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Methodology for finding optimum cell size for a grid based cellular automata traffic flow model

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Abstract

A methodology for determining optimum cell size for a grid based traffic flow model for heterogeneous traffic is proposed in this paper. The cell size is an important factor to determine as it affects the computational efficiency and model accuracy. The objective function minimizes three aspects namely the difference of distance headway in case of cellular automata and grid based traffic flow model, the total number of cells to represent different types of vehicles and multiple of cell width that gives closer representation of the different road widths. The presented method is found better then the previous attempt which tries to find the cell size by trial and error.

Keywords: Heterogeneous traffic flow; Simulation; Grid based approach; Cellular Automata.

Introduction

Deciding a cell size is crucial for the cell-based simulation approach. In the present study, a systematic approach is given to decide the cell size in cellular automata based modelling for heterogeneous traffic flow. In this model, size of the cell is carefully decided according to the types of vehicle. It is decided in such a way that it represents the actual size of vehicles and the total width of the road as close as possible. The physical representation of the vehicle should be kept slightly more than the actual size of vehicle to provide some clearance. The cell length also depends upon the dynamic characteristics of the vehicular movement, as in the cellular automata, distance-headway and speed is considered in terms of number of cells. The cellular automata (CA) traffic flow model developed by Nagel and Schreckenberg (1992) is used for comparison of

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distance headway at different speed. If cell size is taken small, it can represent the physical features of vehicles more accurately but at the same time it will reserve the huge memory for computation. However, in CA based model, the length of the cell affects the dynamic characteristics of vehicle like speed, acceleration, and deceleration. This restricts cell size selection unlike the other heterogeneous models developed where there is no bar except the computational limitations. Considering all these aspects, the maximum possible cell size is decided which gives minimum and maximum desired clearance and the dynamic characteristics as close as to NaSch model.

The optimal cell size selection results in better model performance and satisfies the minimal modelling concept. It also gives better physical representation of the vehicle.

Background

Several simulation studies for heterogeneous traffic have been conducted in the past to capture the mixed nature of traffic flow prevailing in developing countries. These studies are different from those models of homogeneous traffic dominated by cars and heavy vehicles. These models have to capture the manoeuvres and interactions among the various types of vehicle, with varied in dimensions, speed and acceleration characteristics. There is a need to further understand these complex interactions. It is difficult to get the analytical solution in case of high heterogeneity condition; many researchers have used simulation based modelling approach for the heterogeneous traffic flow.

Considerable researches have been conducted for heterogeneous traffic flow in developing countries. Many simulation models were developed based on the grid based approach. Pillai (1975), Marwah and Ramaseshan (1978), Marwah and Bandyopadhyay (1983), Palaniswamy (1983), Isaac (1995), Chalapati (1987), Kumar and Rao (1996), and Ramamayya (1988) have developed simulation model for the heterogeneous traffic flow. Various cell sizes are taken by different researchers depending on the vehicles used for simulation run. However, none of them have given specific procedure for deciding cell size. They have used trial and error methods for deciding a cell size. Sing (1999) has taken a cell size as 1m x 1m to represent the road stretch. Roy (2000) developed a simulation model for the heterogeneous traffic flow. He considered the cell size as 0.28 m x 0.28 m considering update periods of 0.1 seconds. Korlapati (2003) has taken a similar concept for representing vehicles on the road grid. Gundaliya et al. (2004) has taken cell size as 0.9 x 1.9 meters in their simulation models. They have used cellular automata for the first time in grid-based approach for various types of vehicles including motorised and non-motorised vehicles. Lan and Chang (2004) have developed similar model for two wheelers and cars using 1.25 x 1.25 meters cell size.

The cell size decided in the above studies is based on the vehicle types. They have taken the cell size based on the vehicle types and the accuracy of the model performance. No specific guideline is given for determining the cell size in most of the cases. If the cell size is taken small, the model accuracy for the physical representation is high. However, the time taken for the simulation is increased. Singh (1999) has suggested that the cell size should be decided based on the computational criteria as well as lateral and longitudinal clearance of the vehicle. Hence, in the present study, a systematic approach is developed for determining optimal cell size for the heterogeneous traffic flow model using genetic algorithm.

Methodology

In the grid-based traffic simulation model road is divided into a number of uniform cells. The vehicles are then physically represented on the grid as per their sizes. The physical representation of the vehicles in the single lane is shown in Fig. 2. The vehicles then move according to the model criteria taken. In the present study the model developed by Gundaliya et al. (2004) is taken to formulate the objective function for optimum size of cell of the grid. The model developed by Gundaliya et al. (2004) and Lan and Chang (2004) have used CA concept to update the vehicle position. However, the cell size was decided based on type of vehicles. In these models speed is termed as number of cells per time-step. Hence, 1 cell/time-step means that vehicle advances 1 cell length in one time step. Therefore, the cell size also plays a key role for vehicle dynamics and model accuracy in these types of models.

