Circulator/Distributor Model for the Chicago Central Area

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The city of Chicago is evaluating alternative methods for providing for the distribution of commuters to and workers, visitors, and residents in the vibrant and growing central area. A detailed travel model has been calibrated to project ridership on the various circulator/distributor alternatives. The model is based on the Downtown People Mover System travel demand models developed for Los Angeles, Detroit, and Miami. The Chicago central area and the calibration of the circulator/distributor model are described. The calibrated model coefficients are compared with the coefficients used for the Los Angeles, Detroit, and Miami models. Finally, some brief recommendations regarding future circulator/distributor model development and research efforts are presented.

Chicago's central area is one of the most significant, highly concentrated, and exciting activity centers in the Midwest. Historically, the downtown coincided with the elevated loop structure. It is roughly bordered by Wacker Drive on the north and west, Michigan Avenue on the east, and the Congress Expressway on the south. This vibrant area is continually expanding. In the past 20 years significant new multiuse towers have punctuated the skyline. Growth is occurring along the North Michigan Avenue corridor and in areas south and west of the traditional Loop in office, retail, and residential space.

The existing transportation system was planned to serve destinations within the traditional Loop area. In this compact core area, most transit riders were able to walk from their alighting station to their destination. As the central area grows in shape and size, it becomes more and more difficult for the existing transit system to serve all destinations adequately. Expanded development patterns coupled with ever-increasing congestion add to travel times. It is becoming apparent that an expanded transit system is needed to serve the expanding central area, which now stretches 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 approximately 4 mi long by 2 mi wide. Although the area is not completely developed (i.e., growth occurs in spots), these boundaries indicate the limit of current development trends.

The expanded central area is served by various modes of transportation. Commuter rail lines, rapid rail lines, and buses provide service to and through the area. In addition, taxis and private automobiles are prevalent. Because of the expansion of central area, it is no longer reasonable to expect all persons to walk from transit service or parking to their destinations, which may be as far as 2 mi. Thus, the concept of a central area circulator or downtown people mover (DPM) has evolved. The circulator system would provide quick and convenient access within the expanded central area. The proposed system would consist of either buses (the TSM alternative) or light rail transit (LRT).

The Chicago Central Area Circulator Study required a detailed model capable of projecting ridership for the extensive transit system in the central area and the proposed alternative network configurations. The study focused on modeling two major types of trips: those made from central area commuter rail stations to destinations within the central area (distributor trips) and those made wholly within the central area by residents, workers, and visitors to the central area (circulator trips). The modeling of these two types of trips led to the typical model form for modeling DPM systems (*1–3*).

In addition to these types of trips, there was concern about the proper assignment of trips that entered the central area on Chicago Transit Authority (CTA) bus and rapid rail lines. This concern, coupled with the modeling of the distributor trips, required an extensive interface with the regional transportation model maintained by the Chicago Area Transportation Study (CATS). CATS provided basic travel data for regional trips destined for the central area that used one of the six Metra commuter rail stations located in the central area and trips that entered the central area on CTA bus and rapid rail.

The remainder of this paper focuses on model form, model calibration and validation, and lessons learned from the calibration of the model. The final section discusses potential improvements and research for central area circulator/DPM models. The actual model results and recommendations regarding alternatives are not discussed. Readers who are interested in the results and recommendations should contact the City of Chicago Department of Planning for copies of reports written for the Chicago Central Area Circulator Alternatives Analysis.

MODEL FORM

Model form generally refers to the specific mathematical models and relationships used to estimate trip generation, trip distribution, mode choice, and assignment. These are important and will be discussed as appropriate. However, for modeling travel in the central area, the level of detail of the zone and network structure and the market segments modeled are of equal importance. If they are not well defined at the outset of a central area circulator study, it will be difficult to produce reasonable results even with the best travel models available.

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Zone Structure

A detailed zone structure was developed for the Central Area Circulator Study to properly analyze the trade-offs between walking, taking a taxi, and taking another transit vehicle or the circulator/distributor system from the line-haul transit system to the central area destination. Whereas the detailed zone structure was crucial for improving ridership forecasts, increases in the number of zones increased the difficulty of producing socioeconomic projections for those zones. Thus, there was also a practical trade-off restricting the level of detail used in the zone structure.

Figure 1 shows the zone structure used for the Central Area Circulator Study. The 8-mi^2 area modeled included 406 internal zones, 49 "transit external stations," and 51 "automobile external stations." Within the Chicago Loop, most of the zones were block-level zones. Outside the Loop, increasingly large zones were used. Transit external stations were established wherever transit lines crossed the boundary of the study area and at the six central area Metra commuter rail stations: Chicago & North Western Station, Union Station, LaSalle Street Station, and the Randolph Street, Van Buren Street, and Roosevelt Road Metra Electric Stations. The external transit stations were mode specific. If an express bus and several local bus routes crossed the boundary of the study area on the same street, two external stations were established—one for the express bus line and one for local bus lines. This process prevented spurious transfers between modes at external stations.

The commuter rail stations were handled as special cases in modeling travel to the central area. As will be discussed, detailed mode choice models were developed to estimate the number of trips by egress mode from the commuter rail stations to the central area destinations. Four of the six stations are terminals on commuter rail lines, and each of the commuter rail stations is a major transfer point. Commuters are forced to make a decision and are generally offered a number of choices for traveling to their destination at each of the stations. In contrast, bus passengers and rapid rail passengers have multiple points at which they can make a choice regarding travel from the main line-haul mode (crossing the study area boundary) to their destination. Because of the complexity of the choices, the trips made by bus and rapid rail passengers from external transit stations to central area destinations were handled simply through route choice (i.e., transit assignment).

Network Structure

Network coding was crucial to the accurate modeling of ridership on the alternative circulator/distributor systems. EMME/2 was used to code an integrated transportation network for the central area. It would have been possible to use other microcomputer- or mainframe-based transportation planning packages to perform the detailed coding; however, the coding was simplified greatly by using an interactive and integrated network editor. An integrated network was crucial because consistent highway, transit, and walk networks were required to build automobile and taxi paths, transit paths, and walk paths for the area being modeled.

