# A Critical Analysis of an Origin-Destination Survey

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•CAN a standard home interview O-D survey yield a pattern of movement which appears to be illogical? Can an abstract theory produce a pattern of movement which is more logical than that reported by an O-D survey? This paper examines the work-trip and shopping-trip patterns found in the 1957 O-D survey of the Cedar Rapids-Marion area of Iowa, and compares movements predicted by the author's field theory of movement with those found in the O-D survey and those simulated by application of a gravity model. The results of the study cast some doubts upon the validity of this particular O-D survey, and may raise further questions about all such surveys.

## CEDAR RAPIDS-MARION O-D SURVEY

The Iowa State Highway Commission conducted a home interview O-D survey of Cedar Rapids and adjacent Marion during 1957. Figure 1 shows the area and the O-D zones. Every seventh household was interviewed, and the external cordon was established essentially at the combined corporation lines of these contiguous cities. The results of this study, combined with land-use and travel-time data, were used to create a gravity model of the area. This model, in turn, was used as the basis for predicting future movements in seven Iowa cities (6).

Wiant (6) reports that the gravity model was created in the following way:

> Work trip production was related to the labor force residing in each zone. In calculating the number of auto-driver work trips originating in any zone, adjustments were made for transit riders and auto passengers. Zonal employment data were the basic attraction factor for work trips. Other home base trip production was directly related to car ownership and the zonal attraction factor used for this trip purpose was population plus 25 times retail employment. ... Factors were also derived from the Cedar Rapids data to describe the relation of travel time and trip frequency.
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> After "weighting" the model to reflect the true interchange of Cedar Rapids-Marion trips, the traffic model desire line volumes were compared to their home-interview counterparts.

Data on places of residence, employment, and retail trade were supplied to the Iowa State Highway Commission and to the author by the City Planning Commission of Cedar Rapids. Table 3 (Appendix) gives this information, together with coordinates of the centers of activity as selected by the author.

### The Field Theory of Movement

The field theory of land use and the movement of people relating to work trips has been presented (3), and may be expressed

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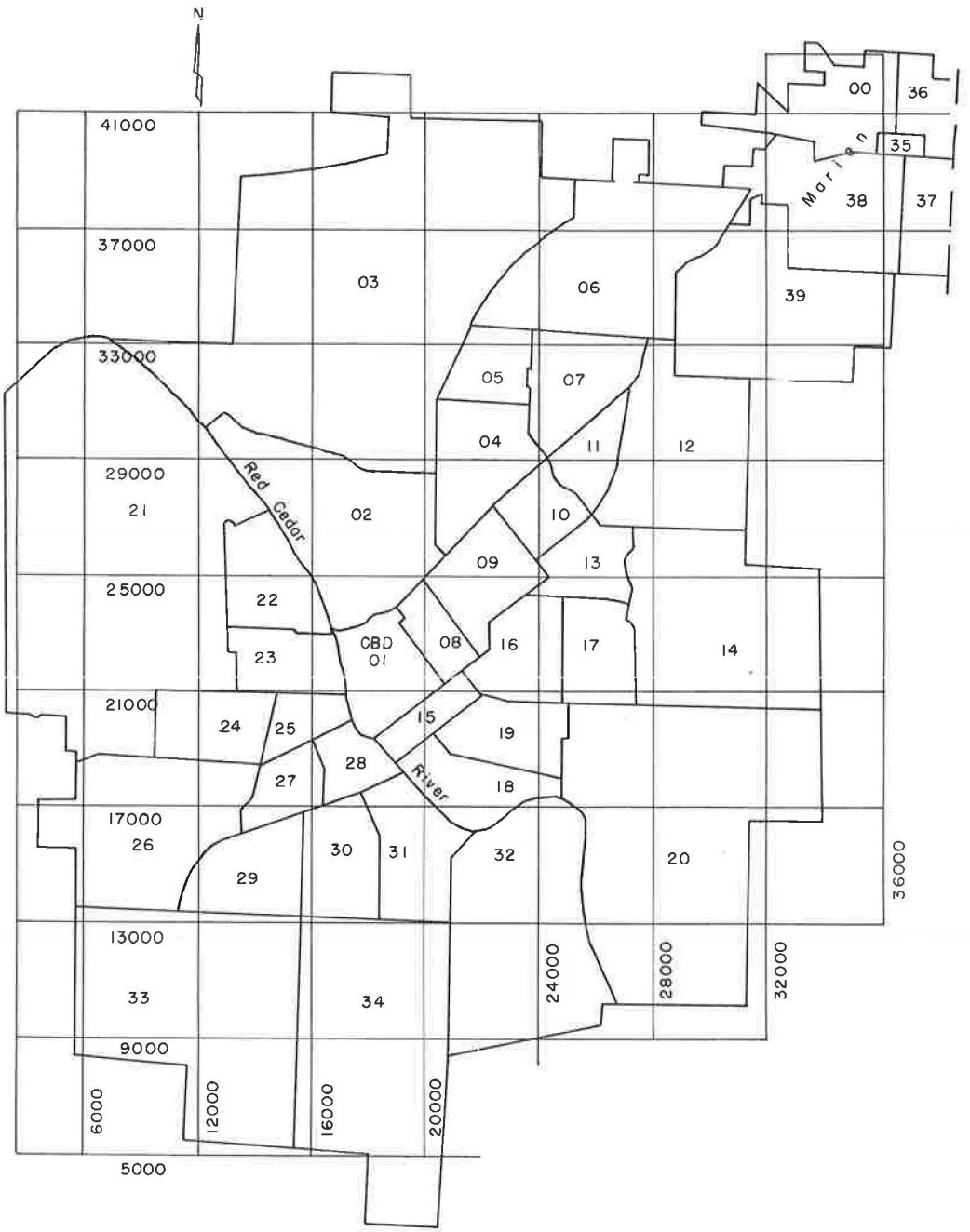


Figure 1. O-D zone map of Cedar Rapids, Iowa.

$$V_{P_iQ_j} = \frac{\frac{Q_j}{R_{ij}} P_i}{\sum_{j=1}^{m} \frac{Q_j}{R_{ij}}} \quad (i = 1, 2, \ldots n) \tag{1}$$

in which

$V_{P_iQ_j}$ = number of one-way work trips from i to j;
$P_i$ = number of workers living in zone i;
$Q_j$ = number of jobs available in zone j; and
$R_{ij}$ = straight-line distance between centers i and j, assuming that there are no physical barriers.

After applying certain balancing iterations, the (n × m) solutions of Eq. 1 will draw the correct total number of workers from each zone of residence and will assign the correct total number of workers to each job site.

A thus-far unreported aspect of the field theory relates to the prediction of shopping trips. Based on the following assumptions:

1. Every household makes a certain average number of shopping trips each day (in particular, one such trip each day will be used for present purposes);
2. The number of retail employees at each shopping center provides a measure of the relative attractiveness of each center; and
3. The straight-line distance between a center of residence and a center of shopping is the proper measure of separation.

The field theory for shopping trips may be expressed

$$M_{H_iS_j} = \frac{\frac{E_j}{R_{ij}} H_i}{\sum_{j=1}^{m} \frac{E_j}{R_{ij}}} \quad (i = 1, 2, \ldots n) \tag{2}$$

in which

$M_{H_iS_j}$ = number of one-way shopping trips from i to j;
$H_i$ = number of households in zone i;
$E_j$ = number of retail employees in zone j; and
$R_{ij}$ = straight-line distance from i to j.

Successive applications of Eq. 2 for i = 1, 2, etc., will assign each household to move to one center of shopping, but will not control, in any way, the total number of shopping trips destined for any center. Since it is a common phenomenon to find certain shopping centers more crowded than others, and since such centers do expand and contract to meet long-term trends in business, it appears obvious that the shopping trip pattern lacks the balancing restraints imposed on work-trip patterns. The number of retail employees in a center seems to be the only logical measure of relative attraction since this quantity is most easily varied to meet short-term changes in demand. Further discussion of these points will be found elsewhere (2).

## PHILOSOPHIES BEHIND O-D SURVEYS, GRAVITY MODELS, AND FIELD THEORY

Caution is the order of the day when one is tempted to say that a new theory gives more reliable results than an established empirical solution to a problem. In previous

applications of the field theory, reasonable comparisons to O-D findings were obtained, but in the present study several major discrepancies were found. Before proceeding, therefore, it may be well to reconsider briefly the philosophy behind each of the three methods of determining trip patterns.

Home interview O-D surveys determine the trips made by a sample of households on a particular day. Normally only vehicular trips are recorded, i.e., auto driver, auto passenger, and mass transit, as was the case in Cedar Rapids. The sample findings are then multiplied by a factor (in Cedar Rapids, 7) to get a representation of the total pattern of movement with a certain expected probability of error. For example, if the expanded volume for a certain movement is 100 trips, two-thirds of the time one must expect that the actual number of trips making this movement is between 70 and 130, while the remainder of the time the error must be expected to be larger (7). Since walking trips are ignored the possibility exists that many intrazonal trips, and perhaps trips between adjacent zones, are not reported. A person who drives to work and stops at a store to shop on his way home will be considered to have made one of the following two sequences of trips: (a) home to work; work to shopping; shopping to home, or (b) work trip; non-home based trip; shopping trip, depending on the nomenclature being used. Finally, the results of an O-D survey are supposed to represent movements on a "typical day," even though the data may have been gathered over a period of six months or more.

