# A Model of the Maximum Generation of Traffic to Planned Shopping Centers

JOHN W. DICKEY, Graduate Research Assistant, The Transportation Center, Northwestern University; and
PAUL W. SHULDINER, Associate Professor of Civil Engineering, Northwestern University

•IN STUDIES of people and their behavior the investigator is often faced with the problem of evaluating the myriad variables and factors which, when taken together, account for much of the observed variation in behavior but which individually account for little. The study of shopping center generation reported in this paper is a case in point. Many factors influence the shopping trip behavior of persons and families. Within the market area, consideration must be given to such types of variables as, for instance, household-descriptive factors, including residential density, family income, family size and composition, and level of auto ownership. Factors based on the transportation system include distance and travel times to various shopping places, the availability of public transit, and the amount of traffic congestion. For the class of variables relating to the shopping center itself, there are the number and sizes of stores in the center, the amount of parking available, the type and cost of goods sold, the quality of service, etc.

Yet, even if all the significant variables could be identified and measured, the problem of determining their separate and joint effects on demand would remain. Taken together, these two considerations imply the need for a greatly expanded storehouse of information, to say nothing of the additional effort needed to analyze and evaluate such data.

When considering the interrelatedness of effects, a third problem presents itself. The factors which have been considered so far have only been associated with the dependent variable, generation, yet generation in itself is not disassociated with other parts of the urban planning process. The way in which future trips from the home are distributed, for example, determines the future attraction of nonresidential land uses and, furthermore, the future systems built to serve this demand will themselves affect the number of trips made. Thus, it seems unwise to consider generation without evaluating the system effects.

All transportation studies have had to face these three perplexing problems in order to produce models which would be of value in estimating future travel. Moreover, limitations of time, money, and personnel have often retarded progress toward obtaining adequate solutions. Individual research projects have also been constrained by the same circumstances. To make matters worse, each study and project has usually changed in some manner the definitional base on which the examination of travel is established.

A few examples may help to emphasize the points suggested above. In the six centers studied by LARTS (9), vehicle trips per day per gross acre of center varied from 132 to 545 with an average of 296; vehicle trips per day per square foot of floor space varied from 0.009 to 0.046 with an average of 0.023; and vehicle trips per day per employee varied from 6.8 to 36.7 with an average of 16.9. In another study, Harding (8) found similar variations in daily vehicle trips per gross acre with rates ranging from 263 to 794 trips. Using an "average" rate for any of these three variables of attraction might result in a discrepancy of more than one-half the average in either direction. An over- or underestimation of such magnitude might well produce serious distortions in planning local and regional transportation facilities. Yet, if, in order to be on the "safe" side,

Paper sponsored by Committee on Origin and Destination and presented at the 45th Annual Meeting.

the maximum observed value of daily generation is used, the actual value could be as little as ⅓ of this maximum number. Overestimation might then lead to significant diseconomies in the system planned to serve a given shopping center. To add to these difficulties there is considerable disagreement among planners and engineers as to the extent to which these variables can be adequately estimated for use in the determination of future shopping center attraction.

In summary, it may be said that some kind of model is needed for furnishing information on centers which have not yet been built, but which are known to be needed in the future. The generation of present-day centers can be found simply by observation, but little is known about these future centers except, perhaps, their locations and probable sizes. It is the job of the transportation planner to estimate future traffic to these centers so that their influence on the transportation system can be measured.

## PURPOSE OF THE MODEL

The model discussed herein represents an attempt to overcome or avoid some of the major difficulties outlined in the preceding paragraphs. It has the property that the more information that is known concerning the nature of a particular center, the more accurate will be the forecast of traffic attracted to that center. Yet the model can provide estimates with as little information as just the gross size of the shopping center plot. A second property of the model is that it provides estimates which will almost always be on the high side—i. e., the planner can assume that, in practically every case, the actual generation of a center will not be greater than the predicted generation. This last statement implies, in a sense, that the model predicts some measure of the maximum possible generation of a given plot.

The mechanism which allows results from such simple inputs is the use of the trips/sales ratio. To start with, it seems reasonable that total sales of a center is a logical indicator of the environment in which the center is placed. If there is high density of residential development near the center, all other factors being constant, there should be higher sales at the center. If transportation is readily available to the center, all other factors being constant, there should be higher sales at the center. And if the management of the center is extremely adept, all other factors being constant, there should be higher sales. Therefore, if a hypothetical center were to be created which would combine the highest sales of each type of store found in actual centers across the United States, this center would represent some unknown yet optimal combination of all the factors which influence sales.

The next step in estimating the maximum potential generation of centers is to translate the optimal combination of sales factors into an expected maximum trip potential. This step is accomplished through the trips/sales ratio. (The trips per sales ratio used in this study were derived from data reported in (1).) Although there is considerable variation in the ratio of trips to sales from one center to another, a figure two standard deviations above the mean (assuming normality) would include 97.5 percent of all possible variations of trips over sales and could therefore be used to transform sales to trips and still be on the "safe" side. Thus, the optimum in terms of sales would tend to be optimum for trips.

