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Trip Distribution in Subregional Analysis

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The paper describes the formulation and calibration of the access and land development trip distribution gravity model (ALDGRAV) for use in highway planning at a subregional level. The model is being used as an element of the thoroughfare analysis process (TAP), which, in turn, is one module of the thoroughfare planning system (TPS). TPS has been developed by the North Central Texas Council of Governments, in close cooperation with the local governments, to answer present planning needs, in particular to provide tools for orderly, inexpensive, and fast response evaluation of small- and medium-scale strategies. TAP provides the analysis capabilities of the system. The paper introduces the hierarchy of objectives, design requirements, and the resulting design decisions of TPS, TAP, and the ALDGRAV trip distribution model. A detailed description of the latter is given.

The North Central Texas Council of Governments (NCTCOG), together with the participating local governments, has developed the thoroughfare planning system (TPS). The system is designed to answer many of the recent needs in the field that have arisen primarily from shifting stress from large-scale, capital-intensive projects to subregional projects. Major objectives of TPS include providing tools for the planning of the principal and minor arterial network that supports the freeway system in the region and tools for evaluating projects such as the annual capital improvement programs of individual communities, on a local scale, and providing support, cost effectively, for the analysis of small- and medium-scale projects within the framework of the regional thoroughfare plan.

TPS is described in detail elsewhere (1). Its major elements include: (a) an approved regional thoroughfare plan complete with design standards, (b) a base inventory of the thoroughfare system with procedures for continuous updates, (c) a thoroughfare information system (TIS) that facilitates the storage and easy access of both inventory data and analysis results, (d) a thoroughfare analysis process (TAP) to evaluate the impact of alternative strategies, and (e) a methodology for evaluating transportation system management (TSM) strategies.

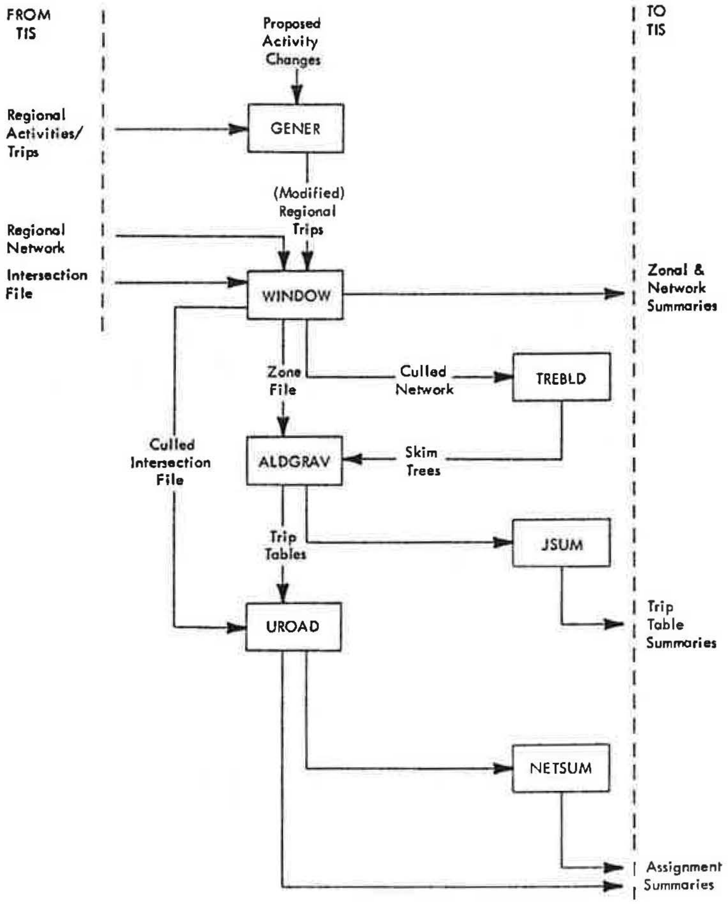
THOROUGHFARE ANALYSIS PROCESS

TAP is the travel simulation component of the TPS and has the following specific design requirements. It must be able to analyze a wide range of potential strategies, such as the effect of land-use changes (e.g., a new shopping center), the effect of major TSM strategies, and small- and medium-scale capital projects, and it should develop and maintain the regional long-range plan and analyze small-scale problems quickly and inexpensively. The structure of TAP is described in Figure 1. Its logic closely follows that of the conventional urban transportation planning system. Major innovations in the system include windowing and streamlined processing.