The transportation network was coded as accurately as possible. This included coding of distances to the nearest 0.01 mi; coding an extensive walk network, including all sidewalks (streets) in the area, as well as pedestrian-only links; coding stair links to represent the time necessary to walk from the center of a subway or elevated platform to the street level; and coding access/egress links from the center platform of each commuter rail station to each possible exit from the station. This level of detail in network coding was necessary because walk was one of the possible modes considered. For example, had the network been coded to the nearest 0.1 mi, substantial differences in results could be obtained with little difference in actual travel times. Consider the estimation of walk travel times from a commuter rail station to two adjacent zones, one 0.24 and the second 0.26 mi from the station. If the network had been coded to only the nearest 0.1 mi, the distances to the two stations would have been coded as 0.2 and 0.3 mi. The modeled travel times using a 3-mph walk speed would have been 4.0 min to the first zone and 6.0 min to the second zone. Using a network coded to the nearest 0.01 mi would result in modeled travel times of 4.8 and 5.2 min to the two example zones.

Market Segments Modeled

Travel models were developed for two times of day: the morning peak period and midday. Two major types of trips were considered: the distribution of regional transit riders entering the central area on commuter rail to their destinations and the circulation of central area residents, workers, and visitors. Six main market segments resulted:

- The morning peak-period distributor market segment (regional commuter rail passengers making work trips to the central area),
- The morning peak-period circulator market segment (central area residents making work trips),
- The midday distributor market segment (regional commuter rail passengers making nonwork trips to the central area),
- The midday worker circulator market segment (central area workers making midday nonwork trips),
- The midday nonworker circulator market segment (central area visitors making midday nonwork trips), and
- The midday resident circulator market segment (central area residents making midday nonwork trips).

The afternoon peak-period distributor and circulator trips were considered to be the reverse of morning peak-period trips for the corresponding market segments.

In addition to these market segments, peak-period and midday trips entering the central area by bus and rapid rail (subway and elevated) were included in the assignment of transit trips. However, they were simply assigned from their "ports-of-entry" to their destinations. Modes used to reach their destinations were based strictly on path choice.

In the application of the models, trips to and from the central area were estimated by CATS using the regional travel model. CATS estimated new trip tables for each model alternative. The trip tables were all based on the same trip

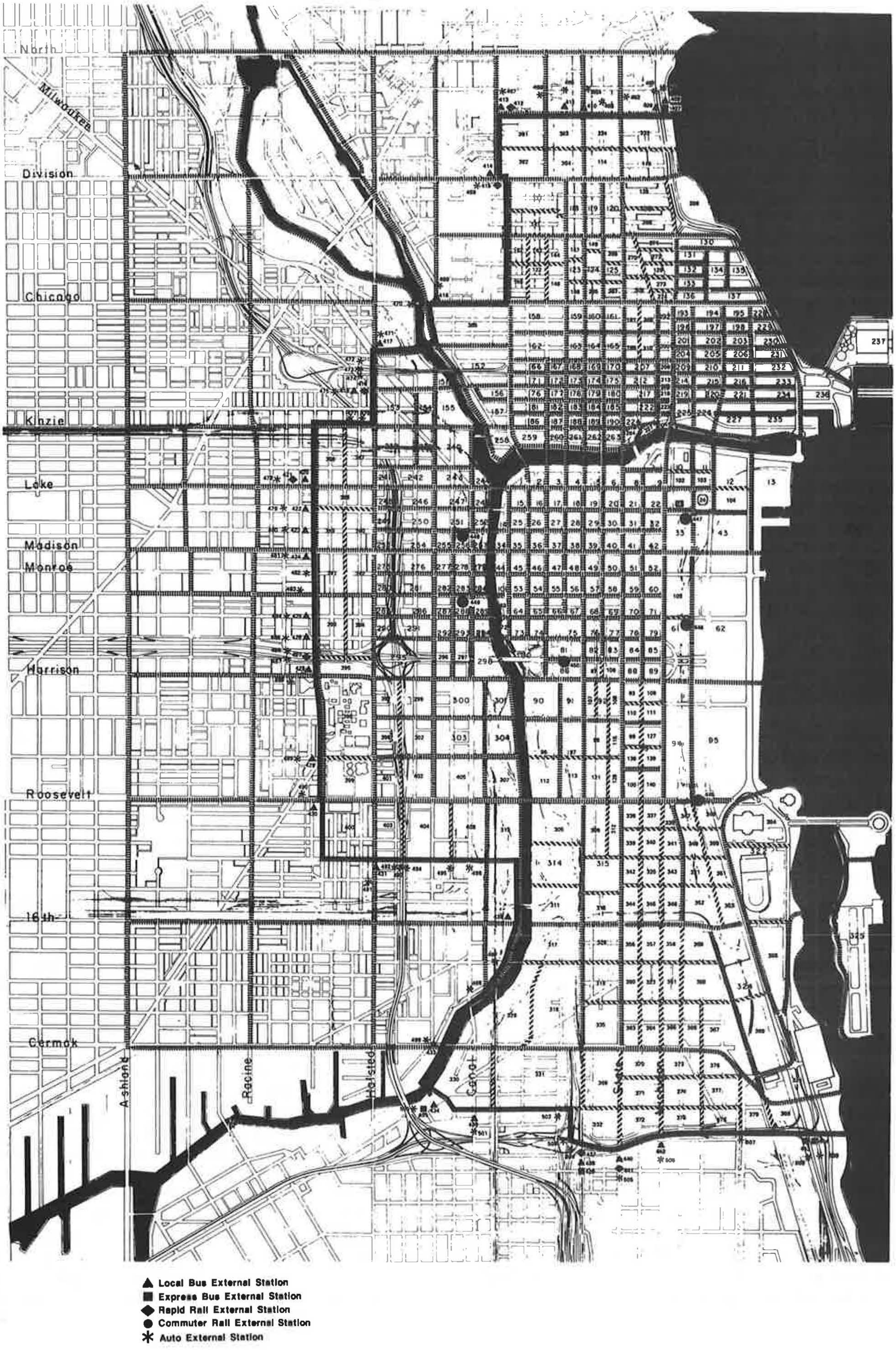

FIGURE 1 Structure of CBD distributor study zone.

distribution results. However, the "external-internal" trips to the central area varied for each alternative, because regional submode shares (bus, rapid rail, and commuter rail) to the central area were affected by the various alternatives.