Since 1955, several attempts have been made to fit gravity models to the results of O-D surveys in the hope that such models might be used to extrapolate the findings of the corresponding surveys to future land-use patterns in the study areas (1, 5, 6). The only theoretical justification offered for such action has been that some combination of coefficients, exponents, and adjustments applied to a particular formula permits the calculation of simulated movements which one is willing to say approximates the findings of a corresponding O-D survey. In the Cedar Rapids study, home to work, other home based, and non-home based trips were simulated by such models.

In contrast to the above empirical approaches, the field theory assumes that, for some unknown reason, people move between centers of activity in accord with "laws" similar to those which govern the movement of various types of particles in physical "fields of force." Eqs. 1 and 2 make no attempt to say which persons will make which trips. Based on such assumptions as outlined, these equations yield the relative probabilities of their respective types of movement without regard for mode of transportation. In three previous studies, in which only work trips have been simulated, the theory has yielded results which have been at least consistent with the results of corresponding O-D surveys (2, 3, 4). One limitation on the theory is that it can deal only with a closed field, and cannot simulate trips across an external cordon.

This paper grew out of an attempt to simulate the work-trip pattern found by the O-D survey of Cedar Rapids by means of the field theory. When it was found that the results of the theory did not, in general, compare favorably with the results of the survey, both sets of data were examined in considerable detail in an effort to find the cause or location of the major discrepancies. The balance of this paper presents evidence on which the following question may be answered: Can something as abstract as the field theory create patterns of movement which are more reliable than those found by an origin and destination survey?

## WORK TRIP PATTERN IN CEDAR RAPIDS-MARION

Eq. 1 was applied, together with three iterations, to simulate a pattern of work trips. Every worker was assigned to a job site within the external cordon, and every job was filled by a worker living within the cordon. Minor adjustment had to be made in the total number of workers and total number of jobs as given in Table 3 (Appendix). Table 4 (Appendix) gives both the total number of workers drawn from each zone of residence and the total number of work trips assigned to each job site by the theory, by the O-D survey, and by the gravity model. (Detailed movements found by the O-D survey and by the gravity model were supplied by the Iowa State Highway Commission.)

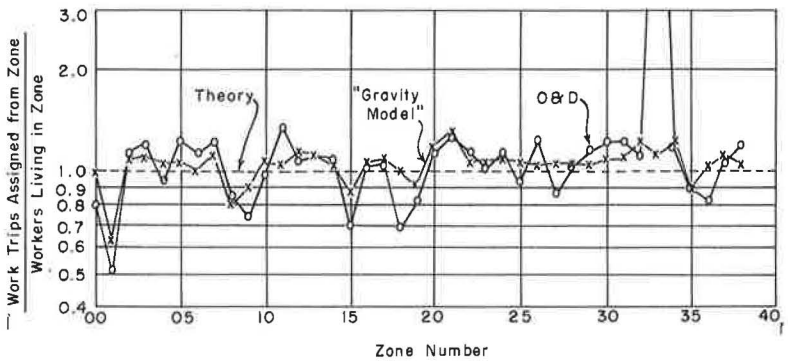


Figure 2. Ratio of work trips by zone of origin.

Figure 2 is based on the data of Table 4 and shows the average number of work trips per worker originating in each zone of residence as found by the three methods of determining movement. Figure 3, also based on Table 4, shows the average number of workers assigned to each job in each zone of employment. In both figures, the average number of workers is plotted logarithmically to indicate that the assignment of 2 workers to a job is an error equivalent in magnitude to assigning ½ worker to a job.

In all of the analyses which follow, gravity model results will be shown in figures, but no comments will be made concerning them.

Where Figure 2 shows ratios greater than unity it would seem that some workers make more than one trip from home to work each day. Such a situation would actually occur if various numbers of workers go home for lunch. Where less than one work trip per worker is made, the zone may have (a) a high rate of unemployment (although it is assumed that Table 3 contains the number of workers actually employed), or (b) a high rate of absenteeism (although the O-D survey is supposed to represent a "typical day"), or (c) a large number of workers who walk to work and are, therefore, of no interest in an O-D survey.

Figure 3 indicates that certain zones were found by the O-D survey to attract more work trips than there are jobs available in those zones, but again trips to eat lunch at home may account for this. Unusually high absenteeism on a "typical day," or workers walking to their jobs would seem to be the only explanations for those zones which appear to attract less than one work trip per available job.

While the field theory, as applied in Figures 2 and 3, creates one work trip for each worker and for each job, if the trips to home for lunch are an important factor in the traffic pattern, the theory can handle them easily. The number of workers living in each zone who go home for lunch can be added to the number of workers living in the

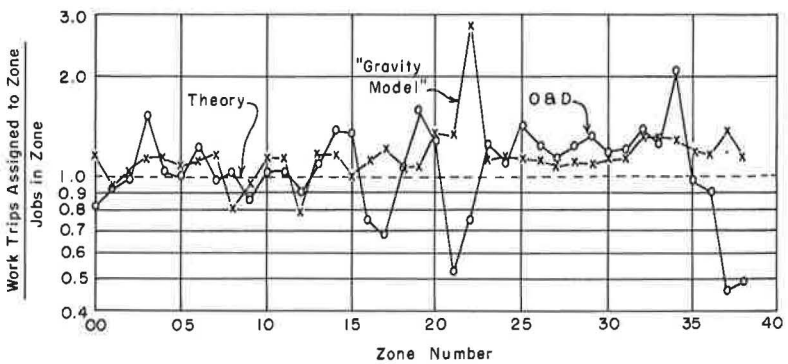


Figure 3. Ratio of work trips by zone of destination.

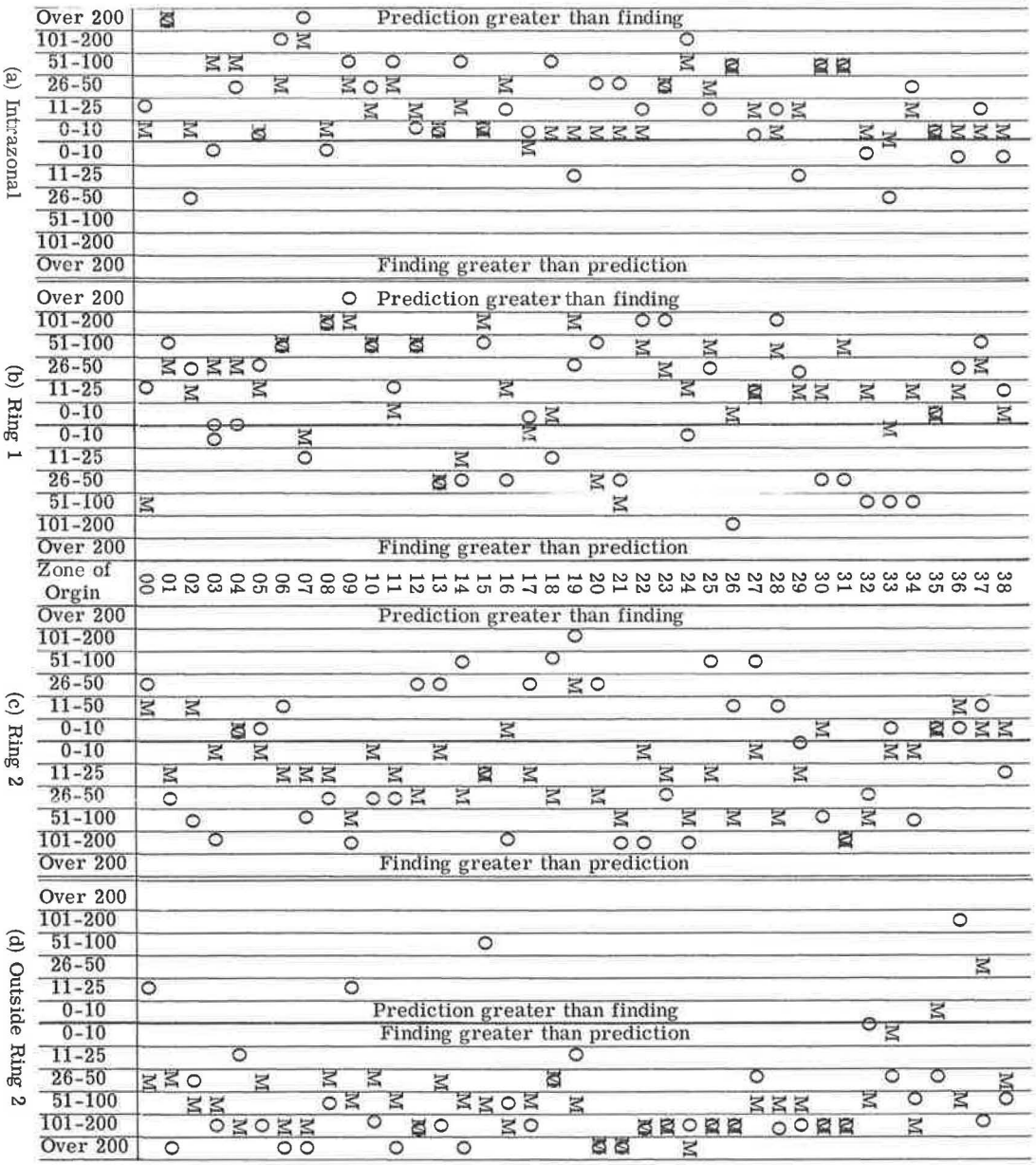


Figure 4. Discrepancies between work trips assigned by theory and found by O-D survey (O) and gravity model (M).

zone, and the number of workers leaving each job site to go home for lunch can be added to the number of jobs at the site to get modified values for P and Q in Eq. 1.

