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Mark Wardman (1997) *Disaggregate Inter-Urban Mode Choice Models: A review of British Evidence with special Reference to Cross Elasticities.* Institute of Transport Studies, University of Leeds, Working Paper 504

1.OBJECTIVES

1.1AIMS OF THE PROJECT

The research reported in this paper forms part of EPSRC project GRK52522 entitled 'National Multi-Modal Travel Forecasts'. The principal aim of this project is to develop a set of national and regional travel demand forecasts by land-based modes. These demand models for car, bus and rail will be based on a hierarchy of techniques and hence there are several strands to this research.
One aspect of the research involves the review of aggregate models, based on collective travel behaviour, and the evidence that they yield on own and cross elasticities. Whilst such models provide a wealth of information on own elasticities, and are particularly well suited to the analysis of the effects of exogenous factors on travel demand, they tend to make little allowance for competitive effects and hence provide little evidence regarding cross-elasticities. Furthermore, their nature is such that there can be only limited segmentation of the elasticities by relevant travel and socio-economic factors.

Another aspect of the study is reviewing the evidence that is provided by disaggregate models where, in contrast to the aggregate models, the unit of observation is the individual decision maker. Since such models examine competition between modes, they are particularly useful in providing evidence on cross-elasticities.

A further aspect of the work will be the actual estimation of relevant demand models and elasticities for a range of circumstances and by a variety of means.

The final stage prior to application of the models is to draw all the evidence together in a consistent manner, drawing upon the strengths of different approaches and the various insights that they provide.

1.2AIMS OF THIS PAPER

The aim of this paper is to review British evidence regarding disaggregate choice models which have been developed to explain inter-urban mode choice. The emphasis of the review is on cross-elasticities for the following reasons:

- Aggregate models are well placed to provide own elasticity estimates, particularly since they include trip generation which is not covered in disaggregate mode choice models.

- Aggregate models provide relatively little information on cross-elasticities in contrast to disaggregate mode choice models.

We will also explore the extent to which the disaggregate models which have been developed can contribute to an understanding of how own and cross elasticities vary with the nature of the market.

A separate paper will review corresponding models of urban travel behaviour (Wardman, 1997), and we note here that there have been far more studies in the urban context, whilst aggregate models are reviewed in Clark (1996).

It is not the purpose of this paper to draw together the definitive cross-elasticities that will be used at the forecasting stage. This requires consideration of the other evidence and recognition of the fact that cross-elasticities may be highly context specific and in particular may vary according to relative market shares. Indeed, it is important to ensure that the cross-elasticities which are used exhibit a consistent relationship, according to economic theory, both amongst themselves and with regard to the own elasticitiems which are used.

1.3STRUCTURE OF THE PAPER

The studies contained in this review are:

i)M1/A1(M) Corridor Cross Mode Elasticity Study
ii)Setting Forth Study
iii)TransPennine Rail Strategy Study
iv)Competitive Modelling Study
v)Regional Pricing Study

Section 2 discusses the background issues relating to the estimation of disaggregate choice models and their elasticity properties and also the relationship between choice and ordinary elasticities. Section 3 provides a review of each study in terms of its model parameters and reported elasticities. A discussion of various relationships obtained from economic theory which are important in deriving a consistent set of elasticities for use in strategic forecasting is provided in section 4. Concluding remarks are provided in section 5.

2.BACKGROUND

2.1MODELLING APPROACH

By far the most commonly used model to analyse discrete choice data is the logit model. All of the applications of disaggregate mode choice models to inter-urban travel in Great Britain have been of the logit form and almost all are of the binary form. Some have been calibrated to Revealed

Preference (RP) data, some have been calibrated to Stated Preference (SP) data whilst others have involved joint estimation of hybrid models on both forms of data.

The multinomial logit model expresses the probability of using some alternative i as a function of the utilities (V) of the k alternatives in the choice set:

$$P_i = \frac{e^{V_i}}{\sum_k e^{V_k}} \qquad \mathbf{1}$$

In the case of choices between just two alternatives (1 and 2), the logit model can be expressed as:

$$P_1 = \frac{1}{1 + e^{V_2 - V_1}} \qquad \mathbf{2}$$

In turn, utility is related to relevant observable variables (X_i):

$$V_i = f\,(\Omega\,\beta_i, X_i) \qquad \mathbf{3}$$

Ω is a scale factor whose purpose is to account for the effect of unobserved factors on choices and it is expressed as:

$$\Omega = \frac{\pi}{\sqrt{6}\,\sigma_k} \qquad \mathbf{4}$$

where σ_k is the standard deviation of each alternative's unobserved effects. Relative valuations are normally expressed in monetary terms; for example, the value of travel time savings is expressed as a monetary equivalent of the time benefit. The marginal monetary valuation (MMV) of variable X_m for alternative i is derived as:

$$MMV(X_{im}) = \frac{\frac{\partial V}{\partial X_{im}}}{\frac{\partial V}{\partial X_{ic}}} \qquad \mathbf{5}$$

where c denotes cost. Given that Ω applies to both the numerator and denominator terms, the estimated relative valuations are independent of the scale of the model.

A potentially undesirable feature of the logit model when there are more than two alternatives is the so called independence of irrelevant alternatives (IIA) property whereupon the cross elasticities are equal (see equation 10). The most common means of allowing for differential substitutability between alternatives is the hierarchical logit model (Ortuzar and Willumsen, 1994). This proceeds by way of a 'nesting structure' whereby alternatives that are more closely associated are placed in the same nest. Thus for choices between car, rail and bus, it is typical to place rail and bus together in the lower nest and for the upper nest to include car and the 'composite' public transport alternative. In this particular example, the probability of choosing car (P_c) would be:where

$$P_c = \frac{1}{1 + e^{V_{pt} - V_c}} \qquad \mathbf{6}$$

$$V_{pt} = \theta \log (e^{V_t} + e^{V_b}) \qquad \mathbf{7}$$

The probabilities of choosing train (P_t) and bus (P_b) would be:

$$P_t = (1 - P_c) \frac{1}{1 + e^{V_b - V_t}} \qquad \mathbf{8}$$

and

$$P_b = (1 - P_c) \frac{1}{1 + e^{V_t - V_b}} \qquad \mathbf{9}$$

Other forms of model which relax the restrictive IIA property have recently been applied (Bhat, 1996; Hensher, 1996) but we are not aware of such applications in Great Britain.

