

Development of Traffic Signal Control Algorithms to Support Future Measure of Effectiveness (MOE)

Abhishek Chinchalpet
Muhammad Z. Hasan

Abstract- Traditional traffic control system uses sensors to make timing decisions. It is associated with the problems of maintenance, limited information, and, non real time data. Vehicle to infrastructure communication has eliminated most of the above problems. With the advent of SAE J2735 standard and IntelliDriveSM, more real time as well as vehicle specific information is available to a traffic signal controller. Two such pieces of information are vehicle occupancy and the engine capacity that are expected to be supported by the standard. The new technology enables an early and periodical detection of approaching vehicles within the communication range and therefore new possibilities for optimizing traffic signal control. Main objective of designing a new adaptive traffic signal control is to take advantage of more complete input data set. This project involves traffic signal control algorithm development utilizing those data elements in order to optimize futuristic measures of effectiveness.

I. INTRODUCTION

On many of the traffic control systems, the signal scheduling for traffic regulation works on a fixed-time basis, where a series of signal timing plans are employed based on the time of the day and day of the week. The time relationship between signals is pre-calculated; based on previously surveyed traffic conditions. Such fixed-time systems cannot be expected to cope with the modern day traffic conditions that vastly vary from time to time.

Furthermore, as traffic patterns change with the passage of time, fixed time plans become outdated, as expected. A crude and rather ineffective way to tackle this problem is to resurvey the area from time to time to calculate new signal timing plans every few years. Experience has shown this procedure to be expensive, and to require resources which are not always readily available. As a result, the development of new plans is either deferred beyond the useful life of the old plans, or improvised changes are made to the plans and timetables; either case results in sub-optimum performance.

The problems of most fixed-time systems make it clear that a more responsive approach to changing traffic conditions is needed. Adaptive traffic control technology holds great promise in our attempt to accomplish this task at hand. The term “adaptive traffic control” has been in use for decades. Initially, a system was considered to be adaptive if it could adjust splits, cycle length and/or offsets within some time period after the collection of data at a junction. This methodology is not adaptive in true sense as it is not real-time, but is a responsive process. Yet, this response is an improvement over static timing plans.

Vehicle-to-infrastructure communications is defined as the wireless exchange of operational data between vehicles

and highway infrastructure, intended to enable a wide range of safety, mobility, and environmental benefits.

II. STANDARD BEING USED

Society of Automotive Engineers (SAE) standard J2735 defines Direct Short Range Communication (DSRC) Message Set Dictionary. Transit vehicles may transmit the relative occupancy of the vehicle under this standard. Person delay data would be very useful in developing more effective timing plans, particularly with respect to transit signal priority. Under most transit signal priority systems today, buses are given priority regardless of the number of passengers. With person delay information, buses could be given higher priority if they truly reduce actual person delay, leading to a much more accurate and effective transit signal priority system.

At present, there is no performance metric for signalized intersection based on emission from the vehicles. It is actually difficult to develop algorithm based on this information as it involves measurement of emission. However, with the existing J2735 Standard it is easily possible to communicate and convey the engine details to a controller. This information could include engine capacity, type of fuel used etcetera. Utilizing these data elements, it would be possible for the traffic signal controller to estimate the emission from a particular vehicle.

This project will involve adaptive traffic control algorithm development based on these data elements of SAE J2735.

III. IMPLEMENTATION AND SIMULATION

The aim is to simulate the proposed adaptive algorithm in order to study and understand the performance enhancements that can be achieved. The proposed adaptive traffic control algorithm is implemented in C++ and a comparative study is done by having 5 different metrics as the criterion for traffic control namely,

- total occupancy of a heading
- total person delay of a heading
- average person delay of a heading
- total emission in a heading
- average emission per person in a heading

In order to come up with an implementation of the algorithm, two major functionalities that ought to be realized were identified and they are – traffic generation and traffic modulation.

It is assumed that each vehicle send the following data frames (conforming to SAE J2735 standard) to the traffic controller.

ID	Latitude	Longitude	Occupancy	Heading	Speed
----	----------	-----------	-----------	---------	-------

Figure 1: Data Frame

To this data frame, 4 new fields name Relative Distance, Waiting Time, Emission values and Person Delay are appended to form a structure which we would refer to as an “entry.”

