Route Assignment

Introduction

The final step in the transportation forecasting process is to determine the actual street and highway routes that will be used and the number of automobiles and buses that can be expected on each highway segment. The procedure used to determine the expected traffic volumes is known as traffic assignment. Since the numbers of trips by transit and auto that will travel between zones are known from the previous steps in the process, each trip O-D can be assigned to a highway or transit route. The sum of the results for each segment of the system results in a forecast of the average daily or peak hour traffic volumes that will occur on the urban transportation system that serves the study area. To carry out a trip assignment, the following data are required:

- number of trips that will be made from one zone to another (this information was determined in the trip distribution phase),
- available highway or transit routes between zones,
- how long it will take to travel on each route,
- a decision rule (or algorithm) that explains how motorists or transit users select a route, and
- external trips that were not considered in the previous trip generation and distribution steps.

Basic Approaches

Three basic approaches can be used for traffic assignment purposes:

- diversion curves,
- minimum time path (all-or-nothing) assignment, and
- minimum time path with capacity restraint.

Diversion Curves

This method is similar in approach to a mode choice curve. The traffic between two routes is determined as a function of relative travel time or cost. Figure 1 illustrates a diversion curve based on travel time ratio.

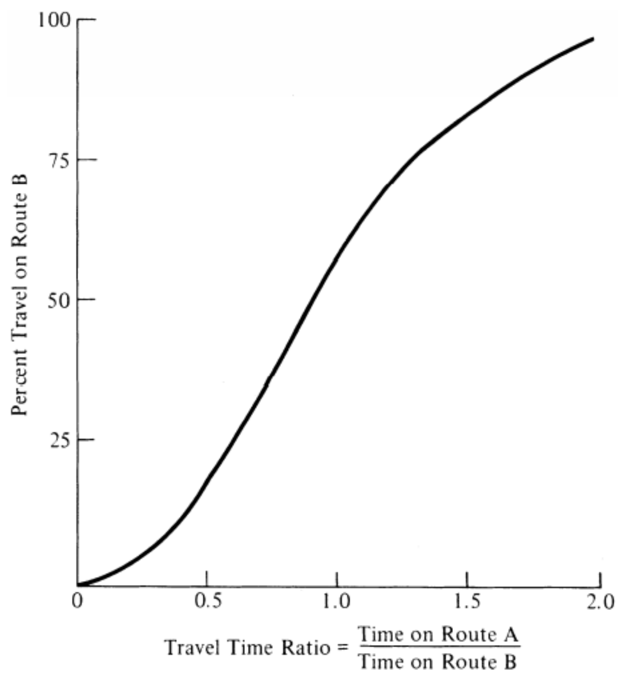

Figure 1 Travel Time Ratio versus Percentage of Travel on Route B.

Minimum Path Algorithm

The traffic assignment process is illustrated using the minimum path algorithm. This method is selected because it is commonly used, generally produces accurate results, and adequately demonstrates the basic principles involved. The minimum time path method assigns all trips to those links that comprise the shortest time path between the two zones. The minimum path assignment is based on the theory that a motorist or transit user will select the quickest route between any O-D pair.

In other words, the traveler will always select the route that represents minimum travel time. Thus, to determine which route that will be, it is necessary to find the shortest route from the zone of origin to all other destination zones. The results can be depicted as a tree, referred to as a skim tree. All trips from that zone are assigned to links on the skim tree. Each zone is represented by a node in the network which represents the entire area being examined.

To determine the minimum path, a procedure is used that finds the shortest path without having to test all possible combinations. The algorithm that will be used in the next example is to connect all nodes from the home (originating) node and keep all paths as contenders until one path to the same node is a faster route than others, at which juncture those links on the slower path are eliminated.

The general mathematical algorithm that describes the process is to select paths that minimize the expression:

$$\sum_{\text{all } ij} V_{ij} T_{ij}$$

where

V_{ij} = volume on link i, j
T_{ij} = travel on link i, j
i, j = adjacent nodes

Example

Finding Minimum Paths in a Network to illustrate the process of path building, consider the following 16-node network with travel times on each link shown for each node (zone) pair. The link and node network is representative of the road and street system. Determine the shortest travel path from node 1 (home node) to all other zones.

