

System Dynamics Based Traffic Flow Simulation

Wenbo Xue, xuewb@yahoo.com

Chris Hudson, chris.hudson@bcuc.ac.uk

Centre for Applied Computing
Faculty of Technology
Buckinghamshire Chilterns University College
Queen Alexandra Road
High Wycombe
Bucks, HP11 2JZ
U.K

***Abstract:** This paper demonstrates the possibility of interconnecting System Dynamics methodology and traffic flow simulation. The main advantage of modelling traffic flow by using the principal of System Dynamics is to provide an easily understood method of building changeable system structures, which can lead to different traffic behaviours through a chain of causes and effects. The work develops a one-lane road section basic model and a roundabout model based on general transportation regulations, including traffic infrastructure controllers, using the System Dynamics software STELLA. Considerations of various influences from the real world are included in the models to make them work as closely as possible to reality. Based on the microscopic cell-level simulation, a macroscopic level is expected to be generated for an overall understanding of the road traffic situation. The research intends to build a flexible object-oriented platform for any road network system, to build, simulate and evaluate its specific road situations for a better transport planning and management.*

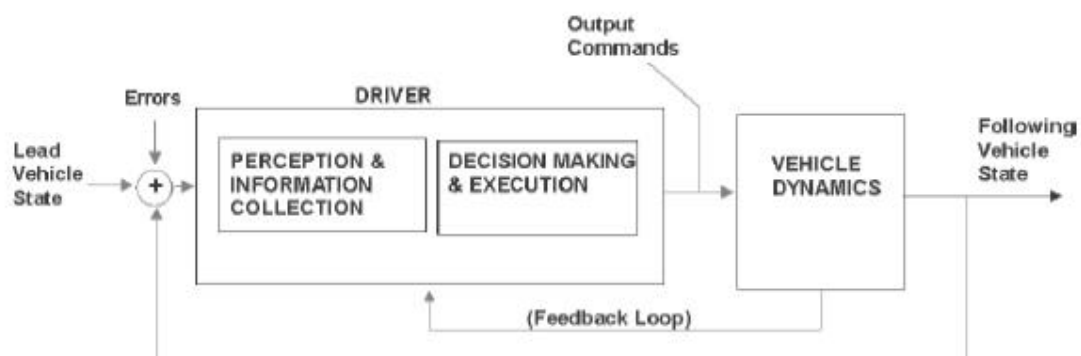
***Keywords:** traffic flow simulation, System Dynamics*

1 Introduction

It is hardly necessary to emphasize the importance of transportation in our lives. Traffic flow theories seek to describe in a precise mathematical way the interactions between the vehicles and their operators and the infrastructure. The scientific study of traffic flow had its beginnings in 1930's, and the field is developing fast based on plenty of seminal works. The studies involve car-following theory, driver behaviour,

traffic wave theory, gap acceptance, queuing theory, lane changing theory etc. etc. Most of these studies focus on the exploration of more accurate relationships between the items of interest in traffic theory (flow, speed, density, space, travel time, response etc.) by establishing mathematical equations and models. Many efforts are emphasized on exploring appropriate parameters or coefficients of the models. Therefore, the appearances of these traditional models are a set of complex mathematical formula.

Car-following concept is one of the most widely used fundamental theories nowadays. What is generally assumed in car following models is that a driver attempts to: (a) keep up with the vehicle ahead and (b) avoid collision. The relatively simple and common driving task of one vehicle following another on a straight roadway where there is no passing can be categorized in three specific subtasks: perception, decision-making and control. (See figure below)



Block Diagram of Car-Following

A more complete representation of car following includes a set of equations that would model the dynamical properties of the vehicle and roadway characteristics. However, traffic systems are characterised by a number of features that make them hard to analyse, control and optimise. That is, road systems are inherently dynamic in nature; the number of units in the system varies according to the time, and with a considerable amount of randomness. Mathematical formula expressions make the traffic theories and models not easy to understand. It is necessary to have an effective way to evaluate and understand them, computer simulation is such a useful tool needed.

Computer simulation in traffic analysis has been worked on since 1955 (Matti, 1999) and has become a widely used tool in transportation engineering with a variety of applications from scientific research to planning, training and demonstration. Traffic simulation models take many forms, each of which satisfies a specific area of application. Applications of traffic simulation are in the areas of (1) traffic control; (2) transportation planning; (3) design; and (4) research. Almost all traffic simulation models describe dynamical systems – time is always the basic independent variable. *Continuous* simulation models describe how the elements of a system change state continuously over time in response to continuous stimuli. *Discrete* simulation models represent real-world systems (that are either continuous or discrete) by asserting that their states change abruptly at points in time.

Simulation models may also be classified according to the level of detail with which they represent the system to be studied:

- *Microscopic* (high fidelity)
- *Mesosopic* (mixed fidelity)
- *Macroscopic* (low fidelity)

There are strong indications that microscopic simulation will come to dominate traffic modelling as the use of parallel computing becomes widespread (John, 2001). One fundamental interaction present in all microscopic traffic simulation models is that between a leader-follower pair of vehicles travelling in the same lane.

In terms of programming languages for computer simulation, they may be classified as *Simulation* and *General-purpose* languages. *Simulation* languages greatly ease the task of developing simulation software by incorporating many features, which compile statistics and perform queuing and other functions common to discrete simulation modelling. *General-purpose* languages may be classified as procedural (e.g. FORTRAN, PASCAL, C, BASIC), or object-oriented (e.g. SMALLTALK, C++, JAVA). Object-oriented languages are gaining prominence since they support the concept of reusable software defining objects that communicate with one another to solve a programming task.