Figures 2 and 3 deal only with the total work trip pattern and do not take into account the possible effects of variations in lengths of work trips. Figure 4, by contrast, is a form of frequency diagram for the distribution of discrepancies between theory assignments and O-D findings of work trips from each zone of residence to four regions of employment. These regions are (a) the zone of origin, i.e., intrazonal; (b) those zones which abut the zone of origin, Ring 1; (c) those zones which are adjacent to Ring 1, called Ring 2; and (d) all other zones, called Outside

Ring 2. For example, Figure 1 shows that zones 03, 04, 06, and 07 form Ring 1 for zone 05, and that zones 00, 02, 09, 10, 11, 12, and 38 make up Ring 2, therefore, all other zones, except 05 itself, are Outside Ring 2. Each part of Figure 4 shows the approximate magnitude of any discrepancies which may exist, and whether the theory or O-D survey gives the larger total movement. Figure 4 (a) shows that in 32 of the 39 zones the theory predicted more intrazonal trips than were found by the survey. Figure 4 (b) shows that in 23 cases the theory assigns more workers to Ring 1 zones of employment than does the survey. Figure 4 (c) indicates that the theory and O-D survey each assigns more than the other in 19 cases, or what one might expect if the theory and survey gave reasonably comparable results. Finally, Figure 4 (d) indicates that the O-D survey, in general, assigns far more workers to job sites Outside Ring 2 than does the theory. In summary, Figure 4 shows that the O-D survey found many more long work trips and many fewer short work trips than were predicted by the theory.

In an effort to determine whether the O-D survey or theory results, as shown in Figure 4, are more logical, the intrazonal work trip pattern was analyzed further. It would seem reasonable to hypothesize that greater opportunities for work close to home, as measured by the product of jobs times workers in a zone, will induce larger numbers of workers to work within their zone of residence. Of course it is possible to have (a) a very large number of jobs available in a zone that houses very few workers, or (b) a very large number of workers living in a zone that includes very few jobs, and either of these cases is likely to distort the hypothesis. Nevertheless, each zone was ranked in ascending order, from 0 to 38, on the product of jobs in the zone times workers living in the zone. Each zone was similarly ranked on the number of intrazonal work trips predicted for that zone by the theory, and found for that zone by the O-D survey. (For purposes of Table 5 and Figure 5, the total number of O-D work trips originating in each zone was multipled by a factor to yield one work trip per worker living in the zone.) Table 5, Appendix, gives these three rankings for each zone, and is arranged by ascending order of product magnitude. This shows, for example, that zone 32 ranks (a) 5 on product magnitude, (b) 4 on intrazonal work trips by theory, and (c) 17 on intrazonal work trips by O-D survey. Figure 5 plots the rankings of Table 5, with the diagonal line of slope 1, and intercept at the origin, representing the hypothesis. With perhaps five exceptional points, the theory fits the hypothesis fairly well, in fact with a coefficient of correlation of 0.936. The O-D results depart rather widely from the hypothesis and have a coefficient of correlation of only 0.378.

## CONCLUSIONS REGARDING WORK TRIP PATTERNS

If the hypothesis underlying Figure 5 can be accepted, i.e., if it is logical to expect that, in general, the greater the opportunity for intrazonal work trips, as measured by the product of jobs times workers in the zone, the greater will be the number of

TABLE 1

DATA ON WORK TRIPS ORIGINATING IN ZONE 30

| Characteristic | By Theory | By O-D Survey |
|---|---|---|
| Workers living in zone | 787 | 787 |
| No. of work trips originated | 787 | 997 |
| Ratio of trips to workers | 1.00 | 1.253 |
| Jobs in zone | 1061 | 1061 |
| Intrazonal work trips | 109 | 55(44[a]) |
| Work trips to Ring 1 | 202 | 231 |
| Work trips to Ring 2 | 409 | 503 |
| Work trips to Outside Ring 2 | 67 | 208 |

[a]Adjusted value used in Table 5 and Figure 5.

such trips, it may be concluded that the theory gives a much more logical pattern of intrazonal work trips than does the O-D survey. But what impact does the intrazonal pattern have on the longer work trips that may be considered to be of greater importance in transportation planning?

Table 1 pertains to work trips originating in Zone 30. This, plus similar data for all other zones as summarized in Figures 2, 3, and 4, would seem to indicate that the O-D survey found progressively more work trips than predicted by the theory as the length of the trips increased. Furthermore, since the O-D survey indicates that many workers make more than one work trip per day it may be concluded that the O-D survey indicates that the longer the work trip the more likely the worker is to go home to lunch.

Even though one cannot say, in the present state of knowledge, that the theory gives the correct pattern of movement, it seems possible to conclude that the work trip pattern presented by the O-D survey is not completely logical.

## SHOPPING TRIP PATTERN IN CEDAR RAPIDS-MARION

The O-D survey determined a pattern of one-way, home-based, vehicular shopping trips. The field theory was applied on the assumption that each household makes one shopping trip per day that originates or ends in the home. The gravity model cannot be considered in this section because it combined shopping trips with all other homebased non-work trips.

For purposes of the theory, a shopping trip is any movement between a home and any place of retail business from a gasoline station or small local grocery store to a major integrated shopping center. With such a comprehensive definition it might be desirable to assume that every household makes an average of two, or even more, shopping trips per day, but for present purposes the assumption of one trip per day will suffice. Solutions of Eq. 2, therefore, insure that every household makes exactly one shopping trip per day, but place no restraints on the total number of shoppers assigned to any single zone of shopping.

Table 6, Appendix, gives the total number of shopping trips originating in each zone and destined for each zone as determined by the theory and by the O-D survey. Figure 6 is based on Table 6 and shows the average number of shopping trips per household originating in each zone. Although it cannot be said that the O-D survey findings are wrong, it seems most unlikely that, on the average, all households in Cedar Rapids-Marion make only one shopping trip every three days (27,365 households and 9,206 internal shopping trips). Figure 6 further indicates that households in zones 15, 32, 33, 34, and 35 average less than one shopping trip every ten days.

Figure 7, also based on Table 6, shows the average number of shopping trips attracted by every retail employee in each zone. Zones 00 and 13 do not have any retail employees, but were assigned one each for study purposes. The theory actually assigns two shoppers to each of these zones while the O-D survey assigns 55 shoppers to zone 00. On the average, the theory assigns 3.58 shoppers to each retail employee with a range in assignments from 2.00 to 4.48 per employee. By contrast, the O-D survey assigns an average of 1.44 shoppers per employee with a range in assignments from 0.24 to 11.20 per employee, omitting consideration of the 55 assigned to zone 00.

