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REFERENCE

1. Parking Policies Study for Montgomery County, Maryland. JHK and Associates, Alexandria, Va., 1982.

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Prediction of Land Use Traffic Impact

C.E. HALLAM AND G. PINDAR

The current procedures for prediction of the traffic impact of proposed land use developments and their parking requirements are based on historical and nonquantitative assessment procedures, which has in many cases led to the preparation by local governments of inappropriate parking codes. Research recently undertaken in New South Wales, Australia, aimed at provision of a more quantitative basis for impact prediction. Surveys were conducted at sites in each of the following land use categories: motels, service stations, car dealerships, dealers of car accessories and tires, hotels, road transport terminals, warehouses, recreation, fast food sites, factories, licensed clubs, office blocks, shopping centers, home units (apartments), homes for the aged (retirement villages), and restaurants. Survey results were analyzed by using linear regression techniques. Descriptive models, where able to be developed, are presented in the form of regression equations. Use of these models should take into consideration their accuracy and the range of independent variables for which they are applicable. In situations where it was not possible to develop models, proposed land use developments may be compared with developments surveyed in the study that possess similar characteristics, and a subjective assessment may be made. The use of the survey data as a standard data base should be of considerable value in maintaining a common standard of impact assessment. The models should improve the accuracy of impact prediction and assist in the development of more reliable parking codes and design guidelines. The degree of transferability of these results to countries other than Australia requires further research.

A major research project has recently been completed by the Traffic Authority of New South Wales, Australia, the aim of which was to develop reliable methods for predicting the impact of particular land uses on traffic conditions. To date, such predictions have been based primarily on subjective historical bases. This research has aimed at putting predictions and assessments on a more quantified basis. The resulting models should be used with caution, and due consideration should be taken for their stated accuracy and ranges of applicability. It was not possible to develop models for every aspect of land use studied. In these situations if a proposed development has similar characteristics to those of one of the survey sites, a direct comparison of the developments could give an indicative estimation of traffic impact.

Information was collected and analyzed on (a) person and vehicle flows generated by the development, the time at which such flows are at a peak, and person and vehicle flows generated during the on-street peak vehicle hour and (b) the parking provision necessary if the parking demand is to be met on site without constraint. The land uses studied in this research were motels, service stations, car dealerships, dealers of car accessories and tires, hotels, fast food sites, road transport terminals, warehouses, recreation, factories, licensed clubs, office blocks, shopping centers, restaurants, homes for the aged, and home units. These land uses, many of which occur in strip development, were selected because they occurred most frequently in development applications submitted for comment to the Traffic Authority. The results can also be used to develop more comprehensive strip development control policies. With changing emphasis from construction to transport system management techniques, the most effective use of the existing road system is becoming increasingly important. Thus planners should ensure that adequate protection is afforded to preserve the integrity of current and future arterial routes.

SURVEYS

For each land use, with the exception of shopping centers and home units, 10 examples were chosen for survey that exhibited a range of types and size of development. Further, the sites chosen were geographically diverse in order to reflect socioeconomic factors (particularly vehicle ownership) and public transport availability. Sites of fairly recent construction with on-site parking provision were preferred. For shopping centers, 33 sites were surveyed. For home units, surveys were conducted by means of postal questionnaire surveys. Of the 2,000 questionnaires distributed, 544 valid replies were received.

With the exception of home units, information was collected by conducting interviews with users and site management personnel together with measurements of person and vehicular flows and parking accumulation. Site and floor areas were measured on site.

Surveys of office blocks, factories, licensed clubs, and some shopping centers were conducted in 1978. The remaining surveys were conducted in 1979 with the exception of restaurants, home units, and homes for the aged, which were conducted in 1981. Surveys were conducted for a period of one day per site except for three of the shopping centers, at which 6-day counts were conducted. In the case of home units, information was requested for one specific day.

ANALYSIS

In consideration of the relatively small number of sample points, the use of complex statistical methods was not considered appropriate, particularly in view of the intended general use of the results. The emphasis was thus on simpler manipulations based on multiple linear regressions.

The resultant models should be used with due consideration for their accuracy. The accuracy is expressed in terms of the correlation coefficient (R^2).

Checks made in the analysis were that multicol-

Table 1. Regression equations for motels.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	FIT R^2	RANGE OF INDEPENDENT VARIABLE
Total Vehicle Trips, TVT (over 7 survey hours)	Floor area - building, A_B	$TVT=8+0.067A_B$	0.94	530 - 3,400
Peak Vehicle Trips, V	Floor area - building, A_B	$V = 1+0.015A_B$	0.92	530 - 3,400
Vehicle Trips - a.m. peak, V_A	Employees, E	$V_A=2+1.76E$	0.88	2-18
Vehicle Trips - a.m. peak, V_A	Floor area - building, A_B	$VA=0.009A_B$	0.80	550-3,400
Vehicle Trips - p.m. peak, V_p	Floor area - building, A_B	$V_p=1+0.008A_B$	0.90	"
Parking Supply Required, PS_R	Number of Units, N Employees, E	$PS_R=N+0.5E$	-	-

Table 2. Regression equations for service stations.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	R^2	RANGE OF INDEPENDENT VARIABLE
Peak Trips, Petrol - IN, PP	Area of Site, A_S	$PP = 0.015\ A_S$	.85	1,110 - 4,570
Peak Trips, Total - IN + OUT, PT	Area of Site, A_S	$PT = 32+0.030A_S$	.84	1,110 - 4,570

linearity of independent variables did not occur and that the coefficients of the independent variables were significantly different from zero. Aspects of the statistical analysis are discussed in more detail later.