There are dozens of traffic simulation programs for either specific purposes or common use, even in result of arising debates of identifying their advantages and

disadvantages. However, according to a review conducted by SMARTTEST in 1999, for example, less than 10 percent of the 50 simulators reviewed had been used with traffic control systems, and always using bespoke systems (Barry, 2003). This maybe partly because simulation accuracy and model feasibility are the key issues that affects a user's belief of simulation. The difficulty with any simulation system is in the dynamic nature of the complexity. Nevertheless, more mature and perfect simulation programs have been developed and employed. The well-known and widely used traffic simulation programs nowadays include PARAMICS, CORSIM, VISSIM, INTEGRATION, and TRANSIMS etc. The common features of these programs are:

a). *Microscopic simulation and traditional models based*

Most of these simulation tools model traffic at the level of individual vehicles, and are stochastic models. They are developed based on traditional traffic models containing a set of mathematical equations. For example, car-following models, gap acceptance models, and lane-change models are embedded in. Traffic flow model in PARAMICS and VISSIM is based on the psycho-physical driver behaviour model developed by Wiedemann 1974 theory. (HPCN-TTN: Traffic, 1997)

b). *Object-oriented programming language*

The power of object-oriented programming language makes it popular in use. Most software experts are keen to use Java applets to achieve their simulation results. Other frequently used programming languages are Visual Basic and C++. These are most advanced and widely used programming languages nowadays and it is easy to find plenty of language programmers. Therefore, these programming languages are chosen frequently for achieving those simulation models.

c). *Graphical User Interface (GUI)*

Almost all traffic simulation programs have user-friendly interface - graphical user interface with 2-dimensional or 3-dimensional visualisations and network building tools. Virtual Reality systems and programming tools become in common use. In PARAMICS, a graphic file (such as an aerial photograph) can be shown as the background for the animation. This visual interface to model statistics gives the user a clear representation and understanding of output.

Many of the programs are developed into more integrated software packages by a large number of experienced transport engineers, researchers and software experts, and are updating with new versions. They can model not only vehicles flow, but also many other traffic performances, such as signal setting, demand/incident/car park/public transport modelling, intelligent routing functionality, and air pollution as well as giving statistical outputs. Although no exact replicate of field observations and no satisfactory replacement models have yet been developed so far, these traffic simulation programs are still very useful tools for transportation management and planning.

2 Traffic Simulations by System Dynamics

2.1 The Methodology and Its Advantages

What System Dynamics attempts to do is to model the basic structure of a system, and thus model the behaviour it can produce, so giving a clear cause-effect relationship. The central concept is to model how all the objects in a system interact with each other through 'feedback' loops, where a change in one variable affects other variables over time, which in turn affects the original variable and so on (MIT 2000). Many different types of problems can be modelled using System Dynamics. In terms of transportation systems, traffic congestion at peak times is a worldwide phenomenon; the possible causes might be the limited road capacity, unsuitable traffic control settings, or unreasonable land use (planning) etc. Attentions have been paid recently by System Dynamics scientists on projects of exploring the solutions between transportation and economy, environment and urban planning factors at the macroscopic levels (Angelo Martino etc., 2000, Davide Fiorello etc., Burkhard Schade etc., 2002). Compared to this, there is less work focusing on microscopic level traffic simulations using System Dynamics, especially lack of research in both specific traffic performance models and generic traffic models.

In comparison with other traffic simulation programs mentioned above, the advantages of employing System Dynamics on traffic flow simulation at microscopic level could be proposed:

- Real world alike model structure

The software's feature (e.g. STELLA) already decides the lifelike shape of the model structure during model building process. Unlike other programming, which the whole model is represented almost in professional programming languages (codes); the models in STELLA are built by graphic tools that can reflect the real world 'image' (shape) directly. This gives users more intuitive perception of the model.

- Clear cause-effect relationships

Based on an established model, all objects (variables) in the model are connected with other objects (variables) via action connectors (they are red lines with arrows in STELLA). Therefore, all cause-effect relationships can be identified easily. The logical relationships between variables are easy to trace from the model layout.

- Simple mathematical equations

There is no need to transfer traditional traffic models that contain sets of complex mathematical formula like other programs do; there are relatively simple expressions between model variables. The complex relationships are decomposed (broken down) into pairs of variable-variable links, which mostly can be expressed by 'if-then-else' logical functions and simple mathematic equations.

- Changeable structure

Similar to some other traffic simulation programs, a System Dynamics based model is a kind of object-oriented form. The model structures can be easily changed, combined and adjusted according to demand, without rebuilding the model from the scratch. Moreover, running part of the model is available in the software, which provides great benefit for reorganizing the model.

- Faster running than real time

Software such as STELLA provides options for choosing simulation speed, which allows the model to run faster than real time. Statistical output is also available.

- Exportable outputs

Like many other programs, the table outputs in System Dynamics can be exported and saved as .dbf files, so that the running results can be displayed or incorporated into programs, such as Excel, GIS, or other software.

The research is to explore a new way to simulate traffic behaviours with the aid of the advantages of System Dynamics, and it is not an intention to compete or replace other traffic simulation programs. From the System Dynamics point of view, it is a new topic and more effort and development need to be done in this direction.

2.2 The Basic Model

The work starts from the microscopic behaviour of road systems. Firstly, the road network is divided into a number of one-lane road sections that is the basic component of road system. Similar to 1-dimentional Cellular Automata (CA) theories in a discrete dynamic system, the basic element of the road section is a ‘cell’, which has binary states and special movement rules for defining the new state of the cell depending on the states of its neighbouring cells.

