MEASUREMENT ISSUES IN THE TRAVEL COST METHOD: A GEOGRAPHICAL INFORMATION SYSTEMS APPROACH

by

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ABSTRACT

A review of the travel cost (TC) literature shows that the base measurements of travel time and distance underpinning many studies are often obtained via crude simplifications. This paper presents an application of the TC method conducted using geographical information system (GIS) software. This permits superior measurement of both travel time and distance providing a more accurate and realistic basis for valuations.

1: INTRODUCTION

Since its original conception by Hotelling in the 1940's (Prewitt, 1949), use of the travel cost (TC) method has proliferated such that it is now the most widely applied revealed preference approach to valuing open-access recreation sites (Freeman, 1993). Given such a relatively long pedigree it is not surprising that the academic debate surrounding the method has moved on from the basic operational issues discussed in early texts (Clawson, 1959; Clawson and Knetsch, 1966) to consideration of sophisticated extensions and refinements such as the integration of leisure-time constraints (Bockstael et al., 1987), consideration of multiple destination trips (Mendelsohn et al., 1992), or incorporation within wider, random utility frameworks (McConnell and Strand, 1994). However, there is good reason to suspect that the base travel distance and duration data underpinning most TC studies have often been obtained through very crude simplifications. These have, in general, been used because of concerns regarding the accuracy of visitors own estimates of travel time and duration, and the difficulty of allowing for road network availability and quality in map based exercises. This paper addresses the measurement issue directly through the application of a geographical information system (GIS), a software package capable of manipulating and interrogating digital, spatially referenced data, to a TC survey of woodland recreation visitors. We argue that the analytical capabilities of a GIS make it the ideal medium through which TC studies should be implemented.

1.1: Measurement issues

The precise derivation of the base data underpinning TC studies is rarely discussed in published papers despite this being initially the most fundamental problem facing the researcher. An illuminating quote from Rosenthal et al. (1986: p.3) underscores this importance and goes some way to explaining the coincident reticence:

"... there is only one primary and essential piece of data: the city and/or county where the recreationalists who visited the site began their trip."

Visit origin is therefore defined as being some central point of an area (usually just the simple geometric centre, rather than even some population weighted measure). Given the extent of the average city, let alone the size of a county, this lack of precision in this `essential' and most basic data is disturbing. Some might argue that the above reference is relatively dated. However, a brief inspection of recent papers, even in the most prestigious journals, indicates that little has changed; as Mendelsohn et al. (1992; p.931) state in a recent TC analysis: "In this study, each county is an origin". Another line of defence might be that, on average, the centre of a city/county might be a reasonable approximation of trip origin. However, living on the side of

a city closest, as opposed to furthest, to a site might well be a very major reason as to why the trip in question occurred. A further problem arises from the fact that site locations themselves are regularly defined in a similar way, giving rise to the possibility of a systematic bias in measurements.

An even greater degree of silence is apparent with respect to how distances are to be calculated between these specified origins and the site. Again one of the few willing to commentate upon this mystic art are Rosenthal et al. (1992: p.17) who admit that the use of maps can be "quite tedious" and so, for major studies, recommend the use of "airline distances" (ie. straight lines) along with the application of "road circuity factors". Even if we ignore the fact that roads are not uniformly circuitous, such an approach assumes that all visitors have an identical availability of roads; a set of circumstances which could in fact only be achieved by laying tarmac for 360° and 800 miles (the outer limit of investigation used in the above paper) around each site.

However, given that it has long been recognised that travel time may be the most important factor determining trips (Knetsch, 1963), perhaps the most worrying facet of the measurement issue is how these already suspect travel distances are then used for the calculation of travel time. Again few commentators have much to say on this issue, but Rosenthal et al. (1986: p.8) make it clear that the most common approach is to assume some constant road speed, and apply this to travel distance (calculated as above) to obtain travel duration. This further generalises an oversimplification in that it assumes that not only road availability but also road quality is identical from all origins (i.e., not only does the tarmac stretch 360° around the site and for 800 miles in every direction, but also traffic congestion and other road conditions are identical from all trip origins).

