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OPTIMIZATION OF TRAFFIC SIGNAL LIGHT TIMING USING SIMULATION

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ABSTRACT

Traffic congestion is one of the worst problems in many countries. Traffic congestion wastes a huge portion of the national income for fuel and traffic-related environmental and socioeconomic problems. Computer simulation is a powerful tool for analyzing complex and dynamic scenarios. It provides an appealing approach to analyze repetitive processes. Simulation helps decision makers identify different possible options by analyzing enormous amounts of data. Hence, computer simulation can be used effectively to analyze traffic flow patterns and signal light timing. This paper discusses a special-purpose simulation (SPS) tool for optimize traffic signal light timing. The simulation model is capable of optimizing signal light timing at a single junction as well as an actual road network with multiple junctions. It also provides signal light timing for certain time periods according to traffic demand. Traffic engineers at the University of Moratuwa, Sri Lanka are testing the developed tool for actual applications.

1 INTRODUCTION

It is a commuter's dream: the road is thick with traffic, but green lights appear with regularity, traffic flows smoothly, and lane changing is minimal. Tailgating is rare. It sounds like a miracle, but it may be just another success story resulting from traffic signal management, one of the most cost-effective ways of keeping traffic moving smoothly and making streets safer (Public roads 2002). Traffic congestion creates multiple problems, such as air pollution, noise pollution, economic problems, and slow vehicle movements. Transportation authorities have progressively installed more flexible traffic signal systems since the first computerized system was commissioned in the early 1960's. The benefits of signal lights that have been reported in areas, include travel time, travel speed, vehicle stops, delays, fuel consumption, and emissions. Among the reported benefits that the city of Abilene experienced following benefits after installing a closed-loop signal system with hardware interconnect and modem link back to a computer. The results of the Abilene signal system upgrade are shown in Table 1.

Table 1: Results of Abilene Signal System Upgrade

Factor	Result	
Travel time	Decreased	13.8%
Travel speed	Increased	22.2%
Number of stops	Increased	0.3%
Delay	Decreased	37.1%
Fuel consumption	Decreased	5.5%
CO emissions	Decreased	12.6%
HC emissions	Decreased	9.8%

Furthermore, accidents have decreased by 6%, injuries decreased by 27%, serious injuries decreased by 100%, and left turn accidents decreased by 89% while in peak hours, peak direction speeds increased 19%, and the intersection delay decreased by 30% during the study period (Traffic signal systems 2003).

Many countries are experiencing rapid growth in the number of vehicles on their road networks, especially in highly populated urban areas. Economic development has a direct impact on transportation and vice versa. Most congested cities in third world countries and many developed cities in North America did not efficiently plan their road network in the early stages, and now it is extremely difficult to re-plan and reconstruct. These countries and cities are facing many problems when widening their roads because of the destruction of valuable commercial buildings near by roads. The only short- and medium-term practical solution may be the use of existing road networks with new technology. The cheapest solution is the construction of roundabouts at junctions. But roundabouts are suitable only for low-traffic-flow densities. Another cheap and effective solution is traffic signal lights. Signal lights can effectively handle fairly high densities of traffic flow, but the efficiency of traffic movements depend on the signal light timing. However, it is necessary to conduct long-term, full-time traffic surveys to calculate optimum signal light timing. Actually, traffic surveys are very difficult and tedious because of the urgency and rapid fluctuations of traffic.

Simulation is a powerful technique for supporting the decision-making process (AbouRizk and Mohamed 2000). Kamarajugadda and Byungkyu (2003) developed a stochastic traffic signal light timing optimization model to consider the day-to-day stochastic variability in the delay during the optimization process. The purpose of this research was to estimate variability in delay at signalized intersections and incorporate the variability in the optimization process. Hoar, Penner, and Jacob (2002) developed a "swarm-based" traffic simulation system that it considered the interactions among individual drivers through the dropping and sniffing of pheromones on a two-dimensional map. The simulation model basically used artificial intelligence to analyze traffic volumes. Hoar, Penner, and Jacob (2002) considered cars as ants and modeled the actual situation. Diaz, Vazquez and Wainer (2003) developed a simulation model with cell-DEVS, and the high level specifications are translated into cellular models that execute those specifications to describe path selections and vehicle routing in the city. There are several other simulation models developed by researchers that use different simulation techniques and procedures.