Modes Considered

Four main modes were considered in the estimation of circulator/distributor travel in the central area: walk, transit, taxi, and automobile. The actual modes available depended on the market segment being considered. The walk, transit, and taxi modes were considered for all market segments. The automobile mode was considered for only those market segments that could have automobiles available—central area residents (peak-period and midday trips), central area workers (midday circulator trips only), and central area nonworkers (midday circulator trips only).

The actual mode considered for the central area circulator/distributor system was LRT. Figure 2 shows the full-build LRT system proposed as the most extensive of the alternatives for the central area circulator system. For most of the market segments, the proposed LRT system was not modeled as a separate, distinct mode in the mode choice models. Rather, the system was considered to be the same main transit mode as the rapid rail, local bus, shuttle bus, and express bus systems serving the central area. This was a departure from many previous DPM modeling efforts.

In all cases, only one set of transit travel paths (skims) was built from the coded network. The LRT system was used in these transit paths only if it was a part of the shortest path. However, EMME/2 determines transit travel times on the basis of multiple transit paths. If two or more efficient transit paths are available between two zones, the transit travel times posted on the transit skims are a composite of the efficient paths (*4*). This is done even if the different transit paths use different transit submodes (e.g., one path uses bus, a second uses an express bus, and a third uses LRT).

The use of the EMME/2 multipath transit model is a departure from previous DPM modeling efforts using UTPS or other all-or-nothing transit path–building algorithms. The EMME/2 multipath algorithm could slightly bias the results toward an LRT system. If two points were served by both bus and LRT and the LRT were a slightly slower mode, EMME/2 would still include the LRT in the impedance calculation and assign trips to the LRT. In contrast, all-or-nothing transit path–builders would ignore the LRT and assign all trips to the bus system. However, the reverse situation could also be true: the LRT might be the slightly faster mode for the interchange.

For midday worker circulator trips and midday nonworker circulator trips, LRT was considered more attractive than bus or rapid rail in the mode choice models. If the circulator was used on the shortest transit travel path, a positive circulator mode bias was added to the transit utility in proportion to the amount of in-vehicle travel time spent on LRT in comparison with the total transit in-vehicle travel time. The effect of this bias on LRT ridership was probably less than that obtained by considering LRT to be a separate, distinct mode, as in previous DPM modeling efforts.

Separate shortest–travel-time paths were built for the walk, transit, taxi, and, when necessary, automobile modes. When transit paths were built, steps were taken to minimize the number of walk-only paths. This resulted in some very short transit paths that, in most regional modeling efforts, would have been considered illogical. However, because walk was considered a competing mode in the mode choice models, this was a desirable result. The mode choice models were "allowed" to determine which short transit (or taxi or automobile) trips were not likely compared with the walk mode.

The building of separate paths obviated the need to consider fares in the path-building process. There was no need to exclude short, illogical transit trips from the path-building process for the reasons just mentioned. Fares and other travel costs were considered explicitly in the circulator/distributor models.

MODEL CALIBRATION PROCESS AND RESULTS

Disaggregate data were not available to perform a rigorous calibration of the logit models used to model the central area distributor and circulator mode use. Thus, an existing model was borrowed and adjustments were made to match observed aggregate data. DPM models from Los Angeles, Detroit, and Miami were considered as donor models. Both the Detroit and Miami models are based on the original Los Angeles DPM modeling work performed in the late 1970s. Apparently the Detroit model was calibrated in much the same way as the Chicago model—an adjustment of model constants and coefficients to match aggregate mode shares. The Miami model apparently used a slightly more rigorous calibration procedure. At the least, the calibration of the Miami model was based on observed travel behavior with a circulator/distributor system in place. However, the basic form of the Miami model was not changed from the form originally developed for Los Angeles.

The Detroit model was selected as the donor model for Chicago for several reasons. First, like Chicago, Detroit is a large northern city, and its climate resembles Chicago's more closely than Miami's does. Second, the implied values-of-time from the Detroit model appeared to be more reasonable than the implied values-of-time from Miami. Finally, because the Miami and Detroit models were both derived from the same root model, Los Angeles, they offered the same benefits in terms of model form.

Adjustments were made to alternative specific constants and to system coefficients. Good aggregate data existed to guide the adjustments. Most of the data were collected as part of ongoing monitoring processes conducted by CATS and Metra. The data included

- Egress mode shares from five of the six commuter rail stations;
- Egress mode shares by distance from the commuter rail stations;
- Average egress trip length from the commuter rail stations by mode;
- Mode shares for midday trips made by central area workers, nonworkers, and residents;
- Average trip lengths for midday trips made by central area workers, nonworkers, and residents; and
- Mode shares and average trip lengths for peak trips made by central area residents.

