SIDRA SOLUTIONS®

Akcelik & Associates Pty Ltd
PO Box 1075G, Greythorn, Vic 3104 AUSTRALIA
info@sidrasolutions.com

Management Systems Registered to ISO 9001
ABN 79 088 889 687

REPRINT

The re-distributional effects of an area traffic control policy

M. J. MAHER and RAHMI AKÇELIK

REFERENCE:

M. J. MAHER and R. AKÇELIK (1975). The re-distributional effects of an area traffic control policy *Traffic Engineering and Control; Vol. 16, No.9, pp 383-385.*

NOTE:

This paper is related to the intersection analysis methodology used in the SIDRA INTERSECTION software. Since the publication of this paper, many related aspects of the traffic model have been further developed in later versions of SIDRA INTERSECTION. Though some aspects of this paper may be outdated, this reprint is provided as a record of important aspects of the SIDRA INTERSECTION software, and in order to promote software assessment and further research.

The re-distributional effects of an area traffic control policy

by M. J. Maher
Department of Probability and Statistics
University of Sheffield
and R. Akçelik
Karadeniz Technical University
Trabzon, Turkey

Introduction. When an area traffic control scheme is applied to an urban road network, the optimal signal timing plan depends on the link flows, which, in turn, can be estimated by means of an assignment model and which are dependent upon link travel times and delays at intersections. These delays are themselves, of course, dependent on the signal timing plan and on the flows. To put this more concisely and mathematically, denote the signal timing plan by a set of parameters x, the delays by d and the flows by q. Then we can write:

$$x_{opt} = f_1(q); \quad q = f_2(d); \quad d = f_3(x, q) \qquad \text{.........(1)}$$

If x is changed, therefore, we would expect changes in d and q, which would then lead to a new x_{opt}. It is not obvious whether continuing this iterative process will give rise to successive improvements in the operation of the network, or a gradual worsening. Intuition and experience of practical travel time/flow relationships and area traffic control policies would tend to suggest that equilibrium will eventually be reached, at which point a small perturbation will not lead to a steady drift of the optimal plan.

It is important at this point to make a distinction between a user-optimising and a system-optimising control policy. A user-optimising policy corresponds to a situation where individual drivers are free in selecting their routes. The resulting flow pattern represents an equilibrium situation in which no driver can reduce his travel time by changing to a different route. On the other hand, a system-optimising policy aims at minimising total network travel time. The corresponding flow pattern is more relevant to traffic control than to observed traffic, i.e. it should be the aim of ths traffic engineer who wants to optimise the traffic flow by various control measures.

Both the user- and system-optimising area traffic control policies are based on the use of optimum signal settings which are usually obtained by minimising total network delay for a given flow pattern. However, a user-optimising policy may not necessarily give the best result. A system-optimising policy will give better results than a user-optimising one, considering both the network and individual vehicle performance. An understanding of the re-distributional effects of an area traffic control policy provides an answer to this problem.

Review

That such re-distributional effects of an area traffic control (ATC) policy are a possibility can hardly be denied, but whether they are of sufficient magnitude to be at all important is a different question. Tillotson[1] pointed out that the current trend in network simulation methods was that the pattern of re-distribution is not predicted. Tillotson argued, however, that the improvements brought to a network by ATC will be generally uniformly distributed and that, therefore, there will be no gain to a driver in changing his route. This may not always be the case, however, because the changes caused by a signal plan may be rather non-uniform. Field tests have been reported by Pontier *et al.*[2], showing that changing the allocation of green time at an intersection to favour a preferred movement and establishing signal progressions along an arterial route has resulted in significant flow changes in the immediate area of the operational changes.

The re-distribution of traffic has been acknowledged in the series of ATC experiments in Glasgow[3,4] at the assessment level. It has been accepted that if a control scheme is altered substantially, there is likely to be a re-distribution of traffic, particularly in the case of commuter traffic. The drivers in Glasgow were allowed a learning period of a week, this being the time traffic was given to re-adjust itself before a new scheme was assessed. Holroyd and Robertson[5] pointed out that, in fixed-time control systems, drivers can learn to adapt their routes and speeds to advantage, because the signal timings are predictable.

