Modeling Urban Traffic Planning through Strategic Decisions – A case from Bangalore, India

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Abstract
This paper deals with reducing the waiting times of vehicles at the traffic junctions by synchronizing the traffic signals. Strategies are suggested for betterment of the situation at different time intervals of the day, thus ensuring smooth flow of traffic. The concept of single way systems are also analyzed. The situation is simulated in Witness 2003 Simulation package using various conventions. The average waiting times are reduced by providing an optimal combination for the traffic signal timer. Different signal times are provided for different times of the day, thereby further reducing the average waiting times at specific junctions/roads according to the experienced demands.

1.0 Introduction

Bangalore is known as the IT hub of India and has been successful in putting India on the global marketing eyes by enticing many MNC's to the city. As the population of these MNC's increase, Bangalore Traffic is likely to face danger in terms of congestion on roads. These will lead to increase in the Average Waiting times at the traffic signals. All these eventually leads to increase in the commuting time and may become a cause for the rise in the accident rates.

This paper deals with simulating the traffic situation at two important junctions in Bangalore city. The traffic situation is analyzed and optimal traffic signal timings is provided that reduces the Average Waiting Times on all the roads. Further observations at the junctions revealed the presence of high demand on particular roads at these two junctions at different times of the day. These situations are also analyzed and different signal times are provided according to the time of the day, that further reduce the waiting times on the roads experiencing high demand respectively.

The junctions selected for the study are Cubbon Road and Arts and Crafts junction (Brigade Road). Shown below in Figure 1 is the pictorial representation of the arena planned for study.

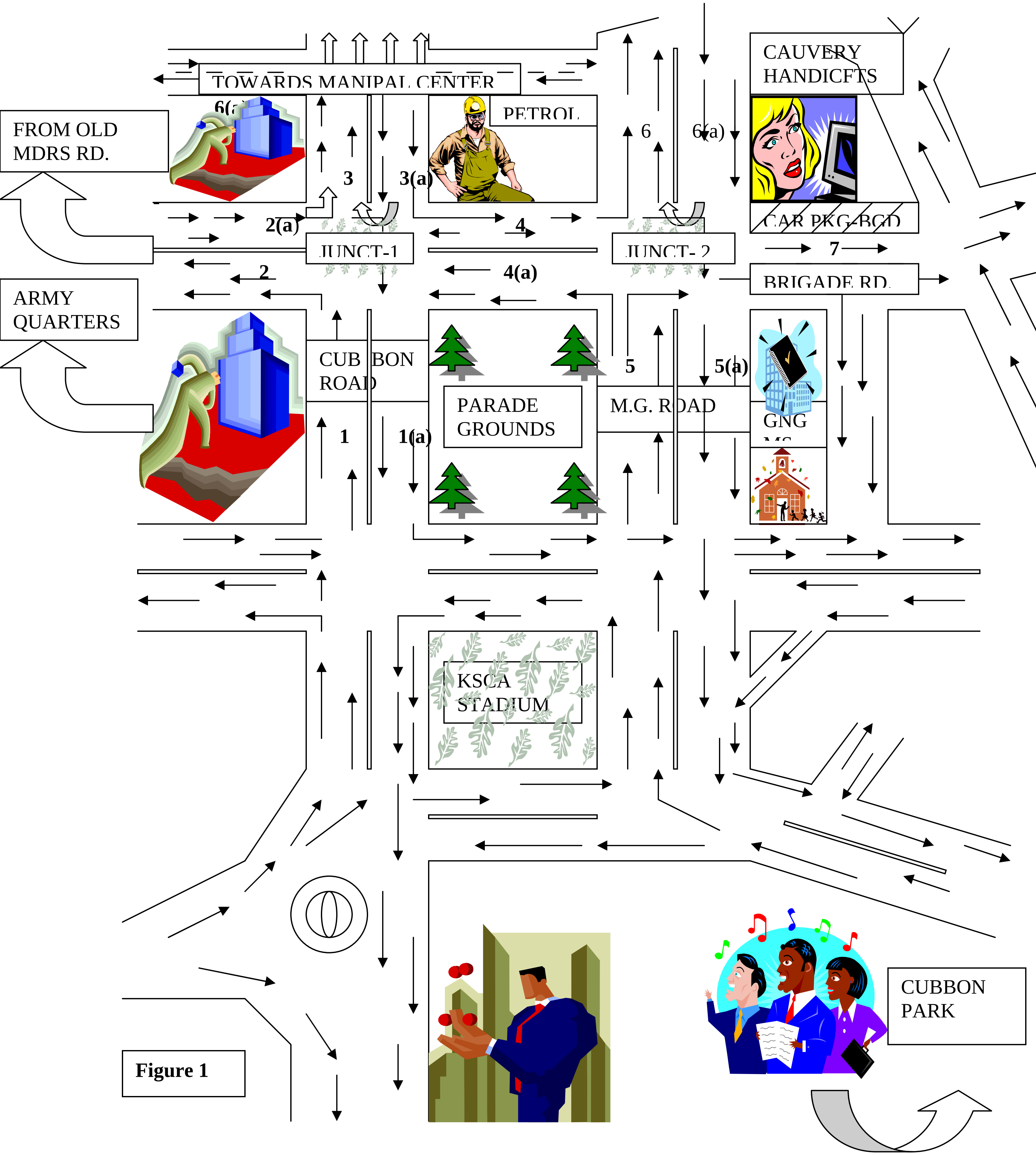
TOWARDS MANIPAL CENTER
FROM OLD MDRS RD.
PETROL
CAUVERY HANDICFTS
3
3(a)
2(a)
4
6
6(a)
JUNCT-1
JUNCT- 2
CAR PKG-BGD
7
2
4(a)
BRIGADE RD.
ARMY QUARTERS
CUB BON ROAD
5
5(a)
PARADE GROUNDS
M.G. ROAD
GNG
1
1(a)
KSCA STADIUM
CUBBON PARK

