Calibration of Transit Networks in Medium-Sized Urban Areas

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•AN EFFECTIVE transportation plan for an urban area should promote complementary and not competitive uses of each travel mode. Therefore, the planning of transit facilities should include a careful analysis of the interaction of the transit network with other modes. The first step in this planning is to inventory and code the existing facilities and the characteristics of the travel on them. The elements of the transportation networks can then be represented within the computer as can also the flow of travel over them. Because the inventoried network represented in the computer must function as nearly like the real network as possible, it must be carefully checked and calibrated so that it can be used with confidence in planning future networks.

Network calibration is the process wherein the network simulated from inventory data is revised by a logical procedure so that travel routed over it by the computer is characteristically similar to that observed on the actual network. Although both are important, the process of calibrating the network can be distinguished from that of checking the network. The purpose of the latter is to ensure the accuracy of the data that describe the network's physical characteristics. The calibration process ensures that there is a comparable relationship between the network and travel as it actually exists and as it is simulated in the computer. Network checking is, therefore, a preliminary requisite to network calibration.

Network calibration is important in transportation planning for several reasons. First, it ensures that the existing operating characteristics of each mode are accurately described. This is important in planning a future system, a major portion of which will normally be composed of the existing one. Second, the estimation of future travel via each mode considers the relative level of service afforded by each mode, which is closely related to network speeds and operating characteristics.

Finally, operational problems involving network components, such as street segments, intersections, or transit routes, are more easily studied within the adjacent network structure than as isolated pieces. A calibrated network permits the study of the operation of different components of the existing system in relationship to the whole. In this way it supplements the inventoried data on components because the inventory does not supply data on component interaction. It also serves as a check on the reasonableness of component characteristics, particularly in response to travel patterns.

In the analysis of transit networks, a calibrated base network has other essential uses. The effect of changes in scheduling, routing, and fares on transit ridership is closely related to the differences in level of service on different portions of the existing network. It is extremely difficult, if not impossible, to manipulate real networks in a trial-and-error manner in order to observe the effects of improvements to that network. Simulated networks, properly calibrated, can be used to observe such effects prior to their implementation. Also, improvement of inefficient transit operation is often facilitated by study of the existing network that, if calibrated, will contain those inefficiences at approximately the correct scale of importance.

This paper documents a method for preparing calibrated transit networks, using network inventory data and travel patterns observed in several upstate New York cities.

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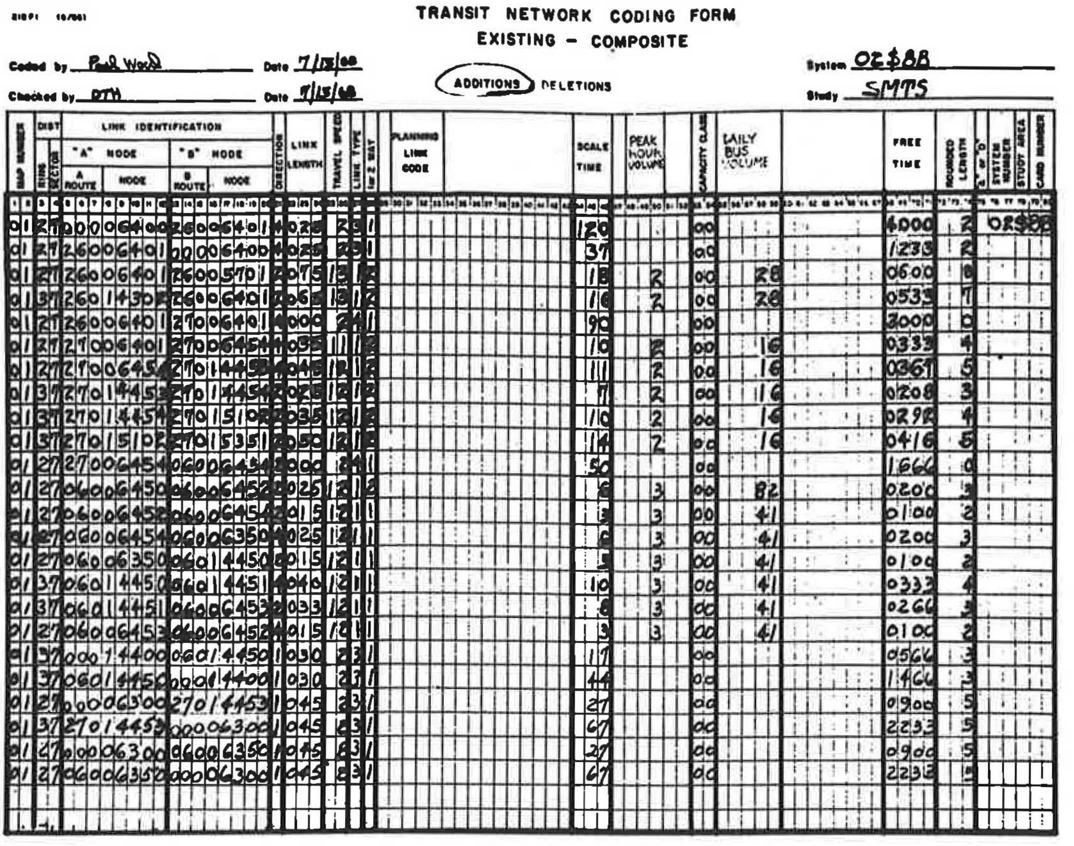

Figure 1. Transit network coding form.