The simulation tool presented in this paper was developed by considering the road network in a third- world country. However, the simulation tool can be applied to any type of road network with few modifications. The special purpose simulation template was created using Simphony 1.05 SPS (Special Purpose Simulation). The concept of the modeling element is the heart of special purpose simulation. The modeling element is an encapsulated model construction block, which contains information on what this block looks like, what resources it contains, the simulation model, and so on. Customization of a given behaviour is supported with the concept of an event. An event is something that is triggered by Simphony to inform certain changes in the model. (Simphony 2000).

This simulation tool allows the end user (traffic engineer) to draw a road network within the Simphony window without any knowledge of simulation. It is "user friendly" software, and no computer simulation knowledge is required to model and activate the tool. It helps to visualise the actual city network and the results can be obtained by "clicking" on individual roads and junctions elements. The end user could analyse many outputs based on simulation results, numerically or graphically.

2 SIGNAL LIGHT TIMING PROCESS

The objective of installing traffic signals is to control the process of sharing the right of way by separating conflicting movements in time. Traffic signals are reported to have been used in Westminster, London as early as 1868. The first three colour light (manually operated) signals were installed in 1918 in New York. Vehicle actuated signals were introduced in the 1930's. Trends of traffic signal technology have changed over time (Bandara 2002). Traffic signal technology has undergone something of a revolution in recent years, but it is a revolution that has gone largely unnoticed by the motoring public. At the present, there are two types of traffic controllers: pre-timed and traffic actuated. Most third-world countries use the pre-timed signal light approach. Here, the signal light times change in constant time intervals. Vehicle demand over the time period is not considered. This type of traffic control is suitable for fairly constant traffic flows; however, it is very rare to find such a traffic flow in the real world.

The other approach is traffic-actuated control. This type of control is better for intersections with irregular traffic patterns; the reality. Traffic patterns completely change from morning to afternoon in many cities because of the movement of working crowd and school children. The fixed signal light timing approach is completely inefficient in such situations. Most developed countries use cameras and sophisticated electronic devices to detect vehicle demands. They use signal light time adjusting techniques that are extremely accurate. However, the best approach for third-world countries is a predetermined timing scale because of their low capital and technology. In this case, the timing data can be stored in a rewritable memory chip, which allows signal lights to function according to the predetermined timing. University of Moratuwa, Sri Lanka has performed research in this area and has implemented several signal lights working on the technique above in the City of Colombo, Sri Lanka. However, they had to predict traffic flow patterns for a relatively long period of time by using surveyed data. It is not practicable to update the timing regularly because of the long-term traffic surveys and traffic calculations needed for each single junction. Another problem was the optimization of signal light timing in a single junction may affect another junction. Traffic patterns may be completely changed because of the signal light timing changes in one particular junction. Then long-term surveys have to be done to update the timing of other junctions. But those updates may affect the previous junctions; In other words, it will be a never ending process. Hence, the best solution is the use of computer simulation to analyse traffic flow patterns.

The user can simulate road network and traffic flow by running the model for any given time and getting optimum timing for signal lights. The simulation tool adopts the traffic actuated approach for the calculations. It consistently checks the demand or number of vehicles available for a particular direction and calculates the signal light timing based on that instantaneous demand. Conversely, the simulation template adopts the technique of on time traffic signal light time adjustment, which is being used by developed countries. The user can also change the flow patterns according to future predicted flow patterns and recognize future congesting junctions.

The idea behind the four-face scheme (Figure 1) has been used to calculate the timing of three-way and four-way junctions in the template. This scheme has no vehicle conflict situations. Vehicle movements of the four-face scheme can be graphically interpreted as follows:

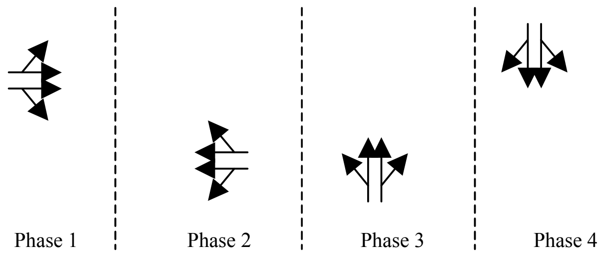

Figure 1: Four-Phase Scheme (No Conflicts), (Each Arrow Represents a Vehicle Movement)

Ordinary traffic signal light calculations assume constant traffic flow for each cycle, but the simulation template is not limited by that assumption. The user can define the vehicle flow patterns as distributions. For example, hourly flow can be given as either a constant value or a stochastic value. It helps to input actual traffic flow patterns in a more realistic way.

