21st Australasian Transport Research Forum
Adelaide, September 1997

Experiences with the Path Flow Estimator on a Leicester City Street Network

Stuart J Clement
Transport Systems Centre
University of South Australia

Michael G H Bell
Transport Operations Research Group
University of Newcastle

Chris Cassir
Transport Operations Research Group
University of Newcastle

Sergio Grosso
Transport Operations Research Group
University of Newcastle

Abstract:

The Path Flow Estimator (PFE) has been developed to support both online urban traffic management and offline transportation planning. It estimates flows and travel times in transportation networks. Given data from vehicle detectors and other forms of sensor, path flows and path travel times are inferred on the basis of a logit path choice model. The delays incurred by congestion are taken into account. The most significant paths in the network are generated by an approximate steepest descent column generation method. To better represent the transitory overloads which characterise congested conditions, a time-dependent PFE has been formulated. Various versions of the PFE have been specified and are being validated for a number of European test sites. This paper reports on the use of the PFE in Leicester City, England. Information from surveys conducted within a portion of the Leicester City road network was used to test the PFE. Constraints on the amount of deviation allowable for the fitted PFE output link flows compared to the measured link flows were imposed. The PFE-fitted path flows were matched against independently path flows and this was used as a measure of the effectiveness of the PFE. To enhance PFE performance, O-D information was used in two ways: as weights and as constraints. Results show that using O-D information can improve the accuracy of PFE outputs significantly.

Contact Author:

Stuart Clement
Transport Systems Centre
University of South Australia
GPO Box 2471
Adelaide SA 5000

telephone: (08) 8302 1862 fax: (08) 8302 1880
email: stuart.clement@unisa.edu.au

Introduction

For many years the largely vehicle-oriented and passive Urban Traffic Control (UTC) concept was used to manage vehicular activity on urban road networks Recently there has been a paradigm shift towards actively managing traffic to achieve broader people-oriented objectives (Oscar Faber 1995) in what the UK Department of Transport describes as Urban Traffic Management and Control (UTMC) The realisation that broader policy objectives are required has been recognised politically (Routledge, Kemp and Radia 1996) largely as a result of growing public awareness of the environmental impact of road traffic Many authorities are now pursuing policies to:

- manage demand and congestion;
- influence mode and route choice;
- improve priority for buses, trams and other public service vehicles;
- provide better and safer facilities for pedestrians, cyclists and other vulnerable road users;
- reduce vehicle emissions, noise and visual intrusion; and
- improve safety for all road user groups.

One of the major outcomes of the paradigm shift to UTMC is that systems will be more flexible than those of UTC systems These older systems were configured around a fixed computer architecture - usually a mainframe - and fixed controller hardware resulting in limited scope for expansion. A requirement for UTMC systems is that they be modular and that their computer systems be open so that different providers of hardware and software components can contribute to these systems Intermodular communication will be via messages and hence different configurations of UTMC systems will appear for different applications One such possible configuration is that of Figure 1 Thus an important aspect of UTMC is the linking of systems like traffic signal control, variable message signs, public transport priority, emissions monitoring, electronic road pricing, traveller information, parking guidance and others via a communications network This provides not only the systems themselves but also users and operators with better information about the state of the transport network

This shift in policy emphasis has been by no means limited to the UK; in fact in many respects it represents a process of catching up with developments in other European countries. The idea of a Datenverbund (meaning the pooling of data from many different sources and sensors) underlies many projects in the European Commission transport telematics programme Siemens are marketing a Traffic System Manager called CONCERT, which achieves the linkage referred to above. One function supported by CONCERT is that of the Traffic Expert, which provides a network-wide overview of the current transport and environmental situation This includes graphical presentations of the traffic flows overlaid on maps of the network It was in this context that the Path Flow Estimator (PFE) was developed. Other uses for this tool include Travel Demand Management (TDM) strategy analysis and are described in the section on PFE implementation