Prediction of peak vehicle trips enables assessments to be made of the impact of the development on the surrounding road system and is usually indicative of the worst-case situation. Average vehicle trips is also a useful parameter in this regard, which gives a picture of the total vehicle trip generation over a long period of time. (In all cases, unless specified to the contrary, trips are two-way totals.) Prediction of peak parking accumulation allows a check to be made on the proposed on-site parking provision. As discussed later, the worst-case situation is based on the days surveyed rather than the highest or 10th-highest hour of the year.

DESCRIPTIVE MODELS

Motels

Data were collected at 10 sites. Surveys were conducted from 7:00 to 10:00 a.m. and 4:30 to 8:30 p.m.

The independent variables, as represented by area of site (A_S), area of building (A_B), number of units (N), accommodation capacity (AC), and employees (E), showed some multicollinearity; A_B, N, AC, and E had strong relationships. Although A_S could be combined with any of these variables, in no case did such a combination offer any increase in accuracy. In fact, A_S had a correlation coefficient of 0.00 for every dependent variable examined. The most important equations developed are given in Table 1.

Service Stations

Data were collected at 10 sites. Surveys were conducted from 7:00 to 10:00 a.m. and 3:30 to 6:30 p.m.

A_S correlates with road frontage length (F), number of pumps (P), and parking supply (PS). A_B is reasonably independent of the other independent variables. F correlates with P. The equations that were developed are given in Table 2.

Five of the service stations studied were self-service and five had attendants and higher generated trips. Nevertheless, the generation rates, expressed as peak trips and petrol per area of site, were not significantly different for the two categories.

A common situation in which knowledge of the traffic generation characteristics of service stations is necessary is that in which a developer wishes to convert a current service station, often uneconomical or disused, into a different land use. A disused service station has zero traffic generation. Such comparisons of alternative land uses should be based on normal generation rates. The argument that a proposed development has greater traffic impact than the current disused development and as such should not be approved is a little hard to sustain unless major traffic growth has occurred since the service station was first established. However, there still should be some leeway to improve on previous inappropriate planning.

Car Dealerships

Data were collected at 10 sites. Surveys were conducted generally in the period 1:30 to 5:30 p.m. (Fridays) but with some variation to represent peak hours at each site.

Correlations between independent variables were

Table 3. Regression equations for car dealerships.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	FIT R^2	RANGE OF INDEPENDENT VARIABLES
Peak Vehicle Trips, PVT	Employees, E	PVT=2+0.57E	.86	4-97
Peak Vehicle Trips, PVT	Area of Site, A_S	PVT=0.0051A_S	.81	1,800-11,370m²
Averate Vehicle Trips AVT	Employees, E Cars on Display, C	AVT=3+0.37E +0.052C	.92	E: 4-97 C: 21-260
Average Vehicle Trips AVT	Employees, E	AVT=0.42E	.86	4-97
Average Vehicle Trips, AVT	Area of Site, A_S	AVT=1=0.0038A_S	.81	1,800-11,370m²
Peak Parking Accumulation, PA	Employees, E Car Yard Proximity, Y	PA=0.69E+3.9Y	.93	E: 4-97 Y: 0-9
Peak Parking Accumulation, PA	Employees, E	PA=3+0.89E	.86	4-97

Table 4. Regression equations for car accessory and tire dealers.

SPECIFIC IMPACT	APPLICABILITY	INDEPENDENT VARIABLES USED FOR PREDICTION	EQUATION	R^2	RANGE OF INDEPENDENT VARIABLE
Average Vehicle trips, AVT	Tyre sites	Road frontage F	AVT = 3+.28F	.86	10 - 42
Average Vehicle trips, AVT	Tyre sites	Road frontage F (M) Employees E	AVT = 2+.23F +.43E	.98	F : 10 - 42 E : 4 - 13
Peak Parking accumulation, PA	All sites	Area of site, A_S (M²)	PPA = .007 A_S	.76	400 - 2,330
Peak Parking accumulation PA	Tyre sites	Area of site, A_S	PPA = 2+.006A_S	.89	750 - 2,330

generally as expected; A_S correlated well with F and E. However, A_S did not correlate with number of vehicles on display (C), which is a little surprising. The equations developed are given in Table 3.

Predictions should not be based on artificial values of E. As shown by the strong relationship between A_S and E, there is an optimum number of employees for a given site. This is evaluated over a period of time by the development's management. The 10 sites surveyed have no doubt achieved a certain equilibrium in this regard. For a new development, if there is uncertainty about the required number of employees, A_S would be a more appropriate descriptor.

Surveys were conducted on Saturdays as well as Fridays. Comparison of the peak and average vehicle trips and peak parking accumulation showed no significant difference between the two sets of data (two-tailed t-test = 5 percent). In terms of prediction model development, the Saturday data were more inconsistent than the Friday data.

The proximity of other dealerships (Y) generally only had a minor effect on trip generation. In the case of peak parking accumulation, correlation was sufficiently high for Y to be included in the equation. This was not the case for the peak and average vehicle trip equations.

Car Accessory and Tire Dealers

Data were collected at 10 sites. Surveys were conducted during the peak 6-hr period on weekdays. This period varied from site to site. Of the 10 sites, 5 were tire retailers and 5 were car accessory outlets.

Independent variables correlated were A_S with F and PS, A_B with E, and PS with F. The strong correlation between A_S and PS (R^2 = 0.94) shows the effects of council parking codes based on A_S.