The introduction of a GIS into this analysis avoids the necessity of making such gross simplifications. Precise grid coordinates can be used for both the site and all origins. The actual availability of roads may be examined along with all the twists and turns of that road network, so that precise travel distances can be measured. Furthermore, the road type for each section of a route is readily incorporated into the analysis so that the GIS can calculate travel distances taking into account road speeds on each of those segments. Consequently more accurate travel times can be determined.

We would argue that such an approach to measurement represents a substantial improvement over that typically used in the current TC literature and subsequently present comparative results to support this contention. However, two problems still remain. First, whether measurement is by adjusted straight line distance or via GIS, both rely on routing assumptions, most commonly that visitors choose routes which minimise travel time. Such a `logical routing' assumption may well be reasonable for the majority of visitors. For example, in their study of recreation in the Forest of Dean, Colenutt and Sidaway (1973) show that minimum

travel time provides an extremely strong explanatory variable in predicting visits. However, such an assumption may not be appropriate for all visits. Cheshire and Stabler (1976) define three categories of visitor: the `pure visitor' who is strongly site-orientated; the `transit visitor' who visits only in passing; and the `meanderer' who gains utility primarily from the journey itself. Assuming use of the logical route is reasonable for the pure and transit visitor although for the latter only a proportion (perhaps zero) of travel costs can be attributed to the site in question. This is also true of the meanderer, however here we have the additional difficulty that routing may be far from straightforward and indeed may be highly circuitous.

This brings us to our second problem, namely that measurement accuracy may not coincide with those visitor perceptions motivating the visit. It may be that the relevant factor determining a visit is not the actual travel distance and duration, but visitors perceptions of these (McConnell and Strand, 1981). Furthermore variance between the actual and perceptual measures may differ both between individuals and systematically with respect to both distance and duration.

One approach to both of these problems is to base time cost calculations upon visitors' estimates of travel duration and directly elicit visitors' estimates of journey expenditure. TGF based on such an approach can then be compared with those derived from GIS measurements of travel distance and duration.

Previous experience of visitor surveys (Bateman et al., 1995a) led us to expect that there would be relatively few meanderers and that most visitors would take logical routing decisions. Here we hypothesise that rounding errors and inaccuracies in stated distance and duration will make our GIS measures superior. However, the reverse can be anticipated to be true for meanderers. The overall impact upon the statistical fit of the TGF is therefore, *a priori*, uncertain.

1.2: Study methodology and limitations

Willis and Garrod (1991a) provide one of the first UK applications of the `individual' TC method. Here the dependent variable is specified as the number of visits made by the individual party to a site within a given period (usually per annum). This differs from the zonal approach originally used by Clawson and Knetsch (1966) where the dependent variable is defined as a visit rate (eg. per 1000 households) from a specified zone over the same period. The individual approach has a number of empirical advantages over the Clawson-Knetsch method[1] and is now predominant in the burgeoning US literature. We therefore adopt an individual TC approach in this study.

Using the GIS we calculate measures of travel time and distance from three definitions of

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[1] For example, individual as opposed to zonal average explanatory variables may be specified. See Bateman (1993) for a comparison, although this also highlights weaknesses in the individual approach; neither is flawless.

the journey origin: a 1km grid reference; District centroids; and County centroids. Details of these calculations are presented subsequently. These are compared together and with reference to visitors own perceptions of these measures. Preferred measures are identified and used to formulate a TGF from which consumer surplus estimates are calculated.

Given that we have been rather critical regarding certain aspects of others studies[2] we feel duty bound to highlight limitations of our own study. This is a simple, single site, TC study, undertaken so as to demonstrate the magnitude of the measurement effect under consideration. In particular it deals poorly with substitute sites and in effect implicitly assumes that these are randomly distributed[3]. This and other failings are the subject of ongoing research, but in the meantime the absolute magnitude of benefit estimates produced should be treated with some caution.

