NATIONWIDE MODEL

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NATIONWIDE HIGHWAY TRAVEL

by

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at

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on
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It is not altogether proper that one person present this discussion of nationwide travel. Actually, it is a complex project—expensive in dollars and in talented and dedicated manpower both within Public Roads and throughout the Nation. It rests on a firm foundation of factual information provided by you over a period of several years. It is supplemented by related data gathered by a wide variety of agencies, and it involves the use of the most modern equipment in ways that perhaps the designer did not fully envision.

In the beginning and to a lesser extent even today, the concept of this project had to be molded to the capabilities of computer equipment. Since the Urban Planning Division in the Office of Planning of Public Roads was already committed to the largest available computers with a definite need to enlarge their capabilities, it seemed logical to assume that the development of procedures to plan a nationwide transportation system would benefit urban areas and vice versa.

The prerequisites in determining the amount of travel in any area are a network to describe the spatial separation, an inventory of trips, and an inventory of the socio-economic characteristics of the population and the area. All of these items have been established in many of our urban areas and in some of our States, but the size of the Nation makes many of the existing techniques inoperative or impractical.

The network is intimately related to zone size. In the United States, the smallest unit of area to which nationwide trip ends have been assigned is the county. In addition there is a considerable amount of information from census and other publications available by counties. From past experience, it was concluded that any units larger than counties would not produce meaningful results. Parenthetically, I would like to add that the dangers of zones that are too large far outweigh the dangers of zones that are too small. If zones are too large, the results are unrealistic. If they are too small, the work of preparing the network and the computer and plotting time increase approximately linearly with the added number of zones, but this added work has the compensating effect of increasing the realism.

The lower limit of zone size, so far as I know, has not yet been established, but the generality that the smaller the zones, the more realistic are the results is usually true.

There are 3,076 counties in the United States. This is about triple the number of zones that can be handled with the usual existing urban programs. To connect the counties, a transportation network is required. A network is described by a series of links or segments each of which is identified by node numbers at each end of the link. When two links meet, they have the same node number at the point of junction. Thus nodes identify intersections of links and describe the only permissible transfer point from one link to another. The concept of these nodes or intersection numbers is perhaps the most critical item in the application of computers to the network problem.

Without going into detail, it is largely the characteristics of the digital computer that dictate the logic that is incorporated into the procedure. As an oversimplification, it requires about eight binary words of computer memory for each node. Until recently the largest available computers had 32,000 words of memory. About 2 years ago, 65,000 words became available. In the near future 65,000 words will be plentiful; 130,000 words will be available, and with a diligent search it may be possible to find 260,000 words of memory. Thus 2 years ago it was possible to foresee a network of 8,000 nodes and today 16,000-or even 32,000-node networks seem feasible. In addition to the advance in computer hardware capabilities, there has been an additional increase in logic and programing techniques. Therefore, today the limitation of the number of nodes is much less severe. Be that as it may, what it is possible to accomplish today rests on programs set in motion about 2 years ago.

If counties are used as zones of origin and destination, 3,076 nodes will be required as centroids to locate beginnings and ends of trips. If the conventional approach is used, at least 3,076 nodes will be required to connect these centroids to the transportation system. Since the average county covers an area of about 1,000 square miles (roughly 30 miles on a side), it would seem appropriate that the transportation system initially investigated should have an average spacing of not more than 30 miles. Such a system would be about 210,000 miles long (about equivalent to the Federal-aid Primary System) and contain approximately 3,350 nodes. In total, therefore, approximately 9,500 nodes would be required which, while attainable today, were beyond implementation 2 years ago.

In order to avoid this difficulty, it was necessary to consider, in at least a modest way, a theoretical approach to the problem. As is frequently the case, this investigation brought to light other concepts which are still being explored, but it did provide a clue to permit a larger network within machine capabilities. If an area is reasonably square and the network is roughly uniform, the following equation provides an approximation of the number of nodes required:

$$N = \frac{L^2}{A(C/2)^2}$$

Where

N = Number of nodes
L = Length of network (miles)
A = Area of region (square miles)
C = Number of connecting links at each node

Note that the number of nodes required for a system of given length in a given area varies inversely with the square of the number of connecters to each node. The number of nodes that can be handled by the computer varies inversely with the number of connecters at each node. Thus, the more connecters to each node, the larger the network that can be accommodated on a given computer.