Figure 1

2.0 Problem

Our objective is to reduce the average waiting time at the Kamaraj and Brigade road junctions, by redesigning the traffic signal timer. After the optimal combination for the traffic signal times is reached, our interest would be to further reduce the average waiting times on the roads which experience high demands at different times of the day. Different combination of the signal times will have to be provided that reduce the congestion at respective times. All these is achieved by modeling & Simulation of 2 junctions.

First we concentrate on junction 1, we start from road 1 (see Figure 1), vehicles have three exit options i.e. roads 2,3,4. Vehicles moving towards road 4 get 58 seconds, and the vehicles moving towards roads 1 and 2 get an extra 50 seconds. The same 50 seconds is provided for the vehicles moving from road 3(a) to roads 4, 1 (no right turn for road 2 is allowed). Vehicles from road 2(a) have three exit options i.e. to roads 1(a), 3, 4. Vehicles have 50 seconds to move towards road 1(a) and an extra 35 seconds to move towards roads 3 and 4. This time is also utilized by the vehicles moving from road 4(a) to road 2, an extra 20 seconds is provided for the vehicles moving to road 1(a) (This has not been accounted for in the study, and has been eliminated at the modeling stage).

2.1 About Traffic Signals – A Brief Note

Traffic signals can be pre-timed or demand actuated. Pre-timed signals repeat a preset constant signal cycle. Demand actuated signals have the capability to respond to the presence of vehicles or pedestrians at the intersections. For the pre-timed signal, the time interval for each signal indication is the time cycle of fixed length and is predetermined on the basis of historic traffic patterns. The advantages of pre-timed signals include (Homburger and Kell, 1989) simplicity of electrochemical equipment that provides relatively easy service and maintenance, programmable signals under peak traffic hours to provide for better handling, providing the pre-timed signal at a lower cost than actuated installation, provision of providing positive speed control that ensures continuous traffic flow at a given speed, along a particular route.

The disadvantage is that they do not recognize or accommodate for the short-term fluctuations in traffic demand, and they may cause excessive delay to vehicles and pedestrians during the off-peak periods.