Road section: the road section is used as the elementary component to build the model. Only one-lane road sections are considered in this work. The definition for a road section is: a length of road separated by ‘interrupters’, which could be traffic lights, pelican crossings or roundabouts at either end of the road; or separated by any branch road without lights or roundabouts. Therefore, the length of a road section can vary from short (if two ‘interrupters’ are very close) to long (if ‘interrupters’ on both ends are far away).

Cells: for specifying details on the road, as in cellular automata theory, each road section is divided into cells, i.e. the road space is represented by a number of uniform grids (see Figure 1). Each cell contains a few bits of data; at each time step the state of

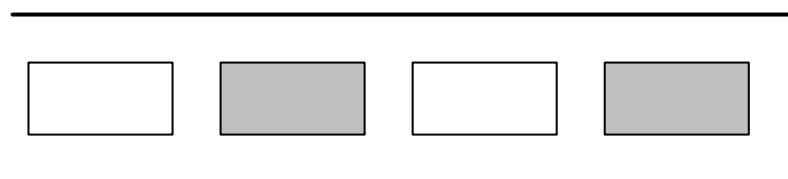


Figure 1: Decomposed Road Space

each cell is computed from that of its close neighbours. In this model, the value ‘0’ is used to represent an empty cell, and the value ‘1’ represents a vehicle in the cell. The cell size could range from 5 meters to 7.5 meters for example. To simplify the model, all vehicles are assumed as cars, and move with a constant speed. In fact, the state and size of a cell can be adjusted in sensitivity analysis.

Rules: from reality experience, a car will move forward only when there is a space in front of it, and will stop when the front space is occupied. Each cell state will be influenced by the cell ahead and at the same time affects the cell behind it. For example, if the value ‘1’ is used to represent a vehicle, and the value ‘0’ represents a gap, rules that govern the movement of vehicles can be made for the three cells (one cell and its two neighbours) that cover all movements on the road. There are eight possible combinations of the three cells, namely 000, 001, 010, 011, 100, 101, 110, and 111. According to this order (assuming vehicles flow into the road section from left to right), the centre cell will change its state to a new state at next time step. Table 1 shows these changes of the **central cell**.

Current State	Next State for central cell
0 0 0	x 0 x
0 0 1	x 0 x
0 1 0	x 0 x
0 1 1	x 1 x
1 0 0	x 1 x
1 0 1	x 1 x
1 1 0	x 0 x
1 1 1	x 1 x

Table 1: Road Section Movement Rules

Note: in this example ‘0’ indicates a space; ‘1’ indicates a car; ‘x’ represents any state of the neighbour cell.

Hypotheses:

- In the basic model example, a six-cell road section is implemented, which indicates that there could be six cars in the road at most. The incoming car will enter into the last cell (the sixth position) when the cell is empty; the car in the first cell flows out when the exit condition is satisfied. The initial values in the model are set as 1, 1, 1, 1, 1, and 0 from cell one to cell six, which means except the sixth position is empty;

there are totally five cars on road at the begin of simulation. (Note: in fact, any value can be used to represent a car or a space as long as they can be identified.)

- There are two hypothetical 'interrupters' at the two ends of the road section. The road section starts with a pelican crossing, and assumes a continuous inflow. This means that when the last cell (cell 6) is empty and the pelican crossing is green for vehicle, a car will enter in cell 6 (it allows one car to flow in at each time step). A traffic light is set at the other side of the section to control the outflow.

- The simulation time is set to 15 time units, where one time unit (each time step) is set to two seconds. When the traffic light remains at red, cars will build up on the road until it is at full capacity (all cells are full). The more dynamic and considerable situation is when traffic light changes from red to green. Therefore, in this simulation example, the traffic light is set from red to green for ten time units, and turns back to red again for four time units. The model uses the value '1' to represent red light; and the value '0' to represent green light.

The Flexibility: All of the above hypotheses are replaceable; which gives the model a wide adaptability to fit different kinds of scenarios in the real world. This includes extending the road section by adding more cells, re-inputting initial cell values for new situations, changing pelican crossing or traffic light initial settings. Another advantage is the ability to replace the traffic lights by pelican crossings or roundabouts, vice versa. The road network re-planning becomes possible on the screen. Where there is traffic congestion, the effect of changes in traffic light systems can be evaluated and the better alternatives could be made out.

According to the movement rules and above hypotheses, the basic model is built in the System Dynamics environment using the STELLA software as shown in Figure 2. The output of the model shown in Figure 2 is displayed in Table 2:

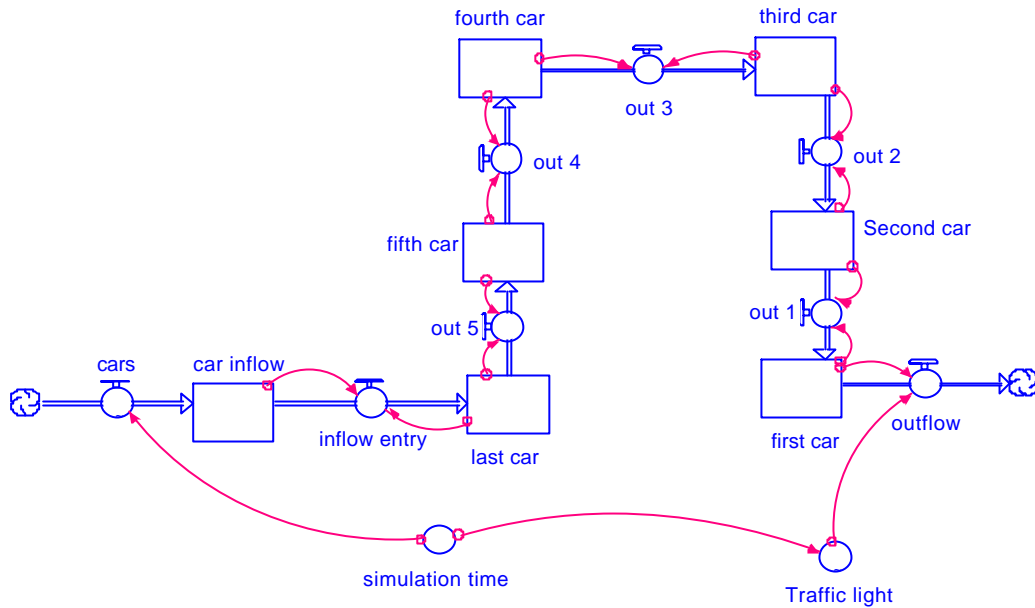


Figure 2: The Basic Model

Time	Entry	6th cell	5th cell	4th cell	3rd cell	2nd cell	1st cell	Out flow	Traffic light
1	1	0	1	1	1	1	1	0	1
2	0	1	1	1	1	1	1	1	0
3	0	1	1	1	1	1	0	0	0
4	0	1	1	1	1	0	1	1	0
5	0	1	1	1	0	1	0	0	0
6	0	1	1	0	1	0	1	1	0
7	0	1	0	1	0	1	0	0	0
8	1	0	1	0	1	0	1	1	0
9	0	1	0	1	0	1	0	0	0
10	1	0	1	0	1	0	1	1	0
11	0	1	0	1	0	1	0	0	0
12	1	0	1	0	1	0	1	0	1
13	0	1	0	1	0	1	1	0	1
14	1	0	1	0	1	1	1	0	1
Final		1	0	1	1	1	1		1

Table 2: Running Result of Basic Model

Note: '0' represents a space; '1' represents a car; in traffic light column, '1' represents red light; '0' represents green light

In table 2, at time step 1 when the exit traffic light is red, five cars build up from cells 1 to 5, and there is a space in cell 6 (This allows an incoming car entering into cell 6 at time unit 2). From time 2, the traffic light turns to green, allowing the car in first cell to flow out. At time step 3, the first cell becomes a space and is ready for the car in cell 2 to move in at time 4. This means that cell 2 will become a space after the car

moves into cell 1, and so on. Meanwhile, when a car in cell 6 is waiting for a space in front of it, no more inflow car can enter in the road section until time unit 8 when the cell 6 is empty again. At time step 12, the exit traffic light changes to red again. The car in the first cell is stopped. However, as cell 2 is a space, cars behind will keep filling up the spaces. The simulation result is matched closely with real world observations logically except differences existed. But the principle of the basic model is the cornerstone for building more complex network models later on.

2.3 Roundabout Model

Each car in the road follows the rule in which its movement is affected by the front cell state and at the same time influencing the car behind it. In terms of traffic light and pelican crossing, they are used to control inflow and outflow of traffic by affecting the state of the last cell or the first cell. By using of graphical function or built-ins functions, different input (scenarios) can be simulated. In the case of a roundabout, vehicle's moving rule for the first cell car is completely different, especially when there are more than two road sections joining together. Therefore, the intersection situation at a roundabout is more complex than road section with traffic light or pelican crossing.

Take the example of a three-road section roundabout, forming a 'T' shape intersection as shown in Figure 3. Each road section is developed on the basic model example described above.

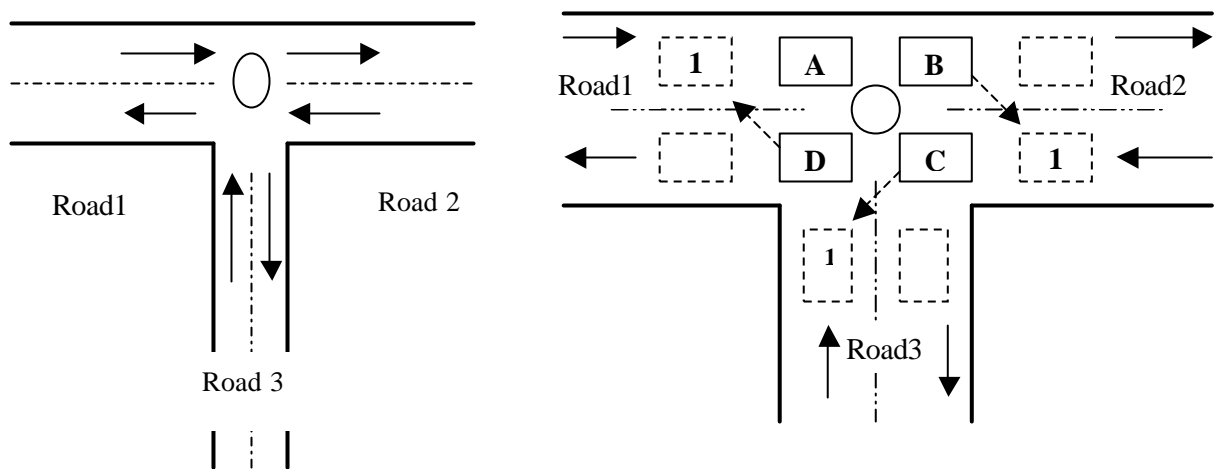


Figure 3 Roundabout Moving Rules

Roundabout Rules: One big difference with the basic model in a roundabout situation is the movement rule (right hand side rule in UK). In the roundabout case shown in Figure 3, the roundabout space is divided into cells similar to road space, e.g. A, B, C, and D; a bigger roundabout needs more cells.

