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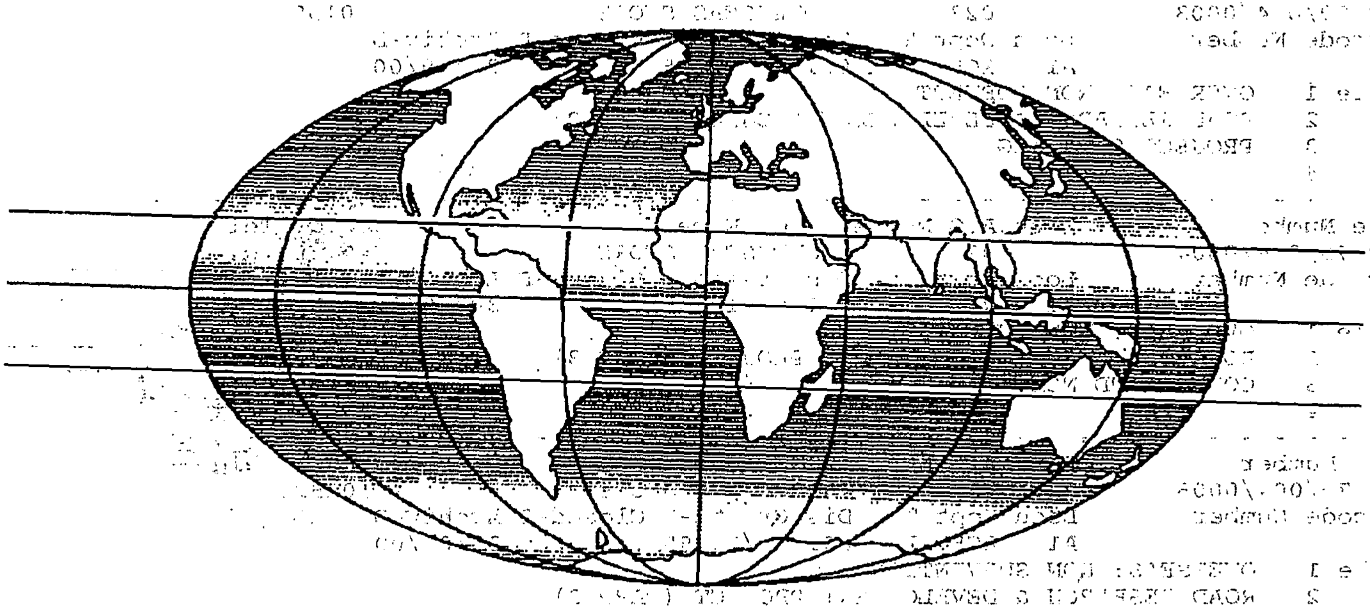
TITLE The choice of traffic signal control in developing cities

by G Gardner



Overseas Centre
Transport Research Laboratory
Crowthorne Berkshire United Kingdom

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The Choice of Traffic Signal Control in Developing Cities

Geoff GARDNER
Overseas Unit
TRL
Crowthorne, Berks
United Kingdom

SUMMARY:

Traffic signals are used throughout the world for the control of traffic at junctions. Mathematical theory and improved technology have led to control methods which minimise vehicle delays. Such methods have been found to work well under UK conditions, but their introduction in Less Developed Countries (LDCs) has not yet been fully tested.

This paper describes the current use, and costs, of traffic signals in developing cities, based on a small questionnaire survey of traffic authorities undertaken in late 1991. It was revealed that a typical signalised junction can cost between 5,000 and 30,000 $US with another 1,000 $US per year for maintenance. Large differences in signal provision were revealed, with some African cities having only one tenth the number of signals per 1000 population compared with some S American ones.

Modern computer controlled systems, with their associated closed circuit television systems and 'high-tech' image are an obvious attraction for a city. In terms of providing the best form of signal control, however, it is important that advanced technologies are seen in the context of the existing standards of traffic control, levels of infrastructure maintenance and institutional arrangements.

