The Monitoring of Intersection Turning Flows in the Gold Coast Area

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Abstract:

This paper describes how to estimate the turning flows at an intersection with the principle of minimum information. The study was carried out at two intersections controlled by the signal coordination system, TRACS The intersections are located on the Gold Coast, one of the fastest growing regions in Australia, and it is important to know the latest traffic patterns at major intersections in the region on a routine basis. The method of minimum information requires the user to supply some prior information to achieve accurate and convergent solutions The accuracy levels for different types of prior information are described. The study shows that reasonable prior information is needed to produce correct estimates at some sites. Default information based on road types is recommended, together with the procedures for putting the method into practice.

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Introduction

The Gold Coast is one of the fastest growing regions in Australia. The current residential population is about 255,000. The total population including tourists could increase to 750,000 during peak holiday seasons. The traffic growth on certain routes has increased by 27 per cent in one year whereas the average growth rate in South East Queensland is about 5 per cent (MRD 1987; QDoT 1990). It is important to automatically obtain the latest traffic patterns at major intersections from a computerised control system, i.e. on-line.

The traffic signals in Gold Coast are controlled by the Traffic Responsive Area Control System (TRACS) of the Queensland Department of Transport (QDoT). The system is being developed as a device, not just to coordinate traffic signals, but also to monitor and estimate parameters such as demand, speed-flow relationship, delay and queue lengths (Lees 1990; Luk 1990). The aim of this paper is to describe the experience of applying TRACS to two Gold Coast intersections to monitor the intersection *turning* or *movement flows*.

Turning flows at an intersection are manually measured for traffic planning studies and intersection designs at present. The collection of these data is therefore labour intensive and is not undertaken at regular intervals. It could cost up to $ 1000 to collect 12-hour turning flows in a four-leg intersection in Gold Coast. On the other hand, traffic counts from loop sensors are now routinely monitored and stored on-line in an area traffic control (ATC) system such as TRACS in Queensland and SCATS in all other states. These loop counts often do not provide a full set of turning movements due to the sharing of a lane for, say, through and right-turning movements, or due to the use of a left-turn slip lane where there is no detector provision. There is thus a need to find a practical method to process routinely collected loop counts and produce turning flows that are up-to-date.

The estimation of a full set of turning flows from the traffic counts collected at the entry and exit approaches has been investigated by researchers such as Hauer, Pagitsas and Shin (1981), Van Vliet and Willumsen (1983), and Maher (1987). The solution method is known as the *principle of information minimisation*. This method (also called the method of maximum entropy or uncertainty) is an active area of research in academic institutions. However, the method has yet to be accepted in transport and road authorities for practical applications. This is mainly due to the complexities of the mathematics involved. The work in Gold Coast is an attempt to implement the theory, making use of the facilities in the TRAC system.

This paper provides the background information on TRACS and the principle of information minimisation. It provides the results of the turning flow estimation in Gold Coast, and recommends how the estimation procedure can be put into practice.

Background

The Traffic Responsive Area Control System

TRACS is now installed in Brisbane and other provincial cities such as Gold Coast, Sunshine Coast, Toowoomba and Cairns. It can select signal plans by time-of-day according to a predetermined time-table. It can also operate in a traffic responsive mode by selecting a plan that matches the prevailing traffic conditions. The system has many user-friendly features and extensive output graphics. Current research activities of the Department focus on the implementation of facilities for monitoring performance.

indices such as demand, speed-flow relationship, degree of saturation, delay, queue lengths and stops (Luk 1991).

In TRACS, traffic counts are routinely retrieved on-line from each vehicle detector every 15 min or every signal cycle. Each signal controller supports up to 16 detectors for gathering traffic counts and other information. The work described in this paper is an example of using the on-line traffic counting facilities in the control system.

The Study Sites

The two intersections are the junctions of Bermuda St with Rudd St and with Nerang Broadbeach Rd in the suburb of Broadbeach Waters (***Fig. 1***). They are 650 m apart and collectively represent a test site for the performance monitoring facilities. The two intersections have quite different patterns of turning flows. The Rudd/Bermuda St intersection, designated as Int. 5025, is a junction of Rudd St west (a local street), Rudd St east (a collector road) and Bermuda St (an arterial road). The other junction, designated as Int 5028, is an intersection of the two arterial roads - Nerang Broadbeach Rd and Bermuda St.