The resultant generation figure for a given center could then be calculated through the use of the trips/sales ratio. The area of those particular stores which have the highest sales added to the area needed to park the vehicles generated by these stores (calculated with the help of the trips/sales ratio) should sum to the total area of plot on which the center is located. The resulting generation figure would then be safely on the high side, yet not unreasonably high.

## PRESENTATION OF THE MODEL

The model may be set up in linear programming format as follows:

maximize

$$T_{VA} = ca\left(\frac{1-t-w}{v}\right) \sum_{i=1}^{n} S_i A_i + e$$

subject to

$$l_i \leq A_i \leq h_i$$

$$\sum_{i=1}^{n} A_i/\sigma_i + \alpha_1 \, dac \left(\frac{1-t-w}{v}\right) \sum_{i=1}^{n} S_i A_i + \alpha_2 e \leq L$$

and delivery trips

$$T_{VT} = f_1 \sum_{i=1}^{n} A_i \text{ or } f_2 \sum_{i=1}^{n} A_i$$

where

- $L$ = gross area of center;
- $\alpha_1$ = area of parking needed per vehicle to be parked (this figure also includes the area needed for aisles, access roads, malls, truck zones, etc., per vehicle);
- $\alpha_2$ = area of parking needed per vehicle (for the e vehicles);
- $A_i$ = gross leasable area of business i;
- $\sigma_i$ = average number of floors on which business i operates;
- $T_{VA}$ = automobile vehicle trips per time period;
- $T_{VT}$ = truck vehicle trips per time period;
- $S_i$ = sales per unit gross leasable area of business i ;
- $a$ = person trips per total center sales;
- $T_p$ = person trips per time period;
- $t$ = percent of persons coming by public transportation per time period;
- $w$ = percent of persons coming by foot per time period;
- $v$ - car loading factor—persons per auto vehicle;
- $c$ = ratio of maximum trips to average trips per time period;
- $d$ = coefficient of accumulation of vehicles in parking lot;
- $e$ = constant of accumulation of vehicles in parking lot;
- $n$ = number of business types;
- $f_1$ = ratio of truck trips to gross leasable area per time period for centers without supermarkets;
- $f_2$ = ratio of truck trips to gross leasable area per time period for centers with supermarkets;
- $l_i$ = lower limit on gross leasable area for business i;
- $h_i$ = higher limit on gross leasable area for business i; and
- $G$ = total ground floor area.

The criterion function (max $T_{VA}$) can be explained in the following manner: The $S_i$ are the sales per unit area of a given business. Multiplying the sales per unit area by the area of each type of business and summing over all the business in the center gives the total sales of the center. Multiplying this resultant number by the person trips per sales ratio yields the number of person trips per period. Assuming the percentage of persons walking and coming by public transit to be negligible (in order to obtain the maximum vehicle trips) and dividing the number of person trips by the number of persons per vehicle gives the number of vehicle trips (automobile) per time period. The function is not complete, however, until the ratio of maximum to average trips has been considered. This requirement is taken into account by use of the c ratio. Thus, the final figure is the maximum number of vehicle trips per time period.

The first two constraints are fairly direct—the areas of the stores of various businesses cannot be lower than a certain value or higher than another value. For instance, a supermarket in a neighborhood center is practically never less than 5280 square feet or more than 21,420 square feet. These constraints might be called technological limitations, that is to say that operation of a supermarket of dimensions outside of the range given would probably be infeasible either because the area would be too small for proper marketing of goods or would be too large to control and manage economically.

The third constraint refers to the total area of the center. By definition, the ground area taken up for parking and that used for stores cannot be greater than that area set aside by the planner for the center. The first term on the left of the inequality is the representation of the total ground floor area occupied by the buildings. The second and third terms are the parking requirements. Note that the terms from the criterion function

$$T_{VA} = ca \frac{1-t-w}{v} \sum_{i=1}^{n} S_i A_i + e$$

are included in the second term, which can be reduced to $\alpha_1 d T_{VA} + \alpha_2 e$. Multiplying the vehicle trips to the center by the ratio of accumulated cars to entering cars gives the total number of cars accumulated in the parking lots. These are the cars which must be parked, taking up space $\alpha_1$ per vehicle. The $\alpha_2 e$ term is an adjustment made to the regression equation constant e. The significance of this adjustment is discussed in the following.

The final equation, the one for delivery trips, is simply the product of the empirical coefficients found by Gruen and Smith (7) and the gross leasable area. It was felt that this single product was sufficient to explain delivery trips since these trips represent such a small portion of the total number of trips.

## VALUES FOR THE CONSTANTS AND COEFFICIENTS IN THE MODEL

The values used for the constants and coefficients in the model are presented in Table 1 along with the reference numbers of the sources from which they were obtained. It should be noted here that the values which are used have been selected so as to produce the greatest amount of generation. For example, the $\alpha_s$ value (see Table 1 for definition of $\alpha_s$) of 275 sq ft/veh was found in reference (3) to be the lowest value for the parking space required by one vehicle. The use of the lowest parking space per vehicle means that, for a center of a given size, more cars can be parked and thus the calculated generation rate can be higher.