Signal timing plans and flow patterns are interdependent, therefore, and it is possible to manipulate the flows by means of a signal timing plan. Flynn and Siu[6] have described a study in which the traffic flow pattern was changed, mainly by means of conversion to one-way streets, to obtain better patterns, as well as obtaining optimum signal timings to improve the network performance. This combination of traffic management schemes and signal timing plans could give a feasible method of route control in which traffic is persuaded to divert from heavily-trafficked routes to more lightly-loaded routes, in order to spread the demand through the network in an optimum manner. This problem has been studied in some detail by Akçelik[7] and this present paper is a section of that work and is devoted to the re-distributional effects of an ATC scheme. The iterative process described earlier is followed through for two simple networks and the changes in x_{opt}, q and d investigated.

Before proceeding with this, the interdependence of signal settings and flow patterns can be explained by their effects on travel time-flow curves (link or route) and this is illustrated in Fig 1. A change in signal settings results in a shift of the whole travel-time/flow curve. On the other hand, a change in flow corresponds to a movement along the curve. For example, a change from curve a to curve b would result in a decrease in delay (from d_1 to d_2) for a given flow q, whereas an increase in flow, say as a result of this improvement, from q to q' would give rise to an increase in delay (from d_2 to d_3).

Simulation experiments

In order that the simulation experiments might demonstrate realistically the relevant effects, the model consists of the following components:

(*i*) A technique for computing optimum signal settings, which is sufficiently sophisticated to give reliable results, but computationally simple enough to avoid having to use very long computing times.

(*ii*) A link speed-flow relationship to simulate the effect of congestion on link travel times. The results of May and Keller[8] were adapted to give an appropriate form of relationship.

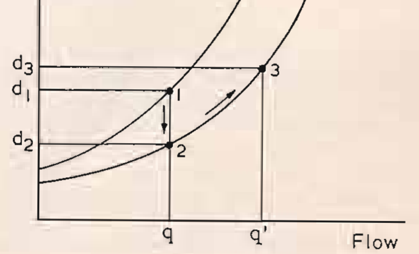
(*iii*) A partial loading assignment model to give a realistic flow pattern. A modified version of the technique given by Steel[9] was used, consisting of eight loading stages followed by a final simulation run to collect the necessary statistics.

(*iv*) A stochastic semi-macroscopic simulation model using a single vehicle type.

The initial data for the problem consist of the network structure and an origin-destination flow matrix. Traffic was assigned to the links in a sensible, but necessarily arbitrary, manner for the first iteration, and an optimum signal plan was calculated for this flow pattern. In successive iterations, the new flow pattern was estimated using the assignment model and this was followed by the calculation of a new signal timing plan. This was continued until there was some sign of the system having settled down to an equilibrium state. In practice, when the signal timings were almost identical to those in the previous iteration, the simulation was stopped. Because of the stochastic nature of the simulation model, a perfectly stable system, in this context, is an impossibility. This iterative process was used to find both the user- and system-optimising solutions.

The two networks used for the tests were quite simple, so that the changes in the flow pattern could easily be recognised, and also to represent a critical section of a larger network. The first network, shown

Fig 1. Interdependence of signal timing plans and flow patterns.



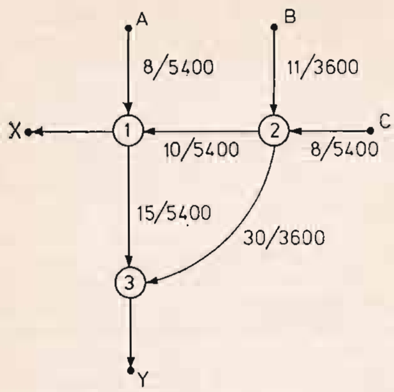


Fig 2. Test network, with free-flow travel time, in sec., and saturation flow, in veh/h, shown alongside each link.

in Fig 2 and with the origin-destination flow matrix shown in Table I, has a heavy flow of 2 000 veh/h southwards from *A* to *Y*, one of 600 veh/h from *B* to *Y*, and flows of 600 veh/h each from *C* to *X* and from *C* to *Y*.