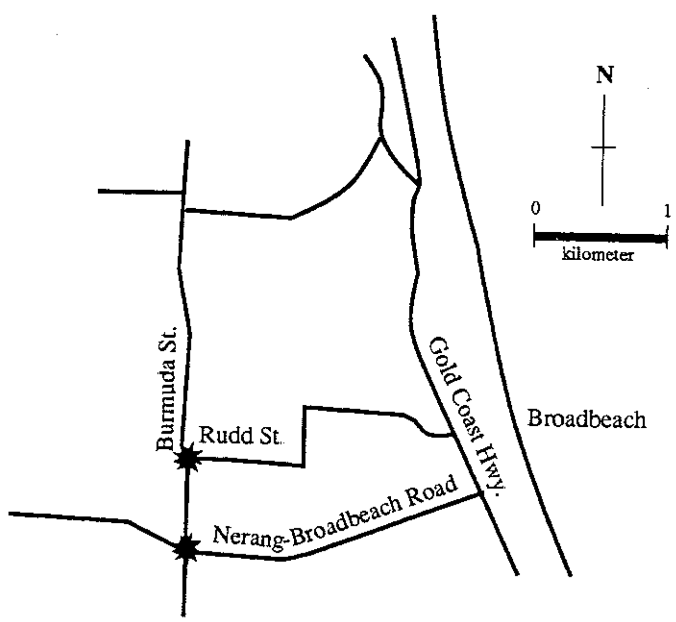

Fig. 1 - Study sites in Bermuda St, Gold Coast

In ***Fig. 2***, detectors 8 and 16 of Int 5025 are shared-lane detectors for through and turning movements. This intersection therefore needs the estimation technique described in this paper to obtain a full set of turning flows. On the other hand, each movement at Int. 5028 (***Fig. 3***) uses a separate detector. The limitation of 16 detectors per intersection in TRACS meant that the through movements at Int 5028 had to use one detector for several lanes as shown. The use of multi-lane detectors led to the loss of accuracy when traffic counts were collected for the present study

The detectors installed in each of the two intersections are numbered from 1 to 16 in ***Figs 2*** and ***3***. The current practice of QDoT is to install detectors at about 35 m on the arrival side of arterial roads for through movements, and near the stoplines for right-turn movements and for movements from side-streets. *Extra* detectors were installed for this study on the departure side and on slip lanes to allow the direct, on-line measurement of each turning movement, against which the accuracy of an estimated flow value was assessed

