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16. Abstract

This report presents the results of a pilot study to determine the utility of developing a particular travel forecasting technique. The technique in question is a gravity-based model which requires ramp volume data as inputs. The model is used to forecast ramp-to-ramp trip tables. The preliminary study indicates that this technique is sufficiently accurate to warrant further investigation.



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# USE OF VOLUME DATA TO REPRODUCE RAMP-TO-RAMP FREEWAY TRIP PATTERNS - A PILOT STUDY

by

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# Use of Volume Data to Reproduce Ramp-to-Ramp Freeway Trip Patterns - A Pilot Study

Introduction. The purpose of the 11 week pilot study sponsored by the Washington State Department of Transportation (WSDOT) was aid in the development and preliminary testing of an estimation procedure to reproduce ramp-to-ramp freeway trip matrices given freeway volume data. The pilot study was directed toward revising a preliminary experiment based on a subset of O-D data collected by the Highway Department in '69-'70 and using the revised approach for an additional experiment with another subset of the same data base. The study goal was determination of the utility of a full-scale development and verification project in this area and preliminary screening of alternative approaches to the representation of the larger network containing the study subsection(s).

State-of-the-Art. For the past few years there has been a surge of interest in the general problem of estimating a trip matrix for urban areas using street volumes as the primary source of knowledge. The problem is a difficult one. Since it is underdetermined, assumptions about trip characteristics must be made to provide additional constraints. Although several interesting approaches have been suggested, the problem remains unsolved. Willumsen (1) provides a good summary on the state-of-the-art in the general problem area. The major difficulties in solving the general problem are a) finding a unique trip matrix solution for a particular pattern of volume data and b) verifying such solutions given the general lack of reliable O-D data in most urban areas.

Unlike the general problem, the freeway problem lends itself more easily to model verification. Trip data are available in most urban areas for subsections of the freeway network. Thus any estimation procedure can be checked against existing data although the accuracy of the observed O-D data is dependent upon the collection method and must be viewed within this context.

The freeway problem is also easier to address than the general problem because of the natural constraints imposed by one-way corridor flows. Thus, in dealing with a restricted network of corridor flows, we avoid some of the problems created by the ubiquitous nature of vehicle travel. The natural constraints on freeway flows reduce the relative number of unknowns, although the problem is still underdetermined.

Although some work on estimating ramp-to-ramp trip tables from freeway volume data has been reported, the results in this area are inconclusive and the theoretical bases of the proposed methods are weak. The primary activity in this area comes from the developers of FREQ6PE (2), a combination traffic simulation and ramp control optimization model. This model requires an O-D matrix for every time interval (e.g. 15 minute intervals) for the period of study (e.g. peak hour period). A computer model called SYNOD (3) has been developed to synthesize the required O-D matrices. Basically it is a simple proportionality scheme that distributes off-ramp traffic to upstream on-ramps.

A major problem with the SYNOD approach is the fact that trip distance or travel time is not a direct factor in estimating trip patterns. Given the structure of the SYNOD approach one can expect significant errors in the form of overpredicting the number of very short trips and very long trips. The authors admit that the proportionality assumption is a crude approximation. In assessing the accuracy of their model they state that it "...does tend to distribute correctly 70-80% of the traffic in most cases...." The level of error in those 20-30% of the cases where the assignment is incorrect is not discussed. It appears, however, that these errors can be substantial.

<u>Description of the Proposed Estimation Procedure</u>. The proposed approach uses a gravity-based model synthesizing the desired O-D patterns. Ramps act as zone centroids (points of entry and exit to the network). Portions of the highway network leading into and out of the study subsection are treated as external

stations. Consider, for example, the hypothetical freeway network shown in Figure 1. In this network, each point of entry or exit is numbered. The symbol E is used to represent external stations. Assume we wish to predict the trip matrix for either the southbound or northbound position of the freeway contained within the dotted boundary line shown. This then is the study subsection. Figure 2 shows its representation for input to the gravity-based estimation procedure. Several major assumptions must accompany this approach in order to change the problem from an underdetermined one to a solvable one. Thus, the following decisions must be made in order to specify the model.

a) What travel propensity function should we assume?

b) Should the origins and destinations at the external stations (Figure 2) be treated as a probability distribution with respect to distance/travel time along the outlying network (Figure 1)?

c) How should such a distribution be calculated?