2: MEASURING TRAVEL DISTANCE AND TRAVEL TIME

2.1: The survey

During March and April 1993 a survey of visitors was undertaken at Lynford Stag, a typical open-access woodland recreation site, located within Thetford Forest, East Anglia. In total 351 parties of visitors were interviewed. Respondents were asked a variety of questions including the following:

(i)   Trip origin (see below);

(ii)   Visitors' own estimates of travel time and travel expenditure;

(iii)   The number of other sites visited during the days trip;

(iv)The proportion of the whole days enjoyment attributable to: (a) time spent travelling; (b) time spent at the survey site; (c) time spent at other sites;

(v)Socioeconomic and preference data thought likely to explain visit behaviour.

Trip origin was the visitor's home or holiday address as appropriate. Interviewers were instructed to gather sufficient detail to enable grid referencing to 1km coordinates.[4] This

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[2] We feel particularly contrite regarding our comments on Rosenthal et al. (1986) and note that at least this study reveals what many others gloss over and is in fact an excellent reference for anyone wishing to find out about the TC method.

[3] To see how it should ideally be done (with the exception of the measurement issue) see Bockstael et al. (1991).

[4] All interviewers had both prior experience of conducting surveys and had successfully completed undergraduate courses in GIS techniques.

necessitated that address information was gathered down to the village or (in towns) equivalent local area level.

2.2: GIS measurements from 1km resolution trip origins

Using the data collected from question (i) above, the 1km national grid reference of trip origin was located by consulting the Ordnance Survey Gazetteer of Great Britain (Ordnance Survey, 1987). This exercise highlighted the importance of geographical factors in the determination of visits. Trip origins were concentrated around Thetford, with over 90% of visitors having set out from within 100 miles of the site. However, as discussed previously, straight line distance is clearly a rather crude determinant of visits and one of the principal advantages of adopting a GIS approach was that it allowed us to account for both the distribution and quality of the available road network.

Digital road network details were extracted from the Bartholomew 1:250,000 scale database for the UK. This source provides information on road classes distinguishing 15 separate categories ranging from minor, single-track country lanes to motorways. Computing time and storage limitations made it impractical to assemble a detailed road network for the entire area covering origins of Thetford visitors (this ranged from near Newcastle upon Tyne in the north to Hampshire in the south). We therefore defined a study area to include the counties of Norfolk, Suffolk and Cambridgeshire, together with adjoining districts in Lincolnshire and Essex[5]. This encompassed over 92% of the visitor origins.

Typical speeds can be assigned to the different classes of road defined in the Bartholomew's database so enabling travel times to be calculated for discrete sections of road. From these, travel times can be calculated for routes across the whole network. Data detailing average travel speeds for differing categories of road were obtained from a variety of sources. This exercise revealed both the paucity of such data and some significant differences in estimates. An initial investigation was undertaken using road speeds given in Department of Transport (DoT) sources as detailed in column (i) and (ii) of Table 1.

INSERT TABLE 1 ABOUT HERE

Travel times from each road segment in the network were calculated via equation (1):

$$\text{travel time} = \frac{\text{length of road segment (in miles)}}{\text{speed (miles per hour)}} \qquad (1)$$

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[5] The Bartholomew's road coverage is stored in map tiles (100 km squares) on the national grid. The relevant map tiles were appended and subsequently clipped using the study area boundary as defined above.

