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OVERVIEW OF SOME RECENT RESULTS ON TRAFFIC CONTROL

by
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Abstract:

This paper presents an overview of the authors' recent research on urban traffic control. Since the technical details are very complicated and well reported elsewhere the emphasis is on placing these results in a traffic context. A fairly complete solution to the optimal control of an isolated intersection is outlined. The extension of these results to networks is sketched. Finally, some interesting areas for further research are given.

1. Introduction:

This paper is intended as an overview of our research on adaptive controls for urban traffic. Since the results described are based on some rather difficult mathematics the emphasis here will be on the ideas, their implementation and their meaning in a traffic context. The mathematical details can be found in the references.

We believe that these theoretical results are relevant to two exciting new developments in urban traffic control. First, the recent successful development of traffic adaptive network control systems by Robertson [1] and Sims [2] demonstrates that traffic adaptive systems can improve traffic flow and that very different practical implementations can be successful. Second, the various microprocessor based controllers now on the market provide great opportunity for new algorithms. We believe that our results contribute to a nascent theory of traffic adaptive control.

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One of the difficulties in developing a useful theory of traffic adaptive control is that the practical problems are both dynamic and stochastic. Most of the previously available mathematical results have been for deterministic dynamical systems or static (equilibrium) stochastic systems. Recent advances in the theory of control for stochastic dynamical systems are, we believe, crucial to developing a useful theory of traffic adaptive control.

We will show that the traffic control problem can be divided into two parts. The first is to estimate the "traffic" from the available data. We have put "traffic" in quotes to emphasize that what is really estimated is some parameters that, hopefully, quantify the mathematically vague term "traffic". Second, one designs controls that use the traffic estimates as their inputs.

Because of the way in which the control problem divides we have organized this paper along similar lines. Thus, the following two sections deal with estimation of relevant traffic parameters. Then, section four deals with control of an isolated intersection. Section five describes some heuristic results on network control. We conclude with some suggestions for further research.

2. Queue Estimation:

We believe that one of the most important parameters characterizing urban traffic is the queue at each intersection at each instant of time. We emphasize that one would like to know the size of each queue at each instant of time. Less detailed information, such as the average queue over some long period of time, can be useful for non-adaptive systems. However, averaged data is only useful for adaptive systems if the average is a good predictor of the instantaneous behavior. Since queue sizes fluctuate considerably from cycle to cycle, especially in light to moderately heavy traffic, the average queue size is not so helpful.

It turns out that good queue estimators can be developed by combining instantaneous data from a detector located around 200 feet upstream from the stop line with properly averaged volume data. Heuristically, the basic idea is as follows. Every time the detector is activated you know the queue has increased by one. The problem is to estimate the unobserved departures and any unobserved arrivals. Both of these estimates are based on some form of volumes (Volume equals number of vehicles passing a point in some time divided by that same time. The units are vehicles/hour or vehicles/second).

In computing volume it is important to realize that the volume is time-varying over a single cycle. This is well known and is, in fact, used in both TRANSYT [3] and SIGOP [4]. Our queue estimators use the two level volume model of SIGOP because this model has fewer parameters than TRANSYT and leads to good results anyway.

Approximately, the unobserved arrivals and departures are accounted for by integrating the arrival volume with a plus sign and the departure volume with a minus sign. The need for a complicated theory arises because these integrated volumes need to be combined with the counts from the detector and this could be done in an enormous number of ways. Using some results from the theory of estimation for point processes we have been able to describe the optimal way of combining the integrated volumes with detector counts [5]. Since the optimum depends on the specific model assumed, this is really a family of optimal queue estimators.

The crucial difficulty in the practical implementation of these estimators is the need to have good time-varying estimates of volume. Estimating volume is considerably easier than estimating queue size because the volume observed at a particular point in the cycle tends to vary slowly. Thus, a reasonable way to estimate volume is to break the cycle into n distinct sub-intervals (n=50 in TRANSYT, n=2 in SIGOP) and separately accumulate the detector counts in each sub-interval over several cycles. Dividing by the total accumulation time should give fairly good estimates of the time-varying volume.

3. Platoon Passage Estimation:

It is well known among traffic engineers that traffic tends to flow in recognizable platoons. Of course, the size of the platoon tends to vary with time in a random manner. This raises the questions:

(1) Is it possible to estimate, based on detector data, the time at which the end of a platoon passes?

(2) Is it useful to know when platoons pass points in the network?

