# Estimating and Forecasting Travel for Baltimore by Use of a Mathematical Model

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Based on such factors as the number of people living and working in various zones and car ownership and the travel time between zones, a mathematical model was used to estimate the origin and destination of travel in the Baltimore area. The model was used to predict the future traffic volumes of proposed highways and the volumes which could be expected if specific mass transit improvements were made. Numerous tests of the model have indicated its reliability and versatility. It proved an economical method of conducting a comprehensive transportation study for the region.

THE BALTIMORE Regional Planning Council, in 1957, began to examine the numerous methods of evaluating the urban transportation needs of their region. Because of limited time and funds, the Council sought a quick, inexpensive, although comprehensive, method of evaluating Baltimore's transportation deficiencies.

After analyzing the available research on urban travel that had been done by the Bureau of Public Roads and others, it was believed that traffic movement could be synthesized from known land use factors. In other words, if certain factors were known about a community, such as the number of people who lived and worked in various zones as well as the car ownership in these zones, it would be possible to estimate the origin and destination of urban travel.

The method that was finally selected was, in effect, an application of a mathematical model. A model, in a descriptive sense, utilizes certain mathematical techniques which involve various steps and equations. More simply, it can be defined as a mathematical statement of observed relationships. For example, surveys of shopping habits have revealed that shoppers follow certain patterns that can be predicted mathematically. With such mathematical procedure and facts on individual residence, travel time to shopping centers, and their size, it becomes possible to estimate or forecast where people will shop. Since these techniques deal with travel habits, they are known as traffic models.

The traffic model used in Baltimore was founded on two simple premises:

1. Frequency of individual trips depends on desires and needs of individuals.
2. Modes of travel and trip destinations reflect personal transportation alternatives and land use distribution.

For instance, an insurance salesman undoubtedly travels more each day than does a mother with three or four small children. The mode of travel either party chooses will depend on the availability of an automobile and/or the adequacy of public transportation services. The destinations of their individual trips will depend on the distribution of land uses—the location of shopping centers, industrial and commercial areas, and residential neighborhoods. In a way, these principles might be summed up as a "theory of opportunity."

## Trip Frequency

The techniques devised in Baltimore relied first on the establishment of trip frequency. Numerous O-D studies indicated that work trips are the most common type in metropolitan areas and total about 40 percent of all trips during an average day. This percentage is higher—often 60 or 70 percent—during peak hours (1).

Another category of trips, those linked to commercial areas, include trips for personal business, shopping, and dining or entertaining. Most of the commercial trips occur in off-peak hours; but 20 percent of peak-hour travel is comprised of non-work trips linked to commercial areas.

Trips for the purpose of visiting friends have been identified as social trips. Although not very important in the whole picture, social trips have a unique characteristic in that their destination is influenced by distribution of population. These trips account for 10 percent of the peak-hour travel and about 20 percent of off-peak travel.

Non-home-based trips consist, for example, of salesmen in door-to-door traveling, or housewives shopping from store to store. These trips represent about 15 percent of the travel in off-peak hours, and 5 percent of the travel during the peak hour.

In arriving at trip frequency in Baltimore, certain modifications within these known percentage ranges were made. The commercial and social trip frequency was based on car ownership. For every 1,000 cars garaged in a residential area, 900 commercial and 700 social auto trips commenced daily. Forty commercial and 15 social started at the peak hour. (The Washington, D. C. Transportation Study revealed about the same number trips return during the peak hour.)

Calculating work-trip frequency involved a more complicated procedure, since the number of work trips is related to employment rather than to car ownership. First,