Although several forms of travel functions have been tested in the past, Voorhees (4) showed rather conclusively that the gamma function gave the best fit when calibrating models to generate total travel matrices. This would appear to also apply to freeway trip tables since one expects a unimodal function discouraging both very short and very long trips. The shape parameter, $\alpha$, was found by Voorhees to be approximately 1.5 for total travel in most cities. Since freeway travel can be expected to tolerate longer distances than other types of trips, one would expect that a distribution less skewed to the left would be appropriate. A preliminary value for $\alpha$ of approximately 3 is suggested. (Note: Our preliminary experiment described in this report indicated, as expected, that the restricted nature of the freeway problem allows some flexibility in the shape parameter. Values of $\alpha$ were varied from 2 to 4 with minor differences in the resulting trip table.) The size parameter, $\beta$, is equal to $\alpha/\bar{d}$ where $\bar{d}$ is the average impedance (e.g. distance or travel time)

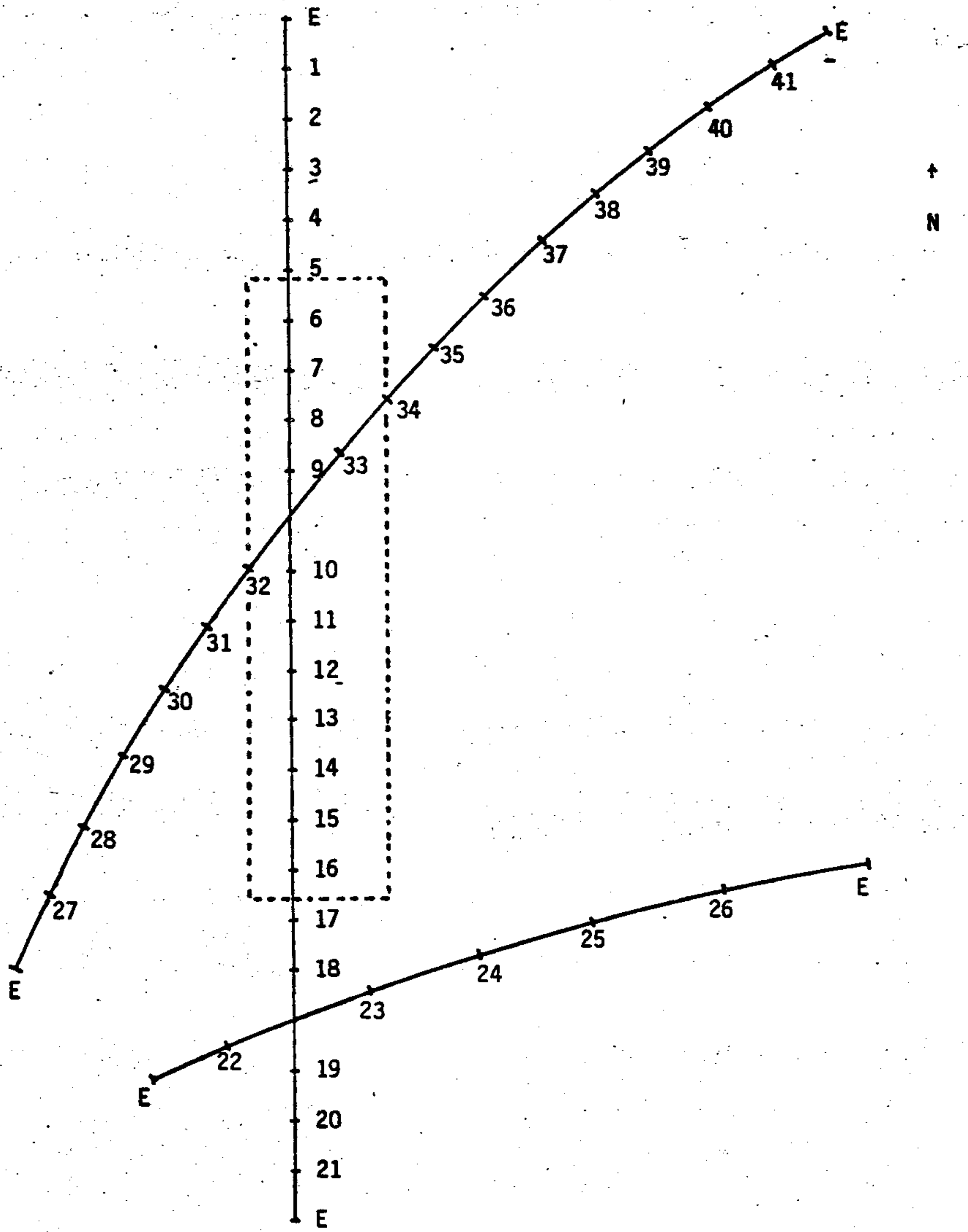


Figure 1. Hypothetical Freeway Network Section

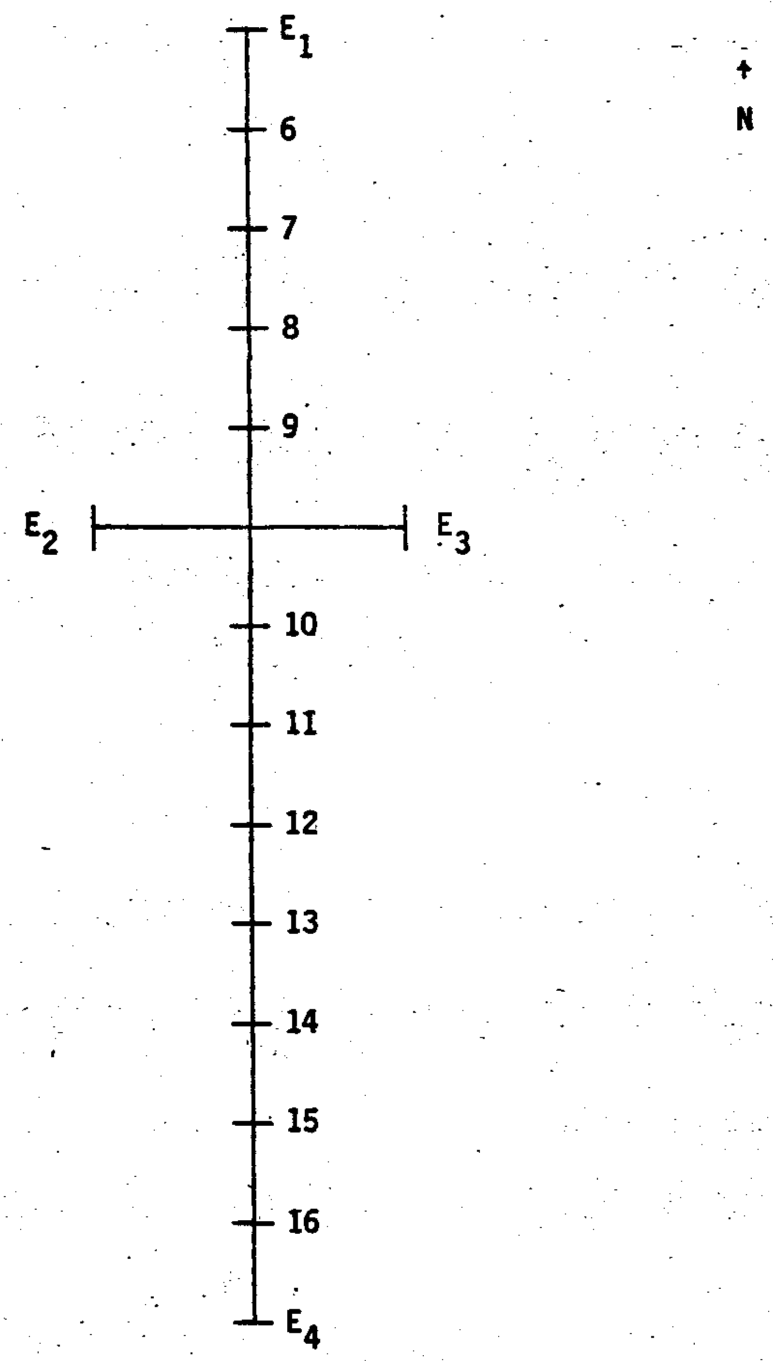


Figure 2. Hypothetical Study Subsection

for the network. Since we know the total number of trips and the link volumes and impedances this can be easily calculated.

Experiment Description. Two experiments were performed in this pilot study using 1969-70 peak hour data obtained from WSDOT for sections of the I-5 freeway. The study corridor for the first experiment included the southbound portion of I-5 beginning at the Boylston entrance ramp and terminating at the Corson exit ramp. Volume data for the evening peak period, July 1970 were used to develop the origin and destination inputs for a gravity-based model. An origin-destination survey was performed by the state highway department for the same time period. The resulting partial trip table from this O-D study is shown in Table 1.