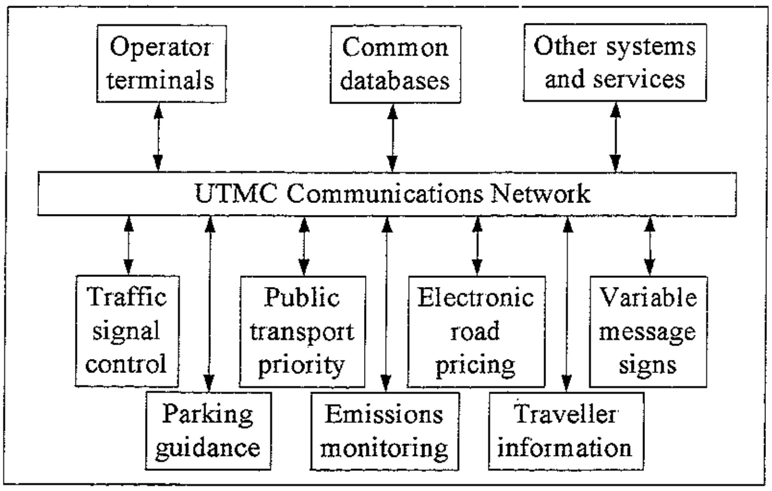

Figure 1 A possible UTMC communications network

PFE origins

The PFE had its genesis in a system reported in Sherali, Sivanandan, and Hobeika (1994) which was essentially an application of linear programming methods and used the assumption that all traffic takes the least cost paths The logit model behind the PFE assigns most traffic to paths of least cost but the interplay between the logit model and the link cost functions results in other paths being utilised

The Path Flow Estimator (PFE) was originally developed for the DRIVE 2 project MARGOT (Bell and Shield 1995; Bell, Shield, Henry and Breheret 1996) Siemens funded subsequent testing of the PFE on data for a small UTC network in Köln, leading to some model enhancements

Inputs

The PFE works with a wide range of input data Some types of which such as network topology information are essential while others such as O-D matrices are optional The PFE has two types of input, *static* and *dynamic* Static inputs relate to the network, namely:

- links (length, number of lanes etc);
- link cost functions;
- presence of detectors for each link; and optionally
- one or more Origin-Destination (O-D) matrices

The O-D matrices are not necessary for PFE operation but one of the major themes of this paper is to show that using O-D trip table data enhances PFE performance

The dynamic inputs relate to measurements of various kinds:
- traffic flow measurements from vehicle detectors;
- for signalised links, green times and cycle times;
- queue data (actual or estimated);
- turning movement proportions; and potentially also
- travel time measurements from *probe* vehicles (for example, buses equipped with some form of Automatic Vehicle Location system)

The core of the PFE is a logit path choice model On the basis of traffic flow measurements for specific links, the delays and flows on the other links are inferred from the interplay of the link cost functions and the logit model described in Bell, Cassir, Grosso and Clement (1997) The most significant paths are generated in an iterative way by a shortest (in this case, least cost) path algorithm The link costs are augmented by shadow prices engendered by any active constraints resulting from link flow measurements After each iteration, the new paths generated are added to the link-path incidence matrix as additional columns (hence, the process of path construction is sometimes referred to in the literature as *column generation*)

Outputs

The outputs of the PFE are path-specific data:
- path flows, from which turning movements and a trip table may be derived; and
- path travel times

In addition, link-specific data may be inferred, eg:
- link flows, where these have not been measured by detectors; and
- link delays

The first version of the PFE considered a steady state environment where in effect all trips are completed and flows cannot exceed pre-specified link capacities This is a poor description of conditions in congested networks because link capacities can become temporarily overloaded, with the excess demand being absorbed by the growth of queues This consideration spurred the development of a *time-dependent* PFE, first reported in Bell, Lam and Iida (1996)