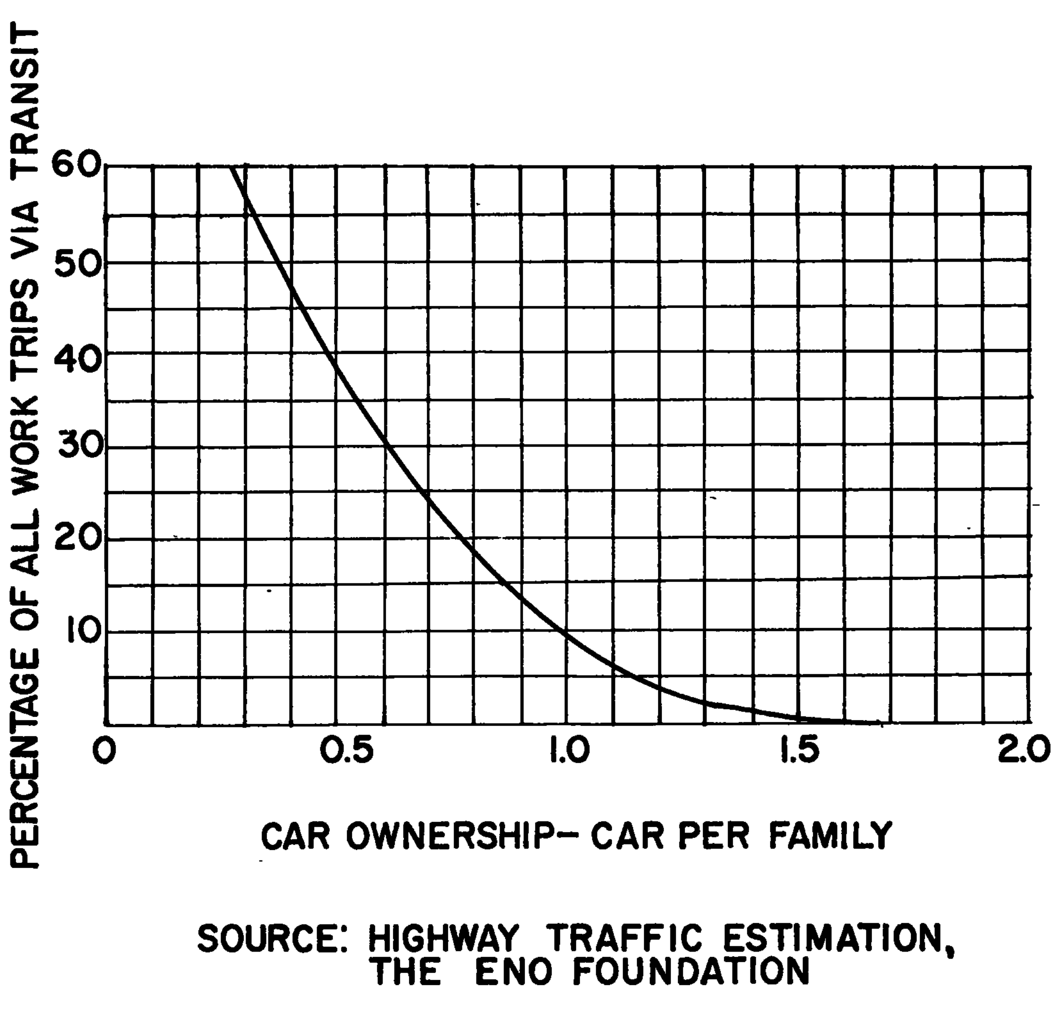


Figure 1. Relationship between transit usage and car ownership.

the number of transit work trips in residential areas was estimated by using the curve illustrated in Figure 1, which was based upon an analysis of 32 different O-D studies by the Eno Foundation. This estimate was then subtracted from the number of workers usually departing daily from a residential district by some form of transportation (85 percent of labor force) indicating the total number of persons traveling by private automobile. Using Figure 2, the number of persons per car was ascertained for each residential area. From these data, it was possible to compile the number of auto work trips starting from each residential area. To simplify computation, it was assumed all work trips would be returning home during the evening peak hour.

To keep the technique simple, only two types of transit trips were considered—work trips and miscellaneous trips. Since frequency of miscellaneous transit trips was assumed to be equal to that of work trips, it was possible to estimate all transit trips from Figure 1. The total number of transit travelers was calculated on this basis and was compared with the known number of transit trips for the area. (The estimate was within 10 percent of the actual, therefore no modifications were made.)

The foregoing steps established the mode of travel and the frequency of work, commercial, and social trips starting from a residential area. Non-home-based-trip frequency was developed in later stages of the procedure.

