TESTING AND COMPARISON OF ALTERNATIVE TRAFFIC ASSIGNMENT TECHNIQUES FOR THE GREATER MELBOURNE ROAD NETWORK

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ABSTRACT: *Recent additions to the traffic assignment literature have introduced theoretical concepts of equilibrium network loading procedures, though validation has largely been confined to synthetic network or small urban road systems. Despite theoretical and practical developments, relatively few applications are being made of equilibrium algorithms in Australia, even though they are available in transport planning packages such as the Urban Transportation Planning System. At the same time, scant attention has been directed towards the development of evaluation criteria which properly assess the accuracy of assignment models and effectiveness of traffic assignment techniques. This paper outlines and demonstrates suitable assignment performance measures. In so doing, the analysis aims to assess the suitability of the equilibrium assignment vis-a-vis conventional assignment techniques, for application to a large Australian urban network. The study will focus upon the Greater Melbourne road network consisting of 4453 modes, 736 zones and 5350 two way links. It is shown that a combination of tests which are sensitive to the objective(s) of the investigation is a more practical alternative than a single measure of assignment performance. This paper also concludes that multipath, equilibrium assignment techniques are better suited to the Greater Melbourne urban road network, and more generally to road networks experiencing congestion.*

INTRODUCTION

The past decade and a half has seen the problem of assigning drivers to large congested urban road networks addressed by a growing array of quantitative techniques. These range from approximate solution techniques such as all-or-nothing and multipath procedures to incremental and iterative capacity restrained algorithms, and more recently, equilibrium network loading procedures.

Relatively few applications are being made of the more sophisticated equilibrium techniques in Australia despite ongoing theoretical and practical developments and their availability in transportation planning packages (such as the Urban Transportation Planning System 1979). Eash, Janson and Boyce (1979) have noted the reluctance of planners to implement the more recent assignment methods and concluded that this is partially attributable to a lack of evidence concerning the new equilibrium techniques performance in large scale operations.

Though a significant proportion of research in transportation planning has been devoted to the development of assignment techniques, scant attention has been directed towards the development of evaluation criteria which assess the accuracy of assignment models and allow the planner to make normative statements about the effectiveness of traffic assignment techniques.

The objective of this paper is to propose and demonstrate suitable assignment performance measures. In so doing, the analysis aims to assess whether the fixed demand all or nothing (A/N) or multipath equilibrium assignment, as outlined in the Urban Transportation Planning System (UTPS) is superior to other Federal Highway Administration (FHWA) techniques (such as fixed demand all or nothing incremental loaded assignments), when applied to a large Australian urban road network.

The paper is directed at those practitioners concerned with the assignment of trips on large urban road networks. It is assumed that the reader is familiar with the assignment techniques currently available in the UTPS and FHWA planning packages,though a brief description of the assignment techniques used in this study and their relative merits is given in Apelbaum and James (1982).

Initially the paper will propose and discuss techniques which may be useful in assessing assignment performance, followed by an outline of the various parameters used in the nineteen test assignments. The study focuses on the Greater Melbourne road network consisting of 4453 nodes, 736 zones and 5350 two way links. The final two sections will summarise and conclude the findings of the study.

TESTING ASSIGNMENT MODEL PERFORMANCE

The problem of selecting an appropriate quantitative measure (or perhaps a combination of measures) is compounded by the various means by which traffic assignment models can be evaluated including the degree of convergence, the extent to which the assignment technique satisfies underlying theoretical considerations and the overall accuracy between the observed link volume counts and assigned volumes. This section will propose and discuss techniques which may be useful in assessing assignment model performance. The tests have been divided into three categories ;

(1) Parametric tests - tests where models specify certain conditions about the distribution of the population from which the research sample was drawn. The significance of the results depends on the validity of the assumptions. The information gain test will be considered in this category.

(2) Non Parametric tests - tests where models do not specify conditions about the distribution of the population from which the sample was drawn; includes ratio, correlation co-efficient, mean and standard deviation of differences, mean absolute error, (percent) root mean square error, Theil's inequality co-efficient, the Chi Square test and Kolmogorov Smirnov two sample test.

(3) Tests of assignment criteria - assess the ability of a particular assignment to satisfy the underlying theoretical philosophy of the assignment methodology (1). Tests to be examined include Murchland's delta, Van Vliet's delta and the error term.

Parametric Test

Batty and March (1976) examined the form of information gain for application in trip distribution model evaluation. The concept is derived from Bayes Theorem which relates prior and posterior probabilities to a monotonic likelihood function. The formulation of information gain, as described by Batty and March, and applied to assignment of fixed travel demand, is described by ;

$$I\ (p^{II} : p^{IIO}) = \sum_i P_i \ln \frac{P_i}{P_i^o} \qquad (1)$$

where P_i^o = prior probability of a vehicle travelling on link i.

P_i = posterior probability of vehicle travelling on link i.

1 In this application, Wardrop's user equilibration criterion, which states that no user can improve his or her travel time (or reduce travel costs) by unilaterally changing routes.

When the posterior probability equals the prior probability then $I\ (p^{II} : p^{IIO})$ equates to zero and the assigned volumes are considered a perfect fit against observed volumes.

Information gain was applied by Smith and Hutchinson (1981) for determining the most appropriate goodness of fit test for alternative trip distribution models. They noted that a simulation which has a single over estimation balanced by a large number of smaller underestimates could appear worse than one in which very large over and under estimates tended to occur in equal numbers. A similar situation is experienced in the analysis of assignment models, and as a result, equation 1 was modified to derive absolute values such that ;

$$I\ (p^{II} : p^{IIO}) = \sum_i P_i \left| \ln \frac{P_i}{P_i^o} \right| \qquad (2)$$

Where $P_i^o = \frac{E_i}{T_E}$ and $P_i = \frac{O_i}{T_o}$

E_i = the assigned volume on link i

T_E = is the total expected (or assigned) trips

T_o = is the total observed trips. (counts)

O_i = the observed volume on link i

Non-Parametric Tests

Non-parametric tests do not imply conditions about the distribution of a population though they do assume that observations are independent events and that the variable being examined has underlying continuity. The assumptions relating to non-parametric tests are considered weaker than conditions specified by parametric tests.

Ratio of assigned to count volumes

This is a commonly used test (Edwards and Robinson 1977, Smith and Brennan 1980; Boyce, Janson and Eash 1981) that ranks assignment performance according to the ratio of assigned volumes to count volumes. It is represented mathematically by ;

$$\text{Mean Ratio} = \frac{\sum^{n} \frac{E_i}{O_i}}{n} \qquad (3)$$

Where E_i = assigned volume on link i,

O_i = observed volume on link i,

n = number of links with both assigned and count volumes in the network or within a particular road category.

Variations of the ratio include ;

- screen line assigned volumes to screen line count volumes
- assigned vehicle miles of travel to count vehicle miles of travel
- route assigned volumes to route count volumes

A ratio of one (1) indicates a perfect fit between assigned and count volumes. Care must be taken in applying the test for assignments where some links in the network are assigned volumes in excess of observed values, whilst others are assigned lower volumes than that observed. The factor to be examined is not the actual value of the ratio, but the magnitude of the difference between the ratio and one (1) such that

$$\text{Mean Absolute Difference ratio} = \frac{\sum_{n} \left| 1 - \frac{E_i}{O_i} \right|}{n} \qquad (4)$$

The point is best illustrated by an example. Assume a six (6) link network with the following assigned to count volume ratios :

Link	Ratio
1	1.35
2	0.65
3	1.40
4	0.90
5	0.60
6	1.10

The ratio test as defined in equation (3) would sum the ratios and divide by the total number of links, resulting in a perfect value of one (1). The implication is that the assignment algorithm accurately simulates existing assignment behaviour which it clearly does not. The more correct value of 0.28 as defined by equation (4) indicates the magnitude of the deviation from unity, the lower the value the better the fit of assigned to observed values. The ratio as defined by equation (3) is still useful in indicating whether the assignment technique under or over assigns trips for a specified network and trip table.

Correlation co-efficient

The sample correlation co-efficient (r) tests the degree of linearity between two independent variables. If there exists n pairs of (Oi, Ei) which represent a sample size n from a bivariate population then;

$$r(O_i,E_i) = \frac{n \sum_i O_i E_i - \sum_i O_i \sum_i E_i}{\left[\left\{n \sum_i O_i^2 - \sum_i (O_i)^2\right\}\left\{n \sum_i E_i^2 - \sum_i (E_i)^2\right\}\right]^{1/2}} \quad (5)$$

The closer $r(O_i,E_i)$ approximates to -1 or +1, the better the fit of assigned to observed volumes.

Mean and standard deviation of differences

The mean and standard deviation (S.D) have the following format ;

$$\text{Mean} = \frac{\sum_i^n (O_i - E_i)}{n} \quad (6)$$

$$S.D = \left[\frac{\sum_{i=1}^n (O_i - E_i)^2 - \frac{\sum_{i=1}^n (O_i - E_i)^2}{n}}{n-1}\right]^{1/2} \quad (7)$$

The mean value, as defined by equation (6), can give misleading results when the differences between observed link counts and assigned link volumes are either positive or negative. In these circumstances negative differences cancel a portion of the positive differences or vice versa.

The mean value being sought and adopted in this study is the mean absolute value described by ;

$$\left|\text{Mean}\right| = \frac{\sum_{i=1}^n \left|O_i - E_i\right|}{n} \quad (8)$$

The lower the value of the mean absolute difference, the better the fit of assigned to count volumes.