Traditional method to determine a pre-timed signal timer is based on some traffic conditions such as approach speeds, street widths, critical lane volumes and so-forth. The work sheet of timing calculations given in Homburger and Kell, (1989), presented a good example to determine a pre-timed signal timer. However, their method treats the critical lane volumes as some constant values and consequently does not take into account the stochastic properties of traffic volumes. On the other hand, waiting lines always exist in an intersection in urban areas, particularly during peak hours. Therefore, the average waiting time (AWT) of approach vehicles is one of the key quality characteristics for the timer design of a traffic signal.

The concept of traffic can be related to the popular queuing phenomenon. Queuing was recognized by the world of mathematics as an object of serious interest, when Feller introduced the birth-death process (Klienrock, 1975). While mathematical models play a vital role in analysis of queuing systems, it has been found the mathematical approach has its limitation (Matloff, 1988). If the queuing theory is applied in the timer design of a traffic signal, it is usually required to assume the Inter Arrival time of approach vehicles follows a well-known density function. However, this assumption may not be tenable; i.e. it is possible that no well density function can be found to describe the inter arrival time of approach vehicles. This situation may be easily overcome by computer simulation. With the development of digital computers, computer simulation becomes a valuable alternative tool for the analysis and study of a queuing system.

2.2 The Validation Process of a Simulation model

Khoshnevis (1994) defines systems simulation as the practice of building models to represent the existing real-world systems, or hypothetical future systems, and of experimenting with these models to find out system behavior, improve system performance, or design new systems with desirable performances. According to this definition, model building plays a very important role in system simulation. A model is created for a specific purpose, and its adequacy or validity is valuated keeping the purpose in mind. In a series of rational and empirical test of a model, if large number of agreements are found with the real-world systems, then our confidence on the model increases. Therefore, the validation process should use statistical tests to see how well the model developed predicts the particular phenomenon under study. If the model is not valid, then any conclusion drawn from the model will be of doubtful value (Law and Kelton, 1991).

The three-stage validation procedure introduced by Naylor and Finger (1967) (Van Horn, 1971) is usually employed to validate a simulation model. The first stage is to formulate a set of hypotheses from already acquired general knowledge of the system to be modeled, or from the knowledge of other similar systems that have already been modeled. The second stage is to validate these postulates empirically using statistical tests. The third stage is to investigate the degree to which the data generated by the model conform to the observed data. The last stage of validation procedure is very important and the final decision concerning the validity of the model must be based on it. An example of the application of the three-stage validation procedure is given in Chou, Liu, and Chang (1986). They studied the queuing in a post office by simulation and found that, in this particular post office, the proposed one-line queuing system was not significantly better than the current three-line queuing system. Most recently, they also conducted a study on the queuing system of a fast food restaurant by employing the three-stage validation procedure to validate the simulation model. In this project, the three-stage validation procedure will be applied to validate the simulation model of the queuing system of an intersection.

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3.0 Data Collection and Analysis

3.1 Objective:

To calculate the exit percentages from each road according to the exit options available.

3.2 Modus Operandi

The vehicles are divided into three categories, and the number of vehicles moving is collected on both the junctions during peak and off-peak hours. Analysis of the same provides us the exit percentages of each vehicle according to the exit options available.

Table 3.1 shows a portion of the format of data collection at Junction 1.

Peak Hour-Junction 1				**6.30-7.30 pm**				**Saturday 26/03/05**
				To Road 1				
From Road 3			**From Road 2**			**From Road 4**		
2 Whlrs	¾ Whlr	H/Y Vh	2 Whlrs	¾ Whlr	H/Y Vh	2 Whlrs	¾ Whlr	H/Y Vh
88	70	3	23	25	2	28	30	4
100	85	4	34	33	1	25	32	2
72	74	6	42	54	5	10	22	3
79	70	6	38	34	3	15	13	3
102	86	0	33	20	1	4	8	2

Table 3.1

2 Whlrs – Two Wheelers, ¾ Whlr – Auto Rickshaws and Four Wheelers, H/Y Vh – Buses and Trucks

3.3 Data Analysis

The peak hours was between 8.30 am to 11 am, and the off-peak hours was between 12.30 pm to 4.30 pm.

Data analysis provides the exit percentages of vehicles from each road according to the available exit options.For Ex: The number of vehicles flowing out of road 1 to all the roads is 4200, 4611, and 4244 on days 1,2, and 3 respectively. Table 4.2 indicates the exit figures for road1.