Figure 8 corresponds to Figure 4 and shows the discrepancies between theory predictions and O-D findings for shopping trips of varying length, namely from each zone of residence to Intrazonal, Ring 1, Ring 2, and Outside Ring 2, as these terms have been previously defined for work trips. Consistent with Figures 6 and 7, the theory predicts more shopping trips of all lengths than were found by the O-D survey, with few exceptions. The few zones of origin for which the survey found more intrazonal than predicted by the theory, and the 12 zones for which it found no intrazonal trips, are rather difficult to explain. Table 2 shows comparisons between the intrazonal shopping trips of zones 00, 06, 12, 14, 21, 26, and 37, which zones show erratic behavior in Figure 8, and the intrazonal shopping trips of nearby zones of comparable size which appear to show more nearly normal behavior. In each erratic case where the O-D survey actually found intrazonal trips, it found appreciably more than one shopper per retail

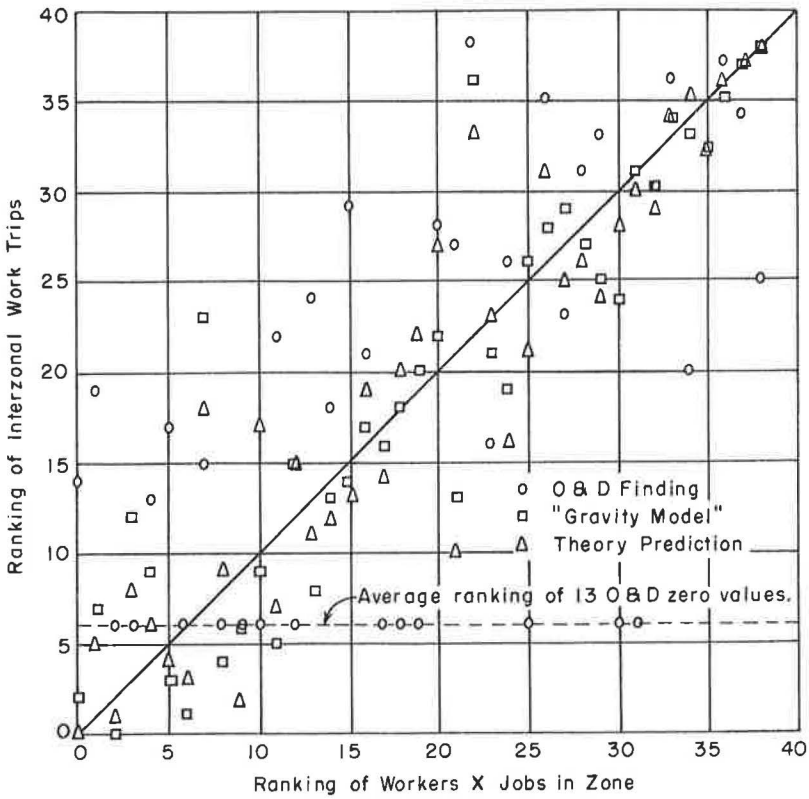


Figure 5. Rankings of intrazonal work trips vs rankings of products of workers times jobs in zone.

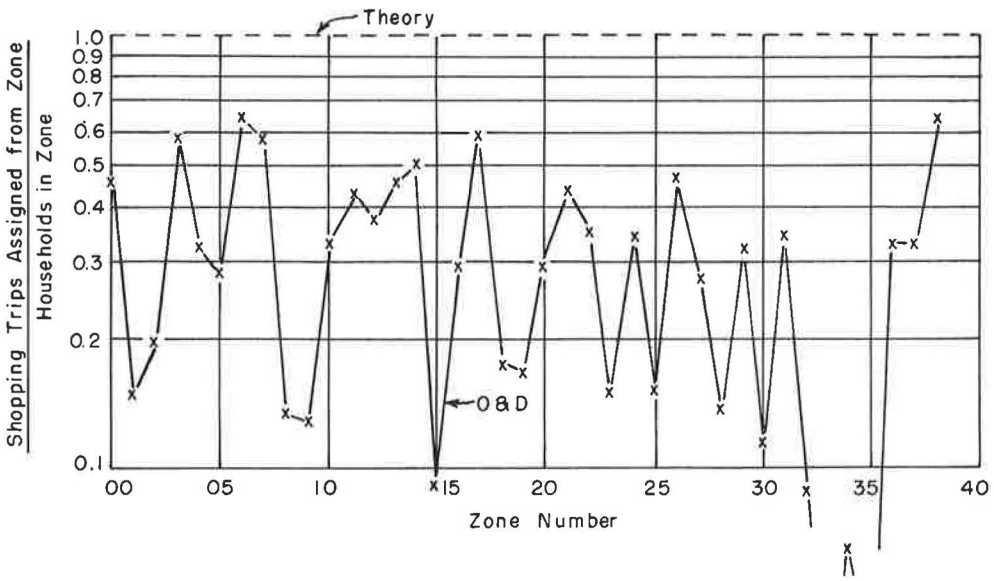


Figure 6. Ratio of shopping trips by zone of origin.

employee in the zone, whereas in the normal case it found considerably less than one intrazonal shopper per retail employee.

If it is reasonable to hypothesize that, in general, the greater the opportunity to make intrazonal shopping trips, as measured by the products of households times retail employees in a zone, the greater will be the number of such trips, Figure 9 can be plotted in a manner similar to that used for Figure 5. Table 7, Appendix, gives the zones ranked in ascending order of magnitude of the product of households times retail employees in the zone, with corresponding rankings by theory predicted and O-D found intrazonal shopping trips, and forms the basis of plotting Figure 9. Again the line of slope 1 passing through the origin represents the hypothesis while the plotted points compare the rankings by theory and O-D survey. As in the case of intrazonal work

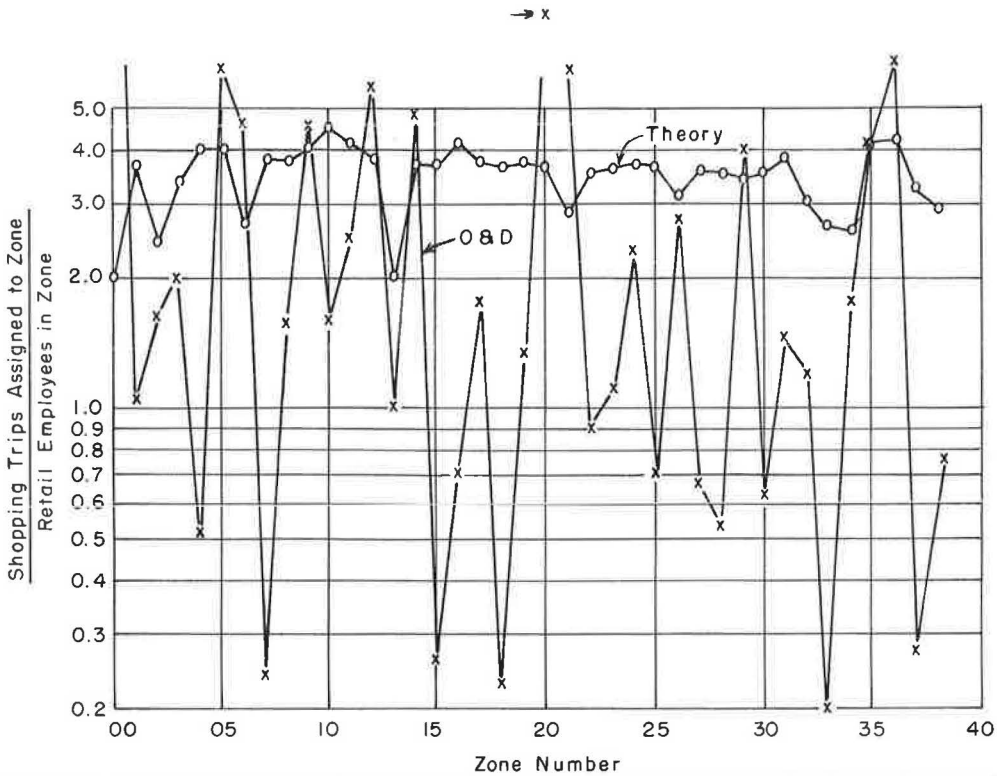


Figure 7. Ratio of shopping trips by zone of destination.

| Zone No. | Behavior in Fig. 8 | Households in Zone | Retail Employees in Zone | Intrazonal Trips by Theory | Intrazonal Trips by O-D Survey |
|---|---|---|---|---|---|
| 00 | Erratic | 532 | 1 | 1 | 13 |
| 37 | Erratic | 400 | 15 | 9 | 0 |
| 38 | Normal | 348 | 21 | 10 | 14 |
| 06 | Erratic | 960 | 205 | 96 | 228 |
| 07 | Normal | 718 | 262 | 146 | 31 |
| 12 | Erratic | 563 | 52 | 24 | 61 |
| 11 | Normal | 553 | 90 | 41 | 15 |
| 14 | Erratic | 1,435 | 88 | 57 | 152 |
| 16 | Normal | 1,373 | 83 | 61 | 14 |
| 21 | Erratic | 1,606 | 78 | 48 | 267 |
| 24 | Normal | 1,071 | 188 | 128 | 59 |
| 26 | Erratic | 917 | 49 | 56 | 0 |
| 22 | Normal | 616 | 50 | 19 | 13 |

