An Evaluation of the Influence of Terminal Times on Gravity Model Travel Time Factors

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This paper presents the findings of an investigation to determine the influence of including or excluding terminal times in the development of travel time factors (friction factors) for a gravity model traffic analysis for a small urban area. This investigation was made by developing travel time factors for the urban area of Rock Hill, S. C. using two procedures. The first procedure developed the factors using only over-the-road driving time as a measure of spatial separation. The second used total travel time (over-the-road driving time plus terminal time) as a measure of spatial separation. Internal auto driver trips for purpose of home-based work, home-based non-work, and non-home-based and truck trips were included in the analysis.

Separate assignments to the street network were made of the trips reported in the home interview and the trips developed by the two gravity models.

Statistical tests comparing the assigned link volumes and CBD zonal interchanges indicated that both gravity models reproduced adequately the trip distribution patterns of the home interview data. The travel time factors developed using both driving time and terminal times were found not to differ significantly from those using only driving time, except in the case of non-home-based trips.

It was concluded that while there were basic differences requiring further investigation the gravity model provided an adequate framework for determining trip distribution patterns using either the model with terminal times or the model without terminal times.

•TO provide a framework for sound decision-making in developing transportation networks, reliable forecasts of future travel must be developed. With these forecasts, proposed alternate transportation systems may be tested and analyzed for the services which they will provide, comparing service benefits of each system with estimated costs.

Two of the key phases in the forecast of future travel patterns are trip distribution and traffic assignment. These phases provide the quantitative data on travel needed to properly plan transportation facilities. The traffic assignment techniques provide an estimate of the probable traffic on each segment of a transportation network. The need for accurate, reliable traffic assignments has accelerated the development of various procedures capable of synthesizing zone-to-zone movements for alternate configurations of land use and transportation facilities. These procedures provide for distributing the trips emanating from each zone in the study area to other zones. Several such procedures, generally referred to as traffic models, have been developed by various organizations throughout the country. The model which has been most widely applied is the so-called gravity model.

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In May 1964, the University of South Carolina entered into a contract with the South Carolina State Highway Department to perform certain technical phases of the Rock Hill Area Transportation Study. One phase of that study required the calibration of a gravity model for the Rock Hill area suitable for use in the development of future travel patterns.

The development of this model would not have been unusual except for the fact that the agreement required the development of travel time factors (friction factors) using both over-the-road driving time alone and total travel time (over-the-road driving time plus terminal time), as a measure of spatial separation, and to evaluate the difference, if any, in these factors.

To date most of the O-D studies which have used the gravity model to develop future travel patterns have subscribed to the theory that terminal times are necessary to obtain reliable travel time factors; while this has been widely accepted, studies have not been carried out to verify the necessity of using terminal times, especially in small urban areas.

Rock Hill is a small urban area located in York County in the north-central portion of South Carolina. The location of Rock Hill in relation to some other urban areas is shown in Figure 1. The study area (Fig. 2) has a population of approximately 40,000, of which 29,500 are within the city limits. The economic base of the area is primarily the textile industry.

GRAVITY MODEL THEORY

The gravity model adapts the Newtonian gravitational concept to the distribution of urban travel patterns. It employs the concept that the interchange of trips between zones in an urban area is dependent upon the relative attraction between the zones and the spatial separation between them as measured by an appropriate function of distance (1). This function of spatial separation adjusts the relative attraction of each zone for the ability, desire, or necessity of the trip maker to overcome the spatial separation between the zones.

In early uses of the gravity model, the mathematical form of the model was used and the exponent b was determined empirically. Early studies have shown that the exponent of travel time varies from 0.5 up to 3.0 depending upon the importance of the trip purpose. In addition to the variation of the exponent by trip purpose, Voorhees has

Figure 1. Location map: Rock Hill, South Carolina.