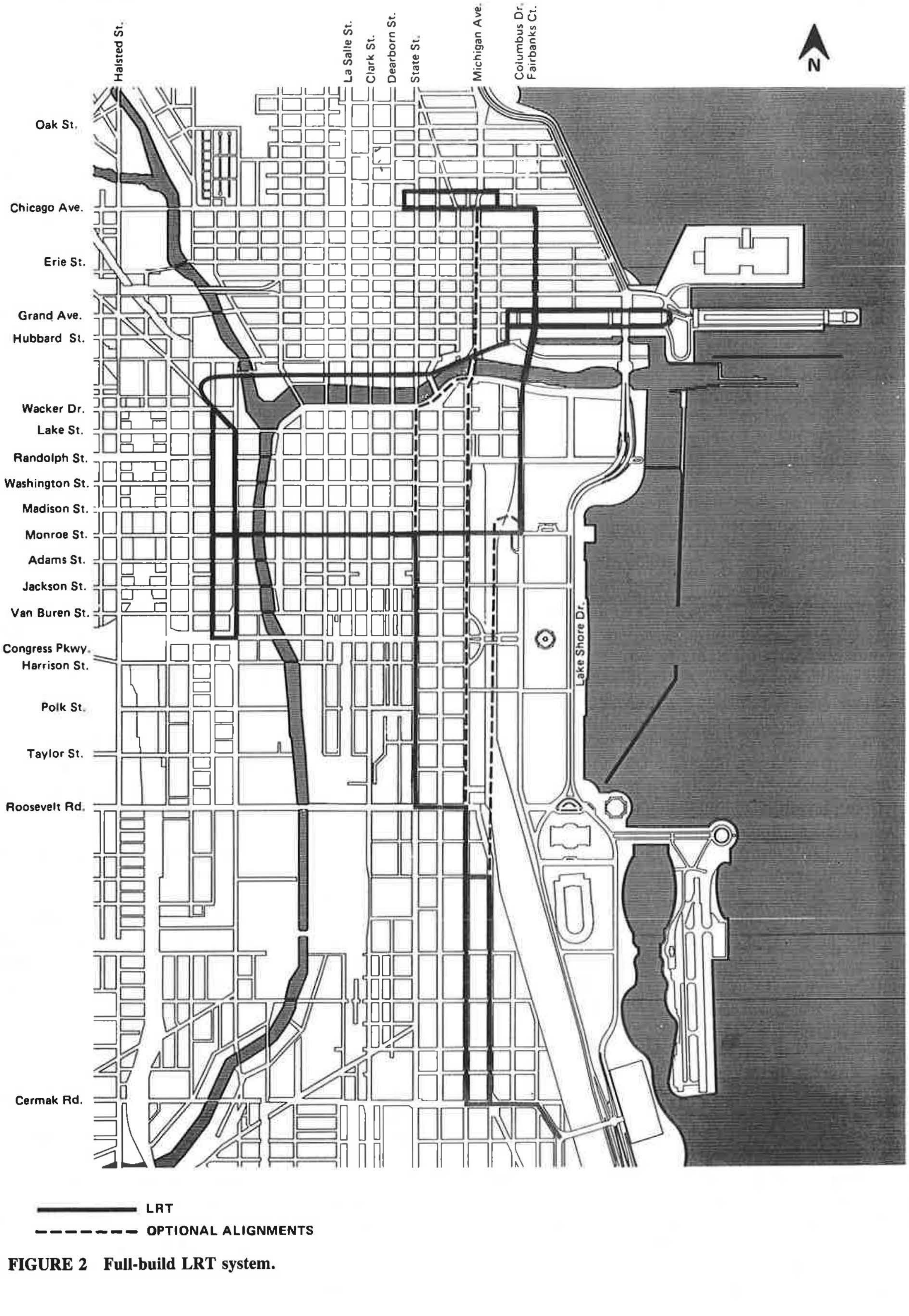

FIGURE 2 Full-build LRT system.

Two types of adjustments were made to system coefficients. The first adjusted the coefficients on travel cost to account for a different base year for measuring travel costs and for the local value-of-time. The value-of-time for central area commuters was assumed to be one-third of the average wage rate of the Metra commuters (as obtained from 1980 census journey-to-work data). The value-of-time for the circulator models for central area workers was assumed to be one-third of the wage rate for those workers. The average wage rate for central area workers is slightly lower than the average wage rate for central area Metra commuters. Finally, the value-of-time for central area nonworkers and midday resident trips was assumed to be one-sixth of the central area wage rate. The use of one-third and one-sixth of the average wage rate was based on guidance from UMTA.

The second type of coefficient adjustment was the modification or addition of a walk distance coefficient. This coefficient was adjusted so that modeled walk mode shares by distance range and average walk distance matched aggregate observed shares. An iterative approach was used to adjust the coefficient.

Alternative-specific constants were iteratively adjusted so that modeled aggregate mode shares matched observed aggregate mode shares. This process used the following formula to guide the adjustment of the constants:

$$C_1 = C_o + \ln \frac{P_1 \times (1 - P_o)}{P_o \times (1 - P_1)} \qquad (1)$$

where

C_1 = revised constant,
C_o = original constant,
P_1 = desired share, and
P_o = share obtained using C_o.

Morning Peak-Period Distributor Mode Choice Model

The morning peak-period distributor mode choice model is a simple logit-based model of the form

$$P_m = \frac{\exp(U_m)}{\sum_j[\exp(U_j)]} \qquad (2)$$

where

P_m = proportion of trips (for an interchange) using Mode m;
exp = the exponential function with the base of natural logarithms, e, as base; and
U_m = utility of Mode m.

Table 1 compares the calibrated coefficients for the Chicago morning peak-period distributor mode choice model with the models for Los Angeles, Detroit, and Miami. Some differences between the Chicago model and the other models warrant discussion. First, the coefficients for travel time and travel cost were set so that the implied value-of-time was equal to one-third of the average wage rate of central area workers who rode the Metra commuter rail service. This method for determining the coefficients for time and cost was consistent with the process used for Detroit. This method results in an implied value-of-time for central business district (CBD) workers that is substantially higher than the value-of-time for workers in Miami. It is slightly higher than the value-of-time for Detroit CBD workers (if the same year dollars were used) and substantially lower than the value-of-time used for the Los Angeles model.

TABLE 1 COMPARISON OF CENTRAL AREA DISTRIBUTOR MODEL COEFFICIENTS

Coefficient/Constant	Los Angeles	Detroit	Miami	Chicago
Walk Constant	2.29000	1.99000	-1.29000	2.74164
Transit Constant	0.20500	0.19860	-3.06200	-0.27072
Circulator Constant	0.00000	0.72500	0.00000	NA
Taxi Constant	NA	NA	NA	-3.13828
Travel Time (minutes)	-0.09790	-0.07419	-0.06370	-0.09000
Travel Cost (cents)	-0.00954	-0.02130	-0.02870	-0.01065
Walk Distance (miles)	NA	NA	NA	-3.00000
Walk Distance (transit paths)[a]	NA	NA	NA	-3.00000
Implied Value of Time	$6.16	$2.09	$1.33	$5.07
Year for Dollars	1975	1975	1986	1985

NA = not applicable.

[a] The walk distance coefficient for transit is applied only to the distance walked for transit access, egress, and transfer.

The second difference was the inclusion of taxi as a viable distributor mode. This was done by adding a taxi alternative-specific constant and adjusting the model constants to provide correct overall mode shares for the central area distributor portion of the model.

Perhaps the biggest difference between the Chicago model and the other models was the inclusion of walk distance as an explanatory variable. The need to add this variable resulted from an analysis of aggregate mode shares summarized by walk distance. Without the use of this explanatory variable, the model tended to greatly overpredict the walk mode share for walk travel times greater than 15 to 20 min. This overprediction of walk shares for the longer walk travel times resulted in an underprediction of transit use for the same walk travel time range. Figure 3 shows a comparison of modeled and observed mode shares by walk time for the walk and transit modes based on the calibrated model. As can be seen, walk shares still tend to be overpredicted and transit shares underpredicted. However, the relative magnitude of the over- and underpredictions was substantially reduced by the walk distance variable.