## Trip Destination

To evaluate destinations of residentially based trips, a gravitational principle was applied. Essentially, this principle states that all trips emanating from residential areas are attracted or "pulled" to various land uses. The strength of this pull is associated directly with the size of land use development and indirectly associated with the distance (or travel time) between the land use and the residential area (2).

Utilizing this concept for transit travel, transit time between zones was used; while auto-travel time between zones was applied for private-vehicle trips.

Transit users, of course, tend to adjust their traveling habits to accord with mass public transportation service. Travel time between zones depends upon transit service. The auto user, being more versatile, however, is influenced by the travel time

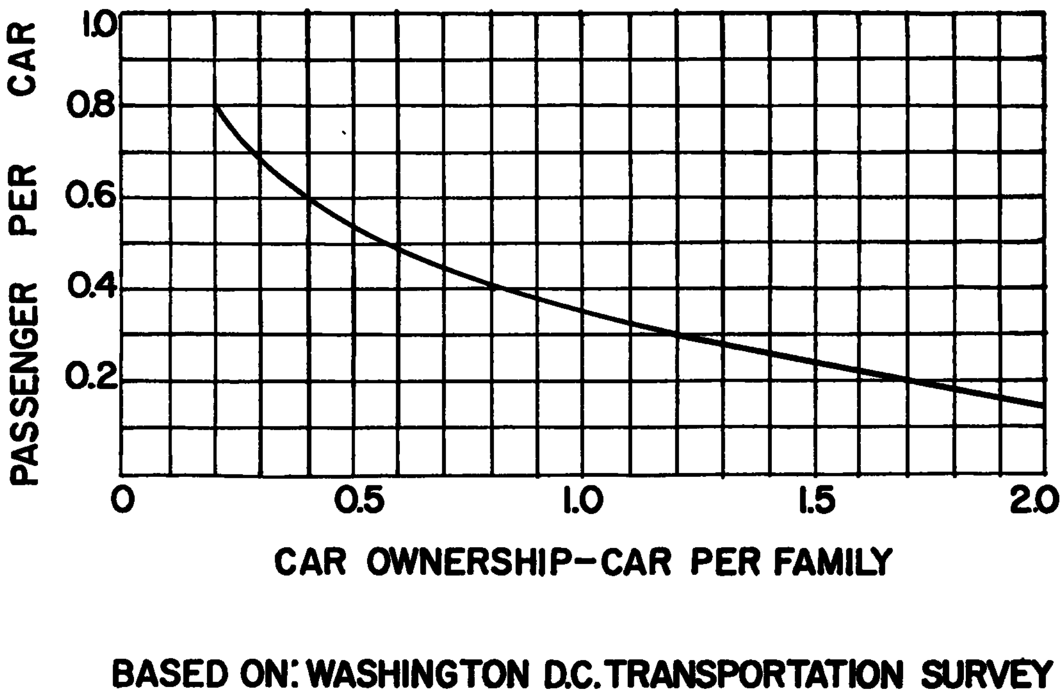


Figure 2. Relationship between passenger per car and car ownership.

permitted by the highway network. And, because most auto and transit travel occurs in the off-peak hours, midday hours were studied.

In selecting suitable factors to express the "size" of the attracting land use for work trips, the total number of people employed in each area was analyzed. For commercial trips, retail employment for each zone was examined to reflect the size of the attractor. This index was selected primarily as a matter of convenience, because the city planners had estimated retail employment in determining the number of workers employed in each zone. For social trips the number of people living in each area was chosen to indicate attractor size.

Working with employment statistics and population figures, it was easier to link the survey with the economic-base data for the area. From experience gained in Baltimore, it was judged that it is more effective to express the size of the attractor in terms of employment and population rather than in acreage of various land uses.

The influence of travel time on trip destination was measured by a series of factors shown in Table 1. (These travel-time factors are based on research that has shown that different factors are necessary for various trip types.)