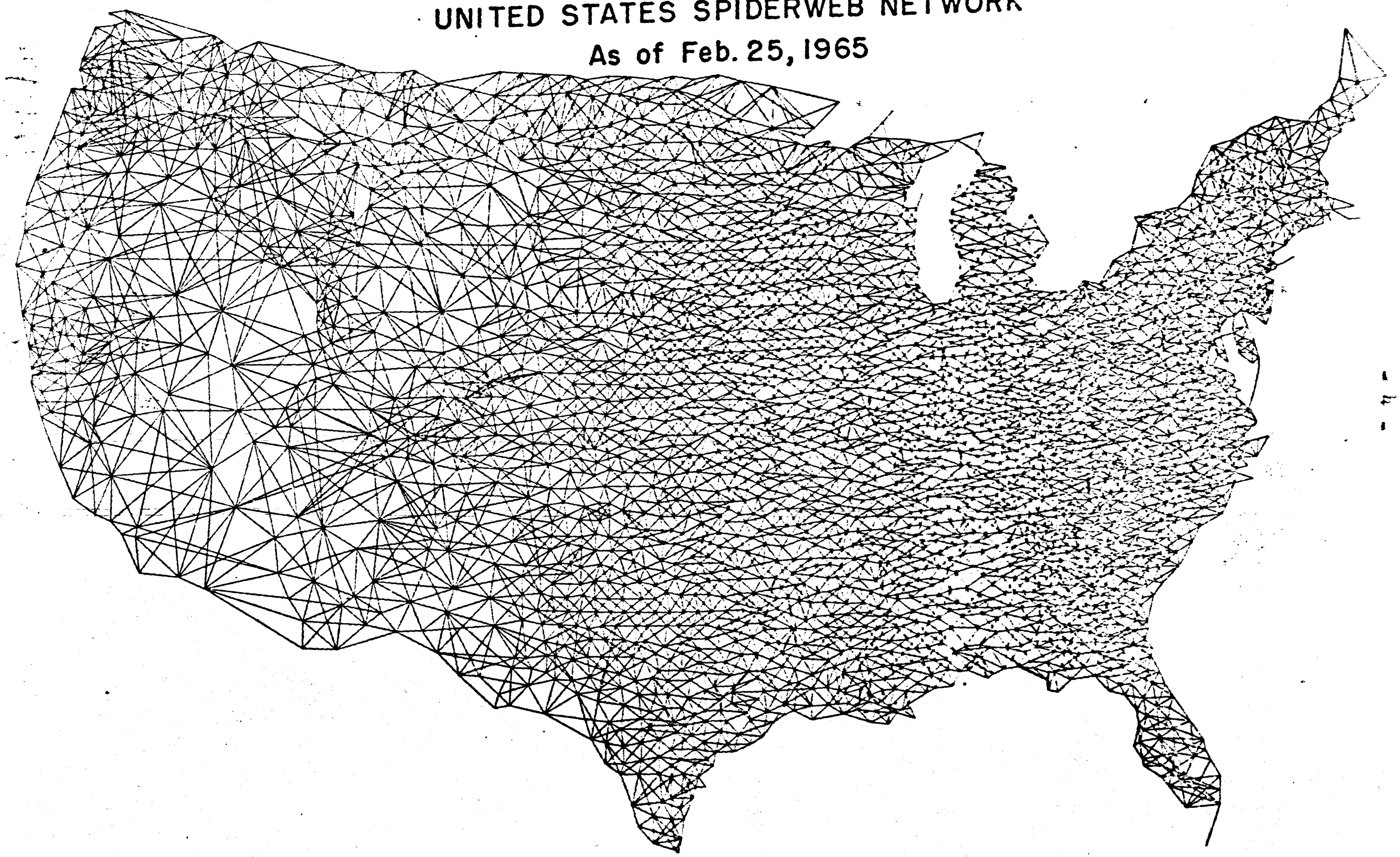
From characteristics of the programs, it is highly advantageous to have the number of connecters equal to an integer power of two. Thus, the only real choice is between four connecters or eight connecters. Unfortunately, eight-way intersections are extremely rare in nature, and the use of eight connecters means that the network will be more schematic than real. This was viewed with considerable alarm in the beginning but has since been found to have substantive advantages in that it measures the potential of routes that do not actually exist.

With these considerations in mind a network was planned with a node at the center of population of each county and each county centroid connected to eight surrounding counties. Due to the variation in size, shape, and location of the individual counties, it was not always possible to connect each county with exactly eight other counties. In 211 cases it was necessary to accommodate more than 8 links from each county. This was accomplished by inserting an additional node (called a dummy node) at these locations which was connected to the county centroid with a link of zero distance. In other cases, particularly around the border, there was no need for eight connecters. In total, the network consists of 3,076 county centroids with an additional 211 dummy nodes connected by a system of 11,487 two-way links. Thus, on the average, each node has almost exactly 7 links (6.99) per node. A map of the system is shown on figure 1.

The network is 440,600 miles long as compared to the Federal-aid Primary System of 242,000 miles, the State Primary System of 460,000 miles, and the total Federal-aid System (FAP + FAS) of 850,000 miles. It is slightly more direct between major cities than the existing system—on the average it is about 13 percent less than the mileage between cities shown in the Rand-McNally atlas.

Figure 1

UNITED STATES SPIDERWEB NETWORK
As of Feb. 25, 1965



Using this network, the spatial separation between all pairs of counties was determined by a minimum path (tree) program as shown on figure 2. This has been accomplished on the IBM 7094 at Texas A&M University at about 2½ seconds per tree and on the CDC 3600 in Washington at about 2 1/3 seconds per tree. Since 3,076 trees are required, the entire operation requires about 2 hours of computer time.

Trips

A second element in the study of travel is an inventory of the trips. In urban areas this is accomplished by obtaining a sample of all trips made within the area. In most statewide studies and in a nationwide study, this type of inventory has not yet been possible. The lack of an inventory is particularly troublesome in that the universe of travel is hard to establish. The universe is principally needed to determine:

1. The trip generation characteristics of each zone

2. The trip attraction characteristics of each zone

3. The effect of spatial separation

To work out of this difficulty, it is necessary to resort to other more specialized studies and from these attempt through mathematical and statistical techniques to infer the nature of nationwide travel. The most important of these special studies is the external cordon survey around most of the larger urban areas. From these it is possible to establish in detail all of the items needed but only for the area enclosed within the cordon. However, each cordon area represents only a small portion of the United States, and each has seemingly an almost unique set of characteristics. It would appear possible to obtain a large number of these cordon area studies and assemble them into a significant portion of the nation, and this is precisely what was originally contemplated. Unfortunately this turned out to be impractical for a number of reasons:

1. Since the cordon area surveys are primarily to establish travel within the cordon, many studies did not take the time to code the external end of the trip to county particularly for trips made outside the home State.