When comparing the capabilities of an assignment technique to simulate flows for a particular road category, a normalising procedure needs to be applied to take account of the difference in average volumes. A percentage mean absolute value was calculated for each road category, according to ;

$$\% \left| \text{mean} \right| = \frac{\left| \text{mean} \right|}{\text{Average Count Volume for the road category}} \times \frac{100}{1} \qquad (9)$$

Mean absolute error

The mean absolute error (MAE) has been applied in the evaluation of trip distribution models (Smith and Hutchinson 1981). For application in assignment model performance assessment, the error equation has been modified to ;

$$\text{MAE} = \frac{\sum_{i=1}^{n} \left| O_i - E_i \right|}{n^2} \qquad (10)$$

The lower the error term, the better the fit between observed and assigned volumes.

MAE is a suitable test for assessing assignment model performance assuming that n, the number of links is the same for all test types. Alternatively, if comparing the ability of an assignment algorithm to simulate link volumes for different link types (for example minor roads and freeways) then the comparison may be biased to that road category type which represents the larger proportion of links in the network.

Root mean square error

The root mean square error is described by

$$\text{RMS error} = \left[\sum_{i=1}^{n} \frac{(O_i - E_i)^2}{n} \right]^{\frac{1}{2}} \qquad (11)$$

The test has received widespread application in recent times (Smith and Brennan 1980, Edwards and Robinson 1977, Oxlad 1976 and Black and Salter 1975). For perfect fit, the RMS error value equates to zero; the least value of the error indicates the best model or the best variation of a particular assignment technique.

The RMS error as described by equation (11) is suitable for comparing assignment techniques over an entire network, as the number of links per road category remains constant. However, when comparing the effectiveness of an assignment technique to simulate volumes for various road types, biases may be introduced by the squaring of differences which are inherently large, due to the large volumes carried by a higher capacity link, and comparing these to low capacity links. To overcome this bias, the percent root mean square error test was applied and is described by ;

$$\%\ \text{RMS error} = \frac{\text{RMS error}}{\text{Av. Count Volume for the road category}} \times \frac{100}{1} \qquad (12)$$

Theils Inequality Co-efficient

A technique determining the ratio of the root mean square error to the sum of the root mean squares of the ground counts and assigned volumes was developed by Theil (1965) and has the following form;

$$U = \frac{\left[\dfrac{\sum_{i=1}^{n} (O_i - E_i)^2}{n}\right]}{\left[\dfrac{\sum_{i=1}^{n} (E_i)^2}{n}\right]^{\frac{1}{2}} + \left[\dfrac{\sum_{i=1}^{n} (O_i)^2}{n}\right]^{\frac{1}{2}}} \qquad (13)$$

U values of zero indicate perfect fit.

Chi Square and Kolmogorov-Smirnov two sample tests

One of the major drawbacks of the previous non-parametric tests is that they do not indicate whether the differences between observed and assigned link volumes are significant. Oxlad recognised this deficiency and proposed that tests of significance, such as the Chi Square (X^2) and Kolmogorov Smirnov (K-S) two sample tests, be considered when testing assignment model performance.

In particular, Oxlad recommended the use of the K-S test for the following reasons;

. when compared with the t test, the K-S test has a higher power efficiency for small samples.

. is more powerful than the X^2 or median test.

Let us briefly consider the mechanics of the Chi square and Kolmogorov-Smirnov two sample test and examine whether both non-parametric tests are indeed suitable for assessing the performance of various assignment techniques.

Chi Square (X^2)

The X^2 test determines goodness of fit between the frequency distribution of the assignment model and that of observed volumes. The hypothesis tested is that the assignment model produces a link volume distribution which is not significantly different from that of the ground counts, on the basis of a defined significant level, which is the probability or risk of falsely rejecting the hypothesis.

The form of the statistic is as follows ;

$$X^2 = \sum_{1}^{n} \left[\frac{(F_{O_i} - F_{E_i})^2}{F_{O_i}} \right] \qquad (14)$$

Where F_{O_i} = number of links with ground counts in i^{th} interval.

F_{E_i} = number of links with assigned counts in the i^{th} interval.

n = number of links.

The values of X^2 are distributed approximately as Chi Square with degrees of freedom equated to (r-1) (k-1),where r is the number of row's and k is the number of columns in the contingency table.

The procedure for assignment model application is to split the link (or route) volumes into categories, determine the frequency per category and evaluate the X^2 value. If the X^2 value is greater than that of the distribution value then the hypothesis is rejected. The user must ensure that the total expected volume is equivalent to the total observed volume. For further detailed theoretical explanation see Siegel (1956).

The Kolmogorov-Smirnov/two sample test

The K-S statistic tests whether two independent samples have been drawn from the same population. Essentially, the two sample test is concerned with agreement between two sets of sample values. If the two samples come from the same population,then cumulative distributions are expected to be equivalent except for random differences. A significant deviation between cumulative distributions is evidence to reject the null hypothesis; that the observed and assigned counts come from the same population.

As with the X^2 statistic, link volumes are split in equal intervals enabling the determination of cumulative frequency distributions. For each interval, one distribution is subtracted from the other. Unlike the X^2 test which considers the relative importance of all deviations, the K-S test focuses upon the largest deviation. (See Siegel 1956, for a mathematical definition of the test).

Though the K-S test is a powerful statistical test when comparing observed and expected distributions, the concept of comparing frequency distributions is detrimental to assessing the capabilities of a particular assignment technique in simulating link or route volumes. Consider the hypothetical network shown in Figure 1.

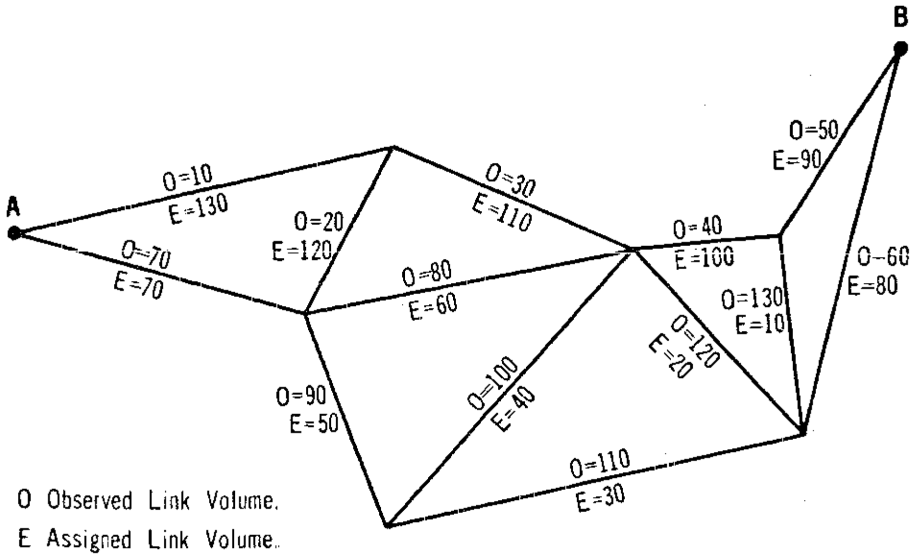

FIGURE 1. HYPOTHETICAL NETWORK.

If a X^2 or K-S two sample test were applied both tests would conclude that the assigned volumes fit the observed volumes as the frequency distributions (assuming equal intervals) are identical. However, inspection of the network volumes indicates sizable differences between the observed and assigned volumes. The only conclusion that can be drawn is that the assignment algorithm produces a similar proportion of trips per interval to that of the observed volumes.

Tests of Assignment Criteria

Previous parametric and non parametric tests relied on comparing assigned volumes to count volumes, and as a result assumed that errors in measuring count volumes were sufficiently low as to not bias results. One means of overcoming the problem of introducing count volumes into assignment performance assessment is to investigate how closely the assignment technique satisfies Wardrop's user equilibrium criteria.

Three such assessment techniques are proposed ;

- Murchland's delta
- Van Vliet's delta
- Error term

Murchland's delta

Murchland (1969) quantified the degree of convergence and showed that an upper limit on the difference between total network travel cost and the cost incurred if all trips travelled via the minimum path is set by δ such that ;

$$\delta_M = \sum_a C_a F_a - \sum_{i,j} T_{ij}\, C^*_{ij} \qquad (15)$$

Where C_a = cost of travel on link a

F_a = flow on link a

T_{ij} = number of trips from origin i to destination j

C^*_{ij} = minimum cost of travel along route R_{ij}

A value of zero indicates perfect fit.

Murchland's δ is, in fact, a measure of excess travel cost.

Van Vliet's delta

Van Vliet adopted a slightly different variation by expressing δ as a fraction ;

$$\delta_W = \frac{\sum_a C_a F_a - \sum_{i,j} T_{ij}\, C^*_{ij}}{\sum_{i,j} T_{ij}\, C^*_{ij}} \qquad (16)$$

A value of zero indicates perfect fit.

Error term

This is adopted by the UTPS program and similarly to Van Vliet's delta and Murchland's delta, can be used as a measure of assignment performance. It is described by -

$$e_2 = \frac{\underset{a}{CaFa} - \sum_{i,j} T_{ij}\, C^*_{ij}}{\sum_{a} CaFa} \qquad (17)$$

SELECTION OF PARAMETER VALUES

As well as assessing the effects of combining various traffic dispersion criteria with network loading algorithms, the study aimed to identify the most suitable set of values from the following input parameters;

- impedance function[1] weightings
- number of equal increments
- number of iterations
- theta (θ)
- delay factors - at freeway exits and entries
- toll values

The parameter specifications for the nineteen test assignments are shown in Table 1 as a two (2) dimensional matrix (impedance function by number of equal increments) for the FHWA, A/N, incremental loading, fixed demand assignments, and a three (3) dimensional matrix (number of iterations by impedance function by theta) for the UTPS A/N or multipath, equilibrium loaded, fixed demand assignments.

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1. The following impedance function was adopted (as prescribed by the FHWA and UTPS programs)
   Impedance = CTIME x T + CDIST x D (Non toll links)
   CTIME = time co-efficient in impedance per hour
   T = travel time per link (in hours)
   CDIST = distance co-efficient in impedance per kilometre
   D = length of link in hundredths of kilometres

   For toll links CTOLL is substituted for CDIST. CTOLL is impedance per dollar of toll.