TABLE 1

TRAVEL-TIME FACTORS

| Travel Time in minutes | Travel-Time Factors by Trip Purpose | | | |
|---|---|---|---|---|
| | Work | Social | Commercial | Non-Home-Based |
| 2 | 4.00 | 5.00 | 8.0 | 8.0 |
| 3 | 2.86 | 3.33 | 7.0 | 7.0 |
| 4 | 2.28 | 2.50 | 6.0 | 6.0 |
| 5 | 1 90 | 2.00 | 4.0 | 4 0 |
| 6 | 1.60 | 1.62 | 2.7 | 2.7 |
| 7 | 1.40 | 1 42 | 2.0 | 2.0 |
| 8 | 1.21 | 1.25 | 1.5 | 1.5 |
| 9 | 1.11 | 1.11 | 1.2 | 1.2 |
| 10 | 1.00 | 1.00 | 1.0 | 1.0 |
| 11 | .93 | .91 | .80 | .80 |
| 12 | 86 | .83 | .68 | .68 |
| 13 | .80 | .77 | 57 | .57 |
| 14 | .75 | .71 | .50 | .44 |
| 15 | .70 | .67 | .44 | .40 |
| 16 | .66 | .62 | .40 | .35 |
| 17 | .62 | .59 | .35 | 32 |
| 18 | .59 | .55 | .32 | .28 |
| 19 | .56 | 52 | .28 | .25 |
| 20 | .53 | .50 | .25 | .22 |
| 21 | .50 | .46 | .23 | .19 |
| 22 | .47 | .43 | .21 | .16 |
| 23 | .44 | .40 | .20 | 13 |
| 24 | .41 | .37 | .18 | .10 |
| 25 | 39 | .34 | .16 | .08 |
| 26 | .36 | 32 | .15 | .06 |
| 27 | .33 | .30 | .14 | .04 |
| 28 | .31 | .28 | .13 | .02 |
| 29 | .27 | .26 | 12 | .01 |
| 30 | .25 | .25 | .11 | |
| 31 | .23 | .23 | .10 | |
| 32 | .21 | .21 | .10 | |
| 33 | .19 | .19 | .09 | |
| 34 | .18 | .18 | .08 | |
| 35 | .17 | .17 | .08 | |
| 36 | .16 | .16 | .07 | |
| 37 | .15 | .15 | .07 | |
| 38 | .14 | .14 | .07 | |
| 39 | .13 | .13 | .07 | |
| 40 | .12 | .12 | .07 | |
| 41 | .11 | .11 | .07 | |
| 42 | .10 | 10 | .06 | |
| 43 | .09 | .09 | .06 | |
| 44 | .08 | .08 | .06 | |
| 45 | .07 | .07 | .05 | |
| 46 | 06 | .06 | .05 | |
| 47 | .05 | .05 | .04 | |
| 48 | .05 | .05 | .04 | |
| 49 | .04 | .04 | .04 | |
| 50 | .04 | .04 | .03 | |
| 51 | .03 | .03 | .03 | |
| 52 | .03 | .03 | .03 | |
| 53 | .02 | .02 | .02 | |
| 54 | .02 | .02 | .02 | |
| 55 | .02 | .02 | .02 | |
| 56-60 | .01 | .01 | .01 | |

The values of these factors reflects the best available data but certain judgment decisions had to be made to fill in gaps in available information (3). Such factors indicate the effect that travel time has on the frequency of trips between areas.

To illustrate the significance of these factors: an industrial zone two minutes from a residential area attracts four times as many work trips as a comparable industrial zone ten minutes distant (see Table 1).

Thus, to figure the destination of work trips starting in a residential zone, the appropriate time factor is multiplied by the number of people employed in various zones. Work trips are subsequently distributed to each employment zone in proportion to that zone's product and the sum of the product for all zones. (An example of this process is included at the end of this paper.)

The number of non-home-based trips beginning in each zone was computed by totaling social and commercial trips attracted to a zone after employing the gravity model. In figuring non-home-based trips over a 24-hour period, the number of trips attracted to a zone for commercial and social purposes was divided by three to conform to the frequency pattern already discussed. The number of peak-hour trips attracted to a zone was divided by eight. The resulting compilation indicates the number of non-home-based trips starting from each area. In estimating the destination of these trips, the proportion of trips attracted to each zone for commercial or social purposes was used to indicate the size of the attractor. The time factors applied are shown on Table 1.

The same general technique may be used in studying truck travel in an urban area. Other studies have shown that the non-home-based-trip pattern is fairly comparable to truck movement patterns in urban areas.