There are hundreds of traffic simulation models that analyse the signal light timing of single junctions. These models experienced the multiple junctions integration problem as discussed above. Most of available multi junction models use single numbers for traffic flow patterns, which is not the actual situation. Developed simulation template overcome both of these barriers.

3 LOGIC BEHIND THE SIMULATION

Vehicles reach a junction from different directions. A junction is the point where vehicles from several roads meet each other. The purpose of signal lights is to minimise traffic congestion in a junction and allow the traffic to flow as smoothly as possible. The main factor that affects a smooth traffic flow is signal light timing. Signal light timing depends on the demand of vehicles in each direction and the demand for each turn. In manual calculations, the average value of each direction flow is taken as the traffic flow.

The simulation tool calculates the timing of a junction by referring to vehicle demand in each and every direction. It is possible to simulate a road network using assumed possible values or actual traffic flow data. In an assumed case, the user can simulate the worst possibilities and most likely possibilities according to present or future traffic demand. The simulation model is not limited to taking the average value of traffic demand to a particular approach. It takes instantaneous traffic demands for timing calculations and allows the user to define the cycle time and cycle checking time. The tool assumes the initial green time for each direction is the same. However, after the first few cycles, it starts to change the timing according to vehicle demand. Thereafter, the vehicles (entities) in simulation will be moved with the new timing. The same procedure will be practiced throughout the simulation process, and the user can define the total simulation time period.

Outputs of simulation are optimum green times for each direction of a junction. Green time will be calculated with respect to the actual time periods of the day. It will help the user to observe the changes in signal light timing throughout the day. Simulation can be run for any time period and can simulate the same time period for any number of times. This advantage in simulation increases the reliability of results**.**

4 STRUCTURE OF THE SIMULATION TEMPLATE

The signal light timing simulation template is a special purpose simulation tool designed to optimize the signal light timing of three-way and four-way junctions. The template has ten modeling elements. These modeling elements are the four-way junction, four types of three-way junctions, two types of roads, vehicle generation, vehicle destroy, and global. The elements are positioned on two layers of the working template. It is shown diagrammatically in Figure 2.

The parent element has been developed using Simphony 1.05 coding language. It allows the user to input common data which are applicable to all elements at the child level. These are amber time, red amber time, starting delay, and all red time. The user can change the values of the elements in Figure 2 according to the actual situation. This feature generalizes the use of the template in any road network in any area.

Child level comprises junctions, roads, vehicle generation, and vehicle destroy elements. Three-way and four-way junctions require the user's inputs to model actual situation. Furthermore, user can define the cycle checking time for each and every junction. Junction elements will calculate the signal light timing by running the program for the defined time duration. The running time can be decided by referring to traffic flow variations in a given area. Cycle checking time is the measure of expected accuracy in signal light timing. Four-way junctions have the same inputs as three-way except with an additional set of inputs for a fourth road (Figure 3). The graphical representation of these elements helps the user to visualize and input data appropriately. Main outputs of the simulation are the graphs of green signal light timing for each junction element. The user can analyse the graphs for the following three types of situations:

1. Select the optimum green signal light timing for a junction for similar pattern (steady) flow.
2. Select the green signal light timing for a certain time period with different flow patterns.
3. Compare graphs with each other to identify the infrastructure changes necessary for junctions according to the high or low green times. (e.g. construct more turning lanes).