The e value requires some special explanation. Cleveland and Mueller (4) found that the accumulation of vehicles in a shopping center parking lot is highly correlated with the number of entering vehicles (generated trips in the model). The r value is 0.87. The least squares regression line corresponding to this relationship is $dT_{VA} + e$ or $0.193T_{VA} + 500$. Therefore, the use of e.

One other aspect of the model needs mentioning at this point. Some businesses, despite their lower sales per square feet, appeared in almost every actual center. It was felt that these businesses should definitely be included in the theoretical centers. To accomplish this in the model, it was necessary to set the lower floor area values of all unnecessary businesses to zero, while leaving the corresponding numbers for the necessary business at their previous level. The error in calculations caused by such a procedure would seem to be slight.

## A SIMPLER COMPUTATIONAL TECHNIQUE

A hand-workable method has been developed which approximates the linear programming model previously discussed. The computing technique is as follows (for both neighborhood and community combined with regional subclasses):

1. Calculate $ca/v = 4.53\,(1.15 \text{ or } 0.68)/1.90 = (2.75 \text{ or } 1.62)$. Note that $t, w = 0$ for maximum vehicle generation.

TABLE 1

LIMITS ON FLOOR AREAS, SALES, AVERAGE FLOORS PER STORE, AND RANKING OF SALES FOR S. I. C. BUSINESS TYPES (13)