ID	Latitude	Longitude	Occupancy	Heading	Speed	Relative Distance	Waiting Time	Person Delay	Emission Value
----	----------	-----------	-----------	---------	-------	-------------------	--------------	--------------	----------------

Figure 2: Extended data frame – “entry”

The entries are sorted based on their headings into 4 queues. Each queue is further sorted based on the relative distance values of the entries. Using the occupancy field of each entry, the total occupancy of the heading is calculated. Using the waiting time field, the total person delay of the heading is calculated. Average person delay is calculated as the ratio of the total person delay to the total occupancy. Using the emission field, the total emission of the heading is calculated. And, finally, average emission per person is calculated as the ratio of the total emission to the total occupancy.

Waiting time of each vehicle is calculated in the following manner.

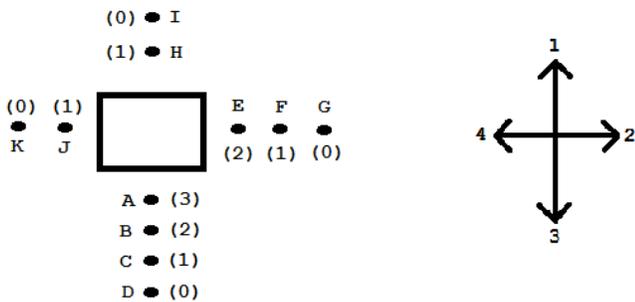


Figure 3: Initial state for wait time calculation

Figure 3 depicts the traffic scenario at a particular instant of time. The numbers within the parenthesis indicate the waiting time of the vehicles represented by a bubble with their vehicle ID written adjacently. The 4way directional diagram to the right in Figure 3 indicates the 4 headings that are being considered. Let heading 1 be given preference and that all the vehicles with heading 1 exit the network. It is assumed that the first vehicle takes 3 units of time to exit the network and every other vehicle following that takes 1 unit of time to exit the network. Figure 4 depicts the traffic scenario after the vehicles have exited the network. Finally, after the addition of new vehicles to the network, the wait times get updated as shown in Figure 5.

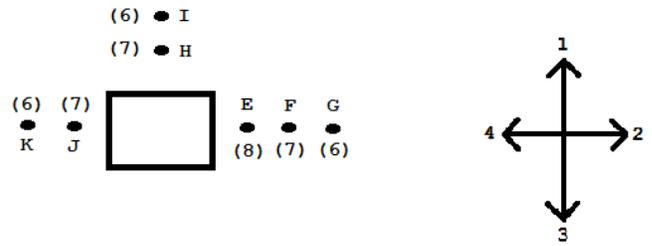


Figure 4: State after vehicles exit the traffic system

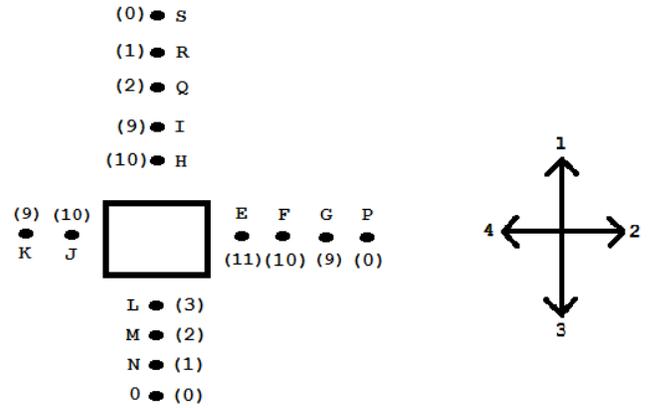


Figure 5: Final state for wait time calculation

Traffic Control Metrics

A brief description of the 5 traffic control metrics that are being considered for traffic regulation follows below.

- *Total Occupancy of a heading:* sum of occupancy values of all the entries with a particular heading.
- *Total Person delay of a heading:* sum of person delay values of all the entries with a particular heading.
- *Average Person delay of a heading:* ratio of Total Person delay to the Total Occupancy of a heading.
- *Total Emission of a heading:* sum of emission values of all the entries in a particular heading.
- *Average Emission per Person of a heading:* ratio of Total Emission to Total Occupancy of a heading.

