Person-Based Dynamic Traffic Assignment for Mixed Traffic Conditions

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Abstract

For developing conditions where mixed traffic conditions prevail, it becomes necessary to add the influence of all types of vehicles. The absence of lane discipline makes modelling even more complex. Patna, the capital of the state of Bihar in India, is an example. In the present study, Patna Municipal corporation (PMC) traffic is analysed using a microscopic dynamic traffic assignment approach. For this, the MATSim (Multi-Agent Transport Simulation) software is used which employs demand generated using an activity based model. Advantages of MATSim include that it traces travellers and their activities throughout the day and that it is able to simulate large regional scenarios. However, its traffic flow model, a so-called queue model, is not very detailed, and so it was unclear if it could deal with heterogeneous traffic.

This paper considers several enhancements to the MATSim queue model, and discusses their capabilities and limitations to simulate mixed traffic. These enhancements reach from the capability to simply add vehicles with different maximum speeds and different sizes into the existing FIFO queue to a two-step procedure where bicycles take capacity away from a mixed car-motorcycle simulation. The enhancements are discussed with a view towards travel time distributions by mode in Patna.

Keywords: Dynamic traffic assignment, MATSim, heterogeneous traffic, mixed traffic, overtaking, multiple mode simulation

7103 words + 6 tables/figures = 8603 word equivalents

1 Introduction

1.1 From the four step process to agent-based simulation

Transport planning is a difficult problem, since many elements of the system interact in complex and often unpredictable ways. For that reason, computational models are used to inform the decision making process. The traditional model here is the four step process (McNally, 2007). Both from a theoretical and from a practical perspective, the four step process is insufficient, at least for the following two reasons:

- The four step process does not allow for any kind of (within-day and day-to-day) dynamical development in the system.
- The four step process does not allow for any kind of disaggregated, "behavior-oriented" decision making.

The second item does, in fact, depend on the first: Without a coherent representation of time-of-day it is difficult to represent issues such as schedule delay, unreliability, being consistently late in an activity chain because of a traffic delay in the morning, spontaneous adjustments, etc.

Two streams of research have developed in order to overcome these difficulties. **Dynamic traffic assignment (DTA)** (Peeta & Ziliaskopoulos, 2001; Carey & Watling, 2003) assigns traffic dynamically over the day, typically with so-called physical queues that grow and shrink. **Activity-based demand generation (ABDG)** generates person-centric activity chains over the day for every member of a synthetic population that represents the real population of a city or region.

DTA and ABDG are conventionally coupled by passing time-dependent, e.g. hourly, origin destination matrices from the ABDG to the DTA. It has been argued (Balmer *et al.*, 2004) that this type of coupling fails to exploit the full potential of behavioral disaggregated modelling, and that rather the synthetic person should be the unit that is passed from the ABDG to the DTA (or more general: "to the network loading model"). There has, in recent times, been a tendency to pass individual trips (i.e. trip starting time, trip starting location, trip destination) instead of aggregated matrices (DynusT www page, accessed 2012). Few projects have moved to a fully person-centric approach, one of them being our own MATSim project (e.g. Balmer *et al.* (2009), also see Miller *et al.* (2004)).

1.2 Mixed traffic

In this paper, it will be argued that the person-centric approach is also very useful for a consistent approach for the consideration of mixed traffic conditions at the regional scale. The problem is especially severe in developing countries where mixed traffic conditions exist. Traffic in India uses a variety of vehicles; these vehicles have different static (dimensions of vehicles) and dynamic (speed and acceleration of vehicles) characteristics. There is no restriction on the movement of such vehicles and hence the lane concept is rare. Since no physical segregation is provided for different vehicle types, vehicular interaction between all vehicle types is also abundant. Cars, buses and other vehicles operating locally are running on the same road space. Other vehicles include bicycles, three wheeler motorised vehicles, and non motorised rickshaws. Despite a low share of cars, congestion and the chances of conflicts are high because of these mixed traffic conditions.

Homogeneous traffic flow models are not able to help designing infrastructure which can provide better mobility and safe movement to heterogeneous conditions. Two roadways having similar physical attributes will have different flow conditions based on homogeneous and non-homogeneous traffic conditions and also on the presence or absence of lane concept. Hence, the study of such roadway conditions, flow characteristics, and travel behaviour in mixed traffic situation are requisites for models which will be effective in such conditions.

2 MATSim

The MATSim framework can be seen as divided into two layers (Nagel & Marchal, 2007; Raney, 2005):

- The first layer is known as the physical layer which represents all physical aspects of the environment. It contains the physical dimension of the road network infrastructure, as well as information about the activities of the agents performed in the physical world. The simulation of the agents in a synthetic version of the physical world is sometimes called a *mobility simulation*. For each simulated individual, the mobility simulation simultaneously executes a mobility plan in the synthetic physical environment.

- The second layer is the *strategic* or *mental layer* which computes the strategies for individuals. All travellers have some daily routine plan which they want to follow. It includes schedules of all activities, locations and travel mode, as well as behavioral parameters which enables people to change their plan in reaction to feedback from the physical layer.

The mobility simulation implemented in MATSim is based on a time step based queueing model (Gawron, 1998). Simon *et al.* (1999) give an algorithm to use the queue model for traffic flow simulation.

The simulation needs a physical boundary condition which will remain unchanged throughout the simulation (the road network), and an initial condition to start the simulation (demographic household data and a sequence of localized activities per synthetic person). These conditions are fed into the simulation as input files. The main part of the simulation consists of repeated iterations of the following three steps:

1. **Execution:** A simulation of all the individuals with their selected plans takes place simultaneously in the physical environment. This execution of the agents' plans is done by the predefined traffic mobility simulation.

