Transportation Network Analysis Techniques for Detailed Travel Forecasts

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The city of Chicago is in the preliminary engineering final environment impact statement phase of planning for a central area circulator system. Because of the wealth of existing bus and transit service and the amount of activity taking place in the central area, detailed modeling of transit options was required. Described here are enhancements to the transportation network coding and analysis made to travel demand forecasting models necessary to properly model the various transit options. These enhancements include determination of travel speeds on the basis of intersection control and signal timings, explicit coding of transit stops, and detailed multipath transit assignments. Finally the reasonability of applying the detailed network processing techniques in typical regional model applications is discussed.

Chicago's central area is one of the most significant and vibrant activity centers in the Midwest. There were approximately 670,000 employees and 56,600 households in the central area in 1985. This level of activity can be sustained only by use of a variety of transportation alternatives. Chicago is served by several commuter rail lines to the far suburbs, rapid-rail lines to the close-in suburbs, and local and express buses within the city proper. In addition taxis and private automobiles are prevalent in the area. The existing public transportation system is focused on the traditional Loop area defined by the elevated rapid-rail tracks. This area is roughly bordered by Wacker Drive on the north and west, Congress Expressway on the south, and Michigan Avenue on the east, as shown in Figure 1. In this compact eight-by-eight-block area most transit riders are able to walk from their alighting station to their final destination.

Expanded development patterns coupled with ever-increasing congestion have resulted in longer travel times within the central area, which now covers a region stretching from North Avenue on the north to Cermak Road on the south and from Halsted Street on the west to Lake Michigan on the east. It is an area approximately 4 mi long by 2 mi wide. As the central area grows in shape and size it is no longer reasonable to expect all travelers to walk from a transit stop or parking location to their final destination. Because the central area is expanding, the concept of a central area circulator, or downtown people mover (DPM), has evolved to provide quick and convenient service within the expanded central area. The proposed system would consist of either an improved bus system or light-rail transit (LRT).

PREVIOUS MODELING EFFORTS

The concept of a central area circulator system has been under study for more than 20 years. The process was formalized in 1989 when the city decided to pursue an Alternatives Analysis/Draft Environmental Impact Statement (AA/DEIS) study for a new transportation system. A detailed model capable of projecting ridership for the extensive transit system in the central area and the proposed alternative network configurations was developed for the Chicago central area AA/DEIS study (*1*) on the basis of modeling for DPM systems developed for Los Angeles, Miami, and Detroit (*2–4*).

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CHICAGO CENTRAL AREA CIRCULATOR PE/FEIS STUDY

The planning for the locally preferred alternative, an LRT circulator-distributor system, has entered the preliminary engineering/final environmental impact statement (PE/FEIS) phase. On the basis of experience in applying the travel forecasting models developed for the AA/DEIS and the need for increasingly detailed travel forecasts, a number of refinements to the circulator-distributor modeling process were made:

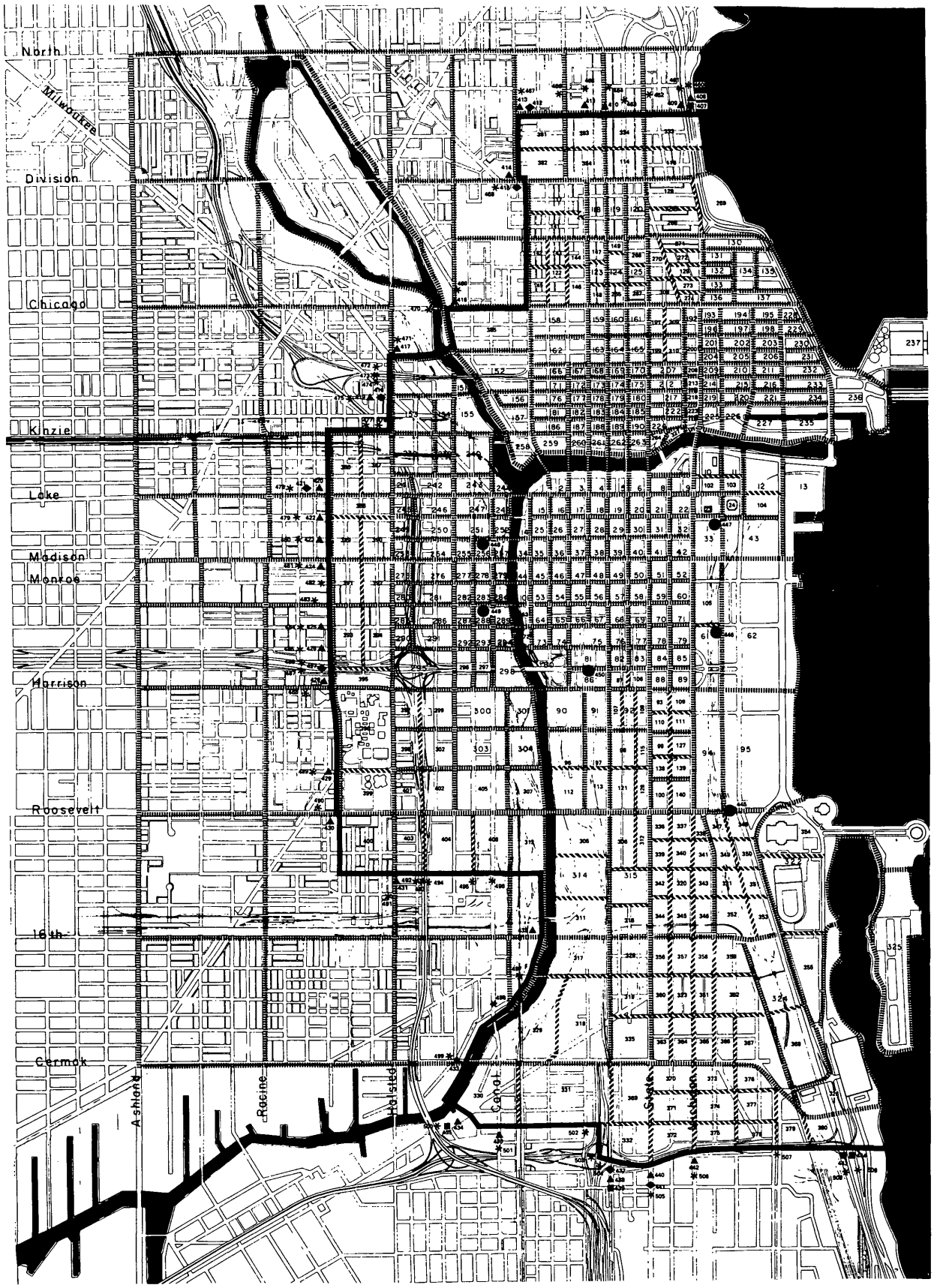
- Representation of the transit, taxi, and automobile networks was refined.
- Coefficients for the distributor mode-choice model were estimated on the basis of locally collected data.
- Model formulations were revised