To	**Days**			**Average**	**Percentage (%)**
Road 2	Day 1	Day 2	Day 3	241	5.60
	236	262	227		
Road 3	Day 1	Day 2	Day 3	2577	60.5
	2541	2790	2372		
Road 4	Day 1	Day 2	Day 3	1438	33.9
	1424	1563	1329		

Similarly all the data is collected for all the roads and analyzed.

After the exit percentages were calculated, data revealed that the traffic intensity was on the higher side at junction 1 during the peak hours, and junction 2 had higher intensity at the off-peak hour. We first develop the model to arrive at the optimal signal times, and further optimize to give two separate combinations for both the junctions at these times.

4.0 Model Development

Model Development is performed in three stages. In the first stage, single direction flow of traffic was modeled. The second stage had traffic flowing in both ways, but under assumed traffic signal timings. The third stage modeled the deterministic situation. Variability was introduced to the model by changing the random numbers specified in the output rules of each road. Several combinations of the traffic signal timings were tried, and the optimal combination is provided at this stage. The following figure shows the optimal combination of the signal timer. This model ensures that the time spent by each vehicle at the traffic junction is minimum

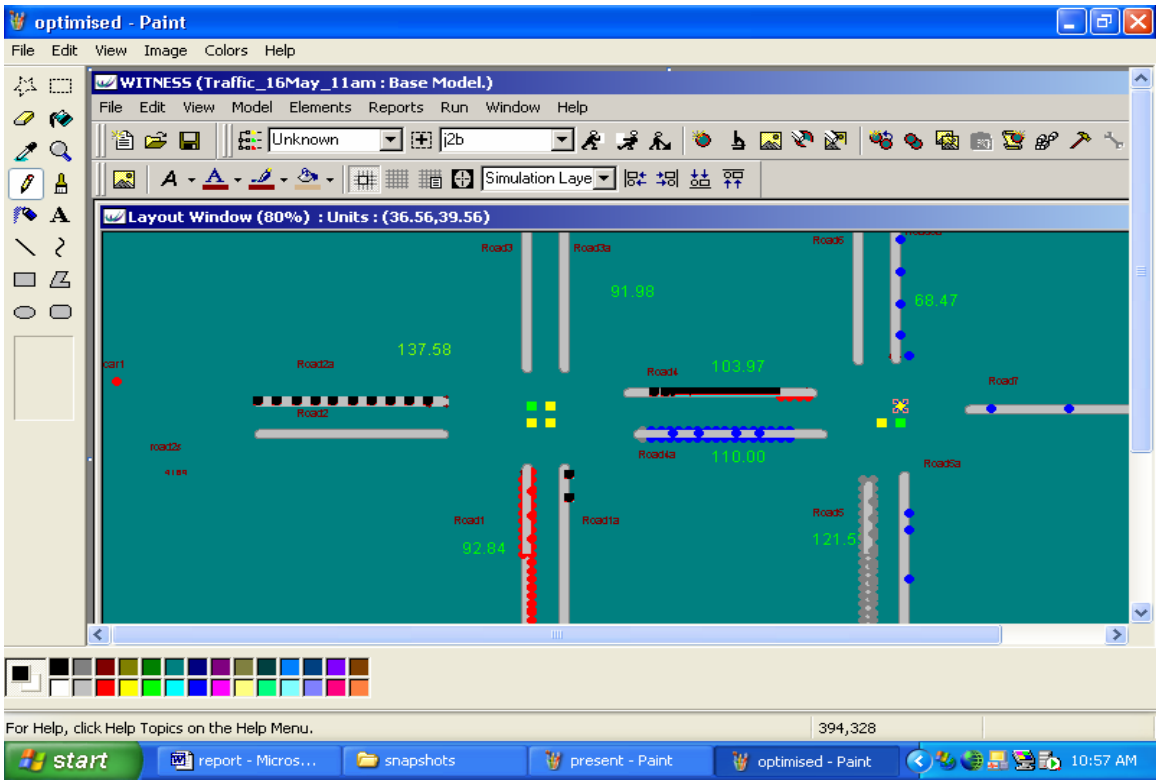


Figure 4.1

5.0 Steps towards Optimality

The following table shows the steps followed in arriving at the optimal combination of the signal times. Here Ji represents the traffic signal i represented by machines as shown in the figure above. The inter arrival time in the first trial was kept at 1 second. Changes were made to the signal cycle times, and a combination was arrived at that provides optimal solution (Table 4.1)