Table I. Flow matrix in veh/h

	X	*Y*
A	0	2 000
B	0	600
C	600	600

The flows q_{BY} and q_{CY} have a choice between taking a heavily-loaded, high-capacity route via node 1, or a more lightly-loaded, lower-capacity route. These routes will be referred to by 'via 1–3' and 'via 2–3' respectively. The resolution of this choice depends on the travel time delays caused by the link flows and on the intersection delays caused by the traffic signal settings. The heavy flow along link (1, 3) is likely to give rise on the one hand to longer travel times, but, on the other hand, to lower delays at node 3 because of a favourable signal progression from node 1 to node 3. The problem has many sides to it and the solution from a driver's viewpoint is not immediately evident.

The initial route choices were assumed to be those given by a symmetrical split:

Flow	Via 1–3 veh/h	Via 2–3 veh/h
B to *Y*	300	300
C to *Y*	300	300

A signal timing plan was calculated for this flow pattern, and after a further assignment of the traffic the route loadings and average travel times were:

Flow	Via 1–3 veh/h	(sec.)	Via 2–3 veh/h	(sec.)
B to *Y*	300	(87)	300	(87)
C to *Y*	600	(74)	0	(80)

Total network travel time = 62·5 veh-h/h

This demonstrates the equal average travel time (user-optimising) principle of the assignment process, in that the travel times of the two routes for q_{BY} are almost equal because the split between the loadings of the two routes is not a simple all-or-nothing split. A new signal plan was calculated and this, in turn, was used to estimate the new flow pattern and average route travel times:

Flow	Via 1–3 veh/h	(sec.)	Via 2–3 veh/h	(sec.)
B to *Y*	420	(87)	180	(88)
C to *Y*	600	(71)	0	(83)

Total network travel time = 60·8 veh-h/h

Further iterations give flow patterns and signal plans not very different from this latest set and so the process had effectively converged to an equilibrium situation. This first network has, therefore, converged quite quickly to a stable user-optimising solution and the total network travel time decreased as the iterative process was followed through. When we move on to the second experiment, we do not get such a simple and satisfactory solution. Before reporting this second test, it should be noted that the final flow pattern does not represent the system-optimising solution, i.e. this flow pattern does not minimise the total network travel time, subject to the O–D flow matrix. The system-optimising solution was found using the same iterative process, but computing a system-optimising flow pattern instead of a user-optimising one at each step. Starting from the user-optimising solution given above, a stable system-optimising solution was found after two iterations:

Flow	Via 1–3 veh/h	(sec.)	Via 2–3 veh/h	(sec.)
B to *Y*	0	(68)	600	(85)
C to *Y*	600	(60)	0	(81)

Total network travel time = 53·7 veh-h/h

The total network travel time could be reduced by about 12 per cent, therefore, by banning right turns at node 2 for flow q_{BY}. It should be noticed that the average travel time for the diverted traffic is reduced as well as for other traffic.

The second test network is slightly more complex and is shown in Fig 3. Table II gives the origin-destination flow matrix:

Table II. Flow matrix in veh/h

	X	*Y*	*Z*
A	0	0	2 000
B	0	0	600
C	600	0	600
D	0	250	250

This time there are three flows which have choices to make about the route to take: q_{BZ} and q_{CZ} have three routes to choose from (2–1–4–5 or 2–3–4–5 or 2–3–5) and q_{DZ} has two (3–4–5 or 3–5). In order to distinguish between the alternative routes, they will be referred to by: via 2–1, via 3–4 and via 3–5.

Again the initial flow pattern was arbitrarily chosen to be that given by symmetry between the available routes (three alternatives for q_{BZ} and q_{CZ}, and two for q_{DZ}):

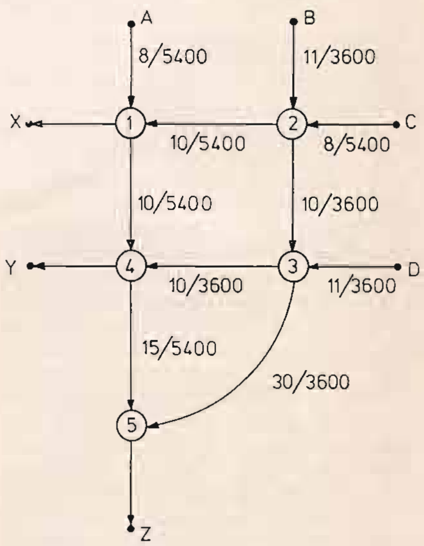
Flow	Via 2–1 veh/h	Via 3–4 veh/h	Via 3–5 veh/h
B to *Z*	200	200	200
C to *Z*	200	200	200
D to *Z*	—	125	125