RESUME

Les feux de signalisation sont utilisés à travers le monde pour la surveillance et la régulation de la circulation automobile aux carrefours. La théorie mathématique et à la technologie perfectionneé conduisent à des méthodes de régulation qui minimisent les temps d'attente des véhicules. On constate que de telles méthodes fonctionnent bien dans les conditions de la Grande Bretagne, mais leur adoption par les pays moin développés n'a pas été tout à fait vérifiée.

Cette communication décrit l'utilisation courante et les coûtes de la signalisation par feux dans les villes des pays en développement, répertoriés à partir d'un petit questionnaire envoyés aux organismes de régulation de la circulation à la fin 1991. Cette enquête nous a appris que la signalisation type d'un carrefour peut coûter entre 5,000 US$ et 30,000 US$, avec 1000 US$ supplémentaires par an pour l'entretien. Nous avons constaté de grandes disparités sur le nombre d'équipements installés, quelque villes Africaines n'ayant seulement que 0.1 fois le nombre de signaux par 1000 habitants mis en service dans quelques villes d'Amérique du sud.

Les systèmes modernes suivis par ordinateurs avec salle de contrôle et télévision en circuit fermé sont une attraction évidente du fait de l'image "high-tech" qu'elle représente. Cependant, afin d'adopter le meilleur système de régulation de trafic, il est important que les technologies avancées soient vues à travers le contexte des standards des systèmes de régulation existants, au niveau de la maintenance des infrastructures et des adaptations institutionnelles.

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Geoff GARDNER
Overseas Unit
TRL
Crowthorne, Berks
United Kingdom

1 INTRODUCTION

Traffic signals are used throughout the world for the control of traffic at junctions. Their use in developing cities is likely to increase, despite some doubts as to their effectiveness and concern over their safety if used incorrectly.

Traffic signals enable pre-determined levels of priority to be given to each approach to a road junction. Originally, the length of green time given to each arm was determined by trial and error. More recently, mathematical theory, and improved technology have led to control methods which minimise vehicle delays. Such methods for improving the performance of traffic signals have been developed at the Transport Research Laboratory (TRL), and these have been found to work well, under UK conditions. The introduction of these control strategies with modern signalling equipment in Less Developed Countries (LDCs) has not yet been fully tested.

This paper describes the current use and costs of traffic signals in developing cities, based on a small questionnaire survey of traffic authorities undertaken in late 1991. The paper begins by describing developments in signal control and their likely applicability under LDC conditions.

2 ISOLATED JUNCTIONS

2.1 Fixed time signals

A simple, isolated set of traffic signals consists solely of the signal heads and posts, and the associated control box which regulates cycle times and green times.Early controllers were simple electro-mechanical devices with a fixed single cycle time, and many of these controllers are still in use overseas (where heat and dust can render their timings inaccurate and unpredictable). Modern controllers use electronic timing and electro-mechanical interlocking relays . The most recent development is the inclusion of microprocessors and solid-state switching for greater reliability and flexibility (IHT/DTp, 1987). These are capable of an almost unlimited combination of settings to reflect different traffic conditions throughout the day.

In the UK it has been found that optimum time settings for isolated signals can be calculated using Webster's Formula (Webster, 1958) which selects cycle time and green times (for each approach) to minimise total delay to traffic using the junction. Where the controller is capable of operating only on a single cycle-time, Webster suggested compromise settings to reflect changing traffic patterns during the day.

For signal controllers that can accommodate different timings for different times of day, separate settings can be used for morning and evening peaks and off-peak periods. For most isolated major junctions which carry a 'tidal' flow, the use of different morning, evening and off-peak 'plans' is one of the most cost-effective means of traffic signal control.

Many computer packages are available which can be used to determine optimum settings for individual junctions and for specified traffic flows. Many of these, for example OSCADY (Burrow,1987) and SOAP84 (FHA, 1985) are based on Webster's Formula, but incorporate recent research findings.

2.2 Vehicle actuated signals

The controller may be linked to inductive loops or other vehicle detectors, which monitor traffic levels on each junction arm. The controller is actuated by the detectors to give priority to the arm on which there is vehicle movement. When there is queuing on both arms , for example in peak periods, the signals revert to fixed time operation.