Signals	Present signal times (secs)	Optimized times (secs)	Present Waiting Time (secs)	Optimized Waiting Time (secs)	Percentage Reduction (%)
J1	58	38	100.08	92.84	7.23
J1(a)	50	40	152.90	137.58	10.01
J1(b)	50	40	108.76	91.98	15.42
J1(c)	35	35	138.07	103.97	24.7
J2	43	35	151.02	110.00	19.6
J2(a)	40	35	149.56	121.5	18.76
J2(b)	80	60	75.62	68.47	9.45

Table 4.1 – Optimal Signal and Average Waiting times

The above combination proved optimal for different Inter Arrival Times of 0.5 seconds, 1.5 seconds, and 2 seconds. The results are given below.

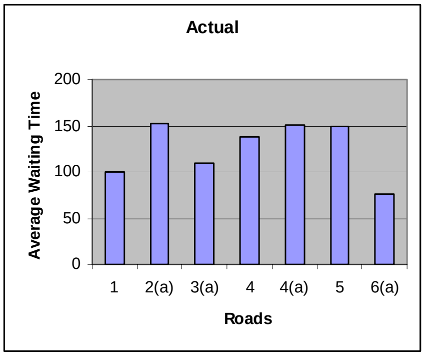
Inter Arrival Time of 0.5 secs							
Roads →	1	2(a)	3(a)	4	4(a)	5	6(a)
Actual	252.20	786.46	137.95	1015.1	157.92	157.20	86.95
Optimal	96.08	139.02	93.73	316.40	111.40	109.20	90.75

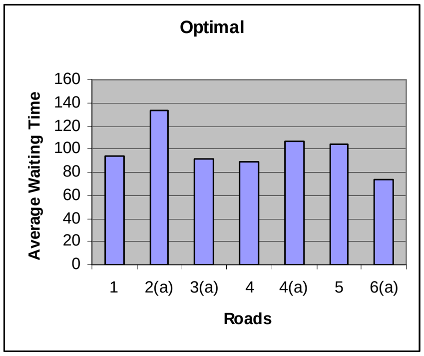
Inter Arrival Time of 1.5 secs							
Roads →	1	2(a)	3(a)	4	4(a)	5	6(a)
Actual	94.16	164.77	109.37	127.44	147.41	147.53	72.64
Optimal	90.38	140.17	90.31	83.27	108.52	100.00	70.91

Inter Arrival Time of 2 secs							
Roads →	1	2(a)	3(a)	4	4(a)	5	6(a)
Actual	99.20	155.95	106.96	125.82	146.15	145.06	72.48
Optimal	88.90	138.47	88.11	82.10	108.30	100.79	68.79

Graphical analysis has been made for individual roads which show significant reduction in the waiting times of the vehicles.