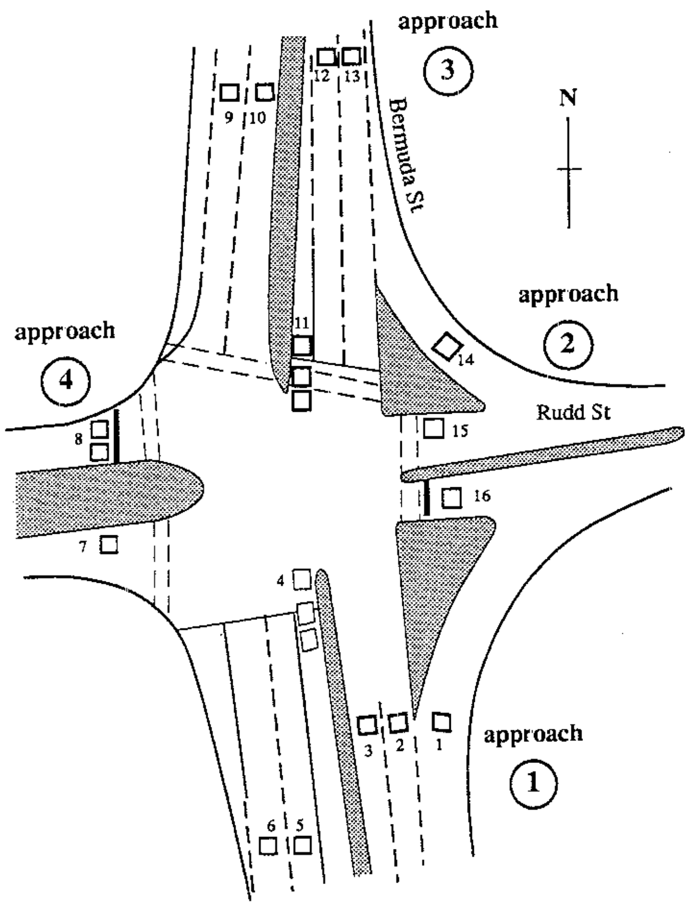

Fig. 2 - Rudd St/Bermuda St Intersection (Int. 5025) showing detector numbers

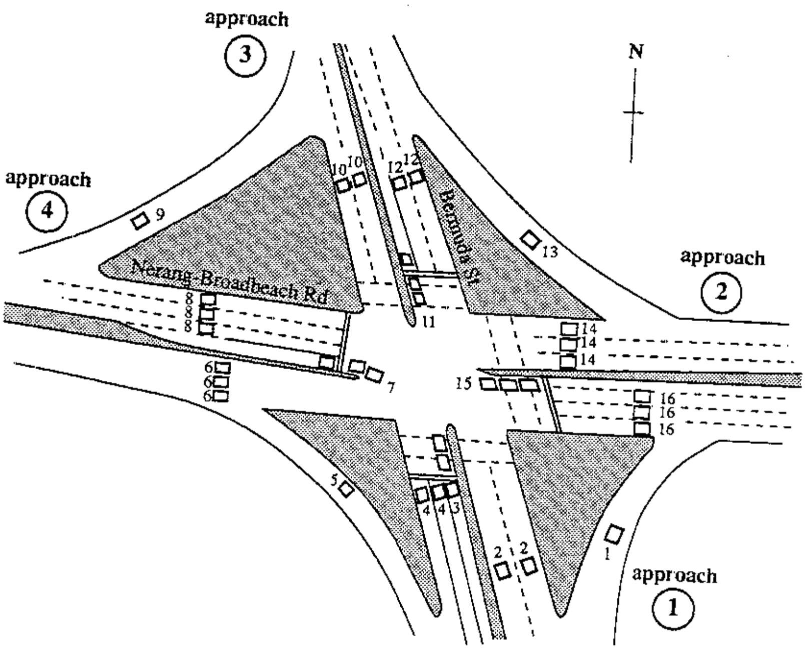

Fig. 3 - Nerang Broadbeach Rd/Bermuda St intersection (Int. 5028) showing detector numbers

Principle of Minimum Information

The development of the theory of information is usually attributed to the work of Shannon (1948) on secrecy codes at the Bell Research Laboratory in the US during the Second World War. A measure of the information (H) associated with an *event* (k) that occurs with a probability p_k is expressed as:

$$H = - \Sigma_k \, p_k \log_2 p_k$$

where $0 < p_k < 1$ and Σ_k *is a symbol representing the summation over the index k.*

Using the example of a dice, the probability p_k of getting 1, 2, ..., or 6 is 1/6 and the information required to determine the outcome is therefore:

$$H = - \Sigma_k \, (1/6) \log_2 (1/6) = 2.58 \text{ bits}$$

This case represents maximum uncertainty or entropy. If the dice is *loaded* so that, say, the probability of getting 1 or 2 or 3 is zero ($p_1 = p_2 = p_3 = 0$) and the probability of getting 4 or 5 or 6 is 1/3 ($p_4 = p_5 = p_6 = 1/3$), then the information required to determine an outcome is less and is given by:

$$H = - 3 \times [1/3 \log_2 (1/3)] = 1.58 \text{ bits}$$

In other words, the loading of the dice increases the information contained and reduces the uncertainty of an outcome.

In the context of estimating turning flows at an intersection, the following two types of information are required (***Fig.* 4**):

(a) the *entry* (origin) flows O_i and *exit* (destination) flows D_j for each approach, and

(b) some prior (often called *a priori*) information about the turning proportions p_{ij} from i to j.

Figure 4 illustrates the case of estimating the 12 unknown flows $\{T_{ij}\}$, i, j = 1 to 4, from eight known entry/exit flows (O_i, D_j) with the assumption that $T_{ij} = 0$ if i = j The formulation of the estimation problem is to find T_{ij} that satisfies the following constraints:

$$\Sigma_j \, T_{ij} = O_i$$

$$\Sigma_i \, T_{ij} = D_j$$

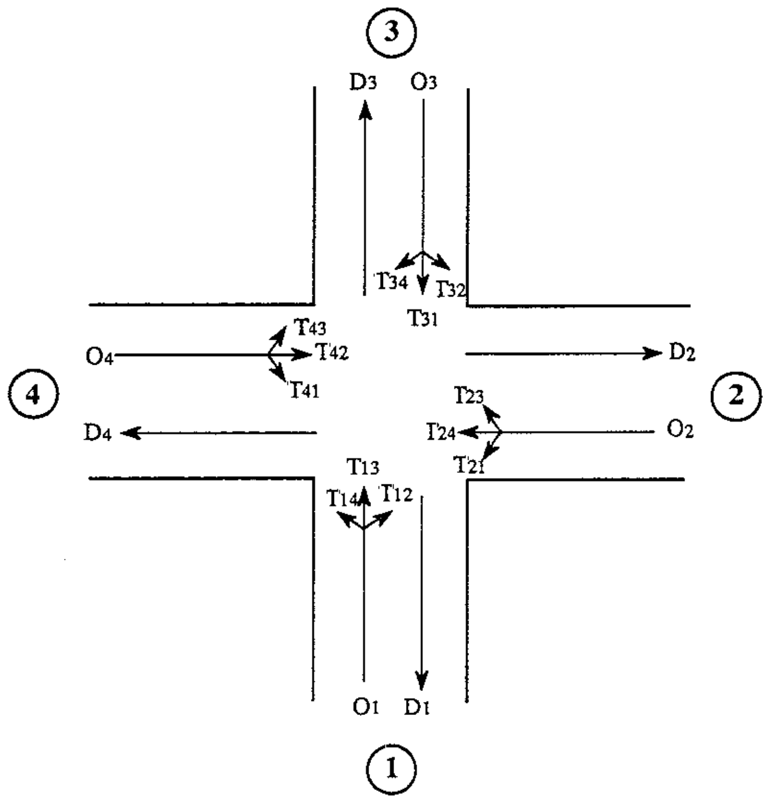

Fig. 4 - An intersection with four entry-exit approaches

The solution is *indeterminate* because the number of unknowns (12) is more than the number of equations available (8). One solution method is to balance the origin flow sums (O_i) and destination flow sums (D_j) iteratively while keeping $\Sigma_i O_i = \Sigma_j D_j$. This is called the *bi-proportional algorithm* and was implemented as a FORTRAN program in Luk (1989). This program, MINFO1, was used to obtain the turning flow estimates described below.

The bi-proportional algorithm attempts to minimise the 'distance' between the prior probabilities p_{ij} and the final solution. The convergent solution is one with the least amount of information in the feasible solution set. Prior information on p_{ij} can be obtained from the local knowledge of an intersection, or from on-site sampling of the turning proportions. In the absence of any such information, one can also assume, as a first guess, that the traffic from entry i is distributed equally to all exits j. In such case, the information content of the $\{p_{ij}\}$ matrix is essentially *zero*. An example of a 'zero prior information' matrix for i, j = 1 to 4 is as follows:

$$\{p_{ij}\} = \begin{bmatrix} 0 & .33 & .33 & .33 \\ .33 & 0 & .33 & .33 \\ .33 & .33 & 0 & .33 \\ .33 & .33 & .33 & 0 \end{bmatrix}$$

The following analysis used this zero information matrix as a reference. It represented the worst case situation, against which the benefit in having some prior information of p_{ij} was assessed

Conservation of Flows

If the turning flows at an intersection are manually observed flows, they are often adjusted if necessary to ensure *consistency* or the conservation of flows, i.e. the sum of entry flows equals to the sum of exit flows ($\Sigma_i O_i = \Sigma_j D_j$). The inductive loop counts retrieved on-line from an ATC system do not usually observe the conservation of flows. Loop counts could be inaccurate if the loop sensor is near the stopline and if the loop length is of similar length to the vehicle length, because vehicles that move slowly together could be treated as a single vehicle by the sensor. Other sources of errors include: undercounting due to one detector for multi-lane loops, overcounting due to single vehicles straddling over two adjacent loops, and transmission errors.

The loop counts from Int. 5028 (*Fig. 3*) were analysed to ascertain whether entry flows add up to the exit flow at each approach. For example, with conservation of flows, the sum of counts from detectors 7 and 12 on the arrival side of the intersection should be identical to the counts from detector 2 on the departure side.

The results in **Table 1** confirm that traffic counts can be quite inaccurate if a single detector is used for multiple lanes. In particular, the stopline detectors 4 and 15 on the arrival side undercounts by 32 per cent when compared with detector 10 on the departure side. Under congested flow conditions in a peak flow period, the discrepancy is expected to be even higher

Table 1 Comparison of entry and exit flow sums at each approach (Int. 5028)

Detectors on departure side		Detectors on arrival side		Percentage difference
Detector number	Flow sum veh/day	Detector number	Flow sum veh/day	%
2	7289	7, 12	7390	1
6	9970	11, 16	9676	- 3
10	8061	4, 15	5466	- 32
14	6664	8, 3	8001	20

The program, MINFO1, has the facility to ensure the conservation of flow and hence to produce a *self-consistent* set of turning flows. The entry and exit flow sums are made equal using the following modification (Van Zuyland 1979):

Let $O_i' = O_i(1+y)$

and $D_j' = D_j'(1-y)$

with $y = (\Sigma_j D_j - \Sigma_i O_i)/(\Sigma_j D_j + \Sigma_i O_i)$

where O_i and D_j are the TRACS-measured entry and exit flow sums, and O_i' and D_j' are the modified entry and exit flow sums.