Implementation of the PFE

The development of the PFE has occasioned considerable interest in both commercial and academic establishments as shown by its involvement in a number of European 4th Framework and other research and development projects summarised in Table 1 The CLEOPATRA project is concerned primarily with the use of the PFE in support of UTMC It is intended to specify the PFE (in particular, define the inputs and outputs) for UTMC systems either currently existing or being developed in four European cities, where in each city its role will be different The PFE will then be validated using offline data In the COSMOS project, the PFE will be integrated into a novel network traffic signal control system called MOTION and tested for performance and accuracy against a more conventional procedure for path flow estimation

Table 1 Implementation projects using the PFE

Project/Sponsor	Objectives
CLEOPATRA	Specification and validation of the PFE for various forms of UTMC system in Turin, Lyon, Toulouse and Athens
COSMOS	Specification and validation of the PFE in support of the MOTION traffic signal control system from Siemens
PTV	Integration of the PFE into the VISION software from PTV GmbH for transportation planning applications
AIUTO	Extension of the PFE to multimodal networks, with specific reference to the city of York
EPSRC	The use of the PFE to study Travel Demand Management packages, with specific reference to the city of York

The other three projects relate to the use of the PFE for transportation planning In conjunction with PTV, a German transportation consultancy, the PFE is being integrated into a suite of programs built specifically for transportation planning In the European AIUTO project, a multimodal form of the PFE is being developed by extension of the network to incorporate mode choice The multimodal PFE will then be applied to study the effects of a park-and-ride scheme in the city of York The multimodal PFE will be used in EPSRC-funded research to study the impact of travel demand management, again taking York as a case study Further extensions to the PFE will be made to take into account the effect of traffic control on mode and route choice There are two research projects being undertaken at TORG both of which are likely to broaden the PFE's offline application horizon The first is the melding of a deterministic user equilibrium model and the stochastic user equilibrium model of the PFE in dynamic situations to account for different classes of drivers eg unguided and guided The second project uses the multimodal PFE to find the differences in cost between a network operating (1) with vehicle ridership at current levels and (2) with vehicle ridership affected by car-pooling activities

PFE principles

The principles governing PFE operation are detailed in Bell *et al* (1997) which also describes the mathematical foundations of its models Here it is enough to describe the PFE approach as a compromise between the steady-state view of the world, which does not describe transitory overload conditions well, and the time-dependent view, which attempts to model the growth of queues during transitory overload conditions and assumes these queues discharge when the overload subsides

Time slices (of between 5 and 15 minutes) are defined, within which a steady-state equilibrium is assumed to prevail The equilibrium delay in one time slice is converted into an equilibrium queue, which is then carried forward to the next time slice This queue modifies the capacity available in the next time slice The assumption of steady-state conditions within each time slice presupposes that all trips within each time slice are completed The significance of this assumption depends on many factors including the size of the time slices. It is not within the scope of this paper to report on the effects of time-dependency

PFE operation

The operation of the PFE (ie the fitting of the PFE to given static and dynamic data sets) is an iterative process involving an outer loop and an inner loop Paths are built as iterations progress and flows are then fitted to the links of the network Where link flows have been counted and provided as input the fitted flows are constrained to lie within a user-defined link measurement constraint interval Where O-D trip table data are available the user can choose to use these values in one of two ways (besides not using them at all): as weights for the assignment of flows to the paths linking the relevant O-D pairs or within a user-defined O-D values constraint interval In the inner loop, the path flows are sequentially scaled so that the constraints, when set, are fulfilled. The process is iterative, because when the path flows are scaled to conform to the last constraint they may no longer conform to the first constraint This scaling process cycles round all the constraints until convergence is achieved It can be shown (Bell *et al* 1996; Bell, Lam and Iida 1996) that if a feasible solution exists, convergence is assured In the outer loop, reduced link costs (including constraint-induced shadow prices) are calculated and new reduced least cost paths are sought Outer iterations continue until no new paths are generated and link flows cease to change significantly

The model resembles the gravity model used for trip distribution There is an exponential deterrence function with a dispersion parameter α which governs the sensitivity to path cost (Bell *et al* 1997) When α is large, path choice is sensitive to path cost hence fewer alternative routes are generated and a relatively small spread of traffic assignment is effected This makes the PFE behave closer to a deterministic user equilibrium model When α is small, more paths are generated and trips are spread evenly across all the paths with little regard to cost

