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A Method for Scoring Urban Freeway Performance

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Abstract:

The freeway will always command a prime focal position with regards road budgets at any level of government because of the large sunk cost involved. The U score has been designed to bring together the concepts of road design, capacity flow and user utility. Through empirically derived coefficients for a capacity flow relationship combined with a deterministic utility equation, this U performance score can be derived. The score may well be used in the freeway planning, or performance evaluation, process or for examining the behaviour of different freeways within the same city or in different cities.

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Introduction

The urban freeway is a high sunk cost infrastructure investment. In order to assess the performance of any freeway it would be conceivably important to address both the economic and operational performance characteristics of the investment. This paper attempts to build a conceptual framework whereby one class of urban road, namely, the freeway can be scored against some measure of the road's engineered capacity and its 'design utility'. The attempt to combine *both* these concepts is preliminary in so far as the framework for either design capacity or utility has been investigated previously at an individual level for roads. However, the combination of *the two* concepts, through the construction of sets of simultaneous equations, more often finds common ground within areas such as taxation theory, although there are differences.

Areas of investigation

The following analysis examines the aspects of behaviour for the urban freeway because data sets were available for this road type. It may well be the case that the behavioural characteristics of the model may not apply to road types who seldom reach a saturation, or congestion, point such as rural arterials or non urban local roads. Urban roads where congestion can occur might well be calibrated for examination by the model.

The specific examples where the model has been put to use was for freeways in the Australian State capital cities of Sydney, Melbourne, Adelaide and Brisbane as they behaved in the NAASRA (National Association of Australian State Road Authorities) technical report of 1984. (See NAASRA 1984.) The freeway characteristics are outlined in Table 1. Some approximations have been placed on the input data which would, in a more thorough investigation, require more precise estimates of such data.

Model construction and definitions

The primary aim of the model is to investigate the mechanics and behaviour of the urban freeway's log U score which is defined by equations 1.1 and 1.2.

$$U = V^{AL} * B^{S} \qquad (1.1)$$

or equivalently;

$$\log U = AL \log V + S \log B \qquad (1.2)$$

where: log U is the score for a given road
A and B are road specific parameters
V is the volume of traffic per lane per hour
S is the vehicle speed, and
L represents the number of lanes available.

The utility equation (1.1) is exponentially increasing in all variables. It should be noted that the road utility is the utility of the road design and not the utility for an individual driver. The design utility becomes greater as the road supports the operation of more vehicles, or in effect, consumes more user vehicles.

TABLE 1. SELECTED CHARACTERISTICS OF MAJOR URBAN ROAD TYPES

City	Road Type	Characteristics (vehicles/lane/hour)	Free speed kms/hr
Brisbane	Freeway	1950-2000	70-90
	Divided Arterial (No parking)	1280-1600	46-70
Adelaide	Freeway	1940-2000	68-84
	Divided Arterial (No parking)	1100-1600	56-76
Sydney	Freeway (outer)	1800	87
	State Highway (divided)	1500	59.5
Melbourne	Unrestricted roads	2000	86-95
	75 and 90 km/hr roads types	1220-1450	70-85

Source: NAASRA 1984 (T8)

The concepts of free-speed and free-time are utilised in equation 1.2. Free-speed S_f is conceptualised as that speed attained by a vehicle, over a distance D, when it is unhampered by other traffic, that is when it is the only vehicle on that road. Free-time T_f is the time it would take that vehicle, travelling a distance D, at a speed of S_f.

A *perfect* urban road, in this case a perfect freeway, is considered as a road whose volume runs at its design capacity V_c. The log U score for such a road is calibrated to equal a 100 point score. This is an arbitrary choice of score. The speed at which this volume is reached is referred to as the critical speed S_c. Equation 1.3 represents these conditions.

$$100 = AL \log (V_c) + S_c \log (B) \qquad (1.3)$$

A second simultaneous equation (1.4) was constructed by defining a score to represent the minimun level of acceptable road performance. In this case a score of 50 points was given for a congestion speed of 25 kms/hour. This choice of score was again arbitrary. It may be argued that a linear score of 25 be chosen to reflect minimun road performance or even a much lower score. The designers could argue that a freeway speed of 60 kms/hour, which in Australia, is a common local urban road speed limit be representative of the minimum required freeway performance level and set an appropriate low score for this speed.

$$50 = AL \log (V_1) + 25 \log B \qquad (1.4)$$

where: V_1 is the volume for that freeway at the 25 km/hour level.