Development of descriptive models proved difficult because of the variation in the nature of the developments. In some cases, the five tire sales sites provided models applicable to that type of development. The equations developed are given in Table 4. In analyzing proposed development of car accessory and tire retailers, because comprehensive models could not be developed, a comparison of the

site characteristics of the proposed site with those surveyed is recommended.

Hotels

Data were collected at 10 sites. Surveys were conducted on Fridays from 3:30 to 10:30 p.m. or later, depending on exact closing hours. It should be noted that the sites surveyed were essentially suburban taverns in which the emphasis is on social drinking rather than accommodations. None of the sites surveyed were of international standards in city central business district (CBD) environments.

Accommodation capacity (AC) strongly relates to licensed area (A_L) and number of motel units or rooms (N); the latter relationship is to be expected. E relates to a varying degree to several of the variables; these are functional relationships.

It was not possible to develop descriptive relationships for peak and average vehicle trips (PVT, AVT). The highest correlation coefficients found were in the range R^2 = 0.51 to 0.53. These were for the independent variable E. Development of a descriptive relationship for peak parking accumulation (PPA) was no better.

The lack of relationships, particularly between the floor areas A_L, A_S, and A_B and peak parking accumulation, points to the problems of relation of parking codes to floor areas. This is further shown by the lack of a relationship between PA and PS.

PA, however, does relate to the dependent variables PVT and AVT. These equations are included here for reference:

$$PA = 10 + 0.613PVT \qquad R^2 = 0.95 \tag{1}$$

$$PA = 15 + 0.889AVT \qquad R^2 = 0.90 \tag{2}$$

It was not possible to develop relationships for the number and percentage of short-stay vehicles. These vehicles, with a length of stay of 0 to 10 min, were considered to be representative of the drive-in liquor store traffic.

It was thus not possible to develop equations to define the traffic operation of a hotel. The data can be used to look for similarities with proposed hotel developments and estimates of traffic impact can be made accordingly.

Warehouses

Data were collected at 10 sites. These sites represent a wide variation in type of warehouse activities. Surveys were conducted for a period of 6 hr. The individual periods were chosen to represent the busiest hours of operation.

A_S strongly relates to all the other independent variables [A_B, PS, E, vehicle fleet (F), and loading and unloading bays (L)]. Correlation between each of the other independent variables is also quite strong, with the exception of F with A_B and with L. Descriptive models with single independent variables were found to be no less accurate than those with several independent variables. The descriptive equations developed are given in Table 5.

Road Transport Terminals

Data were collected at 10 sites. Surveys were conducted for a period of 6 hr. The individual periods were chosen to represent the busiest hours of operation.

The only strong relationships between the independent variables [A_S, A_B, PS_C, PS_T, F, E, and truck fleet (F_{TR})] were between F_{TR} and F and E.

The predictive equations developed are given in Table 6.

Recreation

Data were collected at 10 sites. Surveys were generally conducted in the period 4:00 to 10:00 p.m., although with some variation at specific sites. There was a wide range in traffic pattern and type of recreational land use within the sample.

Analysis was attempted for groupings of all 10 sites and of the 5 squash sites. For the 10 sites, the only strong correlations between independent variables were between A_S and PS and pools (P).

Table 5. Regression equations for warehouses.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	FIT R^2	RANGE OF INDEPENDENT VARIABLES
Peak Truck Trips, PTT	Loading Bays, L	PTT=9+.69L	.84	0- 60
Peak Truck Trips, PTT	Area of Building, A_B	PTT=5+.0007A_B	.82	2,010- 63,700
Average Truck Trips, ATT	Area of Building A_B	ATT=1+.0006A_B	.85	2,010- 63,700
Average Truck Trips, ATT	Loading Bays, L	ATT=4+.56L	.84	0- 60
Peak Vehicle Trips, PVT	Employees, E	PVT=9+.304E	.88	9- 724
Peak Vehicle Trips, PVT	Area of Site, A_S	PVT=11+.0016A_S	.83	1,920-133,000
Average Vehicle Trips, AVT	Area of Site, A_S	AVT=7+.0010A_S	.86	1,920-133,000
Average Vehicle Trips, AVT	Employees, E	AVT=8+.175E	.84	9- 724
Total Peak Parking Accumulation	Area of Site, A_S	PPA=9+.0025A_S	.95	1,920-133,000
Total Peak Parking Accumulation	Employees, E	PPA=.474E	.96	9- 724

For the five squash sites, relationships were present between A_S and PS and E. PS and E were also related. The number of squash courts (S) had negative correlations with A_S, PS, and E.

It was only possible to develop models for average person trips (APT); vehicle trip generation and parking accumulation could not be modeled.

The average number of person trips (IN + OUT) per hour at the 10 sites can be modeled by using A_S as the independent variable:

$$\text{ALL SITES APT} = 35 + 0.0042A_S \quad R^2 = 0.78 \tag{3}$$

At the 5 squash sites, a similar model was developed. Taking into consideration the smaller sample size, it also is indicative only.

$$\text{5 SQUASH SITES APT} = 30 + 0.0046A_S \quad R^2 = 0.86 \tag{4}$$

Recreational land uses are thus difficult to model. Correlation between the number of squash and tennis courts and person trip generation and parking accumulation was particularly bad; in some cases, a negative relationship was found. It is suggested that impact prediction for proposed developments be based on comparison with a similar current development.

Fast Food Sites

Data were collected at 10 sites. Surveys were conducted in the period 4:00 to 10:00 p.m. on what the management considered to be the busiest day of the week.

