Kufa Journal of Engineering
Vol. 7, No. 1, January, 2016, P.P. 54-66
Received 17 August 2015, accepted 18 November 2015

BOOSTING CATEGORISATION SYSTEM IN THE UK TRICS DATABASE AND DEVELOPING NEW TRIP PRODUCTION MODELS

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ABSTRACT

In the UK, TRICS is a national trip generation databases and system. It is recommended to be used in quantifying traffic impacts of new residential developments. Thus, any enhancement in its methodology will positively influence the transport assessment process. This paper has three objectives; first, to examine the possibility of proposing new statistically-proven grouping for the TRICS residential land use subcategories. The second objective is to use the proposed grouping to construct parsimonious models for home-based trip production that can aid in quantifying traffic impact assessment. The third objective is to examine the validity of the developed models against two of the most internationally recognised trip information systems; the UK TRICS and the US ITE *Trip Generation Manual*. The statistical analysis ended up with new more accurate grouping where based on it eight trip production model were built. The developed models were found to be practical and rigorous.

KEYWORDS: Traffic impacts, Transport assessment, Trip generation, ANCOVA, Regression

تدعيم نظام تجميع استعمالات الارض السكنية في قاعدة بيانات UK TRICS و تطوير نماذج جديدة لانتاج الرحلات

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الملخص

في المملكة المتحدة، TRICS يعتبر قاعدة بيانات و نظام توليد رحلات وطني. انه غالبا موصى به ليستخدم في تحديد التاثيرات المرورية للمواقع السكنية الجديدة. لذلك أي تحسين على المنهجية المتبعة في TRICS ستؤثر ايجابا على عملية تقييم النقل. هذا البحث له ثلاثة اهداف؛ الاول، لتحري امكانية اقتراح تجميع جديد - مُحقق احصائيا- للتصنيفات الثانوية لاستعمالات الارض السكنية في قاعدة بيانات TRICS. الهدف الثاني هو لاستخدام التجميع المقترح لانشاء نماذج مقتصدة لانتاج الرحلات التي اساسها البيت التي تستطيع ان تساعد في قياس تقييم الاثار المرورية. الهدف الثالث هو فحص صلاحية النماذج المطورة مقابل اثنين من اهم انظمة معلومات الرحلات المميزة عالميا؛ TRICS في المملكة المتحدة و كراس معهد ITE لتوليد الرحلات في امريكا. التحليلات الاحصائية انتهت الى تجميع اكثر دقةً الذي اعتمادا عليه ثمانية نماذج انتاج رحلات تم بنائها. النماذج المطورة وجدت بانها عملية و دقيقة.

1. INTRODUCTION

According to the UK planning policy guidelines, planning permission stage for housing developments with considerable anticipated travel impact requires land developers to submit transport assessment to the local planning authority (LPA). These documents are essential and have to be attached with their planning application for the proposed development; this is explicitly highlighted in the Planning Policy Statement 13 (PPS13) (Department for Regional Development, 2005), the Guidance on Transport Assessment in England and Scotland (DfCLG/DfT, 2007) and the National Planning Policy Framework (DfCLG, 2012). Depending on these submitted planning documents, the LPA will assess the transport impacts of the new developments and this will influence the final decision to approve or reject the proposals. In consequence, if the data source or methodology adopted by developers or their consulting firms were not sufficiently reliable, biased and often misleading travel volumes and patterns would be submitted.

TRICS is one of the nationally recognized trip generation databases in the UK. It is often recommended to be used in quantifying traffic impacts required in the planning applications in the UK (DfCLG/DfT, 2007). As a result, any enhancement in TRICS methodology will have a positive direct echo for the developers and the LPA and an indirect one on all transport planning stakeholders. Accordingly, this paper has three objectives; first, to appraise the adequacy of the methodology embedded in the TRICS trip generation system for conducting traffic impact analysis for residential developments. TRICS starts by classifying residential sites into groups according to the type and tenure of their dwelling units with the assumption that these groups are mutually exclusive in terms of their trip making behaviour. Hence, more specifically, the goal is to statistically appraise the goodness of this grouping and to propose new grouping. The statistical technique analysis of covariance ANCOVA was used to address this objective. The second objective, accordingly, is to use the statistically-proven proposed grouping to construct more rigorous home-based trip production models that can aid in quantifying traffic impact assessment. The multiple regression analysis technique was employed to address this objective. Third, to examine the validity of the developed models against the UK TRICS and the US ITE *Trip Generation* datasets.