Walk distance can be directly converted to walk travel time, because a constant walk speed of 3 mph is used in the modeling process. Thus, it might be argued that the inclusion of walk distance in the utility function is equivalent to adding -0.15 to the coefficient of travel time for walk trips. This would result in raising the value-of-time for walk trips to $13.52/hr, which is similar to the value-of-time used for the Los Angeles model (if stated in the same year dollars). It is, however, more proper to consider this variable as a "fatigue factor," not as a change in the value-of-time. Alternatively, the inclusion of the walk distance factor can be viewed as an adjustment to account for the effects of out-of-vehicle travel time. Many regional mode choice models have found out-of-

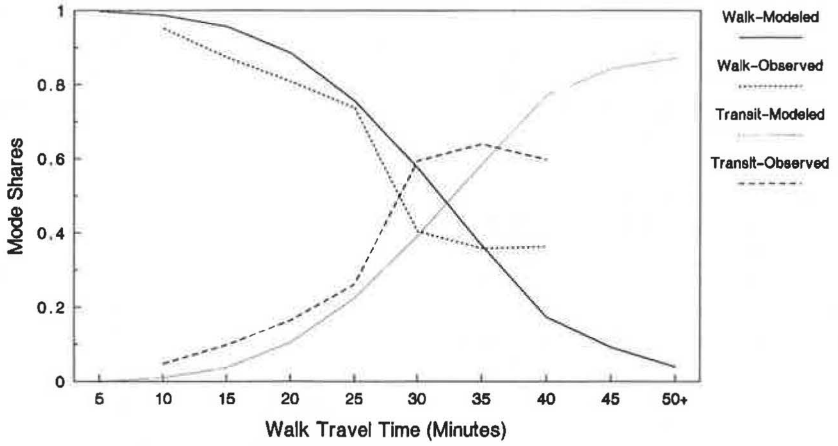

FIGURE 3 Comparison of modeled and observed mode shares for a.m. peak period.

vehicle travel time to be two to three times more onerous than in-vehicle travel time.

Table 2 gives the modeled and observed shares by distance range and the modeled and observed mode shares by commuter rail station. The observed shares are based on a 1985 Metra survey. As is obvious, the model reproduces the observed results closely for the North Western, Union, and LaSalle Street stations. Whereas the match was not as close for the Van Buren and Randolph stations, a separate 1989 survey suggested that walk mode shares for those stations were near 95 percent. This implies that the models were also working properly for those two stations.

Morning Peak-Period Circulator Trip Distribution—Mode Choice Model

The morning peak-period circulator model is a logit-based simultaneous trip distribution-mode choice model of the following form:

$$P_{j,m} = \frac{\exp(U_{j,m})}{\sum_j \sum_m [\exp(U_{j,m})]} \quad \text{for each production zone} \qquad (3)$$

where $P_{j,m}$ is the proportion of trips to Destination Zone j using Mode m and $U_{j,m}$ is the utility of Destination Zone j for Mode m.

Table 3 gives the calibrated coefficients for the Chicago morning peak-period circulator trip distribution–mode choice model. The Los Angeles, Detroit, and Miami DPM models did not include such a market segment. Unlike Chicago, they apparently did not have a CBD population large enough to warrant such a model. The Chicago model used the coefficients of travel time and travel cost determined for the morning peak-period distributor model. This was based on the assumptions that the trip purpose being represented in both the peak-period distributor and circulator models was the work trip and that workers should have similar sensitivities to travel time and travel cost regardless of where they live. The destination zone trip density and logarithm of the destination zone area coefficients were taken from the midday circulator models for workers. The walk distance and walk distance to transit coefficients were adjusted to match observed average trip lengths as closely as possible. Finally, the

TABLE 2 COMPARISON OF MODELED AND OBSERVED EGRESS MODE SHARES FOR COMMUTER RAIL STATIONS

	Walk Share		Transit Share		Taxi Share	
	Modeled	Observed	Modeled	Observed	Modeled	Observed
Mode Shares by Walk Distance (time interval in minutes)						
0-5	100%	—	0%	—	0%	—
5-10	99	95%	1	5%	0	—
10-15	96	87	4	10	1	3%
15-20	87	81	11	16	1	3
20-25	76	74	23	26	2	—
25-30	58	41	39	59	3	—
30-35	37	36	59	64	5	—
35-40	17	36	77	60	5	4
40-45	9	—	84	—	7	—
45-50+	4	—	87	—	9	—
Mode Shares by Rail Station						
Roosevelt	40%	—	53%	—	7%	—
Van Buren	94	88%	5	12%	1	0%
Randolph	95	82	4	14	1	4
North Western	83	84	16	16	1	1
Union	82	81	17	18	1	1
LaSalle	92	91	7	6	1	2
Average	84%	84%	15%	15%	1%	1%

— Indicates that data were unavailable.

TABLE 3 CENTRAL AREA PEAK-PERIOD CIRCULATOR MODEL COEFFICIENTS

Coefficient/Constant	Chicago
Walk Constant	2.69269
Transit Constant	0.54637
Taxi Constant	-1.06622
Auto Constant	0.00000
Travel Time (minutes)	-0.09000
Travel Cost (cents)	-0.01065
Walk Distance (miles)	-4.70000
Walk Distance (transit paths)[a]	-4.70000
Destination Zone Trip Density (trip attr/acre)	0.00767
Ln of Destination Zone Area (in acres)	1.00000
Implied Values of Time	$5.07
Year for Dollars	1985

[a] The walk distance coefficient for transit is applied only to the distance walked for transit access, egress, and transfer.

alternative-specific constants were adjusted to match observed mode shares. Table 4 gives observed and modeled mode shares and average trip lengths by mode. The observed data were obtained from unpublished results of a CATS survey of central area residents.

