Development of a Traffic Modeling System for Detour Planning on the Downtown Seattle Transit Project

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A major transit subway project is being constructed in downtown Seattle, Washington. A 1.3-mi electric-bus tunnel and associated surface-street improvements are in the final design phases and initial tunnel construction has begun; the expected completion date is 1990. The Downtown Seattle Transit Project (DSTP) was initiated by Metro Transit, the city of Seattle, and UMTA to help relieve existing traffic congestion in downtown Seattle and to provide capacity for growth. The tunnel will have three underground stations as well as combined station and staging areas at each end of the alignment. Both cut-and-cover and tunnel boring construction techniques will be utilized on the project. One of the greatest consequences of such a major construction project in a central business district (CBD) can be the adverse impacts on CBD traffic. An important task for project planners has thus been to assess the likely impacts of construction on traffic and to develop traffic maintenance plans that will best facilitate the tunnel construction and keep traffic impacts to a minimum. An innovative and complex traffic modeling system has been developed to aid in this task. Based on three existing traffic planning software programs (LINKOD, MINUTP, and TRANSYT-7F), a modeling chain has been developed that provides a systematic means for assessing the impacts of street closures, detours, and other traffic restrictions; identifies potential "hot spots"; and facilitates the development of traffic control plans to mitigate these impacts. The development and calibration of this modeling system, which has several innovative features likely to be of interest to other traffic modelers, are described. The modeling system organizes the analysis of traffic maintenance schemes as well as provides an ongoing tool for helping to design the longer-range (design-years) traffic improvements. Also included in the paper is a discussion of the effort involved in developing the modeling system and some suggestions for further research to improve the system for future applications.

In an effort to relieve existing traffic congestion in downtown Seattle, to stimulate and meet projected transit ridership demand, and to ensure that the transportation system will have the capacity to accommodate future growth, Metro, the city of Seattle, and UMTA initiated the Downtown Seattle Transit Project (DSTP). DSTP consists primarily of a 1.3-mi electric-bus tunnel and associated surface-street improvements. The tunnel alignment and station locations are shown in Figure 1. The tunnel route generally follows Pine Street west from Interstate 5 in a cut-and-cover structure to Westlake Station in the retail district. The route then runs under Third Avenue in twin-bore tunnels through two additional stations to its southern terminus at the old Union Railroad Station. At either end of the alignment, combined station and staging areas will connect with surface streets and the Interstate highway system via exclusive ramps.

An inevitable consequence of a central business district (CBD) construction project as large as DSTP is the adverse impact on CBD traffic. An important task of DSTP is to assess these expected impacts and to develop traffic maintenance plans that would facilitate the tunnel construction and minimize traffic impacts. A benefit of the project is to provide the city of Seattle with a microcomputer-based assignment package of the downtown area.

OVERVIEW OF MODELING SYSTEM

In order to identify a.m. and p.m. peak-hour traffic management plans, three different transportation and traffic

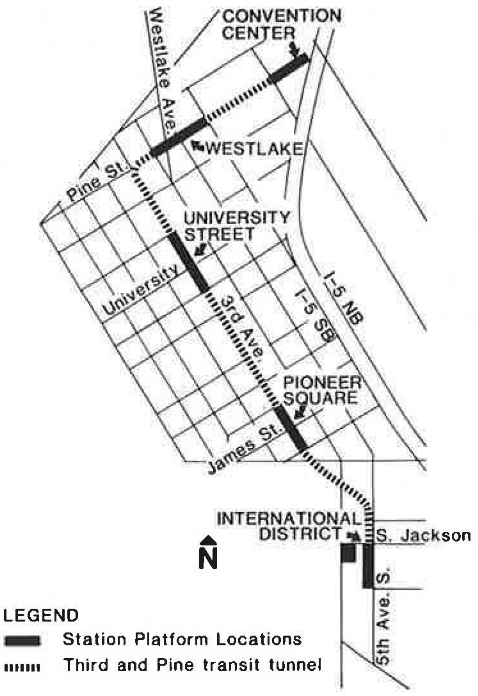

FIGURE 1 DSTP tunnel alignment and station location.

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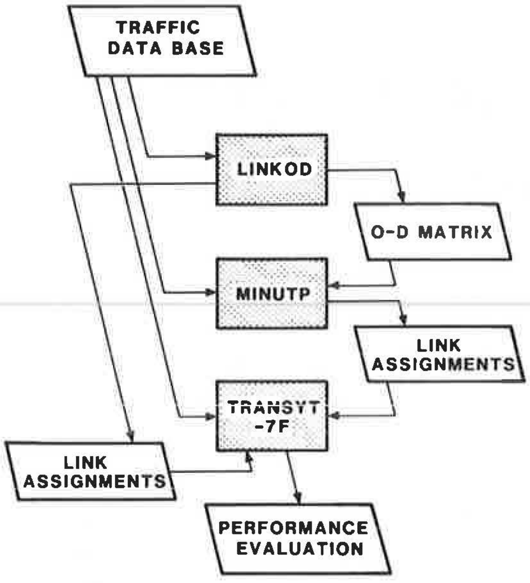

FIGURE 2 DSTP traffic modeling system.

engineering software packages were used sequentially to assess the traffic impacts of construction-related street closures: LINKOD, MINUTP, and TRANSYT-7F. The overall modeling system structure is outlined in the flowchart in Figure 2. The first program, LINKOD, was used to synthesize a trip table for downtown Seattle by using an initial estimate of trips generated and attracted to 253 centers of activity (e.g., parking facilities), along with traffic count information and street network characteristics. The LINKOD/MINUTP network area (Figure 3) consists of the primary CBD plus a fringe area to act as a buffer zone between points of traffic loading and the CBD streets of interest.