A very advanced form of adaptive control for isolated junctions is MOVA (Vincent and Peirce, 1988). Unlike existing forms of 'vehicle actuated' controllers, which simply record the existence of a 'demand' , MOVA quantifies this demand and calculates continuously optimal settings accordingly. MOVA is available for retro-fitting to most modern traffic controllers, as an add-on unit containing a powerful micro-processor to implement the control strategy.

3 SIGNAL NETWORKS

For junctions in a network where the demand at one set of signals is influenced by another set nearby, the synchronisation of the timings of the signals in the network can further reduce congestion and delay. This process of linking signals is known as Urban Traffic Control, or UTC. There are two main types of UTC: fixed-time and adaptive control.

3.1 Fixed-time systems

These require green times for each junction to be calculated in advance. Several different sets of timings, or 'plans' can be used to suit different traffic conditions such as peak and off-peak periods and holidays. Optimisation programs, such as TRANSYT (Robertson, 1969), use traffic count information for the network to establish the settings for each signal. Since its development , TRANSYT has established itself as the world standard; a well set-up fixed-time UTC system is still both difficult, and expensive, to improve upon.

Linking of signals can be maintained by three methods; by **cableless linking** (ie by synchronising the quartz clock fitted as standard in each controller), by connecting controllers with a **hard-wire link**, or in a **dial-up** system, by connecting each controller by telephone to a computer in a central control room . (Some French controllers are also reported to be capable of synchronisation using radio signals (Morrish, 1980)).

If telephone lines are used, calls are made automatically to each junction at the start of each new plan. Some users have reserve plans for predictable incidents (for example, a vehicle breakdown on a river bridge or a major sports event) which can be called up when required. These special plans are selected by the operators on the basis of traffic incident monitoring via radio reports from local authority staff, police or bus companies. Some UTC systems also have closed circuit television (CCTV) monitoring facilities, but the cost-effectiveness of CCTV is not known, and it is not a prerequisite for UTC.

Connecting signals to a central control room has the advantage of allowing extra electronics to be added which will report equipment faults as they happen; this is considered to be a major benefit in the UK where quick response times for maintenance are required.

The biggest disadvantage of **fixed-time systems** is that the signal plans should be re-calculated periodically as traffic patterns change. This requires surveys which can be relatively expensive, and engineer/programmers who are not always available. In some LDCs, the rapid growth in vehicle ownership means that fixed-time plans will very quickly become obsolete. This is often given as the main reason for specifying adaptive technology for cities with high traffic growth rates.

3.2 Adaptive control systems

These constantly alter signal times to suit prevalent traffic conditions without manual intervention. The two most widely used adaptive systems are SCATS (Sydney Co-ordinated Adaptive Traffic System, developed in Australia in 1972 (Sims and Gennaoui, 1986) and SCOOT (Split, Cycle and Offset Optimisation Technique) developed by TRL (Hunt et al, 1981).

SCOOT uses traffic data collected from inductive loops on each junction approach transmitted by telephone to a central computer every few seconds- where settings optimal for all the network are calculated and then sent back to the on-street controllers.

As SCOOT 'knows' the traffic conditions throughout the network, the performance of each junction can be monitored from an ordinary computer terminal. A CCTV monitoring facility is therefore not essential, but is usually requested by city authorities for installation in a central control room.

Because of the number of calculations performed, the computers used in adaptive systems tend to be relatively large, and expensive (though new developments are reducing costs). Maintenance of loop detectors, though not particularly expensive, is time-consuming and needs constant attention. Telephone connections to adaptive systems must be kept open, and are critical to successful operation.

4 LESS DEVELOPED COUNTRY APPLICATIONS

4.1 The operating environment

Almost all research and development of traffic control has been in highly developed countries; traffic characteristics in developing cities can be very different. The main features which will influence traffic operations are:

- there is not, physically, as much road space and roads are not always planned and designed for efficient traffic use.