The modification ensures that $\Sigma_i O_i' = \Sigma_j D_j'$ and equal to a value intermediate between $\Sigma_i O_i$ and $\Sigma_j D_j$. The above transformation is carried out in the program before the *turning flows*, $\{T_{ij}\}$, with i, j = 1 to 4 are calculated.

Analysis and Results of Turning Flow Estimation

Hourly traffic counts at the two study sites were retrieved from TRACS on Wednesday 9/5/1990 and used in the following analysis. MINFO1 produced the estimates for each hour from 7 a.m. to 7 p.m., but the results reported below were based on the a.m. and p.m. peaks. Manual counts previously collected on Tuesday 7/3/1989 for Int. 5025 were also available for comparison with the estimated flows.

Rudd Street/Bermuda Street Intersection

Referring to ***Fig. 2***, the western approach (designated as 4) leads from/to a residential street. From the knowledge of the traffic pattern at this intersection, the percentage of traffic entering this approach from other approaches was set to 4 per cent (p_{i4} = .04 for i = 1 to 3), and the traffic from this approach was assumed to distribute equally to the other three approaches (p_{4j} = 0.333 for j = 1 to 3). It was also assumed that 20 per cent of the arterial traffic turned into the collector road, Rudd St east ($p_{12} = p_{32}$ = .20). The other {p_{ij}} values were $p_{21} = p_{23}$ = 0.48, again assuming equal distribution from entry 2 to exits 1 and 3. Hence, the prior turning proportions {p_{ij}} for this intersection were as follows:

$$\{p_{ij}\} = \begin{bmatrix} 0 & .20 & .76 & .04 \\ .48 & 0 & .48 & .04 \\ .76 & .20 & 0 & .04 \\ .33 & .33 & .33 & 0 \end{bmatrix}$$

The estimation of both the a.m. and p.m. peak flows used the above set of turning proportions. These p_{ij} values can be regarded as a *reasonable* set available from local knowledge of the intersection. As already mentioned, a set that does not make use of prior information is equivalent to p_{ij}'s with uniform distribution, i.e. p_{ij} = 1/3 for i not equal to j. The results for both sets of prior turning proportions were obtained with MINFO1.

Tables 2 and **3** provide the results of comparing the estimates of the turning flows {T_{ij}} with observed movement counts. The summary statistics are shown in **Table 2**. An estimation *error* is defined as the difference between the observed and the estimated turning flow values. The R^2-terms and estimation errors for the cases of *reasonable* and *zero* prior information are given.

All turning flow values are shown in **Table 3**. Note that the total observed counts are 2948 (a.m. peak) and 3270 (p.m. peak) and are similar to the corresponding adjusted loop counts of 3085 and 3051. The estimated turning flows were normalised so that the total count value is the same as the observed value in each peak period. (Normalised values were used to calculate the statistics in **Table 2**.) They were also regressed against the non-zero observed turning flows as shown in ***Fig. 5***.

Table 2 Comparison of estimated and observed turning flows from Int. 5025

Case	Correlation R^2	Mean % error
Reasonable prior information	0.98	- 13
Zero prior information	0.98	- 12

Notes: Mean % error = 100 % x [Σ_k (E_k-O_k)/O_k]/24, where E_k and O_k are the estimated and observed values of turning flow k, k = 1, ..., N and N is the total number of non-zero turning flows in the a.m. and p.m. peaks (N = 24).

Table 3 Observed and estimated turning flows $\{T_{ij}\}$ from Int. 5025

Observed flows
7/3/1989 Tuesday

A M peak

		Exit number 1	2	3	4	Total
Entry no.	1	0	132	1158	18	1308
	2	94	0	282	9	385
	3	904	298	0	4	1206
	4	16	15	18	0	49
Total		1014	445	1458	31	2948

P.M. peak

		Exit number 1	2	3	4	Total
Entry no.	1	0	107	909	16	1032
	2	123	0	254	16	393
	3	1351	426	0	12	1789
	4	28	16	12	0	56
Total		1502	549	1175	44	3270

MINFO1-estimates
(with reasonable p_{ij}'s)
9/5/1989 Wednesday

A.M. peak

		Exit number 1	2	3	4	Total
Entry no.	1	0	144	1398	6	1548
	2	74	0	240	2	315
	3	879	292	0	12	1183
	4	7	9	23	0	39
Total		960	445	1660	20	3085

P M peak

		Exit number 1	2	3	4	Total
Entry no	1	0	70	1048	4	1121
	2	57	0	258	1	316
	3	1202	365	0	19	1586
	4	4	5	19	0	28
Total		1263	440	1324	24	3051

With $R^2 = 0.98$, excellent correlation between estimated and observed values were obtained for both cases of prior information. Due to the dominant flow along the arterial road, accurate estimation was possible even with zero prior information when all entry flows were assumed to distribute equally to all exits. An error of -12 to -13 percent is also acceptable for traffic planning and signal design purposes.

