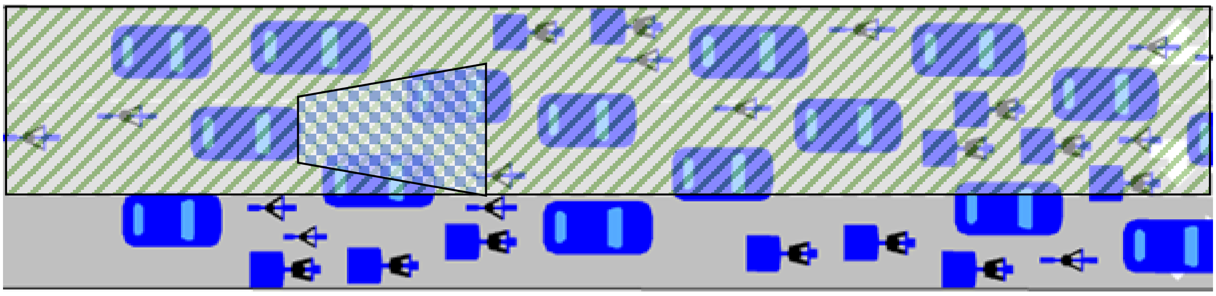
Vehicles passing in a narrow corridor between other vehicles or obstacles reduce their speed due to lateral friction (see Gunnay B., 2007). The maximum speed that can be achieved inside the corridor depends on its width. In corridors wider than the width of the vehicle plus the lateral clearances of both vehicles, the maximum speed is the free flow speed. When the corridor is so narrow that the vehicle barely fits in, the speed must be reduced to almost zero. We use a linear approximation between these two extreme cases.

Figure 3: Desired speed reduced due to lateral friction in narrow corridors

2.3 Path Selection

The vehicles use a path selection model to select their lateral position on the road as a full replacement of the lane based lane changing and gap acceptance models. If the vehicle cannot reach the downstream turning from its current position or if its current leader is preventing it from reaching a satisfying speed (defined as a percentage of current maximum desired speed), the vehicle looks for a new path leading to a better position. The optimal lateral location for each vehicle is computed on the basis of numerous factors including the valid lanes for downstream turnings, current traffic conditions and surrounding vehicles as well as vehicle characteristics such as width, lateral clearance and maximum lateral speed. Many of these characteristics such as the valid lanes are shared with the Aimsun lane based model ensuring a good integration of the non-lane based model with all other modules.

Figure 4: Accessible domain for best location search, hatched defines valid lanes, checked pattern defines reachable locations bound by neighbouring vehicles and maximum lateral speed.



A scan for the vehicles in the accessible domain, using the same technique used for the leaders (see previous section) is performed. Each vehicle found defines a sub-strip of influence in which it is the leader. The width of the vehicle selecting the path defines the minimum width of the strip to be considered. The space is not discretized a priori but each vehicle uses virtual strips whose width and positions are defined by its width and the surrounding vehicles.

The potential improvement in forward space of each strip is then evaluated using the position and speed of the most restrictive leader of each strip. If the improvement is larger than the minimum gain (default: half of the vehicle's length), the vehicle adopts a path heading to a position within this strip. This position can be selected as rightmost, leftmost, center or random (default: random).

The decision to look for a better position can be taken every simulation step given that the vehicle is not currently heading to a new lateral position and that the last decision resulting in a lateral move was taken at least a few reaction times ago. This scheme avoids lateral oscillations.

3. Sensitivity Analysis

Before applying the model to a real scenario we perform some sensitivity analysis to see how different output quantities depend on some of the parameters. We first list the main parameters affecting the capacity and jam density:

The main parameters affecting the jam density are :

- **vehicle's surface distribution** length, width, clearance, lateral clearance and proportion of different vehicle types.
- **maximum lateral speed** as it defines the maximum width of the domain in which a new lateral position is scanned for.
- **minimum gain** required to accept the new lateral position as better (default: half of the vehicle's length).
- **positioning** adopted by the vehicle inside the new slot (default: random).