The first point, network representation and path-building refinements, is the focus of this paper. The last two points are discussed by Kurth et al. in another paper in this Record.

NETWORK MODELING IMPROVEMENTS

In the past AA/DEIS models were used to test several alternative modes and alignments for the circulator. Although the models produced the necessary forecasts for the AA/DEIS, several areas for refinement were identified through the model application process. Network-related refinements were identified for (a) estimation of automobile, taxi, and bus travel times; (b) coding of bus stop locations; and (c) multipath transit assignment improvements.

For the estimation of AA/DEIS speeds the study area was divided into six large districts, with a representative automobile (or taxi) speed in each district. The average speed was applied across an entire district. This simplified method did not explicitly account for signal delay or vehicle acceleration and deceleration delays. The signal delay contributed a substantial amount to the actual travel time. Alternatively, if a signal was not present, the travel time may be less than that obtained with the average speeds. As the trip distances get longer the actual travel speeds more closely



▲ Local Bus External Station
■ Express Bus External Station
◆ Rapid Rail External Station
● Commuter Rail External Station
✳ Auto External Station

FIGURE 1 Central business district distributor study zone structure.

resemble the average travel speed. Since taxi speeds were the same as automobile speeds and bus speeds were a function of automobile speeds, this problem affected all three modes.

Since walk trips were explicitly modeled, the under- or overestimation of automobile, taxi, and bus travel times for short distances adversely affected the mode-choice models. As a result these models had to adjust for the bias in automobile, taxi, and bus travel times for short distances through constants on those modes to match observed mode shares. However as trip distances increased, the automobile, taxi, and bus travel times were more accurately modeled in comparison with the walk travel times. This resulted in possible bias in estimations of walk trips for longer interchanges.

The second area for refinement was in the coding of the bus stops. In the AA/DEIS study the local buses were allowed to stop at any node (at both cross-street and midblock nodes) along the bus line, although the express buses and cross-Loop buses were modeled to stop only at explicit bus stops on selected "bus-only" lanes. Thus the majority of buses provided ubiquitous bus service, with stops at every node. This was in contrast to the LRT lines, which were coded with explicit stop locations. Thus because of coding conventions buses were modeled to provide more accessible service than the LRT.

The third area identified for refinement was in the modeling of multipath transit assignments. The modeling software used to implement the models, EMME/2, provides a robust algorithm for multipath transit path building as part of its normal procedures. However in the transit-rich environment of the Chicago central area, even the normal EMME/2 transit path-building procedures used in the AA/DEIS tended to underestimate the possible paths for many interchanges. This resulted in some large shifts in transit use on specific lines because of relatively small changes in transit travel times. Thus the most detailed transit path-building algorithm in EMME/2, which is normally reserved for analyzing individual transit interchanges, was used in the PE/FEIS.

The PE/FEIS study provided the opportunity to implement the refinements identified above, along with some commensurate improvements to provide additional detail and sensitivity to the models. The specific network-related refinements included the following:

- Automobile and taxi speeds were estimated by using traffic engineering information, including speed limits, intersection control, signal timing, and link length;
- The bus network was coded in detail, including explicit coding of bus stop location and type (such as near side, far side, and midblock); and
- Bus travel times were built up from link length, bus acceleration and deceleration, number and location of stops, speed limits, and bus dwell times.

The purpose of this paper is to discuss the network modeling improvements that were made in the PE/FEIS procedures, in particular the need for increased detail in coding and the use of transit multipaths.

DESCRIPTION OF NETWORK

In a detailed central business study such as the Chicago circulator project it is imperative to code the network in detail. Detailed decisions regarding track alignments and station locations are made in the PE/FEIS. Changes might be as detailed as moving an alignment or station as little as one block, or 440 ft. If the modeling procedures are not detailed, it is not possible to analyze such changes reasonably.