Windowing means that by using computerized procedures subfiles for analysis are built from base data files that describe the zones and networks of the region in much detail. Typically, these subfiles include detailed presentation for the area of interest; the level of detail decreases gradually with distance from the area of interest. Different subfiles are built for practically every analysis.

In streamlined processing, through both the selection of models and the use of computerized procedures, it is possible to go through the whole analysis process for one alternative in one or two computer jobs. At the same

Figure 1. TAP program sequence.



time, the user can easily change the structure of the process in response to special analysis requirements.

CONSTRUCTION OF THE TRIP TABLE

The procedure for constructing the trip table is a major part of TAP. It determines, to a large extent, the structure of the whole process in response to special analysis requirements. The following is a short description of the process as implemented. This description is followed by a discussion of alternative approaches and the reasoning behind the selected approach.

A major input to TAP is the zone data file, which includes (for each of the 7000 traffic survey zones) estimates of activity such as population, employment, service employment, and median income and productions and attractions of vehicle trips by five trip purposes. Such a file is prepared, externally to TAP, for each of the likely planning years, for instance, for each 5-year period until the year 2000.

Through the program GENER, the user can introduce changes in the activity measures for individual traffic survey zones. Using a combined trip generation, mode-split, and auto occupancy model, the program recalculates trip productions and attractions. Thus it is possible to introduce into the process and analyze the effect of proposed land-use changes.

The zone data file is then put into the program WINDOW. Depending on the user-specified window structure, WINDOW aggregates the zone data to form the zone structure used in the analysis. The resulting analysis zones might include individual traffic survey zones within the area of interest, with aggregation of the zones elsewhere according to a five-level hierarchy. Typically, 150 to 300 analysis zones are created by aggregating the original 7000 traffic survey zones. WINDOW also processes the network by culling links from the base network according to their importance in a five-level hierarchy and their distance from the area of interest. Next, the zones are connected to the network through approach links, or directly by load nodes.

Minimum impedance skim trees are built, using the program TREBLD. Trees are built on a prestressed network; i.e., speeds are calculated by considering average expected link volumes. The network might be prestressed to consider average daily loads and/or peak period loads. Impedance is calculated as a linear combination of time, operating costs, and tolls.

The trip file, together with the skim trees, is put into the program ALDGRAV for trip distribution. Trips are distributed separately by five trip purposes using the corresponding skim trees. A detailed description of the trip distribution process is given below.

By using the program UMATRIX, the purpose-specific trip tables are combined and, if necessary, transposed to create the final trip table. At this point, special trips (through and airport trips) are also added to the table.

MAJOR DESIGN CONSIDERATIONS

Trip Generation

It was possible, obviously, to make the trip generation model an integral part of TAP and to require as input only the estimated zone activity levels. This approach was rejected, because in the analysis of small-scale problems there is no need to repeat the entire trip generation for each analysis. Selective updates through GENER are sufficient for analysis of localized land-use effects.

Another major problem was the method for mode-split analysis (or, more accurately, the estimation of the number of auto person trips, given the number of total person trips). Available procedures for mode-split estimation are rather costly and require the input of skim trees by mode, as well as various zone data. It is clearly infeasible to go through such a process for the whole region for every analysis of a small-scale project. Thus, the base trip generation model includes a full mode-split analysis.

Mode split for activity updates (within TAP) is performed by using the resulting zone-split factors. It is implicitly assumed that in most projects of the type analyzed by TAP, system changes are not large enough to cause significant changes in mode split. Obviously, whenever this assumption is not justified, a full-scale mode-split analysis (outside TAP) has to be made.