The NAASRA Volume to Capacity Flow Relationship

To solve for the road specific parameters A and B it is necessary to introduce a second simultaneous equation in order to define the behaviour of the hypothetical freeway being examined. Recourse is now made of equation 1.5 which is a standard capacity flow function which was used in NAASRA 1984 Roads Study. Empirical evidence suggested in the associated technical report that the time to free-time behaviour against the volume/design volume should behave in a quartic manner, that is n equals 4. This same value was adopted by Blunden and Black (1984) and Cochran and Lin (1989). However, in constructing the model, it makes little difference what this value might be, but in this example the the quartic constraint will be followed.

$$T = T_f \left(1 + a \, (q/c)^n \right) \qquad (1.5)$$

In this example $q = V_1$, and $c = V_c$
Typical values of a (alpha) were around 0.5 (0.477 in Blunden and Black ,1984). By rearranging equation 1.5 becomes

$$T/T_f = 1 + a \, (V_1/V_c)^4 \qquad (1.6)$$

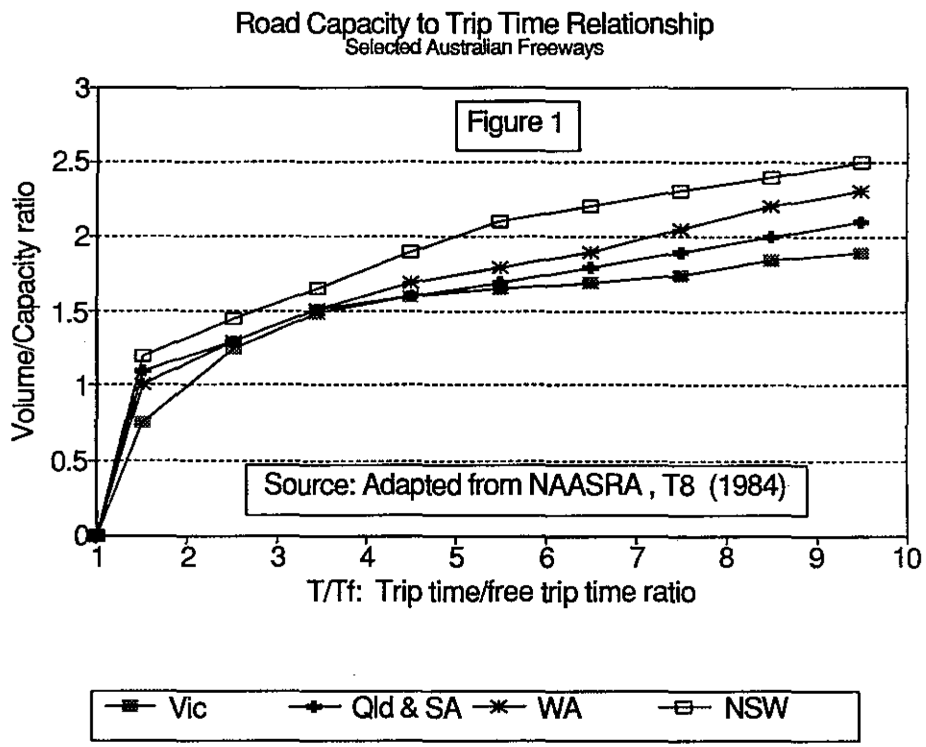
This equation expresses the behaviour of the real trip time to free trip time against the quartic behaviour of the proportion of road volume to design volume occupied. The behaviour of this polynomial is presented in Figure I.

The Time/Speed Transformation

Because equations 1.3, 1.4 are speed and volume reliant and 1.6 is time and volume reliant it is necessary to standardise the equations for a like set of variables, speed and volume being chosen.