Work trips were brought into balance when the gravity model was put to use. If, in its application, too many trips were allocated to a particular employment center, they were adjusted to conform to the estimated number of auto and transit trips destined to a center. This was achieved by multiplying the trips to the center by an appropriate adjustment factor similar to that done in the growth factor technique. These corrective measures were applicable to work trips only.

To estimate the work trips destined to an area, it was assumed that transit usage, in an employment area of low car-ownership, would be high. On the other hand, in an area of high car-ownership transit travel would be low. Trip destination was estimated using this assumption. Therefore, without empirical evidence to the contrary, it was decided that Figure 1 could be used to reflect this relationship, and it was used as the basis for the necessary calculations.

The model was modified also for trips to the downtown area. It was adjusted for the difference in relationships between homes and employment of different occupational classes. From experience in other cities it would appear that this correction is necessary only for trips to the downtown area (1).

The correction for downtown trips was quite simple. It involved an investigation of the model's degree of error regarding downtown trips. (This was achieved by analyzing a previous transportation study for the CBD.)

## Checks

Though the techniques used in Baltimore were based on considerable research, it was considered prudent to make certain checks on the resulting estimates. The question was asked, "Is the traffic movement synthesized through this technique an authentic picture of the traffic actually developing on Baltimore's streets?" To answer this, four screen lines were created which divided the metropolitan area into large segments. Traffic was counted as it crossed these lines and compared with the traffic estimates obtained by using the model. As indicated in Table 2, the screen-line checks were usually within ten percent of the actual traffic counts. Moreover, similar checks were carried out for mass transit and the results indicate a comparable degree of accuracy.

In addition to screen-line checks, information was amassed on place of residence of employees in several industrial plants. This information was checked against estimates developed by the gravity model. As indicated by Table 3, the technique accurately portrays the proportion of trips within specific travel times of the employment area. In making this comparison on a zone-to-zone basis there was a greater deviation between the actual and theoretical estimate. For example, when zone-to-zone volumes were 100, the root-mean square error was around 50 percent; for volumes of 1,000, the error was about 20 percent; for volumes of 10,000, the error was in the neighborhood of 10 percent.[1] This series of checks indicated that the Baltimore traffic model error was about comparable to the statistical error that would result from a five percent home-interview study.

An interesting historical check was based on data from 1926, 1946, and 1958 studies which revealed home-work relationships. For this time span the gravity model was applicable if the appropriate travel time for each era was used, an especially extraordinary finding since travel times have changed drastically over the years.

## Projections

When it was agreed that this method could adequately synthesize existing travel,

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[1] Root-mean square error means that two thirds of the time this error will be less than specified.

TABLE 2

SCREEN LINE CHECKS OF THE BALTIMORE 1958 TRAFFIC ESTIMATES

| | 24 Hours | | | Peak Hour | | |
|---|---|---|---|---|---|---|
| Screen Line | Actual | Estimate | Estimate As Per Cent of Actual | Actual | Estimate | Estimate As Per Cent of Actual |
| A | 487,500 | 457,200 | 94 | 40,100 | 40,300 | 100 |
| B | 384,900 | 399,100 | 102 | 35,400 | 32,900 | 93 |
| C | 323,200 | 365,700 | 112 | 30,200 | 33,700 | 111 |
| D | 254,400 | 280,900 | 110 | 23,000 | 24,100 | 105 |

TABLE 3

COMPARISON OF ACTUAL AND ESTIMATED NUMBERS OF TRIPS, BY TRAVEL TIME FROM THREE MANUFACTURING PLANTS, BALTIMORE—1958

| | Percentages of Trips Within Time Periods | | | | | |
|---|---|---|---|---|---|---|
| Time of Trip | Westinghouse | | Bendix | | Glenn L. Martin | |
| in Minutes | Actual | Estimate | Actual | Estimate | Actual | Estimate |
| 0-10 | 42 | 37 | 32 | 29 | - | - |
| 0-20 | 64 | 60 | 74 | 76 | 24 | 17 |
| 0-30 | 82 | 78 | 94 | 94 | 71 | 64 |
| 0-40 | 97 | 98 | 100 | 100 | 93 | 94 |
| Over 0 | 100 | 100 | 100 | 100 | 100 | 100 |

the same general technique was used to project future travel. But in projecting future travel it was recognized that traffic patterns depend upon the transportation alternatives that are offered the public. Therefore, two general projections were made for 1980. The first was based upon a plan that called for extensive highway improvement with few transit changes; the second was derived from a plan that comtemplated several rapid transit lines and the completion of only the interstate highway systems.