2.2CHOICE ELASTICITIES

A useful indicator of the properties of a demand forecasting model is the elasticity of demand. Given the logit model of equation 1 and a utility function as in equation 3, the point elasticity of demand for mode i with respect to changes in the level of variable X on mode k is:

$$\eta_{ik}^{point} = \frac{\partial V_k}{\partial X_k} X_k (D - P_k) \qquad \mathbf{10}$$

The Kronecker delta (D) equals 1 if i=k and the term represents an own elasticity, else it is zero and the term therefore represents a cross elasticity. It can be seen that a logit model's elasticities will depend not only on market share but also, in general, on the level of the variable for which the elasticity is being calculated. If we specify the utility function as:

$$V_i = \sum_m \Omega \beta_{im} X_{im}^{\lambda_{im}} \qquad \textbf{11}$$

the implied elasticity function is:

$$\eta_{ik}^{point} = \Omega \beta_{km} \lambda_{km} X_{km}^{\lambda_{km}} (D - P_k) \qquad \textbf{12}$$

where D is again the Kronecker delta. The conventional approach constrains the λ's to be one, which implies constant relative valuations but imposes appreciable variation in the elasticity with the respect to the level of its variable. An appropriate measure of the arc elasticity is:

$$\eta_{ik}^{\text{arc}} = \frac{\log \frac{P_{i2}}{P_{i1}}}{\log \frac{X_{k2}}{X_{k1}}} \qquad \textbf{13}$$

where 1 and 2 denote the before and after time periods. The formula effectively estimates a constant elasticity between two points. It is the same measure in both directions and has the same properties as the point elasticity. Unless otherwise stated, any arc elasticities reported here have used the relevant details from the reviewed report to construct equation 13.

2.3CHOICE AND ORDINARY ELASTICITIES

The elasticities obtained from mode choice models clearly do not account for trip generation or suppression, that is, they allocate a fixed number of trips amongst the available modes. There are two ways in which we might deduce ordinary elasticities from the mode choice elasticities.

The first is a pragmatic approach and is that which has been most widely applied. It involves the application of the choice model to determine a new volume of demand for the mode in question to which is added an amount to allow for trip generation. The ordinary elasticity is then calculated using this amended volume of demand for the new situation relative to the volume of demand in the base situation. The problem with this approach is that information is required about the trip generation effect, and its ratio with mode switching may well be variable across different situations. In addition, the generation effect may well vary across different travel attributes and hence application of the procedure when more than one travel attribute varies is not straightforward.

The second approach uses the relationship between mode choice and ordinary elasticities set out by Taplin (1982):

$$O_{ij} = M_{ij} + \eta_j \quad \textit{for all } i \textit{ and } j \qquad \mathbf{14}$$

where O_{ij} is the ordinary demand elasticity for mode i with respect to the price of mode j, M_{ij} is the equivalent mode choice elasticity and η_j is the elasticity of demand for aggregate traffic with respect to the price of mode j. It follows that a way forward in making fuller use of the results of disaggregate choice models is to estimate η_j so that the ordinary elasticity can be inferred. Other possible approaches are outlined by Oum et al. (1992).

3.EMPIRICAL EVIDENCE

There are sufficiently few published disaggregate studies of inter-urban mode choice in Great Britain that we can discuss each in turn in some detail. In each case, we discuss the form of model and the parameter estimates obtained and then turn to the reported elasticities and cross-elasticities. Where possible, the estimated values of time are also reported since these are useful in interpreting a model's reasonableness.

3.1M1/A1(M) CORRIDOR CROSS MODE ELASTICITY STUDY

3.1.1Models

This study (Steer Davies Gleave, 1994) examined the degree of interaction between rail and car in the corridor served by the M1, A1(M) and Midland Main Line. Three SP exercises were conducted, although only the one which examined choices between rail and car is of interest here.
Car travellers were offered nine choices of rail and car described in terms of car cost, rail fare, rail headway and rail time. Other factors were specified to be as for the actual journey, with the rail access/egress time for the current journey offered in the computerised SP exercise but not varied across scenarios. The business and leisure models upon which forecasts were based are given in Table 1.

As would be expected, given that the sample contains solely car users[1], the alternative specific constant (ASC) favours car. The coefficients are of the correct sign, and generally have been estimated with a very respectable degree of precision, with the distance coefficient indicating that the probability of using rail increases with distance.

The relative values are expressed for the group since the cost terms relate to the group and seem reasonable with the exception that headway has an implausibly large value. This will impact on the headway elasticity, and is an issue which arises in some of the other studies. The average car occupancy was 1.55 for business and 2.42 for leisure and these can be used to obtain individual values. Other models were reported which did not adjust cost for car occupancy.

Table 1: M1/A1(M) Corridor Study Business and Leisure Models

	Business		Leisure	
	Coeff (t ratio)	Value	Coeff (t ratio)	Value
ASC-Train	-0.8459 (4.2)	2643.43	-1.5070 (8.1)	3276.08
Acc/Egr-Train	-0.0197 (6.8)	61.56	-0.0052 (2.1)	11.30
IVT	-0.0105 (8.6)	32.86	-0.0060 (8.1)	13.04
Headway	-0.0130 (2.6)	40.63	-0.0149 (3.2)	32.39

[1] As a result of this, the ASC cannot be adjusted to allow for choice based sampling. Given that car users have different parameters to rail users, such a model would be appropriate in forecasting the impact of improvements to rail on current car users but would be less suitable for more general mode choice modelling.

Miles	0.0013 (1.1)		0.0091 (7.3)	
Cost	-0.00016 (6.0)		-0.00023 (10.5)	

Note: The rail fare is multiplied by vehicle occupancy in both models and hence the cost relates to the group. Costs are for the round trip and the other variables are in one-way units. Distance is specified relative to rail. The units are pence and minutes.

3.1.2Elasticities

Forecasts of the amount of switching from car were obtained from the SP models reported above in conjunction with a highway trip database. Given estimates of the number of Midland Main Line passengers per day from a previous study, it is also possible to estimate rail own elasticities. Table 2 presents the rail own elasticities and car cross elasticities for three improvements to rail services.

Although the elasticities relate only to the increase in rail demand attributable to abstraction from car, the rail time and fare elasticities appear plausible. However, as we anticipated, the headway elasticity is much too high.

