Optimal Control of Isolated Traffic Signals

K.-L. Bång, Swedish Transport Research Commission, Royal Academy of Engineering Sciences

The purpose of the study was to examine the properties of conventional fixed-time (FT) and vehicle-actuated (VA) control of isolated, signalized intersections and to develop and test a self-optimizing control strategy giving special consideration to buses and pedestrians. A discussion of the possibilities to apply the developed methods for coordinated signal control was also to be included.

The project was carried out in five stages involving the following main studies:

1. Criteria for signal control,
2. Literature inventory of control strategies,
3. Development of strategies,
4. Simulation, and
5. Field tests.

An unabridged version of this paper is available elsewhere (1).

CRITERIA FOR OPTIMAL SIGNAL CONTROL

Most existing control methods lack explicit criteria for control. To develop and test new control techniques such criteria must be defined and the effectiveness of the control with respect to the criteria must be estimated.

The overall criterion can be to minimize the total community cost at a given traffic demand. From this, lower order criteria such as minimizing the sum of travel time, vehicle operating costs, and environmental costs caused by the traffic can be derived. The cost function has to include for each category of traffic the number of stops as well as delay time multiplied by appropriate unit cost figures. Operationally, the lower order criteria can be applied through a series of short-term predictions at regular intervals of resulting costs if the green light is extended or changed to another phase. Development of a control strategy along these lines is described in the following sections.

DEVELOPMENT OF A SELF-OPTIMIZING CONTROL STRATEGY

A. J. Miller (2) suggested a simple self-optimizing strategy based on the criterion of minimizing total vehicle delay. In Miller's strategy, the decision to extend a phase is made at regular intervals by the examination of a control function. This function represents the difference in vehicle-seconds of delay between the gain made by the extra vehicles that can pass the intersection during an extension and the loss of the queuing vehicles in the cross street resulting from that extension. The same basic idea has also been used to develop a control strategy within the framework of this project. The method has been named traffic optimization logic (TOL). In the TOL method, the extension of the green light is based on calculations at regular intervals h of a control function Φ. This function represents the gain or loss in community cost resulting from extension of the prevailing green light with h s. Figure 1 shows this method in the form of a flow chart.

ESTIMATES OF THE CONTROL VARIABLES FOR PRACTICAL APPLICATION

The TOL method requires that all approaches of the intersection be continually surveyed. Two methods to obtain the necessary traffic information have been tested in the field studies:

1. Derivation from passage detectors situated 30 and 120 m from the stop lines and
2. Direct observation of the analog output from long loop detectors encircling each lane in the approaches. The long loops give an output signal that is roughly proportional to the number of cars within the loop. The loops are divided into segments to provide information on vehicle positions (Figure 2).

Buses are identified by using selective detector equipment with a small passive unit in the bus and loops embedded in the pavement. Pedestrians cannot yet be quantitatively detected although simulations assuming that this can be done have been performed.

SIMULATION

The simulation model used for the studies is a further

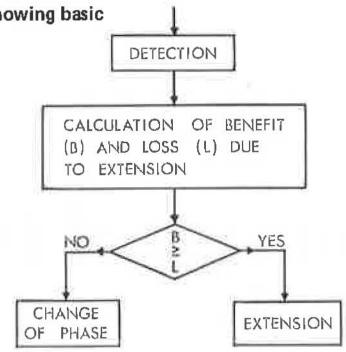

Figure 1. Flow chart showing basic principle of TOL.

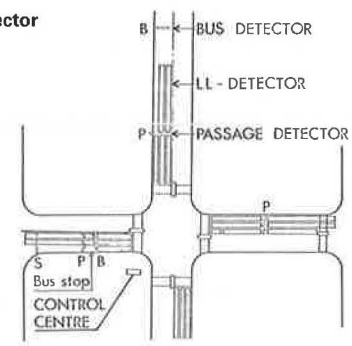

Figure 2. Test site detector installations.

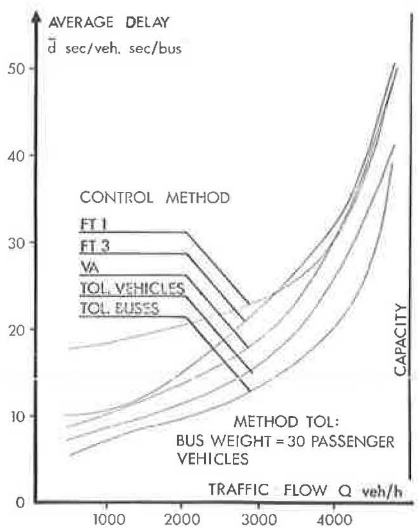

Figure 3. Simulation results for two-phase, four-way intersection.

development of a model presented by Klijnhout (3). The model is event scanning and is written in PL/1. Separate programs are developed for the different control strategies.