TABLE 1: TABULATION OF LABEL NUMBERS BY PARAMETER SPECIFICATION FOR F.H.W.A. AND U.T.P.S. ASSIGNMENTS*

IMPEDANCE FUNCTION									
TIMEWT	1.0	1.0	1.0	2.0		3.0		4.0	
DISTWT	20.0	0.0	1.0	1.0		1.0		1.0	
F.H.W.A. No. of equal Increments 4		1	2	3		4,6+		5	
5		7							
U.T.P.S.	THETA			THETA		THETA		THETA	
No. of Iterations	0.00			0.00	0.15	0.00	0.15	0.00	0.15
4				10			2	12	
5	1					5	4		
6 }						6⊥ 7T╪			
						8⊥			
8					9		3		11'

* Assignment numbers are shown for each category
\+ Delay ~ 1min.
T Toll
⊥ Delay = 1.5
╪ Delay = 3.0

NETWORK DESCRIPTION

The road network used in the study incorporates the 1978 Melbourne statistical division covering an area of 6,110 square kilometres. The total population in 1978 for the fifty-five local government areas therein was approximately 2.67 million, including 1.18 million employed persons.

The network itself is detailed (see Figure 2) consisting of 736 zones, 4453 nodes and 5056 two way links. A wide range of traffic conditions can be observed in the study area including congestion on some arterial links. Each link has been categorized into the following four road groups;

- Minor Roads
- Undivided arterial roads
- Divided arterial roads
- Freeways and freeway ramps

Table 2 shows the proportion of assigned and count links for each road category. The 1978 twenty four hour ground counts were obtained from the Country Roads Board (1978). The 1978 trip table was derived from formulae developed by the Metropolitan Transportation Committee (1969) and suitably altered to take account of lane use characteristics and increased household trip rates.

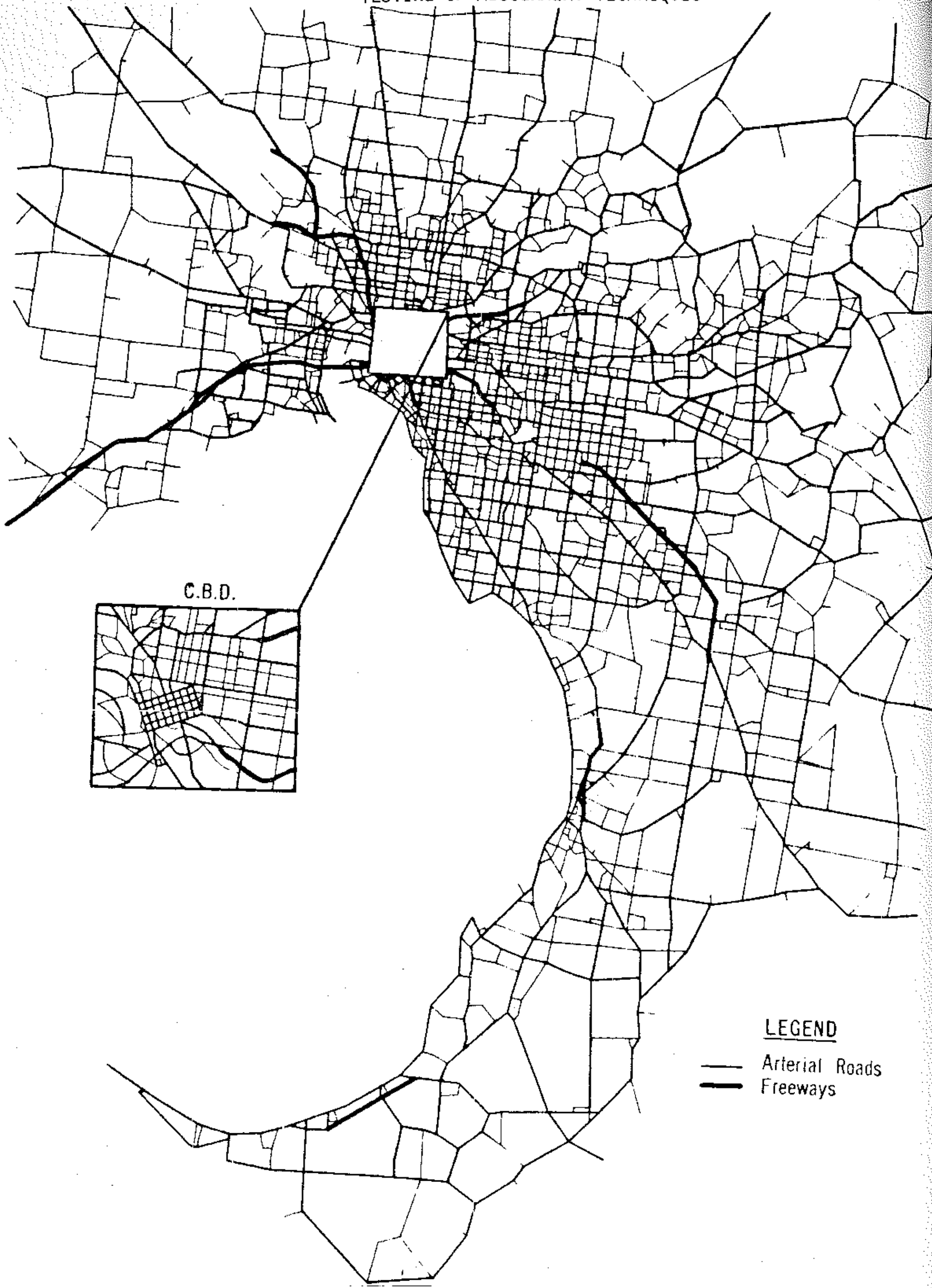
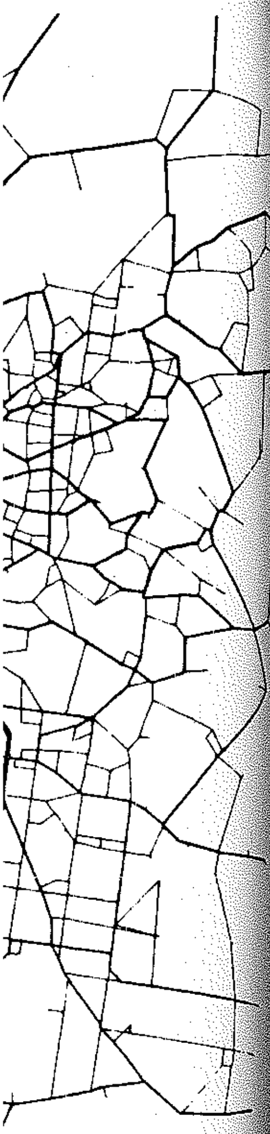


FIGURE 2. THE GREATER MELBOURNE TEST NETWORK.



ETWORK.

TABLE 2: DISTRIBUTION OF NETWORK LINKS.

ROAD CATEGORY	ASSIGNED TWO WAY LINKS		TWO WAY LINKS WITH COUNTS	
	No.	Column %	No.	Column %
Minor Roads	725	14·3	374	24·8
Undivided Main Roads	2530	50·0	861	57·2
Divided Main Roads	1683	33·4	241	16·0
Freeways and Freeway Ramps	118	2·3	30	2·0
TOTAL	5056	100·0	1506	100·0

STUDY RESULTS

The study results will be presented in three(3) segments. The first reviews the capabilities of the statistical measures outlined in the previous section to assess assignment model performance. The relative performance of the assignment techniques as applied to the entire network is then assessed followed by a more detailed discussion of the capabilities of each assignment technique to simulate link volumes for various road categories.

Comparison of Assignment Performance Measures

Information gain

Table 3 shows that the ranking of assignment techniques by the information gain measure is in general agreement with other non-parametric tests. This is not surprising if one considers that equation (2) can be converted to -

$$I\ (P^{II}:\ P^{IIO}) = \sum_i P_i \left| \ln P_i - \ln P_i^o \right| \qquad (18)$$

which is a term incorporating absolute differences.

Although simplistic measures of P_i^o and P_i were adopted in this study, a more thorough interpretation of these probabilities could be obtained by the use of conditional probabilities based upon the probability of a driver choosing a feeder link.

