MODEL BUILDING OF TRAFFIC FLOW ON A THREE LANE ROUNDABOUT USING CELLULAR AUTOMATA MODEL

By

CHALA TOLOSA

A Thesis Submitted to
The Program of Applied Mathematics
School of Applied Natural Science
Presented in Partial Fulfillment of the Requirement for the Degree of
Master's of Science in Applied Mathematics

Office of Graduate Studies
Adama Science and Technology University

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ADAMA,ETHIOPIA

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Approval Page

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Abstract

The purpose of this thesis is to study how cellular automata (CA) can be applied to model three-lane trafic behavior on a roundabout intersection and develop the algorithm used for the simulation of three lane roundabout. Using cellular automata, the models are developed by modeling the detailed space considerations for drivers entering signalized three-lane roundabouts. The flowchart used for the simulation of traffic flow on a three lane roundabout have been developed.

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First of all, I would like to thank the almighty God for His assistance from the beginning to now, enable me to be successful in different directions. Next to this, I would like to thanks my families for their moral assistance and also thanks my best friend T.B. for all she help me. Finally, I would like to extend my grateful gratitude to my advisor Dr. Lemi Guta for his support and encouragement to do this thesis and for his careful and thoughtful comments, suggestion and needed materials.

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Chapter 1

Introduction

1.1 Background of the study

The growing of traffic volumes demand new solutions to accommodate the changing requirements. Building new and safe routes for traffic is expensive and in many areas of the world there is already lack of space. Although these concerns primarily urbanized areas, the lining out of new, multilane highways may be a different problem even through thinly populated areas. In cities even widening of streets may be impossible because of the local housing stock. Consequently, often the only option is to intensify the use of the existing road networks. Most efficient usage of the existing road infrastructure is related to the management and controlling of traffic flows, not forgetting safety and convenience for the people traveling there. Traffic flow modeling is an important step in the design and control of transportation systems. In the research of traffic flow, there have been proposed simplified models that still capture the essentials of the dynamics of the transportation system .Mathematical modeling and computer simulations play important roles in studying the impacts of various policies on vehicular traffic.

Modeling and simulation techniques are integral components of intelligent information systems being used in advanced countries. Recently there has been much of interest in studying traffic flow with cellular Automata models. Cellular Automata models have the distinction of being able to capture micro-level dynamics and relate these to macro level traffic flow behavior.(E.G. Campri and G. Levi 2000)
A cellular automaton (CA) is a discrete model studied in computability theory, mathematics, physics, complexity science, theoretical biology and micro structure modeling. Cellular automata are also called cellular spaces, tessellation automata, homogeneous structures, cellular structures, tessellation structures, and iterative arrays (Wolfram, Stephen 1983).
Cellular automata are dynamical systems in which space and time are discrete. A cellular automaton consists of a regular grid of cells, each of which can be in a finite number of k possible states, updated synchronously in discrete time steps according to local, identical interaction rules. Cellular automata (CA) is a mathematical machine that arises from very basic mathematical principles. Though they are remarkably simple at the start,

cellular automata has variety of applications. It has been used extensively for modeling of single-lane traffic. Some modifications are required to extend these models to two-lane traffic as these generally fail to explain the lane-changing behavior. First traffic flow model using the concept of one-dimensional cellular automata was given by Nagel-Schrekenberg popularly known as Nasch model (K. Nagel and M. Schrekenberg 1992).

The simple mean-field theory approach assumes that the two neighboring sites are completely uncorrelated. A simple model for two-lane traffic was also investigated, but the update rules were not defined in the same manner as in Nasch model. It was found that the fundamental diagram for each lane is asymmetric but the maximum is shifted towards large values of vehicular density $\rho(\rho_{max} > \frac{1}{2})$. The two-lane cellular automaton model based upon the single-cellular automata introduced by Rickert et al. was examined (M. Rickert, K. Nagel, M. Schreckenberg, and A. Latour 1996). It was concluded that for both symmetric and asymmetric version, maximum flow is higher than twice the maximum flow of single-lane model. An introduction of small number of slow vehicles can initiate formation of clusters at smaller densities (W. Knospe, L. Santen, A. Schadschneider, and M. Schrekenberg 1998). For asymmetric lane-changing rules, slow vehicles influence the system performance less than in symmetric case. In two-lane traffic flow model, if the car density is set within a range, the self-organization of the slow and fast lanes was observed in spite of symmetry between two lanes (A. Awazu 1998).

Since the 1980s, cellular automaton (CA) has been applied to research into traffic flow. It can be modified to deal with the effects of kinds of realistic conditions easily, such as drivers behaviour, the style of the vehicles, and the road status, etc. In the city traffic network, the traffic control of the road intersection is very important. There are two control modes: traffic light control and no signal control (e.g. the roundabout crossing).([M.F.Fouladv, Z.Sadjadi and M.R.Shaebani 2004), a cellular automata traffic model of the roundabout crossing is presented. It takes the roundabout crossing as a closed polygon and the traffic capacity of this model is investigated. (R. Wang and H.J. Ruskin 2002) and (R. Wang and H.J. Ruskin 2006), the cellular automata model is used with the offside-priority rule, and the traffic flows of a roundabout crossing with single circle-lane and multi-circle-lane are discussed respectively. To the roundabouts with the same geometry structures, the different traffic rules will induce different capacities. (R.X.Chen , K.Z.Bai and M.R.Liu 2006) adopts a determinate cellular automata model and transforms the roundabout crossing into several bottlenecks. The traffic flow properties at the roundabout crossing are discussed.
Multilane roundabouts have more than one lane on at least one entry and at least part of the circulatory roadway. The number of entry, circulating, and exiting lanes may vary throughout the roundabout. Because of the many possible variations, the computational complexity is higher for multilane roundabouts.(Ryus, Paul, et al 2010)

There are three basic types of roundabouts:

- Conventional roundabout: An anticlockwise, one-way circular roadway around a raised-curb central island for circulating traffic, with more than two approaches that have multiple vehicle entries.

- Mini-roundabout: A one-way circular roadway around a flush central island of up to 4 meters in diameter, usually without flared entries.

- Turbo roundabout : A new type of roundabout that minimizes the conflicts at roundabouts by forcing the motorists to know their direction at the entry approach before entering the roundabout.

1.2 Statement of the problem

In the previous work, many researches have been done on a single lane and double lane traffic model on a roundabout using cellular automata model. In particular (C.Chen, J. Chen, and X. Guo, 2010) studied that in presence of a signalized intersection, existence of a certain combination of density ρ and cycle time which optimizes the traffic efficiency in two-lane model. However, as my investigation they didn't consider optimizing the traffic efficiency on a three-lane road in presence of signalized intersection.Therefore, in this study, we will try to investigate on a three-lane traffic flow on a roundabout using cellular automata model.
So that, the thesis is intended to answer the following basic questions:

- How to advance the model of traffic flow on a three-lane roundabout?

- How to develop the flowchart used for the simulation of traffic flow on a three lane roundabout?

1.3 Objective of the study

1.3.1 General objective

The general objective of the thesis is to build a model of traffic flow on a three lane roundabout using cellular automata model.

1.3.2 Specific objectives

The specific objectives of the thesis are:

- To advance the model of traffic flow three lane on a roundabout.

- to develop the flowchart used for the simulation of traffic flow on a three lane roundabout.