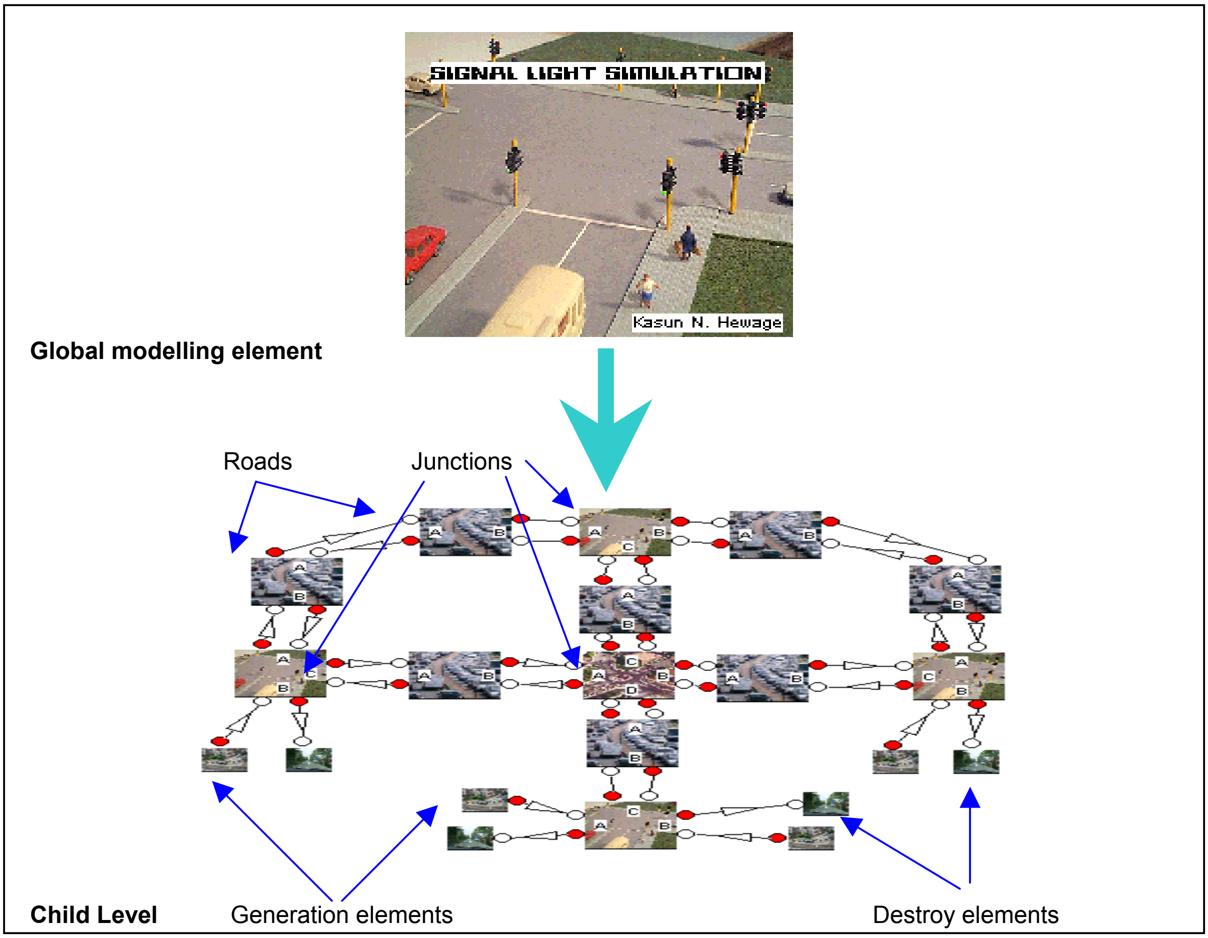

Figure 2: Sample Layout of Elements

Parameter	Value
Cycle checking time (min)	2.00
Signal Light Cycle time (Sec)	60.00
Vehicle turning time	Uniform (1.00,1.50)
Percentage of vehicles from A to B	60.00
Percentage of vehicles from A to C	40.00
Number of lanes from A to B	1.00
Number of lanes from A to C	1.00
Percentage of vehicles from B to A	60.00
Percentage of vehicles from B to C	40.00
Number of lanes from B to A	1.00
Number of lanes from B to C	1.00
Percentage of vehicles from C to A	60.00
Percentage of vehicles from C to B	40.00
Number of lanes from C to A	1.00
Number of lanes from C to B	1.00

Figure 3: Inputs of Three-Way Junction Element

Other than the graphs, the software has the ability to determine road utilization, vehicle queue lengths, and vehicle waiting time. These information are available for each and every junction and approach. The tool gives the mean, first standard deviation, minimum and maximum for each output. The output window of a four way junction is in Figure 4.