TABLE 3: RESULTS OF ASSIGNMENT PERFORMANCE MEASURES FOR THE ENTIRE NETWORK

ASSIGNMENT TYPE ° / TEST TYPE	F.H.W.A.							U.T.P.S.											
	1 A/N 4 INC. TWT=1.0 DWT=0.0	2 A/N 4 INC. TWT=1.0 DWT=1.0	3 A/N 4 INC. TWT=2.0 DWT=1.0	4 A/N 4 INC. TWT=3.0 DWT=1.0	5 A/N 4 INC. TWT=4.0 DWT=1.0	6 A/N 4 INC. TWT=3.0 DWT=1.0 DELAY =1.0	7 A/N 5 INC. TWT=1.0 DWT=0.0	1 A/N 5 EQ. IT. TWT=1.0 DWT=20.0	2 MULTI 4 EQ. IT. TWT=3.0 DWT=1.0	3 MULTI 8 EQ. IT. TWT=3.0 DWT=1.0	4 MULTI 5 EQ. IT. TWT=3.0 DWT=1.0 TOLL	5 A/N 5 EQ.IT. TWT=3.0 DWT=1.0 TOLL	6 A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=1.5	7 A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=3	8 A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL. DELAY=1.5	9 MULTI 8 EQ. IT. TWT=2.0 DWT=1.0	10 A/N 4 EQ. IT. TWT=2.0 DWT=1.0	11 MULTI 8 EQ. IT. TWT=4.0 DWT=1.0	12 A/N 4 EQ. IT. TWT=4.0 DWT=1.0
Parametric Test Information Gain.	2.243	2.216	2.180	2.190	2.192	2.239	2.192	2.072	2.027	2.051	2.016	2.024	–	2.067	2.073	2.191	2.037	2.060	2.038
Non Parametric Mean Absolute Difference Ratio.	0.4386	0.4284	0.4316	0.4327	0.4332	0.4438	0.4336	0.4255	0.4183	0.4247	0.4189	0.4204	–	0.4234	0.4258	0.4425	0.4207	0.4254	0.4225
Correlation Co-eff.	0.8436	0.8416	0.8487	0.8429	0.8491	0.8354	0.8457	0.8501	0.8525	0.8514	0.8544	0.8532	–	0.8434	0.8425	0.8293	0.8508	0.8469	0.8505
Mean Difference.	1326	1463	1411	1414	1403	1252	1327	1422	1343	1446	1379	1367	–	1384	1411	1593	1375	1451	1319
Standard Deviation of Difference.	7093	7106	6934	6961	6943	7230	7038	6840	6756	6787	6709	6735	–	6936	6962	7261	6781	6873	6795
Mean of Absolute Differences.	5391	5433	5328	5338	5311	5409	5321	5180	5087	5143	5069	5084	–	5139	5169	5382	5097	5125	5094
Mean Absolute Error.	3.58	3.61	3.54	3.54	3.53	3.59	3.53	3.44	3.38	3.42	3.37	3.38	–	3.41	3.43	3.58	3.39	3.41	3.38
% Root Mean Square.	40.36	40.58	39.57	39.73	39.61	41.15	40.06	39.37	38.82	39.11	38.60	38.73	42.63	39.86	40.04	41.69	38.99	39.59	39.00
Theils' Inequality Co-eff.	0.1696	0.1712	0.1670	0.1675	0.1669	0.1726	0.1684	0.1656	0.1634	0.1648	0.1626	0.1631	–	0.1682	0.1689	0.1772	0.1644	0.1670	0.1641
Tests of Assignment Criteria. Murchlands. δ	–	22976	72085	115381	165513	552048	31906	10256	14984	9872	20994	24090	76489	67848	57815	21246	33745	37190	66702
Van Vliets. δ	–	0.0239	0.0486	0.0574	0.0654	0.02342	0.0599	0.0012	0.022	0.007	0.012	0.013	0.039	0.039	0.027	0.015	0.025	0.015	0.030
Error Term.	–	0.0234	0.0464	0.0543	0.0614	0.1898	0.0565	0.0012	0.021	0.007	0.012	0.013	0.037	0.038	0.027	0.015	0.024	0.015	0.029

° A/N and MULTI indicate all-or-nothing or multipath traffic dispersion criteria respectively. In the case of UTPS equilibrium assignments these criteria are used in the first iteration only.

INC and EQ.IT. represent the number of increments for the FHWA assignments and the number of equilibrium iterations for the equilibrium assignments respectively.

TWT and DWT represent the time and distance weights of the impedance functions.

DELAY represents the delay imposed on drivers when using freeway ramps.

TOLL adjusts link times to congestion (queueing) at toll facilities.

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In the event that P_i^o and P_i could be accurately determined, the information gain test would provide a more rigorous assessment of the fit of observed to assigned volumes than the non-parametric tests.

Ratio of assigned to count volumes

As previously discussed, the use of the mean of assigned to count volumes for the purposes of comparing assignment techniques, will be misleading when some proportion of the links on the network are over-assigned trips while others are under-assigned trips. Table 4 illustrates this anomaly by comparing the relative ranking of the assignments, according to the mean ratio and the mean absolute ratio. The mean ratio ranks the incrementally loaded assignments ahead of equilibrium loaded assignments, whereas the mean absolute ratio shows preference towards the equilibrium loaded assignments.

Future applications of a ratio test should implement the mean absolute ratio, particularly in circumstances where there is a mixture of over and underassigned links.

Correlation co-efficient

Much has been written about the correlation co-efficient and it is not the purpose of this paper to reiterate the relative merits or otherwise of this co-efficient. The test is a measure of the degree by which a linear relationship can be fitted between the observed and assigned link volumes and as such is a useful performance criteria. Reference to Table 3 indicates that the correlation co-efficient ranks assignments in accordance with other test types.

Mean and standard deviation of differences

Tables 5, 6a and 6b highlight the different ranking interpretations of the mean difference, the absolute mean difference and the percentage absolute mean difference performance measures.

Table 5 indicates that a comparison of the ranking behaviour of both test types results in differing interpretations of the relative performance of each assignment package.

The mean difference test, which does not take account of biases created by positive and negative differences cancelling, ranks incremental loading ahead of equilibrium loading. Alternatively, the mean absolute value ranks the multipath equilibrium loaded assignment ahead of the A/N equilibrium loaded assignment and the A/N incremental loaded assignment.

Tables 6a and 6b show the effect that normalizing the mean absolute difference criteria can have on the ranking of assignment performance for each road category. It is evident that a ranking of the assignment technique's capabilities in predicting flows for particular road categories can be misleading unless a normalising procedure as outlined by equation (9) is applied.

TABLE 4: RATIO OF ASSIGNED TO COUNT VOLUMES

ASSIGNMENT TYPE / RATIO TESTS	F.H.W.A.							U.T.P.S.											
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8	9	10	11	12
	A/N 4 INC. TWT=1.0 DWT=0.0	A/N 4 INC. TWT=1.0 DWT=1.0	A/N 4 INC. TWT=2.0 DWT=1.0	A/N 4 INC. TWT=3.0 DWT=1.0	A/N 4 INC. TWT=4.0 DWT=1.0	A/N 4 INC. TWT=3.0 DWT=1.0 DELAY =1.0	A/N 5 INC. TWT=1.0 DWT=0.0	A/N 5 EQ. IT. TWT=1.0 DWT=20.0	MULTI 4 EQ. IT. TWT=3.0 DWT=1.0	MULTI 8 EQ. IT. TWT=3.0 DWT=1.0	MULTI 5 EQ. IT. TWT=3.0 DWT=1.0 TOLL	A/N 5 EQ IT. TWT=3.0 DWT=1.0 TOLL	A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=1.5	A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=3	A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=1.5	MULTI 8 EQ. IT. TWT=2.0 DWT=1.0	A/N 4 EQ. IT. TWT=2.0 DWT=1.0	MULTI 8 EQ. IT. TWT=4.0 DWT=1.0	A/N 4 EQ. IT. TWT=4.0 DWT=1.0
Mean Ratio	1.0324	1.0224	1.0282	1.0271	1.0283	1.0475	1.0341	1.0472	1.0487	1.0477	1.0508	1.0524	–	1.0596	1.0578	1.0533	1.0524	1.0543	1.0577
(Ranking)	(5)	(1)	(3)	(2)	(4)	(8)	(6)	(7)	(10)	(9)	(11)	(12)	–	(17)	(16)	(13)	(12)	(14)	(15)
Mean Absolute Difference Ratio	0.4386	0.4284	0.4316	0.4327	0.4332	0.4438	0.4336	0.4255	0.4183	0.4247	0.4189	0.4204	–	0.4234	0.4258	0.4425	0.4207	0.4254	0.4225
(Ranking)	(16)	(11)	(12)	(13)	(14)	(18)	(15)	(9)	(1)	(7)	(2)	(3)	–	(6)	(10)	(17)	(4)	(8)	(5)

TABLE 5: MEAN DIFFERENCE, MEAN |DIFFERENCE|, % MEAN |DIFFERENCE|

ASSIGNMENT TYPE / DIFFERENCE TESTS	F.H.W.A.							U.T.P.S.											
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8	9	10	11	12
	A/N 4 INC. TWT=1.0 DWT=0.0	A/N 4 INC. TWT=1.0 DWT=1.0	A/N 4 INC. TWT=2.0 DWT=1.0	A/N 4 INC. TWT=3.0 DWT=1.0	A/N 4 INC. TWT=4.0 DWT=1.0	A/N 4 INC. TWT=3.0 DWT=1.0 DELAY =1.0	A/N 5 INC. TWT=1.0 DWT=0.0	A/N 5 EQ. IT. TWT=1.0 DWT=20.0	MULTI 4 EQ. IT. TWT=3.0 DWT=1.0	MULTI 8 EQ. IT. TWT=3.0 DWT=1.0	MULTI 5 EQ. IT. TWT=3.0 DWT=1.0 TOLL	A/N 5 EQ.IT. TWT=3.0 DWT=1.0 TOLL	A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=1.5	A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=3	A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=1.5	MULTI 8 EQ. IT. TWT=2.0 DWT=1.0	A/N 4 EQ. IT. TWT=2.0 DWT=1.0	MULTI 8 EQ. IT. TWT=4.0 DWT=1.0	A/N 4 EQ. IT. TWT=4.0 DWT=1.0
u Difference	1326	1463	1411	1414	1403	1252	1327	1422	1343	1446	1379	1367	–	1384	1411	1593	1375	1451	1319
(Ranking)	(3)	(16)	(11)	(12)	(10)	(1)	(4)	(13)	(5)	(14)	(8)	(6)	–	(9)	(11)	(17)	(7)	(15)	(2)
u Absolute Difference	5391	5433	5328	5338	5311	5409	5321	5180	5087	5143	5069	5084	–	5139	5169	5387	5097	5125	5094
(Ranking)	(16)	(18)	(13)	(14)	(11)	(17)	(12)	(10)	(3)	(8)	(1)	(2)	–	(7)	(9)	(15)	(5)	(6)	(4)
% u Absolute Difference	30.16	30.39	29.81	29.86	29.71	30.26	29.77	29.20	28.68	28.99	28.58	28.66	–	28.97	29.14	30.34	28.73	28.89	28.72
(Ranking)	(15)	(18)	(13)	(14)	(11)	(16)	(12)	(10)	(3)	(8)	(1)	(2)	–	(7)	(9)	(17)	(5)	(6)	(4)