Table 2: M1/A1(M) Study Elasticities

	Rail Own Elasticity	Car Cross Elasticity
Rail Fare -20%	-0.78	0.006
Rail IVT -20%	-0.55	0.005
Rail Head 30m-20m	-0.67	0.006

The cross elasticities are very low for the network wide model. However, as is apparent from Table 3, they do vary somewhat across different circumstances, being higher where rail is more competitive but still remaining low.

Table 3: M1/A1(M) Cross Elasticities for Train Time by Purpose, Flow and Distance

	Business	Leisure
London to/from Sheffield	0.035	0.088
London to/from Leicester	0.034	0.045
Leicester to/from Sheffield	0.040	0.037
24 to 50 miles	0.015	0.012
51 to 115 miles	0.029	0.031
over 115 miles	0.041	0.080

Note: These cross elasticities are based on a 20% train time reduction.

3.2SETTING FORTH

3.2.1Models

This study was conducted by Oscar Faber TPA (1993) and developed both Revealed and Stated Preference models for travellers making journeys which involved crossing the Firth of Forth. The models were based on choices between car, rail and bus for journeys in the range of 15 minute to 2½ hours car travel time. The SP exercise offered choices between these three modes which were described in terms of in-vehicle time (IVT), headway, cost and bridge toll. Respondents were asked to assume that factors not included in the SP exercise, such as interchange and out-of-vehicle time (OVT), were the same as for the actual journey.

A hierarchical RP model obtained a logsum parameter of 0.94, with a 95% confidence interval of ±0.21. Given the approximation of the logsum coefficient to unity, the multinomial model was adopted. The results of the RP multinomial logit model are given in Table 4, along with the results of the comparable SP model.

Table 4: Setting Forth RP and SP Multinomial Logit Models (All Purposes)

	RP		SP	
	Coeff (t ratio)	Value	Coeff (t ratio)	Value
Car-IVT	-0.0283 (5.8)	7.86	-0.0539 (40.2)	7.19
Bus-IVT	-0.0379 (7.0)	10.53	-0.0596 (47.8)	7.95
Train-IVT	-0.0177 (2.6)	4.91	-0.0542 (33.5)	7.23
OVT	-0.0386 (8.0)	10.72		
Headway	-0.0191 (4.2)	5.31		
Train-Headway			-0.0318 (33.2)	4.24
Bus-Headway			-0.0267 (20.1)	3.56
Bus-INT	-0.4803 (1.5)	133.34		
Train-INT	-1.8730 (1.8)	520.28		
Cost	-0.0036 (7.0)		-0.0075 (25.2)	
Toll			-0.0128 (23.7)	1.71
ρ^2	0.485		0.177	
Obs	733		12461	

Note: Units are pence and minutes for a one-way journey.

In both models the two constants were far from statistically significant and hence were removed. Actual shares of car, rail and bus for journeys across the Forth were reported to be 83%, 14% and 3%. The shares of each model in the RP model were 68%, 27% and 5%. Thus some allowance would have to be made for choice based sampling if the models were to be used to forecast absolute probabilities.

The models appear robust, with coefficients which have the correct sign and which are generally estimated with a high level of precision. The RP model would seem to be more plausible in terms of the variation in values of time across modes, on the grounds that the disutility of time spent in a bus is the highest and that in a train is least, whilst out-of-vehicle time is valued more highly than in-vehicle time (IVT). However, the RP model's value of headway relative to time appears less plausible than the SP model.

The issue of how the parameters varied by purpose was explored only on the much larger SP data set. Separate models were estimated for employers' business trips and for trips for all other purposes. The non-cost coefficients were noticeably similar and hence a more efficient model was estimated which combined the two purposes but allowed the cost and toll coefficients to vary with purpose. The model is reported in Table 5 below, with additionally a dummy variable (DToll) denoting whether the toll level was an increase on the current (40p) level.

Table 5: Setting Forth Business and Non-Business SP Models

	Coeff (t ratio)	EB Value	Other Value
Car-IVT	-0.0543 (40.4)	13.58	6.24
Bus-IVT	-0.0595 (47.3)	14.88	6.84
Train-IVT	-0.0535 (33.0)	13.37	6.15
Train-Headway	-0.0314 (32.7)	7.85	3.61
Bus-Headway	-0.0277 (20.4)	6.93	3.18
Cost-EB	-0.0040 (8.3)		
Toll-EB	-0.0051 (3.7)	1.27	
Cost-Other	-0.0087 (25.8)		
Toll-Other	-0.0109 (10.7)		1.25
DToll	-0.2151 (2.7)		
ρ^2	0.182		
Obs	12461		

Note: EB denotes employer's business.

The business values are higher than the non-business values, as might be expected, but the differences are not as marked as in the M1/A1(M) study. It may be that the relatively low business values here are related to the shorter journeys involved whilst there may be other differences in the characteristics of this sample and the M1/A1(M) study sample.

The toll dummy managed to reduce the toll coefficients but the latter are still somewhat higher than the cost terms. This may be due to the presence of strategic bias in cases where the toll was increased. Alternatively, it could be that the sensitivity to tolls is truly greater than the senstivity to car fuel and parking cost because, for example, not all individuals consider the latter costs in their mode choice decisions.

A hybrid model was estimated using a two stage sequential procedure (Ortuzar and Willumsen, 1994). Utilities were calculated for employers' business (U-EB) and for the other purposes (U-Other) on the basis of the SP coefficients obtained in Table 5. A logit model is then estimated to relate actual choices to these utility measures and also to the variables which were not in the SP model. The results are presented in Table 6.

Table 6: Setting Forth Sequential Hybrid Model

	Coeff (t ratio)
ASC-Train	0.8100 (4.4)
ASC-Bus	-0.5958 (2.1)
U-EB	0.4154 (3.5)
U-Other	0.3550 (7.9)
OVT	-0.0382 (8.0)
Int-Train	-1.947 (1.9)
Int-Bus	-0.5908 (2.0)
ρ^2	0.47
Obs	733

The coefficients on the U-EB and U-Other utility terms in this sequential estimation procedure are interpreted as the ratio of the residual deviations of the SP and RP models. Thus they denote that the residual deviation in the SP data is less than in the RP data.

3.2.2Elasticities

Point elasticities were reported from the overall RP and SP models and these are reproduced in Table 7. The need for rescaling of the SP model is apparent in its generally higher elasticities. The own elasticities are, of course, mode choice elasticities and take no account of generation effects.