1.4 Benefits and Beneficiaries

This study provides a reliable information how can we model three lane traffic behavior on a roundabout intersection using cellular automata model. In particular studying a traffic behavior on a roundabout intersection eliminate crossing conflicts that are present at conventional intersections, thus reducing the total number of potential conflict points and the most severe of those conflict points.

Chapter 2

Literature Review

A cellular automata (CA) is a extremely simplified program for the simulation of complex transportation systems. The first application of the cellular automata for simulation model of traffic flows on street and highways was introduced by Nagel and Schreckenberg popularly known as NaSch Model (K. Nagel and M. Schrekenberg,1992).This model is based on the homogeneous traffic flow. Chowdhury et al. made an attempt to model two kinds of vehicles using cellular automata. This model is a two-lane traffic flow model with two different types of vehicles , characterized by two different values of the maximum speed (v^k_{max}) for k^{th} type of vehicle (D. Chowdhury, D.E. Wolf, and M. Schreckenberg, 1997).
A simple model for two-lane traffic was investigated , but the update rules were not defined in the same manner as in NaSch model. The two-lane cellular automata model based upon the single-lane cellular automata introduced by Rickert et al. was examined (M. Rickert, K. Nagal, M. Schreckenberg, A. Latour, 1996). Several branches and hysteresis in flow-density graph are observed. Results relative to a simple cellular automata model without periodic boundary condition for a highway with variable number of on-ramps were presented (E.G.Campri, G. Levi, 2000). A 2D extended version of the 1D Fukui-Ishibashi model, elaborated by Wang et al, was presented for single-lane traffic to take into account the exchange of vehicles between the first and second lane.
In general lane-changing rule can be symmetric or asymmetric with respect to the lanes or to the vehicles. While symmetric rules treat both lanes equally, asymmetric rule sets especially have to be applied for the simulation of German highways, where lane changes are dominated by right lane preferences and a right lane overtaking ban (W.Knope, A. Santen, A. S.chadschneider, and M.Schreckenberg, 2002). A new cellular automata model by introducing the Honk effect into the basic symmetric two-lane cellular automata model was proposed by (B.Jia, R.Jiang, Q.S. Wu and M.B.Hu, 2005). The set of lane-changing rules suggested by Chowdhury et al.(L.Wang, B.H.Wand and B.Hu 2001) was revised to take the Honk effect into account. A simple lattice-based exclusion model which can be considered as a crude representation of traffic on a two-lane motorway was introduced (R.J.Harrish and R.B.Stinchcombe 2005).Effect of an aggressive lane-changing behavior on a two-lane road in presence of slow vehicles and fast vehicles has been further studied (X.G.Li, B.Jia, Z.Y.Geo and R.Jiang 2006). A highway traffic flow model with blockage induced by an accident vehicle was introduced in which both symmetric and asymmetric

lane-changing rule were adopted (H.B.Zhu, L. Lei, and S.Q.Dai, 2009). Further it is found that vehicles will change lane more frequently when the traffic is heterogeneous with an accident car. In presence of a signalized intersection, existence of a certain combination of density and cycle time which optimizes the traffic efficiency in a two-lane model due to overtaking is studied (C.Chen, J. Chen, and X. Guo, 2010).

Minimum Acceptable sPace (MAP)

We briefly outline the MAP method (H. J. Ruskin and R. Wang 2002) before describing Multi-stream Minimum Acceptable Space (MMAS) models. In the MAP method, the drivers behavior is categorized into four groups: radical, urgent, moderate and conservative. We use a single-lane roundabout to illustrate the MAP method. If a driver accepts a 3-cell space (between circulating vehicles) as the MAP enters the roundabout, behavior is designated as moderate Radical behavior requires one cell space. The driver takes any space on the intersection without consideration of safety. Consequently, this vehicle may delay the oncoming vehicle on the roundabout for two time steps and may generate gridlock (H. J. Ruskin and R. Wang 2002). A 2-cell space corresponds to urgent behavior, which may be the result of such things like misjudgment, over confidence in vehicle acceleration, bad driving habits, urgency on traveling or the phenomenon of priority sharing. The effect is to delay an oncoming vehicle on the roundabout. Conservative behavior corresponds to Minimum Acceptable sPace (MAP) greater than four cells.

Chapter 3

Research Methodology

Vehicles at entrances of multi-lane roundabouts observe the same priority rule as at entrances of single-lane roundabouts. Vehicles on entrance roads of roundabouts moving onto the corresponding lanes of roundabouts need to give way to the vehicles on the roundabouts. The process for a vehicle to pass a three-lane roundabout can be divided into the following subprocesses.

1. Vehicle arrival at the start of an entrance road (e.g. 100 cells away from the roundabout)

2. Pre-determined destination (before allocation to a lane of the entrance road) and lane allocation (on entrance road)

3. Vehicle movement along an entrance road

4. Position delay: vehicles from an entrance road of roundabouts on the left lane (or middle lane) of an entrance road may be halted for Position Delay Time (PDT) if view impeded by adjacent vehicles. The PDT is the time to adjust position to check opportunity to enter the roundabout)

5. Entry (interaction between vehicles from the entrance and vehicles already on the roundabout)

6. Navigation of the roundabout

7. Vehicles exit from the roundabout

Chapter 4

Model Building of Traffic Flow on a Three Lane Roundabout Using Cellular Automata Model

4.1 Major geometric features of a modern roundabout

A roundabout is a type of circular intersection on the road. It is useful to define, identify and clearly understand the geometric features or elements of a roundabout. But not all circular intersections are classified as roundabouts for operational analysis and design purposes according to the capacity study of roundabouts in the UK, geometrical elements of roundabouts played an important part in the efficiency of roundabout operational performance. Good geometrical design will improve not only capacity but also safety, which is a major concern for road design (Brucew. Robinson, 2005). Basic elements for design consideration of roundabout are:

Central Island: is the raised area in the center of a roundabout around which traffic circulates.
Truck Apron: is a traversable portion of the raised center island to accommodate the wheel path of over sized vehicles.
Splitting Island: is placed within the leg of a roundabout to separate entering and exiting traffic and provide vehicle deflection prior to entering the roundabout.
Approach Width: refers to the width of the entering lanes before flaring or any other influence from the roundabout.
Exit Width: is the perpendicular distance from the right curb line of the exit to the intersection of the left edge line and the inscribed circle.
Departure width: refers to the width of the lanes departing from the roundabout at a point where the width is no longer influenced by the roundabout.
Effective flare length: a flare may be used to increase the entry width and capacity of a roundabout by providing additional lanes at the entry. The effective flare length is equal to the distance from the entry width to a point where the approach width is equal