TRANSIT NETWORK INVENTORY

The first step in the preparation of the calibrated transit network is an inventory of the existing routes. Information on the level of transit service is collected for each route segment. This normally includes scheduled peak and off-peak headway, number of daily buses in each direction, speed, fare, route locations, transfer points, and points of route turnbacks or branches.

The transit network is described by series of links defined by two nodes. The node number is composed of eight digits—the first three indicate the route number, the last five, the zone number and node number within that zone. For example the link

320 115 02—320 115 03

indicates route number 320, going from zone 115, node 02, to zone 115, node 03 (1). Additional information about the link is then coded as shown in Figure 1. Normally, the values of free time (travel time in hours) and rounded link length would be calculated from other coded data.

There are three major types of links in the transit network.

1. Mainline links (coded 1 or 2 in column 27 of the form shown in Figure 1) are the portions of the network over which buses actually travel; they are usually two-way. Depending on its operating characteristics, a mainline link may represent any one of a number of transit modes (local bus, express bus, or rail rapid transit.)

2. Access links (coded 3 or 5 in column 27) represent the paths of access from mainline links to zone centroids or loading nodes.

3. Transfer links (coded 4 in column 27) provided for movement from one mainline route to another, usually over a very short distance.

Other link types are available for special uses or composite network analysis. All links are coded as one- or two-way. There are no turn prohibitors, travel on the network being controlled by the coding itself.

Figure 1 is the numerical description of the simple network shown in Figure 2. Figure 2 shows typical bus routes for a residential neighborhood, similar to maps prepared by the transit company; it also shows these links transformed into a series of coded links. Access is provided to those zones adjacent to each route, and transfers between routes at points of divergence are provided. Finally, information taken from schedules on bus speed, headway, and travel time for each route is posted on this map. Information is then entered on the coding form for keypunching.

TRANSIT NETWORK CALIBRATION

Network Characteristics and Variables

Calibration ensures that the coded transit network responds to travel in a manner similar to that of the actual transit network. Therefore, the variables, whose values describe the coded network, should be as independent of each other as possible; that is, each one should be a measurement of a different characteristic of the operation of the network. These characteristics of the network are its spatial extent, its temporal extent, the speed at which it operates, and travel patterns.

The spatial extent of a transit network is the coverage it provides to an area. One measure of this is the number of route-miles operated per square mile of area. This measure determines to a large extent how easily those persons in a given area can reach transit routes. For instance, the influence of a transit route extends to about one-half mile on either side, while the average user walks between 500 and 700 feet to board a transit vehicle (2).

Routes with very poor services should not be included in the coded network. The guide is whether or not the route contributes significantly to transit operation, partic-

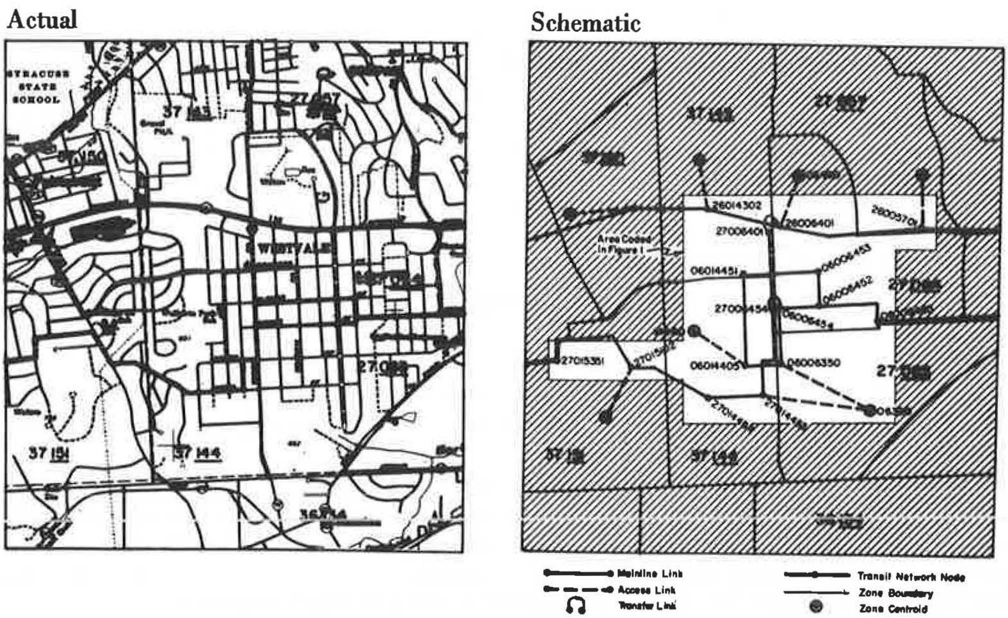

Figure 2. Portion of 1966 Syracuse transit network.

ularly during the peak hour. If it does, then it should be included. Studies in several cities in upstate New York indicate that a reasonable lower limit is a route having one bus during peak hour and four buses during the day in each direction.