The capacity is mostly affected by:

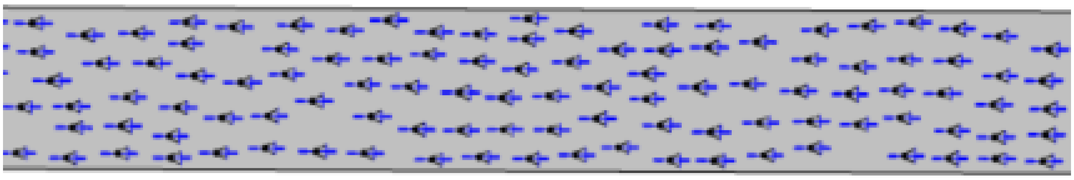
- **vehicle's surface distribution** length, width, clearance, lateral clearance and proportion of different vehicle types.
- **speed distribution** of the vehicles.
- **maximum lateral speed** as it defines the maximum width of the domain in which a new lateral position is scanned for.

- **percentage of maximum desired speed** below which the vehicle looks for a new lateral position (default is 90 %).

In this analysis we only present quantitative results for the dominant parameters. These are connected to the vehicle's heterogeneity, surface distribution and different vehicle type mix also involving different speed distribution. We provide a qualitative description of the effects of varying the other parameters listed above:

- The maximum lateral speed influences both the capacity and jam density. If set too small, vehicles scan a very narrow domain and are unlikely to find a better position, decreasing the jam density. If set to large values, vehicles might cross a large part of the road to reach a better hole but reducing the capacity. Good results are found for lateral speeds scanning a distance corresponding to the width of the largest vehicle in 3 seconds ie.1.5 to 3 km/hr.
- The minimum gain shapes the angle made by the queues. A very small gain makes queues very even and flat whereas a large gain makes them uneven. Large gains also decreases significantly the jam density as vehicles enter available holes less frequently.
- The positioning mostly influences the visual aspect of the traffic (Figure 5 illustrates the random case). Left, right and centre positioning in the holes all favour alignments but might in certain cases increase the jam density.
- Decreasing the percentage of maximum desired speed decreases the number of lateral movements which increases the capacity. The jam density is less affected as varying this parameter from 0.5 to 0.9 only changes the behaviour of vehicles whose leader is driving between 50% and 90% of its desired speed, not the slower ones.

Figure 5: Position of two wheelers at Jam density using the random positioning on an 8 meter wide section.



3.1 Capacity

Using the model, we conduct a first sensitivity study of the capacity as a function of road width for different vehicle characteristics. First we only use one vehicle type, a two wheeler whose characteristics are reported in Table 1 and study the effect of modifying the distribution of the lateral clearance parameter on the capacity. Second we use a mix of 5 vehicle types whose physical characteristics are shown in Table 2 and vary the proportions of each component.

Table 1: Two Wheelers parameters

Parameter	Mean	Stdev	Min	Max
Width (m)	0.7	0.1	0.6	0.8
Length (m)	1.85	0.1	1.75	1.95
Lateral Clearance (m)	0.25	0.25	0.1	0.5
Clearance (m)	0.5	0.25	0.25	0.75

Max Lateral Speed (km/h)	1.8	1	1.5	2.5
Max Desired Speed (km/h)	50	10	30	60
Max Acceleration (m/s^2)	2	1	1.5	2.5
Max Deceleration (m/s^2)	-3	1	-2.5	-3.5

Table 2: Vehicle type characteristics including the mean of the Effective Surface (including clearances) and Recommended PCU values in Urban Indian Roads given by the Indian Roads Congress.

Vehicle type	<Length> (m)	<Width> (m)	<Effective Surface> (m^2)	<Desired Speed> (km/hr)	PCU *value for <10% fleet
Two Wheelers	1.85	0.7	2.8	30-60	0.75
Auto Rickshaws	2.7	1.3	5.8	40-50	2
Cars	3.65	1.5	8.3	45-55	1
Trucks	9	2.45	29.5	45-55	2.2*
Bus	10	2.45	32.5	45-55	2.2*

We simulated an urban section with speed limit of 50 km/hr with width varying from 1 to 14 meters and present the average results from ten replications with different random number seeds. The capacity is displayed in Figure 6 and Figure 7, in veh/hr and in pcu/hr, respectively. There is a very large dispersion in capacities even when expressed in PCU and even for a single vehicle type. This suggests that micro simulation might be a powerful tool in assessing road designs as the capacity of a road section strongly depends on the lateral clearances and mix of vehicle types, quantities that can vary considerably from one place to another. Using PCU seems not to be enough to obtain a good estimate.

Figure 6: Capacity as a function of road width for two wheelers with different lateral clearances and different mix of vehicle types.