2. DATA SOURCES

Globally, there are a number of recognised trip information databases that are highlighted by several researchers; Shoup (2003), Milne and Abley (2009), Douglass and Abley (2011), Soltani and Ivaki (2011), Mousavi et al. (2012), and Currans (2013), among others. These databases are; the UK TRICS trip generation database and system, the US ITE *Trip Generation Informational report* (currently called *Trip Generation Manual*), the New South Wales Roads and Traffic Authority (RTA) Guide to Traffic Generation Developments for Australia, and last but not least the trip generation database provided by the New Zealand Trips and Parking Database Bureau (NZTPDB). For availability issue, only UK TRICS (version 2009a) and US ITE *Trip Generation Manual* (version 2003) databases were employed to address the preset research objectives[1].

The database 'TRICS' (Trip Rate Information Computer System) is the national standard for trip generation analysis in the UK , containing about 7,000 transport surveys at more than 110 types of land uses in the UK and Ireland (TRICS website, 2015). TRICS (version 2009a) is adopted to be the source of both site's description and traffic data used in this study. For residential land uses, descriptive site data includes dwelling unit type, possession type (tenure),

[1] The 2003 version was used since it was the most updated available version in 2009 where this work was done during my PhD study.

site area, site location type, number of dwelling units and bedrooms, and the number of sites in each specific land use category. Alternatively, the traffic data adopted in this work include the total number of inbound (arrivals) and outbound (departures) of trips for each specific development. Trip end totals can be disaggregated into vehicle and total person trips.

The data of residential sites in TRICS are stratified into hypothetically non-overlapping categories to produce representative standard trip rates. This is the main building block underlying the category analysis model used in TRICS (Rhee, 2003). Only weekday surveys were adopted for the analyses in this study since for housing developments the peak periods occur on weekdays (DfCLG/DfT, 2007). These surveys quantify the 12 hour analysis period (7:00 am – 7:00 pm) home-based production trips. In TRICS there are 13 residential land use subcategories; seven of them were suitable to be interrogated in this study. Table 1 lists these subcategories with their mean trip rates and the available number of sites.

It is evident that TRICS classifies these seven housing groups according to their dwelling unit's type (house/flat) and tenure (owned/rented). A full definition of these residential developments is available in the TRICS Online Help File (www.TRICS.org).

Table 1. TRICS 2009a original residential land uses statistics summary

Land Use Subcategory	Mean Trip Rate[a]	No. of Sites
A- Houses privately owned	9.937	65
B- Houses for rent	10.141	8
C- Flats privately owned	5.043	23
D- Flats for rent	6.289	20
K- Mixed private housing	6.645	19
L- Mixed non-private housing	9.911	4
M- Mixed Priv/NonPriv Housing	10.545	14
Total	8.381	153

a Computed as the total site person trips per total site dwelling unit.

Structural environment features such as density, diversity, transport infrastructures and services and accessibility are the typical variables used in travel modelling studies. Utilising the TRICS database, the spatial variables population, housing density, site area, parking density, public transport frequency in addition to the dwelling units characteristics (Housing and tenure type) have been statistically examined in this paper. In TRICS, the population density factor is measured as total population within 500m radii of the site boundaries. The site area is measured in hectares. The housing density represents the total number of occupied dwellings units divided by the site area. The frequency of public transport services near a residential site is given in TRICS as the total number of bus/tram and train services that stop near the site during the counting period (7:00am - 7.00pm). Finally, parking density is computed as total number of on-site parking spaces divided by site dwelling units. For further details, readers are referred to the TRICS website.

In contrast, the US ITE *Trip Generation* database is the most common used source for conducting traffic impact analysis in the United States. It provides aggregate-level regression equations to mathematically formulate the functional relationship between the total site trip ends and one of its physical and measurable parameters such as dwelling units. It also provides trip generation rates and data plots for plenty of land uses. More details can be found in ITE Trip Generation Handbook (2004). Nevertheless, the ITE *Trip Generation* database does not provide site-by-site level analysis; instead it only lists analysis results for specific land use groups. Hence, it is not viable to interrogate the impacts of the spatial and transport provision and services of a site on its trip making behaviour. Moreover, unlike TRICS, the ITE system does not offer multi-modal surveys and hence there is no way to predict pedestrian travel. These limitations in the ITE information system is well outlines by various researchers (for instance see Douglass and Abley, 2011; Mousavi et al., 2012; Shoupe, 2003; Clifton et al., 2015; and Currans and Clifton, 2015).