The temporal or frequency-of-service aspect of a transit network can be measured by the average time a transit user spends waiting for a vehicle once he arrives at the bus stop or station. Also included is the waiting time at transfer points, which may be approximated by the number of transfers occurring over a given period.

The operation of the transit network is measured by travel speed once the transit rider has boarded the vehicle. The operating speed of the vehicle itself is unaffected by network coverage or by frequency of transit service. Door-to-door speed, on the other hand, is affected by these variables, and it is difficult to isolate their effect on overall network speed. Therefore, because it is a more independent measure, vehicle operating speed is used instead of door-to-door speed.

Travel pattern refers to the routing of trips over the network; it is based on trip length or trip duration. If the coded network responds to travel in a reasonable manner, travel distances and travel times should be similar to those on the actual network.

Measures of Network Operation

The process of calibration involves the comparison of estimates of transit network operation with known values, and subsequent revisions to improve agreement between the two. This comparison can be done by assigning known transit trip interchanges determined from the home-interview survey to the transit network, and observing the travel pattern. The parameters observed should measure a variety of aspects of system operation. Table 1 lists the most commonly used control values (in order of rela-

TABLE 1

SOURCES OF VALUES OF VARIABLES USED IN TRANSIT NETWORK CALIBRATION

Variable	Source of Control Value	Source of Estimated Value	Aspect of Network Measured	Percent Error Allowable Between Control and Estimated Values
Operating speed[a]	Company records	Transit network summaries	Speed	5
Route-miles per square mile[a]	Company records	Transit network summaries	Coverage	10
Distribution of travel time[a]	Home interview	Assignment	Trip duration	Similar to control at 0.05 level[c]
Distribution of travel distance[a]	Home interview	Assignment	Trip distance	Similar to control at 0.05 level[c]
Person-hours of travel[b]	Home interview	Assignment	Frequency	5
Person-miles of travel[b]	Home interview	Assignment	Coverage	10
Average trip time[b]	Home interview	Assignment	Trip duration	5
Average trip length[b]	Home interview	Assignment	Trip distance	10
Door-to-door speed[b]	Home interview	Assignment	Speed, coverage, frequency	10
Transfers[a]	Company records	Assignment	Frequency	15
Screenline counts[a]	Survey	Assignment	Trip pattern	20

[a]Variables that are independent of each other.
[b]Variables that depend on the values of other variables.
[c]Using chi-square or Kolmogorov-Smirnov tests.

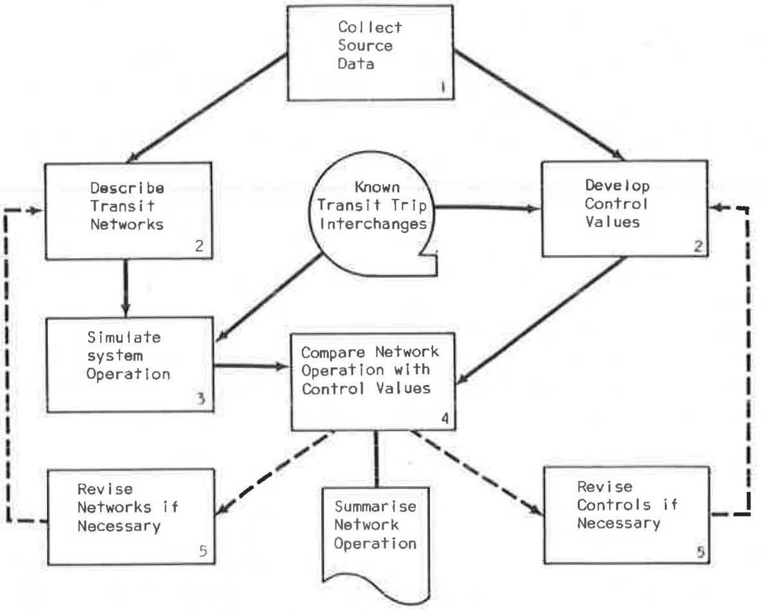

Figure 3. Transit network calibration method.

tive importance) and the allowable tolerance between these and the estimated values in the calibration process. The speed and coverage of the mainline portion of the network, as measured by operating speed and route-miles per square mile, can be calibrated before any attempts are made to simulate travel patterns.

Generally, estimates of transit travel time are more accurate than those of travel distance. This is because trip length is usually calculated from knowledge of the zone-to-zone airline distance using an over-the-road conversion factor, both of which may contain considerable error, especially for trips less than two miles in length. On the other hand, aggregate estimates of travel time are not affected by such variations. Therefore, a maximum error of 10 percent is allowed for variables involving trip length, but errors of less than 5 percent are required for variables involving time. These errors may seem unreasonably restrictive, but close agreement in the calibration of the existing network will increase confidence in travel-time trees and other network-derived data used in analysis of future travel patterns.

Because the number of transfers and screen-line volumes actually counted may vary considerably by day, less accuracy should be required when comparing their estimated and control values. Maximum errors of 15 and 20 percent respectively are recommended. Another useful check is passenger volumes at scattered locations on screen lines.