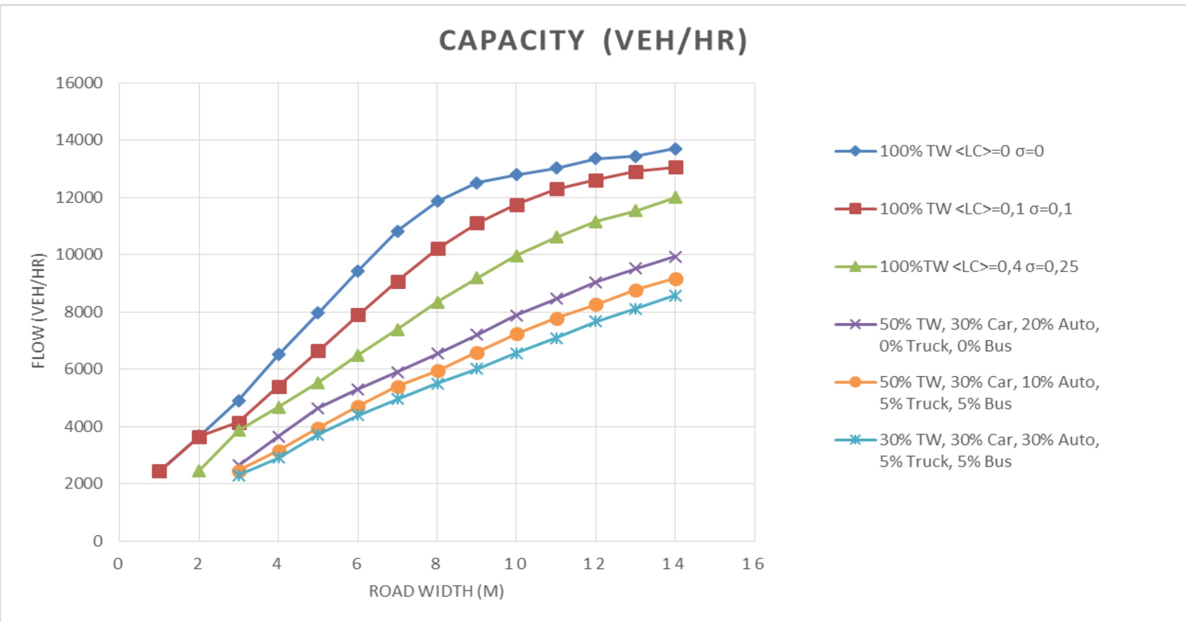
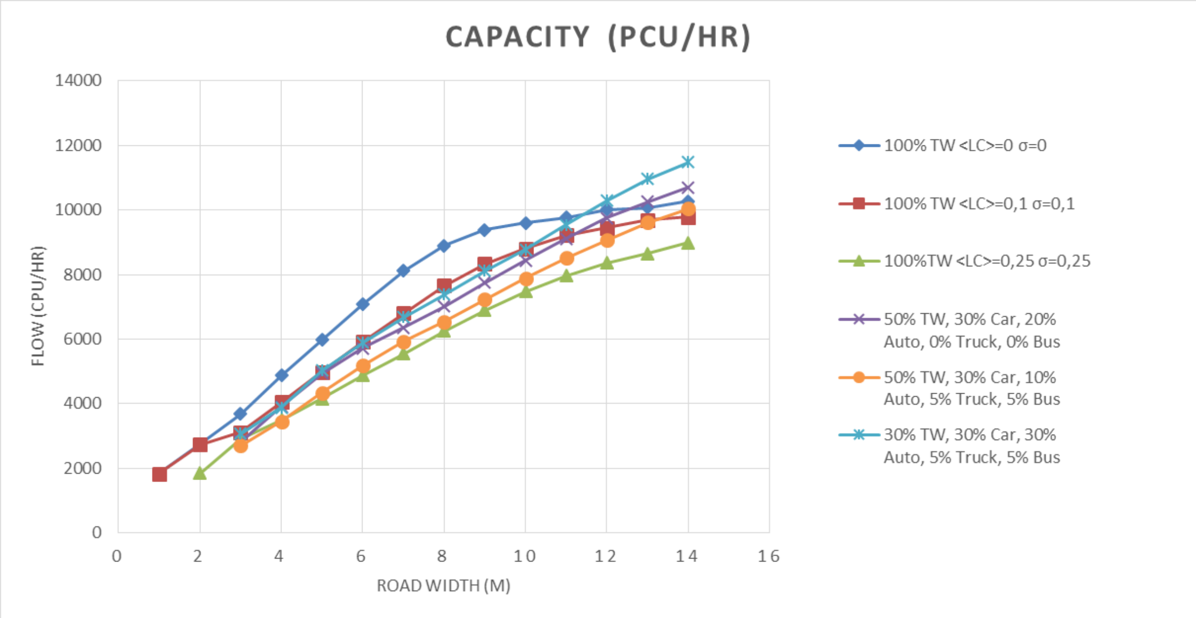


Figure 7: Capacity as a function of road width for two wheelers with different lateral clearances and different mix of vehicle types.