A minimization problem is formulated considering headway distance, total number of cells and road width. The first term in the objective function (Eq. 1) represents the headway difference such that the model reacts similar to the NaSch basic model at all the cell speeds. Hence, as per NaSch model, the speed is taken from 1 to 5 cells / time-step. According to CA, the minimum headway required is the number of cells ahead of the vehicles as per the vehicle speed. This headway is fixed in the case of NaSch model for each speed as shown in column 6 of Table 2. The difference between these headways will be compared with that of grid-based model at the same speed for the given cell. Minimum difference indicates that the model closely represents the dynamic characteristics of NaSch model. The second term in objective function represents the total number of cells of different types of vehicles. The third term represents the difference between the actual width of the road and the width obtained by multiplying number of cells with width of each cell. This objective function is subjected to following constraints. The constraints (Eq. 2 and Eq. 3) ensure that all the vehicle types are having clearance within the limits of desired minimum and maximum clearance. Constraints (Eq. 4 and Eq. 5) take care of cell length and width such that it is always positive. $C1$, $C2$, and $C3$ are the appropriate constant weights for all three objectives in Eq. 1.

$$Min\ f(L_c, W_c) = C1 \times \sum_{i=1}^{5} (d_i^N \times 7.5 - d_i^G \times L_c)^2 + C2 \times \sum_{k=1}^{K} d_k^W \times d_k^L + C3 \times (d_i^{L_n} \times W_c - W_j)^2 \quad (1)$$

Subjected to

$$C^l_{\min} < C^l_k < C^l_{\max}\ \forall K \quad (2)$$

$$C^w_{\min} < C^w_k < C^w_{\max}\ \forall K \quad (3)$$

$$L_c > 0 \quad (4)$$

$$W_c > 0 \quad (5)$$

Where

$$d_i^G = (d_i^N \times \frac{L_c^N}{L_c}) \tag{6}$$

$$d_i^{L_n} = \frac{W_j}{W_c} \tag{7}$$

$$C_k^l = (d_k^W \times L_c - L_k) \tag{8}$$

$$C_k^l = (d_k^L \times W_c - W_k) \tag{9}$$

$d_i^G, d_i^N, d_k^W, d_k^L, d_k^{Ln}$ are integers indicating number of cells.

d_i^N is the distance headway at speed i considering NaSch model, d_i^G is the distance headway at speed i considering cell size of Grid based model, d_k^W is the width of vehicle type k, d_k^L is the length of vehicle type k, d_k^{Ln} is the width of lane (j) considering L_c, where L_c is optimum cell length in meters, L_n is total number of lanes of width W_j in meter of lane (j), L_k is the length of vehicle-type k in meters, W_k is the width of vehicle-type k in meters, L_c^N is the cell length in meters taken as 7.5 meter (NaSch model), W_c is the optimum cell width in meters, C_k^l is the clearance of vehicle type k in meters (lengthwise), C_k^w is the clearance of vehicle type k in meters (width wise), $C_{\min}^l$ is the minimum lengthwise clearance in meters, $C_{\min}^w$ is the minimum widthwise clearance in meters, $C_{\max}^l$ is maximum allowed lengthwise clearance in meters, $C_{\max}^w$ is maximum allowed widthwise clearance in meters, and K is total number of type of vehicle.

The above function is having number of variables and constraints, which are of conflicting nature. Hence, a Genetic Algorithm is used to solve the problem. The objective is to minimize the total square meter for the best representation of cells in grid based modelling approach.

Genetic algorithm

Genetic algorithms (GAs) are a family of computational models inspired by evolution (Goldberg, 1989). These algorithms encode a potential solution to a specific problem on a simple chromosome-like data structure and apply recombination of parameters (reproduction, crossover, and mutation) to these structures for storing critical information. GAs are often viewed as function optimizers, although the ranges of problems to which GAs have been applied are quite broad. An implementation of GAs begins with a population of (typically random) chromosomes, then evaluates these structures and allocates reproductive opportunities in such a way that those chromosomes that represents a better solution to the target problem are given more chances to 'reproduce' than those chromosomes, which are poorer solutions. The 'goodness' of a solution is typically defined with respect to the current population. The working principle of a GAs is illustrated in Fig. 1. The major steps involved are the generation of a population of solutions, finding the objective function and fitness function and the application of genetic operators. In the present study a cell length and cell width are taken as function variables and the optimum function value is obtained. This methodology is explained in the subsequent section.