An integrated highway and transit network was coded for the Chicago central area circulator study area. The highway network was necessary for determining automobile and taxi travel times, whereas the transit network was needed for determining transit mode-specific travel times. A detailed auxiliary (walk) network was also coded to represent walk paths and transit access and egress. Detailed network coding was important because walking was a viable mode and because of the complexity of the transit system in downtown Chicago. The detailed network coding included, for example, the coding of distances to the nearest one-hundredth of a mile and included all sidewalks (streets) and pedestrian-only links in the network as well as stair links to subway or elevated platforms and the coding of access links from transit stops to the street (auxiliary) network with the equivalent distance to represent the proper travel time from the platform to the street level.

A detailed zone structure was also necessary to properly analyze the trade-offs among walking, taking a taxi, and taking another transit vehicle. Although the detailed zone structure was crucial for improving ridership forecasts, increases in the number of zones increased the difficulty in producing socioeconomic projections for those zones. Thus there was also a practical trade-off restricting the level of detail used in the zone structure. The final zone structure contained 406 internal zones with an 8-mi^2 area, as illustrated in Figure 1. Transit external stations were established wherever transit lines crossed the boundary of the study area and at the six central area commuter rail stations. There were 51 mode-specific transit external stations. If several local buses and an express bus crossed the boundary of the study area on the same street, two transit external stations were established—one for the local bus lines and one for the express line. This process prevented spurious transfers between modes at external stations. In addition to transit external stations, 50 automobile external stations were established for possible future use (e.g., performing detailed automobile assignments).

One automobile mode and numerous transit and auxiliary transit modes were used to represent the transportation network. The automobile mode was coded to provide access and egress from zone centroid to zone centroid over the street network. It was used to represent internal-internal automobile travel made by central area residents and internal-internal taxi trip options available to all central area travelers. The transit and auxiliary modes were used in conjunction with another. Auxiliary modes provided access and egress from zone centroids to transit lines and provided for transfer opportunities between nonintersecting transit lines.

Detailed Highway Network Coding and Path Building

The highway network was needed to establish automobile (and taxi) travel times and costs throughout the study area. Automobile and taxi in-vehicle travel times were assumed to be identical. In-vehicle travel times could have been computed by using the AA/DEIS procedures with average speed zones and link lengths. However this procedure had a tendency to incorrectly estimate automobile or taxi travel times for short trips. To solve this prob-

lem it was decided to relate link-specific automobile (and taxi) travel times to traffic engineering information. The total link travel time is composed of the

- *Link traversal time* as a function of link length and speed limit.
- *Delay incurred at an intersection* because of the type of intersection control (*5,6*). Different delay functions were developed for signalized intersections, all-way-stop intersections, two-way-stop intersections and Yield signs. The intersection delay for signalized intersections was taken from the 1985 *Highway Capacity Manual* and is a function of the cycle length, green time-to-length (g/c) cycle ratio, volume-to-capacity (v/c) ratio, and lane capacity (*7*). The four-way-stop function was taken from a report by Meneguzzer et al. (*5*). The delay associated with a two-way stop was based on the all-way-stop equation with some modifications. The delay for Yield signs was taken from the function for signals assuming that the yield operated like a signal with a g/c ratio of 1.0.
- *Loss time* because of vehicle acceleration and deceleration.

To calculate these travel times detailed traffic engineering data were coded on the highway network. This included the following data items for each link:

- Link length,
- Speed limits for all roadways,
- g/c ratios for A.M. and midday for signalized intersections on each approach, and
- Link approach control (e.g., signal, Stop sign, Yield, no control).

The following data items were coded for each node:

- Type of intersection control (signalized, all-way stop, two-way stop, or Yield) and
- Cycle length.

The "congested" automobile and taxi travel times were calculated within the network calculator in EMME/2 by using the travel time functions described above. A set of calibration parameters (average v/c ratios by district) was used to match the modeled automobile speeds with the observed average speeds for 1985. The various components were summed to obtain the total link travel time, which was then stored on the network.

A small number of observed automobile speeds were available for the core area. Although these data were not sufficiently extensive to provide a generalization over the entire study area, they provided a basis for testing the reasonability of the estimated speeds by using the procedures described above. The observed speed data showed substantial variation: speeds on the same roadway rose one year and fell the next year. There was also variation between the morning and evening peak-hour speeds. Most of the peak-hour speeds were between 7 and 10 mph. Table 1 shows a comparison of the observed and modeled automobile speeds for the core area.

Automobile and taxi paths were obtained by running an all-or-nothing assignment on the highway network using the speed in-