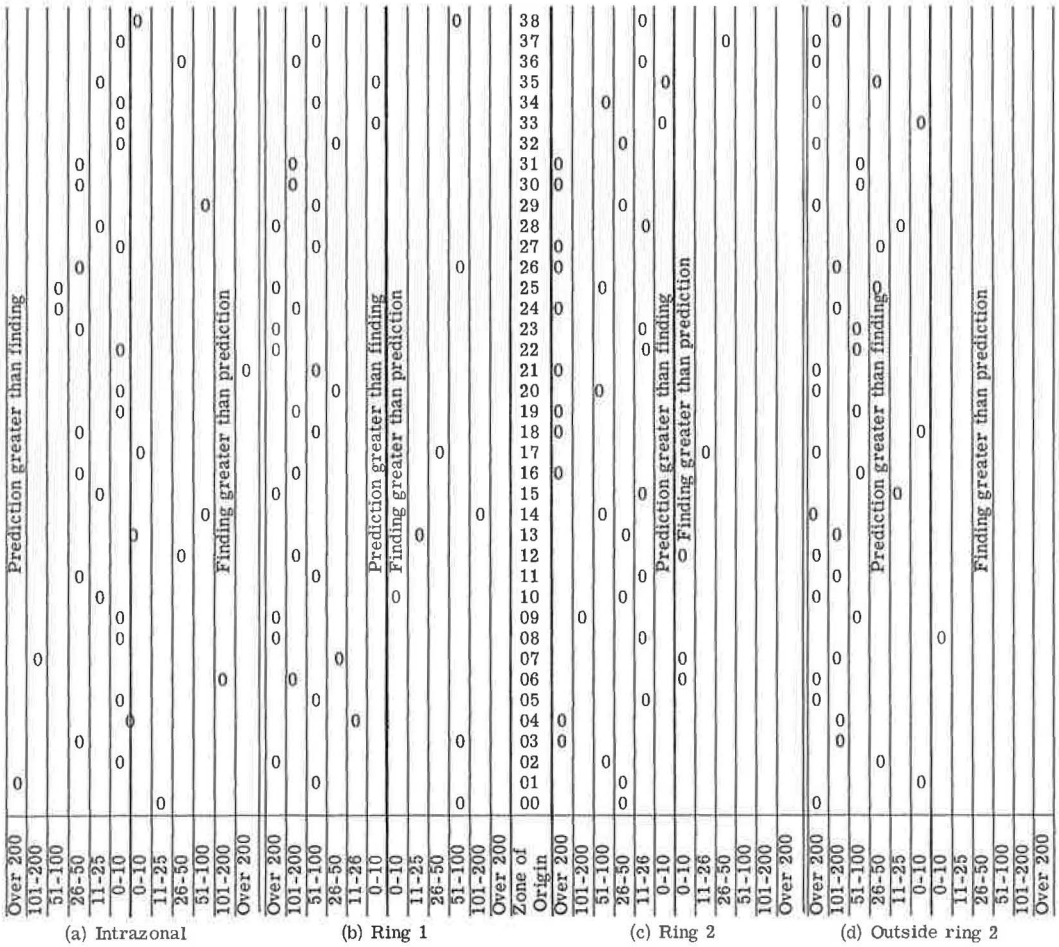


Figure 8. Discrepancies between shopping trips predicted by theory and found by O-D survey.

trips, that the theory gives more consistent results (coefficient of correlation, 0.961) than does the O-D survey (coefficient of correlation, 0.575).

## CONCLUSIONS REGARDING SHOPPING TRIPS

Inasmuch as the theory considers a child walking to a neighborhood store to purchase a loaf of bread to be creating a shopping trip, and the O-D survey reports only movements using vehicles, one might expect that the theory would (a) in general predict a larger total number of shopping trips for each zone than found by the survey, (b) consistently predict more intrazonal shopping trips than found by the survey, and (c) possibly predict a smaller number of long trips than found by the survey. In the Cedar Rapids area the theory actually (a) predicts a larger number of shopping trips originating from every zone, but a smaller number destined for nine zones than found by the O-D survey, (b) predicts more intrazonal shopping trips in only 28 of the 39 zones, and in one zone predicts 200 fewer such trips than found by the survey, and (c) with the exception of one zone, predicts more trips to the region Outside Ring 2 than found by the survey.

Judging from Figures 6, 7, and 8, and associated tables, it seems safe to say that the O-D survey found a pattern of shopping trips that is much more erratic than that predicted by the theory.

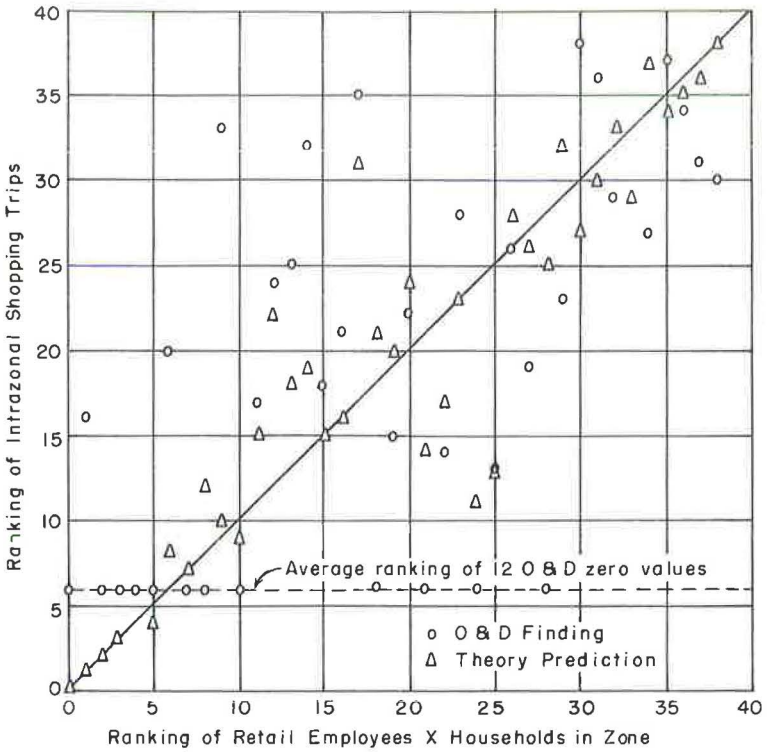


Figure 9. Rankings of intrazonal shopping trips vs rankings of products of retail employees times households in zone.

## TRIPS TO THE CENTRAL BUSINESS DISTRICT

Thus far the CBD has been treated as any other zone, but this area, zone 01, should be considered in some detail because it is the most important generator of work trips (containing over one-third of all the jobs in the study area) and of shopping trips (containing over one-half of all retail employees).

Of the 562 workers living in zone 01, the theory assigns 351 to work in the CBD, while the O-D survey found 23 intrazonal work trips out of a total of 292 work trips originating in the zone. The gravity model created 138 intrazonal work trips out of a total of 357 work trips generated in the zone. The theory assigns 604 of the 768 households in the CBD to shop in that area, while the O-D survey found 53 out of a total of 133 originating shopping trips to be intrazonal. Despite the obvious diversity of these numbers, both the theory and survey may be correct since the former deals with all forms of transportation and the latter covers only movements by vehicle. But what of work and shopping from other zones to the CBD?

The theory assigns a total of 10,008 workers to the 10,260 jobs in the CBD (to limit the number of worker and job digits to 4, the theory assigned 9,999 jobs to zone 01); the O-D survey found 9,635 work trips destined for zone 01; the gravity model assigned 9,522 such trips. The theory assigns 14,127 shoppers to deal with the 3,962 retail employees in the CBD, while the O-D survey found 4,084 shopping destinations in the area. Table 8 lists the work and shopping trips destined for the CBD by zones of origin, and Figure 10 shows the values in graphical form.

The zones are grouped as Intrazonal, Ring 1, Ring 2, and Outside Ring 2, as these terms have been previously defined.

1. For the first ring of zones around the CBD, the theory consistently predicts up to 200 more work trips per zone than found by the O-D survey. This difference might