Table 7: Setting Forth RP and SP Point Elasticities

	SP Model			RP Model		
	Car	Bus	Rail	Car	Bus	Rail
Toll	-0.36	+0.18	+0.17	-	-	-
Car Cost	-1.10	-0.52	+0.53	-0.17	+0.43	+0.36
Bus Cost	+0.35	-0.97	+0.36	+0.02	-0.45	+0.04
Rail Cost	+0.75	+0.78	-1.11	+0.17	+0.35	-0.50
Car IVT	-1.56	+0.75	+0.74	-0.32	+0.70	+0.69
Bus IVT	+0.77	-2.15	+0.82	+0.10	-2.07	+0.17
Rail IVT	+0.74	+0.79	-1.12	+0.12	+0.23	-0.36
Car Acc/Egr	-	-	-	-0.09	+0.25	+0.18
Bus Acc/Egr	-	-	-	+0.02	-0.50	+0.04
Rail Acc/Egr	-	-	-	+0.19	+0.34	-0.55
Bus Headway	+0.17	-0.47	+0.18	+0.04	-0.73	+0.06
Rail Headway	+0.33	+0.39	-0.52	+0.12	+0.22	-0.36
Bus Interchange	-	-	-	+0.01	-0.16	+0.01
Rail Interchange	-	-	-	+0.00	+0.0	-0.01

Some elasticities seem unreasonable, such as all those relating to rail headway, whilst the interchange elasticities are low because many had a zero interchange (see equation 12). A better indicator would have been to examine the effect of, say, an additional interchange. However, most elasticities appear plausible, but it must be borne in mind that no adjustments have been made for choice based sampling and this would affect point elasticities.

3.3TRANSPENNINE RAIL STUDY

This study (Oscar Faber, 1992) was undertaken in parallel to the Trans-Pennine Road Study conducted for the Department of Transport by the same organisation. It was one of the first disaggregate studies of inter-urban mode choice to be conducted in Great Britain. Data was collected on actual choices to allow the development of Revealed Preference models of choices between rail and car and between rail and coach. Corresponding Stated Preference models were also developed. Unfortunately, no distinctions were made according to journey purpose.

3.3.1Rail and Car Models

The rail and car RP and SP models are reported in Table 8. The RP model is based on a very large sample size, achieves a good fit and has coefficients which are of the correct sign and are precisely estimated. An adjusted alternative specific constant (Adj-ASC) which allows for choice based sampling was given.

A somewhat better fit was obtained by the inclusion of the three interaction terms. The effect of these is to reduce the sensitivity to a variable X the larger is the level of the variable with which it interacts. Thus given the interaction of IVT and Cost, and the positive sign of this interaction term, the 'marginal utility of time' ($\partial V_k/\partial X_k$ in terms of the elasticity function of equation 10) would be:

$$\frac{\partial V}{\partial IVT} = -0.0094 + 0.0000027\ Cost$$

which falls as cost increases. Similarly, the level of time will influence the sensitivity to cost variations, as will the levels of access/egress times.

The purpose of the SP exercises was to examine relevant issues beyond the scope of the RP model. These included expected standing time, expected late time and stock type for train, and delay and free flow time for car. For cost reasons, the SP exercises were distributed to only a proportion of those who completed the RP questionnaire. The coefficients of the SP model are of the correct sign and highly significant whilst the goodness of fit is typical of that achieved by these sorts of models. The SP models do not depart from the conventional linear form and note that they have not been used as independent forecasting models.

Table 8: TransPennine Rail and Car RP and SP Model

	RP	SP(1)	SP(2)
ASC-Rail	+1.1284 (7.4)	-0.4521 (7.8)	-1.2915 (5.4)
Adj ASC	-0.0912	-	-
IVT	-0.0094 (10.3)	-	-
IVT-Rail	-	-0.0259 (8.2)	-0.0381 (12.2)
IVT-Car	-	-0.0319 (11.5)	-
Delay-Car	-	-	-0.0366 (6.5)
Free-Car	-	-	-0.0264 (7.9)
Cost	-0.0021 (15.5)	-0.0057 (6.6)	-0.0059 (7.7)
Interchange	-0.3883 (10.0)	-	-
Acc/Egr-Rail	-0.0215 (9.8)	-	-
Headway	-0.0118 (7.8)	-0.0360 (8.1)	-
Acc/Egr-Car	-0.0223 (9.8)	-	-
Expected Late	-	-0.0439 (7.2)	-
Expected Stand	-	-	-0.1249 (9.3)
Electric Sprinter	-	-	+0.1748 (2.2)
IVT*Cost	+0.0000027 (7.4)	-	-
Acc/Egr-Rail*Cost-Rail	+0.0000068 (6.0)	-	-
Acc/Egr-Car*Cost-Car	+0.0000217 (3.8)	-	-
Medium Distance	+0.0716 (5.5)	-	-
Long Distance	+1.4036 (9.4)	-	-
Rail Choices	949 (33%)	1445 (55%)	1996 (59%)
Car Choices	1885 (67%)	1167 (45%)	1380 (41%)
Rho Squared	0.34	0.08	0.13

Note: Units are pence and minutes for a round trip in the RP model and for a single trip in the SP models.

The RP model's values cannot be calculated directly from the parameters given in Table 8 since, as a result of the interaction terms, they are not constant. The average marginal values calculated to the data upon which the models were calibrated, along with the constant values implied by the SP models, are given in Table 9.

Table 9: TransPennine Rail and Car Relative Values

	RP	SP(1)	SP(2)
IVT-Car	5.2	5.59	-
IVT-Rail	7.2	4.54	6.46
Delay Time	-	-	6.20
Free Time	-	-	4.47
Interchange	422.5	-	-
Acc/Egr-Rail	15.7	-	-
Acc/Egr-Car	11.3	-	-
Headway	6.2	6.31	-
Expected Late	-	7.70	-
Expected Stand	-	-	21.16
Electric Sprinter	-	-	29.63

We again observe high values of headway, which we anticipate will lead to headway elasticities which are too high. However, there are a number of desirable features of the results, such as the similarities between the RP and the average of the SP values of time, the value of delay time exceeding the value of free time and the value of access/egress time being somewhat higher than the value of time. The absolute values also generally appear plausible.