Minimum travel time can be calculated by specifying the time from equation (1) as the impedance associated with a particular road segment in the digital network. An algorithm is then used to identify the route between the trip origin and forest site which minimises the cumulative impedance, thereby also isolating the minimum travel time. Utilising the DoT road speeds in Table 1, a series of travel times were calculated for a variety of routes between a sample of towns and villages in the area. These were then compared with those generated by using the alternative road speeds given in Gatrell and Naumann (1992) and the Automobile Associations `Autoroute' route planning software package. Further calibration was achieved by calculation of travel times for a number of routes well known to the authors and colleagues. These assessments consistently pointed to the conclusion that the DoT road speeds given in Table 1 were overestimates of those realistically attainable in the study area[6]. Such a finding reflects the fact that these official road speed estimates suffer from limited information regarding the impact of road junctions and other sources of traffic congestion. Although it was feasible to consult Ordnance Survey maps regarding the topology of motorway junctions it was not practical to conduct a systematic assessment of all junctions (or other traffic constraints) throughout the road network. Accordingly, a sensitivity analysis was undertaken to obtain appropriate adjustment factors by comparing calculated travel times with those regarded as more realistic[7]. Best fit implicit adjusted road speeds are detailed in columns (iii) and (iv) of Table 1.

The calculation of individuals' travel times and distances using the GIS involved three steps[8]. First, the site was identified on the road network and a GIS algorithm used to identify the minimum sum impedance[9] between a specified point (the site) and each unique segment of road. This determines the minimum cumulative time (in minutes) that it takes to reach the start and end point of each road segment. These times are then stored in an output table. Figure 1 plots visitor origins onto the resultant GIS calculated travel time bands which have been simplified to a few category values for this illustration. The figure clearly shows that our GIS travel time zones reflect the distribution and quality of the available road network. This is a substantial improvement upon the concentric travel time zones implicit in studies based on straight line distances (with or without `road circuity' constants)[10].

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[6] To illustrate, the journey from Norwich to Thetford would be expected to take 35-40 minutes. Our initial model using speeds from table 1 suggested a travel time of 31 minutes, whereas using our adjusted road speeds produced an estimate of 38 minutes.

[7] Further details are given in Bateman, Brainard and Lovett (1995).

[8] Full details of these operations are given in Bateman et al (1995b).

[9] The algorithm used works recursively though the entire road network, keeping information about the minimum-impedance route found so far, until all possible route permutations are exhausted.

[10] Further details regarding the definition of these zones and their use within models predicting the number of arrivals at a site are given in Bateman, Brainard and Lovett (1995) and Brainard, Lovett and Bateman (1995).

INSERT FIGURE 1 ABOUT HERE

The second step involved finding the nearest point on the road network for each individual visit origin. Travel times from this point to the site were then extracted by use of both the prepared output table and by interpolation between the two endpoints of each road segment.

Thirdly, the distance travelled by each visitor along these minimal-impedance routes was calculated using our adjusted road speeds using further GIS facilities.

2.3: GIS measurements from District and County centroid trip origins

As noted many US TC studies actually calculate travel time and distance from County centroids rather than more accurate trip origins. The literature is unclear as to whether geographical or population weighted centroids are used. While the latter is likely to be more representative of actual travel time and distance we suspect that it is the former which is being used. Nevertheless so as to avoid any overstatement of any error involved in the use of such approximations, we decided to base our comparative analysis upon population-weighted rather than geographic centroids, the location of which were calculated using a standard GIS algorithm.

It is arguable that in some US states counties are smaller than those in the UK making centroid measures a more accurate estimate of actual distance and duration. Therefore we also calculated population-weighted District centroids. Travel times and distances from both County and District centroids were then calculated as before.

3. RESULTS 1: COMPARING MEASURES

Table 2 details descriptive statistics regarding the various GIS-based measures of travel time with those estimates given by visitors. If we initially set aside the visitors estimate of travel time to concentrate upon the three GIS-based measures, we can clearly see that the effect of moving from the relatively accurate 1km journey origin to measures based on centroids is to lose the variation in estimates for visitors facing relatively short journeys to the site. For centroid measures the shortest journey time now increases to that given by the nearest centroid to the site. This loss of variation increases with the size of the centroid area and is therefore most severe for the County level centroids where the distribution shows that all measures from the minimum to the median are identical. A crude measure of the impact of these effects is given by the mean which increases substantially with centroid area. Clearly TC studies based upon centroids appear to be using measurements which are subject to an upward bias. Given the prevalence of this approach within the literature this is clearly an important finding suggesting that such studies may have significantly overestimated recreation benefits.