The traffic projections for the first plan were based on the Regional Council's forecast of population and employment distribution. Car-ownership forecasting was carried out in several ways for comparative purposes. The method finally selected was based on a Bureau of Public Roads study. It showed that income of household and type of residential area had a direct bearing on the number of cars per household. The study also revealed an increase in car ownership for specific residential areas until the income level reached a range of from $8,000 to $10,000 per year. Beyond this range car ownership leveled off. This means that, in effect, there was a ceiling for car ownership for various types of residential areas (see Table 4). The number of cars expected to be garaged in each residential zone was estimated on the basis of trends of existing car-ownership patterns and anticipated income levels for various zones.

The existing travel times between zones were not used in projecting travel for the first plan; instead, travel times resulting

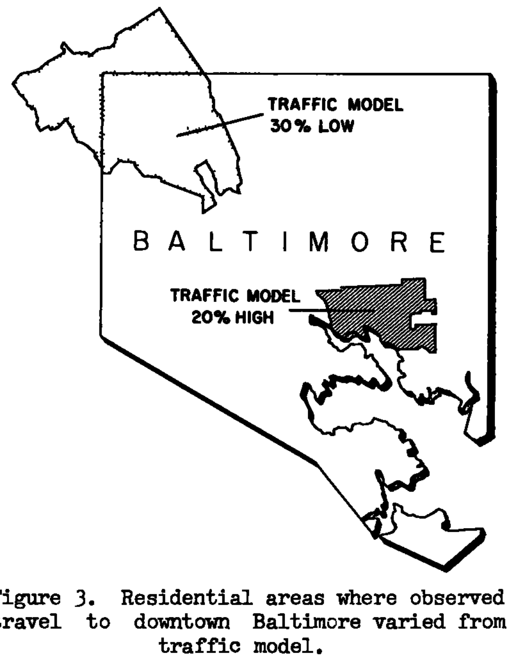



Figure 3. Residential areas where observed travel to downtown Baltimore varied from traffic model.

TABLE 4

CEILING FOR CAR OWNERSHIP PER HOUSEHOLD

| Residence Type | Autos Per Household |
|---|---|
| Single Family | |
| new area | 1.6 |
| old area | 1.0 |
| Two Family | |
| new area | 1.2 |
| old area | 0.9 |
| Row House | |
| good transit and poor parking | 0.4 |
| good transit and good parking | 0.6 |
| poor transit and good parking | 1.0 |
| High Rise | |
| good transit and poor parking | 0.2 |
| good transit and good parking | 0.4 |
| poor transit and good parking | 0.6 |

from the development of an extensive freeway system were employed. This was done to reflect the fact that improved highway facilities tend to increase travel length. In essence the traffic forecasts considered the effects of anticipated increases in population and employment, car ownership, and expected increases in auto speeds.

The traffic projection for the transit plan was accomplished on a somewhat similar basis. Car-ownership patterns in the vicinity of proposed rapid transit lines were adjusted in accordance with Table 4. The auto-travel times between zones reflected a more limited freeway system. Certain changes were made in the land use forecasts, specifically, a 20 percent increase in employment in the CBD.

By using these criteria, a new set of auto and transit patterns was formulated. However, it was recognized that a certain portion of the population would shift from auto to transit travel in the event rapid transit lines became a reality. The estimate of the volume of this shift to rapid transit was calculated with the aid of the curve in Figure 4. The curve was applied to only 75 percent of auto trips, that percentage of trips for which autos were not essential. Completing this step, it was possible to forecast the traffic and auto patterns for the second plan.

Example

To help understand the gravity model and to see how it can be employed to estimate traffic volume, the following example is given.