- For the vehicle in cell 1 on Road 1, when there is no right hand side vehicle in cell D, the vehicle on Road 1 will flow into the roundabout cell A (if it is empty); otherwise, it must wait until the condition is satisfied.
- For the vehicle in the first cell on Road 3, its movement is decided by both cell C and D as well.
- For the vehicle in cell 1 coming from Road 2, its movement is affected by states of cell B and C.
- Each road will face at least two directions after entering roundabout. For Road 1: cars can drive to Road 2, or turn to Road 3 or even turning back to Road 1. Similar to other roads. Therefore, all possible movements of vehicles in the roundabout are:

Car in cell B may move to Road 2 or cell C

Car in cell C may move to Road 3 or cell D

Car in cell D may move to Road 1 or cell A

Because of these alternative ways to exit the roundabout, a figure represented different diversion is added to each car to identify the vehicles' heading direction, e.g. figure '101' indicates that the car is coming from Road 1 before entering roundabout and will turn back to Road 1 again. While '102' is coming from Road 1 and will move to Road 2 after roundabout. And '201' is coming from Road 2 moving to Road 1 etc. Therefore, each car is identified by a value and will have clearly position in the roundabout area.

Simulation Results: A roundabout model linking three road sections is displayed in Figure 4.

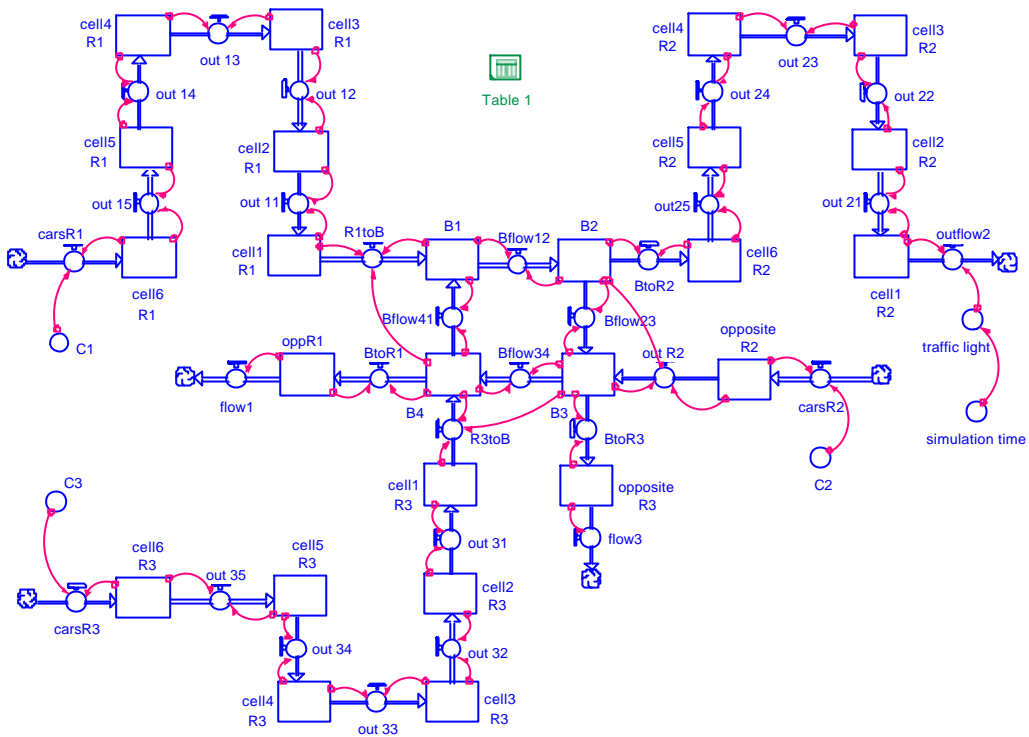


Figure 4: Roundabout Model

Table 3 shows a partial simulation result for Figure 4.

Time	Cell1 Rd1	Rb A	Rb B	Rb C	Rb D	Cell1 Rd 3	Oppo Rd2
1	102	0	0	0	0	301	0
2	0	102	0	0	301	0	201
3	103	0	102	201	0	0	0
4	0	103	0	0	201	301	201
5	102	0	103	201	0	301	0
6	0	102	103	0	201	301	201
7	103	102	0	103	0	301	201
8	103	0	102	0	0	301	201
9	0	103	0	0	301	0	201
10	102	0	103	201	0	302	0
11	0	102	103	0	201	302	201
12	103	102	0	103	0	302	201
13	103	0	102	0	0	302	201
14	0	103	0	0	302	0	201
15	103	0	103	201	302	303	0
16	103	302	103	201	0	303	201
17	103	302	103	0	201	303	201
18	103	302	0	103	0	303	201
19	103	0	302	0	0	303	201
20	0	103	0	0	303	0	201

Table 3: Part of Running Result of Roundabout Model

Note: In the table, 'Rb' indicates 'roundabout'; 'Rd 1' indicates 'Road 1'.

- At time 1, there is one car in cell 1 on Road 1 and road 3, respectively, ready to move into the roundabout.
- At time 2, there is one car in roundabout cells A and D. The car in cell A will move to cell B, and the car in cell D will turn into Road 1 according to the definition of diversion.
- At time 3, the car in cell A “jumps” into cell B, and the car in cell D turns left into Road 1. Meanwhile, there is a new car arriving in cell 1 on Road 1 and ready to move onto roundabout cell A.
- At time 4, there is a car in cell A and C (from cell B which will enter Road 3 according to diversion control), as well as a new car arriving in cell 1 on Road 3.
- At time 5, the car in cell 1 on Road 3 is still waiting because there is a car in cell C at time 4, it will move into cell D at time 6 when cell C is empty.
- At time 8, there is a car in cell A, C, and D. According to the diversion definition, the car in cell C wants to move into cell D, and the car in cell D wants to move into cell A.
- At time 10, the car in cell D can move into cell A after it is empty from time 8. Meanwhile, the car in cell C and a new car arriving in cell 1 of Road 1 will have to wait for a space.