It is worthwhile recalling here that while TRICS is used to develop the new models ITE *Trip Generation Manual* is only utilised to show the validity of these models.

3. PREVIOUS STUDIES

It is regrettable that few studies have been found dealing with the non-overlapping assumption among TRICS residential subcategories. TRICS considers the land use categories and subcategories as the primary discriminate factors in classifying developments according to their trip rates.

Investigating the land use grouping system in TRICS, Maclaine (2007) found that categorising sites into separate TRICS land-use subcategories may not be practical especially when the total number of available surveys are limited. Employing the Chi-Squared statistical test the null hypothesis (Ho) that there is no significant difference between observed and predicted trip rates for each site was examined. The study ended up with just one combination (AB, CD, and KLM as defined in Table 1). Following, Broadstock (2009) investigated the likely impacts of land-use type on travel behaviour in the UK using TRICS (ver. 2004b). Using the Bootstrap semi-parametric technique and based on the developed regression-based models, it was found that traffic characteristics in most cases do not differ significantly between the residential development land uses. It is worthwhile mentioning that all of the developed trip generation models are only for the passenger car mode.

On the other hand, O'Cinneide and Grealy (2008) stated that TRICS is a typical database in Ireland for calculating trip generation of new development at the planning permission stage. However, the study concluded that TRICS results are not accurate for housing developments. In contrast, many researchers such as Melia et.al (2011), Oni (2010), Hounsell et al. (2011) and Zenina and Borisov (2013) have only utilised TRICS as a tool to predict trip rates for developments with specific urban context and socioeconomic characteristics.

4. RESEARCH DESIGN AND STATISTICAL ANALYSIS

This work is devoted to study the home-based production trips (i.e. the home end of the trip maker is either the origin or the destination of the journey) generated from residential areas. The research conducted for this work is based on measured data and hence it is correlational. In addition, the performed analysis is with quantitative nature whereby several statistical models have been constructed. Inferential statistics is utilised and several null hypotheses have been tested. It is widely accepted that parametric tests are powerful and robust, as long as their underlying assumptions are not notably violated. In this work, where ANCOVA and regression analysis are run, an effort has been paid to examine and deal with these analytical assumptions.

Regarding the general linear model ANCOVA, the main underlying four assumptions are, normality, homogeneity of variance, linearity between pairs of covariates (CVs) and between them and the dependent variable (DV), and homogeneity of regression (Elliott and Woodward, 2007). With respect to sampling distribution normality, the Shapiro – Wilk Test has been used as an inferential test for normality. However, results reveal that the null hypothesis (Ho: the sample distribution is not different from normal) is rejected at the 5% level of significance ($\alpha = 0.05$) for some residential groups. As a consequence, a logarithmic data transformation of type

(Ln(x)) is applied, where needed, to the trip rate variable. For the homogeneity of variance assumption, Levene's inferential test of homoscedasticity had been conducted on the log transformed data and homogeneity of between-groups variances was found. Scatter plots has been drawn to examine the linearity assumption between covariates and the dependent variable. Finally, some suggested covariates were discarded after tests shown that they have violated the last assumption of homogeneity of regression. For paper length limitation, detailed computations are not included. However, for more details regarding ANCOVA test assumptions readers are referred to statistical references such as (Elliott and Woodward, 2007 and Hayter, 2007).

In contrast, for ordinary least squares (OLS) linear regression it is vital to check the assumption regarding outliers, residual analysis, linearity and multicollinearity if robust estimates are traced. In outliers' exploratory analysis, specific metrics like centred leverage value, studentised deleted residuals and Cook's distance are verified against their corresponding thresholds. With respect to residual analysis, issues like normality, independence and homoskedasticity are thoroughly examined as well. For example, histograms and q-q plots are used to check normality; studentised deleted residuals (SDresid) statistics for checking variance homogeneity and Durbin-Watson statistics for checking lack of auto correlation (independence) between residuals. For the linearity assumption, a scatter plot for standarised residual (Zresid) against standarised predicted value (Zpred.) is plotted to check whether any unusual pattern for the scattered dots exists. Finally, variance inflation factor (VIF) and Tolerance metrics are usually employed to assess multicollinearty assumption. Regarding sample size, George and Mallery (2009) pointed out that a sample size of at least 50 should be sufficient to develop meaningful correlations. Most of the mentioned above indices and statistics was quantified and verified for the purposes of the current paper. There values have been listed in the regression models summary table as will be shown later. Detailed computation are not listed for manuscript length limitation, nevertheless, interested readers about test assumptions and their diagnostic indices are referred to (Elliott and Woodward, 2007 and Hayter, 2007).