- the roads are called upon to perform a wide variety of functions which includes non-traffic use (for example, the co-existence of market stalls and through traffic on the same road space). Segregated footpaths are often poorly provided or used for other purposes, forcing pedestrians to use the roadway..

- vehicle growth rates are very high (although from a low base).

- vehicle mix can cover a wide range of types and characteristics, from bicycles and ox-carts to articulated trucks.

- driver behaviour may be incompatible with the control techniques which have been developed; lane discipline and observance of signals is poor, while gap acceptance may be unsafe.

- there is little accumulated experience of modern traffic control equipment and strategies amongst police and engineers.

- maintenance facilities and expertise for high technology equipment is limited.

- perhaps most importantly, the institutional commitment towards encouraging efficient highway use is often lacking.

Each of these factors will influence the probability of advanced traffic management methods being successfully transferred to developing cities. The technical problems associated with these differences are not insurmountable. In Beijing, for example, special detector arrangements for bicycles have been developed, and modern electronics are capable of withstanding wide ranges of heat and humidity. It is more likely that institutional, rather than technical, difficulties will hinder the successful operation of traffic control in LDCs.

4.2 Current use

Statistics on the current use of traffic signals are not easily available. In order to acquire more knowledge of their use, a simple questionnaire was sent to a small sample of cities, mostly in the developing world. Responses were received from 17 cities.

Table 1 shows the main results from the survey. The number of signalised junctions has been related to the population of the area served by the traffic authority, to give an approximate comparative measure of service level. (Traffic level would obviously be a better standardisation measure, but this is clearly difficult to establish on a rigorous basis.)

With a few exceptions, cities of S.America and Europe have signal provision in the range 0.2-0.3 signalised junctions per thousand population. Other cities, including some very large South-East Asian ones, have between one half and one tenth this number. In the more well endowed cities there appears to be no relationship between city size and provision of signalised junctions per capita; small cities are just as likely to have as many signalised junctions per capita as large cities.

Linking of signals is widespread in the sample, even in those cities with low levels of provision. Most of this linking is by cable, either telephone links or dedicated cables. Synchronised clocks are used in Santiago (for some signals) and Porto Alegre. TRANSYT in various versions is widely used for signal settings, but many cities seem to have access to, and use, a variety of packages including some they may have developed themselves, and some provided by the hardware supplier.

The ranges of costs of installing and maintaining signals are shown in Tables 2, 3 and 4. Cities have been grouped by Region. Some of the ranges are large and may obviously reflect differences of interpretation that respondents have given to the questionnaire. The higher installation costs recorded for European cities are strongly associated with high labour costs (Fouracre and Gardner, 1992). Maintenance costs are generally higher in Europe, which again must reflect higher labour costs; it may also be the case that there is less toleration of system failure in Europe, though this hypotheses cannot be substantiated from this survey. Generally higher controller costs in Africa and S.E.Asia may be due to high import tax; both Europe and S.America manufacture their own equipment.

Table 1. Number of signalised junctions in sample of cities.

	Pop. million	total	Signalised junctions: per 1000 pop.	% linked
Europe:				
London	7	1800	0.26	72
Budapest	2	534	0.27	66
Prague	1.2	348	0.29	80
S.America:				
Sao Paulo	2	4000	0.33	50
Santiago	4.5	980	0.22	?
Curitiba	1.6	350	0.22	71
P.Alegre	1.0	499	0.49	6
Africa:				
Lagos	8	<50	0.01	0
Nairobi	1.5	27	0.02	52
Harare	1.0	152	0.15	43
S.E.Asia				
Bombay	11	305	0.04	64
Manila	8	329	0.04	94
Bangkok	6	250	0.04	24
Ankara	4	230	0.06	?
Istanbul	4	300	0.08	66
Islamabad	0.4	41	0.1	0
Rawalpindi	0.3	30	0.1	37

Cities with established systems have reported the installation of new signalised junctions to be at about 1-5 per cent of existing sites during the last year. Some cities, notably Istanbul, Bombay and Curitiba, have completed major expansions during the last year.