To validate the LINKOD trip table and the a.m. and p.m. base-case assignments, the trip tables created by LINKOD were assigned to the downtown street network and the assigned volumes were compared with a.m. and p.m. ground counts. Adjustments to link travel times were made in order to reduce differences between estimated and observed volumes.

Once the trip tables for downtown had been created and validated, evaluation of the impact of street closures on traffic patterns could be done with either LINKOD or MINUTP. Both programs were tested for this step. MINUTP is a general transportation planning package that includes subprograms for trip generation, trip distribution, modal choice, and traffic assignment. Only the traffic assignment routines were used for DSTP. Both LINKOD and MINUTP contain traffic assignment subroutines that take into account capacity restraints, and although LINKOD's assignments were found to be somewhat more accurate, both models were deemed capable of producing acceptable assignment results. MINUTP operates locally on a microcomputer, whereas LINKOD operates on a mainframe computer.

With either LINKOD or MINUTP, the process of assessing the impacts of street closures on traffic volumes was the same. The network was modified to reflect street closures or restrictions during various phases of construction, and the trip table was assigned to the modified network. The resulting volumes were then compared with the base assignment (with no closures), which thus provided an estimate of traffic diverted to other streets.

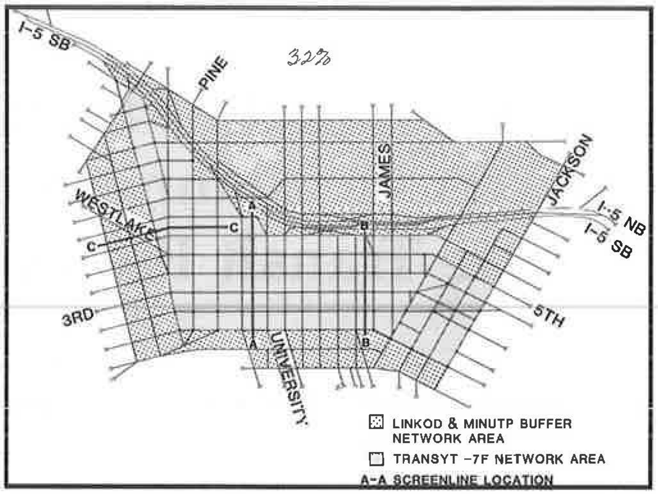

FIGURE 3 DSTP traffic model network area and screenline locations.

The last step in the modeling process was the use of the TRANSYT-7F simulation model, which allows analysis of traffic flow through a street network by producing output and comparing results with measures of effectiveness (MOEs). These measures-of-effectiveness are used to summarize intersection and network performance in terms of delay, travel time, queue length, and fuel consumption. Inputs to the model include volumes, intersection and street geometry, signal timing, and saturation flow rates. Additional parameters such as free-flow speed, platoon dispersion factors (PDFs), bus dwell times, stop penalties, and delay weighting allow manipulation and calibration of a given network. Included in the TRANSYT-7F program are optimization routines for refinement of existing signal timing plans. The volumes that are input into TRANSYT-7F are taken from the traffic assignment step.

The TRANSYT-7F model area (see Figure 3) comprises 119 signalized intersections located in Seattle's CBD. The network is bounded on the north by Stewart Street, on the south by Jackson Street, on the east by Interstate 5, and on the west by First Avenue.

METHODOLOGY

The two most common methods for developing a trip table involve either conducting an origin-destination (O-D) survey or using the transportation planning process of trip generation (based on population and employment figures), trip distribution, modal split, and model calibration. Both of these methods are time consuming and expensive. An alternative to these methods is the use of LINKOD, which utilizes traffic counts to synthesize a trip table, thereby obviating the need for an extensive O-D survey.

Trip-Table Creation Using LINKOD

LINKOD is a FORTRAN program written to run on a mainframe computer and is the result of a 1980 FHWA study *(1)*. To create a trip table, LINKOD requires traffic count information, including (passenger-car) volumes on streets and turning volumes at intersections; parking information, including location and characteristics (numbers of productions and attractions); and physical and geometric information about streets and intersections, including length, direction, number of lanes, and type of facility.

The LINKOD software package program logic is shown in Figure 4. LINKOD includes program modules to develop and edit a network, build paths and skims, distribute trips for small areas on micronetworks, and make assignments by using an equilibrium assignment process. This last step is iterative, assigning and correcting the trip table to best replicate observed traffic flows.

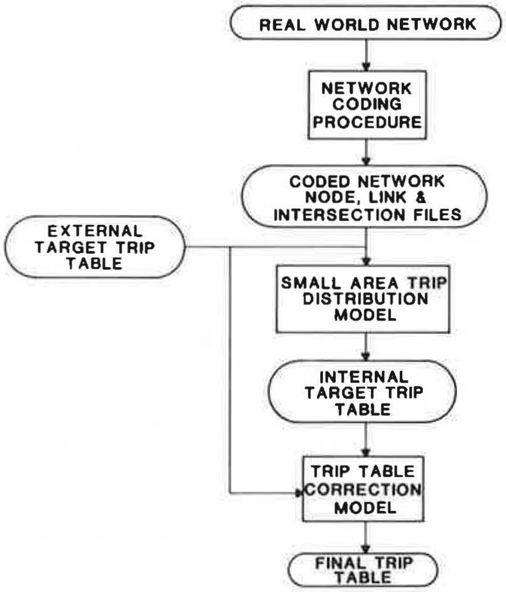

FIGURE 4 LINKOD model logic flow.