Link cost functions

The relationship between link cost and link flow is expressed in the link cost functions fundamental to the PFE. These functions therefore embody the effect of delay. The relationship between link cost and link flow depends on the steady-state component and the form of control at the downstream end of the link. The steady-state environment expects costs to tend to infinity as the capacity of a link is approached In reality costs do not tend to infinity near capacity even in congested networks because transitory overloads are absorbed as queues which are then dissipated later. On the question of the form of control at the downstream end of the link, the PFE has adopted and extended the model of the CONTRAM simulator (Leonard, Tough and Baguley 1978) which distinguishes between three kinds of link: priority links where the capacity depends on geometric factors alone; non-priority links where the capacity depends on geometric factors and conflicting priority flows; and signal controlled links where capacity depends on geometric factors and the signal timings. These distinctions were extended in the PFE to include freeway links for which speed-flow relationships are required. Kimber and Hollis (1979) present general expressions for time-dependent final (residual) queues and delays. The service process can be regular (as in the case of traffic signal control), random (as in the case of a non-priority stream), or somewhere between.

Leicester case study

The PFE has recently been tested for a small network (106 links and microlinks, nine origins, nine destinations) in Leicester, England (see the network representation of Figure 2).

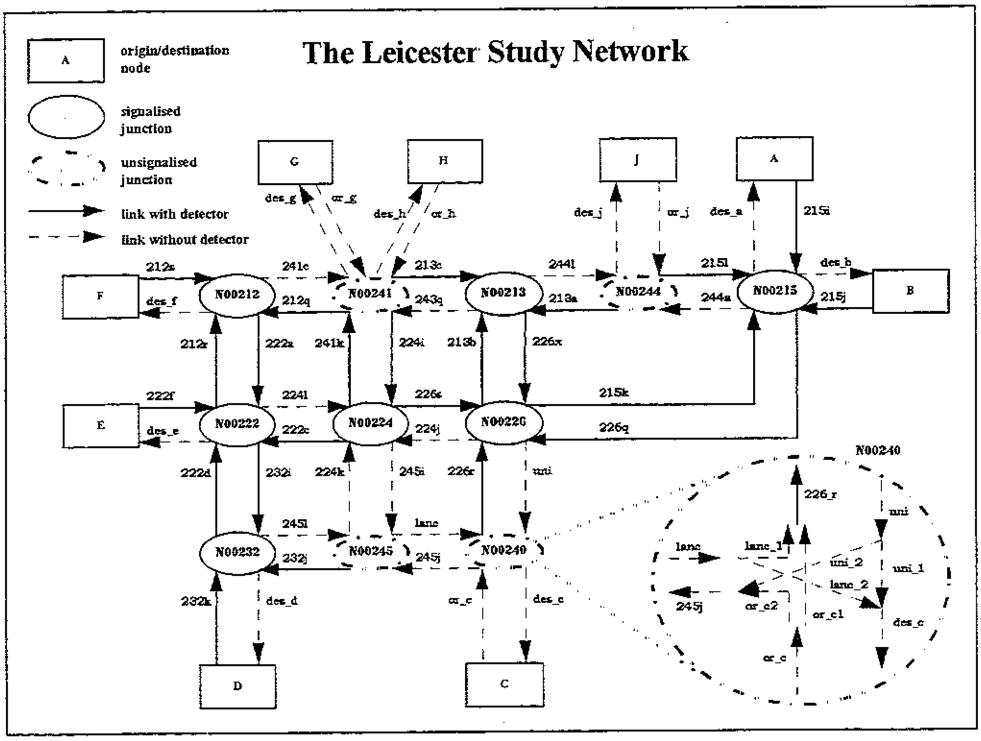

Figure 2 Network topology of the Leicester study area

The data used in the Leicester case study consisted of:

- topological information about each link (length, number of lanes, relationship with downstream links and nodes);
- network assignment characteristics for each link (saturation flow, free-flow speed, type of link, presence of traffic detectors, and whether origin, destination or neither);
- signal timings at intersections (green times and cycle times);
- SCOOT detector traffic counts obtained in 15-minute time slices over a 1 hour study period; and
- an Origin/Destination trip table over the study period

In addition and of particular interest for the case study, path flow data were collected from a registration plate survey conducted over the same time period The survey comprised values in 15-minute time slices over a 1 hour study period. This enabled a direct comparison of the PFE path flow results with the observed path flow data in each of the 15-minute time slices The data were collected for a PhD research project and complete descriptions of the collection processes can be found in Wright (1997).

The representation of the network in Figure 2 shows signalised and unsignalised intersections and differentiates between links with and without detectors This information is contained in the input files to the PFE Also shown is a representation of the microlinks of a node; these represent the different turning movements at junctions

The PFE was run using the set of traffic counts from the first time slice - ie the first 15 minutes of the study period - as link constraints This enabled a comparison with the path flows obtained from the number plate survey over the same time slice

It was found that the value of the parameter α in the objective function was of critical importance. It was found that a high value led to some inconsistencies with the traffic counts as not enough paths were created to ensure the existence of a feasible solution consistent with the link counts constraints Conversely a low value of α allowed more paths to be generated with a bigger traffic spread, but on such a small network too many paths clearly became unrealistic. After experimentation reasonable results were obtained for a range of α between 0.3 and 1.2 though it was realised that further work on the sensitivity of the PFE to changing alpha values was needed There may indeed be a method of directly calibrating α to each network: one possibility is a correlation between α and the mean trip length

The PFE was run in three different modes with $\alpha = 1$ The modes were:

- Link counts only used as constraints - O-D information not utilised;
- O-D trip table values used as weights;
- O-D trip table values used as constraints

O-D information not utilised

For this mode the link measurement constraint interval was set at ±5% and each path flow's weight was set to 1 Thus the PFE could match link flows to within the given tolerance of ±5% of the recorded value and no information about each path's contribution to the O-D trip table was used The scatter of points about the diagonal line of Figure 3 (especially for large flows) suggested that improvements could be made to the use of the PFE It was then decided to develop techniques to use O-D information whenever possible.