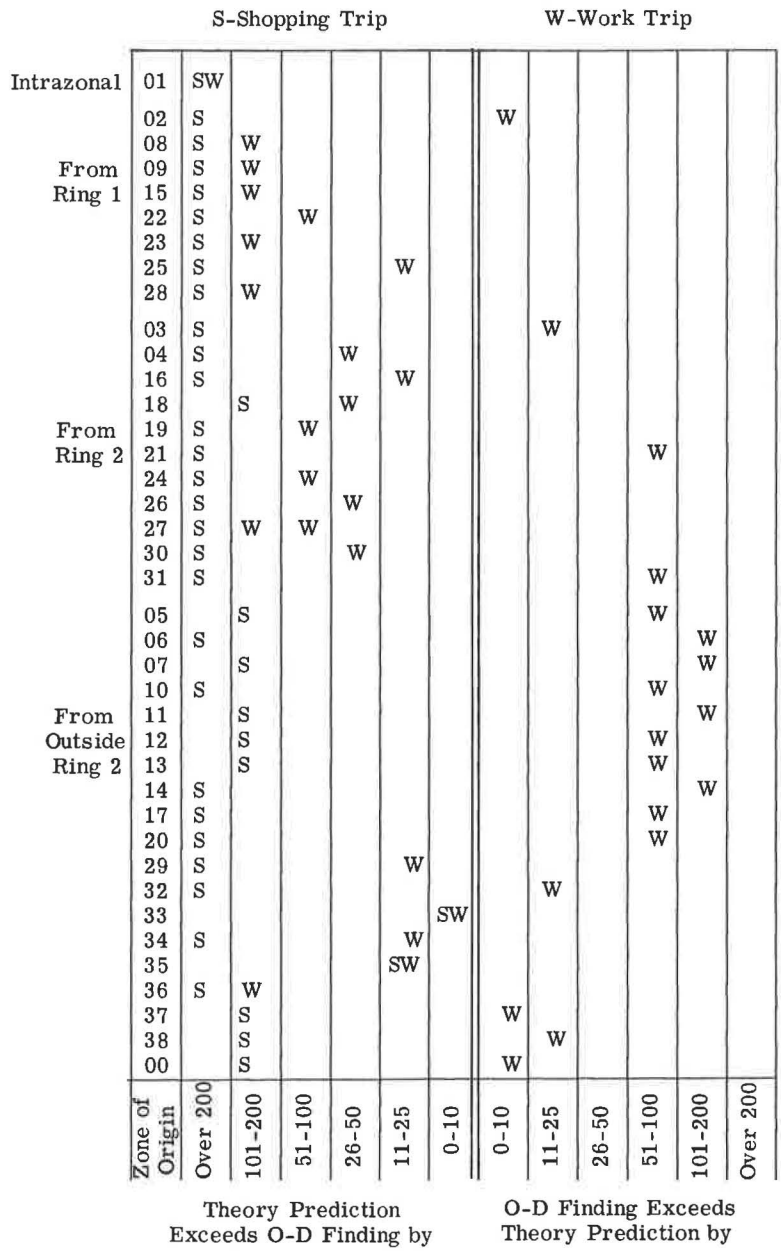


Figure 10. Discrepancies between work trips and shopping trips to CBD predicted by theory and found by O-D survey.

be explained by a combination of circumstances that makes it easy for workers to walk to work but difficult for them to find parking spaces near their work.

2. With two exceptions, the theory predicts considerably more work trips originating in each zone of Ring 2 than were found by the survey. The explanation for this discrepancy is more difficult to find since the minimum walk from this ring is in the order of 10 blocks.

3. Outside of Ring 2, except in Marion and the most remote parts of Cedar Rapids (zones 33 to 38 and 00), the theory predicts many fewer work trips destined for the CBD than were found by the survey. Inasmuch as the theory and survey both assign

roughly the same total number of work trips to the CBD, perhaps the great excess of O-D trips indicates that many people who work in the CBD go to their suburban homes for lunch.

4. The work trips from zones 33 to 38 and 00 present the type of error distribution one might expect if the theory and O-D survey gave reasonably comparable results.

5. When the distribution of shopping trips is considered, without exception the theory predicts more trips, and frequently many more, than were found by the survey. This, however, may be quite reasonable since many people who work in the CBD also shop there, and, because the theory predicts homebased work trips and homebased shopping trips, there is no reason why a person should not go from home to work, from work to shop, and back to home in a single round trip.

On the whole, it seems safe to say that the Cedar Rapids CBD could not survive on the number of work and shopping trips destined for it according to the O-D survey.

## SUMMARY AND CONCLUSIONS

In order to predict future patterns of movement within urban areas, it seems necessary that some logical relationships be found between existing patterns of movement and existing land uses. Future patterns of movement may then possibly be extrapolated from anticipated patterns of land use by applying currently observed interrelationships.

An O-D survey, in itself, can only determine existing patterns of movement to some order of accuracy. A land-use study coupled with an O-D survey provides information for relating the movements to the land uses. Gravity models have been set up on several occasions in an effort to provide the required mathematical relationships for extrapolation.

The field theory of movement merely assumes that the pattern of movement between areas of varying land use develops naturally in accord with certain unexplained physical laws. If the theory can simulate existing patterns of movement with sufficient accuracy, variations in the land-use factors in the equations should produce reasonable approximations of related patterns of movement.

In the case of Cedar Rapids-Marion, one is forced to conclude that the theory does not simulate the patterns of movement found in the 1957 home interview O-D survey with a reasonable degree of accuracy. Careful examination of the movements found by the survey, however, leads to the conclusion that the theory actually predicts a more logical pattern of movement than was reported by the survey. It must be left to the reader to decide whether the O-D findings are correct in spite of appearing to be illogical, or that the survey has yielded an invalid picture of the travel situation in the area of study.

## ACKNOWLEDGMENTS

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# *Appendix*

TABLE 3

BASIC DATA ON CEDAR RAPIDS–MARION, IOWA

| O-D Zone | No. of House-holds | No. of Workers | Coord. of Housing | | Total No. of Jobs | Retail Em-ploy-ment | Coord. of Job Sites | |
|---|---|---|---|---|---|---|---|---|
| | | | $N_i$ | $E_i$ | | | $N_j$ | $E_j$ |
| 00 | 532 | 652(627)* | 41** | 34** | 61 | 0(1)* | 40** | 35** |
| 01 | 768 | 584(561) | 21 | 18 | 10260(9999)′ | 3962 | 22 | 19 |
| 02 | 463 | 419(403) | 27 | 20 | 445 | 68 | 28 | 19 |
| 03 | 1125 | 1452(1396) | 33 | 20 | 381 | 42 | 34 | 19 |
| 04 | 724 | 834(802) | 29 | 22 | 1294 | 79 | 28 | 21 |
| 05 | 492 | 546(525) | 33 | 22 | 54 | 9 | 32 | 21 |
| 06 | 960 | 1125(1081) | 35 | 26 | 766 | 205 | 36 | 29 |
| 07 | 718 | 822(790) | 31 | 26 | 2709 | 262 | 32 | 27 |
| 08 | 314 | 349(335) | 23 | 20 | 908(1169) | 227 | 22 | 21 |
| 09 | 1093 | 1301(1251) | 25 | 22 | 616 | 121 | 24 | 21 |
| 10 | 746 | 813(781) | 27 | 24 | 381 | 61 | 26 | 23 |
| 11 | 553 | 561(539) | 29 | 26 | 630 | 90 | 30 | 27 |
| 12 | 563 | 674(648) | 31 | 28 | 257 | 52 | 32 | 27 |
| 13 | 400 | 535(514) | 25 | 26 | 99 | 0(1) | 26 | 25 |
| 14 | 1435 | 1578(1517) | 23 | 30 | 318 | 88 | 20 | 29 |
| 15 | 308 | 472(454) | 21 | 20 | 1028 | 208 | 20 | 19 |
| 16 | 1373 | 2041(1962) | 23 | 24 | 330 | 83 | 22 | 23 |
| 17 | 712 | 749(720) | 23 | 26 | 129 | 37 | 20 | 27 |
| 18 | 399 | 492(473) | 19 | 22 | 2694 | 273 | 18 | 21 |
| 19 | 679 | 891(856) | 19 | 22 | 123 | 36 | 20 | 23 |
| 20 | 963 | 1324(1273) | 19 | 28 | 103 | 30 | 20 | 29 |
| 21 | 1606 | 2037(1958) | 23 | 10 | 292 | 78 | 20 | 09 |
| 22 | 616 | 893(858) | 25 | 14 | 105 | 50 | 24 | 15 |
| 23 | 628 | 720(692) | 23 | 14 | 633 | 150 | 22 | 15 |
| 24 | 1071 | 1475(1418) | 19 | 12 | 749 | 188 | 20 | 13 |
| 25 | 610 | 710(682) | 21 | 16 | 948 | 268 | 20 | 15 |
| 26 | 917 | 1127(1083) | 17 | 12 | 352 | 49 | 16 | 11 |
| 27 | 560 | 732(704) | 19 | 16 | 399 | 94 | 18 | 15 |
| 28 | 472 | 815(783) | 19 | 18 | 360 | 109 | 18 | 17 |
| 29 | 749 | 962(925) | 15 | 14 | 160 | 22 | 16 | 15 |
| 30 | 665 | 817(785) | 15 | 18 | 1061 | 130 | 16 | 17 |
| 31 | 1073 | 1192(1146) | 15 | 20 | 1170 | 187 | 16 | 19 |
| 32 | 457 | 530(509) | 15 | 24 | 81 | 15 | 16 | 23 |
| 33 | 12 | 18(17) | 11 | 12 | 1041 | 94 | 12 | 15 |
| 34 | 735 | 781(751) | 11 | 18 | 126 | 13 | 10 | 17 |
| 35 | 65 | 89(86) | 39 | 36 | 441 | 148 | 40 | 37 |
| 36 | 1061 | 1300(1250) | 41 | 38 | 325 | 35 | 40 | 37 |
| 37 | 400 | 476(458) | 39 | 38 | 170 | 15 | 38 | 37 |
| 38 | 348 | 399(386) | 39 | 36 | 65 | 21 | 38 | 35 |
| Totals | 27365 | 33360(31999) | | | 32064 | 7599 | | |

*Numbers in parentheses used for theory calculations and comparisons.
**Coordinates in thousands of feet.
′Jobs in Zone 01 reduced to get four digits, difference added to Zone 08.