Statistic	Runs	Mean	First StdDev	Global StdDev	Minimum	Maximum	Graphs
Green time of A	1	11.03	0.18	0.00	10.65	11.21	View
Green time of B	1	10.92	0.05	0.00	10.82	11.05	View
Green time of C	1	11.26	0.38	0.00	10.27	11.71	View
Green time of D	1	10.80	0.51	0.00	10.18	11.89	View
RoadAB_Utilization	1	91.97	27.18	0.00	0.00	100.00	None
RoadAB_QueueLength	1	682.66	242.53	0.00	0.00	880.00	None
RoadAB_WaitingTime	1	955.81	1264.79	0.00	0.00	3988.51	None
RoadAC_Utilization	1	69.72	45.95	0.00	0.00	100.00	None
RoadAC_QueueLength	1	82.62	31.53	0.00	0.00	134.00	None
RoadAC_WaitingTime	1	606.84	785.93	0.00	0.00	2293.11	None
RoadAD_Utilization	1	66.54	47.18	0.00	0.00	100.00	None
RoadAD_QueueLength	1	99.54	34.89	0.00	0.00	150.00	None
RoadAD_WaitingTime	1	675.65	879.58	0.00	0.00	2574.18	None
RoadBA_Utilization	1	89.94	30.08	0.00	0.00	100.00	None
RoadBA_QueueLength	1	663.54	231.92	0.00	1.00	851.00	None
RoadBA_WaitingTime	1	974.09	1286.24	0.00	0.00	4024.66	None
RoadBC_Utilization	1	68.79	46.33	0.00	0.00	100.00	None
RoadBC_QueueLength	1	131.37	48.93	0.00	0.00	183.00	None
RoadBC_WaitingTime	1	764.46	1067.27	0.00	0.00	3400.18	None

Figure 4: Outputs of Four-Way Junction

Figure 5 shows the green time variations for one direction. The flattening tendency of the later stages of the graph indicates the green time reach to an "optimum" value. As indicated in the graph, the simulation has performed for five thousand seconds with a steady flow. Better results can be obtained if the model simulates for a longer period of time.

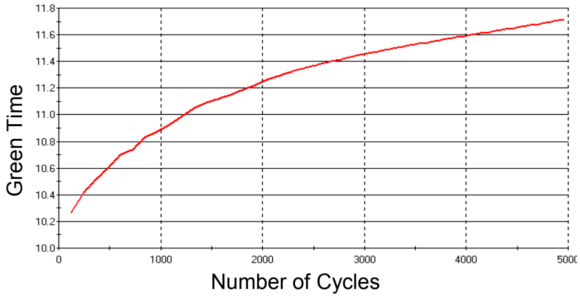

Figure 5: Green Time for a Steady Flow

However, if the flow is uneven, (i.e. with unsteady flow), the output graph can be used to identify green light timing for particular time frames. (Figure 7). In Figure 6, the X-axis represents the simulation time (real time) in seconds, and the Y-axis represents the green time in seconds.

Parameter	Value
Length of Road (km)	1.00
Average Speed (km/h)	Uniform (30.00,40.00)
Traffic generated to 'A' direction	Uniform (1000.00,1500.00)
Time of first create to 'A' direction	0.00
Traffic generating interval to 'A' direction	Uniform (1.00,2.00)
Traffic generated to 'B' direction	Uniform (1000.00,1500.00)
Time of first create to 'B' direction	0.00
Traffic generating interval to 'B' direction	Uniform (1.00,2.00)

Figure 6: Inputs for Road Element

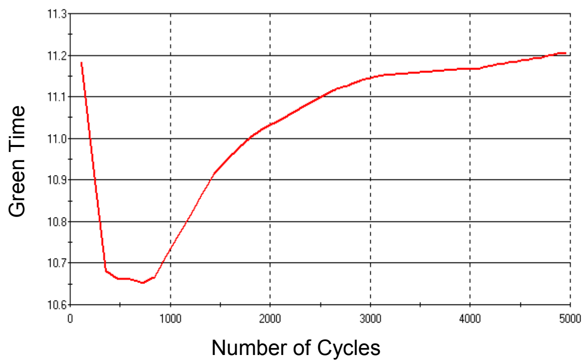

Figure 7: Green Time for an Unsteady Flow

At the start of the simulation, the user has to define a boundary for the road network. The boarder may end up with junctions or roads. To simulate the vehicle patterns of a selected network, vehicles entering and leaving the boundary should be identified. These data can be input using vehicle generation and destroy elements. Typical inputs for the road element are in Figure 6.