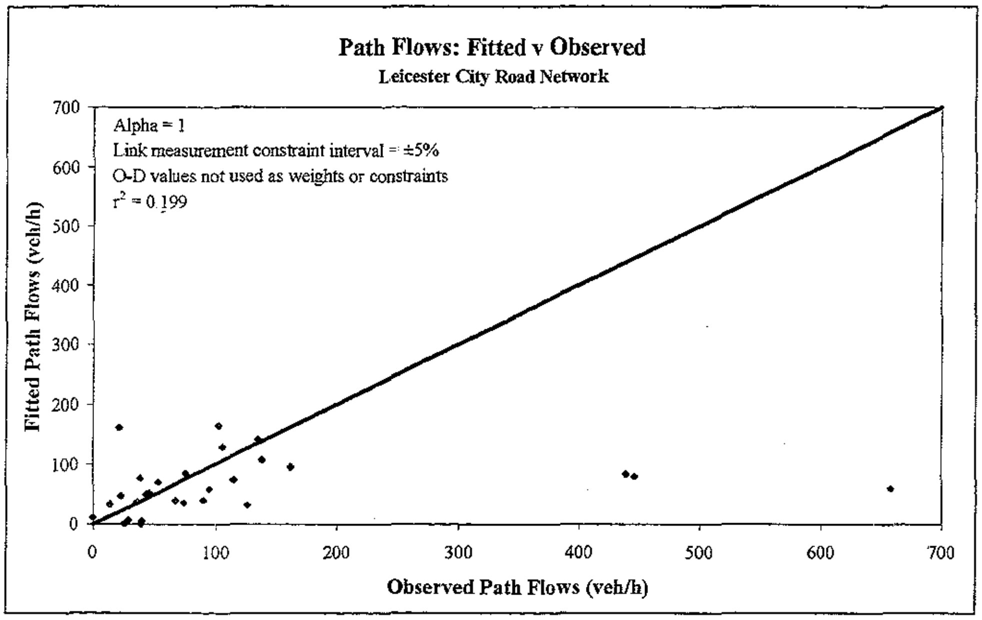

Figure 3 Link measurement constraint interval = ±5% and O-D data not utilised

O-D trip table values used as weights

Again the link measurement constraint interval was set at ±5% but this time each fitted path flow was multiplied by its corresponding trip table element Although the results using this technique (see Figure 4) showed significant improvement (r^2=0 871), it was felt that the O-D data could be used in an even more rigorous way to produce a closer match between fitted and observed path flows

O-D trip table values used as constraints

As in the previous two modes the link measurement constraint interval was set at ±5% but in this test the O-D trip table values were used as constraints; ie it was desired that the path flows reproduce not only the link counts (to within the given tolerance) but also the O-D trip table values The problem with this approach was that the O-D trip table and the traffic counts were not completely consistent. This was expected since (1) the traffic counts and the O-D trip table were obtained from different sources; and (2) the traffic counts were gathered over a 15-minute time slice whereas the trip table survey was conducted over one hour. Therefore it was unlikely that any solution would prove feasible with both sets of constraints: these would have to be relaxed by introducing constraint intervals

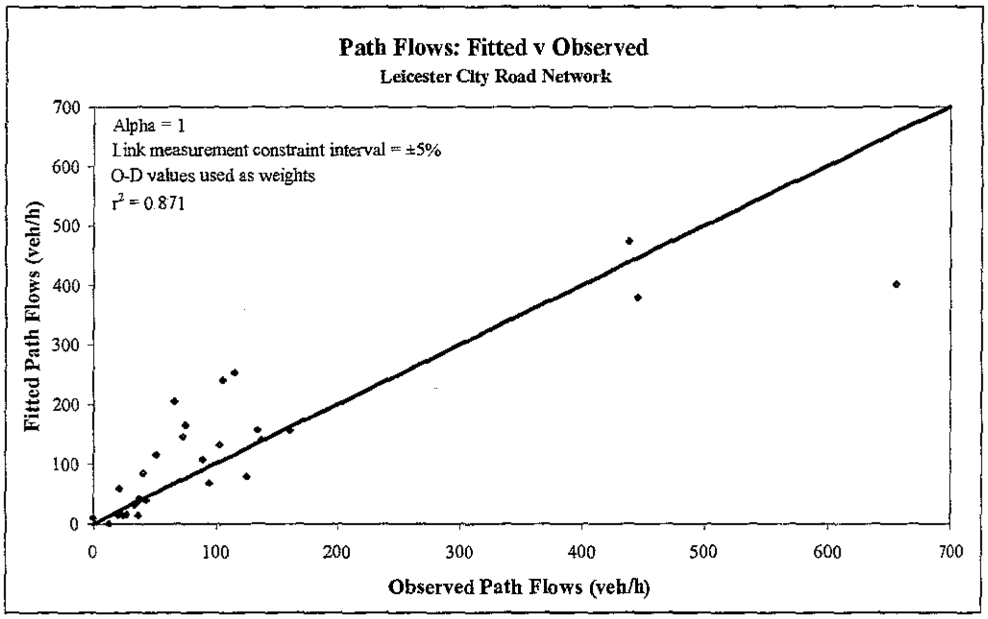

Figure 4 O-D trip table values used as weights

It was desired that the PFE should endeavour to match the link counts in preference to matching the values from the O-D trip table Matching link counts is likely to be the preferred option in most applications of the PFE This is due to the natures of the two types of data: link count data is usually the complete set of loop detector activations over a specified time period and extracted from computer storage; whereas the O-D data is usually a sample and there are more sources of error involved in its collection