TABLE 4

TOTAL NUMBER OF WORK TRIPS DRAWN FROM AND ASSIGNED TO EACH ZONE

| Zone No. | Workers Living in Zone | Total Work Trips from Zone by | | | Jobs in Zone | Total Work Trips to Zone by | | |
|---|---|---|---|---|---|---|---|---|
| | | Theory One-Way | O-D One-Way | Gravity Two-Way | | Theory One-Way | O-D One-Way | Gravity Two-Way |
| 00 | 627 | 625 | 502 | 1275 | 61 | 59 | 50 | 143 |
| 01 | 562 | 560 | 292 | 713 | 10260 | 10008* | 9635 | 19044 |
| 02 | 405 | 403 | 469 | 909 | 445 | 443 | 439 | 936 |
| 03 | 1397 | 1395 | 1683 | 3121 | 381 | 378 | 592 | 890 |
| 04 | 804 | 802 | 755 | 1722 | 1294 | 1295 | 1352 | 2992 |
| 05 | 525 | 523 | 656 | 1130 | 54 | 52 | 54 | 118 |
| 06 | 1083 | 1081 | 1224 | 2168 | 766 | 762 | 949 | 1720 |
| 07 | 791 | 789 | 993 | 1788 | 2709 | 2700 | 2575 | 6430 |
| 08 | 337 | 335 | 287 | 549 | 908 | 1169* | 952 | 1458 |
| 09 | 1252 | 1250 | 920 | 2268 | 616 | 616 | 537 | 1186 |
| 10 | 782 | 780 | 777 | 1708 | 381 | 380 | 400 | 887 |
| 11 | 541 | 539 | 749 | 1148 | 630 | 627 | 654 | 1454 |
| 12 | 650 | 648 | 711 | 1516 | 257 | 254 | 364 | 621 |
| 13 | 515 | 513 | 583 | 1159 | 99 | 97 | 109 | 235 |
| 14 | 1519 | 1517 | 1660 | 3152 | 318 | 316 | 442 | 751 |
| 15 | 454 | 452 | 316 | 794 | 1028 | 1026 | 1380 | 2081 |
| 16 | 1962 | 1960 | 2038 | 4196 | 330 | 329 | 246 | 743 |
| 17 | 720 | 718 | 752 | 1582 | 129 | 127 | 87 | 311 |
| 18 | 475 | 473 | 321 | 946 | 2694 | 2689 | 2925 | 5753 |
| 19 | 857 | 855 | 700 | 1569 | 123 | 121 | 195 | 265 |
| 20 | 1275 | 1273 | 1426 | 3049 | 103 | 101 | 132 | 280 |
| 21 | 1959 | 1957 | 2537 | 5117 | 292 | 289 | 153 | 767 |
| 22 | 860 | 858 | 966 | 1827 | 105 | 103 | 80 | 599 |
| 23 | 693 | 691 | 701 | 1446 | 633 | 630 | 792 | 1418 |
| 24 | 1420 | 1418 | 1604 | 3114 | 749 | 744 | 827 | 1737 |
| 25 | 683 | 681 | 634 | 1424 | 948 | 944 | 1345 | 2150 |
| 26 | 1085 | 1083 | 1345 | 2226 | 352 | 347 | 444 | 792 |
| 27 | 705 | 703 | 603 | 1485 | 399 | 395 | 458 | 866 |
| 28 | 785 | 783 | 791 | 1636 | 360 | 357 | 447 | 797 |
| 29 | 926 | 924 | 1050 | 1902 | 160 | 156 | 211 | 351 |
| 30 | 787 | 784 | 954 | 1704 | 1061 | 1052 | 1274 | 2417 |
| 31 | 1147 | 1145 | 1404 | 2517 | 1170 | 1162 | 1417 | 2710 |
| 32 | 511 | 509 | 563 | 1246 | 81 | 78 | 113 | 213 |
| 33 | 18 | 16 | 140 | 40 | 1041 | 1029 | 1301 | 2725 |
| 34 | | | | | | | | |
| 35 | 87 | 85 | 77 | 152 | 441 | 444 | 428 | 965 |
| 36 | 1252 | 1250 | 1016 | 2559 | 325 | 327 | 293 | 759 |
| 37 | 459 | 457 | 485 | 1029 | 170 | 169 | 79 | 463 |
| 38 | 386 | 384 | 460 | 804 | 65 | 63 | 32 | 150 |
| Totals | 32049 | 31960 | 34024 | 68505 | 32064 | 31960 | 34022 | 68505 |

*Based on adjusted numbers of jobs given in Table 3.

TABLE 5

RANKING OF ZONES BY PRODUCT OF JOBS TIMES WORKERS IN ZONE AND CORRESPONDING RANKINGS OF INTRAZONAL WORK TRIPS

| Zone No. | Product Workers Times Jobs | Ranking by Product | Intrazonal Work Trips by Theory | | Adjusted* Intrazonal Work Trips by O-D | |
|---|---|---|---|---|---|---|
| | | | No. | Ranking | No. | Ranking |
| 33 | 18738 | 0 | 3 | 0 | 4 | 14 |
| 38 | 25090 | 1 | 10 | 5 | 14 | 19 |
| 05 | 28350 | 2 | 6 | 1 | 0 | — |
| 00 | 38247 | 3 | 15 | 8 | 0 | — |
| 35 | 38367 | 4 | 10 | 6 | 0 | — |
| 32 | 41391 | 5 | 9 | 4 | 10 | 17 |
| 13 | 50985 | 6 | 8 | 3 | 0 | — |
| 37 | 78030 | 7 | 30 | 18 | 6 | 15 |
| 22 | 90300 | 8 | 15 | 9 | 0 | — |
| 17 | 92880 | 9 | 7 | 2 | 0 | — |
| 34 | 94878 | 10 | 28 | 17 | 0 | — |
| 19 | 105411 | 11 | 10 | 7 | 29 | 22 |
| 20 | 129471 | 12 | 27 | 15 | 0 | — |
| 29 | 148160 | 13 | 25 | 11 | 32 | 24 |
| 12 | 167050 | 14 | 25 | 12 | 13 | 18 |
| 02 | 180225 | 15 | 25 | 13 | 43 | 29 |
| 27 | 281295 | 16 | 30 | 19 | 26 | 21 |
| 28 | 282600 | 17 | 25 | 14 | 0 | — |
| 10 | 297942 | 18 | 39 | 20 | 0 | — |
| 11 | 340830 | 19 | 55 | 22 | 0 | — |
| 26 | 381920 | 20 | 76 | 27 | 38 | 28 |
| 08 | 393953 | 21 | 24 | 10 | 36 | 27 |
| 36 | 406900 | 22 | 130 | 33 | 163 | 38 |
| 23 | 438669 | 23 | 59 | 23 | 10 | 16 |
| 15 | 466712 | 24 | 27 | 16 | 33 | 26 |
| 14 | 483042 | 25 | 51 | 21 | 0 | — |
| 03 | 532257 | 26 | 126 | 31 | 111 | 35 |
| 21 | 572028 | 27 | 70 | 25 | 48 | 23 |
| 16 | 647460 | 28 | 75 | 26 | 51 | 31 |
| 25 | 647484 | 29 | 61 | 24 | 55 | 33 |
| 09 | 771232 | 30 | 83 | 28 | 0 | — |
| 06 | 829578 | 31 | 113 | 30 | 0 | — |
| 30 | 835007 | 32 | 109 | 29 | 44 | 30 |
| 04 | 1040376 | 33 | 150 | 34 | 114 | 36 |
| 24 | 1063580 | 34 | 158 | 35 | 26 | 20 |
| 18 | 1279650 | 35 | 128 | 32 | 55 | 32 |
| 31 | 1341990 | 36 | 178 | 36 | 125 | 37 |
| 07 | 2142819 | 37 | 304 | 37 | 81 | 34 |
| 01 | 5619438 | 38 | 351 | 38 | 33 | 25 |

*O-D work trips multiplied by factor to make total number of such trips equal to number of workers living in zone of origin.