Trip Distribution

Conceptually, it is possible to treat trip distribution in the same way as trip generation is treated, namely, to distribute the trips outside TAP and to aggregate the resulting trip table for each window. This approach has been rejected, since the cost of a 7000 × 7000-zone trip distribution would be prohibitive. Moreover, connecting the 7000 traffic survey zones to the network (for purposes of skim tree building) would result in an impossibly large network.

In TAP, trip distribution is done after constructing the window by using the 150 to 300 analysis zones typically resulting from the windowing phase. It is possible to use this approach only if the performance of the trip distribution model is not overly sensitive to area aggregation. Nihan and Miller (2) have shown that a properly formulated gravity model possesses this attribute. In a number of applications in New York it was shown that the ALDGRAV model, in particular, gives very stable results under a wide range of aggregation schemes. The ALDGRAV model and its use in TAP are described in detail in the following sections.

TRIP DISTRIBUTION MODEL

The trip distribution model used in TAP is ALDGRAV, a gravity model formulation adapted from the access and land development (ALD) model originally developed by Schneider (3, 4, 5) and further discussed more recently by Kaplan (6).

ALDGRAV Concepts

In TAP, the ALDGRAV model is used to distribute trips from production end to attraction end. Trip productions and attractions, for each traffic survey zone, are calculated apart from TAP and then aggregated according to the creation of analysis zones by program WINDOW within TAP. The trips are then distributed by the TAP version of ALDGRAV, which embodies the following basic assumptions.

1. Probability maximization is applicable to the distribution of trips;
2. For a given group of trip makers, the sensitivity of travel to the disutility is not a single value but ranges over a continuum;
3. The total disutility of travel, incurred by the trips produced from a given zone, must be finite; and
4. For a given zone, the input number of attractions is a surrogate measure of the attractiveness of that zone to trip makers.

The application of probability maximization, with the constraint implicit in assumption 3, yields the ALDGRAV model form. For a more rigorous discussion, the reader is referred to Kaplan (6), from which much of the ensuing discussion is also excerpted. The basic gravity model formulation may be expressed as

$$V_{ij} = V_i[G(F_{ij})A_j/\Sigma_r G(F_{ir})A_r] \tag{1}$$

where

V_{ij} = number of trips produced by zone i and attracted to zone j,
V_i = total number of trips produced by zone i,
$G(\cdot)$ = travel (decay) function representing the rate at which attractiveness declines with increasing travel disutility,
F_{ij} = disutility of travel from zone i to zone j, and
A_j = attractiveness (number of attractions) for zone j.

Equation 1 can be interpreted as a share formula that allocates the total productions from zone i, V_i, among alternative attraction zones, according to their relative attractiveness weighted by their corresponding decay values.

Specific gravity formulations are distinguished by different forms of the travel function $G(\cdot)$. Examples include

1. Inverse power function $G(F) = F^{-a}$,
2. Negative exponential function $G(F) = \exp(-aF)$,
3. Combined inverse power and negative exponential function $G(F) = F^{-a}[\exp(-bF)]$, and
4. Gamma density function, $G(F) = F^{a-1}\exp(-F)/\Gamma(a)$.

The travel function used in ALDGRAV is somewhat more complex than the above functions but can be related to the negative exponential function 2 as follows.

If basic assumption 2 is replaced by the simplified assumption of a single value, a, for traveler sensitivity, one derives the gravity model form (Equation 1) with negative exponential travel function 2. This model has been derived from entropy maximization principles by Wilson (7). However, the ALDGRAV formulation is based on the theoretically more complete assumption 2 that leads to integration over a range of sensitivity values and results in the gravity form with the ALDGRAV travel function