With the exception of seating capacity (S), strong correlations were present between the other independent variables (A_S, A_B, E, and PS). E is thus the best descriptor of the traffic generation of fast food developments. A_S is certainly indicative. One explanation of this behavior is that the number of employees is tailored to suit the demand that develops. Thus this number might be different at the time the development was established from that applying several years later. The equations developed are given in Table 7.

Table 6. Regression equations for road transport terminals.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	FIT R^2	RANGE OF INDEPENDENT VARIABLES
Peak Truck Trips, PTT	Employees, E Area of Building,	PTT=-15+0.39E +0.0007A_B	.94	E:44-228 A_B:650-30,440
Peak Truck Trips, PTT	Employees, E	PTT=-11+0.40E	.89	44-228
Average Truck Trips, ATT	Employees, E Area of Building, A_B	ATT=-7+0.18E +0.007A_B	.92	E:44-228 A_B:650-30,440
Peak Vehicle Trips, PVT	Employees, E	PVT=10+0.44E	.79	44-228
Average Vehicle Trips, AVT	Employees, E Area of Building,	AVT=5+0.21E +0.0010A_B	.82	E:44-228 A_B:650-30,440
Peak Parking Accumulation PA	Employees, E	PA=16+0.47E	.76	44-228

Table 7. Regression equations for fast food sites.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	R^2	RANGE OF INDEPENDENT VARIABLES
Peak Person Trips PPT	Employees, E	PPT = -120 + 46.2 E	0.92	4 - 20
Average Person Trips APT	Employees, E	APT = -50 + 26.2 E	0.91	4 - 20
Peak Vehicle Trips, PVT	Employees, E	PVT = 8 + 15.1 E	0.78	4 - 20
Peak Vehicle Trips, PVT	Area of Site, A_S (m^2)	PVT = -56 + 0.128 A_S	0.75	680 - 2800 m^2
Peak Parking Accumulation, PA	Employees, E	PA = 1 + 2.9 E	0.84	4 - 20
Peak Parking Accumulation, PA	Area of Site, A_S (m^2) Seating Capacity, S	PA = -6 + 0.015 A_S + 0.18S	0.83	A_S : 680 - 2800 m^2 S : 0 - 118

Office Blocks

Surveys were conducted generally between 7:00 a.m. and 6:30 p.m. at 10 sites.

The main independent variables, gross leased floor area (A) and E, are strongly related. This is particularly evident when the area per employee is tabulated.

The equations developed are given in the following discussion.

Peak Person Trips (PPT)

The peak number of person trips (IN + OUT) in any hour can be directly estimated from A (range, 935-14,800):

$$PPT = 64 + 0.037A \quad R^2 = 0.83 \tag{5}$$

PVT

PVT (IN + OUT) in any hour cannot be directly described by any of the independent variables. This points to the important role that mode split plays in vehicle trip generation for office blocks. This is illustrated by the range in percentage of trips by car: 8 percent (CBD) to 85 percent (Pymble). PVT can be calculated from peak-vehicle-hour person trips (PVPT), if the mode split (MS) and car occupancy (OC) are known:

$$PVT = PVPT \times (MS/OC) \tag{6}$$

The accuracy of this equation is as good as the accuracy of the variables PVPT, MS, and OC.

PPA

The peak number of vehicles parked on site or off site but associated with the site can be directly estimated from A (range, 935-14,800):

$$PPA = 28 + 0.025A \quad R^2 = 0.82 \tag{7}$$

If MS and OC can be adequately estimated, PPA can be calculated more accurately. Factored PPA (FPPA) takes mode-split factors out of the direct equation. A is the independent variable used for prediction (range, 935-14,800):

$$FPPA = -49 + 0.076A \quad R^2 = 0.94 \tag{8}$$

PPA can then be calculated as follows:

$$PPA = FPPA \times (MS/OC) \tag{9}$$

The percentage of on-site parking ranges from 16 to 99 and the average is 40 percent. On average only a third of the parking is provided on site and thus is under current conditions and only one-third of the parking is controlled by the application of on-site parking standards.

The data on length of stay are also of interest; the percentage staying less than 1 hr ranges from 11 to 61 percent with an average of 38 percent. This indicates the need for available short-term spaces, possibly requiring a specific code provision for a number of on-site visitor or short-term spaces.

Licensed Clubs

Surveys were conducted in the period 4:00 p.m. to 1:00 a.m. at the 10 sites. There was a strong correlation between the variables E and members (M). There were no other correlations between the independent variables.

The analysis was not successful in providing accurate descriptive models. A was found to be a particularly bad descriptor of trip generation and parking accumulation. Even when it was broken down into bar area, lounge area, games area, and dining area, no descriptive relationships could be found. It thus should not be used as a basis for a parking code.

Auditorium seating (S) is of only marginal importance in the overall trip generation and did not emerge as a useful variable for prediction. Thus the physical characteristics of clubs were not sufficient for the prediction of traffic impact. The only suitable descriptors are those relating to the people using the clubs, E and M.

Indicative models were developed for PPT by using E and M (range of E, 37-257; range of M, 1,400-21,000):

$$PPT = 6 + 3.89E \quad R^2 = 0.75 \tag{10}$$

$$PPT = 132 + 0.04M \quad R^2 = 0.76 \tag{11}$$

The time period of peak person movement (peak vehicle movement was the same) varied from 4:00 to 5:00 p.m. to 8:00 to 9:00 p.m. However, a number of trends were evident. Smaller clubs tended to have peak periods in the late afternoon, evidence of a pattern of members calling in at the club on their way home from work. The larger clubs generally had peak periods from 7:00 to 8:00 p.m. (six sites). The period 6:00 to 9:00 p.m. covers the peak movements of 80 percent of the sites.