5.2 Graphical Analysis for an Inter Arrival Time of 1 sec

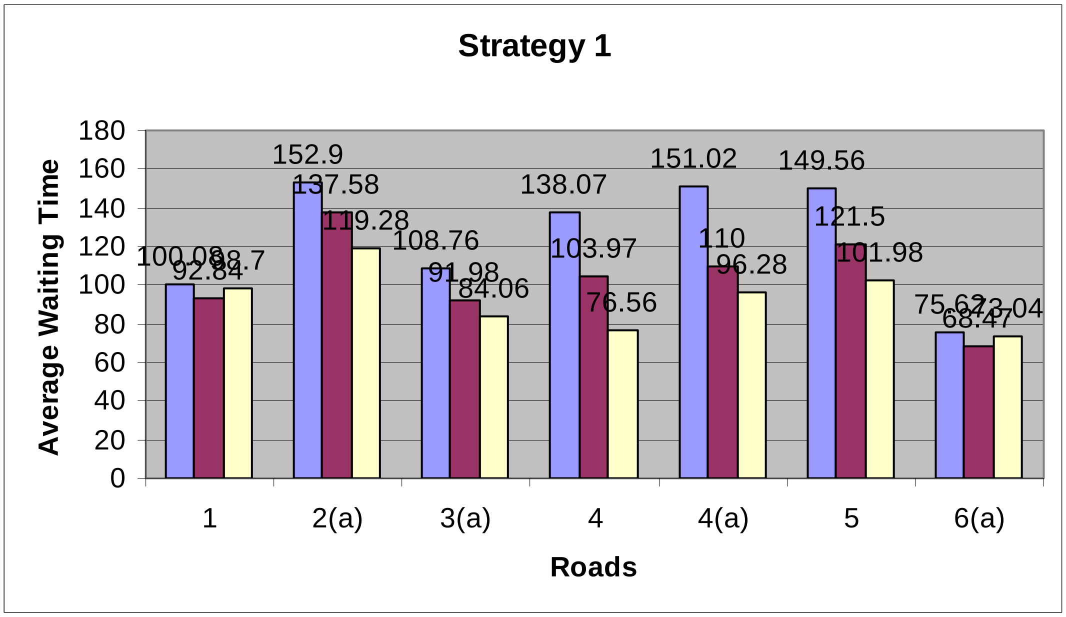




The graphical analysis reveals the decrease in the Average Waiting Times of the vehicles on every road. Any further change made to the above combination leads to increase and decrease in the Average Waiting Times on the roads.

Strategic Traffic Decisions
It was observed that there was more congestion on the road linking junction 1 and junction 2 during the off-peak hours. More than 60% of the road was filled with traffic most of the times. The enticing factor being more shopping malls located on MG road (junction 2). We proposed an alternate signal combination for this period that reduced the waiting time at most of the roads further to the optimal times, and eased the congestion. The AWTs increased marginally on a few roads which could be compromising in nature. Table 5.1 shows the reduction in the AWT on this road and other roads. Graph below gives a comparison between the average waiting times at different levels. Figure 5.2 shows the simulated environment.

Roads	AWT – Optimized (secs)	AWT–From Strategy (secs)	Percentage reduction (%)
1	92.84	98.70	-6.3
2(a)	137.58	119.28	13.3
3(a)	91.98	84.06	8.60
4	103.97	76.56	26.4
4(a)	110.00	96.28	12.5
5	121.5	101.98	16.1
6(a)	68.47	73.04	-6.6