2. **Scoring:** In this step, the score of the selected plan of every simulated individual is determined. Various scoring functions can be used; standard MATSim uses the so-called Charypar-Nagel scoring function (Charypar & Nagel, 2005).

3. **Re-planning:** Re-planning takes place depending on the strategies and their probabilities. Several strategies can be used; some of them are:

    - Time choice
    - Route Choice
    - Mode choice
    - Destination choice
    - Choice between already existing plans

> More than one strategy can be used. Every strategy is assigned a weight, and re-planning takes place depending on the probabilities: If two strategies are assigned equal weights, then each person has an equal probability of using one or the other. In this paper, only route choice and time choice are used.

MATSim also provides a time dependent network, which offers to make changes in the network at predefined time steps. MATSim here allows to change link attributes like flow capacity, free flow speed and number of lanes of any link at any time of day. This kind of time dependent network is important in scenarios like evacuation, accidents etc., where a sudden closure of some lanes or a whole link can occur. In the present paper, it will be used to parametrize the effect of bicycles.

3 Patna Data

Patna, a medium sized city in eastern India, has very poor traffic conditions. The total available road network in Patna is around 5% of the total development area, and thus the city is struggling with congestion problems especially during the peak hours (Singh, 2004). For this study, the area of the Patna Municipal Corporation is taken, and is simply named as "Patna" from now on.

3.1 Household data

The population of the Patna agglomeration area was 5.77 million in 2011 (Census, 2011). The study area includes 72 zones of the Patna Municipal Corporation with a population of 1.57 million for the year 2008. The development of Patna is linear, and along the river Ganga, from east to west. The land use pattern is unplanned and mostly residential. Commercial activities are distributed along arterials and sub-arterials. Most of the industrial activities are in the "old city". The data available is based on a comprehensive transportation planning study conducted on Patna, capital of Bihar (from now on called "Patna comprehensive mobility plan" (Patna CMP); iTrans, 2009). The whole population is divided into two groups based on income level, so-called "slum population" and "non-slum population". Households below poverty line (BPL) are called "slum households". These households do not have even basic amenities; because of their income level they are not able to fulfil their basic socio-economic needs (IPE, 2006). Most of the slums are concentrated along river Ganga, near the railway station, and also in the eastern part of Patna.

3.2 Network data

The road network of Patna is divided into 3 major road categories. The three categories are major arterial, arterial and collector street. Patna is arranged into a linear pattern. It has three corridors, namely Ashok Rajpath, Old bypass and New bypass. These corridors are spreading along the length of the city. 36% of roads have a width less than 5 m, with an accordingly low capacity. These roads are mostly in the eastern part of Patna. Any location inside Patna is at most one kilometre away from an arterial or a sub-arterial.

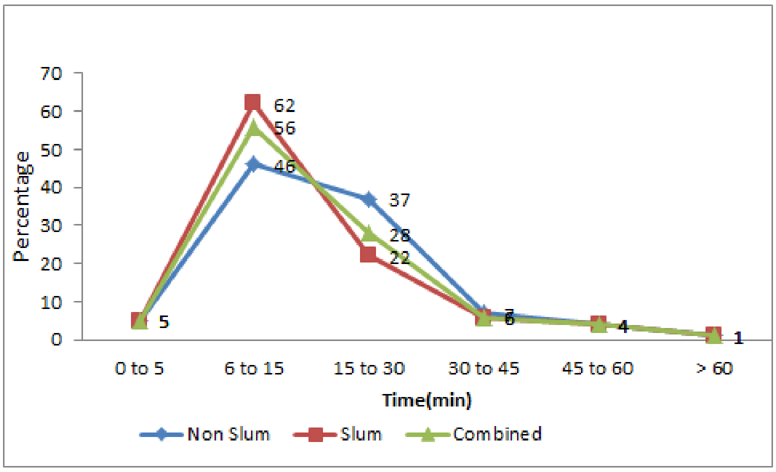
3.3 Count data

The Patna CMP also provides traffic count data for 6 stations. Vehicles are counted hourly between 6 am and 10 pm. These counts are categorised based on the type of vehicles (cars, two wheeler motorised, bus, bicycles etc.). This data is used to validate the dynamic assignment.

Table 1: Average trip length, average trip time, mode share

mode	average trip time (min)	average trip length (km)	share
Mini bus	20.45	5.80	4%
Car	21.43	7.15	2%
Motorized two wheeler (motorcycle)	18.56	5.91	14%
Motorized three wheeler	23.78	7.15	9%
Bicycle	19.94	4.98	33%
Walk	19.28	1.59	29%
Cycle-rickshaw	25.33	5.11	4%

Source : iTrans (2009)



(a) Travel time distribution

Figure 1: Distribution graphs from Patna CMP
Source: after iTrans (2009)

3.4 Trip characteristics

Patna has mixed traffic (see Tab. 1). In particular, it can be observed that bicyle trips form a significant portion of the total trips.

Figure 1(a) shows the distribution of trip times for different population groups. More than 85% of people have a trip time less than 30 minutes.

4 Modelling

4.1 Patna network

To create a digital MATSim network for the Patna scenario, TransCad (TransCAD, 2011) files are used as input files. These files are a part of the data provided by iTrans (2009).[1] The hourly capacity is then computed according to Chandra & Kumar (2003) as

$$Capacity = -2184 - 22.6 \times width^2 + 857.4 \times width \, , \quad (1)$$

where *width* is the width of the road in metres. A minimum capacity of 300 PCU/hr per direction is used, where 'PCU' refers to 'passenger car units'. Free flow speeds of cars are set to 50 km/h, 40 km/h and 40 km/h for arterial, sub-arterial and collector roads respectively. The resulting

[1] A few disconnected links in the network file received from iTrans are joined. This concerns some major arterials, and was checked with google earth. The reasons for the disconnected links are unknown.

network has 3505 nodes and 7542 links.