Traffic Assignment Using LINKOD or MINUTP

To simulate traffic disruptions caused by construction activities in downtown Seattle, a capacity-restrained equilibrium-based assignment algorithm was used to assign the trip tables generated by LINKOD to networks representing various construction scenarios. Each scenario consisted of sets of street closures, capacity restrictions, and other disruptions, representing effects of ongoing, although disparate, construction activities during specific phases of DSTP.

The two computer programs employed to perform the assignments were LINKOD and MINUTP. The process by which the LINKOD trip table is corrected so as to produce volumes similar to input volumes is bypassed in this case. This standard equilibrium assignment aspect of LINKOD was used several times and produced highly satisfactory results.

MINUTP is a privately developed library of microcomputer programs that performs the usual functions of traditional transportation planning with regard to trip generation, distribution, and network assignment *(2)*. For the case described here, only the network assignment module was used. MINUTP has three different assignment methods: all or nothing, all shortest paths, and stochastic. Any one or a combination of these methods can be used in the iterative assignment process. MINUTP was designed primarily for regional transportation forecasting. The input data describing a MINUTP network are less detailed than those describing a LINKOD network—the primary difference is the detailed intersection description file, which is an input to LINKOD but has no counterpart in MINUTP. However, with creative use of the turn-penalty capabilities of MINUTP, a limited level of intersection control is possible. The updated version (May 1986) of MINUTP allows application of turn penalties for individual intersections, thereby providing some degree of fine-tuning of traffic assignments. In addition, preloading of traffic volumes assists in defining through-travel patterns more definitely.

Assessment of Impacts Using TRANSYT-7F

TRANSYT-7F is the most recent version of the computer program TRANSYT (Traffic Network Study Tool), a traffic signal optimization model originally written in England by the Transport and Road Research Laboratory. TRANSYT-7F was developed under FHWA's National Signal Timing Optimization Project. Modifications to the program developed in England included reorganized inputs, U.S. signal timing conventions, improved output formats, estimates of fuel consumption, and the provision of time-space diagrams *(3, 4)*.

Results of the traffic assignments, representing estimates of the magnitude and extent of traffic disruptions, were input to TRANSYT-7F, which has two computational modes: simulation and optimization. For the assignments, the simulation mode was used, allowing the comparison of MOEs to a base case. The base case was a carefully calibrated simulation of conditions existing before major construction activities. Results of TRANSYT-7F simulation were expected to provide a logical and consistent framework for comparing the degree of traffic disruption between phases of construction. In addition, the effects of modifications (to signal timing, for instance) on a local basis could be estimated.

MODEL CALIBRATION AND VALIDATION

Data Collection and Organization

To the extent possible, required data were obtained from existing documents. The Seattle Engineering Department (SED) provided traffic counts, signal timing, and on- and off-street parking information. Printed bus schedules were used for bus volumes, and maps provided network information. On-street surveys by project personnel were needed for travel-time studies, special intersection approach and geometric data, turn restrictions, bus zones, and missing or inconsistent traffic counts. Data were stored and manipulated with a microcomputer spreadsheet program. In all, the data base contained more than 15,000 input entries and 11,000 calculated values.

Network Creation

Because of data input requirements unique to each computer program and because of differences in purpose between programs, a total of six networks (three for each of the a.m. and p.m. peak hours) were created.

The LINKOD networks were very detailed abstractions of the existing street and highway system in the Seattle downtown area; the level of accuracy generally decreased with distance from the CBD. A total of 255 intersections (nodes) and 650 links were included in the network. Productions and attractions (such as parking information) were similarly detailed reflections of existing conditions, because individual parking lots and garages were included in the network.

The network for MINUTP was similar to the network developed for LINKOD, within the constraints imposed by program differences. The primary difference between the networks for the two models was that LINKOD enabled a very detailed description of intersections and associated delays, whereas MINUTP allowed only the input of turning penalties at intersections.

A total of 119 intersections were included in the TRANSYT-7F network. The network also included both automobile and transit links because of the congestion caused by CBD bus operations. However, because of limitations in the network size allowed by the microcomputer version of TRANSYT-7F, two subnetworks were created with enough overlap to allow the combination of the two in a consistent manner. The TRANSYT-7F network differed from the LINKOD network in that a fringe area was not required and intersections having more than four legs required special treatment.

Data Input and Output Considerations

LINKOD Input

LINKOD has three input files: the link file, the node file, and the intersection file. Although the intersection file is optional, its inclusion leads not only to a more accurate trip table, but also to a better matching of existing turning volumes, which is very important because turning-movement volumes are input into TRANSYT-7F. All the data were entered by using a data preprocessing program written in dBASE III, which allowed data to be input by technicians and performed the sorting and file-writing routines required by LINKOD.

MINUTP Input and Output

MINUTP requires only one input file, which is basically a link file. The input requirements for this file are similar to those for the LINKOD link file but are in an entirely different format. MINUTP is capable of modeling networks of up to 8,190 links and 4,095 two-way links. Because the LINKOD network was created before MINUTP, it was possible to manipulate LINKOD data and match the format requirements of MINUTP by using programs developed by the project team. PREMUTP, MUTPT, and CARDIT are utility programs for transfer of data among LINKOD, MINUTP, and TRANSYT-7F that were developed for DSTP (May 1986). MUTPT also extracts MINUTP assigned volumes and inputs them into the TRANSYT-7F preprocessor programs.

TRANSYT-7F Input

Whereas LINKOD and MINUTP require data in a link format, TRANSYT-7F requires data in a node format. Because of the extensiveness of TRANSYT-7F input data, two data preprocessors were used, SIGNAL *(5)* and PRETRANSYT *(4)*. Both assist in the creation of TRANSYT-7F input data. SIGNAL requires geometric and physical information and performs individual intersection analyses that are used subsequently in PRETRANSYT. PRETRANSYT uses the information base established by SIGNAL and, with additional signal timing connectivity and control card information, generates the input files required for TRANSYT-7F.