INSERT TABLE 2 ABOUT HERE.

Table 3 presents tests of the significance of these differences. Here the lower value in each cell (in brackets) gives the significance levels from a non-parametric (Mann-Whitney) test of the similarity of the two measures being compared. Here a value of less than 0.05 would conventionally be taken as implying that the two measures are significantly different. The upper value in each cell gives the modulus t-value calculated from a two-sample t-test. Because of the skewed nature of these distributions all measures were transformed by logs prior to this test to satisfy the requirement of normality.

INSERT TABLE 3 HERE.

Inspection of Table 3 shows that the centroid measures are significantly different from that based upon the more accurate 1km grid reference. This suggests that studies using centroid measures may well be significantly overestimating recreation values by using such simplifications[11].

Inspection of the travel distance measures given by each approach told a very similar story to that of Tables 2 and 3. As before travel distances increased significantly where progressively larger centroids were used.

Clearly then our 1km grid measures appear to be a significant improvement upon those centroid-based estimates commonly featured in the TC literature. However, returning to Table 2 we can see that the distribution and mean of the 1km measure is very similar to that obtained from visitors estimates. (Again this result was repeated for the travel distance measures, as illustrated in Figure 2 discussed below.) This is reassuring but does it indicate that the complexities of the GIS approach can be by-passed by simply asking visitors a few questions? In general the literature on using visitors estimates has not been supportive (Smith and Desvousges, 1986). Nevertheless we feel that there are clear advantages over the centroid measures and may be some interesting complementarity with the 1km (or similarly accurate) GIS measures. To illustrate this Figure 2 plots the ratio of stated to GIS 1km calculated travel distance against the absolute value of the latter.

INSERT FIGURE 2 ABOUT HERE.

Examining Figure 2 shows that, on average, both distance measures coincide reasonably well. The larger deviation between the measures at low distances is as expected and derives, we

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[11]Ongoing research is examining the magnitude of such a bias.

would argue, mainly from rounding error in statements regarding short journeys. We have drawn in (dotted lines) a cone of observations which may fit into this category. Support for such a line of reasoning is given by noting that, for these `rounding-error' observations, roughly as many respondents state travel distances below the GIS calculation as above. As the GIS distance is based on a minimum impedance algorithm (minimum time), those respondent estimates below the equality line seem likely to be subject to some form of error, an error which we argue is due to rounding. For observations within this category, the GIS calculated distance may provide a better basis for cost estimates than does stated distance. As the majority of respondents fall into this category this is an encouraging finding. However, Figure 2 also shows us that for a few respondents calculated distance is likely to be a poor estimate of true distance. Six extreme cases are identified, all lying above the upper 95% confidence interval around the mean. All of these are for stated distances of less than 100 miles and it seems most likely that these respondents are `meanderers'; those whose main objective is enjoyment of the journey rather than time spent on-site. For these individuals the advantages of removing rounding problems are more than outweighed by the error induced by the logical routing assumption underlying the GIS calculated distance.

While the majority of observations fall within our rounding error cone the few observations for which the ratio of stated to calculated distance is large, do cause a problem. Overall then it is difficult to decide, prior to our subsequent analysis, which distance measure is superior.

However, returning to Table 2 we can foresee a problem with any comparative analysis based on these two approaches to measurement. Both the GIS 1km and visitor-estimate methods result in very similar measures of travel time (and distance). Table 3 confirms that they are indeed statistically insignificantly different. This means that both will produce very similar degrees of fit when used as the basis of the travel cost variable in a TGF. Therefore we may expect a lack of statistical guidance as to which is superior and need to rely upon theoretical insights to determine an optimal modelling strategy.