Midday Distributor Mode Choice Model

The midday distributor mode choice model for Chicago has the same form as the morning peak-period distributor model. Like the peak-period circulator model, the midday distributor mode choice model for Chicago does not have a counterpart in the Los Angeles, Detroit, or Miami models. In 1985, approximately 16,000 trips were made to the central area on Metra outside the morning peak period. This was only 15 percent of the total daily trips made to the central area on Metra during the day, but it was not a trivial number of trips. To calibrate the model, the morning peak distributor model was chosen as a base. The coefficient of travel cost was doubled to cut the implied value-of-time in half for two reasons: (*a*) the midday trips were assumed to be nonwork trips and (*b*) travelers making nonwork trips value their time at approximately one-half the level of work-trip travelers. The alternative-specific constants were not modified from the values determined for the morning peak-period distributor model. Table 5 gives the coefficients and constants used for the midday distributor model.

No data were available to guide the adjustment of the midday distributor model constants and coefficients. However, the model results were compared with the peak-period model results for reasonableness. Table 6 gives the comparison. Note that the midday walk shares were consistently higher by distance range interval than the peak shares. This was expected because of the lower value-of-time used in the model. On the other hand, results by commuter rail station were mixed because of differences between the distributions of trips by commuter rail station for the peak and midday periods. The North Western, Union, and LaSalle Street stations were relatively farther from the midday attractors of trips than they were from the peak-period attractors. Thus, the midday walk shares from those stations were lower than the peak-period walk shares. The opposite was true for the Roosevelt, Van Buren, and Randolph Street stations.

TABLE 4 OBSERVED AND ESTIMATED MODE SHARES AND AVERAGE TRIP LENGTHS FOR PEAK-PERIOD CIRCULATOR MODEL

	Mode Share		Average Trip Length (minutes)[a]	
Mode	Observed	Modeled	Observed	Modeled
Walk	51.4%	51.4%	8.5	8.3
Transit	23.2	23.1	21.4	28.0
Taxi	12.6	12.7	20.1	24.9
Auto	12.9	12.8	19.0	37.4

[a] Average trip lengths based on walk travel times between zones for all modes.

TABLE 5 CENTRAL AREA MIDDAY DISTRIBUTOR MODEL COEFFICIENTS

Coefficient/Constant	Chicago
Walk Constant	2.74164
Transit Constant	-0.27072
Taxi Constant	-3.13828
Travel Time (minutes)	-0.09000
Travel Cost (cents)	-0.02130
Walk Distance (miles)	-3.00000
Walk Distance (transit paths)[a]	-3.00000
Implied Values of Time	$2.54
Year for Dollars	1985

[a] The walk distance coefficient for transit is applied only to the distance walked for transit access, egress, and transfer.

TABLE 6 COMPARISON OF MORNING PEAK-PERIOD AND MIDDAY DISTRIBUTOR MODE SHARES

	Walk Share		Transit Share		Taxi Share	
	Modeled	Observed	Modeled	Observed	Modeled	Observed
Mode Shares by Walk Distance (time interval in minutes)						
0-5	100%	100%	0%	1%	0%	0%
5-10	99	99	1	1	0	0
10-15	96	99	4	1	1	0
15-20	87	96	11	4	1	0
20-25	76	93	23	7	2	0
25-30	58	88	39	12	3	0
30-35	37	66	59	33	5	1
35-40	17	38	77	62	5	1
40-45	9	26	84	73	7	1
45-50+	4	13	87	87	9	1
Mode Shares by Rail Station						
Roosevelt	40%	66%	53%	34%	7%	1%
Van Buren	94	97	5	3	1	0
Randolph	95	98	4	2	1	0
North Western	83	82	16	17	1	0
Union	82	76	17	22	1	0
LaSalle	92	91	7	9	1	0
Average	84%	83%	15%	16%	1%	0%

Midday Circulator Trips—Central Area Workers

The midday circulator model for central area workers simultaneously determines trip generation, trip distribution, and mode choice. The model has the following form:

$$P_{f,j,m} = \frac{\exp(U_{f,j,m})}{\sum_f \sum_j \sum_m [\exp(U_{f,j,m})]} \quad \text{for each production zone} \qquad (4)$$

where $P_{f,j,m}$ is the probability of making zero trips or making one trip to Zone j on Mode m and $U_{f,j,m}$ is the utility of making zero trips or making one trip to Zone j on Mode m.

Each of the combinations of alternatives has its own utility function that takes on unique values for each origin zone and in all cases, except for making zero trips, for each destination zone. The utility functions are

$$U(f = 0) = C_0 + A_1 * \text{origin employment density} \qquad (5)$$

$$\begin{aligned} U(f = 1, j, \text{walk}) &= C_w + A_2 \ast \text{walk time} + A_3 \ast \text{walk distance} \\ &\quad + A_4 \ast \text{worker trip attraction density of Zone } j \\ &\quad + A_5 \ast \ln \text{(zonal area in acres)} \qquad (6) \end{aligned}$$

$$\begin{aligned} U(f = 1, j, \text{transit}) &= C_t + A_2 \ast \text{transit time} + A_6 \ast \text{transit walk distance} \\ &\quad + A_7 \ast \text{transit fare} \\ &\quad + A_4 \ast \text{worker trip attraction density of Zone } j \\ &\quad + A_5 \ast \ln \text{(zonal area in acres)} \qquad (7) \end{aligned}$$

$$\begin{aligned} U(f = 1, j, \text{taxi}) &= C_c + A_2 \ast \text{taxi time} + A_7 \ast \text{taxi fare} \\ &\quad + A_4 \ast \text{worker trip attraction density of Zone } j \\ &\quad + A_5 \ast \ln \text{(zonal area in acres)} \qquad (8) \end{aligned}$$

$$\begin{aligned} U(f = 1, j, \text{automobile}) &= C_a + A_2 \ast \text{automobile time} \\ &\quad + A_7 \ast \text{automobile cost} \\ &\quad + A_4 \ast \text{worker trip attraction density of Zone } j \\ &\quad + A_5 \ast \ln \text{(zonal area in acres)} \qquad (9) \end{aligned}$$

In Equations 5 through 9, C_0, C_w, C_t, C_c, and C_a are the alternative-specific constants for zero trips, walk, transit, taxi, and automobile, respectively, and $A_1, A_2, \ldots, A_7$ are calibrated model coefficients.