3.3.2Rail and Car Elasticities

Elasticities were reported for the RP model and these are reproduced in Table 10 using the sample enumeration method. The car cross-elasticities are somewhat higher than for the M1/A1(M) corridor study. This may be because in the TransPennine study only 30% of car users considered themselves to have rail as an alternative and 52% stated that they had no alternative means of travel. This is likely to have been much less of a problem with the M1/A1(M) study given an SP exercise was used and thus model development is not dependent on respondents providing details of modes that are not in their choice set. The elasticities reported below implicitly assume that all car users have train in the choice set and thus adjustments would be required. An appropriate adjustment to the car cross elasticities, given that 70% of car users did not consider themselves to have rail as an alternative and who therefore have a zero cross-elasticity, is to multiply these figures by 0.3. Similarly, the train cross elasticities can be multiplied by 0.5 given that only 50% of train users had car as an alternative. Adjusted figures are presented in brackets.

Table 10: TransPennine Rail and Car RP Model Point Elasticities

	Own	Cross
Rail IVT	-0.79	0.12 (0.036)
Rail Acc/Egr	-0.71	0.11 (0.033)
Rail Interchange	-0.56	0.04 (0.012)
Rail Cost	-0.80	0.09 (0.027)
Headway	-0.32	0.04 (0.012)
Car IVT	-0.09	0.22 (0.110)
Car Acc/Egr	-0.01	0.01 (0.005)
Car Cost	-0.06	0.24 (0.120)

3.3.3Rail and Coach Models

The rail and coach models are given in Table 11. The data sets are not as large as for the car and rail models, which has a noticeable impact on the t ratios in the RP model. However, the coefficients are of the correct sign and retain a satisfactory level of precision. Again, however, the headway coefficient is higher than the IVT coefficient whilst access/egress time has a value little different to IVT.

Table 11: TransPennine Rail and Coach RP and SP Models

	RP	SP
ASC-Rail	+1.1600 (5.7)	+1.4091 (9.6)
Adj ASC	+1.5306	-
IVT	-0.0093 (5.2)	-
IVT-Rail	-	-0.0356 (13.8)
IVT-Coach	-	-0.0329 (14.3)
Cost	-0.0042 (7.2)	-0.0116 (14.6)
Interchange	-0.0711 (1.0)	-
Acc/Egr	-0.0061 (1.9)	-
Headway	-0.0104 (3.6)	-
IVT*Cost	+0.0000052 (4.3)	-
Expected Stand	-	-0.0967 (6.0)
Electric Sprinter	-	+0.5864 (5.7)
Long Distance	-0.3785 (1.7)	-
Rail Choices	339 (57%)	1563 (65%)
Coach Choices	258 (43%)	845 (35%)
Rho Squared	0.19	0.23

Note: Units are pence and minutes for a round trip in the RP model and for a single trip in the SP models.

The relative values are given in Table 12, with the RP values being averages across the circumstances faced by the individuals upon whom the models were calibrated. It is noticeable, and expected, that the values are lower than in the rail and car models, indicating a stronger preference for cost relative to service quality amongst this segment of travellers. It is also noticeable that the values of IVT are lower for coach, when the reverse might be expected, and the SP values of IVT are somewhat higher than the RP values.

Table 12: TransPennine Rail and Coach Relative Values

	RP	SP
IVT-Rail	2.19	3.07
IVT-Coach	1.39	2.83
Interchange-Rail	26.71	-
Interchange-Coach	23.09	-
Acc/Egr-Rail	1.98	-
Acc/Egr-Coach	2.29	-
Headway	3.36	-
Expected Stand	-	8.34
Electric Sprinter	-	50.55

3.3.4Rail and Coach Elasticities

Table 13 reproduces the own and cross point elasticity estimates calculated using sample enumeration on the data used to calculated the RP model. The issue of choice sets again requires some attention here, since only 35% of train users stated that coach was an alternative and 57% of coach users cited rail as an alternative. The figures in brackets again allow for the proportions who have zero cross elasticities.

Table 13: TransPennine Rail and Coach RP Model Point Elasticities

	Own	Cross
Rail IVT	-0.20	0.08 (0.05)
Rail Interchange	-0.02	0.01 (0.01)
Rail Cost	-0.81	0.34 (0.19)
Rail Headway	-0.25	0.11 (0.06)
Rail Acc/Egr	-0.13	0.07 (0.04)
Bus IVT	-0.13	0.77 (0.27)
Bus Interchange	-0.00	0.03 (0.01)
Bus Cost	-0.21	0.78 (0.27)
Bus Acc/Egr	-0.13	0.26 (0.09)

Note: The bus interchange point elasticity is zero because generally no interchanges were involved.

The headway elasticities again appear relatively high whilst the interchange elasticity will have been influenced by the number of zeros in equation 12. Otherwise, the emphasis on cost and its generally higher elasticity than time would seem reasonable for this market segment.

3.4COMPETITIVE MODELLING STUDY

Further analysis of the TransPennine Rail Strategy Study data was undertaken in a study funded by ESRC[2]. This research was based solely on those choosing between car and train and the main emphasis of this work was:

i)to disaggregate by business and leisure travel
ii)to examine the functional form of the utility expression in greater detail.

The functional form examined was that specified by equation 11. The estimation procedure involved searching across a pre-specified range of λ values to identify the best fitting model.

3.4.1Business Travel Model

The results reported in Table 14 are taken from Wardman, Whelan and Toner (1994). The data set is not large and this is reflected in the t ratios which are low compared to others reported in this paper. The coefficients are of the correct sign but, as we shall see, the relative values would not seem to be satisfactory for a model of business travel.

The marginal monetary values were calculated as averages across the individuals in the data set and are reported in Table 15. Whilst the nature of TransPennine trips might be somewhat different to the nature of London based trips, as might be the characteristics of the travellers concerned, the values of time are much too low for business travel.

[2]The research was conducted as part of ESRC project R000233791 entitled 'Measuring the Potential for Diverting Inter Urban Travellers to Rail.

Table 14: TransPennine Business Model

	β	λ
ASC-Car	-1.47200 (3.7)	
Headway	-0.00678 (2.7)	1.0
Interchange	-0.24410 (4.1)	1.4
Time	-1.51500 (3.6)	LOG
Cost-Car	-0.00062 (1.6)	1.0
Cost-Train	-0.01431 (6.1)	0.7
Choices Rail	80 (14%)	
Choice Car	502 (86%)	
ρ^2	0.340	

Note: All variables are specified in round trip units. Costs are in pence and times are in minutes. Time is end-to-end journey time.