There were three external stations representing respectively southbound flows originating upstream from the Boylston entrance ramp, southbound flows terminating downstream from the Corson exit ramp, and eastbound flows which take the Dearborn exit to the I-90 eastbound freeway. The volumes originating or terminating at an external station were assigned access distances to and from the network subsection according to a simple probability distribution. This probability distribution was based on the ramp volume data for the larger network containing the study subsection. Distance from origin ramp i to destination ramp j, $d_{ij}$, was chosen as the measure of travel impedance. A gamma distribution with $\alpha = 3$ and $\beta = \alpha/\overline{d}$ was chosen for the travel propensity function. Table 2 shows the trip matrix resulting from the preliminary model. Although the prediction is close for a majority of cells, there are still some interchanges that require better estimates. (We are assuming that a 10% error margin for all significant cells is the realistic goal of the proposed model, since the O-D survey itself is likely to have measurement errors in this range or even higher.)

OBSERVED SOUTHBOUND RAMP TO RAMP

TRIP DISTRIBUTION, 4:30-5:30 P.M., Summer 1970.

| | | 3 | 4 | 6 | 8 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | On SB \ Off SB | MERCER | STEWART-DENNY | UNION - 7th | COLUMBIA - JAMES | DEARBORN | AIRPORT WAY | FOREST ST. | SPOKANE ST. - COLUMBIA WAY | MICHIGAN - CORSON | ALBRO | E. MARGINAL WAY | EMPIRE WAY | INTERURBAN AVE. |
| 2 | BOYLSTON | 3 | 11 | 16 | 26 | 77 | 18 | 3 | 49 | 21 | 11 | - | 21 | 8 |
| 3 | MERCER | - | - | 7 | 15 | 205 | 5 | 2 | 51 | 22 | 59 | 41 | 91 | 15 |
| 5 | HOWELL | - | - | 19 | 9 | 260 | 9 | - | 232 | 59 | 94 | 25 | 113 | 41 |
| 7 | SPRING | - | - | - | - | 178 | 22 | - | 156 | 52 | 44 | 22 | 83 | 17 |
| 9 | 7th to C.D. | - | - | - | - | 209 | 3 | 6 | 221 | 51 | 78 | 32 | 112 | 15 |

TABLE 1

NIHAN - PREDICTED SOUTHBOUND RAMP TO RAMP
TRIP DISTRIBUTION, 4:30-5:30 P.M., Summer 1970.

| | 3 | 4 | 6 | 8 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 4 | 13 | 16 | 21 | 53 | 10 | 5 | 55 | 26 | 24 | 13 | 29 | 7 |
| 3 | - | 4 | 16 | 36 | 161 | 25 | 13 | 57 | 64 | 79 | 45 | 99 | 26 |
| 5 | - | - | 4 | 16 | 220 | 26 | - | 217 | 89 | 105 | 61 | 140 | 38 |
| 7 | - | - | - | - | 160 | 11 | - | 134 | 71 | 71 | 43 | 102 | 28 |
| 9 | - | - | - | - | 201 | 11 | 11 | 166 | 89 | 90 | 56 | 134 | 37 |

TABLE 2

The differences between Tables 1 and 2 are due, in part, to the fact that Table 1 does not contain noise-free data so a margin for measurement error must be allowed. Other factors might be that travel time may be a better measure of impedance and more importantly, lack of sufficient volume data on the rest of the freeway network forced a "guesstimate" for the Dearborn exit. We did not have volume data for the portion of the network leading out of the Dearborn external station. Thus an access distribution could not be calculated for this station and an average distance was used instead. Another possible source of error is the Spokane street exit. Since this exit is connected to the West Seattle Freeway (a bridge between West Seattle and I-5) it should probably be treated as an external station. In fact, it appears that the treatment of external stations will be the key factor in developing the estimation algorithm. These and other aspects will be investigated during the model development stage of any future project in this area.

All in all, the initial test indicates that even the first-cut model estimates better than the procedure currently being used to synthesize O-D tables. Table 3 shows the results of a trip table estimation using the SYNOD program described earlier. As hypothesized, this technique is less accurate, particularly with respect to overprediction of short trips. In all but a few cells, our preliminary model estimates are closer than the SYNOD estimates. Since the initial experiment used an area with a large number of unique problems, e.g. natural boundaries, 3 bridges connecting the external stations to the outer network, major attractors such as the Seattle Center and Kingdome, the results are certainly not to be generalized. Yet, this does seem to indicate that the research is worth pursuing.