TABLE 1 Selected Automobile Travel Times—A.M. and Midday

					Modeled Travel Characteristics					
					Travel Time (minutes)		Speed (mph)		Observed Speed (mph)	
Street	Dir.	From	To	Distance (miles)	A.M.	Midday	A.M.	Midday	A.M.	Midday
East-West Streets										
Randolph	WB	Michigan	Wacker	0.66	3.9	4.4	10.2	9.0	9.7	8.3[a]
Washington	EB	Wacker	Michigan	0.62	4.2	4.8	8.9	7.8	8.4	7.2[b]
Madison	WB	Michigan	Des Plaines	1.02	6.0	6.5	10.2	9.4	10.1	8.0[b]
Monroe	EB	Wacker	Michigan	0.64	4.3	4.8	9.0	8.1	8.1	5.1[a]
Adams	WB	Michigan	Wacker	0.65	4.2	5.0	9.2	7.8	9.3	6.5[b]
Jackson	EB	Wacker	Michigan	0.65	4.8	5.6	8.2	7.0	7.6	6.5[c]
North-South Streets										
Michigan	NB	River	Oak	0.71	5.4	4.8	7.9	8.8	10.2	11.1[b]
Michigan	SB	Oak	River	0.71	5.6	5.0	7.6	8.5	11.0	11.0[b]
Michigan	NB	Congress	River	0.88	5.4	5.8	9.8	9.1	10.5	11.2[b]
Michigan	SB	River	Congress	0.88	5.8	6.2	9.2	8.6	10.9	9.0[b]
Clark	SB	Wacker	Van Buren	0.70	3.7	4.2	11.3	10.0	9.5	6.0[d]
Dearborn	NB	Van Buren	Wacker	0.74	4.0	4.6	11.1	9.7	7.1	5.3[d]
Franklin	NB	Harrison	Erie	1.35	9.4	9.1	8.6	8.9	10.5	11.4[e]
Wells	SB	Erie	Harrison	1.33	9.3	9.4	8.6	8.5	9.0	7.9[e]

[a]Observed speed from 1988.
[b]Observed speed averaged for 1984, 1985, and 1986.
[c]Observed speed averaged for 1984 and 1985.
[d]Observed speed from 1986.
[e]Observed speed from 1984.

formation from the link speed calculations. All connector links from zone centroids to the network were coded with 3-mph speeds to represent walk access to the street network. The in-vehicle travel times and travel distances over the shortest time paths were summarized into impedance matrices for use in the mode-choice models.

Taxi fares on the shortest paths were calculated in the matrix calculator on the basis of the adjusted taxi travel distance. The 1985 taxi fare structure of a $1.00 drop charge plus $0.10 per 1/9th mi was assumed for all alternatives. Automobile costs were calculated as necessary and include an operating cost of $0.12/mi (in 1985 dollars) along with the parking costs.

Detailed Transit Network Coding and Path Building

Downtown Chicago is served by a multitude of public transit services, including commuter-rail lines, express buses, and local buses, that must be coded into the networks. The commuter-rail lines were assumed to deposit all of their passengers at the appropriate station. Thus there was no need to code the commuter-rail lines. The remaining transit services were coded in full detail, including explicit stop locations, dwell times, and exact line itineraries. No simplifying assumptions were used in the coding of the transit lines. The Chicago Transit Authority (CTA) provided the input information to properly code the rapid-rail lines and all buses. Bus stops were identified as near-side, far-side, or midblock stops. Stair links to the elevated and subway portions of the transit network were included, as were access links representing the distance from commuter-rail platforms to the walk network. The detailed auxiliary (walk) network provided for additional walk access, egress, and transfer between transit lines.

For consistency the bus travel times had to be sensitive to the same traffic engineering information used for obtaining the automobile travel times. Thus the bus travel times were built up in much the same way as the automobile travel times, except that the bus characteristics were used. On the basis of information from CTA, the bus acceleration was set to 1.6 mph/sec, and the bus deceleration was set to 4.7 mph/sec. The bus travel times included the following components:

- Link traversal time,
- Delay incurred at intersections,
- Loss time because of vehicle acceleration and deceleration, and
- Bus stop delay (dwell time)

Bus travel times included a component for bus stop delay that was not included in the automobile travel time calculations. If bus stops were independent of intersections, this delay could simply be estimated and added for each bus stop. However the amount of delay incurred at a bus stop was dependent on the location of a bus stop. For instance near-side bus stop dwell time delay and intersection delay overlap, whereas a far-side bus stop dwell time does not overlap intersection delay.

EMME/2 treats link travel time and transit dwell times independently. Dwell time is coded on the transit network by transit segment (i.e., the portion of the line between bus stops). In addition a transit travel time function is coded on each segment. EMME/2 sums the transit travel time for each link with the dwell time for the segment to determine the total link travel time. Four basic transit travel time functions have been coded on the bus network: one for near-side stops, one for far-side stops, one for midblock stops, and one for no stops.

For near-side bus stops the link travel time function included link traversal time, acceleration and deceleration losses, and the maximum of the dwell time or the signal delay. If greater than zero the increment of dwell time delay over signal delay was also added to the bus travel time.

For far-side bus stops the link travel time function included all of the components of the automobile travel time functions: link traversal time, acceleration and deceleration losses, and signal delay time. For the acceleration and deceleration loss, only the deceleration component was included in the calculation because the dwell time for the far-side stop already included both acceleration and deceleration delays.

For midblock stops the bus stop delay was simply added to the traversal time, acceleration and deceleration times, and the signal delay.

Only those buses with a stop were coded with one of the above transit travel time functions. All other segments were coded with a no-stop transit travel time function. This function was identical to the automobile travel time function, except that the acceleration and deceleration rates used were for buses, not automobiles.

Average dwell times for buses were measured by field observation. The average A.M. peak local bus dwell time was 17 sec, whereas the average express bus dwell time was 30 sec. The average midday dwell time for all buses was 21 sec.