We believe the answer to both questions is yes. We will say more about how to estimate platoon passage times and sizes in a moment. Here, we cite two ways in which this information could be used. One is in the incident detection problem on freeways. The second, and much more important use, is in improving the estimates of queues and volumes. Think about a detector several hundred feet downstream from a stop signal. When the signal turns green the queue at the signal starts to roll thereby changing from a queue to a platoon. At a fairly predictable time, the leading edge of this platoon crosses the detector. If you can accurately estimate the time at which the trailing edge of the platoon crosses the detector you can, from the intervening detector counts, also estimate the platoon size. These estimates can be used to

(a) check the upstream queue estimator and, if it is doing badly, improve it

(b) predict the platoon's arrival at downstream signals.

Passage of the platoon corresponds to a fairly sharp change in volume. Thus, in both TRANSYT and SIGOP platoon passage time can be used to improve the volume estimates.

Since we felt it would be a good thing to have estimates of platoon passage time we tried to find such estimates. Our results are reported in [6], [7]. Again, our estimator is optimal for the model of platoon passage that we use. Our basic model assumes that free flowing traffic satisfies a shifted exponential headway distribution while platooned traffic satisfies a lognormal headway distribution. Both of these headway distributions are fairly standard in traffic modeling. The problem is to model and then detect the transition from one headway distribution to the next.

Set up in this way the traffic problem is equivalent to a problem in stochastic processes called the point process disorder problem. Thus, we used some results on this problem to produce a solution to the problem of estimating the platoon passage time. Of course, there is often a big difference between a mathematical solution and a useable implementation of that solution. In this case, the estimator depends on four fairly standard traffic parameters. Since the estimator is insensitive to these parameter values fairly crude estimates of these parameters can be used.

The details can be found in [6]. Here, we would like to emphasize that the estimator parameters are minimum non-following headway, average non-following headway, an equivalent to average following headway and a parameter equivalent to variance in following headway.

4. Control of Isolated Intersection:

Recently, one of the authors of this paper and a student solved a version of the optimal control of a single isolated intersection [8]. The major assumptions underlying the problem formulation are as follows:

(a) The intersection is the intersection of two one-way streets.

(b) Each arm of the intersection has a single detector located about 200 feet upstream of the intersection.

(c) The performance measure is aggregate delay over a finite interval. Within the limits imposed by these assumptions, the problem is solved in great generality.

Perhaps the most important general result obtained is that the optimal control divides into two parts.

(1) Compute the optimal estimate of the queue size on each link.

(2) The optimal signal setting at each instant of time is a function of only these queue estimates and the latest detector observations.

Strictly speaking, the queue estimate needed is the predicted probability distribution of queue size where the prediction is one time step ahead. This one step ahead prediction is, in fact, the actual output of our fitter/predictor [5].

This decomposition of the control has important implications with regard to implementation. It turns out that the function whose inputs are one-step queue predictions and detector data and whose outputs are signal settings can be computed off-line. Thus, this function can be stored in the traffic control computer. Thus, the only on-line computations required are the calculations of queue estimates. These can be done in a microprocessor, as we have shown [5]. Thus, these results are quite encouraging in the sense that it appears that they can be implemented in a practical system.

However, a considerable amount of work remains to be done. One important question concerns the performance of simpler sub-optimal controllers. If one can find simpler controllers that perform nearly as well as the optimal one then it is sensible to implement the simpler controllers. Using a very crude simulation, two obvious sub-optimal controllers were compared with the optimal one. The optimal control is clearly best in very heavy traffic but all three controls appear to perform similarly in lighter traffic. These results might well change with a better traffic simulation.

Other questions that ought to be studied include refinements in the model. In particular, the actual control function was computed assuming zero lost time. The theory can account for lost time at the expense of more complicated calculations. The model used assumes perfect observation of the arrivals to the queues. This assumption could, and should, be relaxed. Finally, no parametric study has been performed. That is, what happens when (a) one arm of the intersection has much heavier traffic, (b) delay on one arm of the intersection is more heavily weighted than the other? More generally, how sensitive is the optimal control to the traffic parameters?

5. Network Control:

In principle, it would be possible to form a network model by concatenating a collection of our single intersection models. The result would be an extremely unwieldy network model. Even if such a network model could be described it is unlikely that the computations required to derive optimal estimators or controllers could be performed. However, there is a reasonable alternative approach.

This alternative can most easily be described in terms of grafting our intersection model onto one of the existing network models. For example, TRANSYT gives traffic volumes throughout the network. Once arrival and departure volumes are known on an arm of an intersection, our queue estimator can be encoded and will give optimal estimates of queue size at each instant of time. Although our optimal controller for the intersection could also be applied, it is probably unwise to do this. This is because the basic network model, TRANSYT, assumes a fixed signal timing and uses this fixed signal timing to estimate volumes throughout the network.