The car use range reveals that public transport plays little part in trips to clubs. The range is small, from 77 to 98 percent (total person trips); the average is 87 percent.

PVT can only be calculated from the general relationship PVT = PVPT x (MS/OC). PPA could not be related to any of the independent variables. It can be calculated from PVT if this is known (PVT, 89-701):

$$PPA = -10 + 1.46PVT \quad R^2 = 0.84 \tag{12}$$

Its calculation from variables known at the time a development application is made is thus a tenuous procedure. The parking supply on site bears little relationship to PPA.

Estimation of the traffic impact of proposed clubs is thus difficult. The best method would probably be to compare the characteristics of the new club with those surveyed and make a subjective assessment based on the survey results of the most representive club.

Factories

Data were collected at 10 sites. These sites represent a wide variation in type of factory. Surveys were conducted from 6:30 a.m. to 6:00 p.m.

The relationship between A and E is sufficiently strong to prevent their combined use in an equation. The total number of employees was the best variable for prediction. Little improvement in accuracy is provided by the disaggregation of employees into administration and factory categories. Floor area, either total or disaggregated into specific uses, had a bad correlation with all dependent variables investigated. It cannot be used as a predictor. In Table 8 the equations developed are summarized.

Shopping Centers

Shopping centers are an important land use for which predictions of traffic impact are often required.

Table 8. Regression equations for factories.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	FIT R^2	RANGE OF INDEPENDENT VARIABLE
Daily Total Trips TT	Employees E	TT= 103 + 1.977E	0.96	12 - 970
Peak Person Trips (a.m.) PT(A)	Employees E	PT(A) = 11 + 0.463E	0.82	12 - 970
Peak Person Trips (p.m.) PT(P)	Employees E	PT(P) = 6 + 0.645E	0.96	12 - 970
Peak Vehicle Trips (a.m.) V(A)	Employees E	V(A) = 12 + 0.250E	0.80	12 - 970
Peak Vehicle Trips (p.m.) V(P)	Employees E	V(P) = 9 + 0.308E	0.90	12 - 970
Peak Parking Accumulation PA	Employees E	PA = 20 + 0.436E	0.95	12 - 970
Daily Total C.V. Trips TC	Employees E	TC = 36 + 0.155E	0.78	12 - 970
Peak C.V. Arrivals CA	Daily Total C.V. Trips TC	CA = 1 + 0.073TC	0.94	38 - 186
Peak C.V. Departures	Daily Total C.V. Trips tc	CD = 2 + 0.080TC	0.94	38 - 186

Because of their importance, the original data base of 10 sites was extended to a total of 33 sites, covering surveys on Thursdays, Fridays, and Saturdays. At three sites, 6-day surveys were completed. The sample also included five country sites. Only a summary of the analysis is possible in a paper of this length.

The analysis is presented for four groupings of data: Thursdays (sample size, 20), Fridays (sample size, 10), Saturdays (sample size, 10), and Thursdays and Fridays (sample size, 30). The survey periods were Thursdays, 4:00 to 9:00 p.m.; Fridays, 8:00 a.m. to 5:30 p.m.; Saturdays, 8:30 a.m. to 12:30 p.m.

The independent variables A and E are highly correlated. Disaggregating floor area into department stores, [A(D)], supermarkets [A(S)], small shops [A(M)], offices [A(O)], and bars or taverns [A(B)] generally provided no improvement in prediction accuracy. Equations describing behavior on Thursdays and Fridays were developed with A as the single independent variable. For the Saturday data it was found advantageous to use two floor-area variables, A(D) and supermarkets plus small shops [A(SM)]. [These two variables do not include office or bar floor area; note that A = A(D) + A(S) + A(M) + A(O) + A(B).] Floor area is expressed in square meters. The equations developed are given in Table 9.

As can be seen from the large constants in many of these equations, trip generation predictions for smaller shopping centers are not as accurate as those for larger centers. With reference to the Saturday models, use of those models involving disaggregated floor area has been found to give inappropriate answers for some combinations of floor area. Total floor area is generally the preferred variable.

Home Units

A total of 1,970 postal questionnaires were distributed to home-unit owners, from which 544 useful replies were received and subsequently analyzed. In addition, site inspections were undertaken at each block surveyed (107 in all) to ascertain the essential characteristics of each development, including both on-site and off-site parking availability and use.

The independent variables included in the analysis were the size of the unit (U_1, U_2, or U_3, i.e., one, two, or three bedrooms, respectively) and accessibility to public transport. No significant variation was found in any of the dependent variables analyzed as accessibility to either bus or rail increased. Further, it was not possible to develop acceptable regression equations by using the number of one-, two-, and three-bedroom units in each block. Although indicative models were developed, they were rejected because they did not conform with a priori reasoning regarding the magnitude of the estimated coefficients and regression constants. In particular, the magnitude of the regression coefficients deviated significantly from the average generation rates per unit and exhibited large negative constants.

In the absence of acceptable regression equations, generation models were based on the average generation rates per unit for the survey data. The main equations developed are given in the following.