Traffic Generation

We started with entries of 11 vehicles for the first iteration, to verify the working of the algorithm. In order to simulate a traffic pattern and to verify the working of the algorithm, random entries are generated from the second iteration onwards, which get added to the network. It is to be noted that the vehicles that have once exited the network will not enter the network again during the simulation.

Traffic Modulation

One of the five metrics namely total occupancy of a heading or total person delay of a heading or average person delay of a heading or total emission of a heading or average emission per person of a heading is chosen and a decision is taken accordingly. Based on the decision taken, vehicles in a particular heading exit the network as shown in Figure 4. Following this event, random traffic gets added to the network to continue the simulation of the traffic control algorithm i.e. a series of traffic generation cycles followed by traffic modulation cycles occur in a serial fashion.

Overview of the Simulation

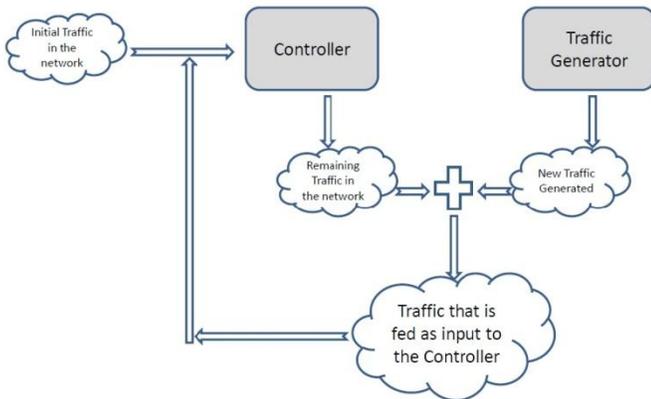


Figure 6: Overview of the simulation process

IV. RESULTS

Following tables provide a detailed analysis of various traffic control parameters for each of the traffic control metric used as the determining factor. The values in green represent the minimum.

Iteration Number	Regular Algorithm	Decision based on Total Occupancy	Decision based on Person Delay	Decision based on Average Person Delay	Decision based on Emission	Decision based on Average Emission Per Person
1	1386	335	335	335	335	376
2	359	189	212	212	189	189
3	293	108	108	108	108	129
4	453	210	210	267	210	264
5	275	161	161	161	161	202
6	515	213	216	216	216	216
7	418	124	124	124	124	124
8	363	219	219	244	244	309
9	112	18	32	32	30	32
10	147	45	63	63	63	63
11	562	231	227	227	258	258
12	196	57	69	69	69	69
13	189	81	81	81	81	123
14	343	105	105	105	126	147
15	181	52	52	52	52	87
Cumulative Value	5792	2135	2214	2296	2266	2588

Figure 7: Comparison of Cumulative Person Delay of the network

Iteration Number	Regular Algorithm	Decision based on Total Occupancy	Decision based on Person Delay	Decision based on Average Person Delay	Decision based on Emission	Decision based on Average Emission Per Person
1	6	5	5	5	5	4
2	6	4	3	3	4	4
3	5	3	3	3	3	2
4	8	4	4	4	4	3
5	8	4	4	4	4	4
6	8	4	5	5	5	5
7	7	6	6	6	6	6
8	6	3	3	3	3	4
9	5	1	1	1	3	1
10	9	3	4	4	4	4
11	7	4	4	4	3	3
12	10	4	4	4	4	4
13	12	5	5	5	5	4
14	7	3	3	3	3	3
15	7	4	4	4	4	2
Cumulative Value	111	57	58	58	60	52

Figure 8: Comparison of Average Person Delay of the network

Iteration Number	Regular Algorithm	Decision based on Total Occupancy	Decision based on Person Delay	Decision based on Average Person Delay	Decision based on Emission	Decision based on Average Emission Per Person
1	57	57	57	57	57	80
2	56	47	56	56	47	47
3	49	33	33	33	33	49
4	54	46	46	54	46	69
5	34	34	34	34	34	45
6	58	49	40	40	40	40
7	57	20	20	20	20	20
8	57	57	57	63	63	73
9	20	10	20	20	10	20
10	15	15	15	15	15	15
11	75	52	54	54	75	75
12	19	14	14	14	14	14
13	15	15	15	15	15	29
14	49	35	35	35	42	49
15	24	13	13	13	13	37
Cumulative Value	639	607	509	523	524	662