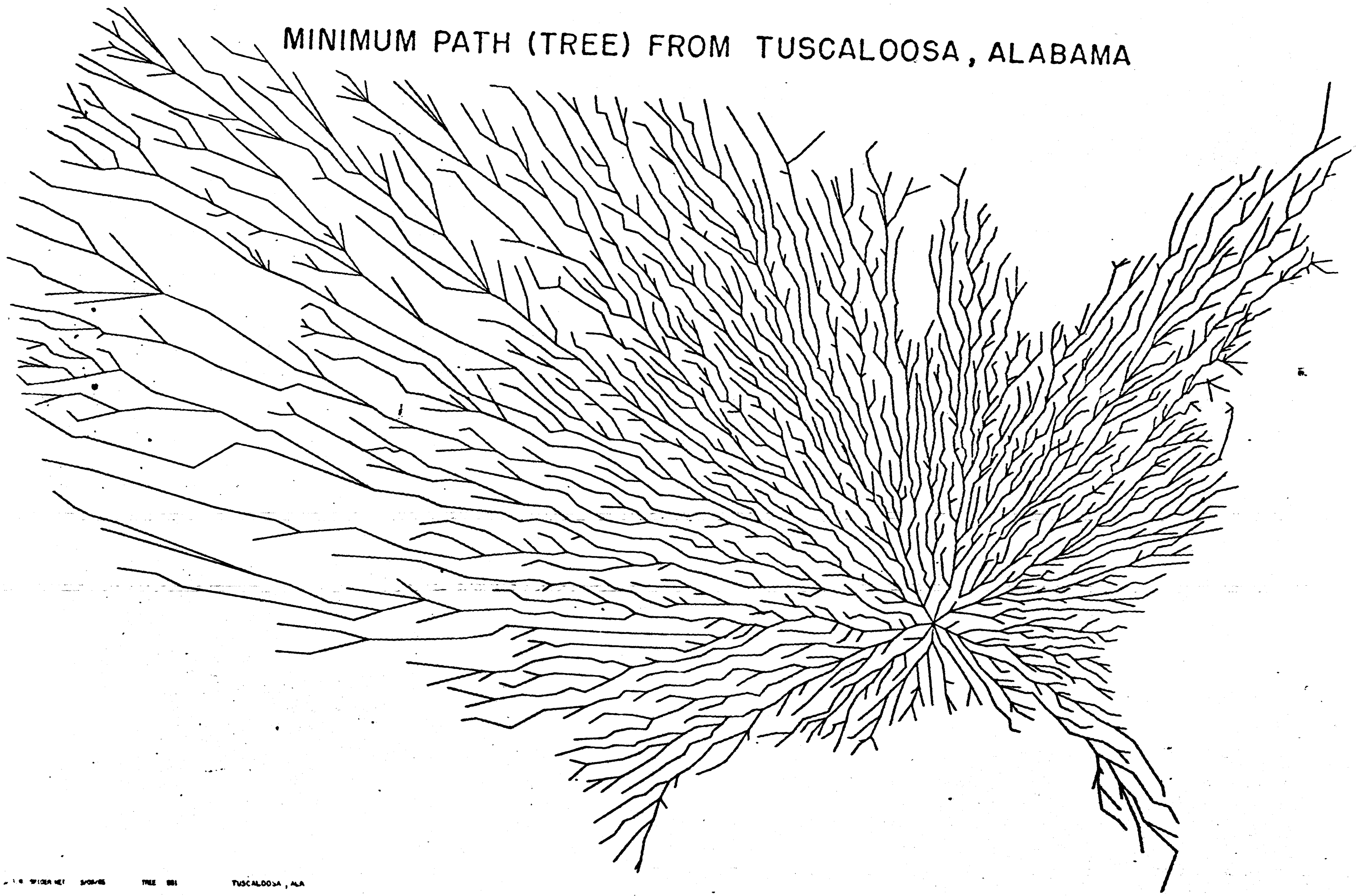
2. Some surveys do not identify the residence of the trip maker.

3. Many of the surveys establish a unique zone numbering system which is extremely time consuming to convert to a standard system.

4. In some cases the editing is incomplete.

On the average it takes about 6 months to convert an external cordon study into a standard format.

Figure 2


MINIMUM PATH (TREE) FROM TUSCALOOSA, ALABAMA
TREE
TUSCALOOSA, ALA

A second source of information is the Road Use studies. These studies are useful in establishing trip generation rates particularly in areas other than those covered by external cordon surveys.

A third source of information that probably has the best potential of providing useful data is the multiple screenline surveys such as those made in the Mississippi Valley States. To date the problems of converting these data into a standard edited format with appropriate factors have made their use impracticable.

In overall perspective there is a very considerable amount of nationwide travel data available, but the cost and time required to place these data into a standardized edited format is formidable. Again, parenthetically, I would like to add that the sets of programs being contemplated for the new generation of computers are being designed to provide tighter controls on the editing process, to standardize codes, and to facilitate recode and reformat procedures.

To permit an evaluation of the overall concept without pursuing each of the facets to completion, it was decided to make a series of approximations or assumptions based on a relatively small amount of data and carry these through the entire process. This procedure has some very definite advantages as follows:

1. All computer programs needed in the process could be tested and modified if needed to accommodate values occurring in the nationwide system.