LINKOD Calibration

Methodology

The ultimate calibration objective was to generate a trip table that, when assigned to the network, would replicate the input (or ground count) volumes within reasonable limits. The initial aim was to generate a trip table that produced assigned volumes of which 80 percent were within ±20 percent of the input volumes. A secondary calibration objective was to generate a trip table that generally appeared to reflect known trip patterns. In the initial runs the resulting trip table indicated a large number of trips from one internal load node to another (e.g., trips from one parking garage to another, which is an unlikely pattern for peak-hour traffic). The assignment of this "initial run" trip table also resulted in accurately assigned link volumes but relatively inaccurate turning-movement volumes. The calibration effort focused primarily on rectifying the pattern of trips between internal load nodes and increasing the assigned volume accuracy for turning movements. Manipulation of the intersection input data file helped increase the accuracy of turning-movement volumes, but additional efforts were necessary to refine the model's accuracy.

The two basic methods of calibrating LINKOD involved manipulating either the program's control-card parameters or its input data. Each of the program modules required control-card input. Every control-card parameter had default values; however, several values were changed in an effort to encourage more trips between internal and external zones. Details of control card parameters used are contained in related documentation.

Further calibration involved the manipulation of the input data, particularly link and intersection impedances and input link volumes. Initial model runs produced a trip table with an unusually large number of trips from one internal load node to another. The assignment of the resulting trip table also tended to underassign link volumes. After some trial runs, the following steps were taken in an attempt to resolve these problems:

1. In the few instances in which the model had calculated abnormally high intersection delay, a more reasonable intersection delay based on field studies and typical delays for other intersections was input.
2. The original coded link impedances included impedance for the link as well as the intersection delay. For links connected to coded intersections (i.e., intersections coded in the intersection file) link impedances were reduced by an amount equivalent to the estimated intersection delay to avoid double-counting of intersection impedance. Reducing these and unusually high intersection impedances encouraged less underassignment on network links.

3. To promote fewer trips between internal load nodes, the impedances on the internal load-node approach links were adjusted. In the p.m. period, trips were encouraged to flow from internal to external load nodes by placing a high impedance (5 min) on approach links coming into internal load nodes and a lower penalty (2 min) on approach links out of the internal load nodes. The reverse of this was done for the a.m. period.

4. Another significant calibration effort involved a "smoothing" of the original input (i.e., observed) link volumes. LINKOD requires volumes in and out of an intersection to be balanced within certain limits. The modelers accomplished this originally by manually adjusting the incoming and outgoing observed aggregate link volumes until they balanced. In this initial effort, however, turning movements were not taken into consideration and hence the balancing process was not as accurate as it could have been. After initial runs of the model, it was determined that rebalancing—or smoothing—the link volumes by taking into account turning-movement volumes was necessary.

Results

In general, it was found that changes in the input data caused more dramatic changes in the model results than did changes in the control-card parameters. However, it was also determined that an appropriate combination of control-card parameters was necessary as a base from which to further calibrate with input data changes. To check the accuracy of the calibrated LINKOD model results, a comparison of input smoothed (observed) volumes with the output assigned volumes was made. The comparison is shown for both macro and micro links. Macro links represent the total directional link volume between two intersections, whereas micro links represent the individual turning movements within each intersection. In general, the a.m. base-case run of LINKOD produced results that were generally superior to those obtained from the p.m. base case.

Macro-Link Comparison Table 1 is a summary comparison of the LINKOD assigned volumes with the macro-link input volumes for both a.m. and p.m. cases. The percentage of links within a given volume range for which assigned volumes fell within 10 and 20 percent of input volumes is shown.

For both the a.m. and p.m. cases, the larger volumes had less error than the smaller volumes. In general, for the macro links, the a.m. LINKOD trip table and assignment process produced better results than did the p.m. table.

TABLE 1 LINKOD MACRO-LINK ERROR SUMMARY BY VOLUME RANGE

	Percentage of Assigned Volumes			
	Within 10 percent of Input Volumes		Within 20 Percent of Input Volumes	
Input Volume Range	A.M. ($N = 51$)	P.M. ($N = 40$)	A.M. ($N = 74$)	P.M. ($N = 55$)
Less than 100	31	19	52	32
100–250	45	18	70	43
250–500	56	36	78	65
500–750	76	54	92	81
Greater than 750	63	51	90	78

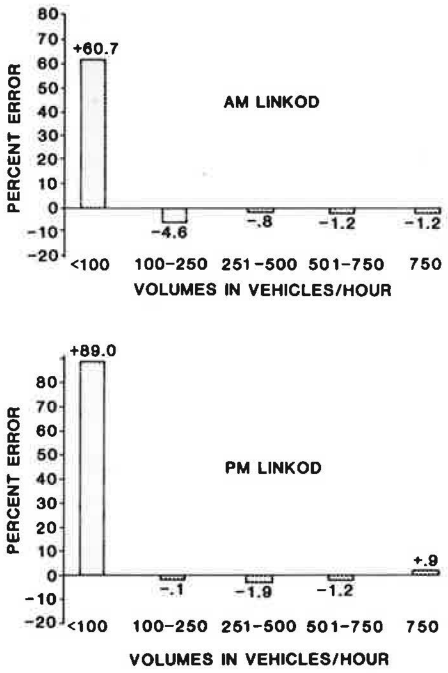

FIGURE 5 LINKOD calibration: percent error by volume for micro links.