| Business S. I. C. [a] | Lower Floor Area Limit, Neigh. Centers (× $10^3 ft^2$) | Higher Floor Area Limit, Neigh. Centers (× $10^3 ft^2$) | Lower Floor Area Limit, Comm. Centers (× $10^3 ft^2$) | Higher Floor Area Limit, Comm. Centers (× $10^3 ft^2$) | Lower Floor Area Limit, Regional Centers (× $10^3 ft^2$) | Higher Floor Area Limit, Regional Centers (× $10^3 ft^2$) | Yearly Sales in Dollars per Sq Ft | | Avg. Floor per Store of Business | Rank of Business Acc. to Avg. Sales | Rank of Business Acc. to Max. Sales |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Avg. | Max. | | | |
| $i$ | $l_{hi}$ | $h_{ni}$ | $l_{ci}$ | $h_{ci}$ | $l_{ri}$ | $h_{ri}$ | $S_{ai}$ | $S_{hi}$ | $\sigma_i$ | $U_{ai}$ | $U_{hi}$ |
| 1. 5231 | 00.00 | 024.94 | 00.00 | 024.94 | 00.33 | 024.94 | 033 | 067 | 1 | 37 | 38 |
| 2. 5311 | 00.00 | 022.00 | 10.16 | 058.50 | 73.45 | 999.90 | 055 | 100 | 3 | 15 | 22 |
| 3. 5331 | 00.00 | 021.42 | 03.84 | 029.25 | 01.04 | 091.36 | 034 | 093 | 1 | 36 | 29 |
| 4. 5392 | 00.00 | 010.00 | 00.00 | 010.00 | 00.00 | 010.00 | 032 | 092 | 1 | 38 | 30 |
| 5. 5411 | 05.20 | 043.07 | 04.40 | 047.20 | 08.05 | 050.63 | 102 | 190 | 1 | 3 | 2 |
| 6. 5422 | 00.00 | 004.89 | 00.00 | 004.89 | 00.44 | 009.78 | 075 | 161 | 1 | 5 | 4 |
| 7. 5441 | 00.00 | 004.20 | 00.00 | 004.20 | 00.50 | 004.20 | 054 | 104 | 1 | 16 | 18 |
| 8. 5462 | 00.00 | 006.05 | 00.00 | 006.05 | 00.00 | 006.05 | 051 | 143 | 1 | 19 | 9 |
| 9. 5499 | 00.00 | 006.35 | 00.00 | 006.35 | 00.00 | 006.35 | 063 | 121 | 1 | 10 | 14 |
| 10. 5531 | 00.00 | 011.70 | 00.00 | 011.70 | 00.00 | 011.70 | 037 | 068 | 1 | 33 | 37 |
| 11. 5541 | 00.00 | 020.00 | 00.00 | 020.00 | 00.00 | 020.00 | 041 | 094 | 1 | 29 | 28 |
| 12. 5612 | 00.00 | 004.05 | 00.15 | 012.96 | 00.42 | 047.68 | 059 | 154 | 1 | 11 | 7 |
| 13. 5621 | 00.00 | 022.50 | 01.02 | 036.32 | 00.64 | 144.20 | 048 | 128 | 1 | 22 | 11 |
| 14. 5631 | 00.00 | 015.91 | 00.24 | 015.91 | 00.24 | 047.73 | 052 | 103 | 1 | 18 | 19 |
| 15. 5641 | 00.00 | 003.15 | 00.00 | 004.23 | 00.79 | 008.59 | 040 | 098 | 1 | 30 | 24 |
| 16. 5651 | 00.00 | 004.41 | 00.00 | 027.90 | 00.00 | 027.63 | 045 | 075 | 1 | 25 | 35 |
| 17. 5662 | 00.00 | 003.38 | 01.32 | 006.30 | 00.90 | 027.00 | 046 | 101 | 1 | 24 | 21 |
| 18. 5712 | 00.00 | 004.03 | 00.00 | 021.15 | 00.00 | 036.15 | 026 | 046 | 1 | 42 | 42 |
| 19. 5713 | 00.00 | 007.12 | 00.00 | 007.12 | 00.00 | 007.12 | 049 | 097 | 1 | 21 | 25 |
| 20. 5719 | 00.00 | 003.75 | 00.00 | 003.75 | 00.00 | 003.75 | 031 | 091 | 1 | 39 | 31 |
| 21. 5722 | 00.00 | 007.51 | 00.00 | 007.51 | 00.00 | 007.51 | 065 | 109 | 1 | 8 | 17 |
| 22. 5732 | 00.00 | 011.50 | 00.00 | 011.50 | 00.63 | 011.50 | 058 | 118 | 1 | 12 | 15 |
| 23. 5812 | 00.00 | 008.20 | 01.20 | 018.40 | 01.30 | 084.00 | 056 | 117 | 1 | 14 | 16 |
| 24. 5813 | 00.00 | 002.79 | 00.00 | 002.79 | 00.00 | 002.79 | 053 | 083 | 1 | 17 | 32 |
| 25. 5912 | 01.28 | 012.83 | 01.38 | 021.06 | 00.90 | 044.24 | 057 | 122 | 1 | 13 | 13 |
| 26. 5921 | 00.00 | 007.20 | 00.00 | 007.20 | 00.00 | 007.20 | 106 | 176 | 1 | 2 | 3 |
| 27. 5942 | 00.00 | 007.10 | 00.00 | 007.10 | 00.00 | 007.10 | 043 | 082 | 1 | 27 | 33 |
| 28. 5952 | 00.00 | 012.10 | 00.00 | 012.10 | 00.00 | 012.10 | 047 | 074 | 1 | 23 | 36 |
| 29. 5971 | 00.00 | 002.48 | 00.00 | 003.40 | 00.40 | 013.28 | 071 | 158 | 1 | 6 | 5 |
| 30. 5992 | 00.00 | 003.96 | 00.00 | 003.96 | 00.00 | 003.96 | 035 | 048 | 1 | 35 | 41 |
| 31. 5993 | 00.00 | 002.16 | 00.00 | 002.16 | 00.00 | 002.16 | 117 | 151 | 1 | 1 | 8 |
| 32. 5996 | 00.00 | 002.75 | 00.00 | 002.75 | 00.00 | 002.75 | 064 | 127 | 1 | 9 | 12 |
| 33. 5997 | 00.00 | 006.15 | 00.25 | 006.15 | 00.25 | 012.30 | 039 | 134 | 1 | 31 | 10 |
| 34. 5999 | 00.00 | 009.18 | 00.00 | 009.18 | 00.00 | 009.18 | 082 | 198 | 1 | 4 | 1 |
| 35. 6000 | 00.00 | 009.72 | 00.40 | 009.72 | 00.40 | 019.44 | 070 | 157 | 1 | 77 | 6 |
| 36. 6400 | 00.00 | 003.56 | 00.00 | 003.56 | 00.00 | 003.56 | 042 | 081 | 1 | 28 | 34 |
| 37. 0000 | 00.00 | 036.00 | 00.10 | 108.00 | 00.10 | 216.00 | 030 | 095 | 3 | 40 | 27 |
| 38. 7211 | 00.20 | 007.78 | 00.20 | 007.78 | 00.20 | 007.78 | 028 | 056 | 1 | 41 | 40 |
| 39. 7215 | 00.00 | 004.50 | 00.00 | 004.50 | 00.00 | 004.50 | 015 | 023 | 1 | 44 | 44 |
| 40. 7221 | 00.00 | 002.28 | 00.00 | 002.28 | 00.00 | 002.28 | 036 | 063 | 1 | 34 | 39 |
| 41. 7231 | 00.20 | 011.88 | 00.20 | 011.88 | 00.20 | 011.88 | 044 | 096 | 1 | 26 | 26 |
| 42. 7251 | 00.00 | 002.15 | 00.00 | 002.15 | 00.00 | 002.15 | 038 | 102 | 1 | 32 | 20 |
| 43. 7830 | 00.00 | 013.50 | 00.00 | 013.50 | 00.00 | 013.50 | 050 | 099 | 1 | 20 | 23 |
| 44. 7911 | 00.00 | 002.83 | 00.00 | 002.83 | 09.00 | 002.83 | 018 | 034 | 1 | 43 | 43 |
| 45. 7931 | 00.00 | 052.20 | 00.00 | 052.20 | 00.00 | 052.20 | 010 | 018 | 1 | 45 | 45 |

[a]See Appendix A for Standard Industrial Classification of Commercial business types.