4: DEFINITION OF TRIP GENERATING FUNCTIONS

As discussed above, we can identify two plausible methods for obtaining the raw data to calculate trip costs: GIS calculations based on 1km grid references and visitors' estimates[12]. Within either of these we wish to undertake a sensitivity analysis upon the unit valuation of both the time cost and travel expenditure elements of total visit costs. Most UK studies have followed the lead of Cesario (1976) in adopting a wage rate approach to the evaluation of travel time. For

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[12] Further permutations are considered in Bateman et al. (1995b).

example, Benson and Willis (1992) follow the Department of Transport in using a 43% wage rate assumption. However, recent studies have suggested that mean values of travel time may be significantly lower than this (Larson, 1993). Accordingly we allowed the wage rate percentage to vary and chose that value which maximised the fit of the model. Various definitions of unit travel expenditure were also tested with model fit again being used to evaluate which was most appropriate[13].

Total travel cost was calculated as the sum of time and journey cost. This was then divided through by a factor relating to the proportion of the days enjoyment which was attributed by respondents to their time on-site at Lynford Stag[14]. This made allowance for the fact that not all of the trip costs could be attributed to this particular site. Such scaling is especially important when, as here, we have evidence of meanderer's and transit visitors amongst the sample.

The adjusted travel cost estimate formed the first of a considerable list of variables which were considered within our TGF analysis. To ensure comparability across tests of differing measurement techniques a consistent list of explanatory variables was used for all analyses as follows[15]:

TC	=	Travel cost (as defined in text)
HSIZE =		Household size
HOLS	=	Respondent on holiday (0-1)
WORK=		Respondent working (0-1)
LIVE	=	Respondent lives near site (0-1)
RATING	=	Scenery rating (1-4)
TAX	=	Respondent is a taxpayer (0-1)
NT	=	Respondent in the National Trust
MDOG=		Main reason for visit is dog walking

An income variable was omitted from the above because of correlation with the time cost element of travel costs. Such a variable was tested within a separate set of TGFs where zero time costs were used, but here the income variable proved insignificant[16]. Statistical tests indicated that a natural log dependent variable (ln VISIT) would fit the data best. The resultant semi-log

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[13] While the value of travel time was allowed to take any wage rate percentage, three unit values of travel expenditure were tested: (i) 8p per mile (Automobile Association estimate of average petrol costs); (ii) 23p per mile (AA estimate of average total running costs); and (iii) visitors estimate. Approaches (i) and (ii) are from Benson and Willis (1992) while method (iii) follows McConnell and Strand (1981).

[14] See question (iv) in section 2.1.

[15] Other variables considered but rejected from the comparative models include: party size; age<25; age>65; membership of any environmental organisation; membership of separate organisations; other main activity dummies.

[16] t-values of the order of 0.7.

TGF is typical of those used throughout the US and UK literature.

Following theoretical and empirical arguments (Smith and Desvousges, 1986) TGFs were estimated using limited-dependent variable, maximum likelihood (ML) techniques (Maddala, 1983) thereby allowing explicit modelling of the truncation of zero and negative visits. Our resultant TGF model and consumer surplus estimator therefore follows the approach of Balkan and Khan (1988) and Willis and Garrod (1991a, 1991b). Here we rewrite our TGF as per equation (2):

$$\ln VISIT_i \ = \ \beta X_i + e_i \tag{2}$$

where: i indexes individuals; X_i is our vector of independent explanatory variables (as defined previously) with coefficient vector β; and e_i are disturbances assumed to be independent, identically distributed $N(0,\sigma^2)$. Given this model, the ML estimator is based on the density function of $\ln VISIT_i$ which is truncated normal as given in (3):

$$f(\ln VISIT_i) = \begin{cases} \dfrac{(1/\sigma)\varnothing[(\ln VISIT_i - \beta X_i)/\sigma]}{(1-\Phi[-\beta X_i/\sigma])} & \text{if } VISIT_i > 0 \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