The simulation results give outputs that fit the roundabout rules and are consistent with the experience in reality. The validity of this model is tested in the following sessions.

2.4 Model Simplification

By linking different basic model components, theoretically, any road system can be modelled. Details of each road section are displayed through cell states. However, when simulating a big area, the screen space will be rapidly filled up. Thus, when cell details of each road section is not necessary to know, while the overall road situation is more important, model can be simplified through decision process diamond function, i.e. road sections can be replaced by brief symbols to simplify the whole layout. In the former roundabout example, after model simplification, a summarized figure of the total number of vehicles (e.g. ‘car R1’) on each road section can be produced, which gives a view of macroscopic level and have more significant meaning for transport management. The simplified model of the roundabout example is shown in figure 5.

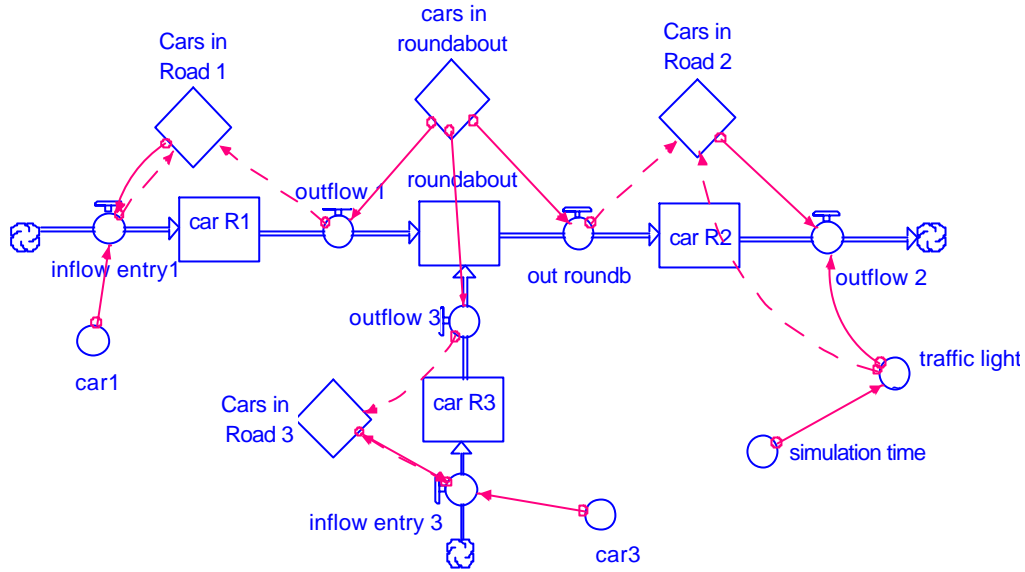


Figure 5 Simplified Model Expressions

2.5 Model Test

2.5.1 Basic Model Test

Several real world tests were did by videotaping for road sections, which covers six cells and one traffic light, one pelican crossing at the two ends of road section. After comparing results, generally speaking, most of the video record data are consistent with the simulated model while differences do observed. Table 4 shows the video behaviour for a 39 seconds' test.

The differences highlighted include:

- Some vehicles speed up when there are enough spaces in front of it. At time 2, the incoming car and the car in cell 4 at time 1 accelerate and move two cell spaces. The speed change is not considered in the basic model at this stage; this will be included in the following model development.
- Vehicles decelerate when approaching 'interrupters'. In table 3 at time 12, the car in cell 2 should move into cell 1 theoretically. However, in reality, because there are pedestrians crossing the road, the car will slow down and ready to stop. This factor is not considered in the model at the moment, and will also be added in later development work.
- Vehicles accelerate gradually at the start. Similarly, when the 'interrupter' disappears, vehicles will take time to accelerate to their normal speed. Therefore,

some of the vehicles will not move into the next cell immediately, such as time 25, 27, 30, 34. The influence will pass backward accordingly.

Time	Inflow entry	Cell 6	Cell5	Cell 4	Cell 3	Cell 2	Cell 1	Pelican crossing
0	0	0	1	0	0	1	0	0
1	1	0	0	1	0	0	1	0
2	0	0	1	0	0	1	0	0
3	1	0	0	1	0	0	1	0
4	0	1	0	0	0	1	0	0
5	0	0	1	0	0	0	1	0
6	1	0	0	1	0	0	0	0
7	0	1	0	0	1	0	0	0
8	0	0	1	0	0	1	0	0
9	1	0	0	1	0	0	1	0
10	0	1	0	0	1	0	0	0
11	0	0	1	0	0	1	0	0
12	0	0	0	1	0	1	0	1
13	1	0	0	0	1	0	1	1
14	0	1	0	0	0	1	1	1
15	0	0	1	0	0	1	1	1
16	0	0	0	1	0	1	1	1
17	0	0	0	0	1	1	1	1
18	1	0	0	0	1	1	1	1
19	0	1	0	0	1	1	1	1
20	1	0	1	0	1	1	1	1
21	0	1	0	1	1	1	1	1
22	0	0	1	1	1	1	1	1
23	0	0	1	1	1	1	1	0
24	0	0	1	1	1	1	0	0
25	0	0	1	1	1	1	0	0
26	0	0	1	1	1	0	1	0
27	0	0	1	1	1	0	1	0
28	0	0	1	1	0	1	0	0
29	0	0	1	0	1	0	1	0
30	0	0	0	1	1	0	1	0
31	0	0	0	1	0	1	1	0
32	0	0	0	0	1	1	0	0
33	0	0	0	0	1	0	1	0
34	0	0	0	0	1	0	1	0
35	0	0	0	0	0	1	0	0
36	0	0	0	0	0	1	0	0
37	0	0	0	0	0	0	1	0
38	0	0	0	0	0	0	1	0

Table 4: Real world video records of basic road section model

Note: ‘0’ represents a gap, ‘1’ represents exactly one vehicle; in ‘pelican crossing’ column. ‘0’ represents no pedestrian, and ‘1’ represents there are pedestrians crossing the road. Vehicles move from cell 6 to cell 1, time step is one second and cell size is about 5 meters.