/* GENETIC ALGORITHM */

formulate initial population
randomly initialize population
repeat
evaluate objective function with the constraint penalties
find fitness function
apply genetic operators
reproduction
crossover
mutation
until stopping criteria

Figure 1:working principle of genetic algorithm.

The GA parameters are tuned to get the near optimum solution to determine the cell size which satisfies the constraints. The total chromosome length is taken as 30 units for representing the cell size variable, length and width. Poll size is taken as 40 units and crossover rate and mutation rate is found to be 0.9 and 0.1 respectively. The libGA software is used for getting near optimum solution for determining cell size.

Case study

In this simulation model, seven types of vehicles differing in size have been considered as shown in Table 1. These seven types of vehicles are again classified as per their dynamic characteristics like maximum speed, acceleration etc.. Therefore, non-motorised vehicles like bicycle, bullock-cart, and pedal rickshaws can be considered by selecting appropriate size and dynamic characteristics. This problem has been solved using Genetic Algorithm. To restrict search area for the width and length of cell the search window is given for width as 0.9 to 1.0 meter and length as 1.0 to 2.2 meter. The distance headway for the NaSch model is taken as shown in column 7 of Table 2 for each speed option. The minimum clearances assumed for this problem are: $C_{\min}^{l}$ =0.1 meters, $C_{\min}^{w}$ =0.1 meters, $C_{\max}^{l}$ =1.2 meters and $C_{\max}^{w}$ =1.0 meters.

Table 1: type of vehicle and dimension details taken for the study.

Sr.No	*Vehicle Type*	*Width (meter)*	*Length (meter)*
1	2W	0.6	1.8
2	3W	1.4	2.6
3	Car	1.7	4.7
4	LCV1	1.9	5
5	LCV2	1.9	6.8
6	HCV1	2.5	8.5
7	HCV2	2.5	10.3

Table 2: speed and distance headway for different discrete models.

Speed in	*GBTFM (0.9 x 1.9 meters)*		*NaSch(CA-7.5)*	
c/ts	Speed (kmph)	Headway (meters)	Speed (kmph)	Headway (meter)
(1)	(2)	(3)	(6)	(7)
1	6.84	1.9	27	7.5
2	13.68	3.8	54	15
3	20.52	5.7	81	22.5
4	**27.36**	**7.6**	108	30
5	34.2	9.5	135	37.5
6	41.04	11.4	-	-
7	47.88	13.3	-	-
8	**54.72**	**15.2**	-	-
9	61.56	17.1	-	-
10	68.4	19	-	-
11	75.24	20.9	-	-
12	**82.08**	**22.8**	-	-
13	88.92	24.7	-	-
14	95.76	26.6	-	-
15	102.6	28.5	-	-
16	**109.44**	**30.4**	-	-
17	116.28	32.3	-	-
18	123.12	34.2	-	-
19	129.96	36.1	-	-
20	**136.8**	**38**	-	-

Where 2W stands for two wheelers, 3W for three wheelers, HCV1 for heavy commercial vehicle type 1, HCV2 for heavy commercial vehicle type 2, LCV1 for light commercial vehicle type 1, and LCV2 for light commercial vehicle type 2.

Total type of lanes considered as L_n is a two-lane road of 7.0 meters width. The single lane length is taken as W_1 = 3.6 meters and two lane width is taken as W_2 = 7.0 meters. In the present study, the weightings of all three constants are taken as equal and hence the value for $C1$, $C2$, and $C3$ are the same. The values of C1, C2, and C3 can be taken as different giving appropriate weightings to the terms in the objective functions. The GA converged after 130 iterations and cell size found as 0.9 meters as width and 1.9 meters as length. The closeness of distance headway of grid based model and NaSch model is given in Table 2. However, this cell size will change as the new vehicles with different sizes are added as well as the minimum and maximum clearance is changed. In the present study the cell size is taken as 0.9 meters and 1.9 meters for the vehicle under consideration.

The dynamic characteristics of the vehicle speed and the minimum distance headway required for the one-second time-step are shown in column 2 and 3 of Table 2 for cell length of 1.9 meters. The cell size is decided based on the different vehicle types and other considerations discussed earlier.