TABLE 6a: MEAN DIFFERENCE, MEAN |DIFFERENCE|, % MEAN |DIFFERENCE| BY ROAD TYPE – A/N INCREMENTAL ASSIGNMENTS

ASSIGNMENT TYPE	F.H.W.A.						
	1	2	3	4	5	6	7
	A/N 4 INC. TWT=1.0 DWT=0.0	A/N 4 INC. TWT=1.0 DWT=1.0	A/N 4 INC. TWT=2.0 DWT=1.0	A/N 4 INC. TWT=3.0 DWT=1.0	A/N 4 INC. TWT=4.0 DWT=1.0	A/N 4 INC. TWT=3.0 DWT=1.0	A/N 5 INC. TWT=1.0 DWT=0.0

u Difference (Ranking)	1326 (3)	1463 (16)	1411 (11)	1414 (12)	1403 (10)	1252 (1)	1327 (4)	1422 (13)	1343 (5)	1446 (14)	1379 (8)	1367 (6)	–	1384 (9)	1411 (11)	1593 (17)	1375 (7)	1451 (15)	1319 (2)
u Absolute Difference (Ranking)	5391 (16)	5433 (18)	5328 (13)	5338 (14)	5311 (11)	5409 (17)	5321 (12)	5180 (10)	5087 (3)	5143 (8)	5069 (1)	5084 (2)	–	5139 (7)	5169 (9)	5387 (15)	5097 (5)	5125 (6)	5094 (4)
% u Absolute Difference (Ranking)	30.16 (15)	30.39 (18)	29.81 (13)	29.86 (14)	29.71 (11)	30.26 (16)	29.77 (12)	29.20 (10)	28.68 (3)	28.99 (8)	28.58 (1)	28.66 (2)	–	28.97 (7)	29.14 (9)	30.34 (17)	28.73 (5)	28.89 (6)	28.72 (4)

TABLE 6a: MEAN DIFFERENCE, MEAN |DIFFERENCE|, % MEAN |DIFFERENCE| BY ROAD TYPE – A/N INCREMENTAL ASSIGNMENTS

ASSIGNMENT TYPE / ROAD CATEGORY	F.H.W.A. 1 A/N 4 INC. TWT=1.0 DWT=0.0			2 A/N 4 INC. TWT=1.0 DWT=1.0			3 A/N 4 INC. TWT=2.0 DWT=1.0			4 A/N 4 INC. TWT=3.0 DWT=1.0			5 A/N 4 INC. TWT=4.0 DWT=1.0			6 A/N 4 INC. TWT=3.0 DWT=1.0 DELAY =1.0			7 A/N 5 INC. TWT=1.0 DWT=0.0		
	u Diff	u|Diff|	% |Diff|	u Diff	u|Diff|	% |Diff|	u Diff	u|Diff|	% |Diff|	u Diff	u|Diff|	% |Diff|	u Diff	u|Diff|	% |Diff|	u Diff	u|Diff|	% |Diff|	u Diff	u|Diff|	% |Diff|
Minor Road	3209	4473	45.52	2699	4241	43.16	2902	4291	43.67	3021	4358	44.35	3060	4407	44.85	29.52	4371	44.48	3223	4451	45.30
(Ranking)	(3)	(1)	(4)	(3)	(1)	(4)	(4)	(1)	(4)	(4)	(1)	(4)	(4)	(1)	(4)	(3)	(1)	(4)	(3)	(1)	(4)
Undivided Main Road	652	5332	30.95	631	5438	31.56	656	5347	3104	696	5320	30.88	701	5270	30.59	483	5402	31.36	661	5216	30.28
(Ranking)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(2)	(2)	(3)	(2)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Divided Main Road	1531	6698	21.96	1978	7067	23.17	1744	6841	22.42	1637	6885	22.57	1588	6796	22.28	2012	6640	21.77	1503	6692	21.94
(Ranking)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(4)	(2)	(3)	(4)	(2)	(3)	(4)	(2)	(2)	(3)	(1)	(2)	(3)	(1)
Freeways	–4487	8007	28.06	5786	7027	24.63	1813	5533	19.39	180	5633	19.74	–563	5843	20.48	–3990	8670	30.39	–4620	8180	28.67
(Ranking)	(4)	(4)	(2)	(4)	(4)	(2)	(3)	(3)	(1)	(1)	(3)	(1)	(1)	(3)	(1)	(4)	(4)	(2)	(4)	(4)	(2)

TABLE 6b: MEAN DIFFERENCE, MEAN |DIFFERENCE|, % MEAN |DIFFERENCE| BY ROAD TYPE – A/N, MULTIPATH EQUILIBRIUM ASSIGNMENTS

ASSIGNMENT TYPE / ROAD CATEGORY	U.T.P.S. 1 A/N 5 EQ. IT. TWT=1.0 DWT=20.0			2 MULTI 4 EQ. IT. TWT=3.0 DWT=1.0			3 MULTI 8 EQ. IT. TWT=3.0 DWT=1.0			4 MULTI 5 EQ. IT. TWT=3.0 DWT=1.0 TOLL			5 A/N 5 EQ. IT. TWT=3.0 DWT=1.0 TOLL			6 A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL		
	u Diff	u|Diff|	% |Diff|	u Diff	u|Diff|	% |Diff|	u Diff	u|Diff|	% |Diff|	u Diff	u|Diff|	% |Diff|	u Diff	u|Diff|	% |Diff|	u Diff	u|Diff|	% |Diff|
Minor Road	3041	4328	44.05	2796	4158	42.32	3058	4304	43.80	2905	4177	42.51	2901	4227	43.02	–	–	–
(Ranking)	(4)	(1)	(4)	(4)	(1)	(4)	(3)	(1)	(4)	(4)	(1)	(4)	(4)	(1)	(4)			
Undivided Main Road	843	5047	29.30	715	5008	29.07	858	5001	29.03	754	4954	28.76	751	4970	28.35	–	–	–
(Ranking)	(1)	(2)	(2)	(1)	(2)	(3)	(1)	(2)	(2)	(1)	(2)	(2)	(1)	(2)	(2)			
Divided Main Road	1558	6407	21.00	1766	6387	20.94	1680	6384	20.93	1678	6381	20.92	1639	6349	20.81	–	–	–
(Ranking)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)			
Freeways	-2800	9193	32.22	-1803	7810	27.37	-3293	9100	31.89	-1745	8269	28.38	-1872	8238	28.87	–	–	–
(Ranking)	(3)	(4)	(3)	(3)	(4)	(2)	(4)	(4)	(3)	(3)	(4)	(3)	(3)	(4)	(3)			

ASSIGNMENT TYPE / ROAD CATEGORY	7 A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY			8 A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=1.5			9 MULTI 8 EQ. IT. TWT=2.0 DWT=1.0			10 A/N 4 EQ. IT. TWT=2.0 DWT=1.0			11 MULTI 6 EQ. IT. TWT=4.0 DWT=1.0			12 A/N 4 EQ. IT. TWT=4.0 DWT=1.0		
	u Diff	u|Diff|	% |Diff|	u Diff	u|Diff|	% |Diff|	u Diff	u|Diff|	% |Diff|	u Diff	u|Diff|	% |Diff|	u Diff	u|Diff|	% |Diff|	u Diff	u|Diff|	% |Diff|
Minor Road	2910	4206	42.80	2949	4223	42.98	3009	4339	44.16	2679	4078	41.50	2977	4224	42.99	2783	4109	41.32
(Ranking)	(3)	(1)	(4)	(4)	(1)	(4)	(3)	(1)	(4)	(3)	(1)	(4)	(4)	(1)	(4)	(4)	(1)	(4)
Undivided Main Road	681	5008	29.07	732	5084	29.51	826	5270	30.59	644	5072	29.44	817	5052	29.32	635	5054	29.34
(Ranking)	(1)	(2)	(2)	(1)	(2)	(3)	(1)	(2)	(2)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Divided Main Road	1220	6404	20.99	1347	6458	21.17	1444	6567	21.53	1820	6444	21.22	1311	6411	2101	1608	6423	2105
(Ranking)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(3)	(3)	(1)
Freeways	4597	9769	34.24	2872	8348	29.26	7979	11483	40.24	2931	6945	24.34	2400	7455	26.13	821	7090	24.35
(Ranking)	(4)	(4)	(3)	(3)	(4)	(2)	(4)	(4)	(3)	(4)	(4)	(2)	(3)	(4)	(2)	(2)	(4)	(2)

The results show that equilibrium loading provides a better fit to observed volumes for divided main roads and undivided main roads, while the incremental loading algorithm was better able to forecast link volumes on freeways and freeway ramps.

The standard deviation of differences is presented in Table 7 to highlight the skewed nature of the difference distribution. Analysis indicated that the difference distribution did not fit a normal distribution, disallowing the option of applying t tests for significance testing to non-parametric performance measures.

The mean absolute difference measure should be applied in preference to mean difference criteria when ranking assignment performance over a network area. If assessing the performance of an assignment algorithm for particular road categories, the percentage mean absolute difference should be implemented.

Mean absolute error (M.A.E.)

The MAE will provide a similar ranking of assignments to that of the mean absolute difference test, as the number of links n, is the same for all assignments. However, when comparing a single assignment's performance for various road categories within the network the ranking becomes a function of the n^2 term, resulting in a grading of road type which reflects the number of links in the road category, rather than the performance of the assignment algorithm.

Reference to Tables 8, 9, 10 and 11 shows that the ranking of assignment performance for each road category coincides with the ranking of road types according to the highest number of links (see Table 2).

Root mean square error (RMSE)

The RMSE and % RMSE ranks assignment techniques in a similar fashion to information gain and mean absolute differences. Table 3 shows that the %RMSE performance measure ranks multipath equilibrium loading ahead of A/N equilibrium loading and A/N incremental loading.