Micro-Link Comparison Figure 5 shows the average percent error by volume for all the micro links (individual turning and through movements at intersections) in the network. Accuracy in turning-movement volumes is important because these volumes are used in TRANSYT-7F. The percent error in Figure 5 represents the percent difference between the volumes assigned using the calibrated LINKOD trip table and the base input (observed) volumes. The results show that the model has a high degree of accuracy in replicating volumes or links that had more than 100 vehicles per hour (vph). Although the low-volume links were assigned with a high percentage error, the absolute errors were typically small. For instance, a particular turning movement may have an observed volume of 25 vph and the model may have assigned it 45 vph. In this case even though the percentage error (+80 percent) is high, the absolute error (20 vph difference) is relatively low.

Another finding was that the accuracy of the micro links within any given intersection was significantly increased when that intersection was coded in the LINKOD intersection file. This was tested and confirmed by comparing the results from model runs both without and with the intersection file as part of the input. In the final LINKOD run, the intersections coded in the intersection file included only those in the core CBD network area. Intersections in the fringe or buffer area were not included. It was assumed that the model's level of accuracy was higher in the core area—the area of interest. The results in Figure 5, however, are aggregated across both the core and fringe areas and hence are less accurate than if they included the core area only.

In comparing the p.m. results with the a.m. results in Figure 5, a significant improvement is seen in the a.m. results. One reason for this may be that the p.m. network was calibrated first and the lessons learned and experience gained in the process enabled calibration of the a.m. network in half the time and

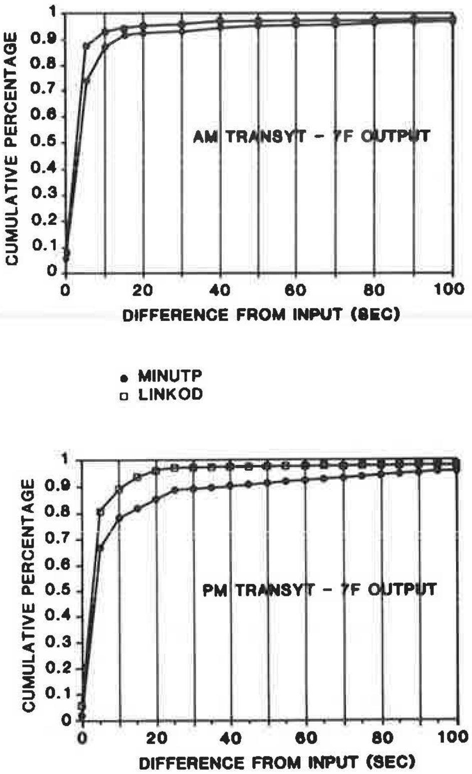

FIGURE 6 DSTP model calibration: difference in TRANSYT-7F calculated average delay using LINKOD and MINUTP output volumes compared with smoothed ground counts.

with better results. Another contributing factor may be that the p.m. case is simply more difficult to model because of the higher degree of diverse trip patterns as compared with the a.m. case.

The purpose of using LINKOD was to generate a trip table that, when assigned, would produce turning volumes with a level of accuracy that, when input into TRANSYT-7F, would produce results similar to TRANSYT-7F results produced when observed volumes were input. A key output from the TRANSYT-7F model is average vehicle delay for each intersection. To test the accuracy of the calibrated LINKOD assigned (output) volumes, they were input to TRANSYT-7F and the resulting average vehicle delays for all the intersections in the core network area were compared with the corresponding TRANSYT-7F average delays generated with observed (LINKOD input) volumes. The results of this comparison are shown in Figure 6, in which the frequency of coded intersections is plotted against the difference in TRANSYT-7F calculated average delay. The plots indicate that for the a.m. case, 95 percent of the intersections had less than a 10-sec difference in calculated average delay using the LINKOD assigned (output) volumes versus that using the LINKOD input (observed) volumes. The results for the p.m. case were slightly more disparate in that 90 percent of the intersections had less than a 10-sec difference in calculated average delay. However, this still represented a relatively high degree of accuracy.

Screenline Comparison One other basic measure used in the calibration process was screenline comparisons of assigned versus observed volumes. In all, volumes across nine screenlines and for each of the downtown freeway ramps were compared. In general, the LINKOD assignment volumes were consistently less than the observed volumes. The percentage differences between observed and assigned volumes ranged from 0.2 to 27.0 percent, but fell primarily between 1.0 and 16.0 percent. Table 2 gives a more detailed breakdown of

TABLE 2 LINKOD AND MINUTP SCREENLINE COMPARISONS

Screenline	Street	Observed Volume, 1985 Smoothed Ground Counts	Percentage Difference LINKOD Assigned over Ground Counts	MINUTP over Ground Counts
A.M. Network				
A–A northbound	University	5	1.20	1.20
	6th	1,260	0.80	0.90
	4th	835	0.94	1.03
	3rd	225	0.68	1.17
	1st	690	0.91	0.61
Total		3,015	0.86	0.89
A–A southbound	1st	215	0.86	0.73
	2nd	890	1.00	1.08
	3rd	230	1.16	1.13
	5th	1,230	0.98	1.01
	University	135	0.63	0.73
Total		2,700	0.98	1.01
B–B northbound	1st	210	1.00	1.70
	3rd	190	0.93	1.53
	4th	755	0.99	1.12
Total		1,155	0.98	1.29
B–B southbound	1st	165	1.02	0.92
	2nd	570	1.00	1.01
	3rd	185	0.90	0.81
	5th	485	1.04	0.88
	6th	1,280	1.00	0.91
Total		2,685	1.00	0.92
C–C eastbound	Virginia	375	0.83	0.77
	Westlake	185	0.77	0.95
	Olive	330	0.92	1.47
	Pike	475	0.75	0.60
Total		1,365	0.82	0.90
C–C westbound	Union	965	0.93	0.99
	Pine	775	1.03	0.62
	Stewart	990	0.75	1.19
	Westlake	155	0.96	0.94
	Lenora	165	1.02	0.73
Total		3,050	0.90	0.94
P.M. Network				
A–A northbound	University	20	1.05	0.75
	6th	1,080	0.84	0.83
	4th	1,250	1.02	0.95
	3rd	330	0.84	0.80
	1st	852	0.93	1.09
Total		3,532	0.93	0.83