Few data were available to validate the bus travel times. Table 2 compares the AA/DEIS modeled speeds, the scheduled CTA speeds, and the PE/FEIS modeled speeds. The AA/DEIS speeds were fairly consistent and close to one another. This was the result of the use of average bus speeds based on "speed zones." In the PE/FEIS model more variation in the modeled speeds resulted. The variations in speeds resulted from the explicit modeling of bus stop locations and intersection delay. The CTA speeds are

TABLE 2 Selected 1985 Transit Line Summaries for A.M. Peak

		Average Speed (mph)		
Line No.	Description	AA/DEIS Model	1985 CTA Scheduled[a]	PE/FEIS Model
120X	CNW/Wacker Exp	10	8	9
121X	Union/Wacker Exp	10	9	10
122X	IL Center/CNW Exp	10	9	12
123X	IL Center/Union Exp	10	9	13
125X	Water Tower Exp	9	8	7
127	CNW/Madison	8	11	10
129	CNW/Franklin	10	13	10
146X	Marine/Michigan Exp	10	10	9
151	Sheridan[b]	9	9	8
157	Streeterville	8	6	8
3	King Drive[b]	11	12	10
36	Broadway[b]	9	10	8
56	Milwaukee[b]	8	10	13

[a]CTA average speeds were calculated using distance and scheduled travel time.

[b]Route numbers 3, 36, 56, and 151 have multiple variations; overall average speed is reported.

scheduled speeds, not observed speeds. The CTA schedules are updated periodically to reflect actual operating conditions.

The CTA rapid-rail routes were coded for every line in the study area. A travel time function was constructed to represent the acceleration, deceleration, and cruise time between each station as a function of the distance. Acceleration and deceleration rates were provided by the CTA, and a maximum speed of 55 mph was assumed.

For the LRT alternatives the Chicago Circulator Design Team provided the route itinerary, station locations, dwell times, and running times between stations. These times varied by the configuration of the system, vehicle performance, and operating and safety considerations.

Transit travel times were saved by component—transit in-vehicle time, transit auxiliary (walk) time, and transit wait time. The average wait time for a transit vehicle was assumed to be one-half the headway. A boarding time penalty of 1 min was used to determine the paths but was not included in the transit impedance matrices.

The disaggregate transit trip analysis techniques embodied within EMME/2 were used to build the transit paths (*8*). This transit assignment technique is slightly different from the normal EMME/2 transit assignment technique. Both transit path-building techniques build multiple transit paths, but the enhanced path builder provided additional path analysis capabilities that were more suited to a transit-rich environment. This will be discussed in the next section.

Because the mode-choice model is a nested logit model with a local and premium transit choice, two sets of transit paths were necessary: local bus submode and premium bus. Local transit paths were allowed to use local services only. Also since walk paths were explicitly modeled, the resulting paths were analyzed to ensure that a local transit mode was in fact used. Walk-only strategies were eliminated from local transit paths. Premium transit included the LRT system and any shuttles providing specialized service between specific interchanges and with limited stops in between. An example of this type of bus service is the commuter shuttle serving Illinois Center from the C&NW and Union commuter-rail stations. Again the resulting paths were analyzed to ensure that premium service was indeed used. Walk-only and walk, local bus strategies were eliminated from the premium transit paths. Walk travel times were built by using "sidewalk" links coded at 3 mph.

TRANSIT MULTIPATHS

In a transit-rich environment the construction of multiple transit paths allows for accurate modeling of individual travel behavior. Because there can be multiple transit paths between origin-destination pairs, it is inappropriate to utilize single-path or all-or-nothing path builders. An all-or-nothing path builder constructs only one path on one mode between any two zones. However if competing services are available, travelers may opt to use different paths. It is unlikely that all transit users use the shortest (lowest-impedance) path. Rather if more than one transit path exists between two points, rational travelers will pick the transit vehicle that arrives at their origin first.

The EMME/2 software package has an improved path-building routine based on the concept of transit strategies (*8–10*). A strategy is a set of rules that allows passage from origin to destination. A strategy is a single element of a transit traveler's choice set. The number and types of strategies are dependent on the information available to the traveler. In EMME/2 it is assumed that the only information available to the traveler waiting at a node is which line is to be served next. The traveler can then make the decision whether to board the vehicle. If two or more alternative services exist between an origin node and a destination, travelers are assumed to split between the alternative paths in proportion to the frequency of service. This occurs as long as the different in in-vehicle travel time is less than the difference in headways of the routes.

Consider the example shown in Figure 2. Three alternative paths between Zone 1 and Zone 2 are shown in Figure 2:

- LRT Path A,
- Local bus Path B, and
- LRT Path C.

Normal, non-EMME/2 shortest-transit path-building algorithms would select only LRT Path A between Zones 1 and 2, since Path A has the minimum travel time. The normal EMME/2 path-building techniques would build a stategy by using both LRT Path A and local bus Path B. The normal EMME/2 path builder will build multiple transit paths from a common node. This common-node access location is defined as the node at which the attached connector link leads to the minimum expected travel time to reach a particular destination. Thus the connector link leaving the zone must be on the minimum path. After that, if appropriate, EMME/2 will build multiple transit paths. The split between two or more alternative paths would be based on the relative frequency of service on the paths.

Although the normal EMME/2 transit path builder is an improvement over the shortest-transit path-building technique, LRT Path C is also a reasonable path. However LRT Path C cannot be accessed at a common node with Paths A and B. Thus in EMME/2's normal path-building routine LRT Path C would not be chosen.