$$G(F) = K_2(2\sqrt{aF})/4aF \tag{2}$$

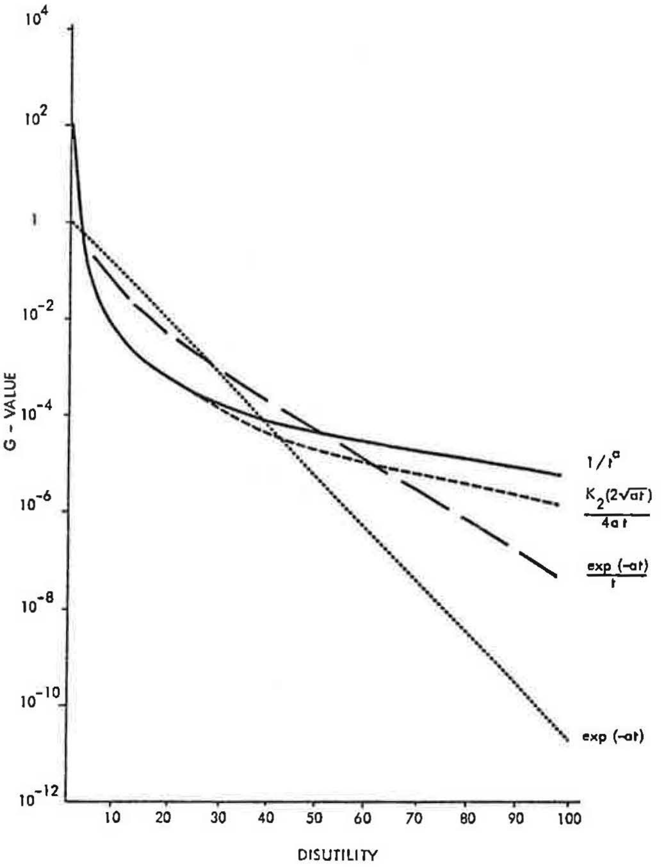
where K_2 is the modified Bessel function of second kind and second order, and a is a value representing an average traveler sensitivity.

For comparison, alternative travel functions are plotted in Figure 2. The value of the a constant was chosen to ensure comparability of the four functions, as follows:

1. $G(t) = t^{-a}$; $a = 2.625$,
2. $G(t) = e^{-at}$; $a = 0.260$,
3. $G(t) = \frac{e^{-at}}{t}$; $a = 0.143$, and
4. $G(t) = K_2(2\sqrt{at})/4at$; $a = 0.100$.

Regardless of the a-values, the Bessel function will always have a faster decay rate than the negative exponential at very small disutility values and a slower decay rate over large disutility values. No such general statement can be made about the comparison with the inverse

Figure 2. Comparison of alternative travel functions.



power or the combined functions.

In its application in TAP, the ALDGRAV model is doubly constrained; i.e., Equation 1 is iteratively adjusted to balance the trips received by each zone to the input number of attractions.

Travel Disutility

For interzone trips from zone i to zone j the travel disutility measure used in TAP is

$$F_{ij} = T_{ij} + TP(AT_i) \tag{3}$$

where

$T_{ij} = W_1 * t_{ij} + W_2 * c_{ij} + W_3 * f_{ij}$ is the total travel impedance from zone i to zone j,
t_{ij} = travel time from zone i to zone j,
c_{ij} = operating cost from zone i to zone j,
f_{ij} = tolls from zone i to zone j, and
W_1, W_2, W_3 = weighting parameters (uniform for the whole region).

$TP(AT_i)$ is a fixed penalty assessed according to the area type, AT_i, of zone i.

Conceptually, the fixed penalty reflects factors such as cost of owning the car, parking costs, and walking time from the parking to the final destination. The fixed penalty may have a different value for each of the four area types used in TAP (numbered by Urban Mass Transportation Administration (UMTA) convention and corresponding roughly to a trip-end density classification)

1 = Central business district (CBD) (20 000+ daily one-way person trip ends per square mile),
2 = CBD fringe (5000-19 999 trips per square mile),
3 = Suburban (1000-4999 trips per square mile), and
5 = Rural (0-999 trips per square mile).