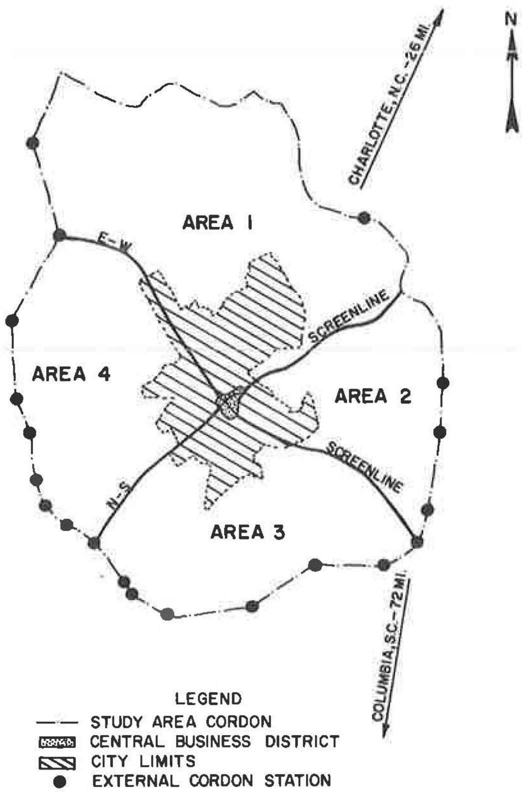

Figure 2. Rock Hill Study Area.

shown that the exponent may not remain constant but will increase as the spatial separation increases (2). This is particularly true where terminal times are not added to driving times in determining spatial separation. However, a constant exponent expresses the areawide effect of spatial separation on trip interchange as a linear logarithmic function of travel time.

To overcome the restriction of linearity for the travel time function and to simplify the computational requirements of the model, later studies have made use of the following form of the model:

$$T_{i-j} = P_i \frac{A_j F_{(t_{i-j})} K_{i-j}}{\sum_{x=1}^{n} A_x F_{(t_{i-x})} K_{(i-x)}}$$

where

T_{i-j} = trip produced in zone i and attracted to zone j;

P_i = trips produced by zone i;

A_j = trips attracted by zone j;

$F_{(t_{i-j})}$ = empirically derived travel time factor which expresses the average areawide effect of spatial separation on trip interchange between zones which are t_{i-j} apart; and

K_{i-j} = a specific zone-to-zone adjustment factor to allow for the incorporation of the effect on travel patterns of defined social or economic linkages not otherwise accounted for in the gravity model formulation.

The use of a set of travel time factors to express the effect of spatial separation on zonal trip interchange, rather than the traditional inverse exponential function of time, simplifies the computational requirements of the model (3). The above form of the model allows for a nonlinear travel time function which allows consideration for the effect of spatial separation generally increasing as the travel time increases.

CALIBRATING THE MODELS

In using the gravity model for trip distribution, several decisions must be made as to the type of model to be developed. In small urban areas, these decisions are somewhat more simplified than for larger urban areas. It was decided to calibrate a 24-hr model using total daily vehicular trips with both origin and destination within the study area and off-peak driving time as a measure of spatial separation.

The trips reported in the O-D study and used in this study were stratified into the following purpose categories: home-based auto driver work, home-based auto driver non-work, non-home-based auto driver, and truck.

Two procedures were followed in developing the gravity model trip distribution curves. The first used over-the-road driving time alone as a measure of spatial separation; the second used total travel time (over-the-road driving time plus a terminal time for each end of the trip). Interzonal driving times were obtained through the standard tree building computer program while an estimate of terminal time was made for each zone. This estimate was based on the type and intensity of land development within each zone and were made on the basis of judgment and a knowledge of the particular zones. Two CBD core zones were assigned terminal times of four and three minutes. One highly developed zone adjacent to the CBD was assigned a terminal time of 3 minutes. Other highly developed zones both in and outside the CBD were assigned terminal times of 2 minutes, and residential and relatively undeveloped zones were assigned terminal times of 1 minute. The minimum terminal time which could be assigned was 1 minute. Of the 99 zones in the study area, 12 were assigned terminal times greater than 1 minute. Eight of the ten zones in the CBD were assigned times of more than 1 minute. Intrazonal driving times were estimated on the basis of the average driving time from the zone centroid to all points on the edge of the zone.