Thus, allowing an intersection controller to deviate significantly from its assumed timing will cause the estimated volumes to be erroneous. Since these estimated volumes are the basis for network coordination, the entire network control will be messed up. All of this is well known to traffic engineers who overcome the problem by limiting the amount by which the individual intersection controller can deviate from the nominal signal timing [1],[2].

All of this is discussed at greater length in our paper [9]. There, we propose the following network control scheme. First, design a nominal open-loop network control using, say, TRANSYT or SIGOP. Second, apply our queue estimation algorithm at most of the intersections of the network. Use the queue estimates to "correct" the nominal signal timings by a relatively small amount (say $\pm$ 10 seconds).

We do not claim any originality for this control scheme. It is similar to the Critical Intersection Control that was tried in Washington D.C. [10]. It is also similar to both SCAT [2] and SCOOT [1]. Since both SCAT and SCOOT appear to be successful there is evidence that our scheme would also work. We suspect that the Critical

Intersection Control scheme did not work well because
(a) their queue estimates were not very good,
(b) it was not tried at a sufficient number of intersections.

Our control scheme has not been tested on even a simulated network. It has been tested on several simulated arterials [9] where it performs fairly well. We are currently trying to convert our heuristic development of the control scheme into a mathematical development.

6. Suggestions for Further Research

We believe that a really useful theory of urban traffic control needs to be both dynamical and stochastic. At present, the theory of stochastic dynamical systems is undergoing rapid development. As a result, we believe that a good theory exists for the description of isolated intersections. This theory has not yet been used to design really good controllers for isolated intersections. We believe that this is an interesting area for work.

A more theoretical challenge is to extend the theory of stochastic dynamical systems to traffic networks. An approach that we are taking is to decompose the network problem into two parts that can be treated separately. The heuristic idea is that volumes change "slowly" while queues and platoons change "rapidly". Then, the fast dynamics can be ignored for purposes of studying the slow dynamics. And, the slow dynamics can be held fixed while analyzing the fast dynamics.

Lastly, we remark that this is an exciting area of research at the present time. The recent practical developments in microprocessor based controllers and in traffic adaptive algorithms proffer a challenge to the theoretician to explain them and to the practitioner to exploit them.

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References

1. Anon., "'SCOOT': A Traffic Responsive Method of Coordinating Signals", Transport and Road Research Laboratory Leaflet, LF930, Dept. of the Environment, Dept. of Transport, Crowthorne Berkshire, RG11 6AU, ENGLAND.

2. Sims, Arthur G., "The Sydney Coordinated Adaptive Traffic System", Proc. of Eng. Found. Conf. on Research Directions in Computer Control of Urban Traffic Systems, Pacific Grove California, Feb. 11-16, 1979, pp. 12-27 (Publ. by American Society of Civil Engineers.

3. Vincent, R.A., Mitchell, A.I., and D.I. Robertson, User Guide to TRANSYT version 8, TRRL Laboratory Report 888, 1980.

References Cont.

4. Anon., SIGOP Traffic Signal Optimization Program Users Manual, Peat, Marwick, Livingston & Co., N.Y. (1968).

5. Baras, John S., Levine, William S. and Tahsin L. Lin, "Discrete Time Point Processes in Urban Traffic Queue Estimation", IEEE Trans. on AC, Vol. AC-24, No.1, Feb. 1979, pp. 12-26.

6. Baras, John S., Dorsey, Arthur J., and William S. Levine, "Estimation of Traffic Platoon Structure From Headway Statistics", IEEE Trans. on AC, Vol. AC-24, No. 4, Aug. 1979, pp. 553-559.

7. Dorsey, Arthur J., Baras, John S., and William S. Levine, "On the Point Process Disorder Problem and its Applications to Urban Traffic Estimation", Proc. of the 1979 Conf. on Inf. Sci. and Systems, Johns Hopkins Univ., Baltimore, Md., March 1979, pp. 37-42.

8. Baras, John S. and Arthur J. Dorsey, "Stochastic Optimal Control of Two Partially Observed Competing Queues", (to appear) IEEE Trans. on AC, Oct. 1981, (Bellman Special Issue).

9. Baras, John S. and William S. Levine, "Some Results on Computer Control of Urban Traffic", Proc. of Second Symposium on Large Scale Systems: Theory and Applications, Toulouse, France, June 1980.

10. Tarnoff, Philip J., "The Results of FHWA Urban Traffic Control Research: an Interim Report" Traffic Engrg. Vol. 45 (1975) pp. 27-35.