AGENT-BASED METHODOLOGY FOR SIMULATION OF HETEROGENEOUS TRAFFIC AT UNCONTROLLED T-INTERSECTION USING GRID BASED CELLULAR AUTOMATA

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ABSTRACT

In the developing countries like India, the traffic is highly heterogeneous, subject to the undisciplined lane behaviour with no segregation of traffic and nonstandard road width, there exist a mix of various types of light and heavy vehicles with wide variation in their sizes, operating condition, even in locations where stop signs are provided on minor streets of an intersection, the rules of priority are not fully respected and vehicles do not always follow the lane movement. Thus, priority unsignalized intersections are treated as uncontrolled intersections by the road users in some countries like India. To study this type of complex traffic flow and associated vehicular interactions, simulation is considered as an effective tool. An agent-based methodology for heterogeneous traffic simulation is proposed in this paper with focus on uncontrolled T-intersection flow modelling. For this we used concept of Grid Based Cellular Automata, which is based on traditional cellular automata model and coding is developed in Java. The paper presents the framework for development of simulation model based on grid based cellular automata for heterogeneous traffic at uncontrolled T-intersection. The contribution of this research work is the development of software objects for various components of road such as vehicle, traffic, link and node. This software can be adopted for heterogeneous traffic simulation programs, in general.

Keywords: Agent-based methodology, cellular automata, uncontrolled T-intersection, heterogeneous traffic.

INTRODUCTION

Roadway link and intersections are the primary components of any road network. Overall performance of a transportation network is influenced by the performance of each road link and each intersection in the network. A bottleneck or congestion at one place can affect the wider area of the network. Thus, in order to evaluate and analyse a transportation network it is necessary to better understand the traffic flow characteristics on road links and at intersections. Analysing and evaluating a transportation facility usually include finding its capacity and performance under demand levels. For any intersection, usually delay is considered as an important performance parameter.
Analysing traffic flow characteristics on the road links is relatively simpler as there are not many conflicting movements. Intersections, on the other hand, handle intersecting traffic moving in more than two directions. Many conflict points exist at an intersection. Thus some control strategy is usually employed at intersections. Although cases of red light violation are observed in India, signals have been reasonably efficient in controlling traffic flow. However, installing signals at all intersections in a network is prohibitively expensive, thus signals are not installed at many relatively low volume intersections even in developed countries. In developed countries, unsignalized intersections are usually controlled by signs which decide the priority of various movements. Efficient enforcement of priority rules has made it possible to cross the intersections with minimum conflicts. However, the situation is totally different in India. Most of such intersections do not have stop or yield sign, and even they exist drivers do not pay any attention. Drivers usually do not care much about the conflicting traffic; they attempt to enter intersection, even if a conflicting vehicle is about to collide. Traffic situation at a typical uncontrolled intersection is shown in figure 1. Traffic signals installed at intersection are not in working condition and there is no police enforcement. Many studies on heterogeneous traffic have concluded that approaches developed for disciplined traffic that exists in developed countries may not be suitable for the traffic in India. At signalized intersections and on link mid-blocks, there is some degree of similarity between traffic in developing countries and that in India. However, the situation at unsignalized intersections is totally different. Most uncontrolled intersections in India witness a chaotic situation, which is uncommon with disciplined traffic. Hence in order to analyse and evaluate such uncontrolled intersections it is important to develop new approach.

Figure 1 – Traffic at uncontrolled intersections in India

Cellular automata methods have their applications primarily in areas of spatio-temporal dynamics. Transportation simulations, with travellers and vehicles moving through cities, fall into that category and thus the use of cellular automata is found as a recent addition to the modelling of the traffic flow with computational efficiency. Many researchers have used cellular automata (CA) for modelling homogeneous and very few for heterogeneous traffic flow. Their studies show that CA application is simple and computationally efficient for traffic flow modelling. In the developing countries like India, the traffic is highly heterogeneous, there exist a mix of various types of light and heavy vehicles with wide variation in their sizes, operating condition, even in locations where stop signs are provided on minor streets of an intersection, the rules of priority are not fully respected and vehicles do not always follow the lane movement. To study this type of complex traffic flow and associated vehicular interactions, simulation is considered as an effective tool. Hence in this paper we propose an agent based methodology for simulation of heterogeneous traffic at uncontrolled T-intersection using grid based cellular automata concept. A concept of grid based cellular automata (GBCA) for uncontrolled T-intersection (GBCA) is proposed by Sangole (2013), considering temporal gap as well as spatial gap and conflict avoiding rule at intersection.

BACKGROUND AND LITERATURE REVIEW

Cellular automata were originally developed as a representation of self-replicating systems, and have been demonstrated as such by Conway's Game of Life in the 1970s and by Wolfram in the 1980-90s (Walfram, 2002). In these systems, the world is representing as a grid and a set of local rules are defined for the system. At each time step, the state (usually "on" or "off") of each cell is updated synchronously using these rules. Both Conway and Wolfram demonstrated global pattern emergence which belies the simple rules in the system.