Percentage RMSE ranks the fit of observed to assigned volumes for each road type in an identical manner to that of the percentage mean absolute difference (see Tables 8, 9, 10 and 11.) There appears to be little difference in the capabilities of both the percentage absolute difference and percentage RMSE to ranking the performance of assignment techniques for each road category.

TABLE 7: STANDARD DEVIATION (S.D) OF DIFFERENCE, S.D OF |DIFFERENCE| AND % S.D OF |DIFFERENCE|

DIFFERENCE TESTS \ ASSIGNMENT TYPE	F.H.W.A. 1 A/N 4 INC. TWT=1.0 DWT=0.0	2 A/N 4 INC. TWT=1.0 DWT=1.0	3 A/N 4 INC. TWT=2.0 DWT=1.0	4 A/N 4 INC. TWT=3.0 DWT=1.0	5 A/N 4 INC. TWT=4.0 DWT=1.0	6 A/N 4 INC. TWT=3.0 DWT=1.0 DELAY =1.0	7 A/N 5 INC. TWT=1.0 DWT=0.0
S.D. Difference	7095	7106	6934	6961	6943	7230	7038
(Ranking)	(15)	(16)	(9)	(12)	(11)	(17)	(14)
S.D. |Difference|	4795	4806	4591	4622	4628	4956	4728
(Ranking)	(12)	(14)	(2)	(6)	(7)	(16)	(10)
% S.D. |Difference|	26.83	26.89	25.68	25.86	25.89	27.73	26.45
(Ranking)	(12)	(13)	(1)	(3)	(4)	(16)	(11)

DIFFERENCE TESTS \ ASSIGNMENT TYPE	U.T.P.S. 1 A/N 5 EQ. IT. TWT=1.0 DWT=20.0	2 MULTI 4 EQ. IT. TWT=3.0 DWT=1.0	3 MULTI 8 EQ. IT. TWT=3.0 DWT=1.0	4 MULTI 5 EQ. IT. TWT=3.0 DWT=1.0 TOLL	5 A/N 5 EQ.IT. TWT=3.0 DWT=1.0 TOLL	6 A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL	7 A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=3	8 A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=1.5	9 MULTI 8 EQ. IT. TWT=2.0 DWT=1.0	10 A/N 4 EQ. IT. TWT=2.0 DWT=1.0	11 MULTI 8 EQ. IT. TWT=4.0 DWT=1.0	12 A/N 4 EQ. IT. TWT=4.0 DWT=1.0
S.D. Difference	6840	6756	6787	6709	6735	--	6936	6962	7261	6781	6873	6795
(Ranking)	(7)	(3)	(5)	(1)	(2)	–	(10)	(13)	(18)	(4)	(8)	(6)
S.D. |Difference|	4610	4642	4582	4605	4622	–	4770	4872	5010	4615	4802	4685
(Ranking)	(4)	(8)	(1)	(3)	(6)	–	(11)	(15)	(17)	(5)	(13)	(9)
% S.D. |Difference|	25.99	26.17	25.83	25.96	26.06	–	26.89	27.46	28.24	26.02	27.07	26.41
(Ranking)	(6)	(9)	(2)	(5)	(8)	–	(13)	(15)	(17)	(7)	(14)	(10)

TABLE 8: RESULTS OF ASSIGNMENT PERFCRMANCE TESTS FOR MINOR ROADS

ASSIGNMENT TYPE / TEST TYPE	F.H.W.A.							U.T.P.S.											
	1 A/N 4 INC. TWT=1.0 DWT=0.0	2 A/N 4 INC. TWT=1.0 DWT=1.0	3 A/N 4 INC. TWT=2.0 DWT=1.0	4 A/N 4 INC. TWT=3.0 DWT=1.0	5 A/N 4 INC. TWT=4.0 DWT=1.0	6 A/N 4 INC. TWT=3.0 DWT=1.0 DELAY = 1.0	7 A/N 5 INC. TWT=1.0 DWT=0.0	1 A/N 5 EQ. IT. TWT=1.0 DWT=20.0	2 MULTI 4 EQ. IT. TWT=3.0 DWT=1.0	3 MULTI 8 EQ. IT. TWT=3.0 DWT=1.0	4 MULTI 5 EQ. IT. TWT=3.0 DWT=1.0 TOLL	5 A/N 5 EQ.IT. TWT=3.0 DWT=1.0 TOLL	6 A/N 8 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=1.5	7 A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=3	8 A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=1.5	9 MULTI 8 EQ. IT. TWT=2.0 DWT=1.0	10 A/N 4 EQ. IT. TWT=2.0 DWT=1.0	11 MULTI 8 EQ. IT. TWT=4.0 DWT=1.0	12 A/N 4 EQ. IT. TWT=4.0 DWT=1.0
Parametric Test Information Gain.	13.87	13.17	12.74	12.97	13.28	13.91	12.98	12.74	12.71	12.63	12.46	12.73	–	12.57	12.71	12.72	12.61	12.48	12.42
Non Parametric. Mean Absolute Difference Ratio	0.4685	0.4676	0.4661	0.4640	0.4666	0.4700	0.4615	0.4551	0.4439	0.4528	0.4433	0.4482	–	0.4446	0.4443	0.4706	0.4445	0.4444	0.4435
Correlation Co-eff.	0.4331	0.4570	0.4707	0.4577	0.4444	0.4300	0.4288	0.3915	0.4341	0.4077	0.4250	0.4105	–	0.4101	0.4087	0.3811	0.4509	0.4104	0.4471
Mean Difference.	3209	2699	2902	3021	3060	2952	3223	3041	2796	3058	2905.	2901	–	2910	2949	3009	2679	2977	2783
Standard Deviation of Difference.	4819	4831	4713	4747	4795	4880	4792	4740	4681	4678	4648	4706	–	4700	4727	4761	4630	4673	4612
Mean of Absolute Differences.	4473	4241	4291	4358	4407	4371	4451	4328	4158	4304	4177	4227	–	4206	4223	4339	4078	4224	4109
Mean Absolute Error.	11.96	11.34	11.47	11.65	11.78	11.69	11.90	11.92	11.46	11.86	11.51	11.65	–	11.59	11.63	11.95	11.23	11.64	11.32
% Root Mean Square	58.86	56.26	56.27	57.21	57.84	57.99	58.72	57.26	55.43	56.82	55.73	56.20	59.74	56.20	56.64	57.26	54.38	56.34	54.76
Theils Inequality Co-eff.	0.3080	0.2848	0.2881	0.2951	0.2990	0.2985	0.3078	0.3054	0.2902	0.3035	0.2950	0.2968	–	0.2971	0.2995	0.3060	0.2828	0.2995	0.2865

TABLE 9: RESULTS OF ASSIGNMENT PERFORMANCE TESTS FOR UNDIVIDED MAIN ROADS

ASSIGNMENT TYPE	F.H.W.A.							U.T.P.S.											
	1 A/N	2 A/N	3 A/N	4 A/N	5 A/N	6 A/N	7 A/N	1 A/N	2 MULTI	3 MULTI	4 MULTI	5 A/N	6 A/N	7 A/N	8 A/N	9 MULTI	10 A/N	11 MULTI	12 A/N

TABLE 9: RESULTS OF ASSIGNMENT PERFORMANCE TESTS FOR UNDIVIDED MAIN ROADS

ASSIGNMENT TYPE / TEST TYPE	F.H.W.A.							U.T.P.S.											
	1 A/N 4 INC. TWT=1.0 DWT=0.0	2 A/N 4 INC. TWT=1.0 DWT=1.0	3 A/N 4 INC. TWT=2.0 DWT=1.0	4 A/N 4 INC. TWT=3.0 DWT=1.0	5 A/N 4 INC. TWT=4.0 DWT=1.0	6 A/N 4 INC. TWT=3.0 DWT=1.0 DELAY =1.0	7 A/N 5 INC. TWT=1.0 DWT=0.0	1 A/N 5 EQ. IT. TWT=1.0 DWT=20.0	2 MULTI 4 EQ. IT. TWT=3.0 DWT=1.0	3 MULTI 8 EQ. IT. TWT=3.0 DWT=1.0	4 MULTI 5 EQ. IT. TWT=3.0 DWT=1.0 TOLL	5 A/N 5 EQ.IT. TWT=3.0 DWT=1.0 TOLL	6 A/N 6 EQ. IT. TWT=3.0 DWT=1.0 DELAY=1.5	7 A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=3	8 A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=1.5	9 MULTI 8 EQ. IT. TWT=2.0 DWT=1.0	10 A/N 4 EQ. IT. TWT=2.0 DWT=1.0	11 MULTI 8 EQ. IT. TWT=4.0 DWT=1.0	12 A/N 4 EQ. IT. TWT=4.0 DWT=1.0
Parametric Test Information Gain	3.79	3.89	3.85	3.82	3.78	3.85	3.69	3.51	3.48	3.47	3.43	3.44	–	3.49	3.53	3.68	3.55	3.51	3.52
Non Parametric Tests Mean Absolute Difference Ratio.	0.4592	0.4458	0.4537	0.4549	0.4548	0.4666	0.4533	0.4440	0.4389	0.4431	0.4395	0.4404	–	0.4438	0.4491	0.4661	0.4470	0.4482	0.4492
Correlation Co-eff	0.7779	0.7789	0.7830	0.7823	0.7845	0.7715	0.7833	0.7957	0.7969	0.7966	0.8025	0.8015	–	0.7950	0.7922	0.7706	0.7893	0.7943	0.7886
Mean Difference	652	631	656	696	701	483	661	843	715	858	754	751	–	681	732	826	644	817	635
Standard Deviation of Difference.	7117	7263	7101	7088	7043	7261	7022	6763	6751	6719	6650	6653	–	6746	6785	7147	6879	6766	6860
Mean of Absolute Differences.	5332	5438	5347	5320	5270	5402	5216	5047	5008	5001	4954	4970	–	5008	5084	5270	5072	5052	5054
Mean Absolute Error	6.19	6.32	6.21	6.18	6.12	6.27	6.06	5.85	5.81	5.80	5.75	5.77	–	5.81	5.90	6.11	5.88	5.86	5.86
% Root Mean Square	41.46	42.29	41.37	41.32	41.06	42.22	40.92	39.54	39.38	39.30	38.83	38.84	41.62	39.34	39.59	41.73	40.08	39.54	39.96
Theils' Inequality Co-eff.	0.1776	0.1792	0.1767	0.1769	0.1759	0.1798	0.1754	0.1717	0.1705	0.1710	0.1685	0.1686	–	0.1705	0.1719	0.1811	0.1730	0.1719	0.1728