In Figure 5 the residential area designated R has 1,000 families within its limits. Each family has one car. There are three commercial areas in the vicinity $C_1$, a mile distant or 5 minutes away by auto with 100 employed in retailing activities; $C_2$ two miles away, or about 10 minutes away by car, with 200 retail employees and $C_3$ four miles away, or 20 minutes away by car, with 400 employees in retailing.

In line with previous discussion on commercial trip frequency, this would mean that 900 trips each day would start from the residential area R. On the basis of calculations shown in Figure 5, 360 trips would be made to $C_1$, 360 trips to $C_2$ and 180 trips to $C_3$.

Imagine, now, a new expressway that would enable residents to travel to $C_3$ in half the time, or 10 minutes. From the calculations shown, the 900 trips would be reoriented in the following manner: 225 to $C_1$, 225 to $C_2$ and 450 to $C_3$ resulting in 675 more vehicle miles or approximately a 40 percent increase. Furthermore, the new expressway would accommodate 270 additional vehicles and would increase traffic by nearly 150 percent.

Similar reorientation in traffic movement would be observed if a new shopping center or another type of land use were established in the vicinity.

## Benefits

As in a conventional type interview of O-D study, this study permits the analysis of several transportation alternatives. The use of a model allows more flexibility and greater opportunity to evaluate these alternatives.

The role of mass transit transportation was clearly defined by studying the two

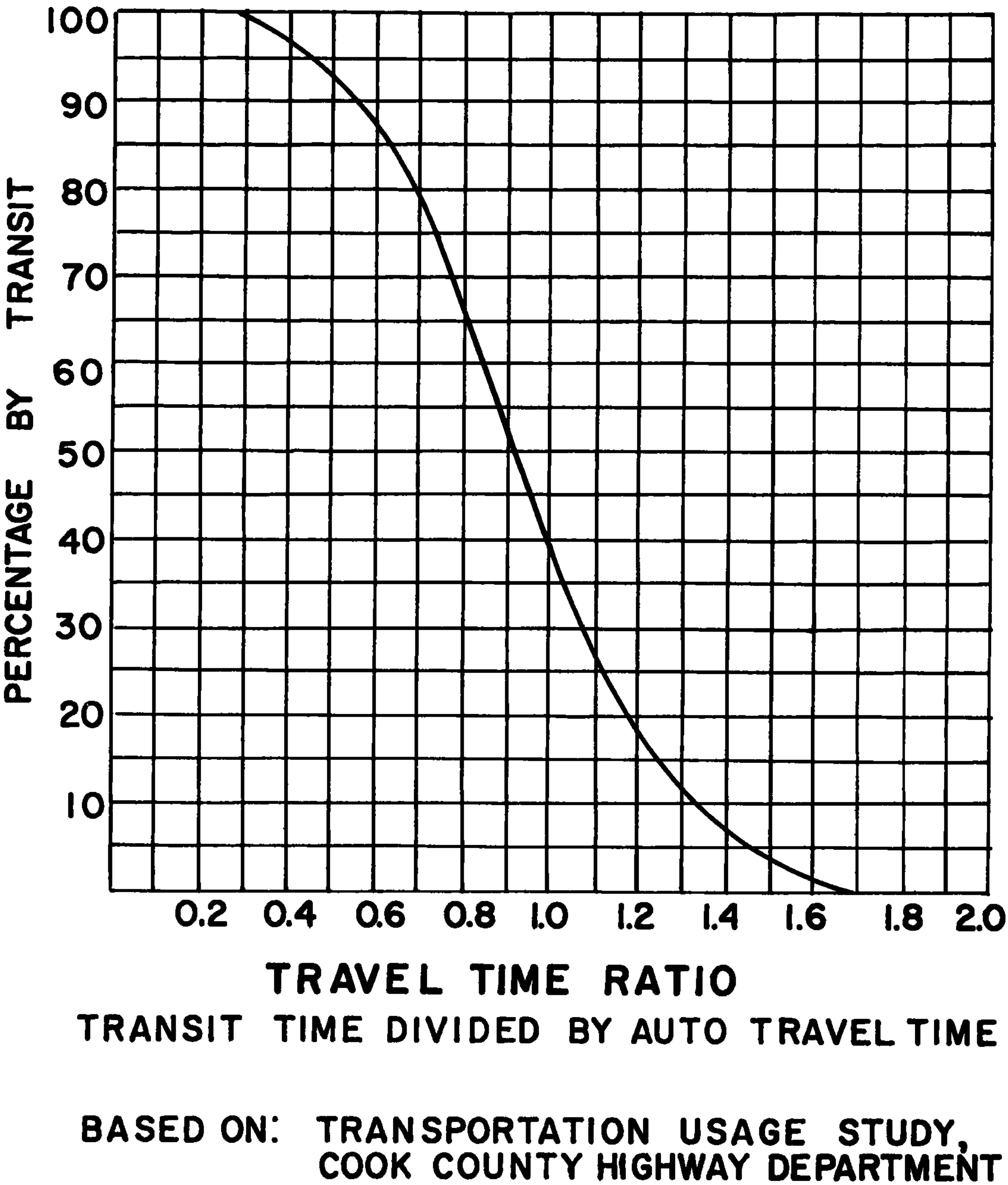
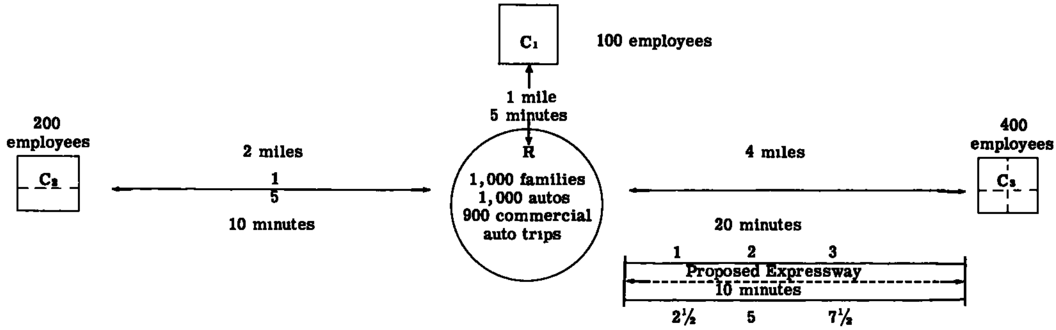