Table 7 compares the calibrated coefficients for the midday circulator model for central area workers with the models used in Los Angeles, Detroit, and Miami. There are several differences between the Chicago model and the others. First, the constant for zero trip making for Chicago is substantially higher than for Detroit and Miami but similar to the constant for Los Angeles. The constant was set to cause the model to match the observed percentage of zero trip makers for the central area in 1985: 39.7 percent. Table 8 gives the modeled-to-observed match for the other calibration measures—the mode shares and average trip lengths. Note that the observed mode shares and average trip lengths were obtained from a central area building survey performed by CATS in 1985.

The coefficient for walk distance is also substantially higher for the Chicago model than for the other cities. The coefficient was set to match an observed average walk trip length of 4.4 min for central area workers' midday trips.

The implied value-of-time for Chicago is substantially lower than for Los Angeles, similar to that for Detroit, and substantially higher than that for Miami. The variation in the values-of-time suggests that the worker model is not stable across urban areas. This is likely, because the model simultaneously projects trip frequency, trip distribution, and mode use. Indeed, one of the problems in calibrating the model for Chicago was the effect of the interaction of the variables—it was difficult to get the model to "settle down."

TABLE 7 COMPARISON OF MIDDAY CIRCULATOR MODEL COEFFICIENTS FOR CENTRAL AREA WORKERS

Coefficient/Constant	Los Angeles	Detroit	Miami	Chicago
Constant—No Trips	9.29400	4.80000	4.98160	11.50000
Walk Constant	3.03400	4.34000	5.03600	6.12823
Transit Constant	2.90000	2.43540	2.80200	0.39150
Circulator Constant	-0.81000	1.08500	-0.05400	0.79697
Taxi Constant	NA	NA	NA	-1.27064
Auto Constant	0.00000	0.00000	0.00000	0.00000
Travel Time (minutes)	-0.09190	-0.05226	-0.05980	-0.05226
Travel Cost (cents)	-0.00896	-0.01500	-0.04120	-0.00750
Walk Distance (miles)	-3.00000	-3.00000	-3.00000	-9.50000
Walk Distance (transit paths)[a]	-4.20000	-4.20000	-4.20000	-1.00000
Destination Zone Trip Density (trip attractions/acre)	0.00767	0.00767	0.00767	0.00767
Ln of Dest. Zone Area (in acres)	1.00000	1.00000	NA	1.00000
Employment Density (employ./acre) (for 0 trip makers)	0.0008552	0.0008552	0.0008552	0.0008552
Implied Value of Time	$6.15	$2.09	$0.87	$4.18
Year for Dollars	1975	1975	1986	1985

NA = not applicable.

[a] The walk distance coefficient for transit is applied only to the distance walked for transit access, egress, and transfer.

TABLE 8 MIDDAY CIRCULATOR MODE SHARES AND AVERAGE TRIP LENGTHS (CENTRAL AREA WORKERS)

	Mode Share		Average Trip Length (minutes)	
Mode	Observed	Modeled	Observed	Modeled
Walk	90.1%	89.5%	4.4	4.9
Transit	6.5	7.0	24.7	24.6
Taxi	1.6	1.7	—	19.0
Auto	1.7	1.8	—	25.5

— Indicates that data were unavailable.

Contrary to the other models used for Chicago, the midday central area worker model included a constant for the circulator mode that was different from the normal transit mode. Unlike the models for the other cities, the constant for the circulator makes it more attractive than transit when all travel impedances are equal. This was done in the Chicago model because the circulator (LRT) was not modeled as an explicit mode separate from transit, but rather as a transit submode. This procedure avoided the independence of irrelevant alternatives problem that would have been obvious if LRT had been considered a new mode. LRT could not be considered substantially different from the bus, subway, and elevated systems already in place in the central area.

Nevertheless, because of its visibility, accessibility, fare collection system, and other unique characteristics, it was felt that LRT would be more attractive than the existing transit system. This is especially true for intra-central-area trips. Specifically, it was assumed that at a point of indifference on an interchange, travelers would choose LRT 60 percent of the time and regular transit 40 percent of the time. This meant that the constant for LRT should be more positive than the constant for transit by the following amount: Delta = $\ln (0.6/0.4) = 0.405$. Note that at the point of indifference (i.e., 50 percent choose bus and 50 percent choose transit), the delta value would be zero.

In the actual application of the model, the added attractiveness of LRT was added to the utility of transit in proportion to the amount of in-vehicle travel time spent on LRT. In other words, if LRT was used for 50 percent of the in-vehicle travel time on an interchange, the utility of transit was only 0.2025 more than what the transit utility would have been if only bus had been used for the entire trip. The full difference (0.405) was added only if LRT was the only transit mode used for the entire interchange.

The LRT attractiveness difference can be equated with travel time or travel cost by dividing by the coefficients of travel time or travel cost, as appropriate. The maximum LRT attractiveness difference is equivalent to 7.8 min of travel time or 54 cents of travel cost.

During the calibration and validation of the model, it was discovered that the trip distribution portion of the model was sensitive to the destination zone trip density. There is a substantial variation in trip density in the central area. It was discovered that several zones were attracting a major portion of the trips from all other zones in the central area. To solve this problem, maximum trip densities were set at two standard deviations above the mean trip attraction density for the central area.

Midday Circulator Trips—Central Area Nonworkers

The midday circulator model for central area nonworkers is a simultaneous trip distribution–mode choice model. It is of the same form as the model used for peak-period circulator trips. However, in the midday circulator model for nonworkers, the destination zone trip density is based on non-home-based trips, not home-based work trips as in the morning peak-period circulator model. Table 9 compares the calibrated coefficients for the Chicago model with the models used for Los Angeles, Detroit, and Miami.

The coefficient for walk distance is substantially higher for the Chicago model than for the other cities. This is the same situation that occurred for the midday circulator model for central area workers. The coefficient was set to match an observed average trip length of 4.4 min. The average walk trip length for nonworkers was assumed to be identical to the average trip walk length for central area workers. Table 10 compares modeled and observed mode shares and average trip lengths for central area nonworkers. As with the midday circulator model for workers, the observed nonworker travel characteristics were obtained from the 1985 central area building survey performed by CATS.