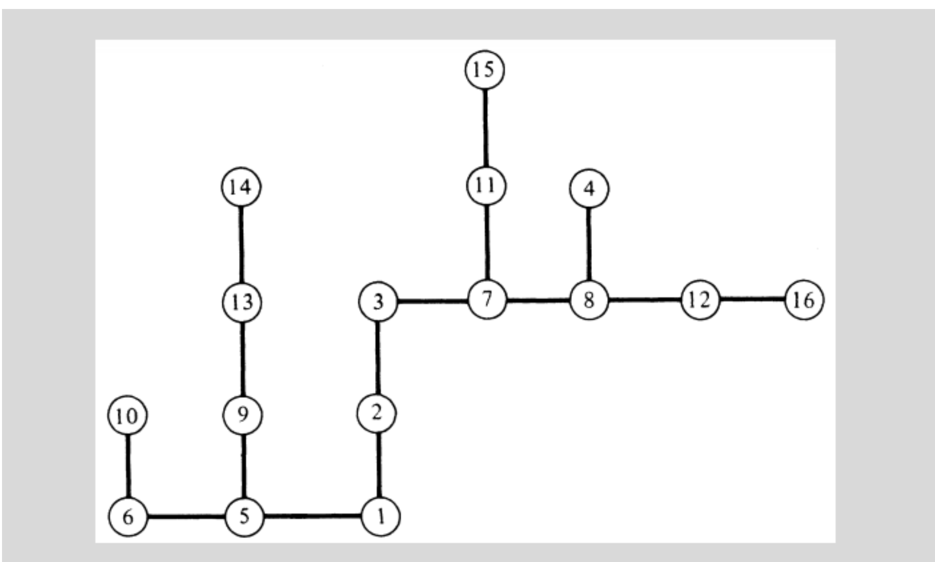

Figure 2 Minimum Path Tree for Zone 1

Solution:

To determine minimum time paths from node 1 to all other nodes, proceed as follows.

Step 1. Determine the time to nodes connected to node 1. Time to node 2 is 1 min. Time to node 5 is2min. Times are noted near nodesin diagram.
Step 2. From the node closest to the home node (node 2 is the closest to home node 1), make connections to nearest nodes. These are nodes 3 and 6. Write the cumulative travel times at each node.
Step 3. From the node that is now closest to the home node (node 5), make connections to the nearest nodes (node 6 and 9). Write the cumula tive travel times at each node.
Step 4. Time to node 6 via node 5 is shorter than that via zone 2. Therefore, link 2 to 6 is deleted.
Step 5. Three nodes are equally close to the home node (nodes 3, 6, and 9). Select the lowest-numbered node (3); add corresponding links to nodes 4 and 7.
Step 6. Of the three equally close nodes, node 6 is the next lowest numbered node. Connect to zone 7 and 10. Eliminate link 6 to 7.
Step 7. Building proceeds from node 9 to nodes 10 and 13. Eliminate link 9 to 10.
Step 8. Build from node 7. Step 9. Build from node 13.
Step 10. Build from node 10, and eliminate link 10 to 11.
Step 11. Build from node 11, and eliminate link 11 to 12.
Step 12. Build from node 8, and eliminate link 3 to 4 .
Step 13. Build from node 15, and eliminate link 14 to 15.
Step 14. Build from node 12, and eliminate link 15 to 16.

To find the minimum path from any node to node 1, follow the path backwards. Thus, for example, the links on the minimum path from zone 1 to zone 11 are 7 to 11, 3 to 7, 2 to 3, and 1 to 2. This process is then repeated for the other 15 zones to produce the skim trees for each of the zones in the study area. Figure 2 illustrates the skim tree produced for zone 1.

Note that link 10 to 14 has been eliminated in the skim tree, although it was not explicitly eliminated in the above analysis. The reason for the elimination of link 10 to 14 is that there was a “tie” between link 10 to 14 and link 13 to 14 where the use of either link will still result in the same number of minutes (10) to reach node 14. The tie was broken by considering how many minutes are required to reach the preceding node (e.g., node 10 for link 10 to 14 or node 13 for link 13 to 14). Table 1 shows that link 10 to 14 was eliminated, since seven minutes are required to reach node 10 but only six units were required to reach node 13.

Table 1 Dealing with Link Elimination when Travel Times are Equal.

Link 13 to 14 option	*Link 10 to 14 option*
Link 1–5 (2 units)	Link 1–5 (2 units)
Link 5–9 (2 units)	Link 5–6 (2 units)
Link 9–13 (2 units)	Link 6–10 (3 units)
Link 13–14 (4 units)	Link 10–14 (3 units)
Total to reach node 14 (10 units)	Total to reach node 14 (10 units)
Total to reach the node preceding node 14 (6 units)	Total to reach the node preceding node 14 (7 units)

Example

Network Loading Using Minimum Path Method. The links that are on the minimum path for each of the nodes connecting node 1 are shown in Table 2. Also shown are the number of auto trips between zone 1 and all other zones. From these results, the number of trips on each link is determined.

Table 2 Links on Minimum Path for Trips from Node 1.