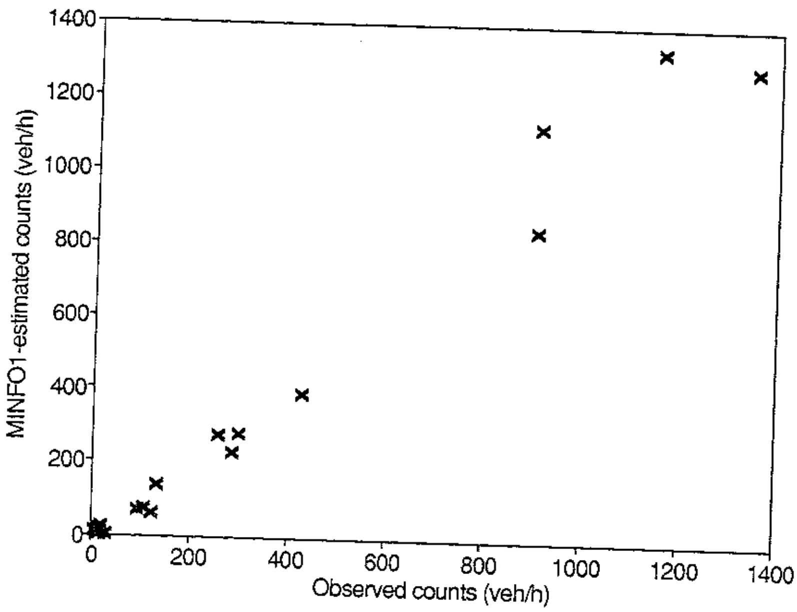

Fig. 5 - Comparison of estimated and measured turning flows at Rudd St/Bermuda St intersection

A second comparison was also carried out for this intersection. This comparison was between the TRACS turning flows retrieved on-line and the estimated turning flows. Two detectors at Int. 5025 are shared-lane detectors - detector 8 of approach 4 in ***Fig. 2*** monitors both the through and the left-turning movements and detector 16 of approach 2 monitors both the through and right-turning movements. Hence, the corresponding turning flow estimates from MINFO1 were aggregated for direct comparison with the TRACS flows. The assessment statistics (using reasonable prior information) are $R^2 = 0.99$ with a mean percentage error of 6 per cent. These statistics are slightly better than those obtained on the basis of single movement flow due to the aggregation, and because the TRACS and the estimated flows were of the same day. The principle of minimum information therefore works well for this intersection.

Nerang Broadbeach Road/Bermuda Street Intersection

The differences between this intersection (Int. 5028) and the previous intersection (Int. 5025) are summarised again below:

(a) It is a junction of two arterial roads and its '*information content*' is minimal - there is more uncertainty in estimating turning flows.

(b) Every movement at this intersection is monitored by a separate detector, but multi-lane detectors were used for all through movements, e.g. detectors 2, 4, and 6.

(c) Due to the rapid development near the intersection, the turning flow pattern will remain variable for some time. Hence, there is the need to implement comprehensive on-line monitoring facilities at this intersection.

(d) Up-to-date manual counts are not available for assessing the accuracy of estimation. The assessment is therefore by comparing TRACS-measured flows and estimated flows.

The analysis began with adjusting the entry and exit flow sums to achieve the conservation of flows. All estimated turning flows were compared with the corresponding TRACS-measured flows at the following three levels of prior information:

(a) *measured* information - the prior turning proportions were determined from the TRACS turning flows measured on-line, and varied by time-of-day:

$$\{p_{ij}\}_{\text{a.m.}} = \begin{bmatrix} 0 & 083 & .492 & .425 \\ .049 & 0 & .317 & 634 \\ .382 & .407 & 0 & .211 \\ 118 & .487 & .395 & 0 \end{bmatrix}$$

$$\{p_{ij}\}_{\text{p.m.}} = \begin{bmatrix} 0 & .084 & .445 & 472 \\ .058 & 0 & .230 & .712 \\ .397 & .418 & 0 & 185 \\ .220 & .485 & .295 & 0 \end{bmatrix}$$

(b) *reasonable* information - this level again represents the availability of historical data on turning proportions or from on-site sampling. The values for both a.m. and p.m. period were as follows:

$$\{p_{ij}\}_{\text{a.m./p.m.}} = \begin{bmatrix} 0 & .1 & .5 & .4 \\ .1 & 0 & .3 & 6 \\ .4 & 4 & 0 & .2 \\ .2 & 5 & .3 & 0 \end{bmatrix}$$

(c) *zero* information - all traffic from each entry was assumed to distribute equally to the three exits, i.e. $p_{ij} = 1/3$ for i not equal to j.