4.2 Demand generation

Travel demand for Patna is generated using a simple activity based demand generation model (Raney & Nagel, 2006; Balmer, 2007) which includes three steps:

1. Generation of a random synthetic population which maintains the demographic structure of real census data under certain statistical limits.
2. Assignment of activity plans to all individuals of the synthetic population generated in the first step.
3. A travel mode is assigned between each pair of activities for each traveller.

Parts of the data in the household survey were unavailable; for such cases the required data was imputed. For the zones 27 to 42, which are central parts of Patna, only home based work (HBW) trips were available. Home based social, home based educational and home based other trips were thus synthetically generated while observing the overall ratio of trips with those purposes to total trips. The share of each mode is also taken from the overall mode share.

This results in 13,121 activity records, 10,110 of them non-slum and 3,011 slum. Every such record is translated into one MATSim person with one MATSim plan. Compared to 1.24 million trips for the 2008 population of Patna (iTrans, 2009), this represents approximately a 1% sample of all trips.

As long as schedule-based transit assignment is not used, decent results with MATSim can already be obtained from 1% population samples (Nagel, 2008, 2011). For Patna, however, trips are distributed rather evenly between many modes. In order to still have a sizeable number of trips in each mode, the Patna population obtained from the survey is slightly expanded to a factor of two. This is achieved by "cloning" every person, and randomly shifting their locations and departure times slightly.

4.3 Configuration parameters

In addition to a network, plans and counts, the simulation takes several configuration parameters. The iterations were essentially run as standard Dynamic Traffic Assignment (DTA) iterations: In every iteration, 10% of travelers were given a new route that would have been fastest in the previous iteration. Travelers could stick with that new route if it indeed yielded a better beformance, otherwise they would switch back to the previously best option.

Parameters required to calculate the score are listed in table 2.

5 Mixed traffic modelling

5.1 Congested modes

Congested assignment (e.g. Ortuzar & Willumsen, 2002; Sheffi, 1985) assumes that route choice, via the network loading, leads to congestion, which in turn affects route choice. In this context, it is important to consider which mode or modes actually cause congestion.

Until the present study was done, MATSim was designed for car traffic as congested mode. However, from Sec. 3.4 it is clear that this would not work for Patna since both motorcycle and bicycle are more important modes than car, and they cause congestion as well. MATSim had in fact previously been applied to congested modes other than cars, namely pedestrians,

Table 2: Configuration parameters

Parameter	Value
Marginal utility of arriving late	-18.0 utils/hr
Marginal utility of distance for bicycle	-0.01 utils/km
Marginal utility for performing activity	6.0 utils/hr
Marginal utility for travelling	-6.0 utils/hr for all modes
Marginal utility for waiting	-2.0 utils/hr
Learning rate	1.0
Time allocation mutator range	7200 sec
Typical duration of home activity	12 hours
Typical duration of work activity	8 hours
Flow capacity factor	0.021
Storage capacity factor	0.063
Count scale factor	47.6

by re-scaling speeds, flow capacities, and storage capacities (Lämmel *et al.*, 2008), but these are link parameters. For this study, we extended the mobility simulation with the option of associating the congested mode with a *vehicle type*, which has maximum speed and passenger car equivalents as attributes. This lays the foundation for having multiple congested modes, which is discussed in Sec. 5.4.

The calculation of passenger car equivalents is discussed below. The maximum speeds of car, motorcycle and bicycle are set to 60, 60 and 15 km/h respectively.

5.2 Uncongested modes

All other modes, which are not simulated on the network, are *teleported*. This means that every time the traffic flow simulation enncounters a leg without a registered vehicle type, it will note a departure, compute the expected arrival time according to the beeline distance of the leg divided by the mode-specific speed, and set a timer. When the arrival is due, the traffic flow simulation will note an arrival and the agent will start its next activity. That is, also trips with modes that are not physically executed in the traffic flow simulation are still logically executed, with the difference that there is no information about the chosen route through the network, and that these trips are not influenced by other events in the system, and in turn are not influenced by them. A big advantage of this is that, in this way, a simulation can be started with an arbitrary set of modes, and most types of analysis (e.g. trip distance distribution by mode, travel time distribution by mode) are still possible. Cleary, they are approximated, but also a congested network loading model is an approximation, albeit a better one.

There is, in principle, a concept called *beeline factor* in MATSim that designates how much detour an actual trip takes compared to the teleported distance. This factor, however, is the same for all modes, which is not considered realistic for Patna where pedestrians can go much more directly than, say, cars. In consequence, the beeline factor is set to 1.0 for all modes, and the issue is dealt with via the mode-specific speeds and postprocessing. The speeds are assumed as 4 km/h for walk, 15 km/h for bicycle and 20 km/h for public transport. The distance travelled by these modes as reported by the simulation will now be the beeline distance. Therefore to calculate the effective distance for those modes, effective beeline distance factors are introduced in the postprocessing. These factors are assumed as 1.1 for walk, 1.2 for bicycle (if teleported) and 1.5 for public transport.

An improved variant for the uncongested modes is provided by C. Dobler (unpublished, but implemented as the "multiModal" option in MATSim). Here, uncongested modes are not teleported, but moved along a network. There is, however, no congestion on the links, but vehicles leave links at their free flow link exit times. Compared to teleportation, this has the advantage that a sequence of links will be noted by the simulation, which may be beneficial for some analyses. This approach was not used for this study, since it is unrealistic to assume that pedestrians would only use the planning network that was available.