This approach is often referred to as agent-based cellular automata. Many researchers have used cellular automata (CA) for traffic flow. In 1992 Nagel and Schreckenberg introduced a very simple cellular automaton model which provides a microscopic description of the vehicular motion using a set of update rules. Although it is one of the simplest traffic flow models, it is nevertheless capable of reproducing important properties of real traffic flow; the model is developed for a single lane traffic known as NaSch model (Wahle et al., 2001). Considering NaSch model as a base model lot of work has been done by many researchers for modelling traffic along the highways as well as at the intersections. Some of the studies related to highways and midblock sections include; Lárraga et al. (2005), Wolf (1999), Ricker et al. (1996), Hu (1999), Lan et al. (2009), Lan et al. (2010), Esser and Schreckenberg (1997), Benjamin et al. (1996), etc. and studies related to unsignalized intersections include Jin et al. (2013), Deo and Ruskin (2006), Ruskin and Wang (2001, 2002 and 2003), Wu et al. (2005), Li and Jia (2009), etc.

Models in most of the studies mentioned above are one- dimensional array of *L* (length) sites. These models may not be sufficient in case of wide variation in traffic conditions, *viz;* vehicle characteristics (e.g. size), operating conditions, road characteristics etc. An attempt for modelling heterogeneous traffic and lane changing movement is made by Gundaliya (2005). Grid based model is developed which allows the movement of small size vehicles (two-wheelers) side by side. Moreover, this model gives fairly good representation of the vehicle's static and dynamic characteristics when vehicles have a variation in their sizes and dynamic characteristics. Road stretch is divided into a grid of cells in this model and each vehicle is represented by one or more cells. The vehicle movement rules are created based on NaSch model. Optimal cell size is decided based on the type of vehicle, clearance, distance headway at various speeds, and minimum number of cells by which all kinds of vehicles can be represented. This study gives a computationally efficient modelling concept for heterogeneous traffic.

Many studies can be found in the literature that focuses on unsignalized intersections with priority. However, very limited work has been done for unsignalized intersections without no priority or limited priority, which are prevalent in India. In the presence of any well-developed methodology often the approach used for sign controlled intersections are used in India which might result in misleading assertion of unsignalized intersections and consequently road network. Simulation is the best tool in such situation in order to analyse and evaluate uncontrolled intersections systematically. Some traffic simulation models were developed for heterogeneous traffic using FORTRAN language (Popat et al., 1989; Kumar and Rao, 1996; Agarwal et al., 1994). Rao and Rengaraju (1998) and Chandra and Parida (2004) developed simulation models using C language. Some studies have been carried out on development of simulation models to understand the heterogeneous traffic using C++ language (Arasan and Koshy, 2005; Marwah et al., 2006). From the above review, it is believed that most of the heterogeneous traffic simulation models are developed using the traditional waterfall algorithm driven structured programming approach for some specific traffic analysis. Unfortunately, little information about the implementation of heterogeneous traffic simulation in agent-based environment is published in the literature. The TRANSIMS model is an agent-based cellular automata model that can model all modes of behaviours (Bush, 2001). It consists of several steps to analyse data to create a population, activities, and movement. It has been used in the USA to model large urban areas, such as Portland, Oregon. However it is not sufficient in heterogeneous traffic condition and wide variation of traffic flow parameters.

SIMULATION FRAMEWORK

The basic idea of simulation modelling is to develop a computer program that replicates the real world condition. In this paper we considered the T-shaped intersection, each approach of intersection is four lane divided with 3.6m as single lane width as shown in figure 2. The entire intersection is divided into grid of cell size 1.2mX1.2m. Each link is numbered as shown in figure 2. Each cell is represented by two dimensional arrays e.g. 3X4 means a cell of 3rd row and 4th column.