In all the iterations following this first one, all the flow from *C* to *Z* goes via 2–1 and all the flow from *D* to *Z* goes via 3–4, so that the only variation in the flow pattern is due to the flow from *B* to *Z*. Below are listed the loadings on the three routes for q_{BZ}, together with the resulting average route travel times (in brackets) and the total network travel time, for the five iterations needed before there was some sign of convergence to the user-optimising solution:

Iteration number	Via 2–1 veh/h	(sec.)	Via 3–4 veh/h	(sec.)	Via 3–5 veh/h	(sec.)	Total network travel time (veh-h/h)
1	0	(99)	300	(94)	300	(95)	86·5
2	200	(113)	100	(113)	300	(110)	93·7
3	300	(111)	220	(110)	80	(115)	93·3
4	360	(111)	160	(114)	80	(116)	91·0
5	420	(113)	150	(112)	30	(113)	91·8

It can be seen that the first iteration turns out to be the best (i.e. the lowest total network travel time), but that the flow pattern is unstable in that drivers are gradually persuaded to travel via 2–1 although the average journey time increases steadily. This happens because the route 1–3–5 is a major arterial and obtains favourable green splits and progressions from the ATC scheme. The corollary of this is that conditions are made worse for traffic not using that major arterial and so more drivers are attracted to it. The process continues until about 70 per cent of q_{BZ} uses the major route and the total network travel time has increased from the initial 86·5 veh-h/h to 91·8 veh-h/h.

Fig 3. Test network with free-flow travel time, in sec., and saturation flow, in veh/h, shown alongside each link.



By comparison, the system-optimising solution was found to have converged to an equilibrium situation after only two iterations starting with the user-optimising solution given above. In the final solution, the flow pattern and average travel times were:

Flow	Via 2–1		Via 3–4		Via 3–5	
	veh/h	(sec.)	veh/h	(sec.)	veh/h	(sec.)
B to *Z*	0	(87)	150	(94)	450	(104)
C to *Z*	600	(78)	0	(89)	0	(99)
D to *Z*	—		250	(77)	0	(91)

Total network travel time = 80·4 veh-h/h

It can be seen that the total network travel time would be reduced by about 12 per cent as a result of a change from the user-optimising to the system-optimising policy, together with a reduction in the average travel time for all traffic including the diverted ones, as in the previous network. It should be mentioned that, in both networks, intersection delays played a major role in determining the user- and system-optimising solutions and link travel time delays had relatively less effect on them. Savings in the total network delays were found to be 21 per cent and 24 per cent in the first and second networks respectively. Experiments on other test networks showed that savings of up to 25 per cent in total network travel time and 41 per cent in total network delay could be obtained due to a change from the user-optimising to the system-optimising control policy.

Conclusions

The purpose of this paper has been fourfold: to point out that the assessment of the benefits of an ATC scheme cannot be made properly without consideration of the re-distributional effects; to emphasise the importance of the interaction between ATC signal plans and traffic flow patterns; to show that the continual optimisation of signal plans can lead to a gradual deterioration of the network performance; and to demonstrate that traffic management measures (such as the banning of turning movements and the introduction of one-way schemes) and route control ideas, can be applied in conjunction with ATC policies to improve the performance of a network.

In the small networks used in the tests, such effects have been noted and the authors believe that these are not due in any way to exceptional circumstances. The scope for considering alternative routes in larger networks is correspondingly greater and so it is expected that the possibilities of observing the effects described here will be higher in such networks. Small networks were chosen here for two reasons: firstly, the length of the simulation runs involved increases with the size of the network; and secondly, it was important to be able to see precisely what changes were happening in the flow patterns and signal plans, and this was clearly easier to do with a small number of flows. The speed of the simulation could be increased by using a simpler, deterministic model rather than the relatively sophisticated stochastic model used here, and this would then allow larger networks to be studied. Some trials with a TRANSYT-type traffic model[10] have been carried out on the networks used in this paper, and the agreement between the results from the two models has been very encouraging. It is planned to carry out further tests on larger networks using this deterministic traffic model.