The similarity of the distributions of travel time and distance may be conveniently compared with a conventional chi-square of Kolmogorov-Smirnov test. A level of significance of 0.05 or 0.10 should be used.

Calibration Process

The method by which the estimated values are compared with control values is schematically shown in Figure 3. Its five basic steps are as follows:

1. Information on transit operation, obtained from company records, includes schedules and route layouts, coverage and bus speeds by route, transfer volumes, and screen-line counts.
2. The transit network is coded from data on scheduled speeds and routing supplied by the company. Network operation variables are derived from company records, and

travel data are obtained from the home-interview file. These provide control values against which the network operation can be measured.

3. The actual network operation is simulated by assigning known transit trip interchanges over the coded network. Estimated values of network variables are obtained from this assignment.

4. The operation of the simulated network is then compared with that of the actual network.

5. Revisions are made to the simulated network if its operation varies beyond the allowable limits with that of the actual network.

Revising the network, of course, implies that one is satisfied with the reliability of control values. In some cases, however, a revision of the controls, not the network, may be justified. This is particularly true in the early phases of calibration, when the collection of source data may not be complete. For instance, if operating speeds over a given portion of route are unavailable and the analyst elects to represent that portion as a function of surrounding portions, he may wish to revise the control speed based on observations of network operation through that segment.

When used in calibrating a network in a specific urban area, this process, simply described here, must, of course, be expanded and warped to fit the particular requirements of that area. Certain portions of source data may be unreliable or lacking altogether, or coding procedures may not permit detailed descriptions of the transit network. On the other hand, special surveys may provide information deemed reliable enough to develop estimates of control values. An on-bus survey, for instance, can yield considerably more data on transit usage than a conventional home-interview survey. These factors should be considered when preparing estimates of system operation.

An Example

Figure 4 shows the calibration process used in the transportation study for the Capital District, the area that includes the New York cities of Albany, Schenectady, and Troy. (The numbers in the lower right corner of the boxes in Figure 4 are used to key these steps to the discussion that follows in which similar numbers appear in parentheses.) The analysis of transit in this region is complicated by the fact that each of the three urban centers is served by a different transit company. Although there is a limited amount of intercity service, the vast portion of the transit service is within city limits. All three companies serve about 70,000 daily riders.

The calibration procedure used in this region is influenced to some extent by these considerations. Because most travel is intracity, the transit network in each urban center is only slightly influenced by the other two networks and may be treated separately. For this arrangement, it seemed reasonable to calibrate each network by city—first, the mainline portion, then access portions, and finally transfer portions.

Data obtained from the three transit companies included schedules, frequency of service, and operating speeds for each route. From these, all routes having at least one bus during the peak hours and four daily buses (each way) were coded as part of the transit network. This accounted for about 75 percent of the total reported route-miles of operation. Visual checks with the real system (1) indicated that additions to the transit network were required, which necessitated reducing the lower limit of route service to one peak-hour bus and two daily buses.

Addition of these routes (2) resulted in the network shown in Figure 5. This network contains about 90 percent of the total route-miles of operation reported by the companies. The control estimate of total route-miles, in this case, was unchanged although additions were made to the network. Alternatively, one might have eliminated that portion of the total route-miles that had very infrequent service and, thus, altered the control value. This course of action would be justified when dealing with very extensive networks in which only a very small portion of routes provide poor service.

Next, data on average bus-miles and bus-hours were developed from the coded transit network (3) and compared with published company statistics. From these figures estimates of average system-wide bus operating speeds were prepared. The results