Normal Resident Parking Demand (RPD)

Predictions of RPD (the number of resident vehicles normally parked overnight at or near the unit) were based on the number of one-, two-, and three-bedroom units in the block:

$$RPD/block = 0.83U_1 + 1.09U_2 + 1.34U_3 \quad (13)$$

Peak Visitor Parking Accumulation (PVP)

Prediction of PVP (the number of visiting vehicles parked at or near each unit during the peak hour) was based on the total number of units in the block

(U_T). This peak period was between 9:00 and 10:00 p.m. on Saturday evenings. As anticipated, no relationship was found between visitor parking demand per unit and the size of the unit.

$$PVP/block = 0.23U_T \quad (14)$$

PPT

Predictions of PPT (the number of two-way resident and visitor person trips generated by each unit during the evening on-street peak period (4:00 to 7:00 p.m.) was based upon the number of one-, two-, and three-bedroom units, respectively. Hourly estimates of trip generation can be made by applying the relevant hourly percentages, viz., 4:00 to 5:00 p.m., 28 percent; 5:00 to 6:00 p.m., 34 percent; 6:00 to 7:00 p.m., 38 percent.

$$PPT/block = 1.31U_1 + 1.76U_2 + 2.44U_3 \quad (15)$$

PVT

Prediction of PVT (the number of resident and visitor vehicle trips generated by each unit during the evening on-street peak period) was based on the number of one-, two-, and three-bedroom units, respectively. Again, hourly estimates of trip genera-

Table 9. Regression equations for shopping centers.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	FIT R^2	RANGE OF INDEPENDENT VARIABLES
		THURSDAYS		
Average Person Trips, AT	Floor Area, A(m^2)	AT = 802 + 0.1243 A	0.82	2400 - 77,100 m^2
Peak Person Trips, PPT	" "	PPT = 1195 + 0.1516 A	0.77	" "
Person Trips, pm. Peak, PTV	" "	PTV = 992 + 0.1223 A	0.81	" "
Peak Parking Accumulation, PA	" "	PA = 115 + 0.0388 A	0.86	" "
		FRIDAYS		
Average Person Trips, AT	Floor Area, A(m^2)	AT = 292 + 0.1095 A	0.96	1,774 - 41,700 m^2
Peak Person Trips, PPT	" "	PPT = 340 + 0.1519 A	0.94	" "
Person Trips, pm.Peak, PTV	" "	PTV = 517 + 0.0915 A	0.94	" "
Peak Vehicle Trips, PVT	" "	PVT = 184 + 0.0658 A	0.89	" "
Vehicle Trips, pm. Peak V(P)	" "	V(P) = 265 + 0.0427 A	0.92	" "
Peak Parking Accumulation, PA	" "	PA = 40 + 0.0365 A	0.96	" "
		SATURDAYS		
Average Person Trips, AT	Floor Area, Dept. Store A(D)(m^2) Floor Area, Super-market + small shops A(SM)(m^2)	AT= -345 + 0.1009 A(D) +0.4371 A(SM)	0.92	A(D) : 0 - 34,600 m^2 A(SM): 0 - 14,100 m^2
Peak Person Trips, PPT	"	PPT =-243 + 0.1341 A(D) + 0.5935 A(SM)	0.91	" "
Peak Vehicle Trips, PVT	"	PVT = -95 + 0.0503 A(D) + 0.2517 A(SM)	0.90	"
Peak Parking Accumulation, PA	"	PA = -91 + 0.0331 A(D) + 0.0838 A(SM)	0.92	"
Peak Parking Accumulation, PA	Floor Area, A	PA = 57 + 0.0386 A	0.82	4,150 - 41,700 m^2
		ALL DAYS		
Average Person Trips, AT	Floor Area, A(m^2)	AT = 579 + 0.1276 A	0.80	1,774 - 77,100 m^2
Peak Person Trips, PPT	" "	PPT = 946 + 0.1597A	0.75	"
Person Trips, pm. Peak, PTV	" "	PTV = 685 + 0.1228 A	0.81	"
Peak Parking Accumulation, PA	" "	PA = 69 + 0.0390 A	0.87	"
Peak Vehicle Trips, PVT	Person trips, pm. Peak Mode Split MS Car Occupancy OC	PVT = PTV x MS/OC	-	-

tion can be made by applying the relevant hourly percentages, viz., 4:00 to 5:00 p.m., 30 percent; 5:00 to 6:00 p.m., 32 percent; 6:00 to 7:00 p.m., 38 percent.

$$PVT/block = 0.88U_1 + 1.09U_2 + 1.45U_3 \quad (16)$$

Restaurants

Surveys were conducted at 10 sites on either a Friday or a Saturday evening, generally in the periods 5:00 to 10:00 p.m. and 6:00 to 11:00 p.m.

All independent variables were highly correlated with each other. In particular, A was highly correlated with the eating area (A_E), the seating capacity (S), the number of tables (T), and E. As such, all descriptive models were based on single independent variables. The main equations developed are given in Table 10.

Homes for the Aged

Ten sites were surveyed, representing a range of sizes and geographical region; they were of fairly recent construction. Two surveys were conducted, the first between 3:00 and 6:00 p.m. on a weekday and the second between 2:00 and 6:00 p.m. on a Sunday.

Strong correlations were found between the accommodation capacity (AC) and E. Accessibility to public transport (PT) yielded weak negative correlations between both of the previous independent variables.

Although predictive equations were developed for both weekends and weekdays separately, for the most part the weekend generation rates were greater than those for the weekday. Therefore, only equations relating to weekend periods are presented together with those for the total (all-week) sample.

Note that all equations use AC as the independent variable, this being the most reliable estimator. Furthermore, AC is intrinsically a more desirable predictive variable. The introduction of PT into the equations containing AC offered no increase in the prediction accuracy (the coefficient for PT was not significantly different from zero).

The equations developed are given in Table 11.