Table 2 Controller costs- cities grouped by Region
(numbers of reporting cities in brackets)

	Basic design '000 US $	Top spec. '000 US $
Europe	7-8 (2)	6-13 (3)
S. America	0.4-1 (4)	3-7 (4)
Africa	2-15 (2)	8-20 (2)
S.E.Asia	4-5 (3)	7-26 (3)

Table 3 Signalised junction investment costs- cities grouped by Region (numbers of reporting cities in brackets).

	Simple junction '000 US$	Complex junction '000 US$
Europe	15-40(3)	30-67 (3)
S.America	4-15 (3)	7-36 (4)
Africa	8-18 (2)	16-27 (2)
S.E.Asia	4-14 (5)	8-55 (5)

Table 4 Maintenance costs associated with traffic signals- cities grouped by Region.

Annual cost per junction	US$	
Europe	2000- 2700	(2 cities)
S. America	650- 2000	(3 cities)
Africa	100- 1300	(2 cities)
S.E. Asia	150- 3200	(6 cities)

From the surveys it may be concluded that the current stock of signal investment in developing countries may range in value between US$ 1-10 million per city. Annual maintenance costs of US$ 0.2-1 millions per city are typical.

4.3 Impact

To off-set these costs, the benefits of signalised traffic control include time and accident savings, as well as some positive impact on emissions. Few studies have been undertaken to quantify these benefits in developing cities; the few recorded impact studies have concentrated on UTC systems which have been shown, for the most part, to be effective investments (eg. Jones et al, 1982, Willumsen and Coeymans, 1987).

Traffic in an urban area can fluctuate rapidly, and the effectiveness of a control device is difficult to measure reliably without long and expensive surveys. Given the uncertainty attached to the performance of signals in LDCs, only the very broadest picture of cost/benefits can be constructed. It is likely that the pattern shown in Figure 1 (which follows the 'law of diminishing returns') would be a common one in many LDCs. For cities at the lowest level of traffic control, as are most in LDCs, the greatest short term economic return will come from a comprehensive study of existing signal timings, with some new UTC-compatible controllers introduced where necessary.

Specific benefits to a city of an adaptive system will depend upon whether that city does not have sufficient skills to re-calculate regularly updated TRANSYT plans, in which case