2. A scale of magnitudes would be established for results and the cost in dollars and effort to achieve the results.

3. New programs and procedures needed to adequately display the results in an understandable fashion could be initiated.

4. A scale of accuracy could be established for the overall process which, if of no other value, would be useful in evaluating future refinements.

5. To the extent that manpower was available, the refinements could proceed simultaneously with the development of the entire process.

A disadvantage is the chance that the results would be so poor that the entire project would be abandoned.

Trip generation

Many of the activities carried on in the United States require travel—the movement of persons or goods. It may involve several different modes—highway, rail, air, water, pipe lines, etc. Due to availability of data and to permit more rapid completion, only highway travel is being considered in this study. Purely as a matter of convenience, the travel is being reported in units of vehicle trips. It should be clear that the units of trips is not fundamental to the process—person trips or tons of goods could be used equally well.

Each area of the United States has the capability of initiating a trip or attracting a trip. Since the ability to initiate or generate trips may depend on different characteristics than the ability to attract trips, it is convenient to separate trip ends into these categories. Most, but not all, trips occur in pairs—from the initiating or generating end to the attracting end and return. A portion of the attracted trips become generators of additional trips to other attractors before returning to the generating point.

Considerable work is currently underway on characteristics that influence the number of trips generated in an area. This will be reported in greater detail in subsequent publications. Population, car ownership, and income are among those factors which are significant.

For the initial study it was decided to use the trip generating value as observed in Washington, D.C. Due to the area included within the cordon, the distance from the Washington centroid to the nearest county exceeded 20 miles. The total number of trips crossing the cordon with either origin or destination in Washington was 132,634 vehicles or about 7 trips per 100 population for trips of over 20 miles. This seems to agree fairly well with road use surveys conducted in 22 States. It was arbitrarily assumed that half of these trips were generated and half attracted.

Trip attraction

Each trip that is generated must be attracted to some place. Therefore, the total number of trip attractions must equal the total number of trip generations. The number of trips attracted to an area depends on the characteristics of the area but probably more importantly depends on the location of the area relative to trip generators and other trip attractors. In other words the number of trips attracted to an area depends on the number of trip generations in concentric rings surrounding the area with adjacent rings having more effect than more distant rings. In addition the number of trips attracted to an area depends on the competition of other similar attractors in the area.

In the initial study it was assumed that the attraction of an area was proportional to the population of the area. This assumption is probably fairly reasonable for work, business, and shopping trips, but is questionable for social-recreation trips. To account for the competition among attraction areas, an attraction index was computed for each county. It consists essentially of summing the number of attractions (proportional to population in the initial study) divided by a function of distance. The distance function will be discussed later.

As might be expected, this attraction index has a wide variation. In magnitude, it is roughly equivalent to the number of attractions (population) 1 mile from each centroid. For Westchester County, New York, it is 1,075,000 and for Phillips County, Montana, it is 1,487. Therefore, a county of 10,000 population in the vicinity of Westchester County, New York, has much less potential of attracting trips than a similar county in the vicinity of Phillips County, Montana.

Spatial separation

The most critical element in developing an equation to describe travel is the selection of an appropriate function of spatial separation. The separation may be measured in distance, time, cost, or any combination of these. For the initial study distance was the primary measure used and was determined from the network previously described.

Due to boundary conditions, the area available for travel at various points within the nation is not constant. Figure 3 shows the land area enclosed within circles of various radii from Washington, D.C., Atlanta, Georgia, and Providence, Rhode Island. The plot is on log-log paper which tends to suppress the absolute magnitude of the difference. Under ideal conditions, it would be possible to reach any point in a 3,000,000 square mile area at a distance of less than 1,000 miles. Each of the cities shown requires more than twice this distance to reach all other areas, and in the case of Providence the distance is almost 3 times (2,760 miles) the theoretical minimum. Note that up to a distance of about 300 miles, the land area surrounding Atlanta is very close to the theoretical but the land area surrounding Providence is less than half of the theoretical.

Since population is not uniformly distributed throughout the United States, the population enclosed within rings of various radii shows an even wider variation as shown on figure 4. In general the population near the cities shown is considerably higher than would occur if the population were uniformly distributed although Atlanta is fairly close to the theoretical line from 100 to 900 miles.

Therefore it appears unlikely that trip length frequency would be a constant as anticipated in the gravity model. This was subsequently shown to be true by observing the trips from Washington, Atlanta, and Providence. Of the trips longer than 20 miles, the percentage going on longer journeys is shown in the following table:

More than	Washington	Atlanta	Providence
30 miles	72.7	29.5	28.2
40 miles	31.4	28.3	6.0
50 miles	21.2	23.8	4.0
100 miles	12.6	11.2	1.5