The simulation results indicated that TOL was considerably more effective than conventional VA and FT control (Figure 3). The vehicles should preferably be detected far in advance of the intersection (100 to 200 m), and the h between the calculations of Φ should be kept as short as possible.

Simulations were also performed that assumed that the pedestrians could be quantitatively detected and considered in the control function. The pedestrian delay was reduced by 10 to 15 percent without significant increases of the vehicle delay.

FIELD TESTS

Field tests comparing TOL with FT and VA were performed in two intersections in Stockholm. A minicomputer (PDP 11/05) mounted in a mobile van served as

Figure 4. Field test results, average delay versus traffic flow.

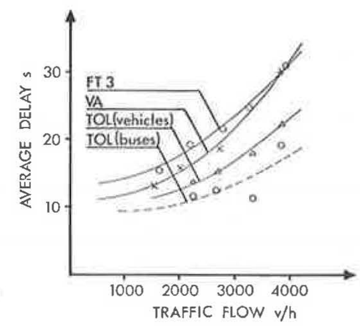

Figure 5. Field test results, proportion of stopped vehicles versus traffic flow.

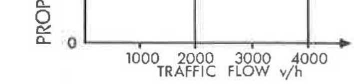

Table 1. Field test results.

Variable	Traffic	Control Mode FT	VA	TOL
Traffic flow, h	Automobiles	2600	2740	2620
	Buses	18	12	20
Average delay, s	Automobiles	21.5 ± 0.9	20.2 ± 3.0	15.5 ± 0.4
	Buses	20.4 ± 2.0	20.0 ± 3.0	12.2 ± 1.2
Proportion stopped, %	Automobiles	68	67	59
	Buses	63	62	55

Note: Limits refer to the 95 percent confidence interval.

Table 2. Benefit/cost ratios for replacement of VA by TOL control.

Traffic	Factor Considered	Benefit/Cost Ratio
Buses	Reduced operational costs	0.13
	Reduced time costs	2.42
	Total	2.55
Automobiles	Reduced operational costs	3.15
	Reduced time costs	7.10
	Total	10.25

Note: Total reduced operational costs for both buses and automobiles = 3.28. Total of all reduced costs for both buses and automobiles = 12.80.

both signal controller and data recording unit during the field experiments. TOL is likely to require a minicomputer or microcomputer even for regular operational use because of the complex control function.

The data collection was performed automatically by using information of signal status, vehicle detector passage times, and the analog detector signals as input. Based on these data, all relevant variables, such as delay, stops, green times, and the like, were derived and recorded on tape. The data on the tapes were later further reduced by a special computer program for statistical analysis.

Examples of results from the field tests are shown in Figures 4 and 5. Figure 4 shows the relationship between average delay and total intersection traffic flow. It shows that TOL gave considerably lower delay values than the other methods did for all traffic volumes tested. Furthermore, it gave an extra reduction of the bus delay. Compared to VA, TOL gave a 20 to 25 percent improvement for the ordinary vehicles and a 20 to 40 percent improvement for the buses. The differences between the curves concerning the vehicles are significant at the 0.05 level.

Table 1 gives the field test results for the whole test period. The differences in mean delay for vehicles are significant at the 0.01 level. The difference for bus delay between TOL and the other methods is also significant. The improvement obtained by replacing VA with TOL has been shown to be cost effective even if only the reduction of vehicle operating costs (largely energy consumption) is considered (Table 2).

COMMENTS

The results of the studies indicate strongly that the TOL strategy when compared to conventional FT and VA control gives substantial reductions of average delay and proportion of stopped vehicles. Further improvements can be given to the buses if they are weighted higher than the other vehicles. The TOL strategy can also be applied for coordinated signal control of nearby intersections. In this case, information on queues and discharge rates is transmitted from each controller to the nearby intersections that are still independently controlled. This method should result in a very flexible type of coordination and offer good possibilities for individual bus priority. A research program to test this method is under way in Sweden.

REFERENCES

1. K.-L. Bång. Optimal Control of Isolated Traffic Signals. Traffic Engineering and Control, Vol. 17, No. 7, July 1976.
2. A. J. Miller. A Computer Control System for Traffic Networks. Proc., 2nd International Symposium on Theory of Traffic Flow, London, 1963.
3. J. J. Klijnhout. A Digital Simulation Model for Single Intersections With Traffic Lights. Traffic Engineering and Control, Vol. 13, No. 4, Aug. 1971.