Determining Travel Time Factors

The optimum set of travel time factors was developed for each trip purpose category by a process of trial and adjustment. This process has been well documented (5, 6, 7) and will not be explained in detail here. Briefly, the travel time factors F_{i-j} were developed in an iterative procedure which was continued until the synthetic trips calculated for each trip length interval closely matched the O-D trips reported for the same interval. Any convenient set of travel time factors may be used to start the iteration procedure; however, in this study an initial set of travel time factors was developed for each trip purpose category using a straight-line curve fitted to the O-D trip length frequency distribution. These factors, together with zonal productions and attractions and travel time matrices, were used to obtain an initial gravity model estimate of zone interchanges. After comparing the resulting synthetic interchanges with the observed interchanges, the initial sets of travel time factors were revised to produce more accurate results. These revisions were made on the basis of comparing the overall trip length frequency distribution curve of the gravity model with that of the actual O-D interchanges. The process was repeated until acceptable criteria were met (5). The completion of the calibration process produces a set of travel time factor curves for each trip purpose which together with projected productions and attractions is used to develop a future trip matrix. In addition to the travel time factor curves, there is a synthetic trip matrix for the total trips available for comparison with the reported O-D trip matrix. The O-D and synthetic trip matrices can be statistically compared directly or assigned to a street network for comparison.

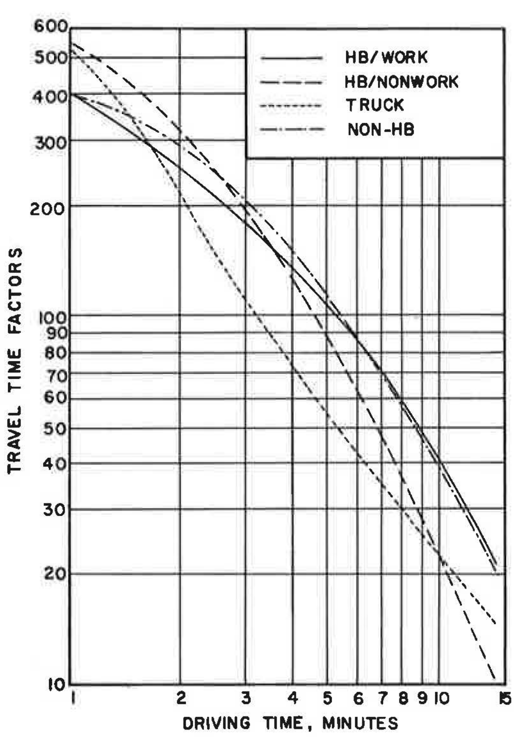

Figure 3. Travel time factors without terminal times.

Developing the travel time factor curves using two procedures resulted in two sets of travel time factors available for comparison. The travel time factors developed from the first procedure using driving time alone are shown in Figure 3. All of the curves shown, with the exception of that for trucks, have a concave shape and could not be approximated with a constant exponent. The concave shape of these curves is undoubtedly due to the absence of zonal terminal times.

Following the development of the travel time factors using driving time only, the model was calibrated using total travel time. The initial set of travel time factors used for this model was obtained by adding

2 minutes to each time interval of the factors developed for the model with no terminal times. Since the minimum terminal time added in any zone was 1 minute, it was necessary to add two minutes to the previous travel time factors in order to make a valid comparison of the travel time factors for a gravity model both with and without terminal time. This resulted in the minimum trip time possible being 3 minutes since the minimum intrazonal time was 1 minute. Using the travel time factors developed by this procedure as a first trial, distributions were made for the gravity model and the resulting trip length frequencies for each purpose were compared with the O-D distributions. On this step, two of the four categories of trip purposes were found to be within the limits of criteria as previously established without additional adjustment. The two remaining internal purposes required one further calibration to fulfill the established criteria.