For intrazone trips the calculation of travel disutility differs somewhat. Generally, intrazone travel time cannot be obtained directly from conventional skim trees. Within ALDGRAV, therefore, the intrazone travel time is estimated as a function of the radius of the zone. This quality is, in turn, divided by the intrazone speed to estimate the average intrazone travel time, to which the fixed penalty is added to yield the intrazone disutility. Note that, within TAP, the calculation of intrazone disutility is of special importance because of the large variations in zone sizes due to windowing. Proper calculation of the intrazone disutilities plays a major role in ensuring stable model performance under varying aggregation schemes.

A special treatment has been established for the distribution of external-local trips. These trips are somewhat unique, due to the fact that they are generally longer than internal trips and that only the within-region portion of these trips is described by the skim trees.

The fixed penalty (TP in Equation 3) can be interpreted, in the case of external trips, as the average impedance of that part of the trip outside the region. This interpretation is fully compatible with the theory of ALDGRAV. By treating the external-local trips as a special trip type, it is possible to assign to them an appropriate fixed penalty, as required.

Another unique attribute of these trips is that their distribution is not as dependent on the value of the intraregional impedance as that of the other trip types. Thus, in order to ensure their smooth distribution within the region, the trips are "flopped"; i.e., the internal end of the trip is considered the production end, while the external station is considered the attraction end.

Calibration of Model Parameters

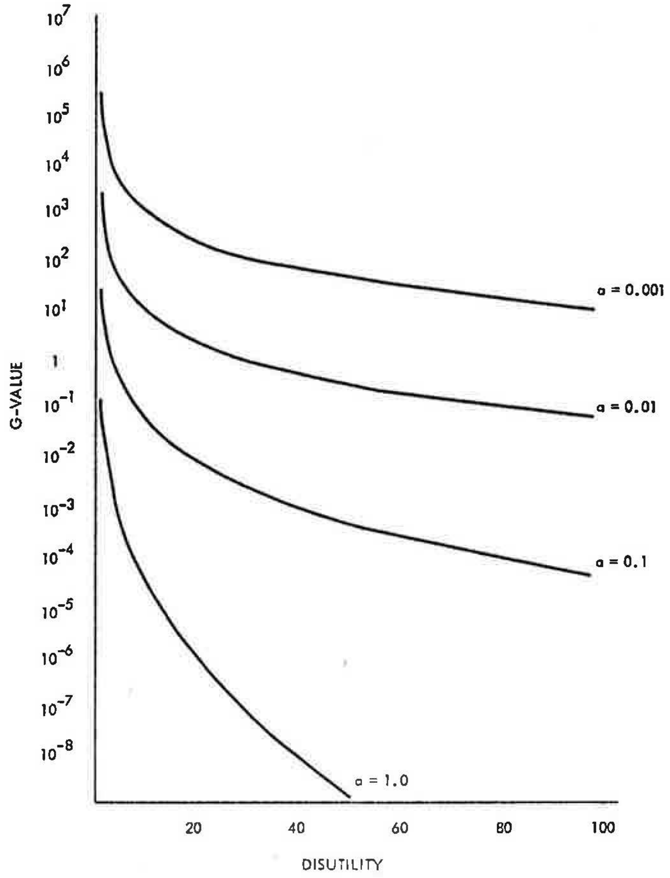
The ALDGRAV parameters requiring calibration, for use in TAP, are (a) the relative weights of the different impedance components, (b) the multiplier constant a, (c) the fixed time penalty TP associated with each area type, and (d) the average speed SI associated with intrazone trips within each area type. These parameters affect the simulation of trip distribution patterns through their effects on travel function and calculation of travel disutility.

Figure 3 shows how the shape of the travel function $G(\cdot)$ is affected by the value of a. With all fixed time penalties set at 0, an increase in a-value determines a sharper rate of declining attractiveness with increasing disutility and hence a shorter mean trip length (disutility).