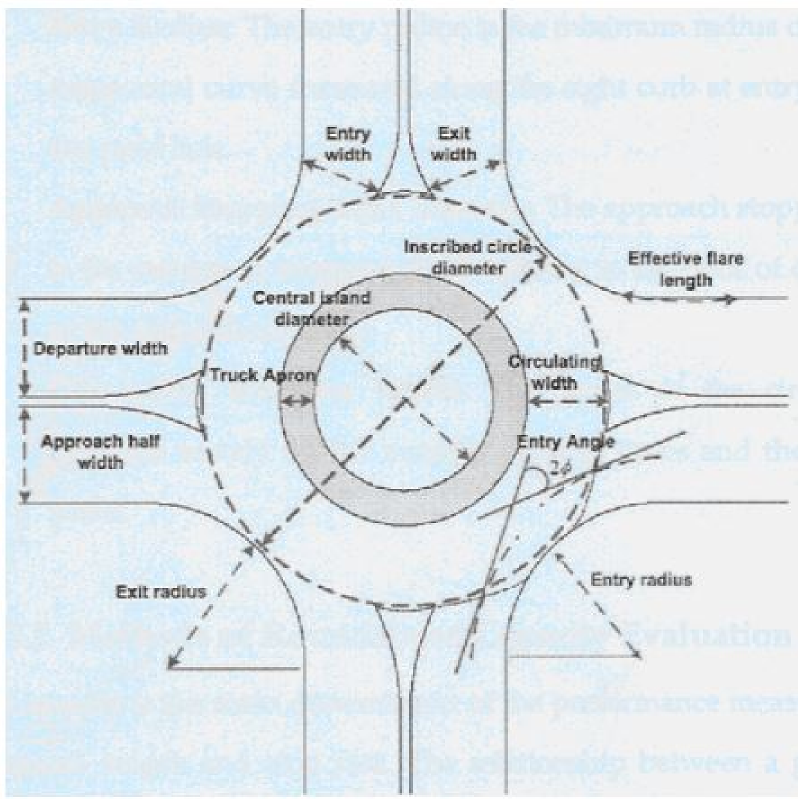

Figure 4.1: Major Geometric features of modern roundabout [B.Robinson 2005]

to half the sum of the entry width and the approach traveled way width prior to influence from the roundabout.
Entry Radius: is the minimum radius of curvature for the compound curve measured along the right curb at entry beginning before the yield line.
Circulating roadway width: depends mainly on the number of entry lanes and the radius of vehicle paths.

A roundabout in its design may have three, four, five or more incoming and outgoing flow directions on which traffic can flow. These flow directions are commonly called arms of the roundabout. But in some countries the most frequent ones are roundabouts with four arms. A roundabout may be a single-lane, double-lane or three-lane. If it is a three-lane, its circulatory roadway must also be of a three-lane and its arms must have at least three-lanes. The same is true for the single- and double-lane roundabouts. In a single-lane roundabout only a single vehicle can enter to the roundabout at a time; others wait at the yield line one after the other. But in a double-lane and three lane roundabout two and three vehicles can approach a roundabout at a time respectively. This is, the major difference that exists between roundabouts.
Modern roundabouts have deflection for the entering traffic usually in the form of raised islands (splitter islands) at entry and a raised central island (Wang and Ruskin, 2002, 2006; Wang et al., 2005).The splitter islands direct traffic toward the central island, which further deflects vehicles to the right. Deflection results in lower speeds and improved safety. According to the give way rule, vehicles from the entry roads of a roundabout give way to those vehicles already circulating on the roundabout. All entering vehicles on the approaches have to evaluate a gap in the circulating flow before entering the circulating traffic. With these entire features, a roundabout has some advantages in comparison to signalized intersection such as yield-at-entry operation, fewer conflict points, allowing more time for drivers to react while reducing crash severity, and vehicles travel in the same direction virtually eliminating the possibility of right angle or head-on collision.
Things to take care on roundabouts
On approaching the roundabouts you have to reduce the speed to about to 20KMPH it will help to gain good control and can give way to other vehicles in the roundabout.
we must give way to the vehicle already in the roundabout and also the traffic from the left side.
Go to right: we can follow same procedure for two lane road, approach in the right lane and stay in that lane. Signal to right. Leave the right hand lane.
Go to straight: If we wish to proceed straight, we can chose either right hand lane or center lane. Important to remember that we have to proceed with the same lane which chosen to enter. That means if we chose center lane to enter we should exit through left hand lane only. If we want to turn right immediate after exiting roundabout we can choose right hand lane to enter. Otherwise can use center lane.
Go to left: If we want to take left or u-turn always take left hand lane Signal left on approach. Signal right once passed second exit. Check vehicle on right when we decided to exit. Also follow the correct lane when exit.

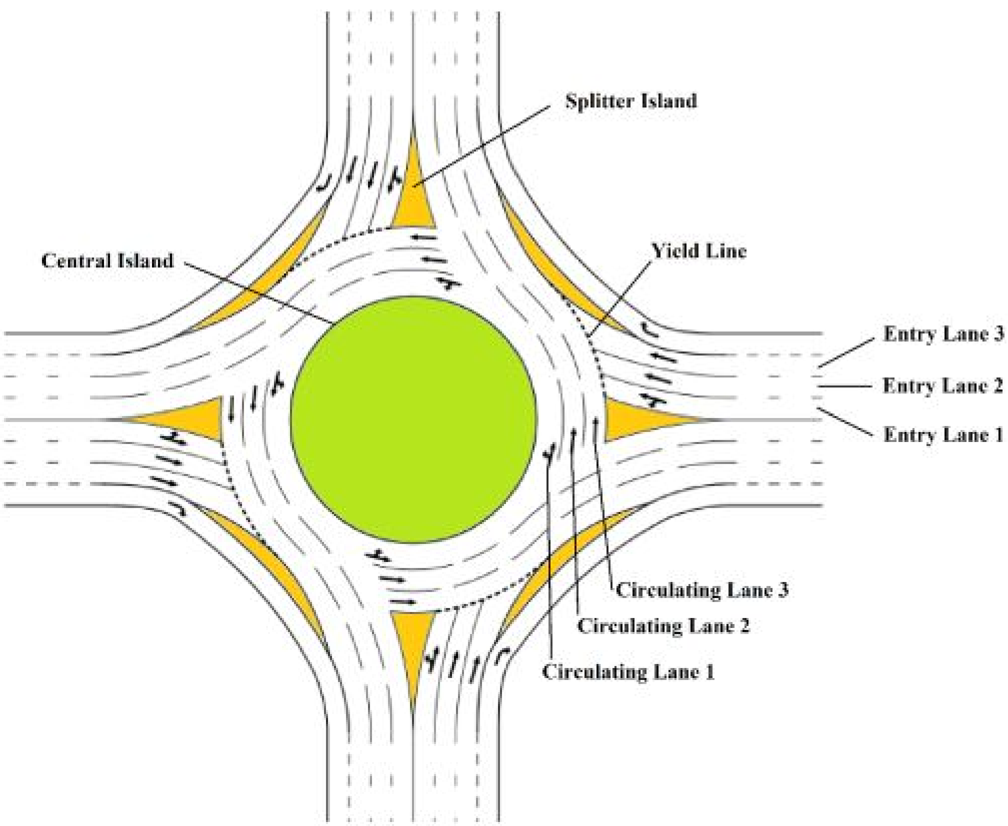

Figure 4.2: Roundabout on Three lane road [A.S. Mohammad 2015]

4.2 Cellular Automata (CA) Model

Cellular Automata model is a model that is applied in dynamical systems with space, time and system states are assumed to be discrete variables. In this model the road is divided into sections of a certain equal length Δx and the time is discretized to equal time steps of Δt. The cellular Automata model describes the traffic system as a lattice of cells of equal size, which is typically the average length of road occupied by one vehicle. The sizes of the cells are chosen so that the speed of a vehicle is equal to one move to the next downstream cell during one time step. The vehicle's speed can only assume a limited number of discrete values ranging from zero to v_{max}. The variables describing phases of each site are updated for every time step. The variables are the speeds of the vehicles, indicating whether the cells of the lattice are occupied or empty or any other parameters, which describe an aspect of traffic flow. The state of a cellular automaton depends on the value of discrete variable(s) at each site. Each road section can either be occupied by a vehicle or is empty and the dynamics are given by update rule as discussed below.