The iterative method used for the determination of user-optimising solutions described in this paper simulates the implementation of current ATC policies. In practice, control schemes are evaluated by measuring new flow patterns and traffic statistics, after allowing for a learning period. However, alternative signal control methods are not evaluated in terms of their pattern of influence on the re-distribution of traffic. In the user-optimising policy currently used in ATC schemes, an optimum signal plan would normally result in the attraction of a larger part of the total demand from the secondary routes to the major routes, which might result in the deterioration of both network and individual vehicle performances. On the other hand, a system-optimising control policy would result in an even distribution of traffic over alternative routes reducing the load on the critical routes and intersections, thus giving substantial gains over a user-optimising policy.

It should therefore be concluded that the relative merits of alternative signal timing techniques should be evaluated considering their re-distributional affects in this context. For example, PLIDENT[11], a traffic-responsive signal control scheme tested in Glasgow, gave a network performance which was considerably worse than with the fixed-time Combination scheme. Apparently, PLIDENT resulted in the attraction of considerable amounts of flow from the non-priority routes to the priority routes, which may explain the deterioration of the network performance. Obviously, there is scope for research on the evaluation of alternative signal control techniques when used with the user- and system-optimising policies, and the implications of the differences between these two control policies may be more important than those of the differences between static and dynamic signal control policies without regard to their re-distributional effects.

An extension of this idea is the effect of traffic control parameters on the number of journeys made through the network, i.e. trip distribution, as well as the routes taken, i.e. traffic assignment. This has recently been considered by Allsop[12], who attempted to develop a theoretical framework to this problem.

ACKNOWLEDGMENTS

The authors wish to thank UNESCO and Karadeniz Technical University for their financial support of R. Akçelik during his period of research at the Institute for Transport Studies at Leeds University.

REFERENCES

[1] TILLOTSON, H. T. Some aspects of traffic simulation. *Surveyor*, **137**, 1971.

[2] PONTIER, W. E., P. W. Miller and W. H. Kraft. Optimising flow on existing street networks. National Co-operative Highway Research Program Report 113, 1971.

[3] ALMOND, J. and R. S. LOTT. The Glasgow experiment: implementation and assessment. RRL Report LR 142. Road Research Laboratory, Crowthorne, 1968.

[4] HOLROYD, J. and D. OWENS. Measuring the effectiveness of area traffic control systems. RRL Report LR 420. Road Research Laboratory, Crowthorne, 1971.

[5] HOLROYD, J. and D. I. ROBERTSON. Strategies for area traffic control systems: present and future. TRRL Report LR 569. Transport and Road Research Laboratory, Crowthorne, 1973.

[6] FLYN, T. E. and C. M. SIU. Comparison of traffic circulation alternatives through SIGOP. *Highway Research Record* 409. Highway Research Board, Washington, DC, 1972.

[7] AKÇELIK, R. Traffic signal and route control in urban areas. PhD thesis, Leeds University, 1974 (unpublished).

[8] MAY, A. D. and H. E. M. KELLER. Non-integer car-following models. *Highway Research Record 199*. Highway Research Board, Washington, DC, 1967.

[9] STEEL, M. A. Capacity restraint—a new technique. *Traff. Engng Control*, **7**, (6), October 1965, 381–384.

[10] ROBERTSON, D. I. TRANSYT method for area traffic control. *Traff. Engng Control*, **11**, (6), October 1969, 276–281.

[11] HOLROYD, J. and J. A. HILLIER. The Glasgow experiment: PLIDENT and after. RRL Report LR 384. Road Research Laboratory, Crowthorne, 1971.

[12] ALLSOP, R. E. Some possibilities for using traffic control to influence trip distribution and route choice in: Buckley, D. J. (Ed.) *Transportation and Traffic Theory*. Elsevier North-Holland, Amsterdam, 1974.