TABLE 2 *continued*

Screenline	Street	Observed Volume, 1985 Smoothed Ground Counts	Percentage Difference	
			LINKOD Assigned over Ground Counts	MINUTP over Ground Counts
P.M. Network				
A–A southbound	1st	450	0.96	0.83
	2nd	1,530	0.96	0.94
	3rd	385	0.79	0.75
	5th	1,260	0.98	1.01
	University	150	0.51	0.79
Total		3,775	0.93	0.92
B–B northbound	1st	450	0.94	0.96
	3rd	209	1.06	1.06
	4th	1,200	0.83	0.74
Total		1,940	0.89	0.84
B–B southbound	1st	400	0.87	0.89
	2nd	1,225	0.94	0.97
	3rd	360	0.85	0.86
	5th	950	0.92	0.87
	6th	880	0.81	0.81
Total		3,815	0.89	0.89
C–C eastbound	Virginia	925	0.77	0.72
	Westlake	100	1.53	1.89
	Olive	925	0.78	0.77
	Pike	1,105	0.79	0.99
Total		3,055	0.81	0.87
C–C westbound	Union	750	0.91	0.85
	Pine	690	0.90	0.87
	Stewart	645	0.83	0.85
	Westlake	230	0.86	0.84
	Lenora	200	0.89	1.43
Total		2,515	0.88	0.90

screenline comparisons for three selected screenlines by showing a.m. and p.m. peak-hour volumes and percentage differences for each screenline link.

Summary and Conclusions

LINKOD was found to be a complex, data-intensive, expensive program to run. Becoming familiar with and calibrating the program was very time consuming. However, once the critical lessons had been learned and calibration was complete, the model produced highly satisfactory results.

MINUTP Calibration

In calibrating the MINUTP base-case network, adjustments were made in order to minimize the difference between the assigned link volumes and the original input volumes to LINKOD (smoothed volumes). Different assignment combinations were tested and various calibration techniques experimented with.

Assignment Methodology

MINUTP provides three methods of assignment, as mentioned previously. Based on the experience with various assignment method combinations and discussions with the developer of the model, the combination of one stochastic iteration followed by two all-or-nothing iterations was found to yield the best results. This is also the combination used most frequently by the developer of the software.

Calibration Techniques

Five calibration techniques were identified: changing speed (which changes travel time of a link), changing capacity in vehicles per hour per lane, changing the number of lanes, using turning penalties, and using turning prohibitions. The most effective methods found for modifying the assignment were to modify the link speeds and to impose turning penalties and prohibitions.

Initial calibration work consisted of changing lane capacities and link travel speeds. Initial runs showed that the MINUTP assignments were very close to the input smoothed volumes on the screenline level but varied significantly at the individual street or link level.

The p.m. network was calibrated first. The assignments did not vary significantly with gradual changes in lane capacities. They were excessively sensitive, however, to gradual changes in link speed. This excessiveness was curbed in two ways, first, to make fewer and more gradual changes in speed and second, to establish turning penalties at the locations where traffic was diverting to the parallel route. Turning prohibitions were also set at those locations in the network where turns are actually prohibited during the peak hours.

Generally, fewer than five changes to speeds or turning penalties, or both, were modified from run to run. Many runs were made with only one or two changes. After each run, volumes were posted on a screenline spreadsheet. New assigned volumes were checked to see whether they more closely matched the smoothed input volumes that the previous MINUTP run had assigned. If most screenline link volumes were worse than before, the changes were undone and a new approach was tried.

The MINUTP assigned volumes were then run through TRANSYT-7F to compare the delay time in seconds for all intersection movements (including left, right, and through) with the delay times that had resulted from inputting both the smoothed volumes (LINKOD input) and the LINKOD base-case assigned volumes (LINKOD output). The TRANSYT-7F run for the p.m. case showed that there were more instances of excessive movement delays from the MINUTP assignment than from LINKOD's base assignment. This can be seen in Figure 6, where for the p.m. case, 90 percent of the average delays calculated using the LINKOD assigned volumes fell within 10 sec of those calculated using the LINKOD input (smoothed) volumes, whereas only 78 percent of the calculated delays using the MINUTP assigned volumes fell within 10 sec of those calculated by using the smoothed volumes. Further calibration of the p.m. case focused on the intersections for which the TRANSYT-7F run calculated unreasonably high delays because of excessive turning-movement volumes. These turning volumes were reduced by placing turn penalties on the movements in question.

Calibrating the a.m. network began by using two different base networks. One was the same as the LINKOD a.m. network. The other was the p.m. calibrated network modified to account for the a.m. changes in the reversible freeway express lanes. The reason for two base networks was to see whether the changes made to the p.m. network would benefit the a.m. network also. As it turned out, the assignment using the original a.m. LINKOD network provided better results at the screenline level than that using the modified p.m. MINUTP network.

As seen in Figure 6, the a.m. network when calibrated provided better results than the p.m. TRANSYT-7F run. This was due in part to having a better trip table (produced by the a.m. LINKOD runs), to being more experienced in calibration techniques, and to generally having fewer vehicle trips in the network.