4.2.1 The Update Rule

The update rule can be expressed in terms of the sequential cells. If there is a vacant cell in front of the cell occupied by a vehicle, the vehicle will move forward one cell in the current time step. If the cell at the front is also occupied, the vehicle will stop there in that time step. The state of the nth cell in the next time step is decided by the states of its own cell , the state of the cell in front and the cell behind in this time step, where t and n express time and position sequence respectively. The states can only be 0 or 1, where 0 means the cell is vacant and 1 means it is occupied by a car. Therefore, the update rule can be expressed as follows:

- If $c_n^t = 1$ and $c_{n+1}^t = 0$, then $c_n^{t+1} = 0$ and $c_{n+1}^{t+1} = 1$
- If $c_n^t = 0$ and $c_{n+1}^t = 0$, then $c_{n+1}^{t+1} = 0$
- If $c_n^t = 1$ and $c_{n+1}^t = 1$, then $c_{n+1}^{t+1} = 1$

4.2.2 Predetermined destination

Drivers take their destination into account before they enter into the roundabout entry road. A four arm roundabout has four entry and four exit directions. A vehicle that entered to a roundabout has four possible exit directions (vehicle's destination). It either turn right, left, make a u-turn or drive straight through the roundabout. Therefore, it is quite logical to assume that drivers' turning direction is predetermined at their entry. According to this assumption, we allocate a lane to each arrived vehicle depending on its destination. The vehicles arrive at the yield-line by moving ahead one cell at each time

step either on the right lane, middle lane or left lane of the entry road according to the lane pre-allocated for it. It is usually hard and time consuming for vehicles in the inner lane to go out of the roundabout and follow its exit direction as they should get a free cell in the outer lane.
Characterizing a given exit for each vehicle before entry is more realistic. This approach is used to characterize each car by randomly giving them a different number. These numbers are equal to the number of cells that the car needs to pass to arrive at the destination exit. For instance, for a roundabout which has four entrance road the CA model has a total of (a+b+c+d) cells, where a, b, c and d are the cells between entrance road (arms) 1 and 2, 2 and 3, 3 and 4, 4 and 1 respectively. The vehicle that comes from arm 1 are signed a, (a+b), (a+b+c) and (a+b +c +d) randomly as shown in Table 1. The four numbers represent the number of cells to pass prior exiting at respective points. If the distribution of vehicles from arm 1 exits at the four different exits then they are known as m_1%, n_1%, o_1% and p_1% respectively, we then randomly assign m_1% of the vehicles with a, n_1% with (a + b), o_1% with (a + b + c) and p_1% with (a + b + c + d) as shown in Table 1.
Also $m_i\% + n_i\% + o_i\% + p_i\% = 1$
i = 1, 2, 3, 4.

Table 1: The numbers assigned for the vehicles

Arm1	Arm2	Arm3	Arm4
m_1%a	m_2%b	$m_3\%c$	$m_4\%d$
n_1%(a+b)	n_2%(b+c)	n_3%(c+d)	n_1%(d+a)
o_1%(a+b+c)	o_2%(b+c+d)	o_3%(c+d+a)	o_4%(d+a+b)
p_1%(a+b+c+d)	p_2%(a+b+c+d)	p_3%(a+b+c+d)	p_4%(a+b+c+d)

4.2.3 Update rule on the Roundabout

The update rule for the roundabout is as follows. If the state in cell n at time step t is larger than one ($c_n^t > 1$), then it shows that there is a vehicle in cell n, the state (c_n^{t+1}) in cell (n+1) in front must be checked to see if it is vacant. If it is vacant (c_n^{t+1}= 0), then the number decreases by one when it moves forward into the cell (n+1) in front (c_{n+1}^{t+1}=$c_n^t - 1$) and cell n will become zero (c_n^{t+1}= 0) in time step (t+1) as shown below. If the state in cell (n+1) is not zero ($c_n^{t+1} \geq 1$) the number in cell n (c_n^{t+1}) will be kept unchanged (c_n^{t+1}= c_n^t) as shown below. As the car moves, its number will finally become equal to one ($c_n^t = 1$) indicating that the car will leave the roundabout in the next time step if the exit is free, and there will be no car in this cell in the next time step (c_n^{t+1}= 0). If the exit is not free, the car will remain there.
Using the same notation as above, the update rule can be simply expressed as follows:

- If $c_n^t > 1$ and $c_{n+1}^t = 0$, then $c_n^{t+1} = 0$ and $c_{n+1}^{t+1} = c_n^{t+1} - 1$
- If $c_n^t > 1$ and $c_{n+1}^t \geq 1$, then $c_{n+1}^{t+1} = c_n^t$

- If $c_{n-1}^t = 0$ and $c_n^t = 0$, then $c_n^{t+1} = 0$
- If $c_n^t = 1$, then $c_n^{t+1} = 0$, if it is able to exit; and if it can not, $c_n^{t+1} = c_n^t$

The update rule on the roundabout is shown in Fig 3.6.

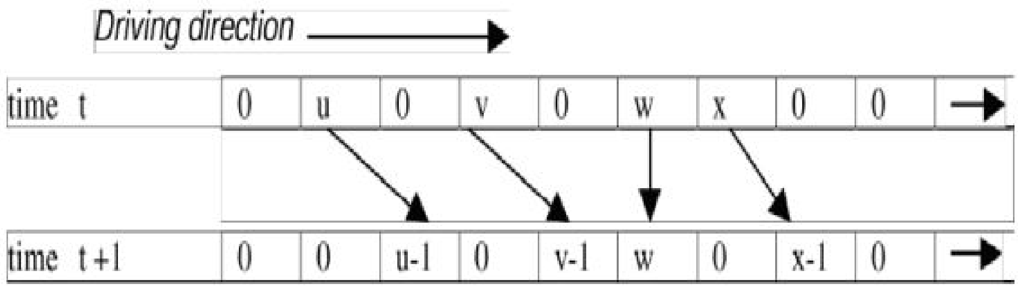

Figure 4.3: The update rule on the roundabout

There are several advantages of using this notation instead of just 0 and 1. Firstly the number does not only mean that the cell is occupied or vacant, but also indicates where its occupant will go. The update rule is the same for any cell on the roundabout as well. When a car drives out of the roundabout, the number automatically becomes zero.
Secondly if we want to visualize the car on the roundabout in the future, its turning indicators may also be visualized, we can simply define it as : if number $c_n^t \geq (a+b+c+d)/2$, its left turning indicator is on; if $c_n^t \leq (a+b+c+d)/4$ the right indicator is on.
Thirdly, this method makes multiple entrance/exit programming possible and it can be applied to simulation of traffic flow where the origins and destinations are known, by assigning the vehicle with a number corresponding to the steps needed to arrive at its destination exit.

4.3 Driving Principle on a Roundabout

Unlike traffic light controlled intersections, roundabouts in general are governed by the priority rule. According to this rule, vehicles waiting to enter a roundabout must give way to vehicles already on the roundabout and vehicles exiting from the inner lane of multi-lane roundabouts additionally have priority over vehicles rotating on the outer lanes of the rotary of the roundabout. A vehicle arrived at the entrance road of a roundabout at either arm will not be allowed to change lane after it entered the roundabout entry road, usually 100 meters away from the roundabout entrance. Thus, the vehicle is assumed to be in its lane as it entered to the entry road, either at the right lane, middle lane or left lane depending on the preference of its destination. As soon as vehicles arrived at the yield line of the entrance of the roundabout at either arm and at either lane, under the offside-priority rule, the vehicles stop and wait at a roundabout entrance by giving way to the vehicles already on the roundabout until they get an appropriate gap (cell number).