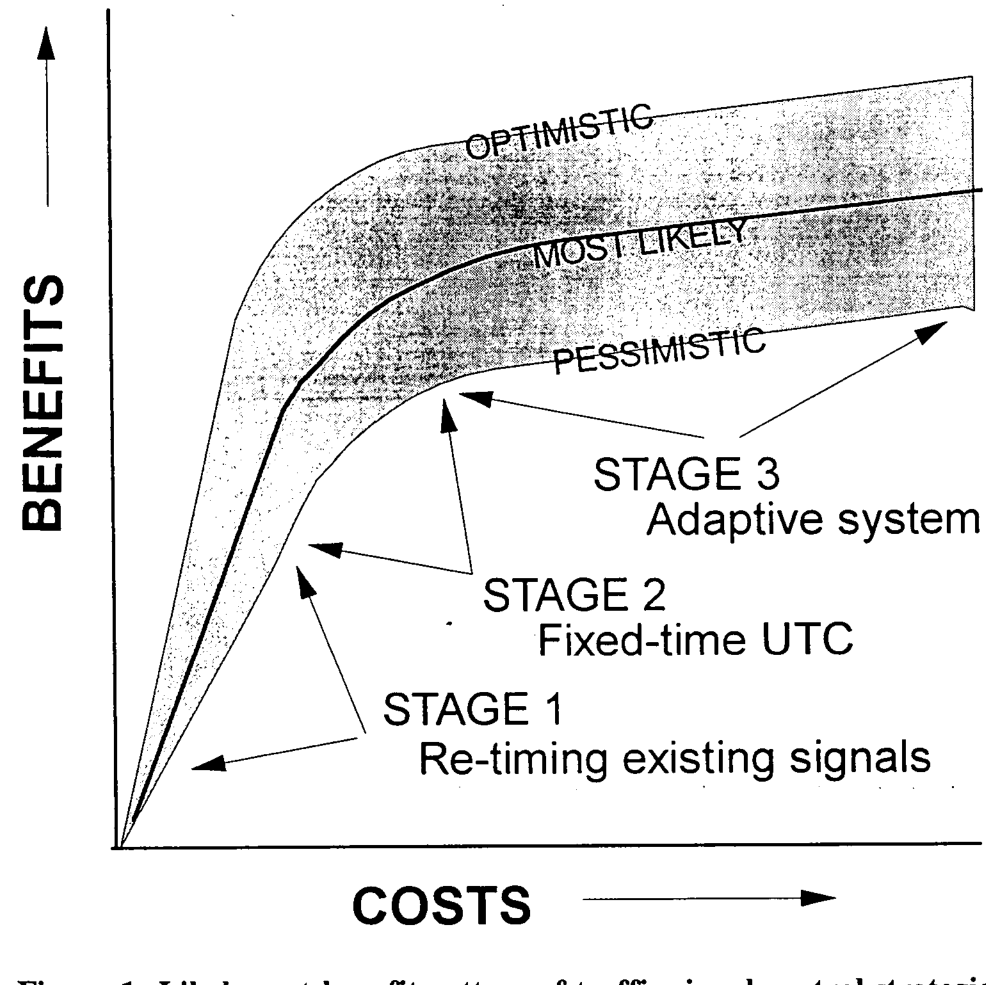

Figure 1: Likely cost-benefit pattern of traffic signal control strategies in Developing Cities

The importance attached to environmental benefits will also influence control strategy choice, since recent versions of SCOOT are capable of sophisticated congestion management techniques which can be used to reduce emissions in sectors of the city.

4.4 Institutional and maintenance requirements

Signal control requires collaboration between a number of interested groups. A single agency with the responsibility for identification, implementation, operation and maintenance of signals is likely to have the best opportunity for success. This is seen with organisations like CET (Traffic Engineering Company) of Sao Paulo, a municipal body set up in 1976 with wide powers to develop traffic management techniques within the city and currently responsible for some 3600 signalised junctions.

In the CET model it is the civilian organisation which takes the lead, though liaising closely with traffic police in monitoring and planning.Quite naturally the traffic police in any city will play a large role in traffic control developments and in many cities they will be largely responsible for such developments. There is no good reason why this should not continue, provided that the personnel involved are properly conversant with traffic engineering and signal control systems, and the traffic police can devote the necessary resources to all the associated activities such as survey work and maintenance. It is of interest to note that in Delhi much of the enthusiasm for installing UTC is being generated by the traffic police.

The public roads department are also involved in the process of signal installation: in some cities they will have the full responsibility and in others they will act in a supporting role to the police or traffic agency. In either situation they will have the task of introducing new road-markings, kerb re-alignment, ducting and loop cutting. This is an important (and often overlooked) aspect, since signals will not be totally effective unless the junction is tailored to their use.

Maintenance, or the lack of it, will be a key element in determining the success of a signal installation. The effects of lack of maintenance are cumulative and, for example, with more than 15-20 per cent of loops inoperative, the benefits of an expensive SCOOT system are unlikely to exceed those of a well set-up TRANSYT system. In addition to the cost (which represents an annual outlay of some 10- 20 per cent of installation cost) signal maintenance requires the sort of highly skilled labour which is in short supply in developing cities. The problems of spares procurement are also likely to play a significant role in signal availability.

5 CONCLUSION

Traffic signals are an important weapon in any city's armoury for fighting congestion. Modern computer controlled systems, with their associated control rooms and closed circuit television are an added attraction in that they present a 'high-tech' image. In terms of providing the best form of signal control, however, it is important that advanced technologies and strategies are seen in the context of the existing standards of traffic control, levels of infrastructure maintenance and institutional arrangements. There are several stages of traffic control development that a city can follow before introducing these advanced systems and there are strong technical and institutional reasons why these should be followed sequentially.

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