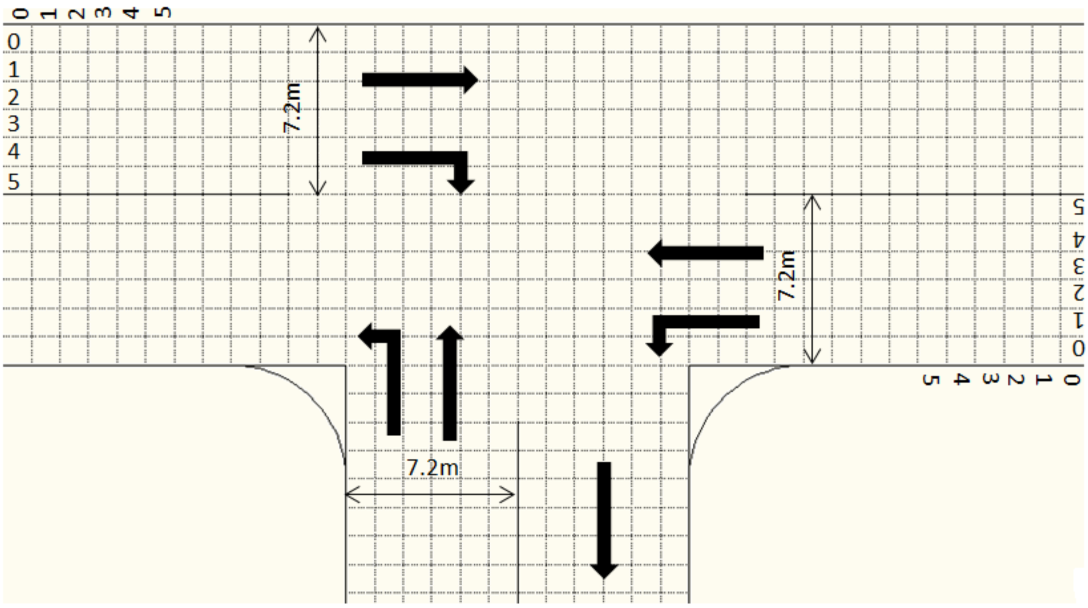

Figure 2 – T-shaped intersection divided into grid of cell size 1.2mX1.2m

The basic logical aspects involved in the simulation model of uncontrolled T-intersection are illustrated in the flow diagram shown in figure 3.
Various input parameters considered are arrival rate (α), simulation time (T), time step (t=1sec) cell size, (here considered as 1.2m× 1.2m), randomization probability (p), maximum speed at intersection in cells/sec (*Vmax*=5cell/sec), maximum speed for turning vehicles at intersection in cells/sec (*Vmaxt*=2cells/sec), vehicle sizes, mode wise proportion of vehicles at intersection, and proportion of turning movements for each approach. Acceleration and deceleration rate for all vehicles is assumed as 1cell/sec. Any traffic simulation model consist of three major steps namely;

1. Vehicle generation
2. Vehicle placement
3. Vehicle movement.

Vehicle generation

In this proposed simulation model the vehicles are generated by using negative exponential distribution. In many literature related to Indian traffic concludes that traffic headways follow the negative exponential distribution.

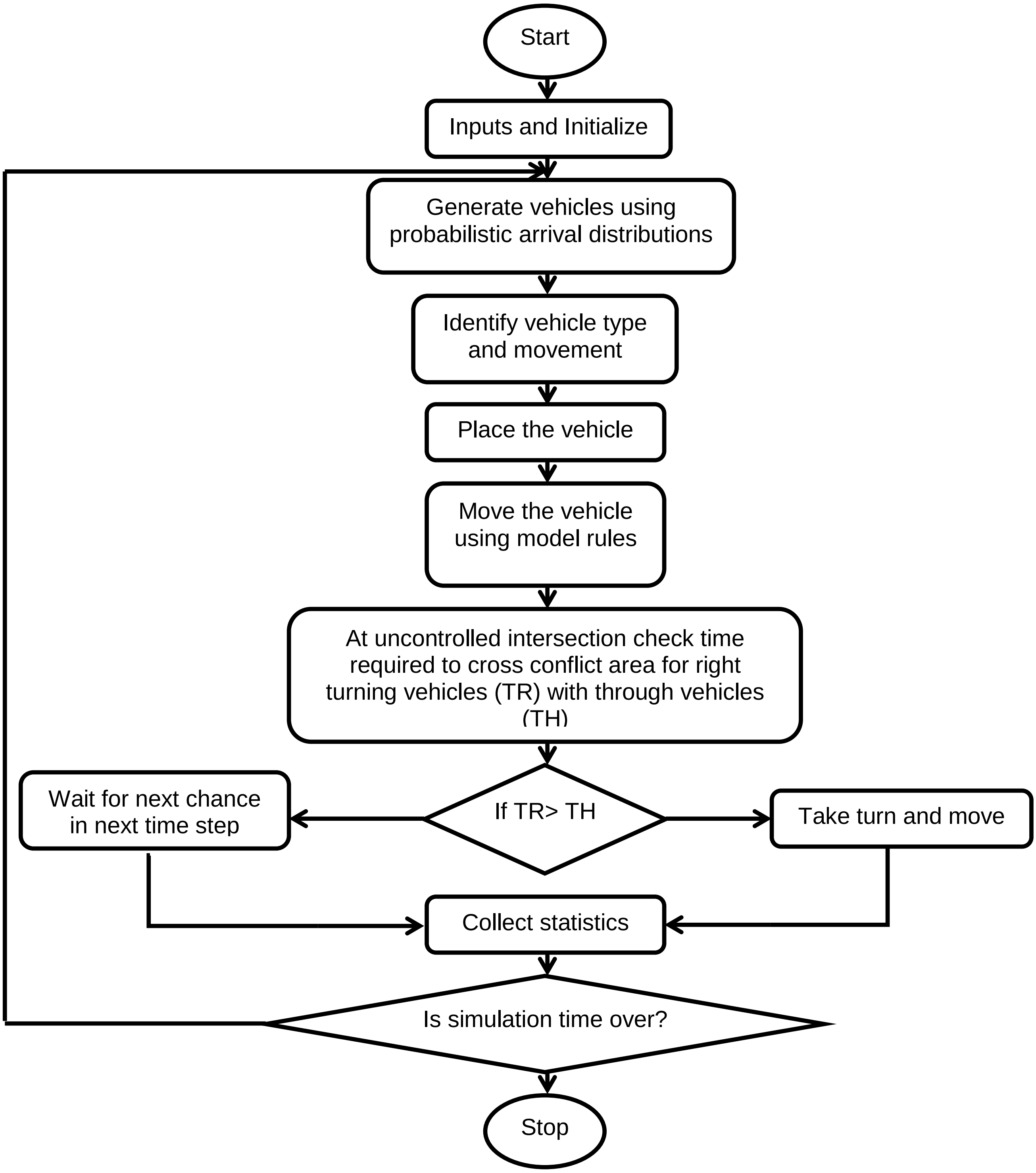

Figure 3 – Flow chart of simulation model framework

The procedure for sampling inter-arrival times from negative exponential distribution is as follows:

$$h = \frac{-1}{\lambda} \ln R$$

Where,
h= Headway or time interval between the arrival of successive vehicle in seconds.
R= Random number in the range (0 to 1), obtained from a pseudo random number generator.
λ= Mean arrival rate vehicle (vehicles per second)