TABLE 6

TOTAL NUMBER OF SHOPPING TRIPS DRAWN FROM AND ASSIGNED TO EACH ZONE

| Zone No. | Households in Zone | Total Shopping Trips from Zone | | Retail Employment in Zone | Total Shopping Trips Assigned to Zone | |
|---|---|---|---|---|---|---|
| | | Theory | O-D* | | Theory | O-D** |
| 00 | 532 | 530 | 246 | 1 | 2 | 55 |
| 01 | 768 | 766 | 113 | 3962 | 14127 | 4084 |
| 02 | 463 | 461 | 92 | 68 | 232 | 110 |
| 03 | 1125 | 1123 | 666 | 42 | 143 | 84 |
| 04 | 724 | 722 | 234 | 79 | 317 | 41 |
| 05 | 492 | 489 | 139 | 9 | 36 | 56 |
| 06 | 960 | 958 | 627 | 205 | 570 | 955 |
| 07 | 718 | 716 | 409 | 262 | 1044 | 64 |
| 08 | 314 | 312 | 41 | 227 | 837 | 358 |
| 09 | 1093 | 1091 | 140 | 121 | 478 | 546 |
| 10 | 746 | 744 | 248 | 61 | 269 | 98 |
| 11 | 553 | 551 | 235 | 90 | 382 | 225 |
| 12 | 563 | 561 | 210 | 52 | 206 | 294 |
| 13 | 400 | 398 | 183 | 1 | 2 | 1 |
| 14 | 1435 | 1433 | 711 | 88 | 318 | 424 |
| 15 | 308 | 306 | 0 | 208 | 747 | 53 |
| 16 | 1373 | 1371 | 409 | 83 | 340 | 59 |
| 17 | 712 | 710 | 418 | 37 | 139 | 66 |
| 18 | 399 | 397 | 70 | 273 | 971 | 63 |
| 19 | 679 | 677 | 113 | 36 | 133 | 48 |
| 20 | 963 | 961 | 282 | 30 | 107 | 336 |
| 21 | 1606 | 1604 | 701 | 78 | 214 | 476 |
| 22 | 616 | 614 | 216 | 50 | 173 | 40 |
| 23 | 628 | 626 | 94 | 150 | 535 | 164 |
| 24 | 1071 | 1069 | 369 | 188 | 687 | 436 |
| 25 | 610 | 608 | 92 | 268 | 960 | 188 |
| 26 | 917 | 915 | 434 | 49 | 149 | 136 |
| 27 | 560 | 558 | 153 | 94 | 325 | 63 |
| 28 | 472 | 470 | 77 | 109 | 381 | 58 |
| 29 | 749 | 747 | 244 | 22 | 73 | 88 |
| 30 | 665 | 663 | 77 | 130 | 443 | 81 |
| 31 | 1073 | 1071 | 369 | 187 | 691 | 275 |
| 32 | 457 | 455 | 40 | 15 | 46 | 18 |
| 33 | 12 | 10 | 0 | 94 | 238 | 19 |
| 34 | 735 | 733 | 46 | 13 | 32 | 23 |
| 35 | 65 | 63 | 0 | 148 | 663 | 617 |
| 36 | 1061 | 1059 | 350 | 35 | 155 | 227 |
| 37 | 400 | 398 | 134 | 15 | 50 | 48 |
| 38 | 348 | 346 | 224 | 21 | 65 | 16 |
| Totals | 27365 | 27279 | 9206* | 7601 | 27279 | 10949** |

*Excludes trips to outside external cordon.
**Includes trips from outside external cordon.

TABLE 7

RANKING OF ZONES BY PRODUCT OF HOUSEHOLDS TIMES RETAIL EMPLOYEES IN ZONE AND CORRESPONDING RANKINGS OF INTRAZONAL SHOPPING TRIPS

| Zone No. | Product Households by Retail Employees | Ranking by Product | Intrazonal Shopping Trips by Theory | | Intrazonal Shopping Trips by O-D | |
|---|---|---|---|---|---|---|
| | | | No. | Ranking | No. | Ranking |
| 13 | 400 | 0 | 0 | 0 | 0 | — |
| 00 | 532 | 1 | 1 | 1 | 13 | 16 |
| 33 | 1128 | 2 | 1 | 2 | 0 | — |
| 05 | 4428 | 3 | 4 | 3 | 0 | — |
| 37 | 6000 | 4 | 9 | 6 | 0 | — |
| 32 | 6855 | 5 | 6 | 4 | 0 | — |
| 38 | 7308 | 6 | 10 | 8 | 14 | 20 |
| 34 | 9555 | 7 | 9 | 7 | 0 | — |
| 35 | 9620 | 8 | 14 | 12 | 0 | — |
| 29 | 16478 | 9 | 12 | 10 | 73 | 33 |
| 19 | 24444 | 10 | 10 | 9 | 0 | — |
| 17 | 26344 | 11 | 8 | 5 | 13 | 17 |
| 11 | 28756 | 12 | 41 | 22 | 15 | 24 |
| 20 | 28890 | 13 | 24 | 18 | 16 | 25 |
| 12 | 29276 | 14 | 24 | 19 | 61 | 32 |
| 22 | 30800 | 15 | 19 | 15 | 13 | 18 |
| 02 | 31484 | 16 | 21 | 16 | 14 | 21 |
| 36 | 37135 | 17 | 60 | 31 | 105 | 35 |
| 26 | 44933 | 18 | 33 | 21 | 0 | — |
| 10 | 45506 | 19 | 31 | 20 | 11 | 15 |
| 03 | 47250 | 20 | 47 | 24 | 14 | 22 |
| 28 | 51448 | 21 | 18 | 14 | 0 | — |
| 27 | 52640 | 22 | 21 | 17 | 11 | 14 |
| 04 | 57196 | 23 | 41 | 23 | 41 | 28 |
| 15 | 64064 | 24 | 13 | 11 | 0 | — |
| 08 | 71278 | 25 | 14 | 13 | 10 | 13 |
| 30 | 86450 | 26 | 50 | 28 | 22 | 26 |
| 23 | 94200 | 27 | 48 | 26 | 13 | 19 |
| 18 | 108927 | 28 | 47 | 25 | 0 | — |
| 16 | 113959 | 29 | 61 | 32 | 14 | 23 |
| 21 | 125268 | 30 | 48 | 27 | 267 | 38 |
| 14 | 126280 | 31 | 57 | 30 | 152 | 36 |
| 09 | 132253 | 32 | 61 | 33 | 51 | 29 |
| 33 | 163480 | 33 | 56 | 29 | 0 | — |
| 07 | 188116 | 34 | 146 | 37 | 31 | 27 |
| 06 | 196800 | 35 | 96 | 34 | 228 | 37 |
| 31 | 200651 | 36 | 122 | 35 | 84 | 34 |
| 24 | 201348 | 37 | 128 | 36 | 59 | 31 |
| 01 | 3042816 | 38 | 604 | 38 | 53 | 30 |

TABLE 8

WORK AND SHOPPING TRIPS DESTINED FOR CENTRAL BUSINESS DISTRICT

| Area of Origin | Zone of Origin | Households in Zone of Origin | Work Trips to CBD by | | Shopping Trips to CBD by | |
|---|---|---|---|---|---|---|
| | | | Theory | O-D | Theory | O-D |
| Intrazonal | 01 | 768 | 351 | 23 | 604 | 53 |
| Ring 1 | 02 | 463 | 141 | 143 | 275 | 53 |
| | 08 | 314 | 212 | 45 | 249 | 11 |
| | 09 | 1093 | 491 | 291 | 665 | 76 |
| | 15 | 308 | 272 | 93 | 238 | 0 |
| | 22 | 616 | 344 | 254 | 365 | 64 |
| | 23 | 628 | 265 | 164 | 352 | 23 |
| | 25 | 610 | 295 | 284 | 371 | 78 |
| | 28 | 472 | 315 | 184 | 285 | 35 |
| Ring 2 | 03 | 1125 | 384 | 406 | 573 | 287 |
| | 04 | 724 | 226 | 192 | 385 | 82 |
| | 16 | 1373 | 738 | 715 | 803 | 104 |
| | 18 | 399 | 157 | 112 | 225 | 29 |
| | 19 | 679 | 282 | 199 | 383 | 74 |
| | 21 | 1606 | 667 | 736 | 859 | 312 |
| | 24 | 1071 | 418 | 516 | 501 | 177 |
| | 26 | 917 | 308 | 258 | 441 | 112 |
| | 27 | 560 | 244 | 71 | 294 | 82 |
| | 30 | 665 | 194 | 164 | 305 | 44 |
| | 31 | 1073 | 304 | 407 | 518 | 141 |
| Outside Ring 2 | 05 | 492 | 140 | 195 | 244 | 56 |
| | 06 | 960 | 223 | 374 | 399 | 155 |
| | 07 | 718 | 135 | 302 | 274 | 137 |
| | 10 | 746 | 243 | 332 | 405 | 106 |
| | 11 | 553 | 129 | 308 | 257 | 103 |
| | 12 | 563 | 104 | 196 | 204 | 46 |
| | 13 | 400 | 168 | 264 | 220 | 71 |
| | 14 | 1435 | 464 | 573 | 740 | 140 |
| | 17 | 712 | 248 | 321 | 398 | 111 |
| | 20 | 963 | 386 | 456 | 476 | 112 |
| | 29 | 749 | 248 | 232 | 361 | 37 |
| | 32 | 457 | 157 | 164 | 242 | 0 |
| | 33 | 12 | 5 | 0 | 6 | 0 |
| | 34 | 735 | 197 | 185 | 364 | 23 |
| Marion | 00 | 532 | 138 | 139 | 215 | 25 |
| | 35 | 65 | 16 | 0 | 22 | 0 |
| | 36 | 1061 | 245 | 144 | 360 | 27 |
| | 37 | 400 | 87 | 97 | 135 | 18 |
| | 38 | 348 | 72 | 96 | 116 | 0 |