EMME/2 has an enhanced path-building technique that is capable of selecting multiple access nodes. The enhanced path-building technique requires additional information regarding reasonable transit access and egress nodes for each interchange and information on how to distribute the trips between the alternative access nodes. In the example shown in Figure 2 the enhanced path builder would select all three paths as reasonable paths between Zones 1 and 2. The selection of an access node or nodes is dependent on several user-defined parameters set within the program (*8*). The probability for an access node to be chosen is computed by using a simple logit model:

$$P_i = \frac{e^{-\Phi u_i}}{\Sigma e^{-\Phi u_j}} \qquad i \epsilon I_a,\ j \epsilon I_a \tag{1}$$

where

I_a = set of access nodes,
u_i = impedance of trip from access node i to destination plus access time from origin coordinates to access node i, and
Φ = dispersion parameter.

The dispersion parameter is specified by the user. A large value for the dispersion parameter will lead to the selection of only one access node (similar to the normal EMME/2 path-building technique), whereas a small value for the dispersion parameter will

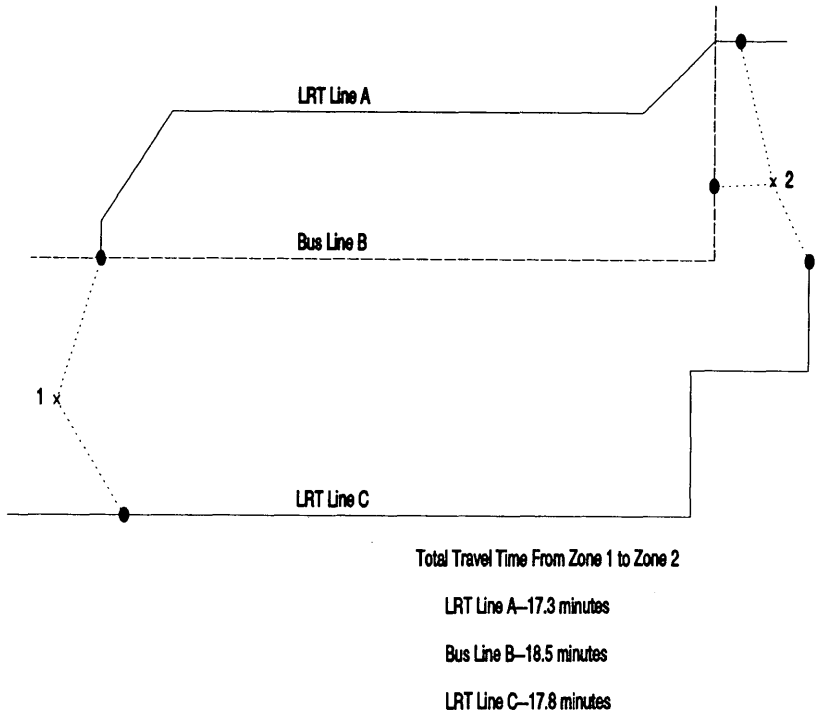


FIGURE 2 Example transit network.

tend to split trips more equally among the alternative access nodes. The travel times used to determine the split are the in-vehicle travel time plus the straight-line access time from the origin zone to the respective access nodes.

EXAMPLE APPLICATIONS AND COMPARISONS

The network and path-building refinements have been applied in the Chicago central area circulator PE/FEIS study. This section discusses an example application and includes comparisons with the AA/DEIS process. A full comparison of the enhanced network with the procedures used in the AA/DEIS was never performed, since the enhanced procedures were developed to address the observed shortcomings of the AA/DEIS procedures. In addition the choice models used in the PE/FEIS study were updated. This made a direct comparison of the differences in AA/DEIS and PE/FEIS results attributable to network processing changes impossible.

Network Refinements

The two refinements made in network coding for the PE/FEIS models have been applied in a simple example to show their effects. Travel times were computed by using various network coding schemes for the walk, taxi, bus, and LRT modes for a cross-Loop street running from the west-side train stations. Table 3 shows a comparison of the selected travel times.

The walk travel times were based on an observed walk speed of 3 mph. The average taxi speed was assumed to be 6.5 mph, as determined in the AA/DEIS study. The AA/DEIS bus travel times were based on the 6.5-mph average speed, plus 1.5 min/mi for dwell time. The LRT was coded in an identical manner for both the AA/DEIS and PE/FEIS studies. The actual bus and LRT stop locations are also shown in Table 3.

In this example the taxi travel times obtained by using the detailed network coding are lower than the travel times obtained by using the 6.5-mph average taxi speed. This occurred because the street modeled had *g/c* times that favored travel along the street. The average speeds account for travel on "local" streets in the central area as well as major arterials. As can be seen in Table 3, as distances increase, the detailed network travel times approached the taxi travel times calculated using the average taxi speeds.

The bus travel times shown in Table 3 demonstrate the effect of the explicit bus stop coding compared with that of "ubiquitous" stop coding. For the ubiquitous stop coding the walk time is 0.4 min to all of the intersecting streets. In comparison the walk time for the detailed stop coding varies for each cross street. For example at Street C the walk time is only 0.4 min, since Street C is a bus stop and only the bus access time is represented. However the walk time to Street B is 2.0 min, since it includes the 1.6 min necessary to walk the 0.08 mi from the Street C stop back to Street B, in addition to the 0.4-min access time. The same is true for the walk time at the Street D intersection.

This example points out the need to explicitly code bus stops. As can be seen in the example the total travel time to the different cross streets varies substantially depending on the location of the bus stop. Total travel times do not necessarily increase with the distance of the stop from the starting location.