The second experiment included estimation of northbound trips on the section of I-5 beginning at the South Center Parkway off-ramp and terminating at the Boyleston on-ramp. This time five external stations were required,

**SYNOD — PREDICTED SOUTHBOUND RAMP TO RAMP TRIP DISTRIBUTION, 4:30-5:30 P.M., Summer 1970.**

| | 3 | 4 | 6 | 8 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 40 | 44 | 15 | 18 | 39 | 6 | 3 | 36 | 13 | 13 | 8 | 18 | 5 |
| 3 | - | 123 | 49 | 59 | 124 | 20 | 10 | 114 | 43 | 41 | 24 | 59 | 17 |
| 5 | - | - | 84 | 100 | 211 | 34 | 17 | 194 | 73 | 78 | 47 | 111 | 31 |
| 7 | - | - | - | 76 | 160 | 26 | 13 | 147 | 55 | 52 | 31 | 75 | 21 |
| 9 | - | - | - | - | 229 | 37 | 20 | 210 | 79 | 75 | 45 | 107 | 30 |

TABLE 3

one representing flows from south of Tukwila, two representing east-bound and west-bound flows from and to I-405, one representing the flows entering at the Dearborn external station and one representing flows north of the Boylston on-ramp. Unfortunately, data were not available to obtain access distributions for any of these external stations and simple average distances were used instead. The results indicate that, as expected, the access distributions derived from volume data on the larger network containing the study subsection are necessary to obtain desired accuracy. As a comparison of Tables 4 and 5 indicate, the results for this second experiment were not as satisfying as those for experiment 1. Due to time limitations, we were unable to improve on this experiment during the pilot study. However, the results are useful in pointing out the importance of the treatment of external stations which supports our intuitive judgement.

Data Received for Future Experiments. During the course of this pilot study we have obtained several data sets for possible future tests of the estimation procedure. Other samples for the I-5 1969, 1970 O-D study have been received. The utility of these data sets in future tests depends to some extent upon the availability of ramp volume data for the I-90 corridor, the West Seattle corridor and the I-405 corridor. If reasonable estimates of these on/off volume data can be obtained, the probability distributions for the Dearborn and Spokane external stations can be calculated, thus providing a better test of the estimation procedure.

A newly collected O-D survey for a section of I-405 has also been obtained during this initial project (5). The 405 data looks promising for a truer test of model accuracy, since ramp volumes for a large section of the network containing the study subsection have also been provided. This will be the most likely data base for our next verification experiment.

OBSERVED NORTHBOUND RAMP TO RAMP
TRIP DISTRIBUTION, 7:00-8:00 A.M., Fall 1969

| | James 10 | Madison 11 | Seneca 13 | Olive Way 14 | Mercer 15 | Lakeview 16 |
|---|---|---|---|---|---|---|
| 1. South of Tukwila | 174 | 107 | 373 | 142 | 213 | 35 |
| 2,3. 405 EB & WB | 18 | 68 | 133 | 65 | 81 | 17 |
| 4. S. 154th | 76 | 15 | 59 | 36 | 33 | 2 |
| 5. Interurban Ave. | 16 | -- | 8 | 8 | 4 | -- |
| 6. Empire Way | 87 | 31 | 124 | 35 | 51 | 10 |
| 7. E. Marginal Way | 13 | 18 | 14 | 8 | 31 | 4 |
| 8. Albro-Swift | 43 | 33 | 141 | 44 | 55 | 8 |
| 9. Harney | 31 | 24 | 10 | 19 | 22 | 8 |
| 10. Columbian Way | 14 | 22 | 38 | 8 | 15 | 10 |
| 11. Spokane | 161 | 83 | 110 | 84 | 29 | 31 |
| 12. Dearborn | 147 | 470 | -- | 147 | 327 | 47 |
| 14. Cherry | -- | -- | -- | 2 | 15 | 4 |
| 15. University | -- | -- | -- | 2 | 4 | 4 |
| 16. Olive Way | -- | -- | -- | -- | -- | 8 |
| 17. Mercer | -- | -- | -- | -- | -- | 2 |