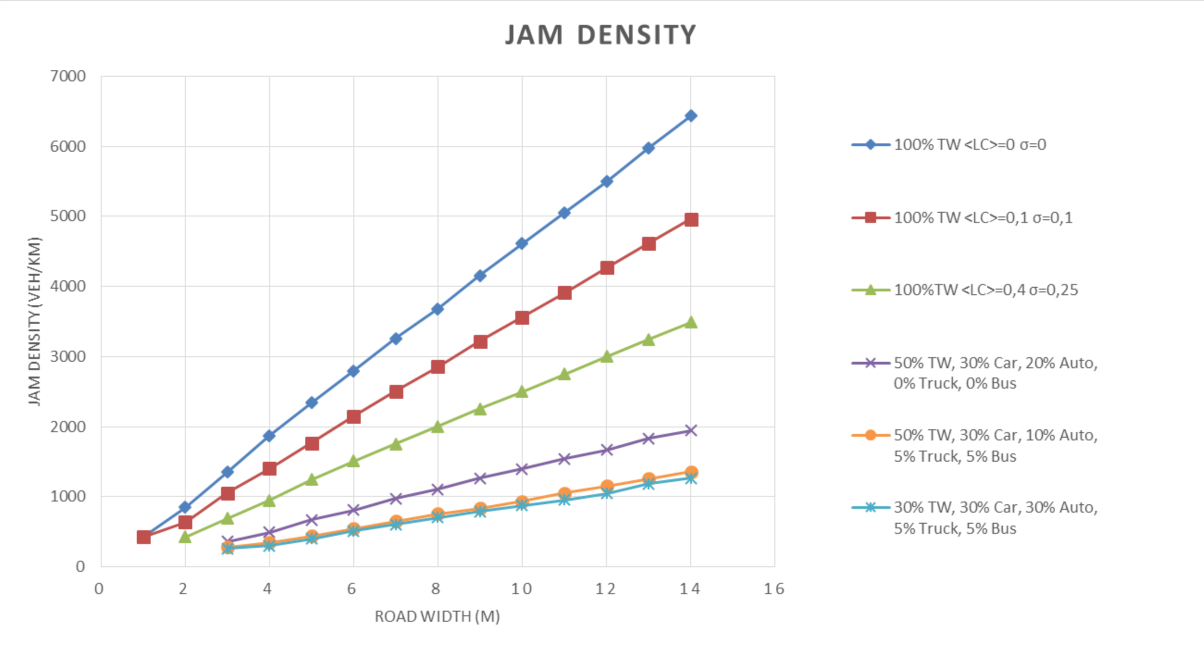
3.2. Jam Density

The jam density strongly depends on the projected area of the vehicles and the distribution of vehicle types composing the traffic but also on how skilful and determined the drivers are to attain a potential slot. We study the effect of the same parameters as for the capacity on the jam density.

The Jam density achieved by the model (see Figure 8) strongly depends on the clearances and mix of the vehicles. The occupation rate of the road surface (computed as the jam density multiplied by the average effective surface of a vehicle over the road surface), is 76% when only two wheelers are simulated and decreases down to 70% for the mixed compositions.

The jam density varies almost linearly with the road width, given that this last one is significantly larger than the vehicle width. The slopes for the different vehicles tested range from 86 to 460 veh/km/m. The impact of the physical dimension of the vehicle is here again considerable.

Figure 8: Jam density as a function of road width for two wheelers with different lateral clearances and different mix of vehicle types.