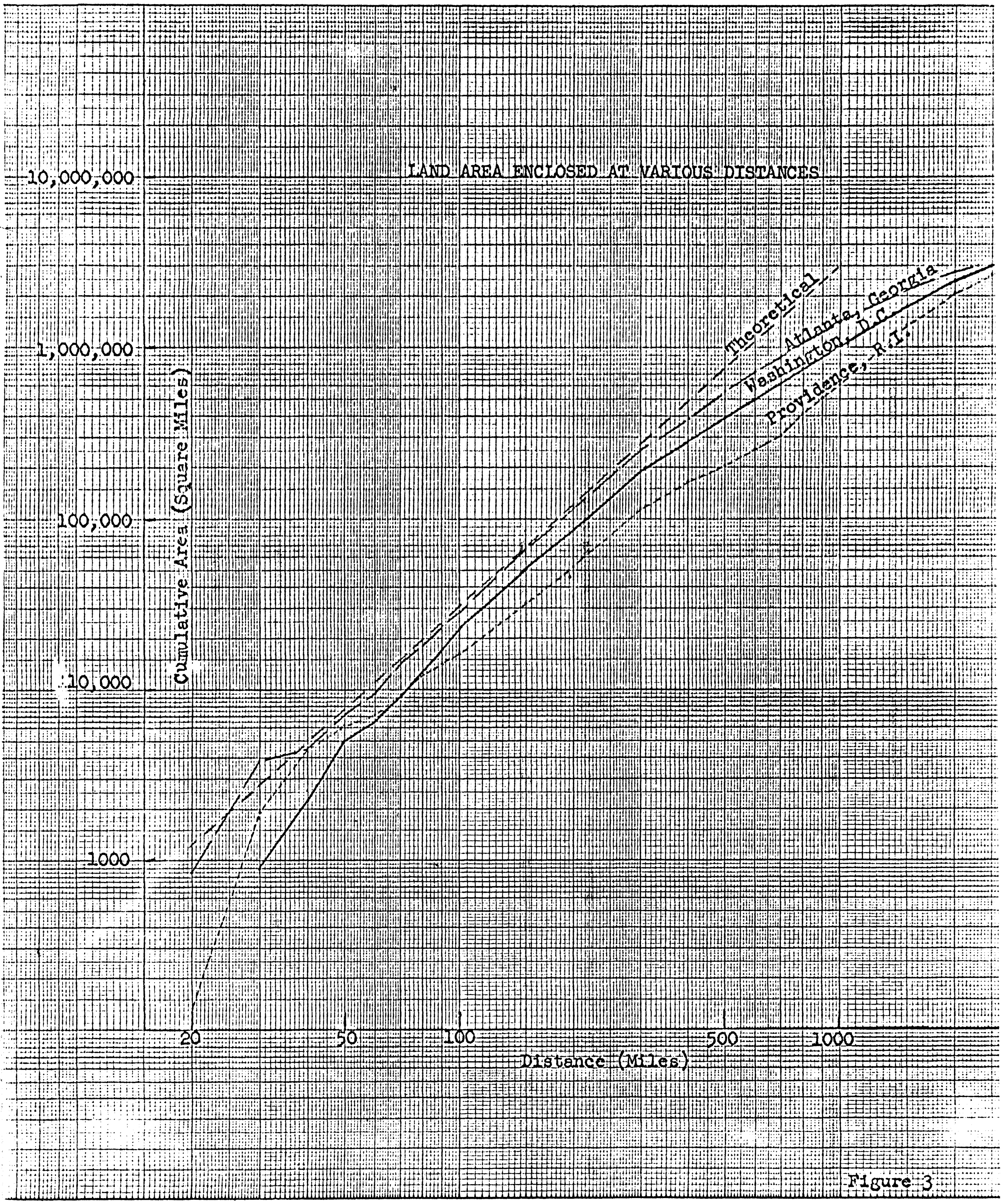

LAND AREA ENCLOSED AT VARIOUS DISTANCES
10,000,000
1,000,000
100,000
10,000
1000
Cumulative Area (Square Miles)
20
50
100
500
1000
Distance (Miles)
Theoretical
Atlanta, Georgia
Washington, D.C.
Providence, R.I.