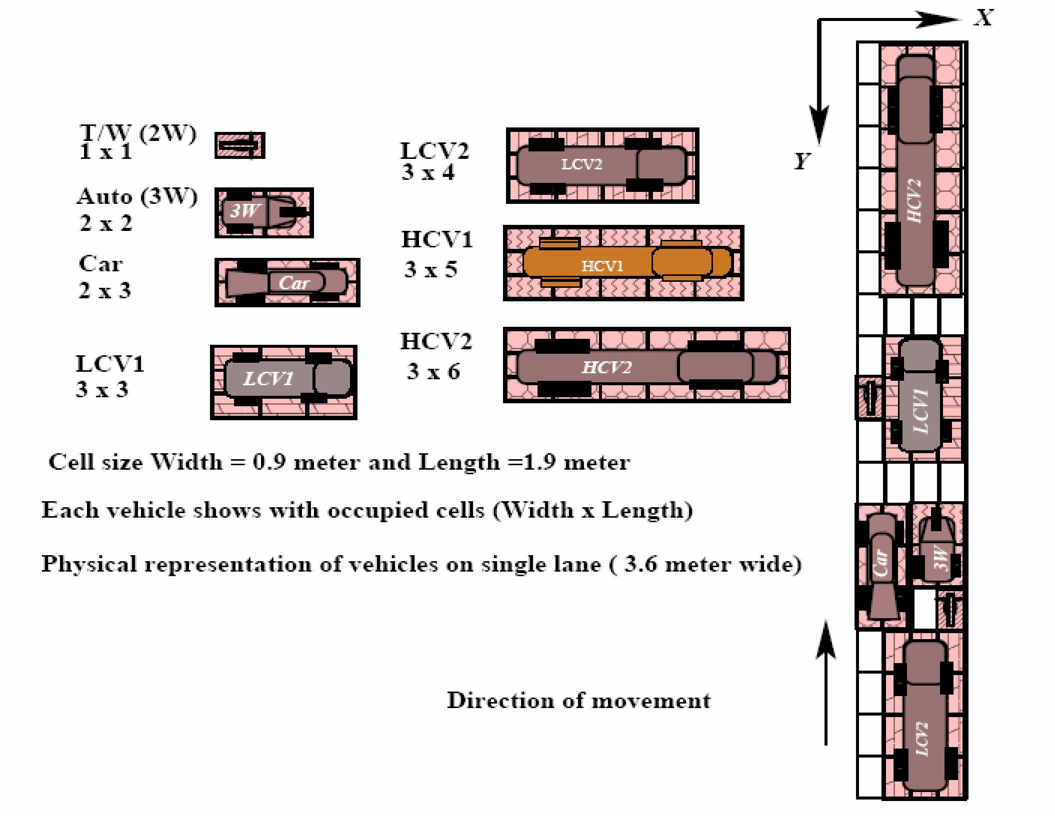

Figure 2: physical representation of vehicles on single lane road.

Results and discussion

The above-formulated problem has been used to find out the optimum cell size for the vehicle types given in Table 1 for the grid based traffic flow modelling. After deciding the cell size, the length and width of the vehicle in terms of number of cells can be obtained by adding clearance to the vehicle's actual length and width. After deciding the size of the vehicle in terms of number of cells in lateral and longitudinal, vehicle can be physically represented on occupied number of cells. This physical representation of the vehicle in the single lane is shown in Fig 2. The left most corner of the each vehicle represents the position of the vehicle in each time-step. Column 2 of Table 3 shows vehicle type, column 3 and 4 show vehicle actual dimensions of width and length taken in model in meters respectively, column 5 and 6 show the dimensions of vehicles in width and length of vehicles in cells, column 7 and 8 are width and length of vehicle representation taken in present study in meters and column 9 and 10 show the minimum clearance on width and length in meters.

Conclusions

The methodology developed is useful to define the optimum cell size, which represents the vehicles as the nearest as the actual size in terms of number of cells. Moreover it also represents the number of lanes as a multiple of cell width as close as possible. The objective function also takes care of dynamic characteristics of the vehicles where the vehicles gaps are represented in terms of number of cells. However, it needs to decide the weightage of all three objectives numerically, which can be universally applied for any type of function. The methodology applied here is for deciding cell size for the seven different categories of the vehicles. This method is further useful to define the cell size in case of heterogeneous traffic flow particularly where vehicles move forward according to the principle of CA based simulation.

Table 3: Vehicle dimensions details with cell size (0.9 x 1.9 meters).

S.No	*Vehicle type*	*Actual (meters)*		*Taken in model (cells)*		*Taken in model (meters)*		*Clearance (meters)*	
		Width	Length	Width	Length	Width	Length	Width	Length
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	2W	0.6	1.8	1	1	0.9	1.9	0.3	0.1
2	3W	1.4	2.6	2	2	1.8	3.8	0.4	1.2
3	Car	1.7	4.7	2	3	1.8	5.7	0.1	1
4	LCV1	1.9	5	3	3	2.7	5.7	0.8	0.7
5	LCV2	1.9	6.8	3	4	2.7	7.6	0.8	0.8
6	HCV1	2.5	8.5	3	5	2.7	9.5	0.2	1
7	HCV2	2.5	10.3	3	6	2.7	11.4	0.2	1.1

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