5.3 PCU calculation

There are several methods available to get passenger car equivalents for different vehicle entities, for example:

- IRC-106 (1990) provides PCU factors of 0.5 and 0.75 for having 5% and 10% (and more) motorcycles in the traffic stream. Similarly for bicycles these values are 0.4 and 0.5 for 5% and 10% (and more) bicycles in the traffic stream.
- According to Mallikarjuna & Rao (2006), the PCU factor for any vehicle depends on the area occupancy measured over space and time; they have used a cellular automata approach. A range of PCU factors for each vehicle entity is given depending on the area occupancy of the vehicle entity.
- Tiwari *et al.* (2007) calculate the PCU factor for non homogeneous traffic using a modified density approach. They provide PCU factors as 0.51 and 0.44 for motorised 2-wheelers and non-motorised 2-wheelers.

The factors stated above are not used in this study since all factors are influenced by the density and are based on a static approach, i.e. an approach that averages over all speeds. Speed, however, is treated separately in MATSim for all vehicles, therefore the use of these factors would overestimate the PCU value for all vehicles. Mallikarjuna & Rao (2006, 2011) calculated the PCU factor using area occupancy. They used cellular automata model. However, also their area occupancy is affected by speed and thus cannot be used here. The approach in the present investigation is, however, similar to that paper. The effective area occupied by vehicle j is calculated, and the ratio of area occupied by vehicle j to area occupied by a passenger car is taken as PCU factor for vehicle j. Other factors affecting PCU are assumed to be same for all vehicles. The dimensions of the vehicle entities and lateral clearance are assumed as mentioned in table 3. Table 3 shows the PCU calculation for the study scenario. All other factors are assumed to be the same for all vehicles.

Table 3: PCU calculation

Vehicle type	Length	Width	effective width	Area	PCU calc	PCU taken
Car	4.1	1.6	2.6	10.4	1	1
Motorcycle	1.8	0.6	1.4	2.52	0.2364	0.25
Bicycle	1.8	0.5	1.3	2.47	0.2195	0.25

5.4 Multiple congested modes without passing

In Sec. 5.1 it was pointed out how the single congested mode could be switched away from car traffic. It is, however, plausible to assume that for Patna having only one of the modes as congested will not be sufficient, thus interactions between modes need to be included.

A first approach investigated in this study is having the queue model simulate several modes together on the same network. In this case, the simulation will observe each vehicle's free speed link travel time, and flow and storage capacity constraints are observed using each vehicle's PCE. Since for this version the queue model is not changed and in its original form does not account for vehicles passing each other, the vehicles remain in first-in-first-out (FIFO) order. That is, a faster vehicle, for example a car, could never pass a slower vehicle, for example a bicycle. Such an arrangement may in fact already be sufficient for vehicles of roughly similar velocities, e.g. for cars and motorcycles. It did, predictably, not work for the combination of bicycles with cars and motorcycles (not shown in this paper).

5.5 Multiple congested modes with passing

As a reaction to the previous version, a very simple replacement was implemented. For this, the ordering of the vehicles for the link exit was no longer in the sequence in which they entered the link, but in the sequence of their *earliest link exit time*, which is the time by which the vehicle would reach the end of the link if it were only constrained by the maximum speed of the vehicle type and the link. Flow and storage capacity constraints are still observed, and the vehicle type specific PCE are taken into account. This means that a faster vehicle can pass other vehicles whose earliest link exit time has not yet been reached. These are the vehicles which are on the link because, even at their maximum free speed, they could not have reached its end yet. It does not include those vehicles which are on the link because they are kept there by a capacity constraint. This behaviour should be approximately correct in the uncongested regime: Here, both vehicle types just pass each other freely. In the congested regime this model predicts that passing is possible during the free speed travel time, but impossible afterwards. In many situations, the former will be wrong, because passing may not be possible anywhere on a congested link. Conversely, it may happen in reality that bicycles are actually *faster* than cars in the congested regime; this is also not picked up by the model. Still, the model has the advantage that it keeps the fast computational performance of the queue model, in that vehicles are only considered when they enter and leave the link, and never in between (Zilske *et al.*, 2012).

5.6 Two step simulation

In traffic jam conditions, bicycles do not stay at the end of the queue. Instead, they pass between the congested vehicles. This passing is not just restricted to bicycles only, but motorised two wheeler also pass cars in the congested regime. This behaviour is very common in countries with a higher share of two-wheelers like India and Indonesia (HCM, 1993). However, in this study it is assumed that only bicycles can pass in the congested regime, and motorcycles will follow lane discipline. The MATSim queue simulation, even in the modified version with passing, will add bicycles to the end of the queue like other vehicles, and agents with bicycles will thus get a higher travel time than is plausible.

Yet, the interaction between slow and fast vehicles is not symmetric: Slow moving vehicles are not much affected by fast moving vehicles like cars and motorcycles (Dey *et al.*, 2006), while cars and motorcycles are affected by the presence of slow moving vehicles on the road. To model this kind of traffic, a two step simulation is used. The first step computes the capacity that the bicycles take away from the road. This is followed by the second step that assigns cars and motorcycles on the remaining capacity. The two steps, in more detail, are:

- **Step 1:** This step is nothing but the model mentioned in Sec. 5.5 above. In this step, the three modes car, motorcycle and bicycle are used as congested modes and these modes are not following FIFO, while the remaining modes will be teleported. It might also be plausible to take bicycles alone in this step, but for the Patna case this resulted in too many bicycles on the major arterials; presumably, the causality is not just from bicycles to cars, but also the other way around. From the output of the simulation, the number of bicycles are counted on each link in one hour time bins.

- **Step 2:** The output plans from step one are used as input plans for step two. In this step only car and motorcycle are used as congested modes and simulated in the queue model. We dynamically adjust the link capacities to account for the capacity consumed by bicycles, whose frequency was determined in the previous step. This is done only for peak hours. These peak hours are taken from the leg histogram of bicycles as 07:00 to 10:00 and 16:00 to 19:00. The adjusted capacities are given by

$$C_{modified} = C_{actual} - n \times p \times csf, \tag{2}$$

where
n = number of bicycles in simulation Step 1
p = PCE equivalent for bicycles from table 3
csf = count scale factor
However, the modified capacity is never allowed to become less than 70% of the original value.