Table 15: Marginal Monetary Valuations for TransPennine Business Model

Headway	Interchange	ASC1	ASC2	Train Time	Car Time
5.89	497	1276	2453	4.92	15.53

Notes: All valuations are expressed in terms of the train cost units, with the exceptions of ASC2, which expresses the ASC in car cost units, and the car value of time. The interchange valuation is based on those who experienced at least one interchange.

3.4.2Business Travel Elasticities

The point elasticity estimates are provided in Table 16. Although the ASC is unadjusted, for the Non-London flows under consideration the share of car and rail may well be fairly representative.

The reported elasticities add further to our concerns regarding this business model. It transpired in the course of calculating such elasticities that 85% of respondents cited car cost to be zero, whereas almost all reported a train cost. This renders the car cost elasticities meaningless, although it may be that the disutility of car cost (say as it enters company decision making) may well have been discerned by the ASC, thus explaining why it so strongly favours train when such a large proportion of the sample chose car. The train own-elasticities are large as a result of rail's low share but they do appear to be too large.

In addition to these concerns about relative values and elasticities, the model could not be recommended for use on London based flows on the grounds that rail is observed to capture significant shares of the market on these flows whereas the model reported in Table 14 would be incapable of explaining this. In general, we would have serious reservations about using the results of this model without supporting evidence from other models or consistency between the elasticities of this model and other elasticity estimates.

Table 16: Point Elasticities for TransPennine Business Model

	Own	Cross
Car Cost	-0.01	0.03
Car Time	-0.05	0.95
Rail Cost	-1.50	0.02
Rail Time	-1.46	0.02
Rail Headway	-1.11	0.01
Rail Interchange*	-25%	1%

Note: * The interchange 'elasticities' here represent the effect on car or train demand of each person having an additional interchange on each leg of their journey.

3.4.3Leisure Travel

The leisure model is reported in Table 17 and is taken from Wardman, Toner and Whelan (1997). The data set is large and the coefficients are all of the correct sign and and highly statistically significant. A distinction is made between the cost coefficients of those travelling alone and those travelling in a group, with the latter denoting the per person cost.

Table 17: TransPennine Leisure Model

	Coefficient	Function
ASC-Car	4.6990 (3.6)	
Adj-ASC	6.07	
Headway	-0.0158 (5.6)	λ=0.9
Interchange	-0.2859 (4.8)	λ=1.0
Time-Car	-2.7621 (8.9)	Log
Time-Train	-1.6512 (6.6)	Log
Cost-Car (Alone)	-0.5120 (7.3)	λ=0.3
Cost-Car (Group)	-0.0828 (3.3)	λ=0.5
Cost-Train (Alone)	-0.0448 (7.2)	λ=0.6
Cost-Train (Group)	-0.0012 (4.2)	λ=1.1
Log-Likelihood	-523.647	
Car Choices	562 (52%)	
Train Choices	518 (48%)	
ρ^2	0.300	

Note: All variables are specified in round trip units in either pence or minutes.

Table 18 presents the average monetary values implied by each model across the situations faced by the individuals contained in the model. Those in groups have lower values which is presumably due to their greater sensitivity to cost changes. The values of interchange are reasonable, corresponding to equivalent time penalties of around 30 minutes which is consistent with other evidence. Whilst headway is actually valued, on average, less than train in-vehicle time, we would normally expect a relatively lower value than that found. Results from Stated Preference studies of long distance leisure travellers have found ratios of the value of headway to the value of rail time of 0.45 (Babtie, 1994), 0.38 (Marks and Wardman, 1991) and 0.59 and 0.45 from Oscar Faber TPA's study reported in section 3.2.1 (Table 4). Urban studies tend to find that headway is valued less than IVT. These results suggest that a headway coefficient of around a half that estimated would be more appropriate.

Table 18: Marginal Monetary Valuations for TransPennine Leisure Model

	Alone	Group
Headway	4.32	3.69
Interchange	136.83	118.32
Time-Car	12.48	8.88
Time-Train	5.02	4.19

Note: The monetary values are expressed in terms of the cost coefficient to which the variable relates and are in pence per minute.

3.4.4Leisure Travel Elasticities

Table 19 presents all the direct and cross elasticities which can be estimated by the model reported in Table 17. The point elasticities have been calculated using sample enumeration and the elasticities have been weighted by the number in the group in order to obtain elasticities with regard to the volume of trips. The elasticity for mode i with respect to variable X on mode j is therefore calculated as:

$$\eta^{i}_{xj} = \frac{\sum_{n} \eta^{i}_{xjn} P_{in} G_{n}}{\sum_{n} P_{in} G_{n}} \qquad \textbf{16}$$

where n is the number of observations in our data set and G is the group size.

The models that we have estimated relate only to those who are choosing between rail and car. The own elasticities must therefore be interpreted with care since no allowance is made for trip generation/suppression whilst the mode choosers within the other market might have different elasticities. However, it is the cross-elasticities which are in greatest need of adjustment since those who do not consider themselves to have rail (car) as an alternative will be unaffected by improvements to rail (car). The results reported in Table 19 have been adjusted for choice set composition. Apart from the headway elasticity, the elasticities appear reasonable, with noticeable differences between the figures for alone and group travel.

Table 19: Point Elasticities for TransPennine Leisure Model

	Own Elasticities			Cross Elasticities		
	Alone	Group	Total	Alone	Group	Total
Cost-Car	-0.21	-0.09	-0.16 (-0.19)	0.25	0.23	0.25
Time-Car	-0.58	-0.34	-0.47 (-0.52)	0.69	0.86	0.73
Cost-Train	-0.57	-0.65	-0.59	0.07	0.04	0.06 (0.06)
Time-Train	-0.82	-1.02	-0.87	0.11	0.06	0.08 (0.09)
Headway	-0.40	-0.52	-0.43	0.05	0.03	0.04 (0.05)
Interchange*	-27%	-33%	-29%	3.3%	1.8%	2.7% (3.0%)

Note: * The interchange 'elasticities' here represent the effect on car or train demand of an additional interchange on each leg of the journey. Cross elasticities have been adjusted to relate to the total market. Vehicle elasticities are given in parentheses.