Vehicle placement

As the mixed traffic on urban roads of India does not follow traffic lanes, there is a need, for the purpose of simulation, to represent the vehicles on the road space with dimensions. Vehicle placement implies placing vehicles considered as rectangular blocks (whose length and breadth represent, respectively, the average overall length and breadth of the different types of vehicles) at the start of the simulation stretch in a suitable position across the width and along the length of the road based on the longitudinal and lateral clearance requirements for the subject vehicle. Figure 4 shows the non-lane based placement in proposed simulation model. In this paper we have not considered lanes changing of vehicles, hence right turning vehicles are placed on right most cells in link and left turning vehicles are placed on left most cells in link. Straight moving vehicles can be placed on any cell along the width of road. If the vehicles don't have empty cell according to the arrival time, then the vehicles are kept in waiting queue so that vehicles can placed in next time step.

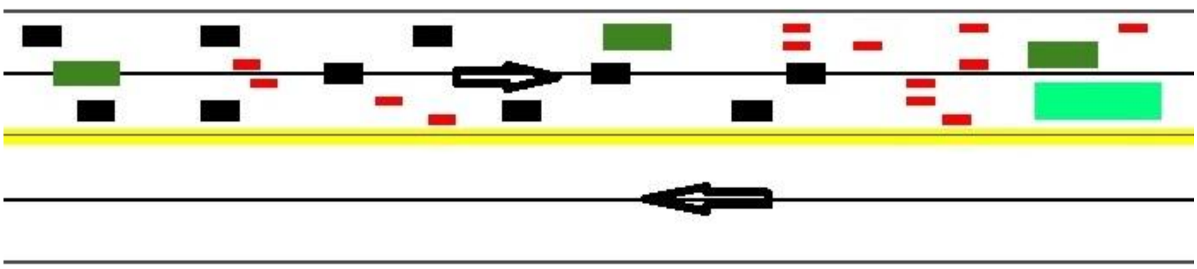

Figure 4 – Vehicle placement on link

Vehicle movement

In proposed simulation model the vehicle movement takes place according to grid based cellular automata rules proposed by Sangole (2013). These rules are based on traditional cellular automata models.

Model rules for straight vehicles

For non-turning vehicles on all lanes and the vehicles tending to turn but not close to the turning cells, the velocity and position are updated according to the Nagel-Schreckenberg (NaSch) CA traffic model.That is:
Velocity update (Considering approach A):
$V_n\ (t+1) = min(V_{max}, V_n\ (t)+1, d_n(t));$ *if rand( ) ≥ p (randomization probability)*
or
$Vn\ (t+1) = max\{[min(V_{max}, V_n\ (t)+1, d_n(t))]-1, 0\};$ *if rand( ) < p*
Position update:
$x_n(t+1) = x_n(t)+ V_n(t+1)$
$y_n(t+1)=y_n(t)$
Here (x_n,y_n) is the position and Vn is the velocity of vehicle n, $dn(t) = (x_{n-1}(t) - d_k^L) - x_n(t)$ is the gap before vehicle n (it is assumed that vehicle $n - 1$ precedes vehicle n), d_k^L is the length of k^{th} vehicle type.

Model rules for turning vehicles

For the turning vehicles, when they approach close to the intersection vehicles reduces their speed. If TC is cell where link ends and intersection starts then check $TC - xn \leq 5$, if yes then the maximum velocity will decrease to $Vmaxt=2$. When the vehicles are at cells x_n from TC − $x_n \leq 5$ to turning cell TC , the velocity update rule changes to:
$V_n\ (t+1) = min(V_{maxt}, V_n\ (t)+1, d_n(t), TC - x_n(t))$
In intersection area the turning vehicles enter into virtual link, discussed detailed in next section under node class and the movement will take place as per straight vehicles.

AGENT-BASED APPROACH

Agent-based systems are a relatively new concept in computing, having been studied since about 1980, and are currently of great interest to researchers. Agent systems are all about autonomy; building systems with some degree of intelligence. Although there is no universally accepted definition, one definition of the term 'agent' is presented below.

> An agent is a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to meet its design objectives (Woolridge, 2002).

Agents are computing entities that receive sensor input from their environment, and can produce actions that influence their environment. Agents usually have a set of actions they can perform, each action having preconditions and aiming to affect their environment. Agents can communicate with each other, allowing them to cooperate, negotiate and coordinate their actions. Agents have objectives and goals; can make plans of actions to perform, and aim to achieve their goals through these plans (Ferber, 1999).