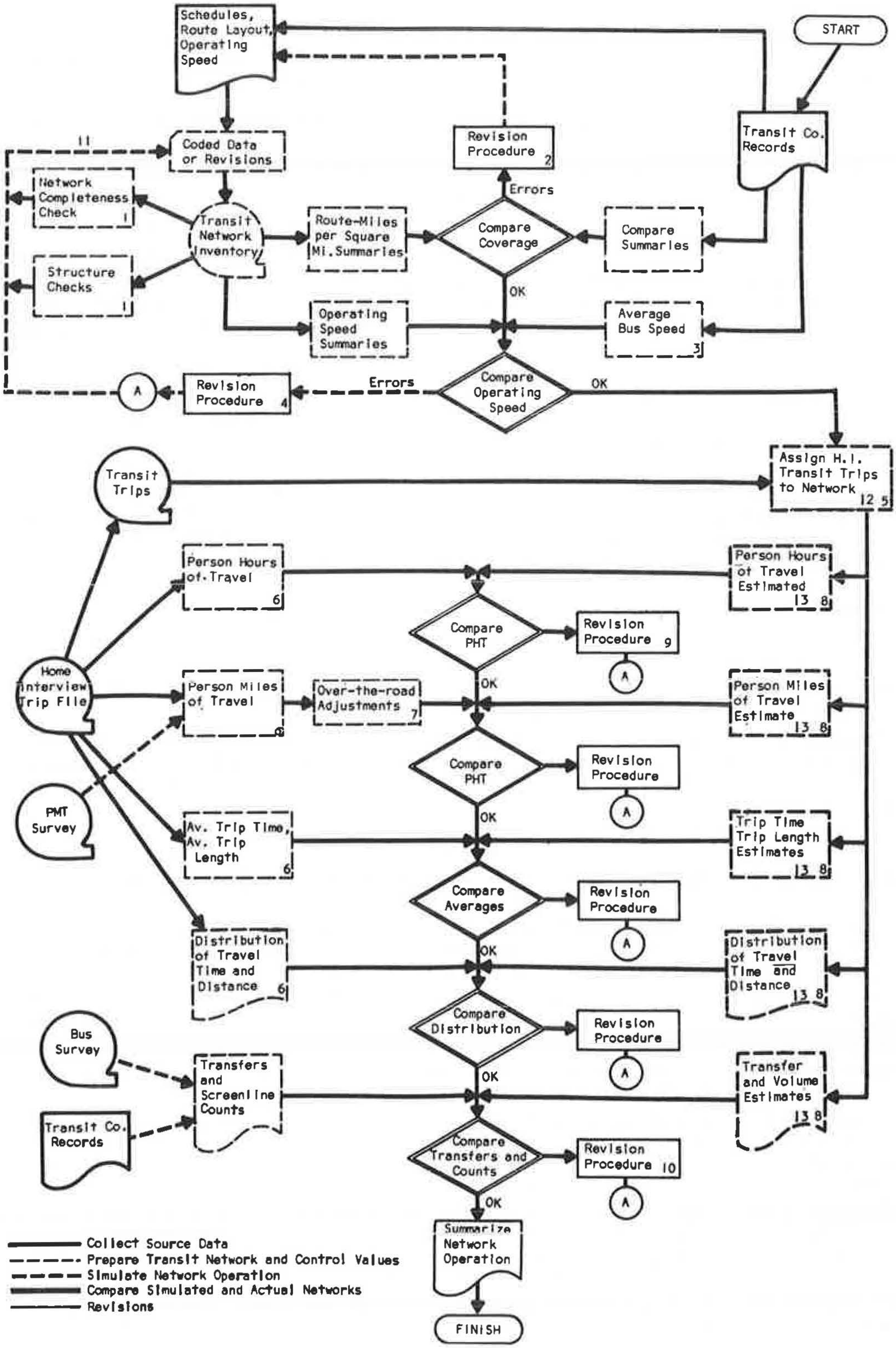

Figure 4. Calibration procedure for the Capital District transit network.