Note: $\alpha_T$ = 325 ft²/veh (3)
$\alpha_s$ = 275 ft²/veh (3)
$\alpha_L$ = 144 ft²/veh (4)
c = 4.53 (10th highest hour) (4)
e = 500 veh(4)
d = 0.193
t = 0
W = 0
v = 1.90 persons/veh
$a_T$ = 0.68 mean ± 0.40 (1)
$a_s$ = 1.15 mean = 0.59 (1)
Rank-correlation of Average Sales & Maximum Sales Rankings = 0.79

Subscripts: n = neighborhood
c = community
r = regional
L = community & regional
a = avg. figure
h = max. figure
i = particular bus. type
s = neighborhood

TABLE 2

VALUES FROM ALGORITHM FOR NEIGHBORHOOD CENTERS USING MAXIMUM SALES FIGURES

| ① | ② | ③ | ④ | ⑤ | ⑥ | ⑦ | ⑧ |
|---|---|---|---|---|---|---|---|
| Business added | $\sum_i A_i/\sigma_i$ | $\sum_i A_i S_i$ | 146.2 × ③ | 72,000 + ② + ④ | 500 + 2.75 × ③ | ⑤/43,560 | ⑥/⑦ |
| | Total ground flr area (× $10^3$ $ft^2$) | Total center sales ($) | Parking area needed ($ft^2$) | Total area of center ($ft^2$) | Generation (cars) | Gross acreage of center | Generation rate (cars/acre per day) |
| Necessary businesses | 6.96 | 1,139.7 | 173,934 | 252,894 | 3,270 | 5.80 | 650 |
| | +9.18 | 1,817.6 | | | | | |
| | 16.14 | 3,007.3 | 439,667 | 527,807 | 8,775 | 12.11 | 722 |
| + 5999 | +43.07 | | | | | | |
| | - 5.28 | | | | | | |
| + 5411 | 53.93 | 11,139.3 | 1,628,565 | 1,754,495 | 31,150 | 40.27 | 763 |

2. Calculate $\alpha_1$ dca/v = (275 or 325) (0.193) (4.53) (1.15 or 68)/1.90 = (142.6 or 101.8).
3. Caluculate $\alpha_2$e = (144 or 275) (500) = 72,000 sq ft or 162,500 sq ft.
4. Introduce the business that must occur in a center into the model along with their minimum floor areas. The minimum areas are used since these businesses are not necessarily the ones with the highest sales (and thus generation).
5. Find the ground floor area requirements for these businesses, G = $\Sigma A_i/\sigma_i$.
6. Find the total sales of the centers = $\Sigma$ $A_iS_i$, i = necessary businesses.
7. Find the area needed for parking, P = (142.6 or 101.8)($\Sigma$ $A_iS_i$) + (72,000 or 162,00).
8. Find the total area of the center, L = (G + P) /43,560. L in acres.
9. Find the generation, $T_{VA}$ = (2.75 or 1.62) ($\Sigma A_iS_i$) + 500. i = necessary businesses.
10. Calculate the vehicle trips/acre = $T_{VA}/L$.

This procedure will usually yield an L value close to the minimum for that class of center under consideration. To derive generation rates for other center sizes, add stores in the following manner:

11. Take the business with the highest sales per square feet and put it in the model along with its maximum floor area.
12. Return to steps 5 to 10 to calculate the generation rate. Note that if the store with the highest sales per square feet is also one of the stores that is a necessary store in the center, then the $A_iS_i$ value in the original calculation must be subtracted. The i index for this process now covers the necessary stores and the added one.
13. Continue to add businesses according to their sales rank, taking the highest ones first, subtracting the previous $A_iS_i$ where necessary.
14. Find the generation rate for any size center (any L value) by referring to a graph formed by a smooth curve through the points of acreage and generation rates corresponding to the use of the maximum floor areas of given businesses in the model.

## EXAMPLE SOLUTION

The following example illustrates the foregoing procedure: (See Table 2): The attempt here is to create a hypothetical neighborhood center which has the highest generation. First, the constants must be calculated.

$$\frac{ca}{v} = \frac{(4.53)\ (1.15)}{1.90} = 2.75$$

$$\frac{\alpha_1 dca}{v} - \frac{275\ (0.193)\ (4.53)\ (1.15)}{1.90} = 142.6$$

$$\alpha_2 e = 144\ (500) = 72,000 \text{ sq ft}$$

Examination of Table 1 reveals that four businesses have lower limits on their floor area ($ln_i$) and therefore must be included in the center. They are 5411 (supermarket), 5912 (drug store), 7211 (laundry), and 7231 (barber or beauty shop). These businesses are entered into the model with their lower floor areas since these stores are not necessarily the ones with the highest sales/sq ft. (Yet, despite their lower sales, they seem to be necessary to draw customers to the center.)