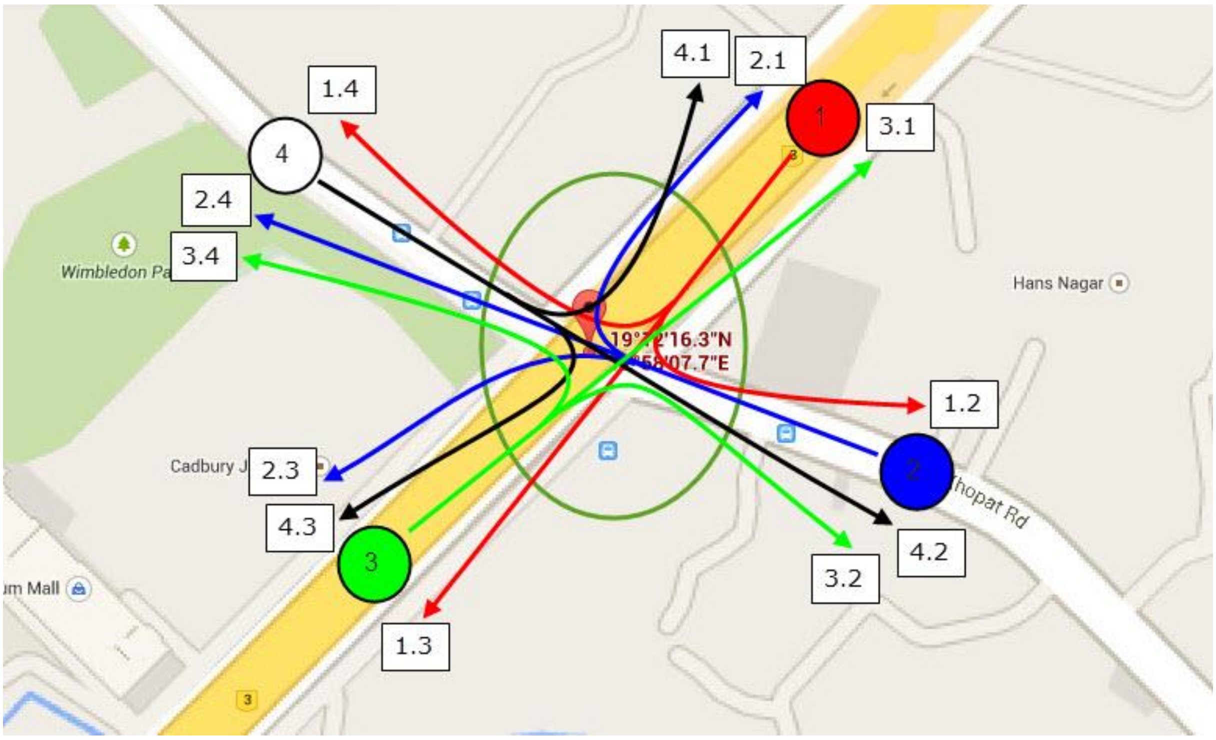
4. Application to Cadbury Junction in the City of Thane, India

Cadbury Junction in the City of Thane, India is an at grade junction under the Eastern Expressway flyover. Currently TSS and Medulla Soft Technologies Pvt Ltd are developing a Hybrid Base Simulation Model for the entire city, extending over 300 intersections and approximately 300 km of road network. Comprehensive data collection was carried out to provide inputs into the model. This included, for the purpose of micro simulation:

1. **Supply**: Mobile Video Mapping, i.e. a vehicle mounted photogrammetry exercise was carried out to map the intersection geometry and available right of way. The output of the exercise was a GIS file which was used as the base for developing the road network.
2. **Demand**: 16 hour videography was carried out from all the requisite angles in order to collect traffic demand data. Turning movement counts with classification of vehicle types was conducted through manual observation. 16 different classifications were tabulated, of which the major ones have been modelled.
3. **Control**: Signal phases and timings were collected from the local authorities and verified through observation of the videos

We simulated one peak hour in the evening from 20:00 to 21:00 using as demand the observed counts obtained on all four main entrance sections. As we had both origin and destination sections for all vehicles, the traffic streams are realistic enough to test whether the model is able to reproduce the capacity of the junction. A scheme of the junction is presented in Figure 9. Traffic from service lanes adjoining the Eastern Expressway was ignored for the purpose of this examination, and adjustments were made in the data to account for this.

Figure 9: Schematic of Cadbury Junction with Section numbers (circled) and turning moments (by colour of origin section).