The travel time factors developed from the second procedure using total travel time are shown in Figure 4. Two of these four curves (home-based work and home-based non-work) have the same travel time factors as shown in Figure 3 with the exception of the addition of the 2 minutes to each time interval. The two remaining curves (non-home-based and trucks) are slightly different (Fig. 5). In the original research carried out for the Rock Hill study, an evaluation of the various travel time factor curves and the trip length frequency distribution curves (not shown in this paper) shows that the non-home-based travel time factors are significantly different when terminal times are used, while the difference in the curves for truck trips can probably be attributed to the model being slightly better fitted in the calibration procedure (8). These findings indicate that there is a significant difference in the travel time factors for non-home-based

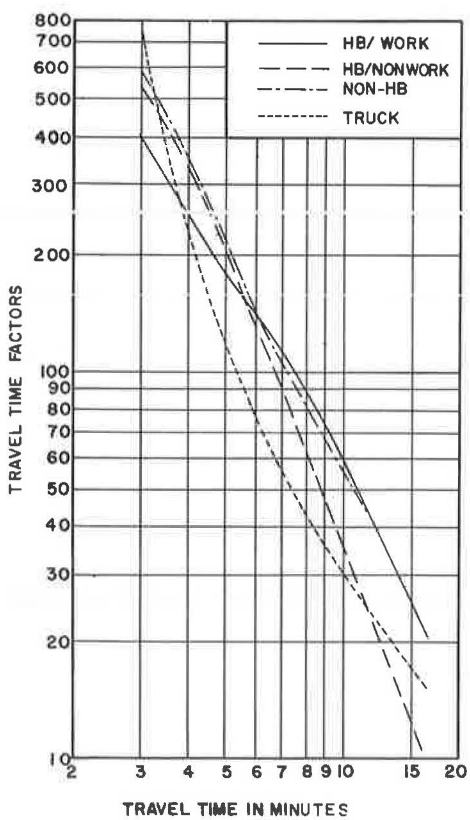

Figure 4. Travel time factors with terminal times.

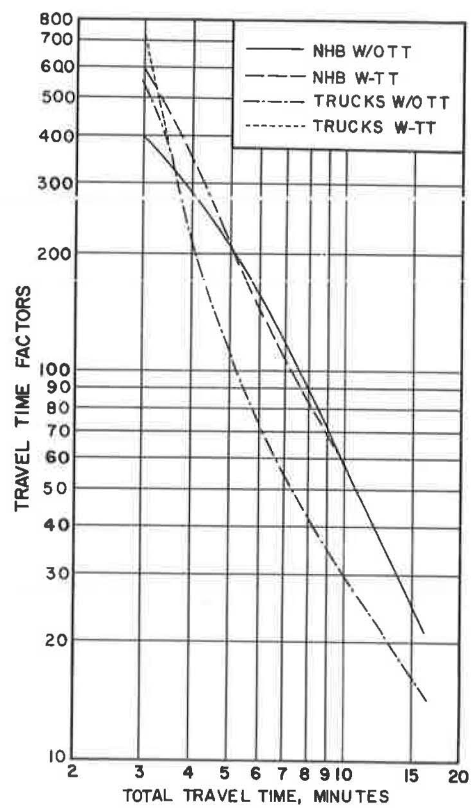

Figure 5. Comparison of travel time factors with and without terminal times.

trips when terminal times are used and when they are not used. This statement should not be interpreted as a conclusion that assignments made to a street network using a distribution made with these sets of travel time factors would be different to the point of influencing a major transportation decision.

These curves, which are a function of total travel time, unlike those which are a function of driving time alone, could, with the exception of trucks, be approximated very closely with a constant exponent.

TESTING THE MODELS

The trip distribution which is produced by the calibrated gravity model is a "synthetic" distribution and is therefore an approximation of actual conditions. It must be realized that variations between the actual and the synthetic conditions developed using mathematical models are inherent in any approximation process. To determine if the models used to forecast future travel patterns are adequate, various statistical tests are made to analyze how well these models reproduce the existing O-D travel patterns. The statistical tests are generally applied only when the gravity model has been calibrated to a trip distribution pattern obtained from an O-D survey.