3.5REGIONAL PRICING STUDY

Although this study (Oscar Faber TPA, 1992) developed a model to explain variations in rail trips in the sample by reference to variation in the travel variables offered in the SP experiment, the form of the SP exercise was identical to one which would be used to develop disaggregate choice models even though the method of analysis is equivalent to methods which can be applied to aggregate data. SP exercises involving laptop computers were conducted on five routes and offered trade-offs between train time, cost and headway, coach time, cost and headway, and car time and cost.

In contrast to the other elasticities reported in this paper, the elasticities estimated by the model are constant and they include generation effects as well as mode switching. They are reported in Table 20 and overall they are consistent with other evidence. There is not a great deal of variation in elasticities across purposes, although the car cross-elasticity is noticeably higher for business and commuting trips. There was also some variation in the elasticity estimates across routes but this was not strong.

Table 20: Regional Pricing Study Elasticities

	Overall	Business & Commuting	Shopping & Pers Bus	VFR & Leisure
Fare	-0.84	-0.82	-0.74	-0.89
Journey Time	-0.66	-0.70	-0.59	-0.62
Headway	-0.15	-0.23	-0.22	-0.13
Car GC	0.41	0.59	0.39	0.38
Bus GC	0.37	0.28	0.30	0.33

The generalised cost cross-elasticities can be decomposed if we know the proportions that the constituent variables form of generalised cost. If we have a relationship between the volume of demand on mode i and the generalised cost of mode j of

$$V_i = \mu GC_j^{\beta} \qquad \textbf{17}$$

and a generalised cost expression of:

$$GC_j = C_j + \lambda T_j + \gamma H_j \qquad \textbf{18}$$

where C, T and H denote cost, time and headway and λ and γ represent the money values of time and headway, the cross-elasticities relating to cost, time and headway are:

$$\frac{\partial V_i}{\partial C_j}\frac{C_j}{V_i} = \beta \frac{C_j}{GC_j} \qquad \textbf{19}$$

$$\frac{\partial V_i}{\partial T_j}\frac{T_j}{V_i} = \beta \frac{\lambda T_j}{GC_j} \qquad \textbf{20}$$

$$\frac{\partial V_i}{\partial H_j}\frac{H_j}{V_i} = \beta \frac{\gamma H_j}{GC_j} \qquad \textbf{21}$$

In other words, the component elasticities are a function of the proportion the variable in question forms of generalised cost. Previous research (Wardman, 1993) indicated that, for the value of time of 2 pence per minute used in this study and a value of headway of half that, fare, time and headway form around 55%, 30% and 15% of coach generalised cost whilst cost and time form around 70% and 30% of car generalised cost.

The cross elasticities of rail demand with respect to coach fare, time and headway are therefore 0.20, 0.11 and 0.06 respectively. The cross elasticities of rail demand with respect to car cost and time are 0.29 and 0.12 respectively.

3.6OTHER STUDIES

There have been a number of other studies which have examined inter-urban mode choice using disaggregate methods whose model parameters and elasticities cannot be reported here for reasons of commercial confidentiality. These studies have usually been sponsored by the railway industry and involve a mix of RP and SP methods (Accent et al., 1989; MVA Consultancy, 1987, 1991; Operational Research Unit, 1986; Toner and Wardman, 1993; TSU, 1989; Wardman et al., 1992)

4.DISCUSSION

We have seen that a choice model's elasticities can vary quite considerably across different situations. Thus it would be sensible to avoid placing too much emphasis on the elasticities derived from a single study and to be careful comparing the elasticities reported across different studies. The logit model's elasticity function presented in equation 12 shows that the own and cross elasticities are strongly related to the market share if the logit models assumptions are satisfied. Under a wide variety of utility functions, the elasticity to variable X will be a function
of the level of variable X and in some cases the relationship will be a strong one. For example, it would seem reasonable to expect the fare elasticity to increase as fare increases, that is, the scope for increasing revenue by increasing fares diminishes as fares are progressively increased.

We might expect elasticities to vary according to the competitive position, as occurs in the logit model. As a mode performs increasingly well in relation to other modes, it will become more difficult to attract further trips to it and indeed there will be some point beyond which no further trips can be attracted. The combination of small changes in demand and high demand will result in a low elasticity. At the other extreme, where the mode is so poor that its demand is zero, the elasticity will be undefined. The elasticity is expected to be high where the mode performs poorly since it is here where there is a large market from which the mode can attract travellers and even a small change in demand would constitute a relatively large proportionate change. A good reason why the cross elasticity will vary, and one which we have encountered in section 3 and had to make adjustments for, is the extent to which there are those who would not switch to other modes. The problem here is of distinguishing between zero cross elasticities which are the result of strong personal preferences and those which stem from the characteristics of the alternative modes.

To further demonstrate the variability of cross-elasticities, which are our prime concern, we can observe the dependence of cross-elasticities on market shares as outlined by Dodgson (1986):

$$\eta^{i}_{xj} \leq |\eta^{j}_{xj}| \frac{S_j}{S_i} \qquad \textbf{22}$$

where S_i denotes the market share of mode i and η_j is the elasticity of demand for mode i with respect to attribute x on mode j. If we have information on diversion factors, we can derive an exact relationship as:

$$\eta^{i}_{xj} = |\eta^{j}_{xj}| \frac{S_j}{S_i} \delta_{ji} \qquad \textbf{23}$$

where δ_{ji} is the proportion of those diverting from mode j who switch to mode i.

This discussion focusses on cross elasticities since this is the principal contribution of disaggregate mode choice models. Aggregate models are better suited to the estimated of own elasticities, since they allow for generation/suppression effects. However, they generally provide little guidance as to cross elasticities.

Table 21 summarises the cross-elasticity estimates listed in this review. Given the problems which have often occured with the headway elasticities, we concentrate solely on the time and cost elasticities which in any event are the most important. Table 21 reflects the inherent variability of cross-elasticities, although what might be regarded to be outlier terms are also apparent.

Table 21: Range of Cross Elasticities

	Car Demand	Rail Demand	Coach Demand
Car Time	-	0.11,0.12,0.69	0.70
Car Cost	-	0.12,0.29,0.36	0.43
Rail Time	0.005,0.036,0.080,0.120	-	0.05,0.23
Rail Cost	0.006,0.027,0.060,0.170	-	0.19,0.35
Coach Time	0.10	0.11,0.17,0.27	-
Coach Cost	0.02	0.04,0.20,0.27	-

Whilst recognising that the use of a single cross elasticity term across different circumstances is less acceptable than using constant own elasticities, we have used the relationships represented by equations 22 and 23 to examine whether the cross elasticities reported in Table 21 are consistent with what might be regarded to be reasonable own elasticities.