6 Results

The different ways of interaction between the modes described in the previous section were tested using Patna data.

6.1 Congested mode: car

First, the simulation was run with its default configuration. In this configuration, only the cars are simulated as congested mode, all other modes of transport are teleported.

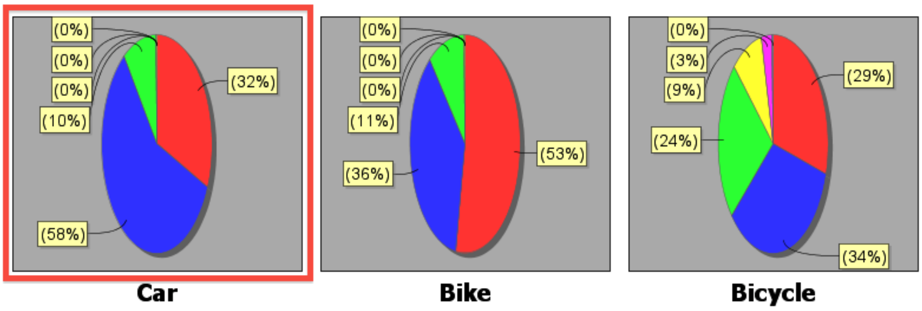
The share of cars is 2% only, therefore it is very unlikely that it causes major congestion. This is indeed confirmed. Neither average scores nor average trip distances change much over the iterations (not shown). Also the departure and arrival time distribution (not shown) show no indication of congestion:

Figure 2(a) shows the travel time distribution for all modes. All car trips have travel time less than or equal to 30 minutes, which is unrealistically fast: The average trip time for cars from the primary survey is more than 20 mins, and the household data is showing that there are some car trips having trip times of more than 30 mins.

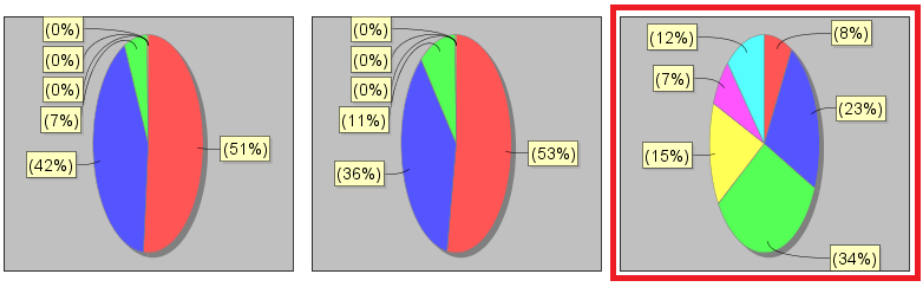
All other modes besides car are teleported, i.e. congestion has no influence. The travel time distributions of motorcycle and bicycle are presented anyways to simplify comparability between figures.

Since PT and walk are always teleported in this study, they will always look the same in the present study. Their trip time distributions are therefore not shown.

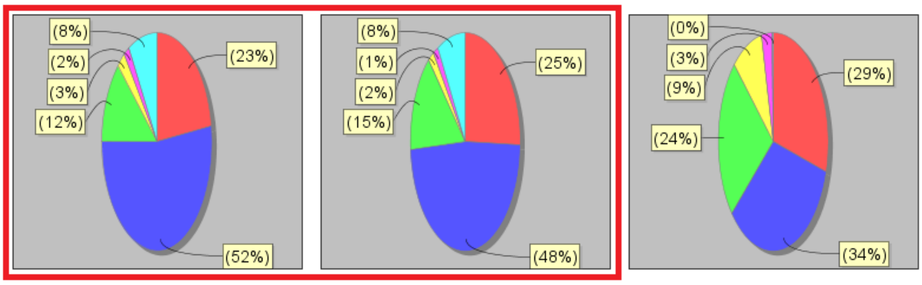
Figure 3(a) shows the comparison of average weekday real count vs. average weekday simulation count for iteration 200. Each dot represents one count station in one direction, the middle line is presenting the equal count line. Clearly, the simulation measures fewer vehicles