The LRT example shown in Table 3 has characteristics similar to those of the bus coding. Walk times are related to the distance

TABLE 3 Example Travel Times from West-Side Train Station to Intersecting Street

	A	B	C	D	E	F	G	H	I	J
Ubiquitous bus stops	X	X	X	X	X	X	X	X	X	X
Explicit bus stops	X		X	X			X	X	X	
LRT stations			X				X			
Distance (miles)	0.00	0.15	0.23	0.31	0.39	0.47	0.55	0.64	0.72	0.80
Walk time (minutes)	0.0	3.0	4.6	6.2	7.8	9.4	11.0	12.8	14.4	16.0
Taxi (using average speeds)	0.0	1.4	2.1	2.9	3.6	4.3	5.1	5.9	6.7	7.4
Taxi (using detailed network speeds)	0.0	0.7	1.2	1.7	2.3	3.2	3.6	4.2	4.7	5.4
Bus (with ubiquitous stops and average speeds)										
In-vehicle travel time[a]	0.0	1.6	2.5	3.3	4.2	5.1	5.9	6.9	7.7	8.6
Walk time (stop-specific)	0.0	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Total travel time	0.0	2.0	2.9	3.7	4.6	5.4	6.3	7.3	8.1	9.0
Bus (with explicit stops and built-up speeds)										
In-vehicle travel time[a]	0.0	1.2	1.2	1.8	1.8	1.8	3.8	4.3	4.9	4.9
Walk time (stop-specific)	0.0	2.0	0.4	0.4	2.0	3.6	0.4	0.4	0.4	2.0
Total travel time	0.0	3.2	1.6	2.1	3.8	5.3	4.2	4.7	5.3	6.9
LRT										
In-vehicle travel time[a]	0.0	1.3	1.3	1.3	1.3	2.6	2.6	2.6	2.6	2.6
Walk time (station-specific)	0.0	3.0	1.4	1.0	2.6	1.4	1.0	2.4	4.4	5.8
Total travel time	0.0	4.3	2.7	2.3	3.9	3.9	3.5	4.9	6.9	8.3

[a]From west side train station to nearest transit stop.

from the closest LRT stop, and in-vehicle travel times are a function of the stop used. The LRT example underscores the importance of explicit coding of bus stops.

The differences between the AA/DEIS and PE/FEIS travel times shown in this example are fairly small—1 to 2 min. Given trips of 3 to 4 mi the difference could be in the 8- to 10-min range. Also in a detailed analysis in which walking is a viable mode even small changes in the travel times could affect the modal shares. The importance of the travel time differences is even more pronounced, since the coefficients of in-vehicle travel time and walk time are different in the mode choice model.

Path-Building Refinements

A second test was set up within EMME/2 to investigate the effects of different path-building and assignment procedures. The test involved two assignments: the first used the normal EMME/2 transit multipath assignment technique, and the second used the enhanced EMME/2 transit multipath assignment technique. For each of the two assignments 100 trips were assigned to selected interchanges over identical networks. All modes (bus and LRT) were assumed to be available to the travelers. The resulting volumes are shown in Figure 3(*a*) and (*b*).

The effect of the enhanced multipath assignment procedure in comparison with that of the normal multipath assignment procedure embodied in EMME/2 is evident if the top diagram in Figure 3 is compared with the diagram below. If the normal and enhanced LRT assignment volumes are compared it can be seen that the assigned volume on the Riverbank LRT route is 349 riders in the enhanced assignment [Figure 3 (*bottom*)] or 151 riders less than the normal multipath assignment [Figure 3 (*top*)]. In the enhanced assignment 56 of the 151 riders are assigned to the Madison Street LRT (the volume increases from 507 in the normal assignment to 563 in the enhanced assignment). The remaining 95 riders are assigned to Madison Street buses.

The enhanced multipath assignment process provides additional stability to the assignment process. With the normal multipath assignment process some "flip-flop" of volumes on the Riverbank and Madison Street LRT lines resulted from relatively small changes in travel speeds or route alignments. This occurred whenever the best stategy changed from the use of the station served by the Riverbank LRT line to the station served by the Madison Street LRT line or vice versa. With the enhanced multipath assignment process changes in travel speeds on one of the lines cause only incremental changes in assigned volumes on the lines.

IMPLICATIONS FOR MODELING PROCEDURES

Several enhancements to the network coding and path-building procedures used for a detailed study of transit alternatives in the central area of Chicago have been presented. The enhancements—calculation of travel times on the basis of intersection control information, explicit coding of bus stops, and detailed transit multipath assignments—were crucial for producing the travel forecasts