Goodness of fit measures were given by log likelihood values, while consumer surplus estimates were calculated via equation (4):[17]

$$CS = \frac{[\ln(Q+1)-Q]}{b} \tag{4}$$

where   Q   = number of visits made per annum
        b   = travel cost coefficient

5: RESULTS 2: CONSUMER SURPLUS ESTIMATES

5.1:Travel expenditure and time cost based on 1km resolution, GIS calculated distance and duration

Here journey distances and duration are as calculated in our GIS analysis of 1km resolution journey origins. The full sensitivity range of unit journey and time costs discussed above are applied. The main advantage of the GIS approach is that it counters the rounding

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[17] A formal proof of (4) is given in Bateman et al (1995b) who also report results from an OLS estimated model.

errors inherent in respondents' estimates of journey distance and duration, while the main disadvantage is the inappropriate representation of meanderers.

Sensitivity analysis showed that a marginal cost (petrol only) travel expenditure assumption (8p/mile) and a small wage rate ($2^1/_2\%$) time cost together provided an optimal fit to the data. Table 4 reports our best fitting model based on 1km resolution GIS calculated journey distance and duration.

INSERT TABLE 4 ABOUT HERE

The model reported in Table 4 fits the data well and has expected signs and significance on all explanatory variables. The travel cost variable is highly significant, easily passing a 1% test, and indicating that visits are inversely related to the sum of journey and time costs. Applying equation (4) to this model gives a household consumer surplus estimate of £3.95 per visit.

5.2: Travel expenditure and time costs based on visitors estimates

Here travel expenditure costs are obtained as per McConnell and Strand (1981), by direct questioning of visitors. Clearly time costs cannot be obtained by quite such a direct route, however, by asking visitors to estimate journey time we get a measure of trip duration to which we can apply our various wage rate conversion factors. The resulting travel cost may capture the behaviour of meanderers better than our GIS calculations but is susceptible to response-rounding errors.

Our sensitivity analysis indicated that a zero wage rate provided the best fit to the data, a result in line with our previous GIS-based model and within the confidence interval estimated by Larson (1993). Our best fitting model based upon visitors estimate measures is shown in Table 5.

This gives a household consumer surplus estimate of £4.53 per visit, a value similar to that obtained from our GIS-based model and well within the limits of convergent validity tests such as those discussed by Mitchell and Carson (1989) with respect to the contingent valuation method.

INSERT TABLE 5 ABOUT HERE

The similarity between the models detailed in Tables 4 and 5 extends beyond valuation estimates to include parameter estimates and the overall fit of the two models which is not

significantly different[18]. Given that the only difference between these models is the way in which the TC variable is measured, and given the results of Tables 2 and 3 this similarity is not surprising. We discuss this and other issues below.

6: DISCUSSION AND CONCLUSIONS

We have compared three approaches to the measurement of the travel distance and duration data underlying travel cost studies:

(i)A GIS-based approach using 1km resolution journey origins;
(ii)A further GIS-based approach using centroid journey origins calculated at both District and County levels;
(iii)Visitors estimates of travel distance and duration.

We have shown that the measures obtained from using centroids diverge both systematically and significantly from those obtained from our more accurate 1km resolution approach. This is not surprising as, within any area journey origins will tend to be spatially distributed towards the site location. This means that, on average, centroid based measures will overestimate travel cost[19]. Given the number of centroid-based studies in the literature this is clearly an important result and one which questions the accuracy of many previous studies.

Comparison of our 1km GIS-based measures with those from visitors estimates is also revealing. These measures are statistically similar and consequently yield similar degrees of explanation and similar consumer surplus estimates. We therefore do not have a statistical indicator of which provides the best measure of actual travel cost. However, comparison of these approaches suggests that our GIS-based method may reduce estimation error for the bulk of `pure' and `transit' visitors while perception-based techniques may better capture travel time and distance for `meanderers'. An obvious avenue for future work seems therefore to investigate the potential for developing practical rules for combining these two approaches to yield a unified optimal method for measuring these fundamentally important variables.