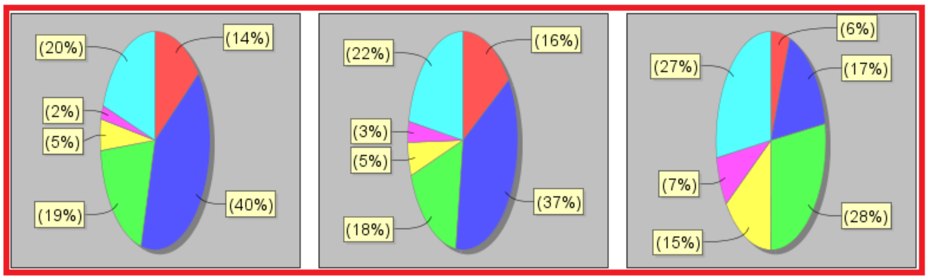
(a) Congested mode car



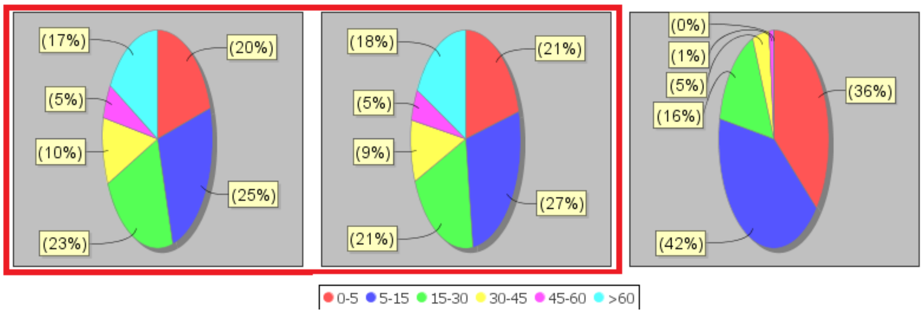
(b) Congested mode bicycle



(c) Congested modes car and motorcycle

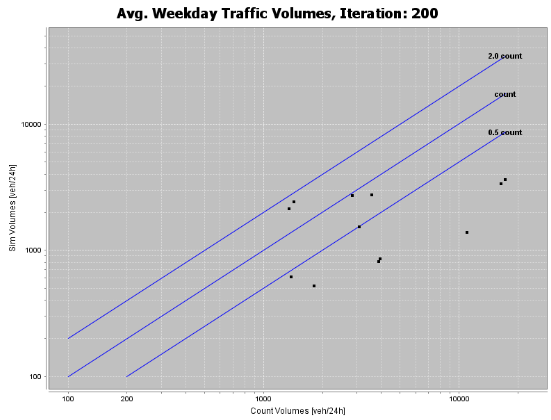


(d) Congested modes car, motorcycle, and bicycle. Also 1st step of 2-step simulation

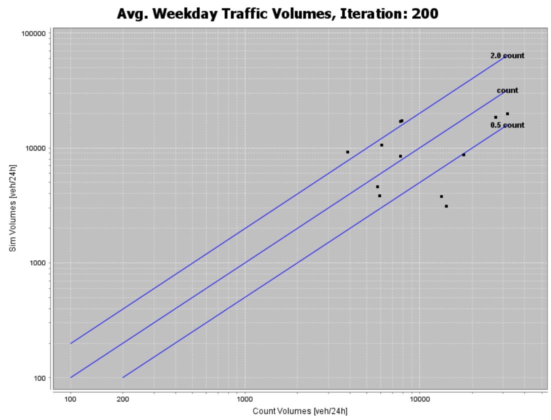


(e) 2nd step of 2-step simulation

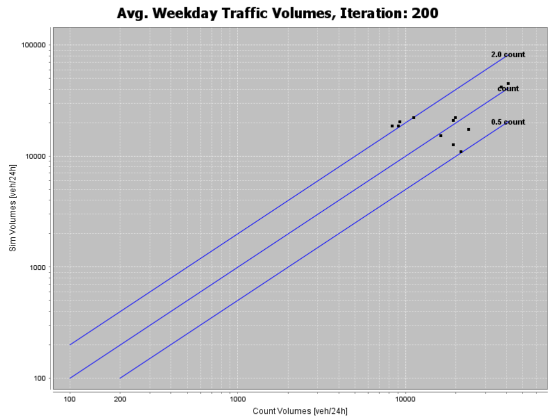
Figure 2: Trip time distributions



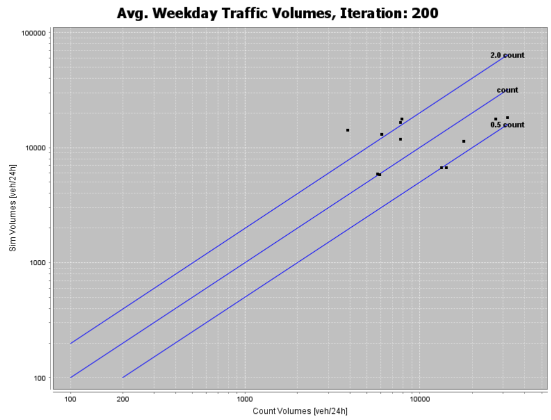
(a) simulation of car only, counts of car only



(b) combined simulation of car and motorcycle, combined counts of car and motorcycle



(c) combined simulation of car, motorcycle, and bicycle; combined counts of car/motorcycle/bicycle



(d) 2nd step of two-step simulation; combined counts of car and motorcycle

Figure 3: Comparison of real count vs. simulation count for iteration 200. Log-log curve between count volume and sim volume.

at the counting stations than reality. Possible reasons include:

- External trips are not included in this study because sufficient data was not available. These external trips have significant ratio of cars as they are coming from outside of Patna.
- Since there is little congestion, cars will take the shortest route, meaning they traverse fewer links than when the situation is congested.

6.2 Congested mode: bicycle

The share of bicycles for the whole population is 33%, and hence this by itself could cause congestion. As bicycles are driven by human effort, cyclists try to minimize distance travelled more than travel time. Therefore, the marginal (dis)utility of distance for bicycle is set to $-0.01\ utils/m$ which means bicycle users are losing 10 units of utility for every kilometre that they travel. For comparison: they are losing 12 units of utility for every hour they are travelling – the addition of 6 units per hour opportunity cost of time plus an additional 6 units per hour spent travelling. In other words, the marginal (dis)utility of distance for bicycle is quite high, prompting bicycles to use short distances even when congested.

Figure 2(b) shows the travel time distribution for different travel modes, in which only bicycle is congested mode and all other modes are teleported. This chart shows that more than 80% of bicycle trips have a travel time less than 45 minutes.

6.3 Congested modes: car and motorcycle

Combined share of cars and motorcycles is 16%, therefore it becomes important to check for the main mode as cars and motorcycles as well. In Indian traffic conditions, motorcycles pass through congested regime and come in front of queue. MATSim does not allow this functionality therefore it is assumed that car and motorcycle users follow lane discipline and therefore every motorcycle will stop at the end of queue; it will leave queue based on its link arrival time. The simulation is therefore also a test of the model that allows multiple congested modes while maintaining FIFO (Sec. 5.4).

The leg histograms (not shown) show that all vehicles reach home again before midnight. However, a significant number of vehicles remains in the system until after 9pm, indicating congestion.