As time = distance/speed it is possible to write

$$T/T_f = (D/S)/(D/S_f) = S_f/S \qquad (1.7)$$



By substituting equation 1.7 into 1.6 a second simultaneous equation has been developed which can be used in conjunction with equations 1.3 and 1.4. By arranging equation 1.6 and substituting 1.7 it can be shown that

$$V_l = V_c \left(\left(S_f/S - 1 \right)/a \right)^{1/4} \qquad (1.8)$$

Equation 1.8 now allows estimation of the road traffic volume for a given road capacity V_c, obtained from Table 1, an estimate of free-speed S_f and an appropriate value of alpha. Values of alpha ranged from 0.15 to 0.5 in NAASRA 1984, whilst Cochran and Lin 1989 opted for 0.15. The NAASRA range of values were adopted in this paper.

When the road volume reaches its design capacity equation 1.8 reduces to expression 1.9 as speed will equal the critical road speed by definition.

$$a = (S_f/S_c - 1) \quad \text{or}$$

$$S_c = S_f/(1 + a) \qquad (1.9)$$

Free-speed was assigned from Table 1 and was set at the upper level of free speeds observed for freeways in Brisbane, Adelaide and Sydney whereas for Melbourne free-speed was set at the highest level for unrestricted roads, that is, 95 kms/hour. Now given any alpha value from the NAASRA range, 0.15 to 0.5, critical speed can be derived from expression 1.9.

Derived freeway volumes from equation 1.8, for a selection of speeds, are presented in Table 2. Table 3 presents the associated log U scores for a freeway lane performing at that speed and volume level. Note that all the following analysis has been carried out at the freeway **lane level**. For total freeway behaviour the lane level volume can be replaced in equation 1.8 by total road volume VL and total road capacity volume V_cL. Two demonstration examples of how the log U scores are constructed are presented in Appendix I.

Caveats placed on the use of the model

1. The model is conceptual in its efforts to combine the empirical capacity flow equation with a hypothetical utility equation.
2. The form of the utility equation was only one of several forms chosen.
3. Both the capacity and utility equations have a large number of tuning variables, eg n, alpha, A, B, V_c, and S_f.
4. The model does not produce a definitive road score but is instead intended to suggest how such a score might be constructed.
5. The model produces a current snapshot of freeway operations after what will have been an established period of growth since

TABLE 2 ESTIMATED FREEWAY VOLUMES FOR SELECTED CAPITAL CITIES
Predicted Volumes

City (Lane capacity)	Free speed	Critcal speed	Coefficients A	B	a	Road speeds 20	50	80	90
Brisbane 2000	90.0	78.3	0.77	2.66	0.15	4396	3039	1911	-
		72.0	0.69	3.00	0.25	3869	2675	1682	-
		64.3	0.54	3.66	0.40	3440	2378	1495	-
		60.0	0.43	4.26	0.50	3253	2249	1414	-
Sydney 1800	87.0	75.7	0.74	2.80	0.15	3919	2683	1573	-
		69.6	0.65	3.17	0.25	3444	2361	1383	-
		62.1	0.49	3.94	0.40	3062	2099	1231	-
		58.0	0.37	4.63	0.50	2896	1985	1164	-
Adelaide 2000	84.0	73.0	0.69	2.95	0.15	4298	2918	1520	-
		67.2	0.60	3.38	0.25	3783	2568	1337	-
		60.0	0.43	4.26	0.40	3364	2284	1189	-
		56.0	0.29	5.09	0.50	3181	2160	1125	-
Melbourne 2000	95.0	82.6	0.82	2.48	0.15	4472	3130	2115	1560
		76.0	0.75	2.76	0.25	3936	2755	1861	1373
		67.9	0.62	3.30	0.40	3550	2449	1655	1221
		63.3	0.52	3.77	0.50	3310	2317	1565	1155