To aid understanding, the agent-oriented approach could be thought of as an extension to the object-oriented (OO) approach. Objects are computing entities that encapsulate some state, have methods to modify their state, and communicate by passing messages. Objects therefore have some form of control over their state, but they do not have control over their behaviour. Agents are considered to have control over their behaviour, meaning that each agent has its own thread of control and can perform actions whenever it chooses without being acted on by any other entity. Although it is possible for all objects to have their own thread of control, it is not central to the OO concept. Agents can use intelligence to define their own steps required to reach the goal, based on the rules they have available. The simulation model proposed in this paper is coded in Java. This section gives details of various system classes used for development of simulation environment.

Vehicle class

Vehicle class defines the conceptual model of vehicles by specifying the common attributes and actions as shown in figure 5. There are four types vehicles are considered in this paper namely; Two-wheeler (2W), Auto-rickshaw (AR), Car and Truck/Bus. Table 1 gives the actual dimensions/sizes and model dimensions/sizes of all vehicles with clearance for both sides of vehicles.

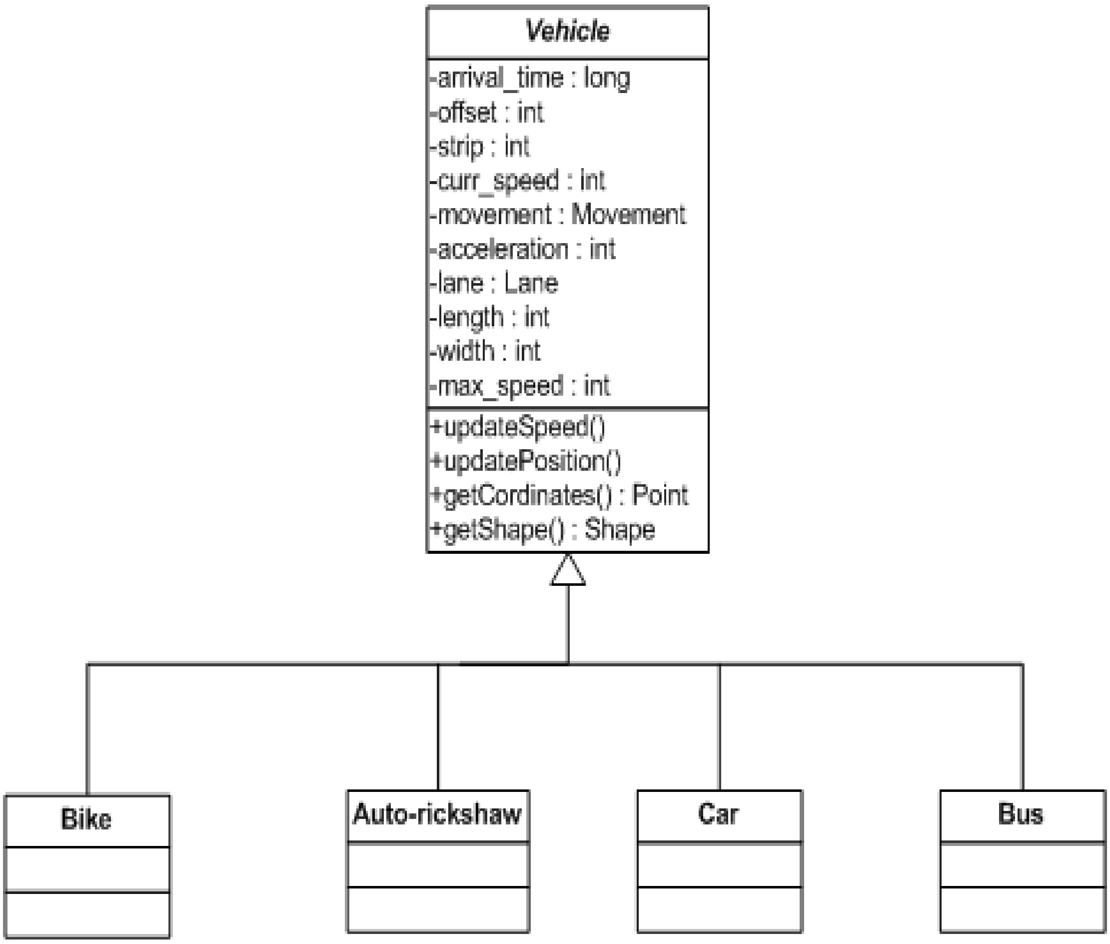

Figure 5 – Class diagram of vehicle

Table 1 – Actual and model vehicle sizes

Sr.No.	Veh. Type	Actual Size (m)		Model size (cells)		Clearance (m)	
		Width	Length	Width	Length	Width	Length
1	2W	0.6	1.8	1	2	0.6	0.6
2	AR	1.4	2.6	2	3	1	1
3	Car	1.7	4.7	2	4	0.7	0.1
4	Bus/Truck	2.5	8.5	3	8	1.1	1.1

Vehicles are defined by rectangular blocks. Figure 6 gives physical representation of vehicles on links.