Figure 3

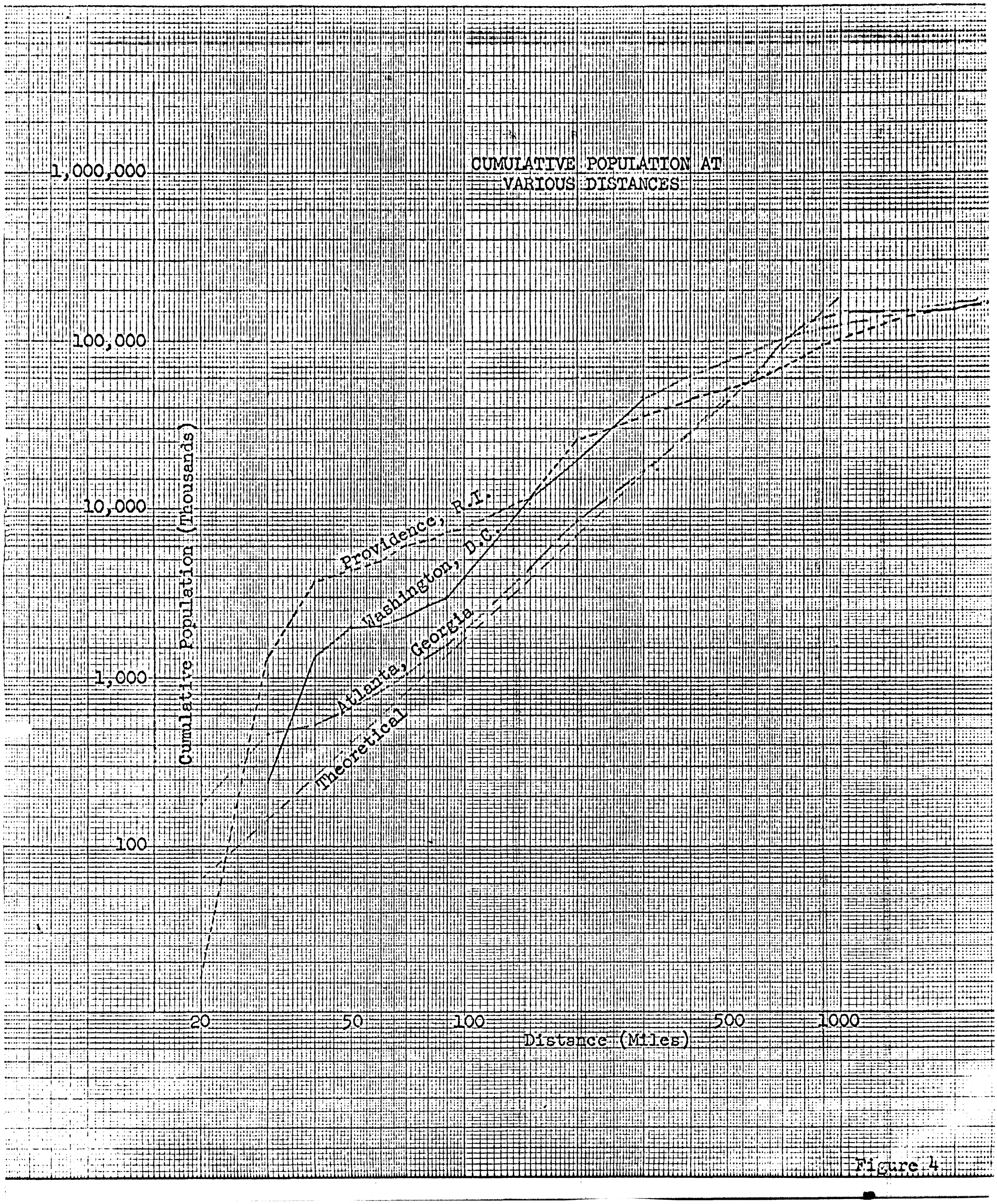

CUMULATIVE POPULATION AT
VARIOUS DISTANCES
1,000,000
100,000
10,000
1,000
100
Cumulative Population (Thousands)
Providence, R.I.
Washington, D.C.
Atlanta, Georgia
Theoretical
20
50
100
500
1000
Distance (Miles)

Figure 4

It seemed possible that the probability of trips per 1,000 attractions would be more nearly a constant for any particular length. Since it already had been assumed that attractions were proportional to population, the trips per 1,000 population at the destination were accumulated.

To smooth the data and at the same time decrease the amount of work, the trips and characteristics of the individual counties were grouped into 10 mile rings. The ring data for Washington, D.C., (which were the first available) were then used as input to a stepwise multiple regression program. The results of this run indicated that a factor of $1/(\text{Distance})^{2.75}$ would explain 98.73 percent of the variance in the number of trips to the individual rings. The addition of other variables did not appreciably increase the correlation.

It was subsequently determined that the distance function was not applicable to trips of less than 20 miles. Rather than delay the initial study to determine an applicable function for short distances, which incidentally is quite difficult, it was decided to assume a minimum distance of 20 miles. This does distort travel between nearby cities and is evident in the results of the initial study. However, it affects only the initial link out of a centroid.

Trip equation

For the initial study the equation used to calculate the number of trips from County A to County B is as follows:

$$T_{A-B} = \frac{G_A A_B}{\Sigma A_A}\left(0.001 + \frac{877,491}{D_{A-B}^{2.75}}\right)$$

Where

T_{A-B} = Trips generated in County A and attracted to County B

G_A = Trips generated in County A
= 0.017 population of County A (initial study)

A_B = Attractions in County B
= population County B (thousands)(initial study)

$$\Sigma A_A = 0.001(\Sigma P - P_A) + 877,491\left(\Sigma \frac{P_n}{D_n^{2.75}} - \frac{P_A}{D_{A-A}^{2.75}}\right)$$

Where

ΣP = Population of the United States (thousands)

$\Sigma \frac{P_n}{D_n^{2.75}}$ = Sum for United States of population (thousands) in each county divided by distance (miles) between County A and each county

In a similar manner the number of trips generated in County B and attracted to County A was calculated by:

$$T_{B-A} = \frac{G_B A_A}{\Sigma A_B}\left(0.001 + \frac{877,491}{D_{B-A}^{2.75}}\right)$$

In the initial study it was also assumed that each trip generated in County A and attracted to County B and vice versa would also return to the initial county. Therefore, the trips with origin in County A and destination in County B and vice versa are equal to:

$$T_{A \text{ to } B} = T_{A-B} + T_{B-A} = T_{B \text{ to } A}$$

A program was written to solve this equation and in so doing it was necessary to resolve some further problems. From the equation it is clear that many of the county to county movements are extremely small—some less than a millionth of a trip. If each movement were reported, the trip table for 3,076 counties to 3,076 counties would require about 4 reels of tape. If only trips of one or more were reported, it was expected that the entire trip file could be written on less than one reel of tape.

However, if conventional rounding techniques were employed, it was expected that rounding to the lower value would substantially exceed the rounding to a higher value. Thus the total number of trips would be substantially reduced. To avoid this difficulty, the fractional part of each trip calculation was continually held in the computer and added to the next value. Whenever the value or the accumulation of fractions exceeded one, the integer portion was written out on tape. Thus, the reported value was always within one trip of the correct value, and similarly, the total reported for all trips was within one trip of the correct value. The use of this technique reduced the trip table from over three reels of tape to approximately one-third of a reel. As a matter of interest trips were recorded from New York to approximately 800 other counties. Due to its central location, trips were reported from Chicago to approximately 2,400 other counties.