Once the vehicle is entered to the roundabout rotary road, it makes a turning maneuver around the central island until it exits from the roundabout. Think of a vehicle on the inner lane of the roundabout rotary that is about to exit at the next arm, since it has a priority over the vehicle on the outer lane of the rotary, this vehicle communicates with a vehicle on the outer lane of the rotary road whenever it wants to exit from the roundabout by giving a sign for the vehicle on the outer lane which is an indication that the vehicle wants to exit from the roundabout at the next arm. As soon as this sign is received by a vehicle on the outer lane of the roundabout it gives way to that vehicle by stopping where it was. Consequently, vehicles on the outer lane and behind the vehicle by which the message is received will be delayed unless there is a significant gap in front of those vehicles so that the vehicle may not be forced to decelerate and come to stop. It is only this rule and the geometry of the roundabout that enables traffic to flow on the roundabout smoothly.

4.4 Vehicles' Arrival at the Entrance Road of a Roundabout

The mean arrival rate is the rate at which vehicles arrive at the entrance road of the roundabout. Mean arrival rate, denoted by λ, is the total number of vehicles, denoted by N, that arrived within some interval of time,Δt, divided by Δt. Mathematically,

$$\lambda = \frac{N}{\Delta t} \tag{4.4.1}$$

Usually it is given in unit of vehicle per second (vps). It describes how many vehicles arrived at the entrance road of a roundabout per second. And the arrival rate is determined using equation (4.4.1) and it can be related to the density ρ, by the following equation:

$$\rho = \frac{\lambda \Delta t}{\Delta l} \tag{4.4.2}$$

Where, Δl is the length of a section of road on which vehicles are distributed during the interval of time Δt. It is impossible to exactly forecast the time when vehicles arrive at the entrance road of a roundabout because of the random nature of vehicles' arrival at the entrance road, but using Poisson probability distribution it is possible to approximate vehicles' arrival rate. A queue occurs when instantaneous demand exceeds instantaneous capacity of the road intersection. The queue-length depends on the inter-arrival times and service processes. The service process here means all stages of the vehicle arriving at the end of the queue and crossing the intersections (hence leaving the queue). Queuing models are characterized by the distribution of inter-arrival times and the distribution of the service times. Two distributions are normally used, Poisson or general distribution (Wang, 2003). In this thesis, we used the Poisson distribution because the random variable, in

our case the number of arrivals (number of vehicles), is a discrete variable.
The form of the Poisson distribution is given by equation (4.4.3).

$$P(r) = \frac{(\lambda \Delta t)^r e^{-\lambda \Delta t}}{r!} \tag{4.4.3}$$

where $p(r)$=probability of arrival of r vehicles in any interval of Δt seconds,
λ = average rate of arrival,
r = number of vehicles expected to arrive during time interval Δt,
Δt = time interval in which r vehicles are expected to arrive.
Equation (4.4.3) is used to find the probability of $0, 1, 2, , v-1$ or v arrivals, for $v \in W$ (set of whole numbers), only during the specific arrival rate of λ. In this paper we analyzed traffic behavior during different arrival rates. Thus, we used equation (4.4.1) to get equation (4.4.4) in order to have different arrival rates. Suppose we have N vehicles counted during some hours of the day. And let N is divided into $N_1, N_2, N_3, , N_i, , N_k$ subdivision of observations such that N_i is the number of vehicles counted between $i-1$ and i hours. And $N_i \neq N_j$, Then, we can calculate the k arrival rates using equation (4.4.4).

$$\lambda_i = \frac{N_i}{\Delta t} \tag{4.4.4}$$

Further, using equation (4.4.4), we can rewrite equation (4.4.3) as follows.

$$P_i(r) = \frac{(\lambda_i \Delta t)^r e^{-\lambda_i \Delta t}}{r!} \tag{4.4.5}$$

Thus, the distribution of the arrival of vehicles is calculated using equation (4.4.5).

4.5 Lane Allocation

In three lane roundabout, approaching vehicles take either of the three lanes of the entry road depending on their turning preferences. Lane is allocated randomly to a vehicle arrived at the entrance road of a roundabout with equal probability of joining either of the three lanes and the vehicle's turning rate is determined at the start of the entrance road of the roundabout according to their predetermined destination. It is assumed again that vehicles are not allowed to change lane once they entered the entrance road of the roundabout until they exit from the system. Because changing lane on both the approach and within the roundabout in general is less likely observed or may be considered as abnormal.

4.5.1 Rules and Regulations for Three Lane Roundabouts

The rules and regulations to drive in a three-lane roundabout are almost similar to the conventional two lane roundabouts. Figure 4.2 shows the typical three lane roundabout with channelized right turn movements and also lane configuration and movements allowed on each lane.
According to the official road user code for Abu Dhabi [Abu Dhabi 2013], the rules and regulations for lane movements on three lane roundabouts are as follows:

- Vehicles in entry lanes 2 and 3 can drive through if the right turn is channelized; if not, then entry lane 3 can be used for both through and right maneuvering.
- Vehicles in entry lane 3 can maneuver both straight through and right.
- Vehicles in circulating lanes 2 and 3 should be turn right and straight through.
- Vehicles in circulatory lane 1 can maneuver both u-turn and left.

4.5.2 Types of Violations on Three Lane Roundabouts

Although there are a number of violation types in three lane roundabouts, the following are considered the major ones:

(A) Yield Line Violation

(B) Circulatory Lane Change Violation

(C) Entry Lane Change Violation

(A) Yield Line Violation

The vehicles should stop before the yield line on the entry lane to give the right of way to the vehicles circulating in the roundabout. The entry lane vehicles should be cautious that they dont block the view of other drivers in the entry lane and also not to disturb the flow of the vehicles at the outermost circulatory lane. For this purpose yield lines are marked at each entry lane. If the vehicles dont stop before the yield line while waiting for an appropriate gap between circulating vehicles, a yield line violation occurs.(A.S. Mohammad 2015)

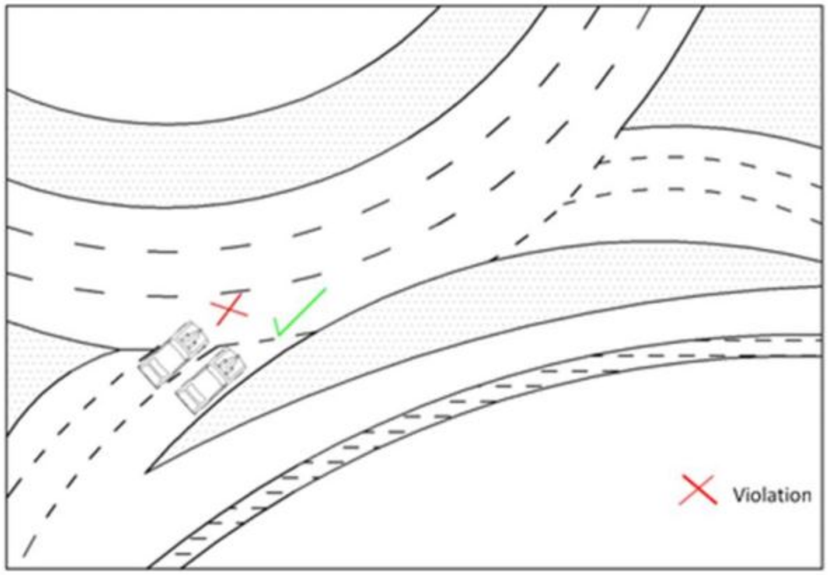

Figure 4.4: Yield Line Violation [A.S. Mohammad 2015]