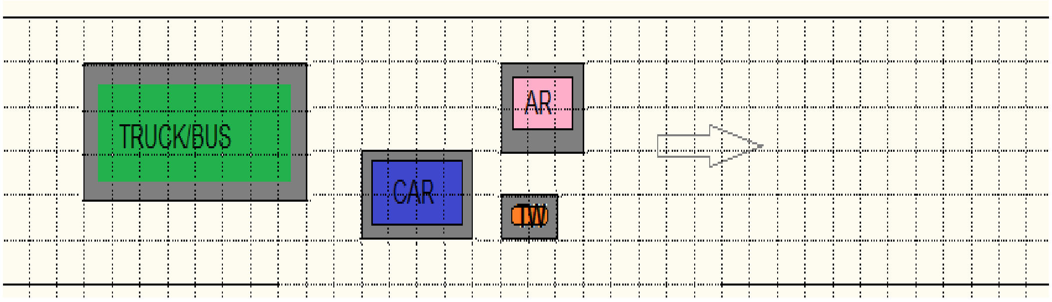

Figure 6 – Physical representation of vehicles on link

The data variables such as clearances, speeds and acceleration represent the characteristics of the vehicle. The member functions of Vehicle class i.e. update speed is responsible for movement of vehicles. Turning movement class decides that the vehicle should take left or right turn or go straight at intersection.

Network representation

Link and node are the basic components of any transportation network. Class Link and Node defines the protoype or blueprint of elements of road section. The network representation of all classes is shown in figure 7. The common attributes of Link class are length, width and volume of the link. Link cane divided into number of lanes, strips. Node class is the class where link starts (generator) and end (sink).

Unsignalized class of node is intersection part. At intersection the traffic comes from all approaches, since it is connected to more than two links. In order to handle the turning movements we introduced virtual link which is circular arc as shown in figure 8. This virtual link is divided into cells with outer arc length equal to 1.2m. Separate virtual link is provided each type of turning movement. The cells occupied by each vehicle in virtual link and straight vehicles through intersection are mapped on single rectangular grid, so as to know the cell occupied in intersection by all vehicles. Thus intersection class gives the common attributes regarding mapped cells from virtual link class, arc length of virtual link, cells in each virtual link etc.