Figure 2(c) represents the travel time distribution for all modes. More than 90% of the trips of car users, and motorcycle users as well, have a travel time less than 45 minutes. The average simulated trip time for cars and motorcycles is 18 minutes, while table 1 shows average survey trip times for cars and motorcycles of 21 and 18 minutes respectively.

6.4 Congested modes: car, motorcycle and bicycle

This simulation adds bicycle as congested mode. This simulation corresponds to MATSim with multiple congested modes not following FIFO as mentioned in section 5.5.

Figure 3(c) compares the real count data vs. simulation count data for average weekday traffic volume. This comparison validates the results generated from MATSim as mostly points fall nearly equal count line.

Figure 2(d) shows the travel time distributions of the combined car/motorcycle/bicycle simulation. All three congested modes have large shares of travel times above 60 min. This is unrealistic: Although we do not have the travel time distribution by mode for Patna, figure 1(a) shows the overall travel time distribution presented in iTrans (2009), based on the primary survey. According to that distribution, trips having a travel time more than 60 minutes are very few.

In addition, the average trip time from simulation is more than 50 minutes for cars and motorcycles and more than 60 minutes for bicycles, compared to 21.43/18.56 and 19.94 in Tab. 1. Overall, the number of trips having large travel times is too high.

This can in part be traced back to the bicycle-only simulation (Sec. 6.2): Even with only bicycles using the full flow capacity of the network, trip times were fairly high. This has now become even worse (compare the bicycle plot of Fig. 2(b) with the bicycle plot of Fig. 2(d)). The interpretation at this point is that, using the design numbers from the Indian Road Congress (IRC-11, 1962; IRC-106, 1990), the capacity of the network is insufficient to carry the demand.

6.5 Second of the two step simulation, with main modes: car and motorcycle, with reduced capacity

There may be circumstances where one does not want to have the bicycles included in the microscopic simulation. Reasons for this may be that the simulation of a large number of bicycles consumes computational ressources that one wants to spare, or the fact that the bicycle trip lengths may not be sufficiently well calibrated to be of practical relevance. Yet, running the simulation without bicycles on the full network generated implausible little congestion (Sec. 6.3). In such situations, it may be attractive to parameterize the capacity effect of the bicycles by removing the capacity consumed by them, and then run the car+motorbike simulation just on the remaining capacities. This is investigated in this section. Section 5.6 explains details, in particular how the effect of bicycles is included into the simulation.

Figure 3(d) shows the comparison between the real count vs. simulation count for average weekday traffic volumes after 200 iterations. Almost all the counts are between 0.5 count and 2 count lines, which validates the simulation model. These counts include only cars and motorcycles.

Fig. 2(e) shows once more the travel time distribution for this simulation. The implausibly low congestion levels from the simulation with car and motorcycle only (Fig. 2(c)) are replaced by significant congestion levels, visible in the larger travel times in Fig. 2(e). Also, those travel times have not changed very much from Fig. 2(d), indicating that the parameterization of the capacity effects of the bicycles was largely successful.

7 Discussion

Overall, although the results from the simulation are not matching exactly the results in the primary survey, they are similar enough to explain the Patna traffic so that the simulation could be used for scenario analysis. Depending on the needs, a choice can be made between a simulation including bicycles, or a simulation that parameterizes the capacity reduction effects of the bicycles. Both approaches leads to plausible results.

As stated earlier, the congestion levels generated by the bicyles seem to high. This is even visible when the bicycles use the full capacity of the roads, without competition from other modes. A reason may be that actual capacity in urban areas is larger than the numbers from the Indian Road Congress (IRC-106, 1990; IRC-11, 1962) for a given the road geometry. Another reason may be that in particular bicycle PCEs (passenger car equivalents) are too high, meaning that in reality the flow capacity of a car corresponds to more than four bicycles. As yet another possible explanation, the PCEs that one needs to insert into a queue-based simulation like MATSim may be different from the PCEs for static assignment models. Such an investigation was beyond the scope of the present study.

8 Conclusions

This work provides a way to simulate modes other than car which could not be simulated earlier in a simple and computationally fast queue model. A new functionality is added to MATSim such that new vehicle types can be defined with their maximum speed and PCE (passenger car equivalent). This contributes towards the simulation of multiple modes, which is necessary for representing heterogeneous traffic conditions of developing nations.

Technically, this is achieved by inserting vehicles with different maximum speeds and different space consumption into the queue. These vehicles may or may not be following first-in-first-out approach. Based on the requirements, the simulation may replace the use of first-in-first-out approach in cases when overtaking is plausible by an approach where vehicles at the end of a link are sorted by their free speed link exit times. The approach shows plausible results as long as it can be assumed that the different vehicles cannot pass each other any more when there is congestion.

Sometimes including bicycles in the simulation may not be desired, while their capacity reduction effects, however, cannot be neglected. For such conditions, a two-step solution was investigated. The first step is used in order to find the routes that the bicycles are taking. From that, a capacity reduction is calculated. A mixed car-motorcycle assignment is then done, using the reduced capacities.

Overall, the investigation has shown that it is possible to apply microscopic, activity-based assignment also to mixed traffic conditions, while maintaining similar computational performance. This makes the approach useful for many areas where mixed traffic conditions are the rule.