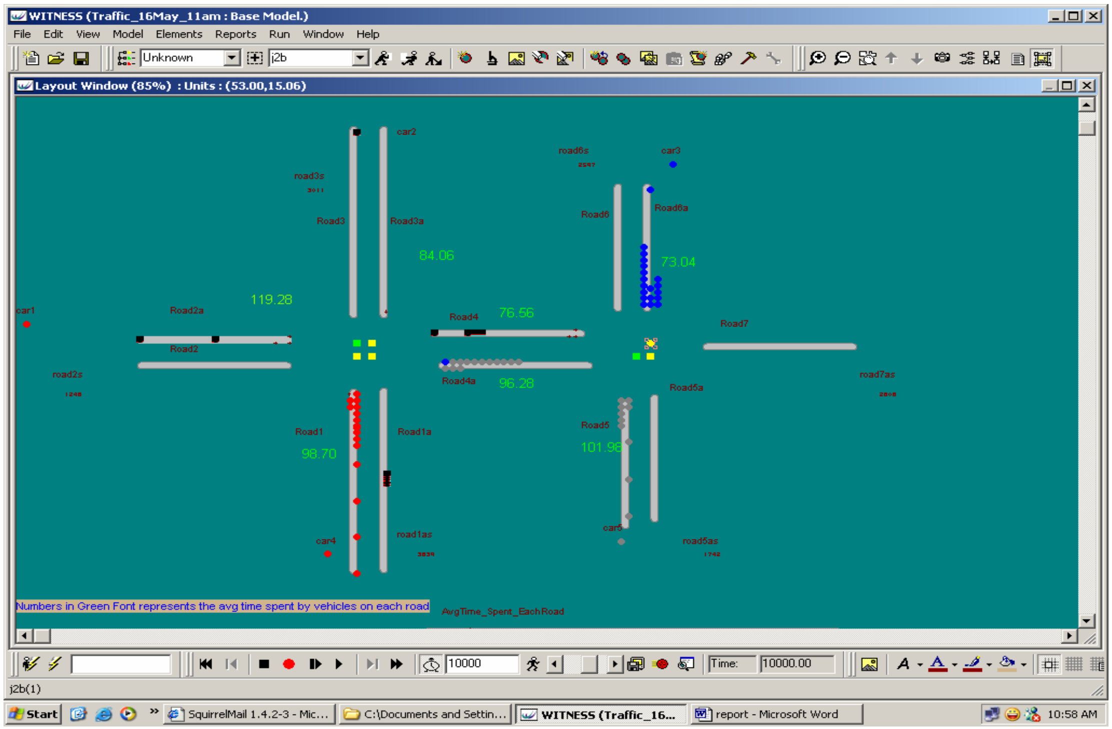
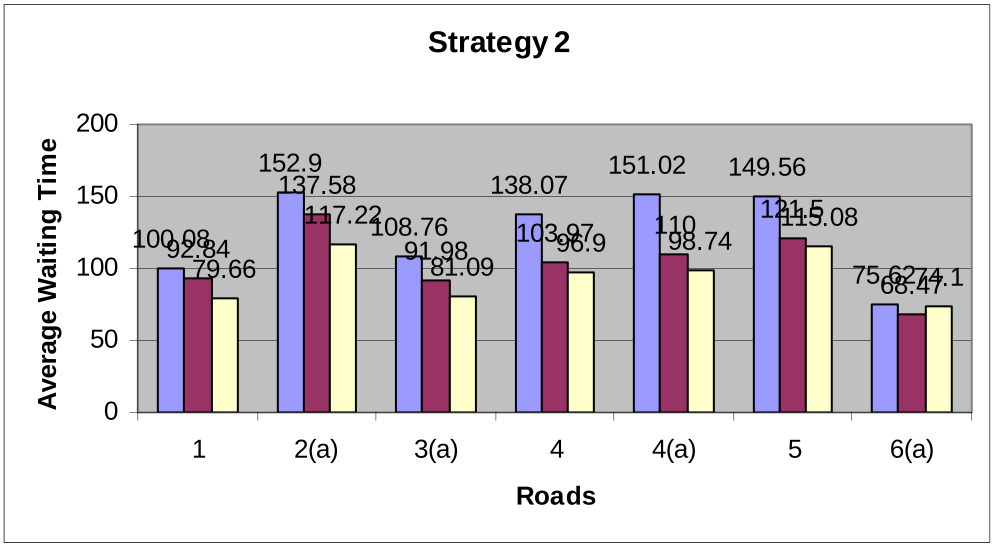


Figure 5.2

During the peak hours, the situation used to change. Junction 1 experienced more traffic as number of government and private business houses are situated around that junction. But at the same time all these vehicles were not becoming the input for junction 2, as there are many diversions from junction 1. So the traffic situation at junction 2 remained under controllable limits and the optimal signal times provided worked. We had to provide an alternate signal timing at junction 1 that reduces the AWT's for each approaching vehicle. Table 5.2 shows the reductions due to changes. Graph below gives the pictorial comparison. Figure 5.3 depicts the simulated environment.

Roads	AWT – Optimized (secs)	AWT–From Strategy (secs)	Percentage reduction (%)
1	92.84	79.66	14.19
2(a)	137.58	117.22	14.79
3(a)	91.98	81.09	11.83
4	103.97	96.90	6.80
4(a)	110.00	98.74	10.23
5	121.5	115.08	5.28
6(a)	68.47	74.10	-8.2

It is seen that AWT on road 6(a) goes up by 6 seconds (approx), which is compromising.