The total sales for this group is

$$\sum_{i=1}^{4} A_i S_i = (5.28)\ (190) + 1.28\ (122) + 0.20\ (56) + 0.20\ (96) = 1.1897\ 10^6 \text{ dollars}$$

The ground area requirements are

$$G = \sum_{i=1}^{4} A_i/\sigma_i = \frac{5.28}{1} + \frac{1.28}{1} + \frac{0.20}{1} + \frac{0.20}{1} = 6.96 \text{ thousand sq ft}$$

The area needed for parking is

$$P = \frac{\alpha_1 dca}{v} \sum_{i=1}^{4} A_i S_i + \alpha_2 e = 142.6\ (1189.7) + 72,000 = 173,934 + 72,000 \text{ sq ft}$$

This makes the total area needed as

$$G + P = L = 173,934 + 72,000 + 6960 = 252,894 \text{ sq ft or } 5.80 \text{ acres}$$

The generation is

$$T_{VA} = \frac{ca}{v} \sum_{i=1}^{4} A_i S_i + e = 2.75\ (1189.7) + 500 = 3270 \text{ cars}$$

This makes the generation rate of 3270 cars/5.80 acres or 650 cars/gross acre.

Now assume that the generation rate was desired for a plot greater than 5.80 acres. The next store added would be for that business which has the greatest sales/sq ft figure which, in this case, is a miscellaneous retail store (5999) (for example, a trading stamp redemption store). Including this store in the model adds (see Table 1) 9180/1 or 9.18 thousand sq ft to the ground floor area and 9.18 (198) or 1817.6 thousand dollars to the total center sales, thereby causing a total area need of:
6960 + 9180 +(146.2) (1189.7 + 1817.6) + 72,000 = 6960 + 9180 + 439,667 + 72,000 = 527,807 sq ft or 12.11 acres.

The corresponding generation is 2.75 (1189.7 + 1817.6) = 8275 cars.

This makes the generation rate 8275/12.11 = 722 cars/acre.

Note that a 10-acre limit set on the size of neighborhood centers has already been exceeded, so that calculations could stop here, but the addition of another store would help illustrate the problem of subtraction mentioned before.

The business with the next highest sales/sq ft is the supermarket (5411). Notice that a supermarket has already been included as one of the necessary stores so that if it is included again, this time at its maximum floor area, the minimum floor area will be counted twice. To rectify this error, one need only subtract the minimum floor area from the calculations

$$\sum_{i=1}^{5} A_i/\sigma_i = \frac{5.28}{1} + \frac{1.28}{1} + \frac{0.20}{1} + \frac{0.20}{1} +$$

$$\frac{9.18}{1} + \frac{43.07}{1} - \frac{5.28}{1} = 53.93 = 53,930 \text{ sq ft}$$