In the Leicester study a relatively small links constraint interval of ±5% was set since matching the link counts was paramount to matching the trip table values Experimentation with the O-D constraint interval showed that for the PFE to converge to a solution the smallest possible interval was ±30 veh/h about the trip table values

Larger constraint intervals produced solutions that were not as good a match as that shown in Figure 5 As the O-D constraints are relaxed their influence decreases and vanishes when the constraints are inactive. Hence O-D information is important Percentages for the O-D constraint intervals could not be used due to large variations in orders of magnitude of the trip table values which ranged from 1 to 650 veh/h

As can be seen in Figure 5 using the O-D trip table values as constraints gave a yet better correspondence between the fitted flows and the observed flows

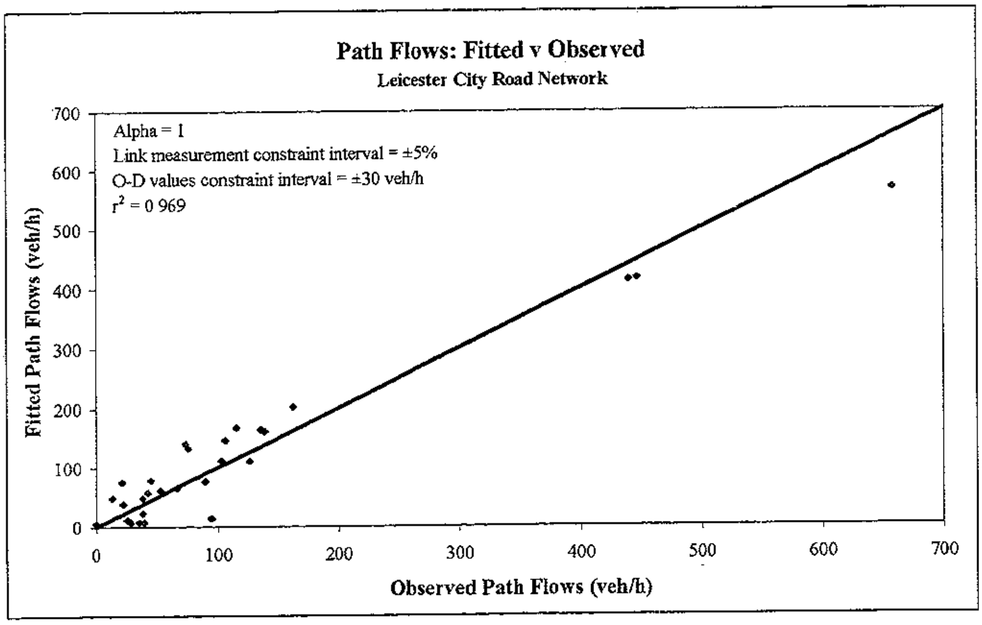

Figure 5 O-D trip table values used as constraints

The main point to emerge from the use of this technique was that it showed promise of tuning the PFE to the input data set especially once the effective range of α was found In the Leicester case the results obtained through the use of 1-hour O-D trip table values as constraints while using 15-minute detector counts suggested that in an online application - where O-D trip tables cannot be consistent with dynamic link counts - the technique could be successfully applied Thorough tests on all available time slices are required In particular the effect of varying the constraint intervals for flow counts and O-D data needs investigation In addition tests where progressively less information is given to the PFE need to be performed For instance a comparison of the effectiveness of the PFE would be possible by incrementally reducing the amount of O-D data used as constraints for example by selectively relaxing the corresponding interval constraints These tests could be extended to investigate whether some O-D data (eg that related to critical paths) have more effect than others on PFE performance

There is a possibility that the input data required to test the PFE on another network will be available from one of the implementation projects outlined in an earlier section It may also be possible to obtain queue activity data from one of these projects This would help overcome one of the problems of performing time-dependency tests using the available Leicester data; the PFE assumes there are no queued vehicles at the start of the first time slice