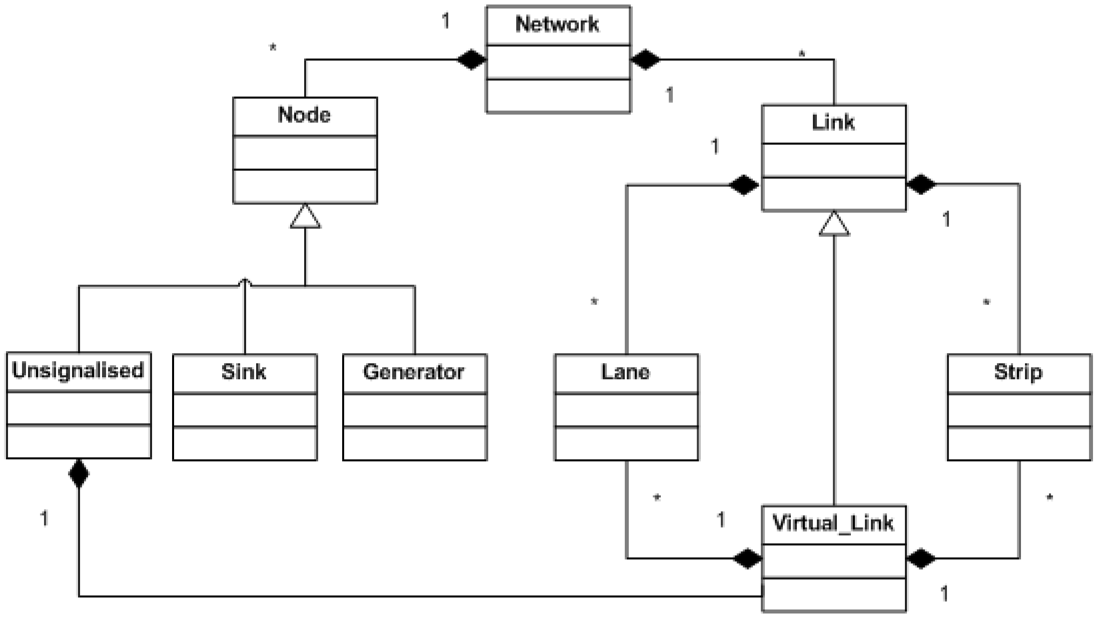

Figure 7 – Network representation with system classes

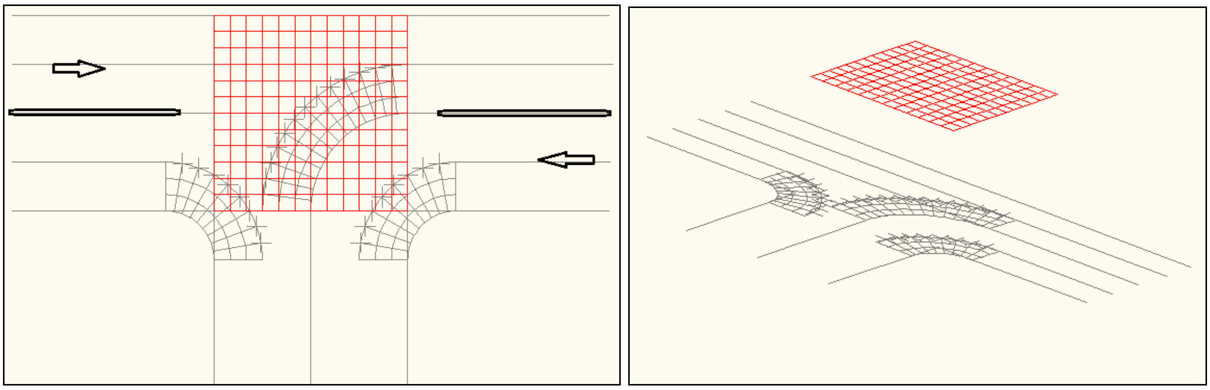

Figure 8 – Virtual links at intersection

Interaction Diagram

Sequence diagrams are a type of interaction diagram that show the flow of messages through a system as a particular function is being executed. Figure 9 is a sequence diagram describing the sequence of events that occur during a simulation run. It describes a single time-step, and during normal use, this sequence would be repeated for the duration of the simulation.

MODEL APPLICATION

Coding for simulation model is done in Java. Three-dimensional (3D) visualizations have been created with the support of OpenGL, which gives more user-friendly and realistic presentations. Model is being calibrated and validated for data at various uncontrolled T-intersection.

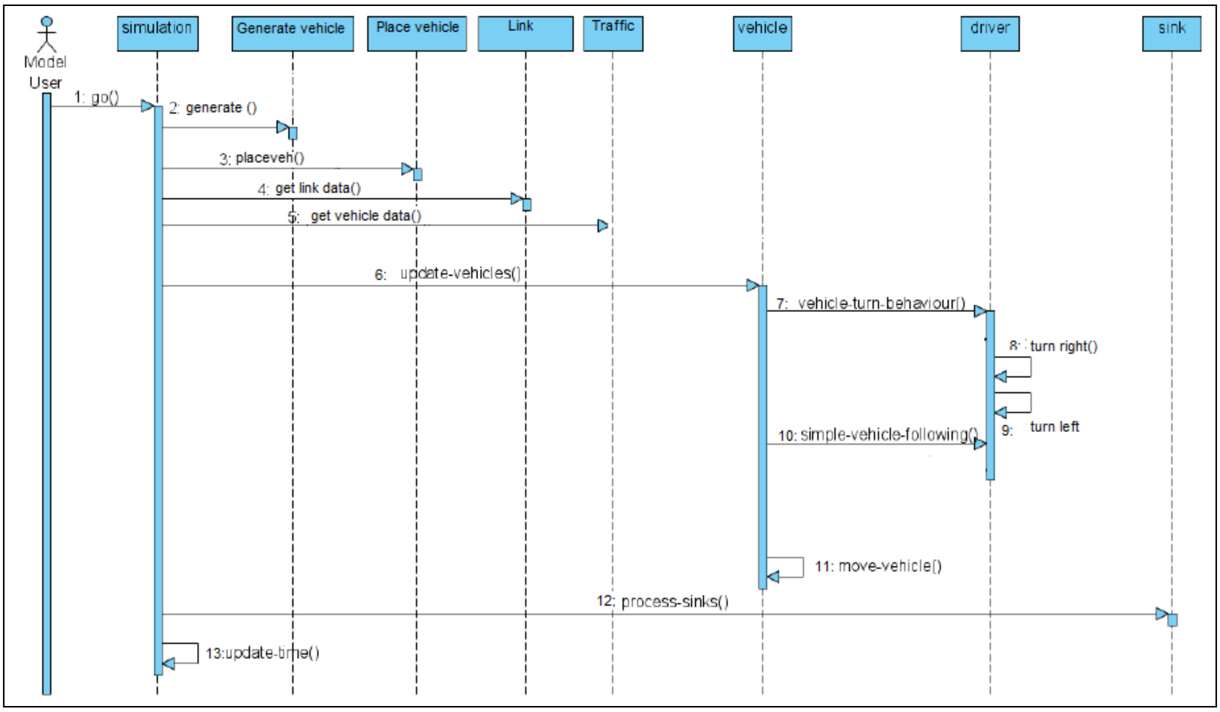

Figure 9 – Sequence diagram of simulation program

Figure 10 shows the snap shot of simulation model of T-uncontrolled intersection. This software can be adopted for heterogeneous traffic simulation programs, in general. By using the features of links and nodes network based simulation model can be developed as shown in figure 11.