The total sales for the center is

$$\sum_{i=1}^{5} A_i S_i = (5.28)(190) + 1.28(122) + 0.20(56) + 0.20(96) +$$

$$9.18(198) + 43.07(190) - 5.28(190) = 1.1139 \times 10^7 \text{ dollars}$$

Now multiplying by the constants, the resulting generation rate is

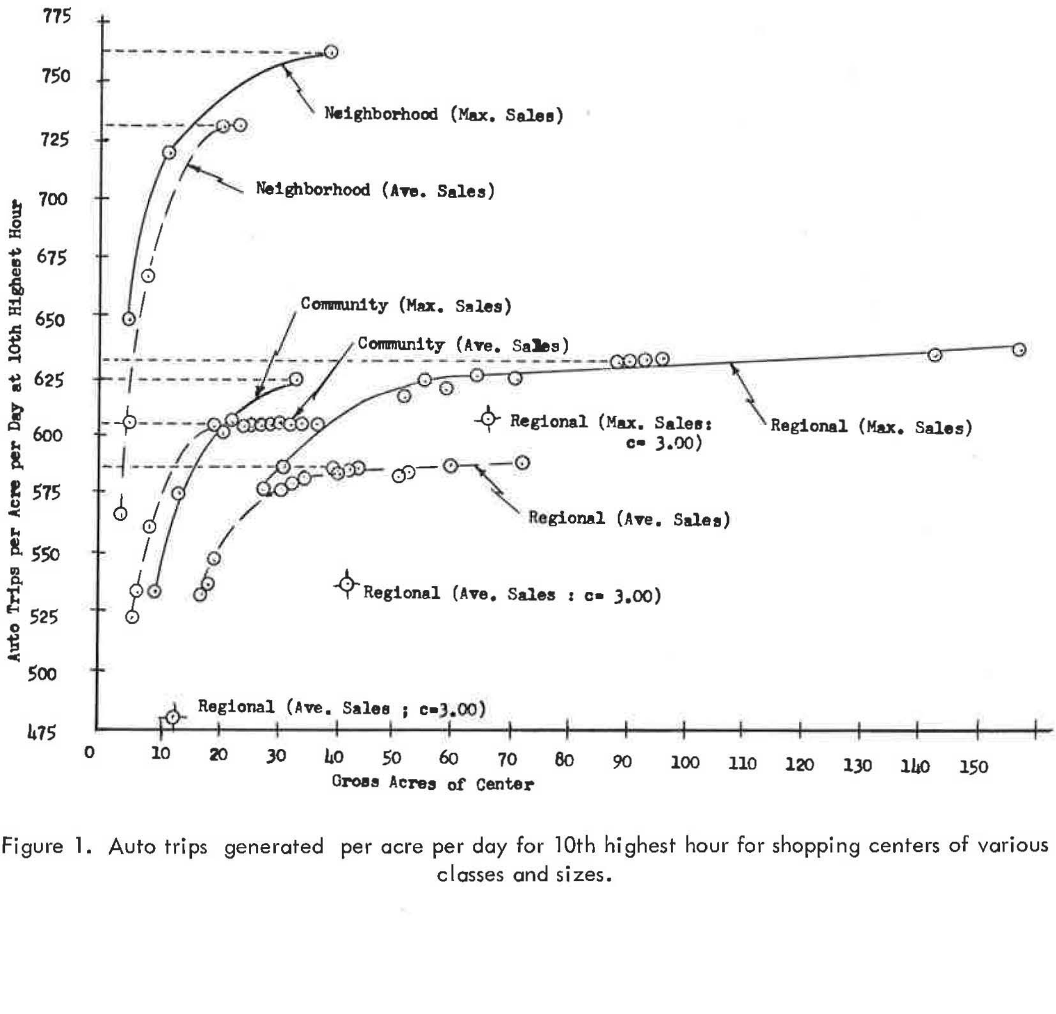


Figure 1. Auto trips generated per acre per day for 10th highest hour for shopping centers of various classes and sizes.

$$763 \frac{\text{auto trips}}{\text{gross acre}} \text{ for an area of } 40.27 \text{ acres}$$

As a final exercise, suppose that the generation rate for a center located on a plot of 9.00 acres is desired. Entering Figure 1, which is a plot of all the results obtained through the model, it is possible to determine the generation rate for any size center. For the case of the 9.00-acre center, an approximate maximum generation rate of 690 cars/gross acre is obtained.

## RESULTS

The generation or attraction rates which were obtained from the evaluation of the model are presented graphically in Figure 1. The points plotted represent that stage in the calculations where the maximum area of a given store was absorbed into the center. There are two curves for each class of center, one based on the assumption that all businesses are selling at rates close to their maximum potential, and the other based on the assumption that selling is only at the average rate. There are also a few other example points which indicate the sensitivity of generation rates to the lowering of highest hourly attraction, i.e., if the c value is lowered from 4.53 for the 10th highest hour in the year to 3.00 for the 50th highest hour.

Attention is directed to the shape of the resulting curves. Apparently the curves rise steeply in the beginning because of the influence of the businesses which have been forcefully included because of their presence in almost all actual centers. These businesses do not necessarily have the highest sales. Eventually the influence of their less-than-highest sales is overcome and the curves flatten out. It would seem wise that, in order to use the results of this study, these beginning influences should be neglected, and the model generation values should be obtained by proceeding vertically from the point on the abscissa representing the size of the land plot of the center until the dotted extension line is reached. The ordinate value corresponding to this intersection would then be the desired generation figure.

## CONCLUSIONS

On the basis of the model, the maximum expected generation rates for three classes of planned centers of various sizes can be calculated. It should be stressed at this point that, if the only information available is the size of the proposed center, all that is required is to enter Figure 1 in order to obtain an estimate of a reasonable maximum value for the generation of the center. It should be kept in mind that these estimates are based on combinations of factors selected in such a manner as to produce maximal

TABLE 3

| Parameters Used in Model | Value Assumed in Simple Maximal Model |
|---|---|
| Type of store | The store types which have the highest sales plus those commonly found in all centers |
| Size of store | The greatest floor area for highest sales stores<br>The least floor area for commonly found stores |
| Sales of store type | Highest sales per square foot |
| Person trips/sales | Two standard deviations above mean $A_{I'} = 0.68$, $A_S = 1.15$ |
| Car loading factor | A low value 1.90 persons/vehicle |
| Peak vs average number of trips | Tenth highest hour 4.53 |
| Accumulated vs generated vehicles | Regression line |
| Parking area per vehicle | A low value $\alpha_L = 325$ ft$^2$/veh, $\alpha_S = 275$ ft$^2$/veh |
| Average number of floors per store type | Assumed equal to one for most all types |

generation figures. Examination of Table 3 will reveal, for example, that the lowest value of parking space per vehicle was used so that more cars could be squeezed into the available parking area.

The simple approach is suggested when only the area of the future center is known. If additional information becomes available, the more detailed approach outlined in the sample problem can be used with appropriate values for the known variables in order to achieve a more accurate (and probably lower) value for the expected generation rate. For example, if the actual types of stores and corresponding floor areas were known for a center soon to be placed in operation, these values could be used directly in the detailed technique to obtain a more accurate rate. (In this case, the known businesses would be assigned their highest sales figures along with the higher values of trips/sale and peak to average ratios.) In another case, it might be known that the future owner does not wish to plan for the 10th highest hour but for the 50th instead. Again, this could be incorporated into the procedure by lowering the peak to average ratio from 4.53 to 3.00. The results of such a policy would then be incorporated into the model program.