Differences in mean trip length by area type can be simulated by adjusting the fixed penalty TP associated with each area type. Consider, in Figure 3, the curve associated with a = 0.001: the addition of TP to the disutility moves the ordinate to the right, i.e., shifts the curve to the left. Thus, the rate of decline in attractiveness becomes more gradual over the range of interest, and the mean travel disutility increases.

The a-value and the TP values determine the mean interzone travel disutility. With a and TP fixed, the intrazone speed, SI, can then be adjusted to determine the intrazone percentage of trips for each area type. By decreasing SI the intrazone disutility is increased, and hence the intrazone percentage is decreased. Adjustments in SI do not affect the interzone disutilities, F_{ij}, and therefore have no direct effect on interzone trip

Figure 3. G-values versus disutility by a-values.



lengths, although in practice the latter may be slightly affected because of the competition for trip ends implicit in the balancing of trips received with input attractions.

Calibration Procedure and Criteria

The calibration procedure is based on accurate approximations of observed average interzone trip length (or travel time) by area type and of the interzone percentage of trips, by area type. The rationale for these approximations is that vehicle kilometers of travel (VKMT), or vehicle hours of travel (VHT), by area type are thereby accurately approximated, since VKMT equals mean trip length times percentage of interzone times number of trips and VHT equals mean travel times percentage of interzone times number of trips.

As an additional check on the validity of the model parameters, of course, simulated and observed volumes are compared for closeness of fit, particularly on major interchanges.

The calibration itself is conducted in an essentially stepwise cut-and-try fashion. From an initial set of parameter values, the multiplier a is first adjusted to roughly approximate regional mean trip length (or travel time), but with allowance for adjustment within each area type. The fixed penalties, TP, are then adjusted to approximate the mean within each area type. Finally, the intrazone speeds, SI, are set to give the correct intrazone percentage. Although the effects of the parameters are interrelated, with the aid of manual calculations the calibration procedure thus organized can accomplish the basic criteria in three to five test runs.

CALIBRATION RESULTS

This section documents the calibration of ALDGRAV for distribution of vehicle trips in TAP for each of the following trip purposes: home-based work, auto driver (HBW); home-based non-work, auto driver (HNW); non-home-based, auto driver (NHB); truck and taxi (T&T); and internal versus external (I/E).

Calibration Results

The base data for calibration were taken from origin-destination survey data compiled in a 1964 home interview survey conducted in the Dallas-Fort Worth area. The trip data were redefined in production-attraction format and expanded to form vehicle trip tables for each of the five trip purposes. The zone structure used in calibration consists of 504 regional analysis areas (RAAs), plus 18 external stations. For analysis purposes, the RAAs are aggregated into 39 jurisdiction districts. The districts and external stations are shown in Figure 4. The calibration effort utilized travel-time skim trees compatible with the trip tables in zone structure, base year, and peak versus off-peak conditions.

Shown in Tables 1, 2, and 3 are the calibration results for HBW, HNW, and NHB trip purposes, which collectively constitute more than 80 percent of vehicle trips in the region. A comparison of observed and simulated trip patterns with respect to the basic criteria, interzone percentage, and average interzone time, is shown. Both observed and simulated trip tables were aggregated (squeezed) for comparison of district-district interchanges, and a classification of major interchanges by percent error is shown for each trip purpose. Also shown are the calibrated parameters.

To briefly evaluate the calibration results, the interzone percentage and the average interzone travel time have generally been matched quite closely, even when broken out by area type. For major interchanges, the accuracy summaries are encouraging, particularly in view of the fact that these results were obtained without the use of K-factors. (Aside from the usual questions of behavioral validity and temporal stability, K-factors present additional problems for planning with a flexible zone structure.)

The errors did not appear to be systematic except in the case of HNW and, to a lesser extent, NHB. For these trip purposes, the simulated within-district percentages tended to be lower than observed. As noted above, however, simulation results were accurate in the interzone percentages, as well as in the average interzone impedance. The implication is that there is a propensity, particularly in HNW travel, to go either to a neighboring zone or to a distant one, which is not fully captured in the model. In other words, for interzone trips, the observed impedance distribution curve is flatter, or less peaked, than the simulated curve. Possible solutions would be to go to a long and a short stratification (this creates problems in definition) or to separate home-based shopping from other HNW purposes. This is one of the issues to be addressed in future research.