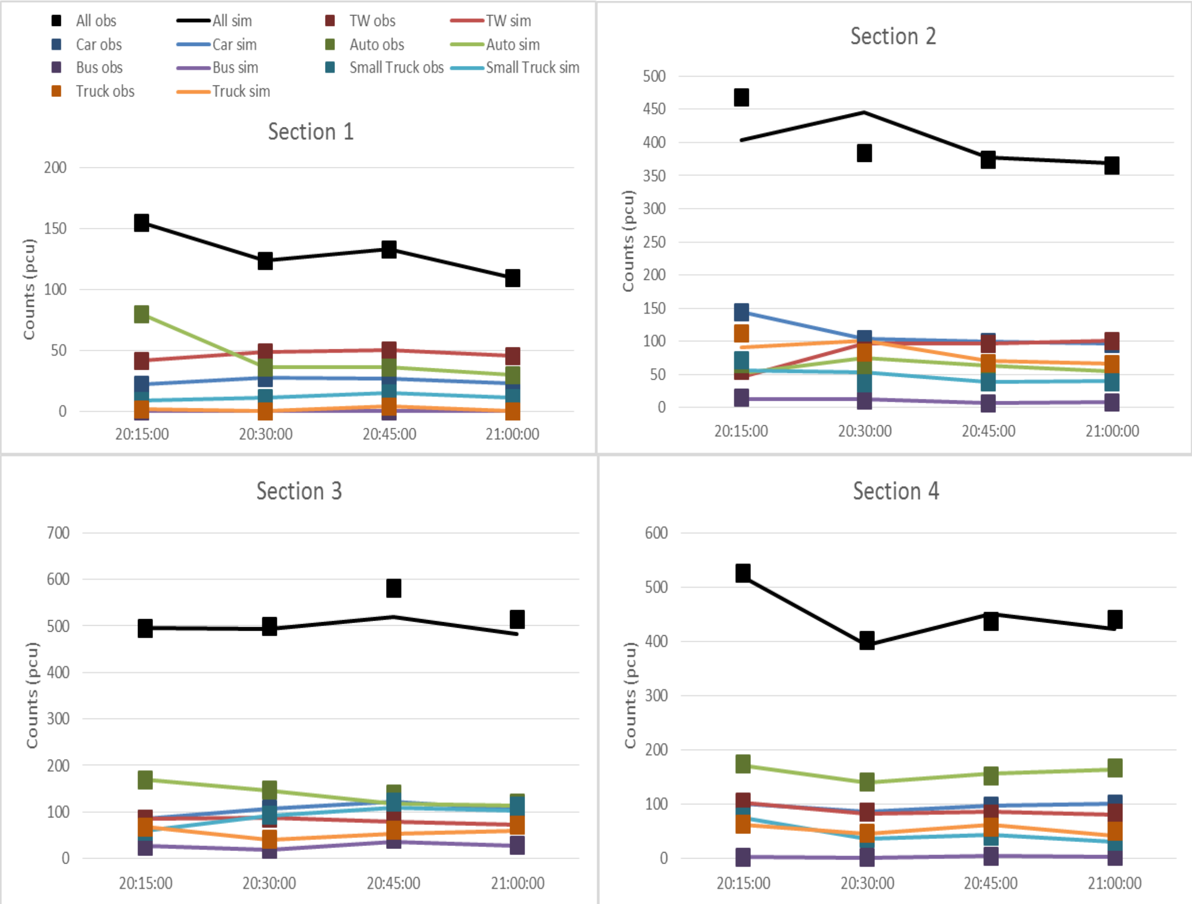
We merged some of the 16 vehicle types and removed the ones having a contribution less than 0.5%. We are left with 6 vehicle types reprsentative of the traffic of that Junction in the 20:00 – 21:00 period. From the observations it is striking that the vehicle type distribution largely differs depending on the origin section of the junction. We report the different proportions in Table 3. This indicates that the demand needs to be very well characterized in order to conduct a microsimulation study as both the capacity and jam density strongly depend on it.