From	*To*	*Trips*	*Links on the Minimum Path*
1	2	50	1–2
	3	75	1–2, 2–3
	4	80	1–2, 2–3, 3–7, 7–8, 4–8
	5	100	1–5
	6	125	1–5, 5–6
	7	60	1–2, 2–3, 3–7
	8	30	1–2, 2–3, 3–7, 7–8
	9	90	1–5, 5–9
	10	40	1–5, 5–6, 6–10
	11	80	1–2, 2–3, 3–7, 7–11
	12	25	1–2, 2–3, 3–7, 7–8, 8–12
	13	70	1–5, 5–9, 9–13
	14	60	1–5, 5–9, 9–13, 13–14
	15	20	1–2, 2–3, 3–7, 7–11, 11–15
	16	85	1–2, 2–3, 3–7, 7–8, 8–12, 12–16

To illustrate, link 1 to 2 is used by trips from node 1 to nodes 2, 3, 4, 7, 8, 11, l2, 15, and 16. Thus, the trips between these node pairs are assigned to link 1 to 2 as illustrated in Table 2. The volumes are 50, 75, 80, 60, 30, 80, 25, 20, and 85 for a total of 505 trips on link 1 to 2 from node 1.

Table 3 Assignment of Trips from Node 1 to Links on Highway Network.

Link	*Trips on Link*	
1–2	50, 75, 80, 60, 30, 80, 25, 20, 85 =	505
2–3	75, 80, 60, 30, 80, 25, 20, 85 =	455
3–7	80, 60, 30, 80, 25, 20, 85 =	380
1–5	100, 125, 90, 40, 70, 60 =	485
5–6	125, 40 =	165
7–8	80, 30, 25, 85 =	220
4–8	80 =	80
5–9	90, 70, 60 =	220
6–10	40 =	40
7–11	80, 20 =	100
8–12	25, 85 =	110
9–13	70, 60 =	130
11–15	20 =	20
12–16	85 =	85
13–14	60 =	60

Solution:

Calculate the number of trips that should be assigned to each link of those that have been generated in node 1 and distributed to nodes 2 through 16 (Table 3). A similar process of network loading would be completed for all other zone pairs. Calculations for traffic assignment, as well as for other steps in the forecasting model system, can be performed using the microcomputer program TRIPS.

Capacity Restraint

A modification of the process just described is known as capacity restraint. The number of trips assigned to each link is compared with the capacity of the link to determine the extent to which link travel times have been increased by the additional volume placed on the formerly empty link. Using relationships between volume and travel time (or speed), it is possible to recalculate the new link travel time. A reassignment is then made based on these new values. The iteration process continues until a balance is achieved, such that the link travel time based on the loaded volume does not change with successive assignments.

The speed–volume relationship most commonly used in computer programs was developed by the U.S. Department of Transportation, and is depicted in Figure 2. It is called a link performance function and expressed in the following formula:

$$t = t_0\left[1 + 0.15\left(\frac{V}{C}\right)^4\right]$$

Where:
t :travel time on the link
t_0: free-flow travel time
V: volume on the link
C: capacity of the link

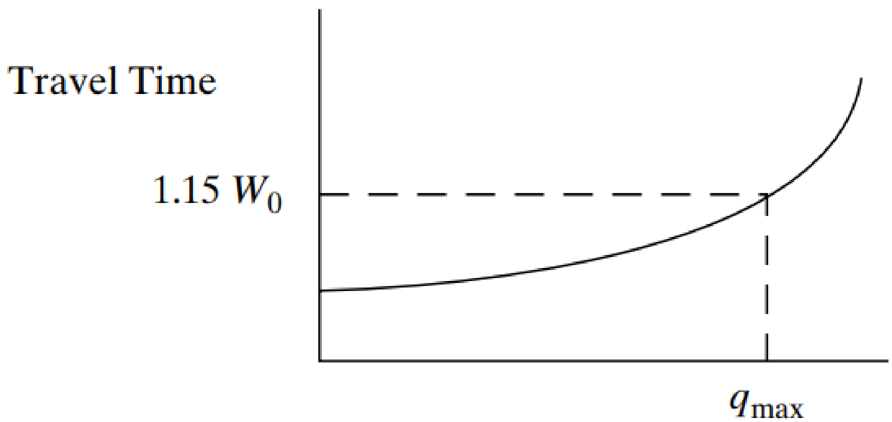

Figure 2 Travel Time versus Vehicle Volume.

The capacity restraint relationship given in previous Eq. can be generalized by allowing the coefficients to be adjusted to corridor-specific or roadway-type, as follows.

$$t = t_0\left[1 + \alpha\left(\frac{V}{C}\right)^{\beta}\right]$$

where

t = travel time on the link
t_0 = free-flow travel time
V = volume on the link
C = capacity of the link
α and β are link or roadway-type specific parameters

One study of freeways and multilane highways found the parameters (as a function of free flow speed) shown in Table 4. Alternatively, a traffic engineering study can be conducted for a specific corridor and the model fitted to the collected speed and volume data to determine appropriate values for a and b.