To summarize, proper removal of outliers and data transformation techniques were the main mathematical remedies adopted in this paper to satisfy the ANCOVA and regression analyses assumptions. Finally, for all ANCOVA and regression analyses performed in this work, the level of significance is 5% unless otherwise stated. The software package employed for conducting the statistical analysis is the IBM SPSS Statistics (ver. 17).

5. FINDINGS AND DISCUSSION

5.1. ANCOVA analyses

The statistical analysis technique ANCOVA is employed to address the first objective; that is, to examine how mutually exclusive the housing groups are and hence to examine whether better new grouping is needed. The statistical tactic ANCOVA is an extension to the traditional analysis of variance test in which the objective is to compare several sample means to examine if there is sufficient evidence to infer that their population means are also unequal. Additionally, to determine which sample means are significantly different and by how much (George & Mallery, 2009). In this study the samples are the seven residential sub land uses while the comparing factor is the total 12-hour person home-based production trip rate (based on dwelling unit). The rationale behind adopting the analysis of covariance is the suspicion that there might be other variables (spatial characteristics) that could confound the relationship between the dwelling units characteristics (type and tenure) and the total trip rate. It is well reported that conducting such analysis can contribute notably to the statistical power of the test (See for instance Pourhoseingholi, 2012). In the current ANCOVA analysis, the dependent variable is the trip rate, the independent variables is the housing categories and the potential confounding variables that need to be controlled for are the covariates.

SPSS generates several ANCOVA output tables, only key tables will be listed and interpreted. Table 2, F-statistic table, shows the significance of the ANCOVA whole model when no covariates were considered. The table demonstrates the test results of the null hypothesis Ho: there is no significant difference among all the group means being compared. The means here are the total person trip rates (lnDtrate) transformed using the logarithm function. The statistics show that the null hypothesis is rejected (P-value = 0.000, α = 0.05). In other words, there is at least one trip rate mean which obviously differs from others.

Table 2. ANCOVA output of the tests of between-subjects effects (without Covariates)

Source	Type III SS	F	Sig.
Corrected Model	9.544[a]	16.936	.000
Intercept	300.245	3196.714	.000
Housing group	9.544	16.936	.000
Error	13.243		
Corrected Total	22.787		

*Dependent Variable lnDtrate

In order to investigate which best regrouping could be adopted, the Gabriel multiple comparison test method embedded in the SPSS ANCOVA routine was used. Table 3 shows the best statistically-proven proposed homogeneous subsets for the seven housing groups. It is obvious that the subsets 1 and 4 are the only non-overlapping (mutually-exclusive) ones with the highest p-values. Table 3 also shows that there is no significant difference between the mean trip rates of both Houses subcategories (A and B) regardless of their tenure type (privately owned or for rent). Similarly, no significant difference could be noticed between the mean trip rates of the both Flats subcategories (C and D) in spite of their tenure type. Accordingly, the seven original TRICS residential subcategories can be regrouped according to the similarity in their trip-making behaviour into two new combined groups:

Housing: House-Like Trip Behaviour (HLTP = {HPO, HFR, MNPH, MPNPH})

Housing: Flat-Like Trip Behaviour (FLTP= {FPO, FFR, MPH})

Considering the available variables in TRICS2009a, five built environment metrics were initially chosen as potential covariates; site population, dwelling density, site area, parking density and public transport frequency. Applying ANCOVA assumptions mentioned previously, the site area and housing density variables have notably violated some of these assumptions and hence were excluded. Accordingly, to examine the potential confounding influence of the remaining covariates, ANCOVA has been run again with the three covariates:

Table 3. Homogeneous Subsets grouping suggested by SPSS using Gabriel's test for the Ln(Dtrate)[a] dependent variable

Housing groups	N	Subset for alpha = 0.05			
		1	2	3	4
C- FPW	22	1.5937*			
D- FFR	19	1.7968	1.7968		
K- MPH	20	1.8566	1.8566	1.8566	
B- HFR	7		2.0618	2.0618	2.0618
M- MPNPH	11		2.0933	2.0933	2.0933
A- HPO	65			2.2596	2.2596
L- MNPH	4				2.2784
P-value		.629	.415	.054	.886

* Logarithmic transformation mean trip rate for housing type C.

population density, parking density and public transport provision.