5 APPLICATIONS OF SIMULATION TEMPLATE AND CHALLENGES

Simulation is a relatively cheap and accurate method for analysing traffic data for signal light timing. It is suitable for countries with less capital for infrastructure development. As mentioned earlier, an efficient transportation system is the key factor for economic development. Hence, the best available option for these countries is to optimize the use of the existing road network. Some third world countries are experiencing rapid growth in construction activities in their cities, but they pay less attention to traffic generation and congestion caused by these projects such as shopping complexes, commercial centres, residential high rises, and so. The simulation tool has facilities to input future expected data to several areas of road network and decide the most suitable location for such developments. Alternatively, it is possible to locate the traffic congestion in certain areas of city caused by construction activities.

Traffic surveying is a tedious and time-consuming task. This simulation tool will reduce the number of traffic surveys in a given road network. User can input several vehicle patterns and identify signal light timing for the worst situations such as congestion from vehicle collision. The simulation tool can be used to proactively forecast such uncertainties.

6 LIMITATIONS OF THE SIMULATION TEMPLATE

The simulation tool has been developed by considering three way and four way junctions. It is not capable of handling more than four way junctions. Furthermore, the model adopts a four-phase signal light scheme for simulation. There are other schemes such as three-phase (Type A), three-phase (Type B), leading (advance) green, lagging green, etc. The model in this paper assumes that pedestrians cross the road during vehicle stop times in each direction (red signal light times).

However, it is possible to update the model to tackle any type of junction and traffic situations.

7 CONCLUSION

The simulation template could be used well in third world countries. These countries do not have resources to conduct traffic surveys and analyse data for long time periods. However, the model provides a better platform to analyse traffic data in a cost-effective and efficient manner. It needs less resources and less expertise to operate. It has the flexibility to analyse future traffic and signal light timing. The graphical representations of outputs are easier to analyse and understand.

The simulation tool also provides many statistical data such as mean, standard deviation, minimum, maximum, and so on. In addition, the output (statistics) window provides more data such as vehicle queue length, waiting time, and road utilization. The end user can simply position the required road network using the template icons. Furthermore, user has the flexibility to draw any type of road network with three-way and four-way junctions and can change the values of inputs according to the actual traffic demand of a particular intersection.

The simulation model used coding and the common template in Simphony 1.05 for elements. Use of the common template with the aid of user elements for modeling is relatively challenging. However, it is a flexible approach.

The main challenge of any computer tool is the accuracy of input data. Wrong inputs give wrong results (Garbage in - Garbage out). The template is unable to identify wrong data, and it will calculate results according to erroneous inputs. Therefore, it is important to input correct and sound data to obtain accurate results. Current testing at the University of Moratuwa, Sri Lanka will truly benefit the use of quality inputs for further validation of the model.

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REFERENCES

AbouRizk, S. and Y. Mohammed. 2000. Simphony-An integrated environment for construction simulation. *Proceedings of the 2000 winter simulation conference*, ed. Joines J.A., Barton R.R., Kang K., and Fishwick P.A., 1907-1914. Phoenix, Arizona.

Bandara, J. 2002. Traffic highway capacity design-Traffic signal design. *Traffic signal design*, University of Moratuwa, Sri Lanka.

Diaz, A., V. Vazquez and G. Wainer. 2003. Vehicle routing in cell-devs models of urban traffic [online]. Available online via `<http://www.sce.carlton.ca/faculty/wainer/papers/ESS01Routing.pdf>` [accessed on June 12, 2004]

Hoar, R., J. Penner and C. Jacob. 2002. Evolutionary Swarm Traffic: If Ant Roads Had Traffic Lights [online]. Available online via `<http://pages.cpsc.ucalgary.ca/~pennerj/SuRJE/EvolutionarySwarmTraffic.pdf>` [accessed on June 12, 2004]

Kamarajugadda, A. and P. Byungkyu. 2003. Stochastic Traffic Signal Timing Optimization. Centre for ITS implementation research. Research report number: uvacts-15-0-44 [online]. Available online at `<www.gmupolicy.net/its/pdfweb/SignalOptimization.pdf>` [accessed on June 15, 2004]

Public Roads. 2002. Managing traffic flow through signal timing [online]. Available online via `<http://www.tfhrc.gov/pubrds/janfeb02/timing.htm>` [accessed July05, 2003].

Simphony. 2000. Guide to the development of special purpose simulation templates with Simphony. University of Alberta.

Traffic Signal systems. 2003. [online]. Available online via `<http://www.its.dot.gov/tcomm/itibeedoc/tss.htm>` [accessed July 05, 2003].

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