Figure 9: Comparison of Total Occupancy of the network

Iteration Number	Regular Algorithm	Decision based on Total Occupancy	Decision based on Person Delay	Decision based on Average Person Delay	Decision based on Emission	Decision based on Average Emission Per Person
1	27.2	27.2	27.2	27.2	27.2	32.5
2	29	21	29	29	21	21
3	12	9	9	9	9	12
4	22	28	28	22	28	28
5	4	4	4	4	4	9
6	38	26	26	26	26	26
7	15	7	7	7	7	7
8	18	18	18	14	14	21
9	18	9	18	18	9	18
10	10	10	8	8	8	8
11	17	18	17	17	17	17
12	11	4	4	4	4	4
13	12	12	12	12	12	14
14	17	19	19	19	13	17
15	11	3	3	3	3	14
Cumulative Value	261.2	215.2	229.2	219.2	202.5	248.5

Figure 10: Comparison of Cumulative Emission of the network

Iteration Number	Regular Algorithm	Decision based on Total Occupancy	Decision based on Person Delay	Decision based on Average Person Delay	Decision based on Emission	Decision based on Average Emission Per Person
1	0.477193	0.477193	0.477193	0.477193	0.477193	0.40625
2	0.517857	0.446809	0.517857	0.517857	0.446809	0.446809
3	0.244898	0.272727	0.272727	0.272727	0.272727	0.244898
4	0.407407	0.608696	0.608696	0.407407	0.608696	0.405797
5	0.117647	0.117647	0.117647	0.117647	0.117647	0.2
6	0.655172	0.530612	0.65	0.65	0.65	0.65
7	0.263158	0.35	0.35	0.35	0.35	0.35
8	0.315789	0.315789	0.315789	0.222222	0.222222	0.287671
9	0.9	0.9	0.9	0.9	0.9	0.9
10	0.666667	0.666667	0.533333	0.533333	0.533333	0.533333
11	0.226667	0.346154	0.314815	0.314815	0.226667	0.226667
12	0.578947	0.285714	0.285714	0.285714	0.285714	0.285714
13	0.8	0.8	0.8	0.8	0.8	0.482759
14	0.346939	0.542857	0.542857	0.542857	0.309524	0.346939
15	0.458333	0.230769	0.230769	0.230769	0.230769	0.378378
Cumulative Value	6.976674	6.891634	6.917397	6.622541	6.431301	6.845318

Figure 11: Comparison of Average Emission Per Person of the network

V. CONCLUSION

From the tables, we can conclude, fairly decisively, that

- The algorithm which bases its decision on **Total Occupancy of the Network** works best in optimizing both the *Total Occupancy of the Network* and *Cumulative Person Delay of the Network*.
- The algorithm which bases its decision on **Average Emission Per Person of the Network** works best in optimizing both the *Average Emission Per Person of the Network* and *Average Person Delay of the Network*.
- The algorithm which bases its decision on **Total Emission of the Network** works best in optimizing the *Total Emission of the Network*.

VI. ACKNOWLEDGMENT

Abhishek Chinchalpet would like to thank Dr. Muhammad Hasan for his support in the writing of this document and in providing constant and valuable inputs in the development and implementation of the proposed adaptive traffic control algorithm.

VII. REFERENCES

- [1] Brian Smith, Ramkumar Venkatarayana, Hyungjun Park, Noah Goodall, Jay Datesh, Corbin Skerrit, "IntelliDrive Traffic Signal Control Algorithms".
- [2] SAE Surface Vehicle Standard, "Dedicated Short Range Communications (DSRC) Message Set Dictionary".
- [3] Christian Priemer and Bernhard Friedrich, "A Decentralized Adaptive Traffic Signal Control Using V2I Communication Data", Proceedings of the 12th International IEEE Conference on Intelligent Transportation Systems, St. Louis, MO, USA.
- [4] Chen Cai, Yang Wang, and Glenn Geers, "Adaptive Traffic Signal Control using Vehicle-to-

Infrastructure Communication: A Technical Note", IWCTS'10, Nov 2, 2010 San Jose, CA, U.S.A.

- [5] Woong Cho, Sang In Kim, Hyun kyun Choi, Hyun Seo Oh, and Dong Yong Kwak, "Performance Evaluation of V2V/V2I Communications: The Effect of Midamble Insertion", 1st International Conference on Wireless VITAE 2009.