The analysis revealed two important points. First, the entire model and the housing type variable are still significant (P-value = 0.00). The second is that whereas parking density and transit provision have no considerable effects (P-values are 0.39 and 0.36 respectively) on the mean trip rates, site population has only a marginal one (P-value = 0.09). In general, the ANCOVA model was slightly improved by reducing the unexplained variation (error) from 13.24 to 12.85.

Table 4. ANCOVA output of the tests of between-subjects effects

Source	Type III SS	F	Sig.
Corrected Model	9.610[a]	11.130	.000
Intercept	2.596	27.057	.000
lnPTMF	.080	.835	.362
lnPOP500	.280	2.918	.090
lnPrkDen	.072	.751	.388
HouTypsCode	6.994	12.151	.000
Error	12.855		
Corrected Total	22.465		

*Dependent Variable :lnTPtrHH

In consequence, based on the ANCOVA results, several findings could be achieved. The type of possession (tenure) of a dwelling unit does not significantly affect the total trip rate of its residents. This finding could be interesting for local planners and housing policy by helping them to better understand the travel impacts of existing or proposed residential developments on transport networks and parking demand. The analysis results also revealed that the original seven TRICS (2009a) housing subcategories can be safely regrouped into only two: HLTB and FLTB. With this improved new categorisation, the conceptual framework of the category analysis model implicitly embedded in TRICS is strengthened. Survey time (and hence effort and cost) is saved. In addition, the sample size in each subcategory is increased and hence the database will be eligible for more rigorous inferential statistics.

Finally, the analysis also stated that variation in the provision of public transport and parking density have no considerable impacts on the production trip rates of a housing site. Site population has only a moderate effect. Nevertheless, it is worthwhile pointing out that these variables might have more observable impacts on other trip making indicators rather than the total person trip rate such as the mode share proportions or journey distance.

5.2. Multiple regression analysis

As stated earlier the multiple regression technique was utilised to address the second objective. That is to develop trip production models based on the two new developed housing groups. There are two sets of equations; each set contains four regression equations. While the dependent variable in the first set is the total 12 hour (7:00am – 7:00pm) home-based person trips (TPeo) generated from the site, the total vehicle trips (TVeh) is the dependent variable in the second set. The dependent variable in each group of equations was modelled using four explanatory variables separately. These are; the number of dwelling units in the development site (Du), the total bedrooms (TBed), the site area (SArea) and the housing density (HDen). In order to provide a more representative model, the effect of housing unit type and tenure were also included as other independent variables. A dummy code technique is employed to model this extra categorical variable. A tabulated summary for the eight regression model's parameters and the statistics of the residual and assumption checking analyses is listed in Table 5. Table 5 shows that the total number of dwelling units in a development is the best factor to explain the variation in the total person and vehicle home-based trips alike (R^2 values are 0.903 and 0.889 respectively). This contentedly supports the current study's adoption for dwelling unit as the trip rate parameter in the earlier ANCOVA analyses. In contrast, results confirm that the housing density is the worst factor in terms of accounting for the change in trip ends. This finding can be quite useful for TRICS users and local planning agencies in order to end up with reasonable traffic/transport impact predictions.

6. WORKED EXAMPLE

In order to attain the third objective regarding examining the validity of the developed regression models and also to show their applicability, hypothetical example with ten different cases was chosen. The developed regression model results were compared with two internationally recognised trip generation databases: the UK TRICS 2009a and the US *Trip Generation Informational Report* (Institute of Transportation Engineers, 2003). The ITE *Trip Generation manual* is a widely accepted trip rates and equations source in USA and Canada.

Example: Using the TRICS2009a system, ITE *Trip Generation Manual* 2003 and the developed trip production models, predict the weekday total 12 hour (7:00am – 7:00pm) person and total vehicles trip ends generated from the following residential development sites:

Houses privately owned with 100 dwelling units.

Houses privately owned with 250 total bedrooms.

Houses privately owned in 2 hectare site area.

Houses for rent with 250 total bedrooms.

Flats privately owned in 1 hectare site area.

Flats privately owned with 100 dwelling units.

Flats for rent with 100 dwelling units.

Mixed non-private housing with 250 total bedrooms.