Summary and Conclusions

In general, it was found that the advantages of using MINUTP instead of LINKOD for assignment purposes outweighed the lower level of accuracy that MINUTP provides. MINUTP provided the necessary accuracy in identifying "hot spots" when run through TRANSYT-7F and allowed application on a microcomputer to proceed easily and inexpensively when compared with the mainframe utilization of LINKOD.

MINUTP does not provide quite as good an assignment as does LINKOD; however, it provides an assignment that is acceptable in terms of identifying hot spots when run through TRANSYT-7F, especially when the updated version of MINUTP, which allowed more detailed control of intersection turning movements and preloading of through trips, is used.

The primary advantages of MINUTP are that it is an easy microcomputer program to use, the turnaround time between runs is short, and the computer costs are relatively low (especially when compared with those using LINKOD on a mainframe computer in a remote office).

In addition, MINUTP has several features that enable a more thorough analysis of the traffic assignment, such as select link analysis capabilities, path tracing, convenient trip table manipulation, and preloading of volumes onto certain links.

TRANSYT-7F Calibration

The TRANSYT-7F network included both transit and automobile links. These links are modeled as either shared stoplines (automobile and transit share lanes) or exclusive links (transit-only lanes). In general, it was difficult to model transit operations accurately in the networks. TRANSYT-7F is limited in its ability to account for the delays caused by passenger loading, skip-stop operation, and other elements of transit operations. Despite these problems, it was decided that including transit in the model was necessary because congestion due to transit operations would be a controlling factor in the development of mitigating measures via use of the TRANSYT-7F model.

The process of calibrating the TRANSYT-7F model to match existing conditions required extensive data collection, including travel-time studies, flow-profile analyses, maximum queue data, manual counts, and spot speed studies. Five north–south avenues and nine east–west streets were selected for these data collection activities on the basis of their classification as major CBD surface routes. The five data collection activities were performed concurrently on a given route to obtain a peak-hour "snapshot" of traffic flow on the route. Thirty-five intersections were included during both a.m. and p.m. peak hours.

Sensitivity Analysis

Before use of the calibration data, a sensitivity analysis was performed on the coded TRANSYT-7F network. Four coding variables were tested for sensitivity: the platoon dispersion factor (PDF), which adjusts the rate at which platoons of vehicles disperse as they leave a queue; bus dwell time, which places an impedance on a bus link to simulate passenger loading activities; saturation flow, which quantifies the maximum number of vehicles that can travel on a link during a 1-hr period (continuous green time); and speed, which represents free flow or the unconstrained travel speed along a link. In the test for sensitivity, input values were varied incrementally. The sensitivity of the model to these changes was evaluated by posting average delay on the link to which the changes were made. In general it was found that the average delay calculated for a given link was not sensitive to changes in PDF and bus dwell time. Average delay was found to be sensitive to changes in free-flow speed and saturation flow. Spot speed studies were performed under uncongested conditions to approximate the initial free-flow speed estimate. Though changes in the input speed would assist in replicating existing delay, it was decided not to change input developed from field studies. For saturation flow, however, initial estimates were made by using the 1985 *Highway Capacity Manual (6)*. Though this provided a sound initial estimate, it was not able to fully account for the complexity of congested urban traffic conditions. TRANSYT-7F is reasonably sensitive to changes in the saturation flow input. Because it was believed that the initial estimate of saturation flow did not fully account for existing conditions, manipulation of this input was selected for calibration of the networks.

Travel-Time Comparisons

Calibration was performed by comparing travel times output by the model with those observed in the field. An iterative process of changing the saturation flow on individual links was performed until comparable travel times were achieved. The extent of change to the initial saturation-flow value was limited to maintain reasonable estimates of this input. In addition, an attempt was made to maintain comparable saturation-flow input along streets and avenues that had similar or identical characteristics.

A comparison of TRANSYT-7F travel-time output versus observed travel time along major arterials for the final calibrated versions of the a.m. and p.m. networks showed that travel times for both networks were matched within a range of ±18 percent, with many of these within 5 percent. Figure 7 shows this comparison for both the a.m. and the p.m. case. In general, comparative travel times on the longer north–south routes matched better than those on the shorter east–west routes. This is due largely to the difficulty in performing a random travel-time study on the shorter routes. Third Avenue was difficult to calibrate because of large peak-hour transit

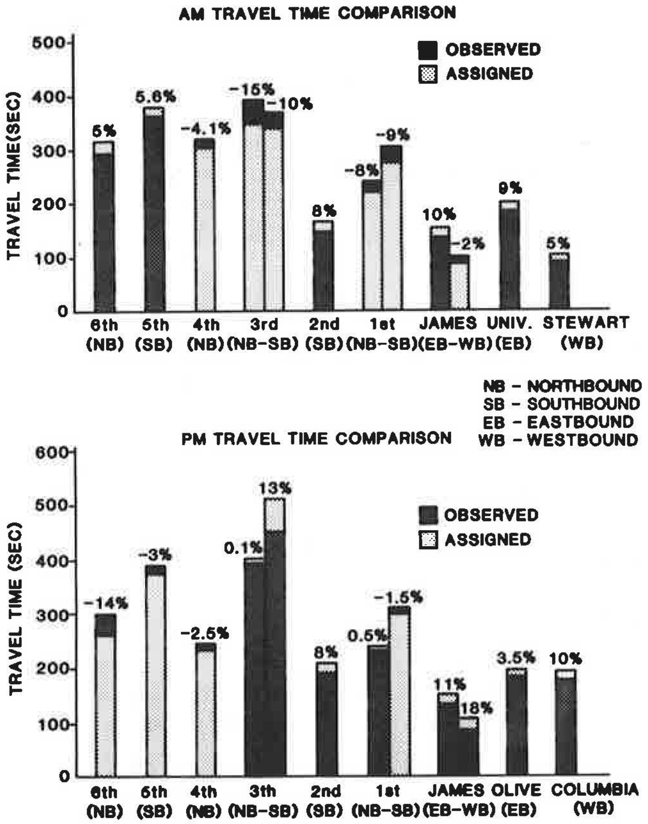

FIGURE 7 TRANSYT-7F calibration: peak-hour travel-time comparisons on major CBD streets.