TABLE 9 COMPARISON OF MIDDAY CIRCULATOR MODEL COEFFICIENTS FOR CENTRAL AREA NONWORKERS

Coefficient/Constant	Los Angeles	Detroit	Miami	Chicago
Walk Constant	2.92200	2.87680	3.82400	5.58921
Transit Constant	1.31800	4.35300	1.01100	2.78463
Circulator Constant	-3.15500	1.93800	-1.03800	3.19010
Taxi Constant	NA	NA	NA	-1.00428
Auto Constant	0.00000	0.00000	0.00000	0.00000
Travel Time (minutes)	-0.08780	-0.16900	-0.05810	-0.05226
Travel Cost (cents)	-0.01096	-0.09657	-0.04280	-0.01500
Walk Distance (miles)	-3.00000	-3.00000	-3.00000	-9.00000
Walk Distance (transit paths)[a]	-4.20000	-4.20000	-4.20000	-9.00000
Destination Zone Trip Density (trip attractions/acre)	0.00378	0.00378	0.00378	0.00378
Ln of Dest. Zone Area (in acres)	1.00000	1.00000	NA	1.00000
Implied Value of Time	$4.83	$1.05	$0.81	$2.09
Year for Dollars	1975	1975	1986	1985

NA = not applicable.

[a] The walk distance coefficient for transit is applied only to the distance walked for transit access, egress, and transfer.

When the implied values-of-time are compared across the three cities for the circulator model for central area nonworkers, the same patterns emerge as in the circulator model for central area workers. Specifically, the Chicago value-of-time is substantially lower than the value-of-time used for Los Angeles, similar to the value-of-time used for Detroit, and substantially higher than the value-of-time used for Miami.

Midday Circulator Trips—Central Area Residents

The midday circulator model for central area residents is a simultaneous trip distribution–mode choice model. It is of the same form as the model used for peak-period circulator trips and the midday circulator model for nonworkers. For the midday circulator model for central area residents, the destination zone trip density is based on home-based nonwork trips. Table 11 gives the calibrated coefficients for the Chicago

TABLE 10 MIDDAY CIRCULATOR MODE SHARES AND AVERAGE TRIP LENGTHS (CENTRAL AREA NONWORKERS)

	Mode Share		Average Trip Length (minutes)	
Mode	Observed	Modeled	Observed	Modeled
Walk	92.7%	92.2%	4.4	4.9
Transit	3.5	3.7	24.7	24.7
Taxi	0.9	1.0	—	17.9
Auto	3.0	3.2	—	38.7

— Indicates that data were unavailable.

TABLE 11 MODEL COEFFICIENTS FOR MIDDAY CIRCULATOR TRIPS (CENTRAL AREA RESIDENTS)

Coefficient/Constant	Chicago
Walk Constant	6.35276
Transit Constant	3.51171
Taxi Constant	-0.69088
Auto Constant	0.00000
Travel Time (minutes)	-0.05226
Travel Cost (cents)	-0.01500
Walk Distance (miles)	-10.00000
Walk Distance (transit paths)[a]	-10.00000
Destination Zone Trip Density (trip attr/acre)	0.00378
Ln of Destination Zone Area (in acres)	1.00000
Implied Values of Time	$2.09
Year for Dollars	1985

[a] The walk distance coefficient for transit is applied only to the distance walked for transit access, egress, and transfer.

TABLE 12 MIDDAY CIRCULATOR MODE SHARES AND AVERAGE TRIP LENGTHS (CENTRAL AREA RESIDENTS)

	Mode Share		Average Trip Length (minutes)	
Mode	Observed	Modeled	Observed	Modeled
Walk	92.0%	92.1%	4.9	5.3
Transit	4.0	3.8	24.7	28.0
Taxi	1.0	0.9	—	24.9
Auto	3.0	3.2	—	37.4

— Indicates that data were unavailable.

model. Table 12 gives the observed and modeled mode shares and average trip lengths by mode for the midday resident trips. Los Angeles, Detroit, and Miami did not use a comparable model for their DPM models.

SUMMARY

A useful central area circulator/distributor model has been calibrated for Chicago based on the DPM modeling methodology originally performed for Los Angeles. A number of interesting lessons were learned during the calibration of the models. This led to the following conclusions and recommendations regarding DPM models.

First, detail is critical. A great amount of detail was used in defining the Chicago central area zone structure and transportation network. If the model calibration were performed again for Chicago, additional detail would probably be used in describing the transit system. There are difficulties in acquiring the data necessary to develop detailed networks and the socioeconomic data for detailed zones. However, the detail is crucial to properly model the utilities of the different choices available in circulator/distributor models.

In future model calibration efforts, attempts should be made to move away from simultaneous model forms. Whereas simultaneous model forms might be theoretically satisfying, they are very difficult to control in practice. In addition, when the circulator/distributor models are transferred from one urban area to another, it can be easy to "forget" the distribution parts of the models in attempts to match mode shares. Although they are not the subject of this paper, simultaneous trip distribution–mode choice models make it difficult or impossible to isolate the effects of system changes in alternatives analyses.

Attention should be paid to average trip lengths and mode shares by average trip length in the calibration of circulator/distributor models. It is interesting to compare the various models from Los Angeles, Detroit, Miami, and Chicago and speculate on the effects of the different coefficients on the model results. In many ways, the Chicago models are similar to the Los Angeles models. The Los Angeles models had a high value of travel time. On the basis of the need to add the coefficient of walk distance to the Chicago model, it is likely that the high value-of-time in the Los Angeles model was compensating for the disutility of walk distance. In contrast, if a model with low values-of-time had been used in Chicago (similar to the Miami models), the coefficient of walk distance would have been even more important to keep the modeled travelers from walking "forever."

Another change that might be appropriate for circular/distributor models would be to disaggregate travel-time into out-of-vehicle and in-vehicle travel time as is done in many regional mode choice models. This change would make the circulator/distributor models more consistent with the regional model and decrease the importance of the walk distance coefficient.

This model development effort highlighted the need for additional research into the modeling of circulator/distributor trips. The circulator/distributor models for Detroit, Miami, and Chicago are all derivatives of the Los Angeles model developed in the late 1970s. The Detroit and Chicago models adjusted the Los Angeles model constants and coefficients to match observed aggregate travel characteristics. The Miami model was apparently recalibrated in a more rigorous manner; however, the basic structure was not changed from the structure originally developed for Los Angeles. Experience in the development of the Chicago model suggests that changes in the basic model structure used for circulator/distributor models could improve both the understandability and the reasonableness of the models. However, such changes will require a concerted effort to collect and analyze circulator/distributor mode choice data from cities with circulator/distributor systems.

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