Mixed private housing with 100 dwelling units.

Mixed private / non-private housing with 100 dwelling units.

Following is the illustrative procedure for case-1 (Houses Privately owned with 100 dwelling units).

a. Using developed regression models

The direct substitution of the number of dwelling units (100) in model equation no.1 (Table 5) and impute (1) for the dummy variable yields 956 total person home-based trips. Alternatively, according to trip production model no.2, the estimated total generated vehicles are 515.

b. Using TRICS 2009a System

At first, the "Houses privately owned" residential subcategory should be selected. Next, the multi-modal counts option should be used. After selecting "dwelling units" as the trip rate parameter, their range (maximum and minimum) should be adjusted to produce a representative sample of sites. A range of sites with 50 and 150 minimum and maximum dwelling units respectively has been adopted to attempt to get a sample of sites with average dwelling units as close as possible to 100. This approach is recommended by TRICS Good Practice Guide (TRICS website, 2015). Moving on without any further fine-tuning yields a mean total person trip rate of (9.866) and hence a total estimate of trip ends of 987. Or we can choose the Vehicles option to get the trip rate figure 5.725 and hence 572 total vehicles.

c. Using ITE Trip Generation 2003 informational report.

The calculation is not applicable for the total person trip rate since this report simply does not contain multi-modal counts. In contrast, for predicting the total vehicles, both the ITE regression equations listed in the Single-Family Detached Housing category (ITE, 2003, pp. 268) and the Residential Condominium/Townhouse category (ITE, 2003, pp.366) were run and the average value was computed.

A summary of the analysis results of all the ten cases above are listed in Table 6.

Table 5. Regression models and residual analysis summary

Model No.	Regression Eq.	Model inferential statistics						Residual Analysis			Model Assumption		Outliers Analysis		
		R	R^2	ANOVA Sig.	Constant t-Sig.	IV t- Sig.	Dummy IV t-Sig.	Normality	Homoscedasticity	Independence-Durbin-Watson Dist	Linearity	Multicollinearity-VIF	Max. Cook's Distance	Max. SDResid.	Max. Cent. Leverage Value
1	ln TPeo = 1.953 + 0.945ln Du + 0.558 DVHLTB*	.950	.903	.000	.000	.000	.000	Ok	Ok	1.758	Ok	1.0	.07	3.1	.03
2	ln TVeh = 0.989 + 0.974 ln Du + 0.770 DVHLTB	.943	.889	.000	.000	.000	.000	Ok	Ok	1.378	Ok	1.0	.08	3.2	.03
3	ln TPeo = 1.664 + 0.881 ln TBed + 0.220 DVHLTB	.941	.886	.000	.000	.000	.000	Ok	Ok	1.699	Ok	1.0	.05	2.5	.04
4	ln TVeh = 0.719 + 0.905 ln TBed + 0.403 DVHLTB	.941	.885	.000	.000	.000	.000	Ok	Ok	1.557	Ok	1.0	.06	2.7	.04
5	ln TPeo = 6.009 + 0.745 ln SArea - 0.119 DVHLTB	.89	.793	.000	.000	.000	.000	Ok	Ok	1.706	Ok	1.2	.08	3.3	.05
6	ln TVeh = 5.226 + 0.820 ln SArea - 0.030 DVHLTB	.937	.878	.000	.000	.000	.000	Ok	Ok	1.818	Ok	1.2	.07	2.6	.04
7	ln TPeo = 6.968 - 0.284 ln HDen + 0.50 DVHLTB	.426	.181	.000	.000	.019	.022	Ok	Ok	1.727	Ok	1.3	.07	2.5	.05
8	ln TVeh = 6.523 - 0.373 ln HDen + 0.644 DVHLTB	.500	.250	.000	.000	.004	.006	Ok	Ok	1.662	Ok	1.3	.08	2.4	.06

* Dummy variable: 1 for HLTB and 0 for FLTB. Du = total number of dwelling units. TBed= total number of bedrooms.
SArea = area of the site in hectares. HDen= site housing density. TPeo= total number of person (all modes) trip ends.
TVeh= total number of vehicle trip ends.