The advantage of the model (and algorithm), then, is that the more information that is available to the planner, the more he can narrow his calculations toward a reasonable generation rate. Yet, he is assured that his resultant value for generation will be on the high side of the actual value except under the most improbable circumstances. If no information other than plot size is known, the maximum limit presented in Figure 1 can be used.

Added to this advantage is simplicity of calculation. The method of estimation which has been presented does not require a complicated computer program but can be hand-solved for an approximate value in a short period of time.

One shortcoming in the proposed model is the inevitable change in several of the parameters over time. This is especially true of the sales parameter, due to changes in prices of goods and services. Nevertheless, the model has been checked against existing rates found in the available literature (5) and has been found to give good results in practically every case.

To sum up, what has been presented is a procedure rather than an answer. On the other hand, the "grand" maximum values have been calculated for reference in those cases where the planner simply has no basis from which to infer further information concerning the nature and characteristics of the future center other than the gross acreage of the plot.

## REFERENCES


1. Berry, B. J. L. Commercial Structure and Commercial Blight. University of Chicago, Dept. of Geography Research Paper No. 85, Chicago, Ill., 1963.
2. Berry, B. J. L., and Tennant, R. J. Chicago Commercial Reference Handbook. University of Chicago, Dept. of Geography Paper No. 86, Chicago, Ill., 1963.
3. Burrage, R. H., and Mogren, E. G. Parking. Pp. 241-268, The Eno Foundation, Saugatuck, Conn., 1957.
4. Cleveland, D. E., and Mueller, E. A. Traffic Characteristics at Regional Shopping Centers. Yale University Bureau of Highway Traffic, New Haven, Conn., 1961.
5. Dickey, J. W. A Model of the Maximum Generation of Traffic to Planned Shopping Centers. Unpublished Master's Thesis, Northwestern University, Evanston, Ill., June 1965.
6. First National Bank of Arizona. Shopping Center Study. Research and Development Dept., Oct. 1961.
7. Gruen, V., and Smith, L. Shopping Towns U.S.A., The Planning of Shopping Centers. pp. 74-98, 115-132, Reinhold Publishing Co., New York, 1960.
8. Harding, C. H. V. Shopping Centers: Planning and Design for Traffic and Traffic Generation. ITTE, Univ. of California, Berkeley, Aug. 1960.
9. LARTS—Preliminary Results—1961 Shopping Center Study. Prepared for the 14th California Street & Highway Conf. of the ITTE at UCLA, Jan. 1962.

10. Special Generator Study No. 1—Westgate Shopping Center. Madison Area Transportation Study, State Highway Commission of Wisconsin, Urban and Advance Planning Section, Madison, Wis., May 1963.
11. Shuldiner, P. W. Non-Residential Trip Generation Analysis. The Transportation Center, Northwestern Univ., Evanston, Ill., Nov. 1965.
12. Silver, Jacob, and Hansen, Walter G. Characteristics of Travel to a Regional Center. Public Roads, Vol. 31, No. 5, pp. 101-108, Washington, D. C., Dec. 1960.
13. The Dollars and Cents of Shopping Centers. Urban Land Institute, Washington, D. C., 1963.

# *Appendix A*

SOME CLASSIFICATION OF BUSINESS TYPES[a]

| S.I.C. No. | Business Type | S.I.C. No. | Business Type |
|---|---|---|---|
| 5231 | Paint, glass, & wallpaper | 5912 | Drugs |
| 5311 | Department stores | 5921 | Liquors |
| 5331 | Limited price variety | 5942 | Books |
| 5392 | Dry goods & general merch. | 5952 | Sporting goods |
| 5411 | Grocery—supermarkets | 5971 | Jewelry |
| 5422 | Meat markets | 5992 | Florists |
| 5441 | Candy, nut, and confectionery | 5993 | Cigar stores |
| 5462 | Retail bakeries manufacturing | 5996 | Camera & photographic supply |
| 5499 | Food stores, not elsewhere classified | 5997 | Gift, novelty, & souvenir |
| 5531 | Tire, battery, & accessory dealers | 5999 | Miscellaneous retail |
| 5541 | Gasoline service stations | 6000 | Banks |
| 5612 | Men's & boys' clothing | 6400 | Insurance agents |
| 5621 | Women's ready to wear | 7211 | Power laundries—family and commercial |
| 5631 | Millinery | | |
| 5641 | Children's and infant's wear | 7215 | Self service laundries |
| | | 7221 | Photographic studios |
| 5651 | Family clothing | 7231 | Beauty shops |
| 5662 | Men's shoe stores | 7251 | Shoe repair shops |
| 5712 | Furniture stores | 7830 | Motion picture theatres |
| 5713 | Floor covering stores | 7911 | Dance halls, studios, etc. |
| 5719 | Micellaneous home furnishings | 7931 | Bowling, billiards, etc. |
| 5722 | Household appliance | | |
| 5732 | Radio & television | | |
| 5812 | Eating places | 8000 | Offices |
| 5813 | Drinking places (alcoholic) | | |

[a]From: Bureau of the Budget, Standard Industrial Classification Manual (S.I.C.), Washington, D.C. Government Printing Office, 1957.