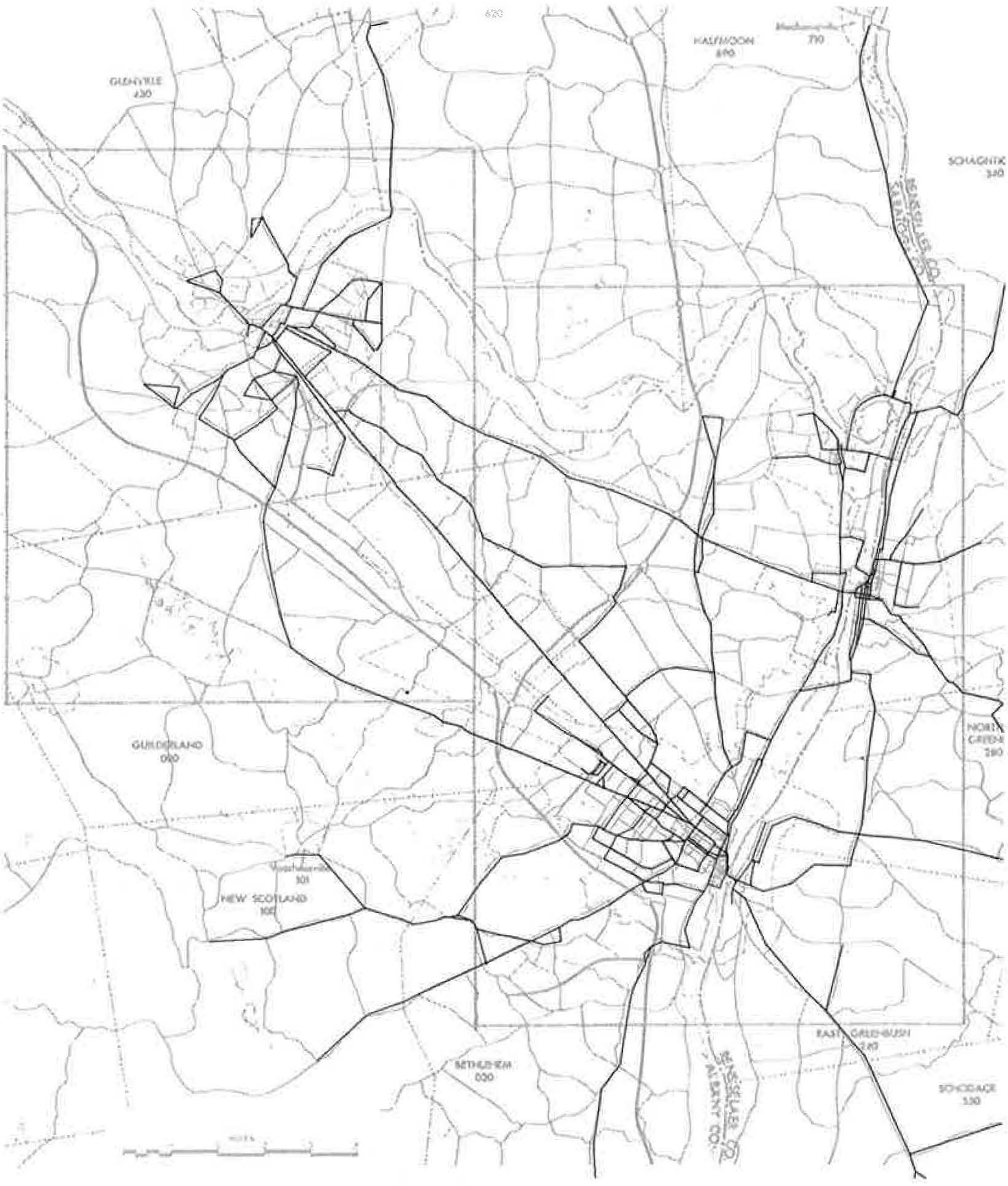

Figure 5. Base transit network—Capital District transportation study.

are given in Table 2. This analysis showed that the characteristics of the mainline portion of the network agreed well with system characteristics.

In many cases, however, the actual operating speed of the network may be faster than that of the real transit networks. This is because the network, although correctly described from published company schedules, does not include delays in operation caused by traffic congestion, breakdowns, or frequent stops. If the mainline speed of the coded network is inordinately high, it should be examined for errors and omissions of this type. Appropriate revisions (4) can then be made.

TABLE 2

COMPARISON OF ACTUAL AND ESTIMATED MAINLINE OPERATING CHARACTERISTICS OF THE TRANSIT NETWORK

City	Bus-Miles			Bus-Hours			Operating Speed		
	Actual	Estimated	Percent Error	Actual	Estimated	Percent Error	Actual	Estimated	Percent Error
Albany	12,910	12,120	- 6.1	1,300	1,250	- 3.8	9.9	9.7	-2.0
Schenectady	3,650	3,350	- 8.2	318	300	- 5.7	11.4	11.2	-1.8
Troy	1,270	1,120	-11.8	164	140	-14.7	7.8	8.0	+2.6
Total	17,830	16,590	- 6.9	1,782	1,690	- 5.2	10.0	9.8	-2.0