The results are shown in **Table 4** and illustrated in ***Fig. 6***. The R^2-terms for the cases of measured and reasonable prior information are about 0.9 with a mean error less than 7 per cent. There is a large increase in the percentage error in the absence of any prior information. This is due to the nature of Int. 5028 - an intersection of two arterial roads with uncertain turning proportions. An intersection of this type would require some prior information to obtain meaningful estimates. The results also indicate that a good knowledge of the local intersection is sufficient for MINFO1 to produce a high level of accuracy.

Figure 7 further illustrates the close correlation between the estimated and measured turning proportions at the reasonable level of prior information over a 24 h period for the movements from entry 2 to exits 3 and 4.

Table 4 Comparison of estimated and TRACS turning flows from Int. 5028

Case	Correlation R^2	Mean % error
Measured prior information	0.92	2
Reasonable prior information	0.90	- 7
Zero prior information	0.36	- 49

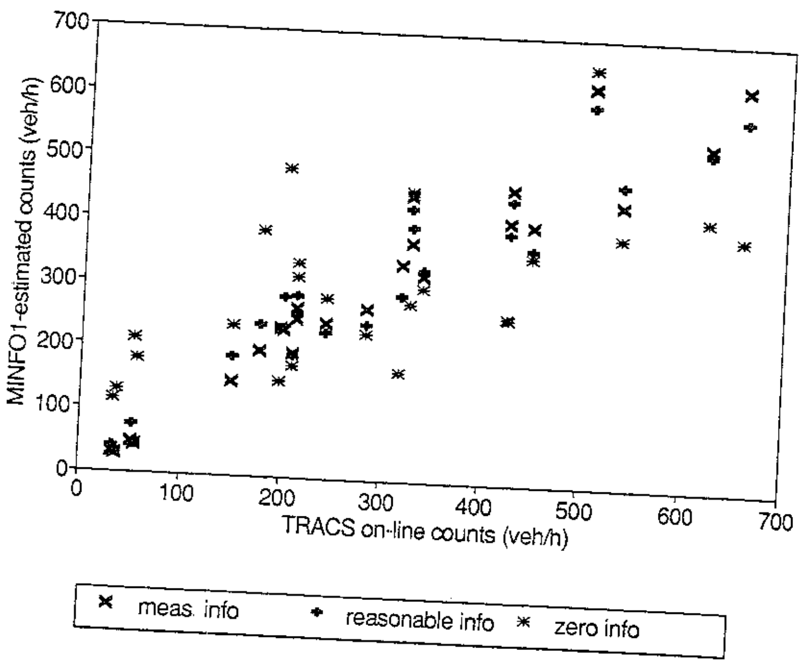

Fig. 6 - Comparison of estimated and TRACS turning flows at Int. 5028 with three levels of prior information

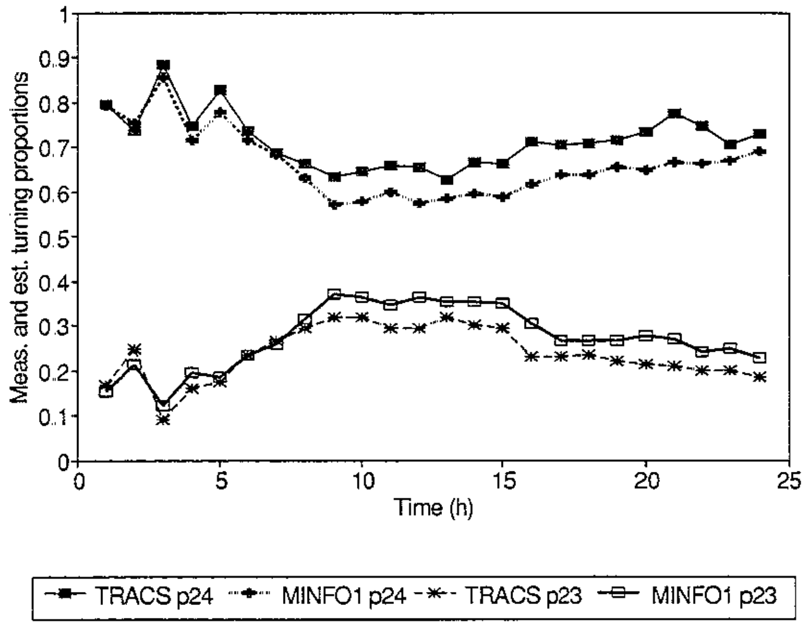

Fig. 7 - Variation of turning proportions from entry 2 to exits 3 and 4 at Int. 5028

Discussion

Default Prior Information

The results from the two intersections in Bermuda St suggest that meaningful prior turning proportions are required at some intersections to obtain correct estimates of turning flows. Apart from the local knowledge or on-site sampling, it is also possible to determine sensible values from the road types at an intersection. **Table 4** summarises the average values reported in Hauer et al. (1981) for the city of Toronto and those obtained by the first author for Parramatta, Sydney.