volumes. Third Avenue was modeled with separate transit and automobile links. In order to simulate the extensive congestion on Third Avenue, automobile links were given a low saturation flow. In many cases, even these low saturation flows did not result in delays comparable with those experienced in the field. Calibration was also difficult where sizable pedestrian volumes significantly inhibited traffic flow and with the steeply graded east–west streets. Overall, though, a very reasonable representation of existing traffic conditions in the CBD was attained. Delay and saturation-flow analyses performed since calibration have correlated closely with the input and output of the original calibrated models.

PROJECT APPLICATIONS AND RESOURCE CONSIDERATIONS

The modeling chain described in this paper can best be applied in large construction projects in complex urban settings, such as major downtown freeways or transit systems, or in the evaluation of complex signal networks. The utilization of LINKOD, a very detailed network-based model, was found to be moderately time consuming but necessary as opposed to developing a detailed micro trip table from a traditional regional model base. Once the project team became familiar with the intricacies of the LINKOD model, development of the data base input file and application became more straightforward and less time consuming for the MINUTP portion.

The models were developed by two teams of analysts working in parallel over a 6-month period. During that span, a.m. and p.m. networks were developed for each of the three separate models.

The LINKOD and MINUTP models were developed by one team of analysts for 255 intersections, an area that included major CBD approach arterials and freeways (Figure 3). This team used LINKOD to formulate a.m. and p.m. trip tables and, using the MINUTP assignment package, applied that trip table to the 255-intersection network. The effort required to do this is estimated at approximately 7 hr per intersection for developing the a.m. and p.m. trip tables using LINKOD and another 4 hr per intersection to extract, code, and calibrate the two MINUTP networks using LINKOD as a basis.

The TRANSYT-7F model was developed for a CBD core study area of 119 intersections by the second team of traffic analysts (Figure 3). The level of effort per intersection for the TRANSYT-7F model is estimated at approximately 20 hr per intersection for combined a.m. and p.m. conditions.

The total effort is estimated at about 2.4 person-years. The distribution of time, for planning purposes, that was needed to define, develop, calibrate, and validate the models is estimated as follows:

Project Activity	*Percent of Total*
Data collection	9
Model definition and software development	14
P.M. model development and calibration	43
A.M. model development and calibration	30
Model documentation	4

The teams developed the p.m. model configuration initially and modified the coded p.m. network to replicate the a.m. network, thereby reducing effort and time considerably in completing the second network.

Model definition efforts included the research and evaluation of available software for application to a microcomputer environment. The development of software to link the three models together represents a major element of this task. The mainframe LINKOD network files were reformatted into MINUTP microcomputer files to develop a microcomputer-based network. A more efficient translation of MINUTP assignment output to TRANSYT-7F input files was also provided. Following this major investment of time and effort, about 40 hr is required to define and code network changes to MINUTP and produce TRANSYT-7F output for evaluation of street closures in the core CBD area during given construction phases.

CONCLUSIONS

The DSTP traffic modeling system represents a systematic approach for detour planning during major construction projects. The modeling chain is appropriate when the transportation engineer needs to develop a trip table independent of regional models for a complex signal network. Because of the level of effort entailed, the most cost-effective application for the model chain is for large projects or those with complex signal networks. It has several advantages over the traditional, more ad hoc detour-planning procedures in that it has the capability to test numerous "what if" situations and to objectively quantify associated impacts. On the basis of the projected impacts, traffic control plans can be developed and then tested with this approach. The investment in the modeling system during planning phases of the project has benefits in later phases in that it is a tool that can be used for preliminary engineering and final design as well as for input into traffic operations both during and after construction.

Calibration results of the modeling system, as described in this paper, have proven highly satisfactory. Application of the system for facilitating detour planning during the DSTP construction is still in the initial stages. As application of the system and the DSTP construction progress, several opportunities will exist to compare actual field results with predictions by the modeling system. The city of Seattle has proposed a traffic counting program scheduled to run throughout the DSTP construction that will provide valuable input toward this end. Throughout its use, the system will be evaluated as it is currently structured in order to refine and improve any steps that appear to reduce its effectiveness in practical applications. Further research will focus on streamlining and documenting the procedure so as to generalize the process for application to other projects. Areas for improvement will become clearer as current application of the system progresses; however, some specific areas have already been identified:

- A lack of consistency of level of detail exists among the three software packages. Although LINKOD and TRANSYT-7F are extremely detailed in their coding conventions and output content, MINUTP is not as suitable for detailed analysis. Other software packages with similar functions to MINUTP should be examined for their potential use as the intermediate package between LINKOD and TRANSYT-7F. Alternatively, a microcomputer version of LINKOD would be beneficial.
- The data acquisition and model calibration procedures need to be streamlined, well defined, and documented in order to facilitate a more cost-effective model development phase on future projects.
- In order to facilitate more effective analysis and presentation of the modeling system results, an analysis and priority ranking of the system's various outputs needs to be conducted and templates summarizing the desired outputs need to be developed.

Research on these and other areas identified will be ongoing during 1988.

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