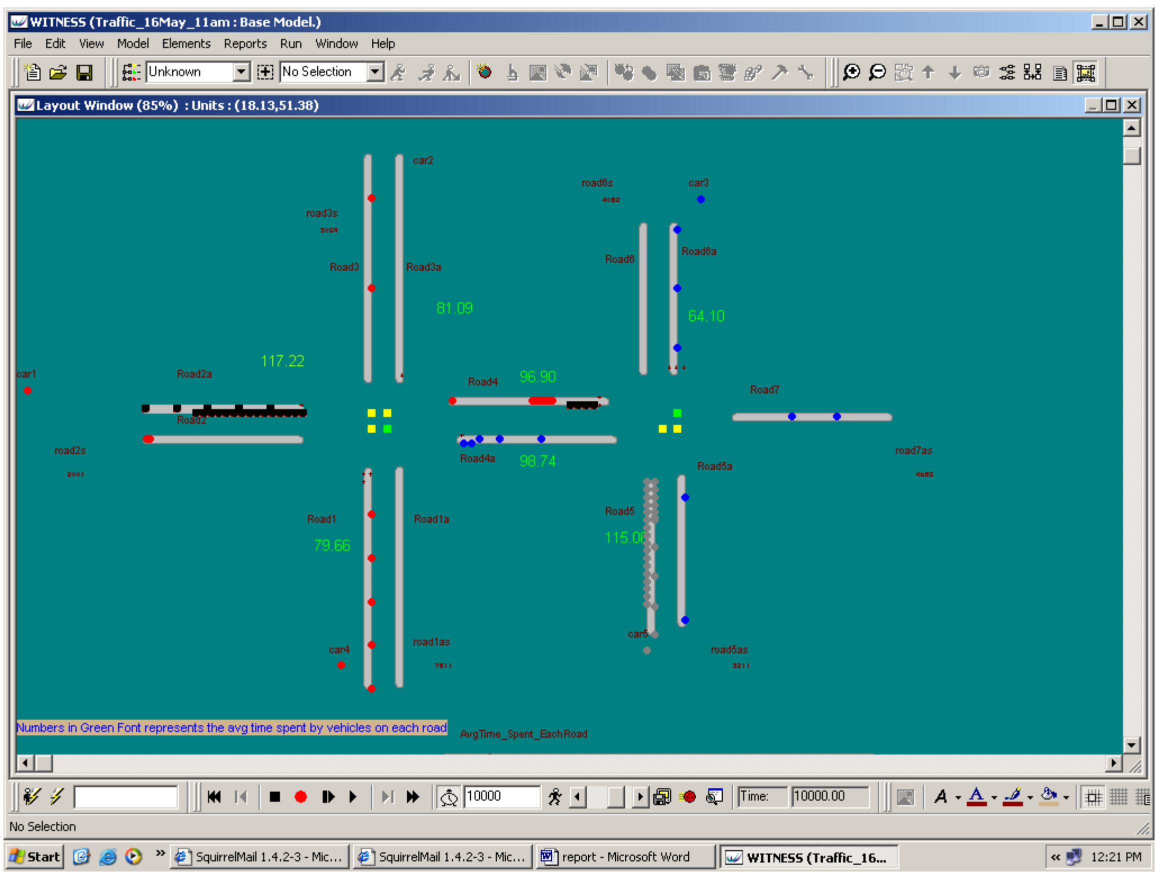


Figure 5.3

Despite adopting different strategies at different times, the resulting Average Waiting Times from the strategies remained less than those in the deterministic situation.

6.0 Conclusion

In this paper, computer simulation has been applied to design the timer of a pre-timed traffic signal. Various strategies are tried out and different signal combinations are provided at peak and the off-peak hours. The model is tested for variability such that it can apply to real world conditions.

The following Table indicates the Optimized time for the Signal Timer at any point in time at both the junctions.

From	**To**	**Deterministic (secs)**	**Optimized (secs)**	**Percentage reduction (%)**
1	2	108	78	27.8
	3	108	78	27.8
	4	58	38	34.4
2(a)	3	85	75	11.7
	4	85	75	11.7
	1(a)	50	40	20
3(a)	4	50	40	20
	1(a)	50	40	20
4(a)	2	35	35	-
	1(a)	55	35	36.3
4	5(a)	40	35	12.5
	6	120	100	16.7
	7	40	35	12.5
5	6	43	35	18.6
	4(a)	43	35	18.6
	7	43	35	18.6
6(a)	4(a)	80	60	25
	5(a)	80	60	25
	7	80	60	25

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