Table 3: Proportion of the different vehicle types in the traffic observed on Cadbury Junction

Vehicle type	%Overall	%Section 1	%Section 2	%Section 3	%Section 4
Two Wheelers	35	54	36	30	35
Cars	29	22	35	28	29
Auto Rickshaws	18	20	10	19	23
Bus	2	0	1	4	0
Small Trucks	8	5	7	12	6
Large Trucks	8	1	12	7	7

Figure 10 shows the results obtained by the simulation compared with the observations. Overall the model is able to reproduce the data and only three points have a difference greater than 5 %. In Section 2, the very large rate of Trucks (12%) renders the model very dependant on the order of arrival as a group of trucks might considerably decrease the capacity of the road. On average, the model does not manage to send enough trucks through the junction from section 1 between 20:00 and 20:15, however this is compensated in the next quarter of hour. In Section 3, the data show an increase of traffic of 14% in the period 20:30 and 20:45 that is above the model's capacity. Section 3 has the peculiarly to have mainly traffic turning right and left and only few going straight. The turning speeds in the model might be slightly underestimated. However overall we achieve a very good fit to the data. The same simulation with Aimsun default lane based simulator yield lower counts by 20% on average for Sections 2, 3 and 4.

Figure 10: Simulation results for each of the four entrance sections.



5. Conclusion

We have developed a new model in the Aimsun micro simulator that allows the activation of non-lane based movements by vehicle type and section. This renders the model very flexible and able to simulate situations ranging from the specific behavior of motorcycles in lane based flows to fully non-lane based traffic including vehicle types with a wide range of characteristics such as those in Indian traffic.

A first sensitivity study derives the range of capacities and jam densities accessible by the model. This first sensitivity analysis should be extended to all parameters including varying multiple parameters at the same time.

Both the capacity and jam density largely depend on the effective physical surface of the vehicles as well as on the mix of vehicle types. Microsimulation seems to be a better tool than PCU based estimates with which to predict the road capacity of a new design, given that sufficient information is known about the demand.

We have applied the model to a busy Junction in India at evening peak hour. The model was able to fit the observed fifteen minutes counts with an overall error of less than 5%; counts that could not be attained using the default lane based model.

References

Gipps, P.G. (1981). A behavioural car-following model for computer simulation. Transportation Research Part B: Methodological 15(2), p. 105-111

Gunnay B. (2007). Car following theory with lateral discomfort. Transportation Research Part B 41, p 722-735.

Helbing D. & Molnár P. (1995). Social force model for pedestrian dynamics. Physical Review E 51, nº. 5: 4282

Khanorkar, A.R. Ghodmare, S.D. and Khode B.V. (2014). Impact of Lane Width of Road on Passenger Car Unit Capacity under Mix Traffic Condition in Cities on Congested Highways. Int. Journal of Engineering Research and Applications ISSN: 2248-9622, Vol 4, Issue 5 (Version 2) pp 180-184.

Lee, T.-C. (2008). An agent-based model to simulate motorcycle behaviour in mixed traffic flow, PhD thesis, Imperial College London, UK.

Li, R.J., Bin J. and Xiaomei Z. (2011). Theory and application of modern traffic flow Simulation study and blocked traffic bottleneck inhibition, 212-266.

Liang X., Mao B. and Xu Q. (2012). Psychological-Physical Force Model for Bicycle Dynamics. Journal of Transportation Systems Engineering and Information Technology; 12(2), pp: 91-97.

Mahapatra G. and Maurya A.K. (2013). Study of vehicles lateral movement in non-lane discipline traffic stream on a straight road. 2nd Conference of Transportation Research Group of India, Procedia - Social and Behavioral Sciences 104, pp 352-359.

Mallikarjuna, C. Budde Tharun and Dibuyendu Pal (2013). Analysis of the Lateral Gap Maintaining Behavior of Vehicles in Heterogeneous Traffic Stream. 2nd Conference of Transportation Research Group of India, Procedia - Social and Behavioral Sciences 104, pp 370-379.

Mathew T.V. and Ravishankar K.V.R. (2011). Car-Following behaviour in traffic having mixed vehicle-types. Transportation Letters: The international Journal of Transportation Research 3, pp 113-126

Mathew, T., Munigety, C. and Bajpai, A. (2013). Strip-Based Approach for the Simulation of Mixed Traffic Conditions. Journal of Computing in Civil Engineering.

Nagel K. and Schreckenberg M. (1992). A cellular automaton model for freeway traffic. Journal de physique I 2 (12), pp 2221-2229

Vasic J. and Ruskin H.J. (2012). Cellular automata simulation of traffic including cars and bicycles. Physica A: Statistical Mechanics and its Applications, 391(8), pp 2720–2729

Yao, D., Zhang, Y. Li, L., Su, Y., Cheng, S. & Xu, W. (2009). Behavior modeling and simulation for conflicts in vehicles-bicycles mixed flow. IEEE Intell. Transp. Syst. Mag., vol. 1, no. 2, pp 25-30.