- Drivers’ behaviour differences. Sometimes, even when the situation is normal (no speed restrictions ahead), different drivers will make different decisions on speed changes. At times 34, 36 and 38, the same car ‘hesitates’ to move forward three times.

- To compare model outputs with real world situations, the road section needs to be divided into imaginary cells during video testing, to match the model. Therefore, human error and inaccuracy may exist in the cell division and imagination, which could affect the testing results as well.

2.5.2 Roundabout Model Test

The roundabout model has different movement rules to the basic road section model. Figure 6 shows a roundabout model where each space is divided into 8 cells. The results of a 43 seconds' video test is shown in Table 5.

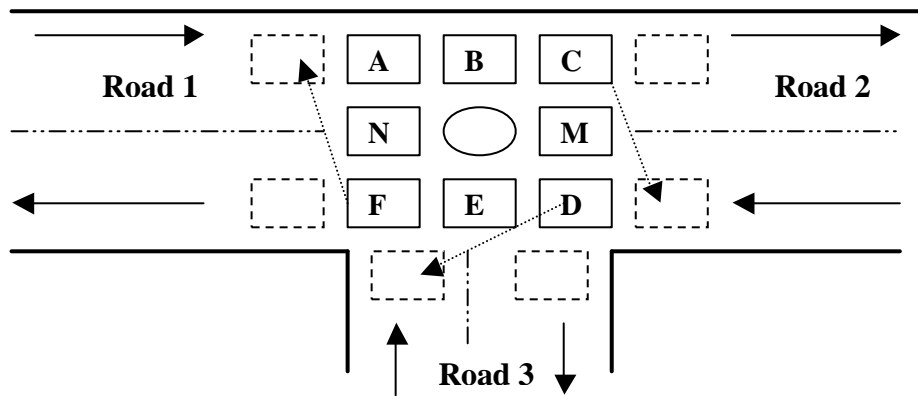


Figure 6 The testing roundabout

Most of the videotape results indicate that the roundabout rules used in the model are consistent with reality; however, differences do exist. These include:

- Many roads have two or more lanes flowing into a roundabout; these may contain more vehicles than the one-lane road situation. For instance, at time 3, there are two cars coming from Road 1 at the same time from different lanes. Also, as more cars move into the roundabout, there is less distance between them, such as at time 2. The car moves into cell B immediately just after the front one leaves. This happens sometimes and can be considered in the multiple lanes model stage.
- There is a zebra crossing on Road 2 near the roundabout on this case study, which causes vehicles in cell A and cell B to wait while people are crossing the road. In this roundabout, most of the vehicles (around 95%) coming from Road 1 and will enter Road 2 (the town centre direction) instead of turning into Road 3. Therefore, some cars flowing out of Road 2 (opposite town centre) pay less attention to the state of cell C, which means they may not wait for an empty cell at C exactly and will directly move into cell D at times 3, 34 and 37.

Time	Cell1 Rd 1	A	B	C	M	D	E	F	N	Cell1 Rd 2	Cell1 Rd 3
0	1	1	1	0	0	0	0	0	0	0	1
1	1	0	1	1	0	0	0	1	0	0	0
2	1	0	0	1	0	0	0	0	0	1	0
3	1	2	0	0	0	1	0	0	0	0	0
4	1	1	2	0	0	0	1	0	0	0	0
5	1	1	1	1	0	0	0	1	0	1	0
6	1	0	1	0	1	0	0	0	0	1	0
7	0	1	0	1	1	0	0	0	0	1	0
8	0	0	1	0	0	1	0	0	0	1	0
9	0	0	0	1	0	0	0	0	0	1	0
10	0	0	0	0	0	1	0	0	0	1	0
11	1	0	0	0	0	0	1	0	0	1	0
12	1	1	0	0	0	1	0	1	0	0	0
13	1	0	1	0	0	0	1	0	0	1	0
14	1	0	0	1	0	1	0	1	0	0	0
15	1	0	0	0	0	0	1	0	0	1	0
16	1	1	0	0	0	1	0	1	0	1	0
17	1	0	1	0	0	0	1	0	0	0	0
18	1	1	0	1	0	0	0	1	0	0	0
19	1	0	1	0	0	0	0	0	0	1	1
20	1	1	1	0	0	1	0	0	0	0	1
21	1	0	1	1	0	0	1	0	0	0	1
22	1	0	1	1	0	0	0	1	0	0	1
23	1	1	1	1	0	0	0	0	0	0	1
24	1	1	1	1	0	0	0	1	0	0	0
25	1	1	1	1	0	0	0	0	0	0	0
26	1	1	1	1	0	0	0	0	0	0	1
27	1	1	1	1	0	0	0	1	0	0	0
28	1	1	1	1	0	0	0	0	1	0	0
29	1	1	1	1	0	0	0	0	1	0	0
30	1	1	1	1	0	0	0	0	1	0	0
31	1	1	1	1	0	0	0	0	1	0	0
32	1	1	1	1	0	0	0	0	1	0	0
33	1	1	0	1	0	0	0	0	1	1	0
34	1	0	1	0	0	1	0	0	1	0	0
35	1	1	0	1	0	1	0	0	0	0	0
36	1	1	0	1	0	0	1	0	0	1	1
37	1	1	1	0	0	1	0	1	0	0	1
38	1	0	1	1	0	0	0	1	0	0	0
39	1	0	1	1	0	0	0	0	1	1	0
40	1	0	0	0	1	0	0	0	1	1	0
41	1	1	0	0	1	0	0	0	0	1	0
42	1	0	1	0	0	1	0	0	0	1	0

Table 5: Real world records of roundabout model

- Drivers' behave differently at roundabout entrances. Some drivers prefer to wait longer to ensure the right hand side vehicles are far away enough before moving into the roundabout; while some drivers prefer to enter the roundabout just in time.
- During testing, each cell's precise position is difficult to identify. At each testing time unit (each second), some vehicles may stay between two cells. All these may cause inaccurate judgement for some individual vehicles.