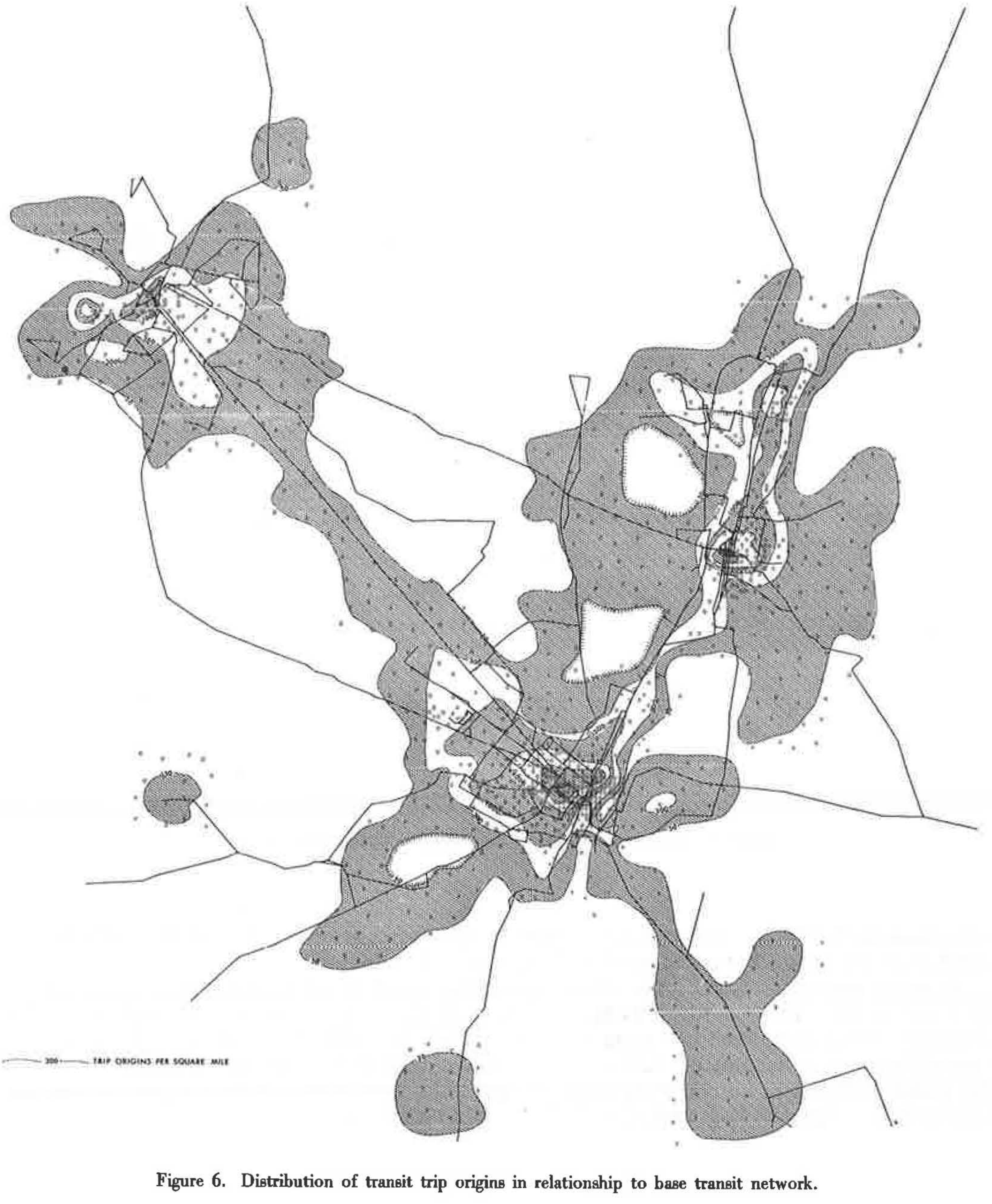

Figure 6. Distribution of transit trip origins in relationship to base transit network.

In the Capital District, the pattern of transit trips is closely aligned to the location of the transit network. Figure 6 shows the base transit network and the spatial distribution of transit trip origins (shown by the pattern of dots). Density contours indicate that the limit of existing service is in the range of 50 to 100 transit trip origins per square mile. This is about 5 percent of the total trip-origin potential. Using this technique, the analyst can check the reasonableness of the spatial location of each transit route. These criteria may also be used as guides in planning the extent of the future network.

The calibration may now proceed to the next stage, that of simulating travel over the network. This is usually done by assigning known transit trip interchanges to the network (5) and observing the resulting travel pattern. Control values used in this portion of the calibration may be derived from trip data obtained in the home-interview survey or from other supplemental studies.

Two important pieces of data are the distributions of travel time and distance, from which the average trip duration, average trip length, total person-hours of travel, and total person-miles of travel are obtained (6). The reported trip lengths are adjusted (7) to reflect over-the-road travel (3). Control values derived from the Capital District home-interview file are given in Table 3.

The outputs of the first transit assignment (8) are estimates of each of the control values. Table 3 shows that these estimates are, for the most part, not acceptable. The estimate of person-miles of travel (PMT) is within 10 percent of the control value, but person-hours of travel (PHT) is considerably outside. Because travel speed over the mainline portion of the network has already been calibrated (Table 2) in the preassignment phase, a low PHT estimate at this point would indicate an inordinately high speed on access links. This is confirmed by comparison of the estimated door-to-door speed (8.3 mph) with the control value (5.8 mph).

TABLE 3

COMPARISON OF CONTROL AND ESTIMATED VALUES OF VARIABLES BEFORE AND AFTER TWO ASSIGNMENTS

Variable	Values				Percent Error			
	Control	Assignment Estimates			Control	Assignment Estimates		
		Pre	1st	2nd		Pre	1st	2nd
Operating speed, mph[a]	10.0	9.8	—	—	5.0	-2.0	—	—
Albany	9.9	9.7	—	—	5.0	-2.0	—	—
Schenectady	11.4	11.2	—	—	5.0	-1.8	—	—
Troy	7.8	8.0	—	—	5.0	+2.6	—	—
Dist. of travel time	—[a]	—	—[a]	—[a]	—[c]	—	—[b]	—[c]
Person-hours of travel	37,231[d]	—	28,533	37,061	5.0	—	23.3	-0.5
Person-miles of travel	216,750[d]	—	234,843	228,373	10.0	—	+ 8.3	+5.4
Average trip time, min	32.1	—	24.6	32.0	5.0	—	-23.3	-0.5
Average trip length, min	3.1	—	3.4	3.3	10.0	—	+ 8.3	+5.4
Door-to-door speed, mph	5.8[d]	—	8.3	6.1	10.0	—	+43.1	+5.2
Transfers	8,600[e]	—	5,700	9,100	15.0	—	-33.7	+5.8
Total transit trips	69,500	—	—	—	—	—	—	—

[a]See Figure 5.
[b]Different at 0.05 level using Kolmogorov-Smirnov test.
[c]Similar at 0.05 level using Kolmogorov-Smirnov test.
[d]From home-interview survey.
[e]From Table 2.