TABLE 10: RESULTS OF ASSIGNMENT PERFORMANCE TESTS FOR DIVIDED MAIN ROADS

ASSIGNMENT TYPE / TEST TYPE	F.H.W.A.							U.T.P.S.											
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8	9	10	11	12
	A/N 4 INC. TWT=1.0 DWT=0.0	A/N 4 INC. TWT=1.0 DWT=1.0	A/N 4 INC. TWT=2.0 DWT=1.0	A/N 4 INC. TWT=3.0 DWT=1.0	A/N 4 INC. TWT=4.0 DWT=1.0	A/N 4 INC. TWT=3.0 DWT=1.0 DELAY =1.0	A/N 5 INC. TWT=1.0 DWT=0.0	A/N 5 EQ. IT. TWT=1.0 DWT=20.0	MULTI 4 EQ. IT. TWT=3.0 DWT=1.0	MULTI 8 EQ. IT. TWT=3.0 DWT=1.0	MULTI 5 EQ. IT. TWT=3.0 DWT=1.0 TOLL	A/N 5 EQ.IT. TWT=3.0 DWT=1.0 TOLL	A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=1.5	A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=3	A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=1.5	MULTI 8 EQ. IT. TWT=2.0 DWT=1.0	A/N 4 EQ. IT. TWT=2.0 DWT=1.0	MULTI 8 EQ. IT. TWT=4.0 DWT=1.0	A/N 4 EQ. IT. TWT=4.0 DWT=1.0
Parametric Test Information Gain.	9.42	9.77	9.43	9.51	9.40	9.16	9.37	8.55	8.60	8.57	8.60	8.60	–	8.68	8.77	8.88	8.67	8.64	8.72
Non Parametic Tests Mean Absolute Difference Ratio	0.3252	0.3234	0.3223	0.3272	0.3255	0.3257	0.3252	0.3205	0.3160	0.3221	0.3182	0.3167	–	0.3274	0.3280	0.3237	0.3106	0.3320	0.3124
Correlation Co-eff.	0.8218	0.8213	0.8257	0.8230	0.8249	0.8079	0.8223	0.8290	0.8280	0.8309	0.8289	0.8252	–	0.8203	0.8120	0.8257	0.8369	0.8256	0.8334
Mean Difference.	1531	1978	1744	1637	1588	2012	1503	1558	1766	1680	1678	1639	–	1220	1347	1444	1820	1311	1608
Standard Deviation of Difference.	8679	8874	8662	8730	8681	8847	8673	8440	8420	8386	8410	8491	–	8629	8851	8692	8242	8542	8325
Mean of Absolute Differences.	6698	7067	6841	6885	6796	6640	6692	6407	6387	6384	6381	6349	–	6404	6458	6567	6444	6411	6423
Mean of Absolute Error.	27.79	29.32	28.38	28.57	28.20	27.55	27.77	25.52	25.45	25.43	25.42	25.29	–	25.52	25.73	26.16	25.67	25.54	25.59
% Root Mean Square	28.83	29.74	28.90	29.06	28.87	29.68	28.80	28.08	28.15	27.98	28.06	28.29	31.35	28.51	29.29	28.67	27.61	28.28	27.74
Theils' Inequality Co-eff.	0.1326	0.1370	0.1330	0.1335	0.1326	0.1381	0.1323	0.1310	0.1319	0.1312	0.1313	0.1323	–	0.1325	0.1362	0.1334	0.1293	0.1318	0.1295

TABLE 11: RESULTS OF ASSIGNMENT PERFORMANCE TESTS FOR FREEWAYS AND FREEWAY RAMPS

TABLE 11: RESULTS OF ASSIGNMENT PERFORMANCE TESTS FOR FREEWAYS AND FREEWAY RAMPS

ASSIGNMENT TYPE / TEST TYPE	F.H.W.A.						
	1	2	3	4	5	6	7
	A/N 4 INC. TWT=1.0 DWT=0.0	A/N 4 INC. TWT=1.0 DWT=1.0	A/N 4 INC. TWT=2.0 DWT=1.0	A/N 4 INC. TWT=3.0 DWT=1.0	A/N 4 INC. TWT=4.0 DWT=1.0	A/N 4 INC. TWT=3.0 DWT=1.0 DELAY =1.0	A/N 5 INC. TWT=1.0 DWT=0.0
Parametric Test Information Gain.	87.18	63.45	68.10	70.67	73.05	95.88	88.39
Non Parametric Tests Mean Absolute Difference Ratio.	0.3744	0.3060	0.2686	0.2745	0.2861	0.3961	0.3800
Correlation Co-eff.	0.8993	0.9339	0.9247	0.9186	0.9190	0.8784	0.8968
Mean of Difference.	-4487	5786	1813	180	-563	-3990	-4620
Standard Deviation of Difference.	9615	6527	6829	7337	7512	10350	9718
Mean of Absolute Differences.	8007	7027	5533	5633	5843	8670	8180
Mean Absolute Error.	266.89	234.22	184.44	187.78	194.78	289	272.67
% Root Mean Square	30.67	30.28	24.38	25.29	25.96	38.31	37.20
Theils' Inequality Co-eff.	0.1439	0.1428	0.1067	0.1075	0.1089	0.1514	0.1458

ASSIGNMENT TYPE / TEST TYPE	U.T.P.S.											
	1	2	3	4	5	6	7	8	9	10	11	12
	A/N 5 EQ. IT. TWT=1.0 DWT=20.0	MULTI 4 EQ. IT. TWT=3.0 DWT=1.0	MULTI 8 EQ. IT. TWT=3.0 DWT=1.0	MULTI 5 EQ. IT. TWT=3.0 DWT=1.0 TOLL	A/N 5 EQ.IT. TWT=3.0 DWT=1.0 TOLL	A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=1.5	A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=3	A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=1.5	MULTI 8 EQ. IT. TWT=2.0 DWT=1.0	A/N 4 EQ. IT. TWT=2.0 DWT=1.0	MULTI 8 EQ. IT. TWT=4.0 DWT=4.0	A/N 4 EQ. IT. TWT=4.0 DWT=1.0
Parametric Test Information Gain.	105.35	91.44	102.33	98.13	97.20	–	138.51	121.69	179.87	91.48	122.69	93.18
Non Parametric Tests Mean Absolute Difference Ratio.	0.4062	0.3604	0.4123	0.3786	0.3822	–	0.4007	0.3618	0.4393	0.3027	0.3389	0.3358
Correlation Co-eff.	0.8310	0.8745	0.8470	0.8582	0.8631	–	0.6909	0.7428	0.6068	0.8516	0.7559	0.8444
Mean of Difference.	-2800	-1803	-3293	-1745	-1872	–	4597	2872	7979	2931	2400	821
Standard Deviation of Difference.	10821	9094	10350	9683	9563	–	13352	12361	14649	9385	12333	9797
Mean of Absolute Differences.	9193	7810	9100	8269	8238	–	9769	8348	11483	6945	7455	7090
Mean Absolute Error.	317.00	269.32	313.79	285.14	284.07	–	336.86	287.87	395.96	239.48	257.07	244.47
% Root Mean Square	38.53	31.95	37.47	33.90	33.58	51.52	48.72	43.74	57.68	33.91	43.30	33.86
Theils' Inequality Co-eff.	0.1556	0.1313	0.1502	0.1393	0.1377	–	0.2221	0.1938	0.2787	0.1514	0.1890	0.1452

Theil's Inequality Co-efficient

Tables 3, 8, 9, 10 and 11 show that Theil's Inequality Co-efficient produces a similar ranking of assignment performance to that of mean absolute error, RMSE and the absolute ratio test.

Murchland's Delta

As is shown in Table 3, the A/N or multipath equilibrium loaded assignment achieves a greater degree of convergence than the A/N incrementally loaded assignments. The assignment that converges best is a multipath equilibrium assignment with a time weight of three and a distance weight of one.

The assignment with a time weighting of one and a distance weighting of twenty has similar converging capabilities to the best ranked assignment, though the majority of other performance tests shows that an impedance value of three times time plus one times distance is the most appropriate.

The reason for this apparent anomaly can be found in the mechanics of the equilibrium loading process. The iterative loading nature of the equilibrium algorithm alters travel time only, via capacity restraint formulations. If the time weighting in the impedance function is only a small proportion of the total impedance,then convergence is achieved much earlier than for an assignment which has a predominantly time weighted impedance function. As a result,it can be concluded that Murchland's delta alone is not an appropriate measure of assignment performance.

Murchland's delta can only be applied, as a measure of assignment performance, when comparing assignment algorithms with similar impedance values. In these circumstances,it is a useful indicator of the algorithm's ability to obey Wardrop's user equilibrium principle.

Van Vliet's Delta and the Error Term

Table 12 shows the total system impedance (C_1) and minimum system impedance (C_2) for each assignment. As expected these values increase according to the impedance function weightings.

Van Vliet's delta and the error term can give misleading results when comparing assignments of different impedance functions. The numerators of both measures assess the degree of convergence of the assignment technique. Though two assignment algorithms may converge to the same degree, the algorithm with the greater impedance value will generate greater user costs and ultimately larger C_1 and C_2 values. As C_1 and C_2 are denominators in the error term and Van Vliet's delta respectively, it is not surprising, in these circumstances, that the assignment algorithm with the greater impedance value will result in lower values.