Comparison of Street Network Assignments

After each of the gravity models had been calibrated, the internal gravity model and O-D trip interchanges were assigned, by the all-or-nothing method, to the existing street

TABLE 1

COMPARISON OF O-D AND GRAVITY MODEL ASSIGNMENTS WITHOUT TERMINAL TIMES

Link Volume	No. of Links[a]	Average Link Volume		Mean Difference	Percent Mean Difference	Standard Deviation	Test Statistic t	Table Value, $t_{\alpha/2;\ n-1}$[b]
		O-D	G.M.					
0-999	748	347	381	34	9.8	60	15.49[c]	1.96
1000-1999	241	1359	1399	40	2.9	133	4.67[c]	1.96
2000-2999	92	2429	2417	12	0.5	168	0.69	1.99
3000 and over	43	4424	4352	72	1.6	177	2.67[c]	2.02
All links	1124	891	918	27	3.3	110	8.17[c]	1.96

[a]Total links with zero gravity model volume and zero O-D volume, 140; total links with zero gravity model volume and non-zero O-D volume, 6.
[b]5 percent significance level.
[c]Significantly different.

TABLE 2

COMPARISON OF O-D AND GRAVITY MODEL ASSIGNMENTS WITH TERMINAL TIMES

Link Volume	No. of Links[a]	Average Link Volume		Mean Difference	Percent Mean Difference	Standard Deviation	Test Statistic t	Table Value, $t_{\alpha/2;\ n-1}$[b]
		O-D	G.M.					
0-999	755	349	379	30	8.6	59	13.97[c]	1.96
1000-1999	237	1361	1398	37	2.7	130	4.38[c]	1.96
2000-2999	91	2438	2436	2	0.1	157	0.12	1.99
3000 and over	44	4380	4294	86	2.0	287	1.98	2.02
All links	1127	888	912	24	2.7	109	7.39[c]	1.96

[a]Total links with zero gravity model volume and zero O-D volume, 141; total links with zero gravity model volume and non-zero O-D volume 2.
[b]5 percent significance level.
[c]Significantly different.

network, and a simple statistical analysis of the differences between the actual and synthetic volumes were made for each of the models. The results of these tests for the comparison of the O-D and the gravity model volumes both with and without terminal times are given in Tables 1 and 2, respectively. The tables show the average O-D and gravity model link volume, the difference and percent difference in the average volume, the standard deviation of the difference, and Student's t statistic for each volume grouping. The t statistic results from Student's t test for the equality of means where the observations are paired (9). The observations in this case are the individual network links and the pairing effect results from the network being loaded with the O-D trip distribution and then being tested against the same network loaded with each of the gravity model distributions.

Tables 1 and 2 indicate that the difference in the O-D and gravity model volumes is never large enough to influence a transportation decision. The mean differences between the O-D and gravity model volumes are, in all cases, not greater than 10 percent and the majority of the link volumes show considerably less than 10 percent difference. Three of the volume groupings and the total grouping for the model with terminal times show mean differences and percent mean differences, which are lower than those found for the model without terminal times. The standard deviation of the differences follows the same pattern, although this difference is extremely small.

While it appears that there is no practical difference in the O-D and gravity model values shown, the t statistic indicates that there is a significant difference statistically in several of the volume groupings and in the total grouping for both of the models. The three volume groups which show no significant difference are those with a relatively low number of links. This can be explained in part by the fact that the t statistic value

TABLE 3

COMPARISON OF O-D AND GRAVITY MODEL ASSIGNMENTS WITHOUT TERMINAL TIMES[a]

Link Volume	No. of Links	Average Link Volume		Mean Difference	Percent Mean Difference	Standard Deviation	Test Statistic t	Table Value, $t_{\alpha/2;\ n-1}$[b]
		O-D	G.M.					
0-999	11	552	636	84	15.2	133	2.10	2.23
1000-1999	21	1537	1584	47	3.1	157	1.37	2.09
2000-2999	9	2437	2451	14	0.6	141	0.30	2.31
3000 and over	16	5991	5876	115	1.9	225	2.04	2.13
All links	57	2739	2742	3	0.1	188	0.12	2.00

[a]Includes only those links of the street network located within the CBD.
[b]5 percent significance level.