In order to operationalise equation 22, we assume on the basis of experience of numerous studies that the time and cost own elasticities for are -0.2 and -0.1 for car, -0.65 and -0.90 for rail and are both -1.1 for coach. We also take the market shares for car, rail and coach for inter-urban travel to be 0.83, 0.12 and 0.05 as cited in Wardman et al. (1997). In order to operationalise equation 23, we additionally require estimates of the diversion factors. Our assumptions are set out in Table 22.

Table 22: Assumed Diversion Factors

	Car	Rail	Coach	Not Go
Car to:	-	30%	15%	55%
Rail to:	50%	-	20%	30%
Coach to:	10%	40%	-	50%

Table 23 provides the deduced cross-elasticities. The need to derive the exact relationships is quite clear in the case of the rail and coach cross-elasticities since the upper bounds are so high as to be virtually meaningless. There are eight cases in Table 21 where there are multiple cross-elasticity estimates. In six out of these eight cases, there is a good degree of consistency between the deduced cross elasticity of Table 23 and the set of elasticities in Table 21. The exception to this is for the coach cross-elasticities with respect to rail time and cost where in each case the deduced cross elasticity lies outside the range of the estimated cross elasticity. In the remaining four cases, the consistency between the estimated and deduced cross-elasticities is mixed.

Table 23: Deduced Cross Elasticities

	Car Demand	Rail Demand	Coach Demand
Car Time	-	≤1.38 =0.41	≤3.32 =0.50
Car Cost	-	≤0.69 =0.21	≤1.66 =0.25
Rail Time	≤0.09 =0.045	-	≤1.56 =0.31
Rail Cost	≤0.13 =0.065	-	≤2.16 =0.43
Coach Time	≤0.07 =0.007	≤0.46 =0.18	-
Coach Cost	≤0.07 =0.007	≤0.46 =0.18	-

Note: The ≤ figures are obtained from equation 22 and the = figures from equation 23.

Headway seems to have a large effect where car users are concerned. This is observed in both RP and SP models. This could be because headway is a truly large effect, because it is something that car drivers particularly dislike since they are used to and appreciate the convenience of being able to travel when they want, or it could be a modelling problem, for example stemming from misreporting in RP models or not relating well to headway variations in SP models.

One way to check is to use equation 23 and deduce the cross elasticity of car demand with respect to rail headway given our above assumptions regarding diversion factors and relative market shares and an estimate of the rail headway elasticity. We take a value of -0.15 to be appropriate for the rail headway elasticity since this value is reported in both Oscar Faber TPA (1992) and was estimated to rail ticket sales data by Wardman (1994) as cited by the Monopolies and Mergers Commission (1996). This yields a headway cross elasticity of 0.01 which is much lower than implied by the models. Thus it would seem that the headway coefficients obtained from disaggregate choice models should be treated with caution.

There are two other relationships which can be used to guide the selection of cross elasticities to be used in strategic modelling and to ensure consistency between own and cross elasticities and also within the set of cross elasticities. The 'Slutsky symmetry' equation provides the following relationship between price (P) cross elasticities:

$$\eta_{pj}^{i} = \eta_{pi}^{j} \frac{P_j V_j}{P_i V_i} \qquad \textbf{24}$$

where V is the volume of travel. The application of equation 23 requires the assumption that income effects are negligible or that income elasticities are the same across modes. We believe the former assumption to be reasonable given the small proportion of expenditure that is on long distance travel.

Another useful expression is that sum of price elasticities is zero. If we assume that the demand for transport is independent of other markets, in other words there is a fixed transport budget, then the elasticities must observe the following relationship:

$$\sum_{j=i}^{n} \eta_{ij} + \eta_{iy} = 0 \qquad \textbf{25}$$

where there are n modes and η_{iy} is the elasticity of demand for mode i with respect to income. However, if the demand for transport is not independent of the characteristics of all other goods, it is necessary to account for this cross elasticity. The issue of the equivalent relationship for journey time, where the total amount of time is constrained, requires further attention.

Given that equation 24 applies across modes, we have a system of demand equations which we can use to check the consistency of the elasticities both within and across modes. It would also be possible to deduce unknown elasticities within the system providing that sufficient information on other elasticities is available (Toner, 1994).

5.CONCLUDING REMARKS

This paper has provided a review of British evidence regarding disaggregate mode choice models in the inter-urban travel market. It has concentrated on the contribution that such models can make in the area of cross elasticities between modes.

There are relatively few published studies of disaggregate analysis of inter-urban travel behaviour in Great Britain. This is particularly unfortunate given that we would expect the cross elasticity to vary somewhat across different circumstances and especially in relation to modal share. It is because of this expected variation in cross elasticities that we have not attempted to provide a set of recommended elasticities.

An important issue that must be borne in mind in application of the models reported here is that they are often calibrated on those who have a real choice between the modes in question and hence it would not be appropriate to apply the model where the choice set has a somewhat different composition. For example, those who are car users and would not consider travelling by rail would be omitted from a rail-car choice model as would be those rail users who do not have a car. Equivalent procedures must be adopted at the forecasting stage otherwise the cross elasticities will be higher than they should be.

A related issue is the extent to which, for example, individuals not considering some modes to be part of their choice set is a function of the preferences of the individual, that is the β's in equation 3, and the attractiveness of each mode, that is the X's in equation 3. Further research in this area is required.

The evidence shows that there is variation in the cross elasticities but, with the exception of the headway elasticities as we have discussed, they generally seem to be of an appropriate order of magnitude according to economic theory with reference to own elasticities given various assumptions about market shares and diversion factors.

It is strongly recommended that any strategic forecasting models ensure a degree of consistency between the elasticity properties of the models and economic theory. This involves consistency both between own and cross elasticities and also within the cross elasticities which are used. This paper has briefly outlined some of the theoretical aspects of consistency, and it should be noted that these are not always satisfied by standard choice models such as logit. Further consideration

might include the consistency of complete demand systems and consistency between elasticities for different variables.

Since the relationship between cross and own elasticities is a particularly useful one, given the relatively large amount of information on own elasticities, we recommend that research effort be directed towards a better understanding of relative market shares and of diversion factors.

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