Figure 4. Transit assignment curve.




| Existing "Pull" | Travel Friction | % of Total "Pull" | No. of Trips | Vehicle Miles |
|---|---|---|---|---|
| from $C_1$ = 100 | 2.00 = 200 | 40 | 360 | 360 |
| from $C_2$ = 200 | 1.00 = 200 | 40 | 360 | 720 |
| from $C_3$ = 400 | 0.25 = 100 | 20 | 180 | 720 |
| Total "Pull" | = 500 | 100 | 900 | 1,800 |
| "Pull" after Expressway is Built | | | | |
| from $C_1$ = 100 | 2.00 = 200 | 25 | 225 | 225 |
| from $C_2$ = 200 | 1.00 = 200 | 25 | 225 | 450 |
| from $C_3$ = 400 | 1.00 = 400 | 50 | 450 | 1,800 |
| Total "Pull" | = 800 | 100 | 900 | 2,475 |

Figure 5.

alternatives mentioned previously. The survey revealed that Baltimore transit services, no matter how extensive, cannot be considered a substitute for highway improvements. Nor will they drastically reduce highway building requirements. These conclusions could not have been drawn without the use of a traffic model.

This mathematical model has provided Baltimore's planning staff with a clearer conception of the city's traffic problems and, further, has helped it to envisage the effect that land use arrangements have on traffic patterns. Factually, any type of land use plan can be evaluated with such a model, and it is possible to investigate many transportation alternatives and to decide on the one making most "transportation sense."

## SUMMARY

The use of mathematical models in highway planning work offers many advantages:

1. It assures better understanding of the factors that influence traffic patterns.
2. It also provides a better factual basis for plans, and permits more thorough testing and evaluation of alternatives.
3. By proper use of models, more realistic plans can be developed since it will permit one to analyze more effectively factors that influence traffic patterns.
4. Traffic models are low-cost (approximately $25,000 for the Baltimore study), technically simple and require only a limited staff.

The benefits that can accrue from application of mathematical models of this type certainly justify more exploration of these techniques. With the achievement of more effective mathematical models, urban highway planning will become a more exacting science.

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