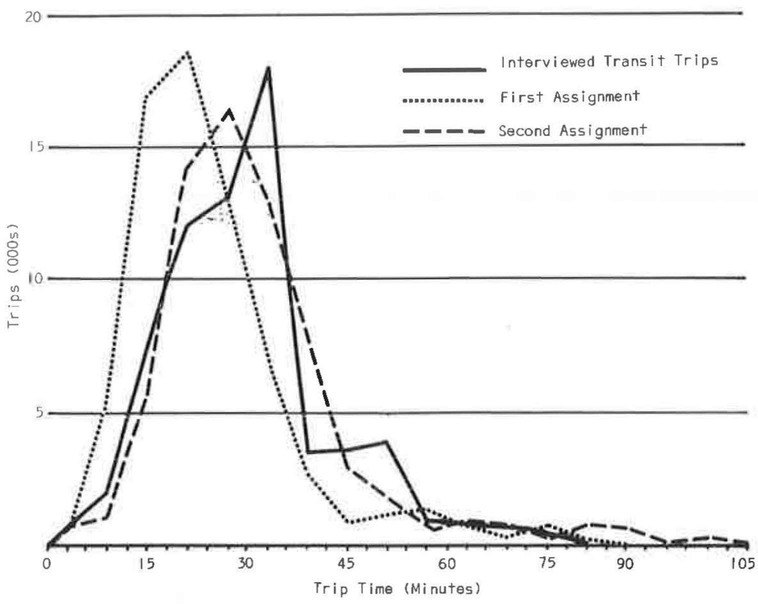

Figure 7. Distribution of transit travel time.

Access speed may be high for a number of reasons. The analyst may have overestimated the number of persons boarding transit vehicles from automobiles (park-and-ride, kiss-and-ride) and, therefore, provided too much access at automobile speeds. Also, for those areas where automobile access is legitimate, the automobile speeds themselves may be too high. This might result from use of average or free automobile speeds when, in fact, a major portion of transit travel occurs during peak hours when automobile speeds are restrained because of congestion. Again, walk speeds on access links may be overestimated. Finally, wait time, which is included in the calculation of access speed, may be underestimated. This might occur when congestion or other delays increase transit vehicle headways to values greater than those reported in schedules.

At any rate, a major revision to the network at this point (9) should be a reduction of access speeds. The reduction factor required should be somewhat less than the ratio of speeds (0.70) because a major influence of network speed is due to mainline movement, not to access movement. In the Capital District, time spent on access links represents about 61 percent of total travel time; the adjustment factor, therefore, should be 0.61×0.70 or 0.43. Note that we have determined to make all of this adjustment in travel time, not in trip length, even though the estimate of average trip length is also in error by 8 percent. This course of action is justified, as Figure 7 shows, because the distribution of travel time estimated from the first assignment is similar in shape to the distribution of interviewed or control data, but is shifted to the left. An across-the-board factor applied to all travel times will adjust the distribution mean without materially altering its shape.

One other adjustment that should be made at this point is in transfer volumes. The estimated value is 34 percent low, indicating that travel over these links is extremely difficult. The problem may be simply an overestimate of transfer time. Transfers normally require a headway time of about half that of the route being boarded, but some scheduling of arrivals at transfer points can reduce this considerably, particularly for routes with headways greater than 30 minutes. In this case, analysis showed that such an error had occurred throughout the system. Therefore, reducing the time required to make transfers by a factor of 5700/8600, or 0.66, is justified and should result in a closer agreement (10).

These revisions are then applied to the access and transfer portions of the network respectively (11). Known transit trips are then reassigned (12) to the adjusted network and new estimates of PHT, PMT, average trip time and length, and transfers are obtained (13). As data given in Table 3 show, this second assignment indicates that the network is now simulating actual network travel fairly well. Virtually all error in estimates of total PHT and average trip time has been eliminated, and the error in PMT has been reduced to 5 percent. The distribution of travel time, as obtained from the assignment, is similar to the control distribution (Fig. 7) at the 0.05 level, using the

Figure 8. Travel over base transit system.

Kolmogorov-Smirnov test. Factors applied to transfer time result in a slight overestimate of transfer volumes, but the estimate is well within allowable limits. Unless further refinement in PMT is desired, the network should now be considered calibrated.

Travel over the base network is shown in Figure 8. The flow increases uniformly toward each of the city centers, with the Albany center attracting about two-thirds of all travel. Intercity movement is confined to the Albany-Schenectady and Albany-Troy corridors. However, all portions of the network, except the outermost routes, carry some travel.

The calibrated network may now be used to analyze characteristics of the actual network that it represents. Summaries of route-miles, bus-miles, and average loadings per mile, by zone, are useful in locating areas of further concentration. Sets of travel-time trees for each zone show how the network is loaded by assigned trips. Measures of interzonal separation can also be developed for use in the analysis of modal-split and accessibility models.

SUMMARY

The calibration of transit networks plays an important part in the transportation planning process. Successful network calibration depends on the reliability of available source data and the ability to simulate the real network and travel over it. As many different aspects of system operation as possible should be analyzed to ensure similarity between the actual and the simulated networks. Variables chosen to represent the characteristics of the network in the calibration process should measure route coverage, frequency of service, and travel speed.

The initial phase of calibration involves the mainline portion of the network. Checks on bus-miles of operation and average operating speed ensure that this portion of the network is correctly described. This phase should be completed before any attempt is made to simulate travel.

Patterns of travel over the transit network can then be analyzed for similarity with actual travel characteristics. This phase of calibration is concerned with simulating operating characteristics by revising the network so that the distributions of travel time and distance are similar to independently derived distributions. Other useful measures are average trip time and length, person-miles of travel, person-hours of travel, transfers, and screen-line counts.

In general, a transit network of average complexity can be calibrated in two to three assignments, given, of course, previous agreement between actual vehicle speeds and those posted or reported by the operating agency.

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