TABLE 4

COMPARISON OF O-D AND GRAVITY MODEL ASSIGNMENTS WITH TERMINAL TIMES[a]

Link Volume	No. of Links	Average Link Volume		Mean Difference	Percent Mean Difference	Standard Deviation	Test Statistic t	Table Value, $t_{\alpha/2;\ n-1}$[b]
		O-D	G.M.					
0-999	11	552	626	74	13.4	142	1.73	2.23
1000-1999	21	1537	1551	14	0.9	162	0.40	2.09
2000-2999	9	2437	2449	12	0.5	104	0.35	2.31
3000 and over	16	5991	5782	209	3.5	244	4.26[c]	2.13
All links	57	2739	2702	37	1.4	209	1.34	2.00

[a]Includes only those links of the street network located within the CBD.
[b]5 percent significance level.
[c]Significantly different.

is calculated as the product of the mean difference and the square root of the number of observations divided by the standard deviation of the differences. The lower the number of observations, the lower the t statistic. This seems to indicate that where statistical comparisons of traffic assignments such as these are made, the extremely high number of observations (links) tend to show a significant difference in cases where a practical difference may not occur.

To evaluate this phenomenon further, the same comparisons were made for those links in the CBD only. This comparison, which has relatively high average link volumes and a low number of observations for each grouping, is given in Tables 3 and 4 for each of the models. Again, the mean differences for both models have no practical difference. However, only one of the volume groupings for the two models shows a significant difference statistically. This can probably be attributed in part to the lower number of observations and to the higher standard deviations of the mean differences, which result in lower t statistics. Again three of the volume groupings for the model with terminal times show mean differences, percent mean differences, and standard deviations which are lower than those found for the model without terminal times. However, in this case, the total grouping shows a greater difference in the model with terminal times. Although the differences appear to be smaller between the O-D and gravity model with terminal times than between the O-D and gravity model without terminal times this difference is believed to be insignificant.

Comparison of CBD Zonal Interchanges

While the results of the loaded street network comparison were revealing, it was felt that a large number of the trips made over these links were between zones which would be influenced very little by the presence or absence of terminal times. Therefore, in an attempt to isolate the influence of terminal times on the zonal interchanges, those zones in the CBD which had terminal times greater than 1 minute were analyzed for zonal interchanges with each other using the paired observations technique. It was felt that the influence of terminal times would be the greatest on intra-CBD trips because the terminal time as a proportion of the total trip time would be larger for these trips than for any others. The results of these analyses are given in Tables 5, 6, and 7. Tables 5 and 6 compare the O-D zonal interchanges with the gravity model interchanges for the model with and without terminal times; Table 7 shows a comparison of the zonal interchanges produced by each of the models. The same values are shown in these tables as were shown for the street network assignments.

TABLE 5

COMPARISON OF O-D AND GRAVITY MODEL ZONAL INTERCHANGES WITHOUT TERMINAL TIMES[a]

Origin Zone	Average Zonal Interchange[b]		Mean Difference	Standard Deviation	Test Statistic t	Table Value, $t_{\alpha/2;\ n-1}$[c]
	O-D	G.M.				
1	101	128	27	49	1.55	2.37
2	18	21	3	4	2.12	2.37
3	11	11	0	7	—	—
4	9	11	2	6	0.94	2.37
5	28	32	4	6	1.89	2.37
6	30	32	2	9	0.63	2.37
8[d]	7	8	2	7	0.81	2.37
9	24	29	5	7	2.03	2.37
All zones	28	34	6	19	0.89	2.37

[a]Includes only those zones within the CBD assigned a terminal time greater than 1 minute.
[b]Average number of trips originating in the origin zone and terminating in all other zones within the CBD.
[c]5 percent significance level; 8 observations per zone.
[d]Zone 7 was within the CBD but was not assigned a terminal time greater than 1 minute.