TABLE 3. LOG U FREEWAY SCORES FOR SELECTED CAPITAL CITIES

City (Lane capacity)	Free speed	Critcal speed	Coefficients A	B	a	Road speed 20	50	80	90
Brisbane 2000	90.0	78.3	0.77	2.66	0.15	45.3	73.6	101.6	-
		72.0	0.69	3.00	0.25	44.7	76.6	108.3	-
		64.3	0.54	3.66	0.40	43.7	81.8	119.8	-
		60.0	0.43	4.26	0.50	42.9	85.7	128.4	-
Sydney 1800	87.0	75.7	0.74	2.80	0.15	45.1	74.8	104.1	-
		69.6	0.65	3.17	0.25	44.4	78.1	111.3	-
		62.1	0.49	3.94	0.40	43.3	83.7	123.7	-
		58.0	0.37	4.63	0.50	42.4	72.7	133.1	-
Adelaide 2000	84.0	73.0	0.69	2.95	0.15	44.8	76.1	106.8	-
		67.2	0.60	3.38	0.25	44.1	79.7	114.6	-
		60.0	0.43	4.26	0.40	42.9	85.7	128.1	-
		56.0	0.29	5.09	0.50	42.0	90.3	138.4	-
Melbourne 2000	95.0	82.6	0.82	2.48	0.15	45.7	71.8	97.8	105.9
		76.0	0.75	2.76	0.25	45.1	74.5	103.8	113.1
		67.9	0.62	3.30	0.40	44.2	79.2	114.0	125.2
		63.3	0.52	3.77	0.50	43.5	82.6	121.6	134.3

the freeway was built. However, in the planning stages only estimated growth volume sensitivities could be used within the model.

Conclusion

The concepts persued in this paper focus on two important considerations associated with urban road analysis. Firstly, the use of the operational constraint equation which dictates the road speed and volume relationship which was utilised by NAASRA in 1984. Such estimates, with proper calibration of the alpha parameter, should provide a useful tool into road planning strategies. Secondly, the log U scoring mechanism attempts to provide an easily interpretable numeric representation of the utilisation of the road type examined, in this case the urban freeway. The scores reflect how near or how far from congestion a road is by attempting to score the road utility which is comprised from a volume and speed component score, equation 1.2. Despite the limitations of the functional form of the utility equation this concept of defining a level of satisfaction for road volume and speed should be central to the road planning mechanism as well as the infrastructure investment planning process. This paper has attempted to combine aspects of road capacity performance and road utility and therefore moved one small step beyond the cited literature.

APPENDIX I EXAMPLES OF LOG U SCORE CONSTRUCTION

Example 1.

Derivation of the road specific parameters A and B for a four lane freeway (assume Brisbane) which flows at its design capacity and where all traffic reaches critical speed.

From equation 1.8 $V_i = V_c$; This equation reduces to equation 1.9. Assuming, for this example, that alpha takes on the lowest value of 0.15 then the critical speed can be calculated as

$$S_c = 90/(1 + 0.15) \text{ , or}$$

$$S_c = 78.3 \text{ (rounded)}$$

Using this result equation 1.3 can be confirmed. That is,

$$100 = 4A \log 2000 + 78.3 \log B \qquad (E1)$$

To determine the volume relationship for equation 1.4 for a congestion speed of 25 kms/hour equation 1.8 is used;

$$V_i = 2000((90/25 - 1)/ 0.15)^{0.25}$$

$$= 4081 \text{ (rounded)}$$

Equation 1.4 therefore becomes;

$$50 = 4A \log 4081 + 25 \log B \qquad (E2)$$

Solving equations E1 and E2 produces values for A as 0.77 and B as 2.66.

Example 2.

Find the number of vehicles that would be travelling on a four lane Melbourne freeway at 94 kms/hour/lane and determine the associated log U score. Assume alpha is 0.15.

From equation 1.8 the volume can be derived; eg,

$$V_i = 2000((95/94 - 1)/ 0.15)^{0.25}$$
$$= 1032 \text{ (rounded)}$$

From equation 1.2 and values from Table 2;

$$\log U = 4 \times (0.82) \log 1032 + 94 \log 2.48$$
$$= 22.76 + 85.37 = 108.13$$

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LITRES: A Proposal for an Application of Information Technology to Urban Commuting

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Abstract:

The LITRES concept exploits information technology to harness two complementary transport system features, vehicle re-use and ride sharing, to combat the major threats to cities posed by continued use of the private motor car. It is claimed that lower generalised costs and the potential to create a different mentality towards the motor car will persuade users to adapt to the system. When information technology is combined with new vehicle technology, the system can make large cities ecologically sustainable while still answering the demand for the ad hoc convenience of the motor car.

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