(B) Circulatory Lane Change Violation

The circulating vehicles should maintain a particular lane according to their exit leg, if they do not, it is considered a circulatory lane change violations. The vehicles circulating in the innermost lane have the privilege to go through or turn right on the next exit leg, whereas the vehicles moving on the middle and outermost lane in the roundabout should turn right at the next coming exit.(A.S. Mohammad 2015)

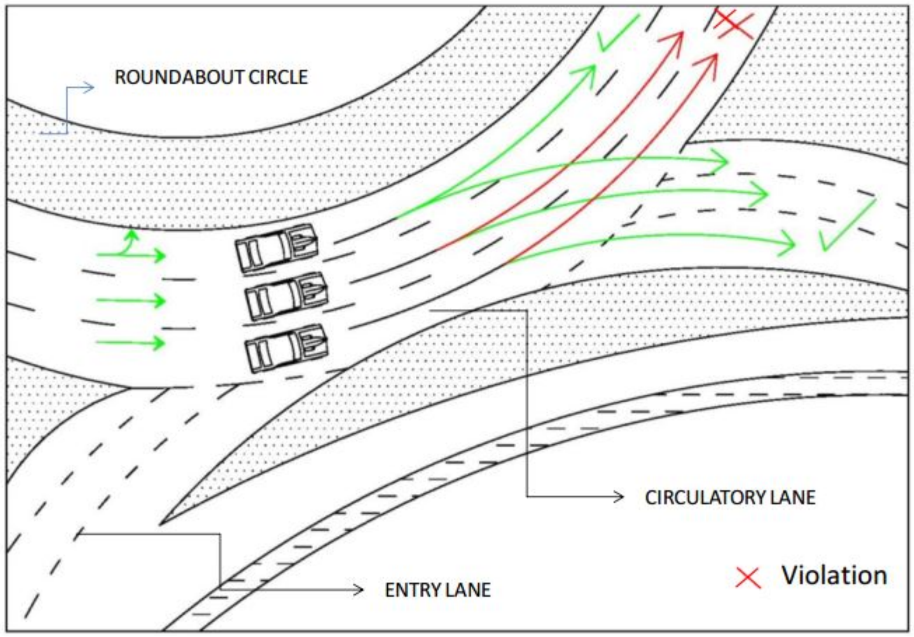

Figure 4.5: Circulatory Lane Change Violation [A.S. Mohammad 2015]

(C) Entry Lane Change Violation

The drivers entering the roundabout should select the appropriate lane in advance based on the desired movement in the intersection: right, through, or left. Vehicles should not change their lane when entering the circulatory lanes or during the circulation in the roundabout. The vehicles entering from the innermost lane should circulate in the roundabout in the innermost circulating lane. Similarly, the vehicles entering from the middle and outermost lanes should travel in the middle and outermost circulating lanes, respectively. When drivers change lanes after entering the circulatory lanes, it results in an entry lane change violation.(A.S. Mohammad 2015)

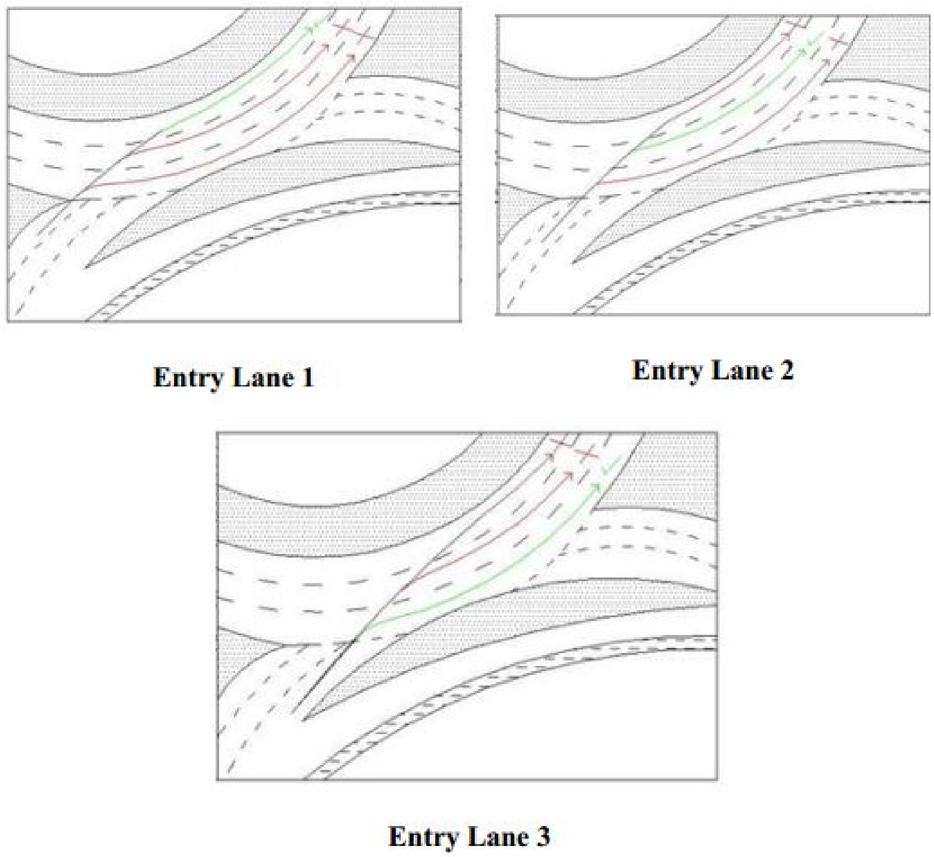

Figure 4.6: Entry Lane Change Violation [A.S. Mohammad 2015]

4.6 Entry to the Roundabout

A vehicle arrived at the yield line at either lane, will be assigned a probability to which direction it is to exit from the roundabout with the number of cells it traverses. Having this assignment it waits at the yield line until it gets an appropriate gap that enables it to enter into the roundabout facility. Thus, it needs to check an appropriate gap depending on its driver's behavior to enter into the roundabout.

We use three CA-rings (three cellular automata rings with the same center but different diameters) to simulate three-lane roundabouts. All rings have the same number of cells and vehicles can move ahead one cell in each time step when they navigate the roundabout. In other words, we assume that the vehicles in all lanes traverse the same number of radians in the same period of time. This assumption is permitted by the fact that the speeds of a vehicle driving in different rings (with different radius) are different. The shorter the radius, the lower speed that vehicle can move.