The omission of zero trip volumes from the trip table has an attribute that is slightly irritating at the moment but may be more troublesome in the future. Heretofore a conventional trip table for each zone consists of a record on tape—essentially a list of numbers called words. The first word contains an identification of the zone number from which the trips are coming and also the number of words that follow in this particular record. The second word is always the number of trips to zone 1, the third word is always the number of trips to zone 2, and continuing the (n+1) word is always the trip to zone n. The position of the word in the record therefore indicates the zone number to which the trips are going.

If, however, the zero volumes are to be omitted from the trip table, the one for one correspondence has been destroyed, and it is necessary to have an identification zone number in each word in addition to the number of trips.

If it is necessary to squeeze two values into one word, two additional constraints follow which will be, at best, irritating to a large group of potential users. These are:

1. The words should be written in a binary mode rather than BCD (decimal) mode. This is true for a multitude of reasons, but it does mean that the large class of decimal machines such as the 1401, 1410, and 7010 cannot be used.

2. The FORTRAN program language cannot be used because it has no instructions in its vocabulary capable of packing or unpacking two values into one word.

The advantages are simple. For the nationwide study, the trip file is on one reel rather than four, and each time the program is run, a saving of over $100 results.

A new generation of computers is becoming available. One of the most popular will have a word size of 32 bits compared to the 36 bits and larger for some of the current machines. If the sign position is kept free, up to 4,000 zones and trip values of 500,000 can be accommodated in 1 word. This appears to be satisfactory but most of the safety margin has been removed.

Results of the first study

With the factors and assumptions previously described, the vehicle trips from each county to all other counties were computed and loaded on the nationwide network. This was completed in December of 1965. The results were given in roughly 200 tabulation sheets which, in effect, were equivalent to a final exam for the process. The grade would be established by the agreement or lack of agreement with the travel measured on the ground. In the light of the gross nature of some of the assumptions, the results were approached with some misgivings.

The first check was the volume assigned across the Straits of Mackinac as compared to the volume on the bridge. The agreement was startling. During the period 1960-63, there was an annual average daily traffic volume on the bridge that agreed exactly with the volume in the model. The only question involved was precisely what time does the model represent and was purely academic.

The model was checked with the ground counts at

1. The Tucson external cordon

2. A north-south line across the United States at about the west edge of North Dakota

3. The east border of Missouri

4. An east-west line through Florida

5. The south border of Michigan

The results of these tests indicated that the basic model was surprisingly accurate. There seemed to be no need for gross readjustments but rather detailed refinements.

To provide a more comprehensive analysis of the model, each of the regional offices of Public Roads was requested to compare the model assignment with actual ground counts at each of the State borders. These checks were completed by the State highway departments in a very short time, and all results were received by February 15, 1966.

The details provided by this check continue to yield a wealth of information. In overall total 11.1 million vehicles were counted crossing State boundaries while 11.2 million were assigned by the model. This figure is misleadingly good.

In general the model is low, illustrated by the fact that the counts and assignment agree within 10 percent in 12 States, the assignment is more than 10 percent high in 3 States, but more than 10 percent low in 33 States. Analysis has led to a set of tentative conclusions as follows:

1. Vehicle ownership must be one of the most important factors in trip generation. Trips in the New York City-New Jersey area were overestimated by more than $3\frac{1}{2}$ times. Approximately 80 percent of the families in Manhattan own no vehicle which is 4 times the national average of 20 percent.

2. Population appears to be a reasonable indicator of trip attractions except for recreational travel where it is significantly deficient. Receipts for hotels and motels seem to provide better correlation but probably measure an effect rather than a cause.

3. Trips between two areas, the centers of which are 20 miles apart, will contain a preponderant number of trips less than 20 miles long. The basic trip generation rate should therefore be increased.

4. The distance function for the attenuation of trips of less than 20 miles long appears to be more complex than distance raised to a constant power.

5. Travel in large areas such as the nation appear to follow definable principles better than in smaller urban areas probably because the mixture of activities in a zone is more homogeneous.

6. Advantages would undoubtedly accrue if trips were separated by vehicle type and purpose, if the zones were made smaller and the network larger.

Presentation of nationwide assignments

After the initial study had been checked as previously described, the results were still essentially hidden on 200 sheets of paper. It was important to be able to grasp in some manner the overall results of the initial study.

In early 1966 techniques had been developed and used many times in plotting networks and trees and inserting numbers on each link denoting the volume. This is accomplished by going directly from computer tape to a mechanical plotter. This approach is fine for detail but provides no basis for continuity of pattern. General Electric was persuaded to develop a procedure which would automatically plot a band width on each link proportional to the volume in the usual configuration of a traffic flow map with perhaps one added feature. The volumes on the nationwide network varied from 1 vehicle to 1.5 million vehicles. To avoid overlapping to such a degree that the pattern would be unintelligible, it was decided to limit the band width to 1/4 inch. If all volumes were plotted to this scale, 1/100 inch, which is hardly discernible, would represent 60,000 vehicles which is a monstrous load. Therefore the volumes were stratified roughly by type facility and plotted in different colors. Volumes above 25,000 were assumed to require more than 4-lane divided; 4,000 to 25,000 were assumed to require 4-lane divided; 1,000 to 4,000 were assumed to require a high type 2-lane highway; 400 to 1,000 an intermediate type facility, and less than 400 a low type facility. The band width within each volume group then reflected the proportion of the load within the limits of the group.