USE OF RESULTS

It is considered that the models presented can be of practical use in predicting the traffic impact and parking requirements of proposed developments. The models are only valid for the range of independent variables used to derive them. They cannot be extrapolated with confidence. Attention should also be drawn to the correlation coefficient. Ideally the prediction interval should be calculated for a given case. The 90 percent prediction interval is suggested; that is, for a given independent variable, for example, building floor area, the prediction of the dependent variable, for example, peak

Table 10. Regression equations for restaurants.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	R^2	RANGE OF INDEPENDENT VARIABLE
Peak Person Trips PPT	Seating Capacity, S	PPT = 23 + 0.782 S	0.76	60 - 220
Peak Vehicle Trips, PVT	Gross Floor Area A	PVT = 18 + 0.098 A	0.77	50 - 655
	Seating Capacity, S	PVT = 3 + 0.356 S	0.76	60 - 220
Average Vehicle Trips, AVT	Gross Floor Area A	AVT = 7 + 0.065 A	0.81	50 - 655
Peak Parking Accumulation, PPA	Employees, E	PPA = 4 + 2.702 E	0.89	4 - 32
	Gross Floor Area A	PPA = 17 + 0.094 A	0.67	50 - 655

Table 11. Regression equations for homes for the aged.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	R^2	RANGE OF INDEPENDENT VARIABLE
Peak Weekend Person Trips, PWEP	Accom. Capacity, AC	PWEP = - 2 + 0.336 AC	0.96	29 - 379
Peak Person Trips - All Week, PPT	Accom. Capacity, AC	PPT = 0.330 AC	0.98	29 - 379
Peak Weekend Vehicle Trips, PWEV	Accom. Capacity, AC	PWEV = - 7 + 0.191 AC	0.96	29 - 379
Peak Vehicle Trips, PVT	Accom. Capacity, AC	PVT = -6 + 0.199 AC	0.96	29 - 379
Weekend Peak Parking Accumulation, WEPA	Accom. Capacity, AC	WEPA = - 5 +0.171 AC	0.93	29 - 379
Peak Parking Accumulation - All Week, PPA	Accom. Capacity, AC	PPA = - 5 + 0.195 AC	0.93	29 - 379

vehicle trips, will be inside the prediction interval limits in 90 percent of the cases. In the absence of any information indicating that a high or low estimate would be more appropriate, the value as calculated by the equation should be used.

DISCUSSION

It is not feasible, in a paper of this length, to discuss the study in any detail. Instead it is the intention here to highlight the nature of the study and to briefly present the findings. Nevertheless, there are a number of points that need to be made.

Statistical Analysis

A major problem in this research was the development of descriptive models that could be used by the average engineering and planning practitioner. This requirement suggested multiple linear regression techniques as being appropriate. Thus the research could be criticized because the relationships and models developed were functional rather than causal. This is not a problem in situations where the underlying causal variables move together with the functional variables. Problems could arise when data representative of one point in time are used to predict change, if the proposed development caused a change in the overall system itself. However, given the information known at the time that a development application is made, complex behavioral models cannot be readily applied.

There are more complex alternatives to linear regression for analysis of particular independent variables. As an example, for a particular data set, models of the following forms with the correlation coefficients (R^2) as given were examined:

Model Type	R^2
$Y = ax + b$	0.85
$Y = a + bx + cx^2$	0.87
$Y = a \exp(bx)$	0.89
$Y = ax^b$	0.91

In the search for the highest R^2, it could be concluded that a model of the form $Y = ax^b$ would be most appropriate. However, would it be most appropriate for every data set? Could the prediction of confidence intervals be just as easily calculated? Could the practitioner get an adequate feel for what the model was doing? It was concluded that linear regression models were the most appropriate for everyday practical application.

However, the possible pitfalls for the practitioner must still be recognized. The meaning of the R^2 must be understood. It is a useful measure of the relative accuracy of a model when models with the same dependent variables are compared. However, as an absolute indicator of how good a certain model is, it is not, on its own, as useful.

It is not appropriate to use R^2 to compare the goodness of fit of models with different dependent variables. It is not even strictly correct to compare models with the same dependent variable but with a different number of independent variables unless correction is made for the varying degrees of freedom.

There is no absolute value of R^2 above which a model can be considered acceptable or good. One extreme data point in an otherwise grouped distribution can substantially affect the R^2. Models based on small sample sizes are particularly prone to this effect. Variable definition and the level of aggregation of the data can also have an impact.

Design Hour

Resources were not available to investigate seasonal trends in generation. Thus the results cannot be directly factored to such parameters as the 10th highest hour. Nevertheless, the results give peak results for the seasonal time surveyed. Pilot surveys, usually based on interviews of management at the particular land use being surveyed, determined the peak day of the week and obtained general indications on the peak time of the day. Before resources are used in gathering seasonal figures, the anticipated prediction interval of the end result must be considered. Such factors as car occupancy and mode split can be difficult to predict accurately beforehand. Use of the results often makes quantum changes important. For example, is an additional lane necessary to service a development? It is not possible to construct 0.35 of a lane. This type of end use makes knowledge of seasonal variations interesting but not essential except in specific circumstances.

Generation Rates for Shopping Centers

It has often been suggested that vehicle trip generation rates at shopping centers decline as the gross leased area of the centers increases. The general effect of this was observed but was difficult to quantify. In selecting the sample for the shopping centers, care was taken to get a large variation in area. Analysis was attempted by using data in specific ranges of gross leasable floor area; 5 000 m^2 and 30 000 m^2 were the dividing points. The results were inconclusive, neither proving nor disproving the hypothesis. The analysis could have been more thorough if information on the length of stay in the parking lot had been available, because this would also appear to be relevant. However, it should be pointed out that the trip generation behavior observed at sites with floor areas less than 5 000 m^2 was fairly random.