TABLE 6

COMPARISON OF O-D AND GRAVITY MODEL ZONAL INTERCHANGES WITH TERMINAL TIMES[a]

Origin Zone	Average Zonal Interchange[b]		Mean Difference	Standard Deviation	Test Statistic t	Table Value, $t_{\alpha/2;\ n-1}$[c]
	O-D	G.M.				
1	101	110	9	21	1.24	2.37
2	18	18	0	4	—	—
3	11	9	2	6	0.94	2.37
4	9	9	0	5	—	—
5	28	26	2	5	1.13	2.37
6	30	28	2	7	0.81	2.37
8[d]	7	7	0	6	—	—
9	24	23	1	6	0.47	2.37
All zones	28	29	1	9	0.31	2.37

[a]Includes only those zones within the CBD assigned a terminal time greater than 1 minute.
[b]Average number of trips originating in the origin zone and terminating in all other zones within the CBD.
[c]5 percent significance level; 8 observations per zone.
[d]Zone 7 was within the CBD but was not assigned a terminal time greater than 1 minute.

TABLE 7

COMPARISON OF GRAVITY MODEL ZONAL INTERCHANGES[a]

Origin Zone	Average Zonal Interchange[b]		Mean Difference	Standard Deviation	Test Statistic t	Table Value, $t_{\alpha/2;\ n-1}$[c]
	G.M. (w/oTT)	G.M. (w/TT)				
1	128	110	18	28	1.28	2.37
2	21	18	3	4	2.12	2.37
3	11	9	2	2	2.83[d]	2.37
4	11	9	2	3	1.89	2.37
5	32	26	6	6	2.83[a]	2.37
6	32	28	4	7	1.61	2.37
8[e]	8	7	1	3	0.94	2.37
9	29	23	6	7	2.43[d]	2.37
All zones	34	29	5	11	1.29	2.37

[a]Includes only those zones within the CBD assigned a terminal time greater than 1 minute.
[b]Average number of trips originating in the origin zone and terminating in all other zones within the CBD.
[c]5 percent significance level; 8 observations per zone.
[d]Significantly different.
[e]Zone 7 was within the CBD but was not assigned a terminal time greater than 1 minute.

There is no statistical difference for any of the origin zones for either of the two models; however, it is believed that the model with terminal times is more closely approximating the O-D zonal interchanges. This is indicated by the lower mean differences and standard deviations for this model. The t statistic is lower as a result.

Table 7 shows that there is a significant difference in the synthetic zonal interchanges for the two models for zones 3, 5, and 9 while the other origin zones show no significant difference. This lends further evidence to the conclusion that the model using terminal times is reproducing the CBD zonal interchanges more accurately than the model without terminal times.

An evaluation of the findings of the street network comparison and the CBD zonal interchange comparison seems to be indicating contradictory findings. That is, the street network comparison shows no practical differences in the two models, while a comparison of the CBD zonal interchanges shows a difference. This difference can be resolved by considering the fact, mentioned previously, that the CBD street network links would be carrying a large number of trips which would not be influenced by the presence or absence of terminal times. These trips are those which are passing through the CBD to some other zone in the area of those trips which begin outside and terminate inside the CBD.

Comparison of Accessibility Indices

The denominator of the gravity model formula, called the accessibility index, is used as a measure of a zone's accessibility to the attractions of a particular trip purpose. For instance, that zone which shows the largest accessibility index value for home-based work trips is the zone with the greatest accessibility to employment throughout the study area. The accessibility index is calculated using travel time factors and zone attractions. Since the travel time factors are meaningful only in their relationship to each other, it follows that zone accessibility indices are important only in their relationship to each other. Table 8 gives the accessibility indices of each trip purpose for the gravity model both with and without zone terminal times. Both the maximum and minimum accessibility are given,with the corresponding zone number and the ratio of the maximum accessibility to minimum accessibility. In all purpose categories, the gravity model with zonal terminal times has an accessibility ratio which is lower than that for the model without terminal times. In all internal trip purpose categories except home-based work, the zone which had the maximum accessibility for the model without terminal times did not have the maximum accessibility for the model with terminal times. The significance of these results becomes important when attempting to use the gravity model as a measure of accessibility for alternate street systems. If terminal times are not used in the gravity model then any zone which has a terminal time reduction in the future will not show an increase in relative attraction in proportion to what it should show. This would undoubtedly affect the CBD more than other parts of an urban area.