NEED FOR FURTHER RESEARCH AND DEVELOPMENT

In spite of the generally satisfactory performance of TAP and its procedure for constructing trip tables in particular, there are still a number of areas where more study is needed and likely to be highly cost effective. The following list of subjects to be studied reflects our

Figure 4. District definition and external stations.

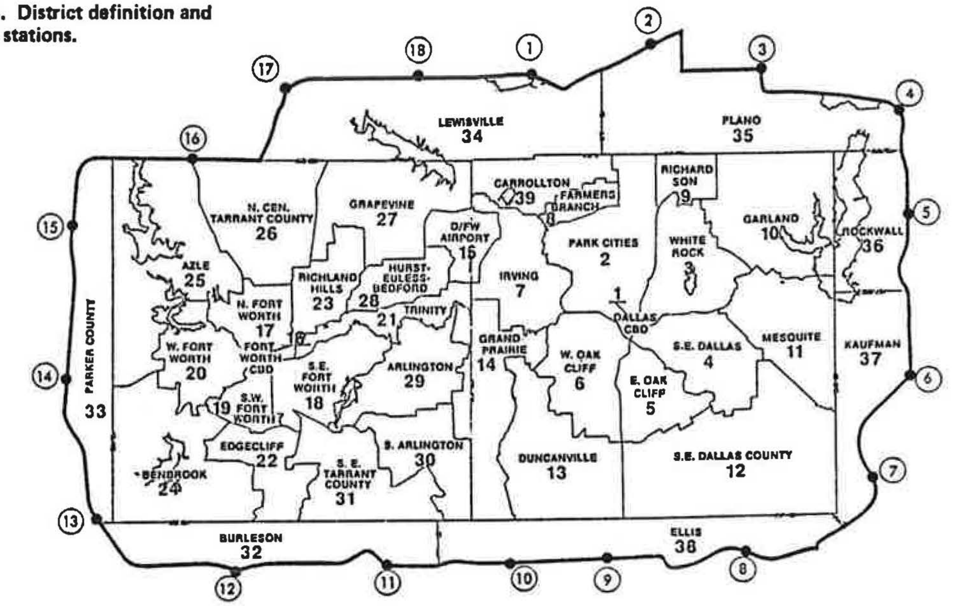


Table 1. HBW auto driver trips.

			Observed		Simulated	
Area Type	No. of Trips	Percentage of Total	Percentage of Interzone	Average Travel Time (min)	Percentage of Interzone	Average Travel Time (min)
1. CBD	1 748	0.2	100.0	8.9	98.8	8.2
2. CBD fringe	140 936	20.1	95.3	12.7	95.9	12.1
3. Suburban	514 652	73.4	92.6	16.5	93.1	16.6
5. Rural	44 184	6.3	79.4	24.2	84.8	24.2
Total	701 520	100.0	92.4	16.1	93.1	16.1

Note: Percentages of error for all district-district interchanges greater than 5000 trips were 0-10 for 14, 10-20 for 11, 20-30 for 5, 30-40 for 4, 40-50 for 0, and 50-60 for 1; the parameters used were a = 0.54 and SI 150 for TP 12, SI 400 for TP 12, SI 600 for TP 10, SI 600 for TP 3, and SI 600 for TP 3.

Table 2. HNW auto driver trips.

			Observed		Simulated	
Area Type	No. of Trips	Percentage of Total	Percentage of Interzone	Average Travel Time (min)	Percentage of Interzone	Average Travel Time (min)
1. CBD	3471	0.2	98.4	8.0	98.7	8.0
2. CBD fringe	295 006	17.0	79.5	9.7	82.4	9.2
3. Suburban	1 322 180	76.2	67.5	10.6	66.8	10.5
5. Rural	113 702	6.6	56.0	16.5	55.6	16.6
Total	1 734 359	100.0	68.8	10.7	68.8	10.6

Note: Percentages of error for all district-district interchanges greater than 10 000 trips were 0-10 for 9, 10-20 for 13, 20-30 for 3, but none above; the parameters used were a = 1.20 and SI 150 for TP 13, SI 420 for TP 5, SI 420 for TP 3, SI 500 for TP 0, and SI 500 for TP 0.