Table 4 Roadway-type Specific Parameters for Capacity Restraint.

	Freeways			*Multilane Highways*		
Coefficient	*70 mi/h*	*60 mi/h*	*50 mi/h*	*70 mi/h*	*60 mi/h*	*50 mi/h*
α	0.88	0.83	0.56	1.00	0.83	0.71
β	9.8	5.5	3.6	5.4	2.7	2.1

Example (Computing Capacity Restrained Travel Times)
In previous Example, the volume on link 1 to 5 was 485, and the travel time was 2 minutes. If the capacity of the link is 500, determine the link travel time that should be used for the next traffic assignment iteration.
Solution:

$$t_1 = t_0\left[1 + 0.15\left(\frac{V}{C}\right)^4\right]$$

$$t_{1-5} = 2\left[1 + 0.15\left(\frac{485}{500}\right)^4\right]$$

$$= 2.27 \text{ min}$$

Total System Cost Assignment

In conjunction with capacity restraint, Eq. below will result in an equilibrium assignment,

$$t = t_0\left[1 + 0.15\left(\frac{V}{C}\right)^4\right]$$

Where no single user may reduce their individual travel time by changing travel paths. However, user-equilibrium assignment is not necessarily the method that results in the lowest total travel time for all travelers. Rather a total system cost assignment may be an option if the lowest total cost (as compared with lowest individual cost) is preferred. If a system cost assignment is used, route selection decisions are no longer made by the motorist but are the responsibility of the transportation agency.

To illustrate the potential benefits of a system cost assignment, consider a simple highway network shown in Figure 3 below

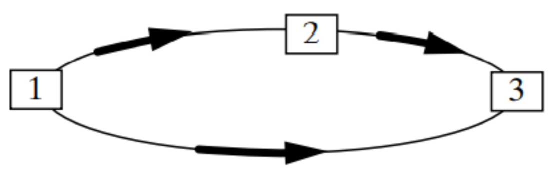

Figure 3. Three-Zone Highway System

In this situation, there are two origin zones (1 and 2) and one destination zone (3). If 400 travelers desire to travel from zone 2 to zone 3, they have but one option: use Link23. If 300 travelers desire to travel from zone 1 to zone 3, they have two options: (1) Link12 and Link23 in succession or Link13 separately.

The travel times for each link be given by the following relationships:

$$\text{Travel time}_{12} = \frac{3}{1 - \text{volume}_{12}/10{,}000}$$

$$\text{Travel time}_{23} = \frac{3}{1 - \text{volume}_{23}/1000}$$

$$\text{Travel time}_{13} = \frac{12}{1 - \text{volume}_{13}/100{,}000}$$

An equilibrium assignment where each of the travelers from zone 1 to zone 3 individually chooses the fastest route will result in a total system cost of about 7198 minutes, as shown next. Only those traveling between zone 1 and zone 3 can reduce driving time by changing routes.

Results of an Equilibrium Assignment for a Three-Zone Highway Network

Link	*Link Volume*	*Link travel Time*	*Travel time between Zone 1 and Zone 2*
Link_{12}	132.73	3.04	12.02
Link_{23}	532.73	8.98	
Link_{13}	167.27	12.02	12.02
Total system cost			7198

Consider the situation where drivers must use a prescribed route. For example, all 300 motorists traveling from zone 1 to zone 3 could be told to use Link13. Under this scenario, the travel time for these motorists will increase slightly—from 12.02 to 12.04 minutes, and the travel time for the motorists who must travel between zone 2 and travel to zone 3 will experience dramatically lowered travel times. The net result will be a lower system cost as shown in the following table where the total travel time has been reduced from 7198 to 6011 minutes.

Lowest System Cost Assignment

Link	*Link Volume*	*Link travel Time*	*Travel time between Zone 1 and Zone 2*
Link_{12}	0	3.00	9.00
Link_{23}	400	6.00	
Link_{13}	300	12.04	12.02
Total system cost			6011

In general, the assumption of user-equilibrium assignment is a more realistic basis for depicting individual decision making, since each traveler acts on what they consider to be their own best interest. The lowest system cost assignment may be of use for evaluating potential benefits of public interventions, such as traffic management strategies or improvements to infrastructure.
For example, a public entity might choose to subsidize rail freight capacity if it found that total system costs for the rail and the adjacent interstate facility could be reduced, or variable message signs may direct motorists away from congested areas.
The process of calculating the travel demand for an urban transportation system is now completed. The results of this work will be used to determine where improvements will be needed in the system, to make economic evaluations of project priority, and to assist in the geometric and pavement design phases. In actual practice, the calculations are carried out by computer, because the process becomes computationally more intensive as the number of zones increases.