Conclusions

The Path Flow Estimator was developed partly as a response to the changing objectives of traffic signal control and partly as a tool for transportation planning purposes The changing objectives of traffic signal control are embodied in the Urban Traffic Management and Control framework and the PFE is currently being applied in this context in a number of test sites in Europe The PFE has been implemented in an offline environment in a commercial transportation planning software package, is being extended to include multimodal networks and is being used to investigate some travel demand management strategies at specific sites

The results of the tests on the Leicester road network reported in this paper show that the accuracy of the PFE can be enhanced by using available O-D trip table data where the flow counts were recorded during the period that the O-D data were collected The improvement in results from non-use of O-D data through using them as weights to applying them as constraints are encouraging

Further work and development

Further tests are possible on the available data set One possibility is to perform the same set of tests as reported here for each of the other three flow count time slices thus checking the contention that O-D data can be used as an enhancement More tests would investigate the queuing effects (time-dependency) by running the PFE for different successive time slices using the same O-D data

Further tests on the Leicester network and any other urban network would require a data-gathering exercise so that investigations into the effects of using different O-D data on the same set of input data can be performed What is required is another set of concurrent flow count data and O-D data (ie Survey B data) covering the same study period but gathered on a different day The Survey B O-D data would then be applied as constraints on the PFE which would be using the Survey A flow count data as link measurement constraints in either the individual time slice tests or the time-dependency tests Of course tests where Survey B flow count data were used as link measurement constraints and Survey A data used as O-D constraints would also be possible If the tests where one set of trip table values were applied to several not necessarily concurrent sets of flow counts were successful then this technique would be applicable (in some circumstances) when the PFE was used in dynamic situations ie using historical O-D data with realtime flow counts

An extended set of data gathered for Survey B would include queue characteristics at the beginning and end of each time slice This data could be used to check the results of time-dependency tests on successive time slices

Acknowledgements

The development of the software has been made possible by support from the European Community, Siemens AG and the UK Engineering and Physical Science Research Council The authors would like to acknowledge the significant contributions made by Caroline Shield, Dr Jessica Anderson and Dr Wafaa Saleh to PFE development

References

Bell, M G H and Shield, C M (1995) A log-linear model for path flow estimation, pp 695-9 of *Proceedings of the Fourth International Conference on the Applications of Advanced Technologies in Transportation Engineering* Capri

Bell, M G H Shield, C M Henry, J-J and Breheret, L (1996) A stochastic user equilibrium (SUE) path flow estimator for the DEDALE database in Lyon, pp 75-92 of Bianco, L and Toth, P (eds) *Advanced Methods in Transportation Analysis*, Springer-Verlag: Berlin, Heidelberg

Bell, M G H Lam, W H K and Iida, Y (1996) A time-dependent multiclass path flow estimator, *Proceedings of the 13th International Symposium on Transportation and Traffic Theory*, Lyon

Bell, M G H Cassir, C Grosso, S G and Clement, S J (1997) Path flow estimation in traffic system management, to be presented at *Eighth International Federation of Automatic Control Symposium on Transportation Systems,* Chania, Greece

Kimber, R M and Hollis, E M (1979) Traffic queues and delays at road junctions, *TRRL Laboratory Report* LR909

Leonard, D R Tough, J B and Baguley, P C (1978) CONTRAM - A traffic assignment model for predicting flows and queues during peak periods, *TRRL Laboratory Report* LR841

Oscar Faber TPA (1995) Framework report for the development of Urban Traffic Management and Control Systems, For the UK Department of Transport, February 1995

Routledge, I W Kemp, S and Radia, B (1996) UTMC: the way forward for Urban Traffic Control *Traffic Engineering and Control 37* (11), 618-23

Sherali, H D Sivanandan, R and Hobeika, A G (1994) A linear programming approach for synthesising origin-destination trip tables from link traffic volumes, *Transportation Research B 28* (B), 213-34

Wright, S D (1997) A linear programming approach to path flow estimation in SCOOT controlled road networks, PhD thesis, University of Newcastle upon Tyne, England