In addition, because of the proportionally greater effect of the constants in the models at this lower floor area range, subjective and comparative assessments of specific centers might be more appropriate when such new centers are assessed.

Effect on the Adjacent Road Network

The effect that the particular development proposal has on the adjacent road network must be assessed in order to provide improved facilities where necessary to safely accommodate any additional traffic on the road system and maintain the efficiency of that system. Further, it is frequently necessary to seek contributions from developers to fund such facilities where these are necessary, and as such it is desirable that the specific impact created by a particular development be quantifiable.

In this regard it is instructive to use an example to highlight the issues involved; take the case of shopping centers. The usual method of defining the traffic impact of a shopping center is as follows:

1. Survey and evaluate the existing situation in the vicinity of the development during a chosen design period, often the afternoon peak hour;
2. Define the scale of the development, floor area, parking supply, shopping mix, and so on;
3. Estimate the vehicle generation of the center during the design period;
4. Assign those trips to the road network and add them to existing flows; and
5. Evaluate the ability of the network to handle the extra traffic.

The critical word in the above sequence of activities is "add." It has long been recognized that a shopping center does not rely wholly on newly generated trips but to some degree picks up trips that were already in progress or diverts them from a short distance away. Conventional wisdom suggests that newly generated trips form the bulk of traffic to a new shopping center and that ignoring the other trips is a sensibly conservative approach, akin to the engineer's factor of safety.

In a paper by Slade and Gorone (1), however, limited research at one center in Washington, D.C., showed that only 35 percent of trips were newly generated and that 65 percent were merely diversions of trips already on the road network. Further research is needed on this. It is interesting to note that as part of the Traffic Authority surveys of shopping centers, shoppers were questioned whether the particular center surveyed was the only place in which they intended to shop. On average about 50 percent of the shoppers indicated that they would be shopping elsewhere as part of their shopping trips, which suggests that current procedures for assessing the impact of these developments do indeed need reviewing.

CONCLUSIONS

The generation models presented in this paper are somewhat limited inasmuch as they offer a simplistic static solution to what is in reality a complex dynamic phenomenon. However, it is considered that they are an improvement to the status quo and will give more useful predictions than those based on more historical and subjective bases. Although the applicability of these results in countries other than Australia has not been investigated, it is hoped that the results nevertheless will be of some assistance in furthering general research on land use traffic generation. It is also hoped that the information presented will assist in the development of more realistic parking standards.

REFERENCE

1. L.J. Slade and F.E. Gorone. Reductions in Estimates of Traffic Impacts of Regional Shopping Centres. ITE Journal, Jan. 1981.

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Public Management in a Time of Declining Resources

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In Minnesota, as in many states, construction, maintenance, and operating costs are increasing while highway revenues from gasoline consumption are decreasing. The result is a severe budgetary crisis that requires retrenchment of the organization. The retrenchment process at Minnesota's Department of Transportation (Mn/DOT) involved several different approaches. Convincing the state's highway users and Mn/DOT's employees of the necessity for making large cutbacks was deemed essential, and numerous ways of accomplishing this were used. At the heart of retrenchment are decisions about who is to be laid off and what activities and projects are to be scaled down or terminated. The department used various methods to earmark such reductions. Finally, because pressure to meet established informational and decision-making needs heightens during retrenchment, developing and putting to use tools such as computer systems and packages becomes more important.

Transportation agencies today are faced with the problem of how to make the transition from growth to decline. It is an adjustment that will have to be made in virtually all of the public sector as programs are reduced. The age of rapid growth is giving way to the age of slowdown, as Kenneth Boulding has labeled it (1). The public sector, which has expanded enormously over the last four decades, can no longer presume increasing revenues and expenditures. However, almost all public management strategies are predicated on expansionist assumptions (2).

In transportation the peak of highway construction was in the 1950s, 1960s, and 1970s. The U.S. Interstate system was developed. The states built, expanded, realigned, and connected trunk highways and constructed bridges and bypasses. With this gigantic effort came an unparalleled expansion of the public work force.

Minnesota's construction peak came in 1967 to 1969. In 1973 the Arab oil embargo caused oil supplies to diminish and gasoline prices to rise throughout the rest of the decade. To economize, drivers bought small cars that got better gasoline mileage. The gasoline tax has been the principal source of Minnesota highway funds, but because the amount of revenue is a function of the amount of gasoline used, economizing has dealt a critical blow to the state's highway revenues.

Gasoline consumption in Minnesota is expected to decrease an average of 2.2 percent annually through the late 1980s. In the 6 years preceding the embargo, gasoline consumption in Minnesota increased an average of 5.8 percent annually. If that trend had continued, state gasoline revenues, including the three gasoline tax increases approved by the state legislature since 1972, would have totaled $2.68 billion between 1973 and 1982. Instead, gasoline revenues for the 10-year period totaled $2.04 billion. Economizing in Minnesota has resulted in $640 million less in highway revenue during the 10 years.

At the same time that gasoline consumption was dropping, construction, maintenance, and operating costs were increasing. Higher oil prices after the 1973 embargo meant rapidly rising building and maintenance costs because of the oil in materials such as asphalt and concrete and the fuel use of heavy equipment.

As a result Minnesota's highway construction cost index soared in the last decade and a half. From a base of 100 in 1967, it climbed to 292 in 1981. An additional index reflecting cost of maintenance and operations, based on a nationwide average, rose to 218 in 1978 from a base of 100 in 1967.