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References

BALMER, M. (2007). *Travel demand modelling for Multi Agent Transport Simulations: Algorithms and Systems*. Ph.D. thesis, ETH Zurich. 5

BALMER, M., CETIN, N., NAGEL, K. & RANEY, B. (2004). Towards truly agent-based traffic and mobility simulations. In *Autonomous agents and multiagent systems (AAMAS'04)*, New York, NY. 1

BALMER, M., RIESER, M., MEISTER, K., CHARYPAR, D., LEFEBVRE, N., NAGEL, K. & AXHAUSEN, K. (2009). MATSim-T: Architecture and simulation times. In A. Bazzan & F. Klügl, eds., *Multi-Agent Systems for Traffic and Transportation*, 57–78, IGI Global. 1

CAREY, M. & WATLING, D. (2003). Introduction to a special issue of networks and spatial economics on dynamic traffic assignment. *Networks and Spatial Economics*, **3**, 403–406. 1

CENSUS (2011). Census of India 2011. http://www.censusindia.gov.in/. 3

CHANDRA, S. & KUMAR, U. (2003). Effect of Lane Width on Capacity under Mixed Traffic Conditions in India. *Journal of Transportation Engineering*, **129**, 155–160. 4

CHARYPAR, D. & NAGEL, K. (2005). Generating complete all-day activity plans with genetic algorithms. *Transportation*, **32**, 369–397. 2

DEY, P., CHANDRA, S. & GANGOPADHAYA, S. (2006). Speed distribution curves under mixed traffic conditions. *Journal of transportation engineering*, **132**, 475–481. 8

DYNUST WWW PAGE (accessed 2012). see dynust.net. 1

GAWRON, C. (1998). An iterative algorithm to determine the dynamic user equilibrium in a traffic simulation model. *International Journal of Modern Physics C*, **9(3)**, 393–407. 2

HCM (1993). *Indonesian Highway Capacity Manual, Part-I Urban Roads*. Directorate General of Highways Ministry of Public Roads, 09th edn. 8

IPE (2006). *City Development Plan for Patna under JNNURM*. Urban Development department, Bihar Urban Development Agency. 3

IRC-106 (1990). *Guidelines for Capacity of Urban Roads in Plain Areas*. Indian Roads Congress. 7, 12, 13

IRC-11 (1962). *Recommended Practice for the Design and Layout of CYcle Tracks*. IRC. 12, 13

ITRANS (2009). Comprehensive mobility plan for Patna urban agglomeration area. Tech. rep., Department of Urban Development, Govt of Bihar, India. 3, 4, 5, 12

LÄMMEL, G., RIESER, M. & NAGEL, K. (2008). Bottlenecks and congestion in evacuation scenarios: A microscopic evacuation simulation for large-scale disasters. In *5th Workshop on Agents in Traffic and Transportation (ATT) @ Autonomous Agents and Multiagent Systems (AAMAS) '08*, Estoril, Portugal. 6

MALLIKARJUNA, C. & RAO, K.R. (2006). Modelling of passenger car equivalency under heterogeneous traffic conditions. In *22nd ARRB Conference, Canberra, Australia*. 7

MALLIKARJUNA, C. & RAO, K.R. (2011). Heterogeneous traffic flow modelling: a complete methodology. *Transportmetrica*, **7(5)**, 321–345. 7

MCNALLY, M.G. (2007). The four step model. In *Handbook of Transport Modelling*, University of California, Irvine. 1

MILLER, E., DOUGLAS HUNT, J., ABRAHAM, J. & SALVINI, P. (2004). Microsimulating urban systems. *Computers, Environment and Urban Systems*, **28**, 9–44. 1

NAGEL, K. (2008). Towards simulation-based sketch planning: Some results concerning the Alaskan Way viaduct in Seattle WA. VSP Working Paper 08-22, TU Berlin, Transport Systems Planning and Transport Telematics, see www.vsp.tu-berlin.de/publications. 5

NAGEL, K. (2011). Towards simulation-based sketch planning, part ii: Some results concerning a freeway extension in Berlin. VSP working paper, TU Berlin, Transport Systems Planning and Transport Telematics, see www.vsp.tu-berlin.de/publications. 5

NAGEL, K. & MARCHAL, F. (2007). Computational methods for multi-agent simulations of travel behaviour. In K.W. Axhausen, ed., *Moving through nets: The physical and social dimensions of travel*, Elsevier. 2

ORTUZAR, J.D.D. & WILLUMSEN, L.G. (2002). *Modelling Transport*. John Wiley and Sons, Ltd. 5

PEETA, S. & ZILIASKOPOULOS, A.K. (2001). Foundations of dynamic traffic assignement: The past, the present and the future. *Networks and Spatial Economics*, **1**, 233–265. 1

RANEY, B. & NAGEL, K. (2006). An improved framework for large-scale multi-agent simulations of travel behaviour. In P. Rietveld, B. Jourquin & K. Westin, eds., *Towards better performing European Transportation Systems*, 305–347, Routledge, London. 5

RANEY, B.K. (2005). *Learning Framework for Large-Scale Multi-Agent Simulations*. Ph.D. thesis, Swiss Federal Institute of Technology Zurich. 2

SHEFFI, Y. (1985). *Urban Transportation Networks: Equilibrium Analysis with Mathematical Programing Methods*. Prentice-Hall, Inc, Englewood Cliffs, New Jersey 07632. 5

SIMON, P.M., ESSER, J. & NAGEL, K. (1999). Simple queueing model applied to the city of portland. *International Journal of Modern Physics C*, **10(5)**, 941–960. 2

SINGH, S.K. (2004). Road accident analysis: A case study of Patna City. *Urban Transport Journal*, **2(2)**, 60–75. 3

TIWARI, G., FAZIO, J. & GAURAV, S. (2007). Traffic planning for non-homogeneous traffic. *Sadhana*, **32**, 309–328. 7

TRANSCAD (2011). Transcad, transporation planning software. http://www.caliper.com/tcovu.htm. 4

ZILSKE, M., SCHRÖDER, S., NAGEL, K. & LIEDTKE, G. (2012). Adding freight traffic to matsim. VSP Working Paper 12-02, TU Berlin, Transport Systems Planning and Transport Telematics, see www.vsp.tu-berlin.de/publications. 8