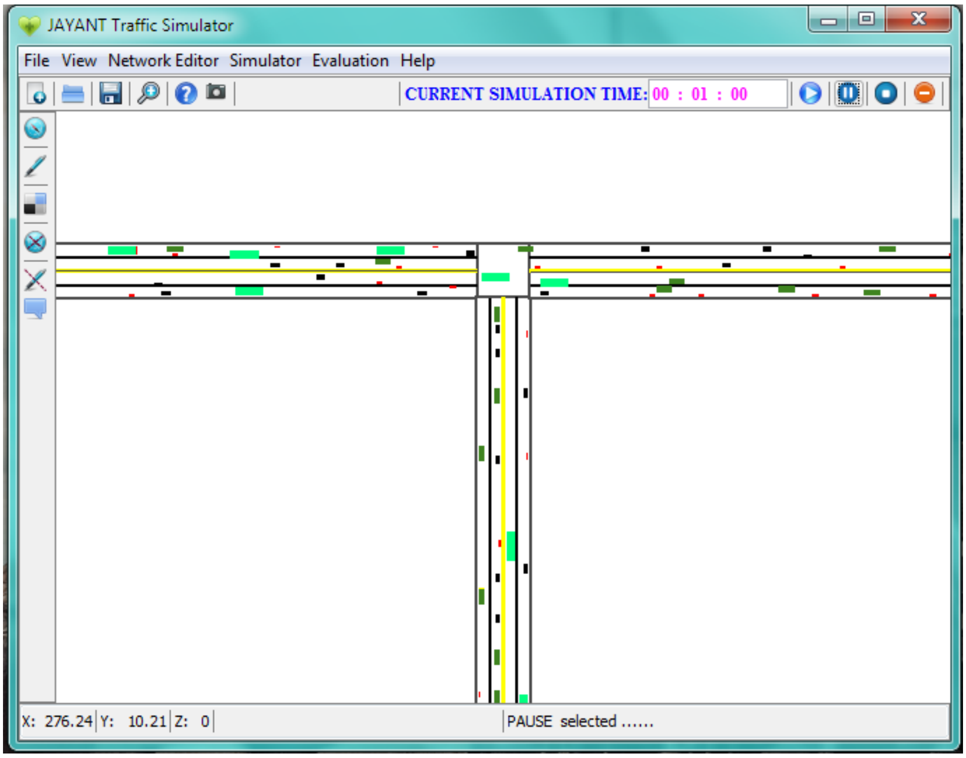

Figure 10 – Snap shot of uncontrolled T-intersection simulation

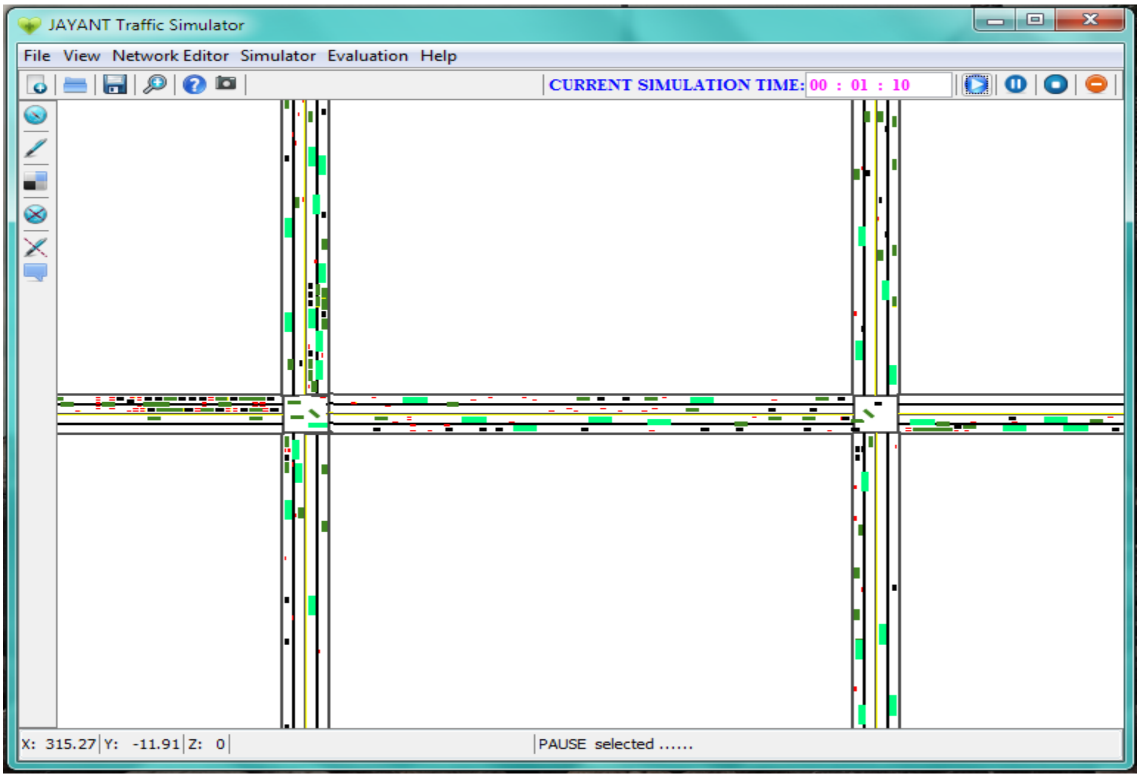

Figure 11 - Snap shot of network simulation

CONCLUSIONS

In this paper, a flexible agent-based model has been proposed for simulating heterogeneous traffic. The model is being calibrated and validated. Data is collect and data extraction is in process. The developed model for heterogeneous traffic flow conditions can be effectively used for mid-block and intersection studies under various roadway and traffic conditions as prevailing in developing countries like India. The future work should include refining the model, including mandatory lane changing near intersection and overtaking for heterogeneous traffic condition.

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