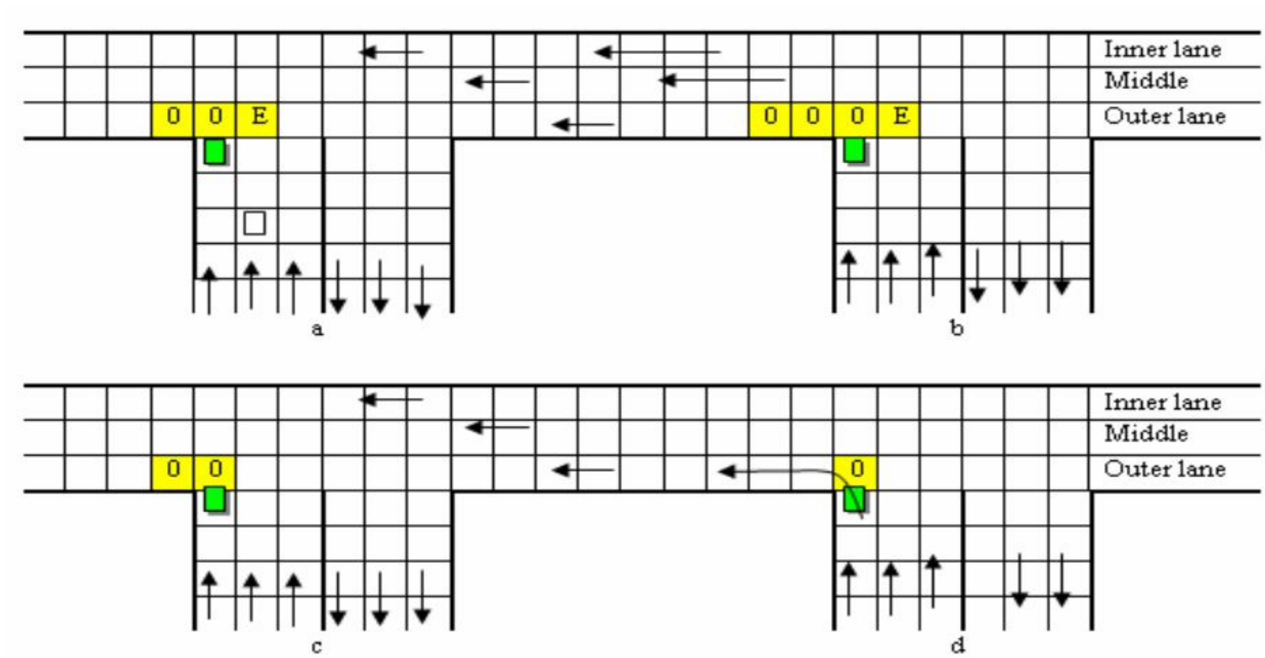

Figure 4.7: vehicle on the left lane of the entrance road with (a) rational (b) conservative (c) urgent and (d) radical driver behavior [Ruili wang 2005]

In this thesis, we use vehicles on the left, middle and right lanes of the entrances of three-lane roundabouts to show the interaction among drivers. In order to simplify the representation, the shape of the arc of a roundabout with an entrance road can be changed to resemble Fig. 4.7-4.9, which look like T-intersections. The paths of vehicles in the entrance road are shown in Fig. 4.7(d), 4.8(d) and 4.9(b), while the paths of vehicles exiting from the roundabout are shown in Fig. 4.9(c). When a vehicle on the middle or right lane of the entrance road needs to change lane from the outer lane to the middle and/or inner lane on the roundabout, it crosses two cells diagonally. Likewise, this is true for the vehicles coming from the inner lane (and/or the middle lane) to the outer lane (see the curved arrows).

In other words, when the vehicle changes lane on the roundabout, it moves ahead for one cell at the same time.

For a three-lane roundabout, the required conditions for the target vehicle (shaded) in the left lane of the entrance road in this time step are indicated by the spaces required (shaded cells) in Fig. 4.7(a)-(d), based on four different driver behaviors. Fig. 4.8 and 4.9 show entering vehicles from the middle and right lane of the entrance road of a three lane roundabout.

The requirement for each cell is indicated by 0 or E, where 0 means that the cell must be vacant and E means that the cell is either vacant or occupied by a non circulating vehicle. A non-circulating vehicle is one either just entering the roundabout from an entrance road or about to leave the roundabout in the next time step. All space requirements are

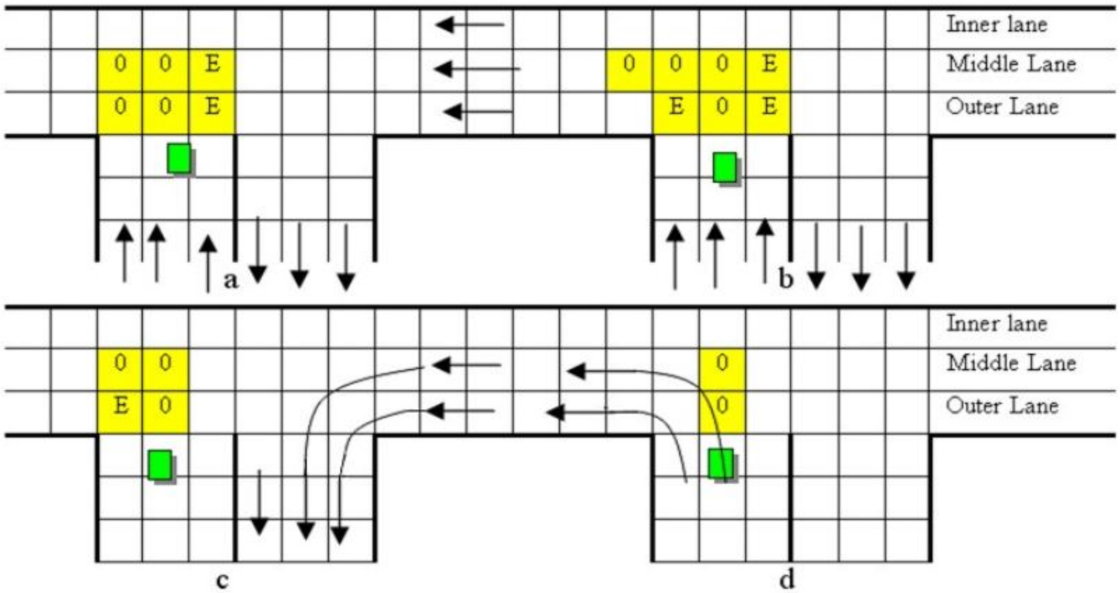

Figure 4.8: vehicle on the middle lane of the entrance road with (a) rational (b) conservative (c) urgent and (d) radical driver behavior [Ruili wang 2005]

indicated cell by cell (with the same notation, either 0 or E).

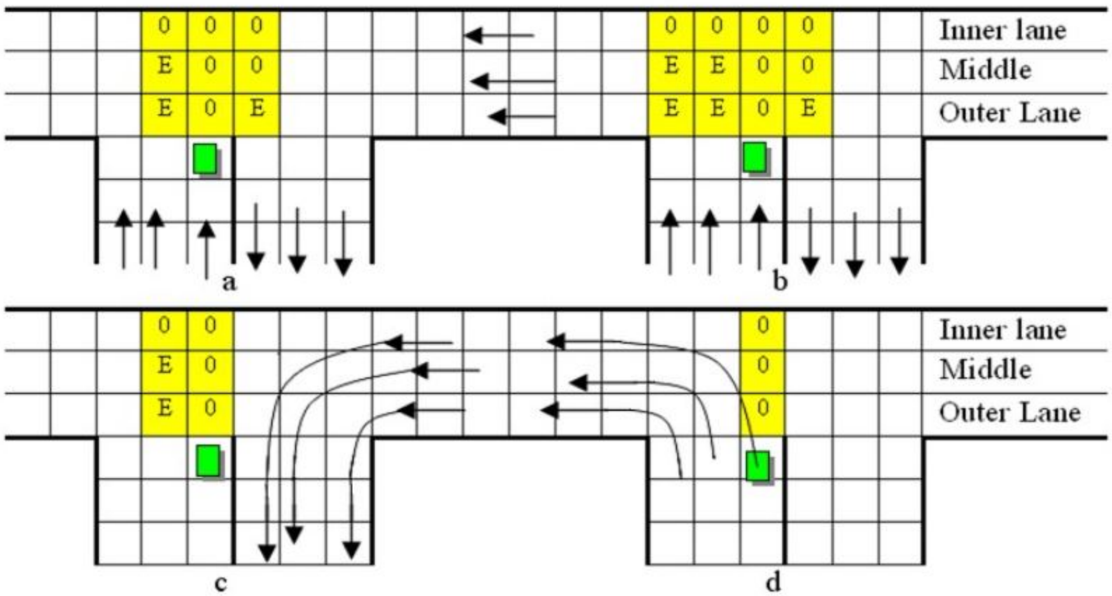

Figure 4.9: vehicle on the right lane of the entrance road with (a) rational (b) conservative (c) urgent and (d) radical driver behavior [Ruili wang 2005]