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[18] Tested using a log-likelihood ratio test (χ^2 distribution) as detailed in Thomas (1993, pp.71-73).

[19] Strictly speaking this bias will almost always apply where geographical centroids are used and generally be less true where population-weighted centroids are used. However, we have allowed for this by using the latter approach in our comparison which still leads to significant overestimates of travel time and distance.

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Figure 1: Zones illustrating GIS calculated individual visitor travel times (in minutes)

Figure 2: Ratio of stated to GIS calculated distance against GIS calculated distance

Table 1: Road speed estimates

Road Type	Average Road Speed (mph)			
	DoT estimates		GIS adjusted road speeds	
	Rural (i)	Urban (ii)	Rural (iii)	Urban (iv)
Motorway	70	50	63	35
A-Road Primary Dual Carriageway	60	40	54	28
A-Road Other Dual Carriageway	55	35	50	25
A-Road Primary Single Carriageway	50	35	45	25
A-Road Other Single Carriageway	40	25	32	18
B-Road Dual Carriageway	40	25	36	18
B-Road Single Carriageway	30	17	24	12
Minor Road	20	15	14	11

Sources: column (i) and (ii) from Department of Transport (1992, 1993)

Table 2: Descriptive Statistics for travel time (minutes) estimated by four methods

Method	Mean	s.e. mean	st. dev	min	Q1	Median	Q3	max
Visitors estimates	49.0	2.1	39.8	1.0	24.0	40.0	65.0	270.0
GIS calculation from 1km grid reference	48.1	2.0	37.1	1.6	25.8	42.0	63.7	262.0
GIS calculation from District centroid	52.6	1.9	34.7	27.0	27.8	47.7	64.2	260.6
GIS calculation from County centroid	61.5	1.7	31.8	45.2	45.2	45.2	75.0	261.3

Table 3:Significance of differences between travel time measures calculated by four methods

	GIS calculation from 1km grid reference	GIS calculation from District centroid	GIS calculation from County centroid
Visitors estimates	0.09 (0.88)	4.76 (0.03)	7.99 (0.00)
GIS calculation from 1km grid reference	-	4.60 (0.01)	9.22 (0.00)
GIS calculation from District centroid	-	-	6.79 (0.00)

Table 4: Best fitting ML model based on GIS estimates of journey distance and duration (journey cost @ 8p/mile; time cost @ 2.5% of wage rate).

Variable	Coefficient	Std. Error	t-ratio
Constant	-0.4853	0.5923 0.0240	-0.819
TC	-0.0777	0.0542	-3.235
HSIZE	0.0719	0.5333	1.326
HOLS	-1.4729	0.4534 0.3946	-2.762
WORK	1.7408 2.2770	0.1579	3.840
LIVE		0.2417 0.2370	5.771
RATING	0.5050	0.2465	3.198
NT	-0.4629		-1.915
TAX	0.4416 0.6066		1.863
MDOG			2.461

Log-likelihood value = -454.59   n = 351

Table 5:Best fitting ML model based on perceived journey duration and cost
(travel expenditure as stated by respondent; zero time cost)

Variable	Coefficient	Std. Error	T-ratio
Constant	-0.4897	0.5930	-0.826
TC	-0.0677	0.0230	-2.943
HSIZE	0.0970	0.0544	1.784
HOLS	-1.4705	0.5367	-2.740
WORK	1.8232	0.4544	4.013
LIVE	2.2512	0.3971	5.669
RATING	0.4694	0.1569	2.991
NT	-0.4849	0.2425	-2.000
TAX	0.3994	0.2380	1.678
MDOG	0.6492	0.2468	2.630

Log-likelihood value = -455.47   n = 351