There are some similarities in the range of values from these two cities. The turning proportions from collector roads to arterial roads are in the range from 17 - 30 per cent, and are higher than those from collectors to collectors (less than 20 per cent). It is recommended that these should be the *default* values in the absence of historical or on-site measured data. The collating of left- and right-turning proportions at typical sites for different road types is useful and is recommended to research students.

Table 4 Default turning proportions p_{ij} based on road types

	Toronto*				Parramatta			
	Collector		Arterial		Collector		Arterial	
Turn type	LT	RT	LT	RT	LT	RT	LT	RT
Collector	.20	.18	.17	.35	20	.10	.32	.30
Arterial	.05	.04	12	.12	10	.06	-	-

* For consistency in this table, a left turn (LT) and a right turn (RT) in Toronto have the same meaning as those in Sydney;
\- Data not available.

Implementation

The principle of minimum information can be put into practice in the following ways:

(a) Automatic vehicle counters are used to collect traffic flows on all entry and exit approaches of an intersection, i.e. to collect the set of $\{O_i, D_j\}$. The turning flows are then determined with a program such as MINFO1.

(b) Turning flow proportions are sampled at different times of the day. These values are used as the prior information to estimate turning flows from traffic counts retrieved from a signal control system at 15 min intervals. A team of counting officers (at \$ 1000 per day) can be scheduled to sample turning proportions at, say, four intersections in one day instead of collecting 12-hour flows for one intersection. The cost of obtaining 12-hour turning flow estimates becomes \$ 250 per intersection.

(c) MINFO1 can be easily implemented in TRACS and run as an on-line, concurrent task in the background. (A listing of the program is provided in Luk (1989)). It can also be used as an off-line program to produce a consistent and complete set of turning flows off-line at the two intersections in Bermuda St, and at any other intersections.

(d) At sites where the entry and exit flows, $\{O_i, D_j\}$, are incomplete due to, say, the absence of detectors at left turn slip lanes, the principle of minimum information can still produce a convergent solution. The accuracy of estimation will be affected and prior information becomes critical in achieving a correct solution. This issue was investigated with data retrieved from the SCAT system in Melbourne. A second but similar computer program, called MINFO2, was developed to handle such cases and readers are referred to Luk (1989) for more detail (see also the discussion on network implication below).

As a result of this study, the Nerang District installed a second controller at the intersection of Nerang Broadbeach Rd and Bermuda St to provide extra detector channels (because TRACS supports only 16 detectors per controller). Each lane of traffic flow is now monitored by a detector. This should further improve the accuracy of all turning flow estimates.

Network Implication

The principle of minimum information was implemented in the computer program, ME2 (Van Vliet and Willumsen 1983) for estimating origin-destination (OD) trip matrices for a network from traffic counts. The estimation of intersection turning flows is a special case of the network OD estimation problem. This is because a network problem involves trip estimation, not only from origin i to destination j, but also the paths selected for these trips. At an intersection, there is no uncertainty on the choice of path - only one path is needed for a movement from i to j. A *convergent* solution is most likely a *correct* solution. The equivalent network problem would have more uncertainty in a convergent answer. It is hoped that the studies in Gold Coast and Melbourne, together with MINFO1 and MINFO2, would cast some light into overseas software that is often treated as a 'black box'.

Conclusions

This paper has demonstrated the practicality of utilising the principle of minimum information for estimating a complete set of turning flows at intersections where traffic counts can be retrieved from a traffic control system. Routine reporting of these turning flows can now be achieved at two study sites in Gold Coast by making use of the TRACS counts and a computer program such as MINFO1. These turning flows will be consistent, i.e. they will observe the conservation of flows, and can be available at any time of the day. If the need to study the flow pattern is urgent and frequent, it is recommended that MINFO1 be implemented in TRACS as an on-line subroutine.

The method of information minimisation requires the user to supply some prior information on the turning flows. This study has found that reasonable prior information at some intersections are necessary to secure convergent and accurate estimates of the turning flows. Average values based on the road types at an intersection are recommended as the default prior turning proportions. Procedures for putting the method into practice are outlined and substantial cost savings can be achieved with this method.

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