TABLE 12: TOTAL SYSTEM COSTS AND MINIMUM SYSTEM COSTS

ASSIGNMENT TYPE / TEST TYPE	F.H.W.A.							U.T.P.S.											
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8	9	10	11	12
	A/N 4 INC. TWT=1.0 DWT=0.0	A/N 4 INC. TWT=1.0 DWT=1.0	A/N 4 INC. TWT=2.0 DWT=1.0	A/N 4 INC. TWT=3.0 DWT=1.0	A/N 4 INC. TWT=4.0 DWT=1.0	A/N 4 INC. TWT=3.0 DWT=1.0 DELAY =1.0	A/N 5 INC. TWT=1.0 DWT=0.0	A/N 5 EQ. IT. TWT=1.0 DWT=20.0	MULTI 4 EQ. IT. TWT=3.0 DWT=1.0	MULTI 8 EQ. IT. TWT=3.0 DWT=1.0	MULTI 5 EQ. IT. TWT=3.0 DWT=1.0 TOLL	A/N 5 EQ.IT. TWT=3.0 DWT=1.0 TOLL	A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=1.5	A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=3	A/N 6 EQ. IT. TWT=3.0 DWT=1.0 TOLL DELAY=1.5	MULTI 8 EQ. IT. TWT=2.0 DWT=1.0	A/N 4 EQ. IT. TWT=2.0 DWT=1.0	MULTI 8 EQ. IT. TWT=4.0 DWT=1.0	A/N 4 EQ. IT. TWT=4.0 DWT=1.0
C1 (X10,000)	42.3	98.3	155.5	212.6	269.8	290.9	56.4	893.0	212.8	211.1	212.2	212.1	216.7	217.7	215.6	156.7	158.6	271.4	273.9
C2 (X10,000)	–	96.0	148.2	201.1	253.2	235.7	53.2	892.0	211.3	210.1	210.1	209.7	209.1	210.9	209.8	154.5	155.2	267.7	257.3

Summary of Results

No single criterion will best assess the performance of a set of assignment techniques. Indeed, a combination of tests seems most appropriate, the selection dependent on the objective of the performance assessment.

Table 13 shows the tests that are most suitable for application in testing the accuracy of assignment output.

In view of the theoretical and practical requirements to attain convergence, initial investigation should centre on the convergence capabilities of the assignment algorithm. Murchland's delta is a suitable criteria assuming similar impedance weightings.

Ranking based purely on the convergence capabilities of a technique is unsuitable as input parameters (such as impedance values and capacity restraint definitions) can alter link volumes without appreciably altering the loading algorithm's convergence capabilities. Further investigation should be conducted to assess assigned link volumes against known counts. Of the five recommended tests in group 2 of Table 13, emphasis should be placed on information gain as it is a more rigorous test.

If assessing the performance of assignment techniques for various road categories, normalising procedures need to be introduced. Of these, percentage mean difference and percentage root mean square error have been proposed and recommended.

Overall Assignment Performance

Initial investigation based upon Murchland's delta (Table 3) showed that for each impedance value, the equilibrium loading process outperformed the corresponding incrementally loaded assignment.

Of the top ten assignments (as ranked by Murchland's Delta) the recommended parametric and non parametric tests favoured the following equilibrium assignments ;

- Five equilibrium iterations, the first by multipath criteria TWT(1) = 3.0, DWT(1) = 1.0
- Five equilibrium iterations, the first by A/N criteria TWT = 3.0, DWT = 1.0
- Four equilibrium iterations, the first by multipath criteria TWT = 3 0, DWT = 1 0

Five of the six parametric and non parametric tests ranked the top three assignments in the order presented above

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1 TWT and DWT are the time and distance weightings respectively for the impedance function.

TABLE 13: CLASSIFICATION OF ASSIGNMENT PERFORMANCE TESTS.

RECOMMENDED	NOT RECOMMENDED
1. Tests of assignment criteria.	
Murchlands Delta	Van Vliets Delta
	Error Term
2. Tests for fit of assigned to observed volumes – all road categories.	
Information Gain	Mean Absolute Error
Mean Absolute Difference	Mean Difference
Root Mean Square Error	Mean Ratio
Absolute Mean Ratio	Chi square two sample
Theil's Inequality	Kolmogorov – Smirnov two sample
Correlation Co – efficient	
3. Tests for fit of assigned to observed volumes – individual road categories.	
Percentage Mean Difference	
Percentage Root Mean Square Error	

Overall, the major difference between the various assignments is the manner in which driver trips are loaded (that is equilibrium versus incremental) rather than the criterion which is adopted to disperse trips (that is all-or-nothing versus multipath).

Road Segment Analysis

The links in the network were split into four road types :

- minor road - average count volume of 9826 vpd
- undivided arterial road - average count volume of 17, 228 vpd
- divided arterial roads - average count volume of 30,407 vpd
- freeway and freeway ramps - average count volume of 28,533 vpd.

The purpose of the segregation was to assess the suitability of various assignment techniques to each of these road types.

Minor roads

Table 8 shows the results of the assignment performance tests for the minor road category. Generally, it can be concluded that equilibrium loaded assignments provide a better fit to observed volumes than incremental loaded assignments, though the ability of each assignment to forecast link volumes for minor roads is considerably less than the network as a whole.

Undivided main roads

The results of the assignment performance tests for undivided main roads is shown in Table 9. Preference is directed to equilibrium loaded assignments with the technique ranking in at least the top six of assignment techniques for each measure of performance.

The results of this road type reflect the network as a whole, which is not surprising in view of the fact that fifty seven percent of the links in the network constitute undivided main roads.

Divided main roads

As is shown in Table 10 the equilibrium loaded assignment provides link volumes which best fit observed link volumes. However the trend towards equilibrium loaded assignments is not as strong as that shown by the previous road types.

The assignment techniques providing the most satisfactory result are ;

- Four equilibrium iterations, the first by A/N criteria TWT = 2.0, DWT = 1.0,
- Four equilibrium iterations, the first by A/N criteria TWT = 4.0, DWT = 1.0,
- Five equilibrium iterations, the first by A/N criteria TWT = 3.0, DWT = 1.0.

Two conculsions can be derived from this analysis. Firstly, A/N traffic dispersion criterion is preferred as an initial solution rather than the multipath criterion. Secondly, the wide disparity of impedance values indicates that the choice of impedance function is perhaps not as critical, for this road type, as originally expected.

Freeways and freeway ramps

Table 11 shows the results of the assignment performance tests for freeways and freeway ramps. Contrary to the results for each of the previous road types, incremental loaded assignments more accurately assign drivers than equilibrium loaded assignments. The following assignment inputs best fit the observed volumes ;

1. Four increments, A/N criteria
   TWT = 2.0, DWT = 1.0,

2. Four increments, A/N criteria
   TWT = 3.0, DWT = 1.0,

3. Four increments, A/N criteria
   TWT = 1.0, DWT = 1.0.

Equilibrium loaded assignments are based upon the premise that equilibrium is attained between the supply of and demand for road infrastructure, which is most likely to occur when demand approaches or exceeds capacity. In 1978, the demand for the thirty freeways and freeway ramps fell far short of the supply.

In addition the speed-flow relationships adopted for freeway terminals and ramps (see Farrow, 1975) may need adjustment to incorporate more realistic travel delays for near and over capacity situations.

CONCLUSIONS

This paper has proposed and demonstrated various traffic assignment performance measures. Emphasis was directed towards ascertaining which combination of assignment options currently available from the UTPS and FHWA packages was best suited to simulating 1978 link volumes for the Greater Melbourne Urban road network.

It was concluded that :-

. no single criterion best assesses the performance of a particular assignment technique.

. the selection of assessment measures is dependent on the objective of the performance assessment.

. initial investigation should centre on the convergence capabilities of the assignment algorithm. Murchland's delta has been proposed for this purpose.

. if observed volumes are available, comparison can be made with assigned volumes using information gain. Mean absolute difference, root mean square error, absolute mean ratio, Theil's inequality co-efficient and correlation co-efficient can also be applied to rank various assignment techniques.

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   TWT = 2.0, DWT = 1.0,

2. Four increments, A/N criteria
   TWT = 3.0, DWT = 1.0,

3. Four increments, A/N criteria
   TWT = 1.0, DWT = 1.0.

Equilibrium loaded assignments are based upon the premise that equilibrium is attained between the supply of and demand for road infrastructure, which is most likely to occur when demand approaches or exceeds capacity. In 1978, the demand for the thirty freeways and freeway ramps fell far short of the supply.

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. no single criterion best assesses the performance of a particular assignment technique.

. the selection of assessment measures is dependent on the objective of the performance assessment.

. initial investigation should centre on the convergence capabilities of the assignment algorithm. Murchland's delta has been proposed for this purpose.

. if observed volumes are available, comparison can be made with assigned volumes using information gain. Mean absolute difference, root mean square error, absolute mean ratio, Theil's inequality co-efficient and correlation co-efficient can also be applied to rank various assignment techniques.

- comparisons of various road groups for a particular assignment technique should use a normalising criteria. Percentage mean difference and percentage root mean square error were recommended.

- for the Greater Melbourne urban road network, equilibrium network loading procedures provide a better fit to observed volumes than incremental loaded assignments.

- the equilibrium loaded assignment is better suited to networks where demand approaches or exceeds the supply.

- volumes on minor road links, undivided main road links and divided main road links were better estimated by equilibration techniques while freeway links were better served by incremental loading procedures.

- the top three ranked assignments all incorporated impedance functions reflecting three times travel time plus one times distance.

- the selection of appropriate impedance function weightings and traffic dispersion criteria will marginally enhance assignment accuracy. Maximum improvement in assignment performance can be achieved through the correct selection and application of an appropriate network loading procedure.

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