4.7 Interaction on Roundabouts

Immediately after entering a roundabout, the vehicles from the middle and right lane of the entrance roads move from the outer lane into the middle and inner lane respectively. They are assumed to move along the middle lane and inner lanes until they arrive at their destinations (exit roads). In other words, they do not change lanes except on entering and exiting.
For a three-lane roundabout, exit of the vehicles on the outer and middle lanes is expected to be free flow. Nevertheless, exit of the vehicles on the inner lane may be blocked by vehicles driving on the middle lane. The Give-Way Rate (GWR) is a probability assigned to this random result of driver interactions. The probability ranges from 0 (no driver gives way) to 1 (all drivers give way).

4.8 Exits from the Roundabout

Once a vehicle's turning direction is identified, the number of cells it traverses will be known before entering into the roundabout. Then, the vehicle enters into the roundabout after getting the appropriate gap (the required cell number) with an appropriate number of cells (the distance that it needs to travel according to its turning directions). The number of cells assigned to the vehicle is equal to the number of cells that the entered vehicle has to traverse to arrive at its destination exit.If the entered vehicle completes all the cells given to it by moving one cell at each time step according to the update rule the

vehicle exits from the roundabout.
Vehicles entered a roundabout will arrive at their destination after some time by traversing a quadrant or quadrants of the roundabout. When a single vehicle exits from the roundabout, it leaves one cell empty because in the assumption a vehicle moves a cell at a time. The cell left by an existing vehicle at time t may or may not be occupied at time t+1, but at this time the next cell must be empty because the exiting vehicle moved to the exiting road of the roundabout. At the time this is done, the next vehicle will accelerate at the next time step so that the empty cell will be occupied leaving a gap behind. The gap will be accumulated at the next arm of the roundabout which helps the waiting vehicles enter the roundabout as long as it is appropriate for the driver's behavior. Otherwise it continues to be accumulated in the same way until an entering vehicle occupies at the other arm. This is very important for the study of the traffic situation at a roundabout.

Chapter 5

Result and Discussion

5.1 Assumption

In the developing flowchart for simulation of three lane roundabout with four arms and three entrance lane is considered with the following assumptions:

i. The vehicle entered to the roundabout on the outer lane turn right or go straight through the roundabout.

ii. The vehicle entered to the roundabout on the inner lane turn left or make a u-turn.

iii. The vehicle entered to the roundabout on the middle lane turn right or go straight through the round about.

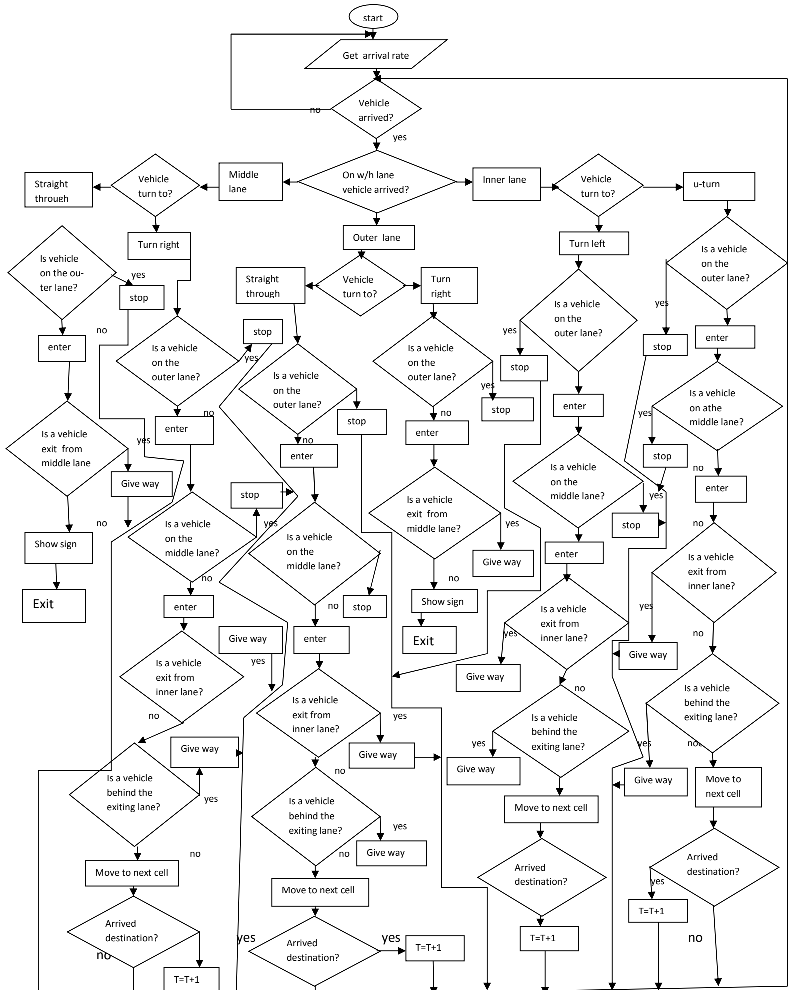

Figure 5.1: Flow chart program used for the simulation of three lane roundabout

5.2 Discussion

In this study, we developed flowchart to be used for the simulation of three lane roundabout using cellular automata model. Vehicles arrived at entrance road of the roundabout can enter to the roundabout either on the outer lane, middle lane or inner lane of the entry road according to the lane pre-allocated for it. The vehicle arrived must wait until it get the appropriate gap. For a three-lane roundabout, exit of the vehicles on the outer and middle lanes is assumed to be free flow.
From the flowchart, we understand that the priority rules of the vehicles flow in the circulation and the vehicles enter to the roundabout. The vehicles enter to the round about gives the priority to the vehicles on the circulating lanes and vehicles on the circulating lanes give priority to exiting vehicles. The vehicles exiting from the roundabout is show sign when they arrive their destination.

Chapter 6

Conclusion

Modeling multilane roundabout is a complex activity due to drivers' behavior and interaction occurs between the vehicles. But to reduce the complexity, we have been used cellular automata models and update rule of roundabout.
Cellular automata model also lack the accuracy of the time-continuous, still have the ability to reproduce a wide range of traffic phenomena.
In this thesis, due to the simplicity of the model, the flowchart used for the simulation of three lane traffic flow on a roundabout have been developed.
This developed flowchart was also useful to reduce the violation of traffic flow and vehicle delay on a roundabout.

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