Table 3. NHB auto driver trips.

			Observed		Simulated	
Area Type	No. of Trips	Percentage of Total	Percentage of Interzone	Average Travel Time (min)	Percentage of Interzone	Average Travel Time (min)
1. CBD	76 582	8.5	98.6	11.5	96.1	11.3
2. CBD fringe	204 907	22.8	86.8	10.3	89.1	9.8
3. Suburban	586 337	65.1	75.9	11.6	76.2	11.5
5. Rural	32 688	3.6	57.6	17.5	58.2	17.5
Total	900 514	100.0	79.6	11.4	80.2	11.2

Note: Percentages of error for all district-district interchanges greater than 5000 trips were 0-10 for 16, 10-20 for 14, 20-30 for 11, but none above; the parameters used were a = 1.2 and SI 100 for TP 25, SI 450 for TP 9, SI 450 for TP 7, SI 550 for TP 2, and SI 550 for TP 2.

present major concerns; it is not intended to be comprehensive or exhaustive.

Multimodal Windowing

The extension of the present capabilities of TAP to multimodal analysis seems, naturally, to be the next order of business. The unimodal capabilities of TAP are clearly insufficient for modern planning. The problems of windowing for transit analysis might be rather complicated; specifically, the structure of transit networks will require more involved network culling techniques, compared to the techniques used for highway networks. Moreover, conventional mode-choice models are rather sensitive to area aggregation (because of the importance of access-egress impedance). They might perform poorly within the framework of windowing, where skim trees are available only for the aggregated zones, which might be rather large.

Trip Distribution for Microassignment

Within TAP, the ALDGRAV model produces trip tables that can be used for microassignment. In some instances, in order to attain sufficient precision in the microanalysis, analysis zones are very small, only a few blocks. There is, as yet, very little experience with the performance of ALDGRAV (and practically all trip distribution models) in such small-scale analysis. A careful study of this issue is much needed.

Need and Justification for Precision

There are a number of areas in which certain increases in the complexity and costs of the analysis might make the results of the analysis more precise. Examples include

1. Making the relative weights of travel cost and time a function of income in impedance calculations,
2. Relating fixed impedance penalties to measurable zone attributes such as cost and availability of parking,
3. Further stratifying home-based non-work trips to short and long in order to attain better duplications of observed trip-length distributions, and
4. Using a number of paths rather than only one path for calculating impedance (the ALDGRAV theory, for example, suggests that both the minimum time path and the minimum cost path should be considered).

In spite of the long experience in travel forecasting, it seems that these issues have never been studied thoroughly. Various assertions, based primarily on so-called behavioral and theoretical considerations, on these subjects have been made; however, there is a need to study these issues by comparatively analyzing them with observed data, as well as by weighing the potential increase in the precision of the results versus increasing the cost of acquiring data and the complexity of the analysis.

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Recent Structural and Empirical Findings in Trade-Off Analysis

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This paper reports on three recent investigations by the New York State Department of Transportation's Planning Research Unit into empirical and theoretical aspects of trade-off analysis, a multidimensional attitude scaling procedure. First, the possible influence of the length of the questionnaire was investigated. Fatigue bias was found to be substantial, and use of abbreviated questionnaires and a random order of items is suggested. Second, tests were made for a degradation in response accuracy, with substantially shortened questionnaires. No significant loss of information was found in reductions of up to 50 percent of a 10-matrix design. Third, the effects of different utility integration rules were studied. Some differences were found but they are too small to be of practical importance. The research concludes that the trade-off procedure is a powerful, robust approach that can be used with confidence.