Screenline Comparisons

Comparisons were made of the O-D volumes and the gravity model volumes crossing both of the screenlines which had been established in the Rock Hill area. The first of these was the Southern Railroad tracks running in a general east-west direction and designated as the north-south screenline (direction of vehicular movement) and the Southern Railroad tracks running in a general north-south direction and designated as the east-west screenline. Each of the screenlines runs through the central area of Rock Hill and intersects to divide the study areas into four separate areas (Fig. 2).

The results of the O-D and gravity model screenline crossings are given for the model with and without terminal times in Table 9. The north-south screenline shows

TABLE 8

COMPARISON OF ZONAL ACCESSIBILITY INDICES[a]

Trip	Without Terminal Times			With Terminal Times		
	Accessibility Index		Ratio Max/Min	Accessibility Index		Ratio Max/Min
	Maximum	Minimum		Maximum	Minimum	
Home-based work	20514	4546	4.51	14470	4091	3.54
Zone No.	(59)	(68)		(59)	(52)	
Home-based non-work	67487	10779	6.26	52041	9965	5.22
Zone No.	(1)	(32)		(12)	(32)	
Non-home-based	53575	13928	3.85	47079	12409	3.79
Zone No.	(6)	(32)		(12)	(68)	
Trucks	11688	2490	4.69	9372	2400	3.91
Zone No.	(1)	(32)		(12)	(32)	

[a]Denominator of the gravity model formula.

TABLE 9

COMPARISON OF SCREENLINE CROSSINGS O-D VS GRAVITY MODEL ASSIGNMENTS TO STREET NETWORK

Screenline	Without Terminal Times			With Terminal Times		
	O-D Crossings	G. M. Crossings	Ratio G. M. /O-D	O-D Crossings	G. M. Crossings	Ratio G. M. /O-D
East-West	32716	34040	1.040	32716	34060	1.041
North-South	29484	30446	1.033	29484	30544	1.036

slightly better results than the east-west screenline for both models; however, the difference is small and cannot be considered significant. The results of the models with and without terminal times are practically the same when comparing the sets of data from each model; however, there is apparently no significant difference in the two sets of comparisons.

CONCLUSIONS

In that phase of the original research study dealing with the Rock Hill area gravity model there were a considerable number of conclusions which were reached on the basis of evaluation of the study findings. Most of these conclusions, as would be expected, simply substantiated the findings of earlier studies. However, some of these conclusions were relatively new and will need further investigation in later studies. The conclusions which are presented here are those which were reached after a careful evaluation of the data contained in this paper only.

It would appear that the findings indicate that the use of terminal times in the gravity model for small urban areas is not critical. However, there is sufficient evidence to warrant further study of the use of terminal times in the gravity model for large urban areas where the numerical variation of the terminal times between zones may be high. It is therefore concluded that the gravity model formula provides an adequate framework, within the normal limitations of accuracy expected, for determining trip distribution patterns for Rock Hill using either the model with terminal times or the model without terminal times.

There is a significant difference in the travel time factors for non-home-based auto driver trips when terminal times are used than when not used. This conclusion does not necessarily imply that the trip distribution resulting from the use of different time factors would necessarily show a significant difference.

When over-the-road driving time alone is used as a measure of spatial separation, the relationship between travel time factors and time cannot be expressed by a constant exponent. However, the reverse of this is true when using total travel time; that is, the relationship between travel time factors and time can be closely approximated by a constant exponent. It follows that when travel time factors are developed for a gravity model using driving time alone these factors cannot safely be changed to include terminal times by simply adding an interval of time for this terminal time. It should be noted that the key words are "safely changed." The travel time factor curves for two of the four trip purposes were found to adequately reproduce the O-D trip length frequency distribution curves for the model using terminal times simply by adding an interval of 2 minutes to the curves using no terminal time.

The inclusion or exclusion of zone terminal times significantly affects the relationship of the zone accessibility indices.

The comparison of the screenline crossings for the gravity models with and without terminal times showed no significant difference.

In summary, it appears that an adequate measure of spatial separation for small urban areas, considering all of the various factors involved in applying the gravity model, is over-the-road driving time alone.

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