Table 6. Summary of the worked example analysis results

	Case description	TRICS 2009a		ITE Trip Generation 2003		Multiple Regression Model	
		TVeh	TPeo	TVeh	TPeo	TVeh	TPeo
1	Houses privately owned, Du =100.	572	987	840	NA	515	956
2	Houses privately owned, TBed= 250	544	1017	NA	NA	455	854
3	Houses privately owned, SArea= 2 hect.	295	527	NA	NA	318	606
4	Houses for rent, TBed = 250.	476	NA	NA	NA	455	852
5	Flats privately owned, SArea, = 1hect.	262	487	NA	NA	186	407
6	Flats privately owned, Du= 100	203	450	641	NA	239	548
7	Flats for rent, Du = 100.	239	674	751	NA	239	548
8	Mixed non-private, TBed = 250.	NA	NA	NA	NA	455	853
9	Mixed private housing, Du= 100	276	530	966	NA	239	548
10	Mixed priv/non-priv housing, Du= 100	469	884	966	NA	515	956

The letters NA in the ITE *Trip Generation* column stand for the non-applicability of using this informational report here either because it has no multi-modal counts or there are no equivalent statistics for the current trip rate parameter. In contrast, these letters in TRICS column refer to the shortage in data to develop adequate representative sample of sites. This drawback stems an extra point in favour of adopting the current regression models against TRICS. Finally, aside from the simplicity of the calculation, the researcher recommends the use of the regression-based trip end figures since it has resulted from an approach with statistically sound procedures and measurable goodness of fit statistics.

The wide discrepancy between the ITE *Manual* and both TRICS and the current models total vehicle trip ends can be attributed to two reasons. First, the difference in time period, while the counting period in TRICS and the developed model is 12-hr (7:00am-7:00pm), in the ITE *Manual* is 24-hr average weekday. Secondly, according to the ITE *Manual*, most of its residential sites are located in suburban areas. Hence it is expected that the trip ends results will be biased towards these sites' travel behaviour which is usually more car-dependent than those located in or near urban areas. In contrast, the differences between TRICS and the developed regression models is most likely due to the unusual sites (sites with very high or low trip rates) existed in TRICS database which were removed as outliers in the developed multiple regression models.

7. CONCLUSIONS

Regarding the UK TRICS database and system, the ANCOVA analysis results revealed that the original seven TRICS (2009a) residential subcategories can be regrouped according to the similarity in their trip-making behaviour into only two mutually-exclusive main combined housing groups: House-Like Trip Behaviour (HLTB) and Flat-Like Trip Behaviour (FLTB).

Three conclusions can be drawn from the above finding. First, the type of possession (tenure) of a dwelling unit does not significantly affect the total trip rate of its residents. This finding could be interesting for local planners and housing policy by helping them to better understand the travel impacts of residential developments. Second, survey time (and hence effort and cost) is saved. Finally, the sample size in each subcategory is increased and hence the database will be eligible for more rigorous inferential statistical analysis. Last but not least, the analysis of potential confounding showed that neither the variation in the provision of public transport or parking density nor the site population have statistically significant influence on the total person trip rates. This can be informative for the transport planners so as not to invest in the transit and parking availability if their target is to reduce the total amount of travel. However, these variables might have more observable impacts on the mode share proportions and trip length than on the total generated travel.

In contrast, based on the multiple regression analysis several findings are worthy to be highlighted. Of the four studied site-specific parameters (dwelling units, total bedrooms, site area and housing density), the first three are found to have a high influence on the total generated person and vehicle home-based trips alike. They all show strong and significant relationships with the number of trips (R^2 values for all the six regressions range from 0.903 to 0.793 while P-value = 0.0). Whereas the dwelling unit parameter is the one with the highest R^2 values for both travel counts, housing density has the lowest values. Hence, it is not advised to be adopted as a travel behaviour indicator.

A worked example with ten different cases is employed to prove the effectiveness and applicability of the developed regression-based trip production models. The predictions of developed models have been compared with predictions obtained from the TRICS 2009 system and the 2003 ITE *Trip Generation Manual*. The comparison evidently showed that unlike TRICS 2009a and ITE 2003 *Manual*, the developed models were capable of dealing with all the ten cases. TRICS is ineffective in dealing with some cases due to inability of creating a representative sample of sites in the original TRICS 2009a database. Similarly, the ITE 2003 *Manual* was for several cases ineffective because of the lack of similar sites or travel counts.

To summarise, the analysis findings support the recommendations of the UK National Planning Policy Framework in that TRICS as an accepted trip generation system to be employed in preparing traffic impact analysis. Nevertheless, TRICS should be applied carefully and in line with the findings of this paper if the user is to arrive at valid estimates.

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