2.5 Model Improvement

In terms of the differences between simulation results and videotape test, model is improved by considering some of the real world situations, such as speed up, acceleration and deceleration.

- Speed up: the model adds a variable producing '0' or '1' randomly to consider and control the car needs speedup or not when there are two spaces in front of it.
- Acceleration: when the traffic light changes from red to green, the car in the first cell won't move out immediately, it will be delayed one time unit to move out after the traffic light just changes, this is added in the model.
- Deceleration: when traffic light turns from green to red, the car in the second cell will slow down to the first cell, so there is one time unit delay after the traffic light changes to red.

After considering these factors in the model, the simulation result is more close and realistic to the real world behaviours.

3 Conclusions and Discussions

3.1 Conclusions

This research shows that the System Dynamics methodology can be applied to the micro-simulation of traffic flow. It includes the individual vehicle simulation and overall traffic situation. From observations of real world phenomenon, the model produces logical and reasonable results while there are some individual differences. The most distinct advantage of using System Dynamics to build models is the ease in which features can be changed, so allowing the rapid prediction of different results. In the basic model, the length of the road section is variable by adding or reducing cells; all inputs such as cell initial values, time step, simulation time, pelican crossing and traffic lights etc. are easily adjusted. The roundabout model also has options to change.

The purpose of individual vehicle simulation on road sections is to get the overall view of road traffic (such as 'car R1' in the model simplification example, which is the total number of the cars on road 1), which represents the congestion level of the road. In the case of heavy road congestion, possible solutions can be test through adjusting road junctions (pelican crossing, traffic lights and roundabouts) by

reassigning in the model. This flexibility provides traffic planners with many potential options to optimise road system layout.

3.2 Future Work

The work described in this paper is in the first stage of using of System Dynamics methodology for traffic flow simulation. There are still many areas for further development. These include:

Case Study

Based on the above achievements, a case study for a big area including three traffic lights and one roundabout, hundreds of vehicles road sections model is being built and simulated. More attention is paid on macro level result through flow, speed with time outputs and statistical calculations. Even includes the simulation results of different transport management scenarios, for instance, traffic light adjustment, transportation infrastructure re-planning etc. More real world survey and test is necessary, and finally, a better traffic system setting for the study case is expected to find out.

Model Development

- *Traffic light model*: except the basic road section and roundabout model, another important traffic component – traffic light is indispensable for the traffic system. An intelligent traffic light model has been completed and is ready to be applied in the traffic simulation system.
- *User-friendly Interface*: the current model output is in table format; understanding the results is based on the understanding of the data and requires expert knowledge of the model. It is necessary to present this technical format in an easy to understand way, such as using a graphical interface, a virtual reality animation technology or even a 3D representation.
- *GIS Display*: for a large area network system, GIS technology can be used to display some geographical results for better understanding. For example, simulation data of flow density on each road section can be linked to a GIS database to reflect road congestion levels, by showing various thickness of road lines.

References

Advanced Traffic Analysis Centre (2003) North Dakota State University, Description of VISSIM

<http://www.atacenter.org/tst/vissim.php>

Angelo Martino etc. (2000) The ASTRA Platform For The Strategic Assessment Of European Transport Policies, Sustainability in the Third Millennium, 18th International Conference of the System Dynamics Society 2000

Barry Daniels (2003) Microsimulation – What comes next? Traffic technology international, Annual Review, pp172-177

Burkhard Schade etc. (2002) Evaluating Economic Feasibility of Environmentally Sustainable Scenarios by a Backcasting Approach with ESCOT (Economic assessment of Sustainability Policies Of Transport), 20th International Conference of the System Dynamics Society, 2002

Davide Fiorello etc. (2002) The ASTRA-Italia Model for Strategic Assessment of Transport Policies and Investments, 20th International Conference of the System Dynamics Society, 2002

HPCN-TTN: Traffic (1997) New simulation tool to support improved traffic flow planning

www.cordis.lu/esprit/src/exhib20.htm

Matti Pursula (1999) Simulation of Traffic Systems – An Overview, Journal of Geographic Information and Design Analysis, vol.3, no.1, pp1-8

MIT (2000) *System Dynamics*, MIT System Dynamics in Education Project [online], <http://sysdyn.clexchange.org/sd-intro/home.html>

John Taplin (2001) Simulation Models of Traffic Flow,

<http://www.esc.auckland.ac.nz/Organisations/ORSNZ/conf34/PDFs/Taplin.pdf>

Larry E. Owen, Yunlong Zhang, Gene McHale etc. (2000), Traffic flow simulation using CORSIM, Proceeding of the 2000 Winter simulation conference, J.A. Joines, R.R.Barton, K. Kang, and P.A.Fishwick, eds.

Overview(1998) the Los Alamos National Laboratory Public Information Office

<http://www-transims.tsasa.lanl.gov/overview.html>

Xue&Hudson etc. (2003) Modelling Transport System, the 3rd European E-government Conference, presentation, Dublin, July 2003