TABLE 4

NIHAN - PREDICTED NORTHBOUND RAMP TO RAMP
TRIP DISTRIBUTION, 7:00-8:00 A.M., Fall 1969

| | James 10 | Madison 11 | Seneca 13 | Olive Way 14 | Mercer 15 | Lakeview 16 |
|---|---|---|---|---|---|---|
| 1. South of Tukwila | 141 | 151 | 224 | 80 | 109 | 18 |
| 2,3. 405 EB & WB | 54 | 78 | 123 | 39 | 54 | 8 |
| 4. S. 154th | 20 | 22 | 33 | 14 | 17 | 3 |
| 5. Interurban Ave. | 18 | -- | 22 | 12 | 16 | 3 |
| 6. Empire Way | 110 | 120 | 191 | 74 | 106 | 19 |
| 7. E. Marginal Way | 25 | 28 | 44 | 17 | 25 | 4 |
| 8. Albro-Swift | 59 | 71 | 130 | 55 | 91 | 17 |
| 9. Harney | 36 | 44 | 81 | 39 | 60 | 14 |
| 10. Columbian Way | 10 | 14 | 33 | 20 | 33 | 9 |
| 11. Spokane | 60 | 67 | 131 | 79 | 132 | 36 |
| 12. Dearborn | 240 | 293 | -- | 165 | 243 | 43 |
| 14. Cherry | -- | -- | -- | 1 | 6 | 7 |
| 15. University | -- | -- | -- | 1 | 1 | 4 |
| 16. Olive Way | -- | -- | -- | -- | -- | 3 |
| 17. Mercer | -- | -- | -- | -- | -- | 1 |

TABLE 5

Conclusions. The pilot study provided useful information for the research design of a full scale study in this important area. First, the study results indicate that the goal of easy-to-obtain, reasonably accurate ramp-to-ramp trip estimates is reachable provided that sufficient network volume data exist for the desired time-period. The software developed during this project has convenient terminal access. The hand calculations required for the access distributions for external stations are simple and require about one-half person-hour for each data set. Other preparations include recording ramp volumes and distances along the freeway. These can then be entered directly by terminal and edited interactively. The computer cost for each run is insignificant, usually less than $1. If the computer cost of data set-up and editing are included the cost is still usually less than $10.

Other useful information obtained from the pilot study led to the following preliminary conclusions.

- The accuracy of this estimation procedure depends heavily on the treatment of external stations.
- Access distributions rather than average access measures must be used for external stations.
- The estimation procedure appears to be more accurate than current estimation procedures, although this requires further testing.
- Use of separate impedance functions for external-interval and internal-interval trips should be investigated in future studies.

In summary, the pilot study provided a helpful basis for future research in this area. The estimation procedure appears to be simple and practical enough to warrant further development. Questions regarding its expected accuracy could not be answered in such a limited study, but indications are that this technique may prove to be more accurate than existing procedures. This remains to be seen.

## DEFINITION OF TERMS

Access Distribution - A probability distribution of the random variable, $d_E$ (distance to or from an external station).

Centroids - Points of access to or egress from the study network. In our case these are ramps or external stations.

External Stations - Centroids on the boundary of the study network representing trips originating or terminating outside the study boundary.

Gamma Distribution -

$$F_{ij} = \frac{\beta^{\alpha}}{\Gamma(\alpha)} d_{ij}^{(\alpha-1)} e^{-\beta d_{ij}}$$

where

$\alpha$ = shape parameter

$\beta$ = size parameter

$d_{ij}$ = distance between i and j

$i$ = origin centroid

$j$ = destination centroid

Gravity Model - the solution to the two equations

$$T_{ij} = \frac{O_i X_j F_{ij}}{\sum_j X_j F_{ij}}$$

$$\sum_i T_{ij} = D_j$$

where

$X_j$ = unknown normalizing parameter determined through an iterative solution procedure

$O_i$ = origins at centroid i

$D_j$ = destinations at centroid j

$F_{ij}$ = travel propensity factor for the ij pair

$T_{ij}$ = trips from i to j

Impedance - A variable measuring resistance to travel, usually distance, travel time or travel cost.

O-D Data - Origin-destination data, i.e., the observed trip table.

Probability Distribution - The set of probabilities associated with different possible values of a particular variable, such as distance to an external station.

Travel Propensity Function - An inverse function of the impedance between two centroids. Commonly used are

$$F_{ij} = \frac{1}{d_{ij}^{\beta}} \quad \text{or} \quad F_{ij} = e^{-\beta d_{ij}} .$$

The gamma function was chosen for this study.

Trip Matrix or Trip Table - The set of values of $T_{ij}$ for all i and j centroids.

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