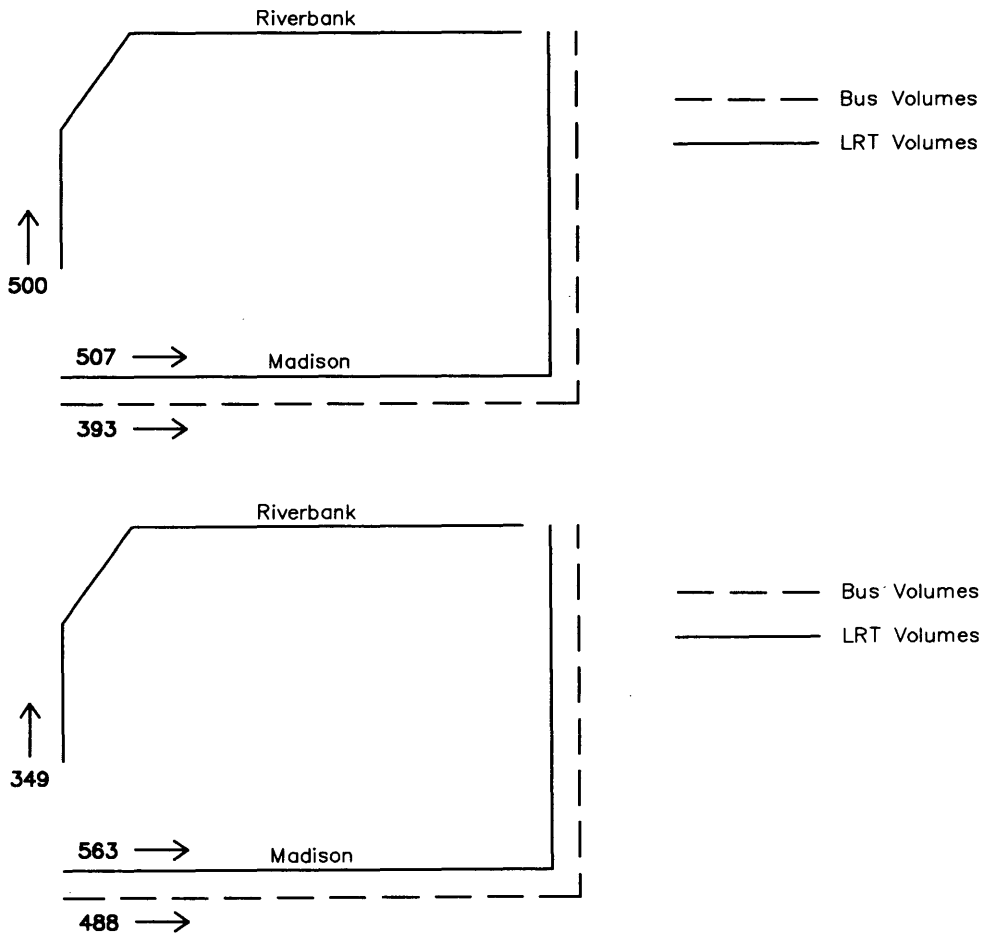


FIGURE 3 Example transit assignment: (*top*) normal and (*bottom*) enhanced travel assignment.

necessary for station sizing and route design for the PE/FEIS. The examples demonstrated the modeling error that could be introduced into the process by simplified network coding and processing techniques. Although this effort was necessary for the Chicago central area circulator PE/FEIS, it might be asked whether this level of effort is necessary for regional planning or an AA/DEIS.

It took approximately three times as long as normal to incorporate the detailed traffic engineering information and explicit bus stops. In addition considerable amounts of time and effort were expended in obtaining the data and processing it into a usable format. After this initial investment the time necessary to code alternatives was probably doubled.

One of the major reasons for the increased network detail was the extreme detail necessary for the central area modeling process. Most zones were defined by blocks, the walk mode was explicitly modeled, and taxi, automobile, and bus travel times were directly affected by the location and timing of traffic signals. Most regional modeling processes do not approach the detail of the central area circulator modeling process. Zones typically encompass many blocks, the walk mode is not explicitly modeled (except for bus access, egress, and transfer), and the highway network does not generally include detail for every street in the area being modeled. On the basis of that observation the increased network processing effort described in this paper is probably unwarranted for most regional modeling processes.

Nevertheless some of the enhancements described in this paper should be considered (possibly in a simplified form) for regional modeling processes. The detailed bus stop coding might be appropriate for most modeling processes in central business districts (CBDs). In many regional modeling processes zones in CBDs are typically small, a detailed walk network is generally coded, and the CBD is typically the focus of most transit services and the transit ridership. Thus incorporation of the detailed bus stop coding procedures and possibly the intersection-based travel time calculations in the CBD would be warranted for many regional modeling processes.

In addition the Clean Air Act Amendments of 1990 and Intermodal Surface Transportation Efficiency Act (ISTEA) legislation might also support increased highway network coding and pro-

cessing detail. The use of average speeds based on, for example, facility type and area type ignores the impact of intersection control on specific streets. This has an impact on the final speeds estimated by the models and subsequently affects air quality calculations. Use of the intersection-based speed estimation procedures described in this paper or simplified versions of those procedures could be an important step in improving speed estimates from traffic assignments. Also the desire to explicitly incorporate nonmotorized modes in regional travel models would also foster the use of increased network coding detail.

The detailed transit multipath assignment procedures described here are most pertinent for detailed studies. However, the normal transit multipath assignment capabilities (such as those incorporated in EMME/2) are important wherever transit services compete. In many suburban areas the transit paths and impedances from the multipath assignment process will be the same as the paths and impedances from traditional shortest-path assignment techniques. As transit service increases, however, the multipath procedures will provide more realistic estimates of travel impedances than shortest-path assignment techniques. For example in the case in which an interchange is served by two differrent bus lines that have only one intermediate stop not common to both lines, the shortest-path algorithms will select only one of the lines, whereas normal multipath assignment algorithms will consider both lines in the calculation of transit impedances. Competing transit services occur in many cities, especially in the fringe and urban areas around CBDs.

Although some of the increased detail described in this paper may be unwarranted for regional modeling processes, the Clean Air Act Amendments of 1990 and ISTEA will require increased detail in network coding and analysis for regional models. The work reported in this paper has demonstrated that increased detail in network coding and processing can be implemented by using readily available modeling software.

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