The volumes resulting from the initial loading are shown as an attachment. Due to space limitation only the three heaviest volume groups have been shown and the band widths have been omitted.

System selection

Although refinements are being made to the model and the volumes are present rather than future volumes, a set of principles have evolved that should prove useful in selection of an optimum system.

The volumes shown on the assignment are interzone trips. In this particular case they represent intercounty movements and in total account for 658 million vehicle-miles per day or about 31 percent of the 2.1 billion vehicle-miles per day traveled in the United States. Since most intraurban trips are not included in the model, a more logical comparison may be to the total rural vehicle miles of 1.14 billion vehicle miles per day or the Federal-aid Primary rural vehicle miles of 608 million vehicle miles per day.

The above illustrates a principle that zone size must be commensurate with the universe of travel being investigated. Therefore the model as it exists today is only potentially useful for intercounty travel which is approximately equivalent to 31 percent of the total vehicle-miles, 58 percent of the rural vehicle-miles, or 108 percent of the rural Federal-aid Primary vehicle-miles.

An attribute of traffic assignment is that the network must be completely defined before the procedure starts. Thus, the initial study made the tacit assumption that all links were of equal quality. The results, however, indicate that 770 miles of the network would have no load, and 59,474 miles would have less than 100 vehicles per day and so forth as far as intercounty travel is concerned. In actual practice and in conformity with good and logical reasons, the design of the highway is commensurate with the volume to be carried. The alinement, grades, sight distance, access control, surface type, and a variety of other standards are much better for a highway carrying 10,000 vehicles per day than for one carrying 100 vehicles per day. Related to this is the very obvious preference the motorist has for well-designed highways.

If an impedance can be established for each link that is commensurate with the design standards of that link, then some of the traffic on low volume links will be diverted to other links with higher volumes and therefore designed to a higher standard.

This impedance, when viewed by the logic incorporated in the assignment process, is equivalent to a reduction in speed, and the minimum path selected reflects the impedance on each link. The amount of impedance for each traffic volume is subject to more thorough theoretical and empirical study, but to observe the effects the following values were arbitrarily selected to replace the one unit per mile inherent in the initial system:

Two-way link volume	New impedance	Equivalent speed
0	3.00	20 m.p.h.
100	2.40	25 m.p.h.
200	2.00	30 m.p.h.
300	1.71	35 m.p.h.
500	1.50	40 m.p.h.
750	1.33	45 m.p.h.
1,000	1.20	50 m.p.h.
2,000	1.09	55 m.p.h.
4,000	1.00	60 m.p.h.
10,000	0.92	65 m.p.h.
25,000	1.00	60 m.p.h.
50,000	1.09	55 m.p.h.
Over 2,000,000	1.20	50 m.p.h.

When the new link values were used to reload the system, the volumes as shown on the attachment for the second load were obtained.

Based on the volumes obtained from the second load, the process was repeated. Unfortunately the plots for the third load were not available for this paper, but a summary of the results are available on table 1.

The effects of the process are apparent in the table and on the maps. Although all systems provide access to every county, the length of the system needed to accommodate this travel (i.e., the mileage of non-zero links) decreases sharply for each of the three loads but is accompanied by a very modest increase in vehicle-miles. Using the first load as a base, the vehicle miles of travel for the second load increase by 1.8 percent but the extent of the system is decreased by 29 percent, and for the third load the vehicle-miles of travel increase by 2.7 percent but the extent of the system is decreased by 43 percent. Strangely enough the third system provides better service than the second system if the impedances are viewed in terms of traveltime.

It is redundant to observe that other considerations are involved in the selection of a transportation system, but this is an application of the current state of technology. In the beginning the goal was the development of a procedure to accommodate nationwide travel, and the work was relentlessly pushed to achieve this objective. Along the way numerous paths have been opened but left unexplored. In overall perspective the amount of work remaining is probably greater than the amount originally contemplated for the entire study.

Attachments 2:
Initial loading of nationwide spiderweb network
Second loading of nationwide spiderweb network

Table 1

Summary of Assignments on Nationwide Network

Volume	Assignment 1				Assignment 2				Assignment 3			
	Miles 1/	Pct.	Vehicle miles 2/	Pct.	Miles 1/	Pct.	Vehicle miles 2/	Pct.	Miles 1/	Pct.	Vehicle miles 2/	Pct.
0	0.8	0.2	-	-	128.5	29.2	-	-	191.6	43.5	-	-
1-399	176.1	40.0	30.6	4.7	131.6	29.9	18.7	2.8	92.8	21.0	12.5	1.8
400-999	124.3	28.2	82.7	12.6	61.7	14.0	40.3	6.0	43.5	9.9	28.9	4.3
1-4K	116.1	26.3	216.2	32.8	82.3	18.6	171.3	25.6	71.4	16.2	153.6	22.7
4-25K	21.6	4.9	157.8	24.0	34.6	7.9	263.2	39.4	39.4	9.0	305.5	45.2
Over 25K	1.7	0.4	170.3	25.9	1.9	0.4	174.8	26.2	1.9	0.4	175.1	26.0
Total	440.6	100.0	657.6	100.0	440.6	100.0	668.3	100.0	440.6	100.0	675.6	100.0
Vehicle hours 2/			10.93				12.04				11.89	

1/ Miles are reported in thousands of miles.

2/ Vehicle miles and vehicle hours are reported in millions per day.