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The effectiveness of travel demand management actions in suburban activity centers : case study

Carlos Felipe G Loureiro

To the Graduate Council:

I am submitting herewith a thesis written by Carlos Felipe G Loureiro entitled "The effectiveness of travel demand management actions in suburban activity centers : case study." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.

Arun Chatterjee, Major Professor

We have read this thesis and recommend its acceptance:

Frederick J. Wegmann, Jack Humpherys

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To the Graduate Council:

I am submitting herewith a thesis written by Carlos Felipe G. Loureiro entitled "The Effectiveness of Travel Demand Management Actions in Suburban Activity Centers - Case Study". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.

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Associate Vice Chancellor
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Date November 25th, 1991

THE EFFECTIVENESS OF TRAVEL DEMAND MANAGEMENT ACTIONS IN SUBURBAN ACTIVITY CENTERS -- CASE STUDY

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Carlos Felipe G. Loureiro

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DEDICATION

This thesis is dedicated to my friend Alcides who inexplicabily decided to quit fighting towards our former dreams of happiness by seizing the profound inner peace.

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Very special thanks are extended to my parents Ronald and Carísia who have devoted their lives solely to teach their sons how to face the world as human beings.

ABSTRACT

This research attempted to estimate the effectiveness of travel demand management (TDM) programs in mitigating traffic congestion problems at two suburban activity centers in Tennessee cities. The approach used by this study consisted of analyzing one intersection in each study site, and determining probable changes in their levels of service due to the implementation of a preselected set of TDM strategies under different employer participation scenarios. Models for predicting reductions in peak hour vehicle trips were identified from previous researches. The study also examined if there was any scope of reducing traffic congestion through low-cost traffic engineering improvements.

The results led to the conclusion that the ability of TDM programs focused on the employees of a SAC to alleviate the traffic congestion problems of developing suburban activity centers may be limited. Areawide TDM measures would be necessary to affect a larger portion of traffic and to achieve significant reductions in travel. Although traffic engineering improvements were found to be more effective than demand control actions, the role of TDM measures as a supplementary and/or long term strategy should not be neglected.

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CHAPTER I

INTRODUCTION

During the past decade the locational pattern of traffic congestion in urban areas has changed. Today heavy traffic is not limited to the Central Business District (CBD) and the radial corridors that lead to it. The suburban areas of many communities now are plagued with serious traffic congestion problems. In addition to the locational change, there has been a change in the temporal pattern of traffic congestion. The morning and afternoon peak periods have expanded, and the lunch hour traffic is also experiencing congestion problems in some cases. Although these changes are not totally unexpected, the magnitude of suburban traffic congestion has exceeded the expectation of transportation planners in many cases.

Traffic problems are serious especially in suburban areas that have a high concentration of activity units. These high density mixed land use developments are referred to as suburban activity centers (SAC's). Traffic problems at these locations present a challenge to transportation planners because some of the traditional supply oriented solutions may not be effective in these cases. First, the standard approach of solely increasing highway capacity has proved to be self-defeating. As Orski stated, new and better roads improve accessibility, and greater accessibility increases land values. Higher land values, in turn, dictate a more intensive use of land, which generates more traffic, which fills up the improved highways (Orski 1990). Second, traditional public transit oriented solutions such as fixed-route transit services do not attract much ridership in these areas because of the dispersed travel pattern, and the automobile ownership of the residents in suburban areas.

Transportation planners now are exploring the effectiveness of demand oriented strategies. This approach is referred to as travel demand management (TDM), and strategies of this category are intended to complement traditional supply oriented actions by modifying travel behavior and mode choice. The effectiveness of TDM strategies in different situations has not been established clearly, and the purpose of this study is to examine this issue in the context of SAC's in Tennessee cities.

Study Approach

Two SAC's were selected for a detailed examination of the existing problems, and an assessment of the effectiveness of TDM strategies in alleviating these problems. The two SAC's selected are: Cedar Bluff Area in Knoxville, and Maryland

Farms Office Park in Brentwood. Although they differ in certain characteristics, these two areas have some similarities such as their distance from CBD, interstate access, the use of private automobiles by residents and employees, and low vehicle occupancy rates. Interviews with planners and public officials in Knoxville and Brentwood as well as discussions with residents of these areas revealed that the most serious transportation problem perceived by most of these persons was traffic congestion. Further, the most severe traffic congestion in each case involved a specific intersection adjacent to the respective SAC's.

The approach used by this study (Figure 1) was to analyze the problematic intersections in depth, and determine how effective a set of pre-selected TDM strategies would be in reducing the traffic congestion at these locations. The study also examined if there was any scope of reducing traffic congestion through low-cost traffic engineering improvements such as an altered signal timing scheme. Specifically, detailed traffic data were gathered at each location/intersection, and the existing level of service (LOS) was determined. Then on the basis of the experience at other locations where TDM programs were implemented, estimates were developed for probable reductions in peak hour vehicle trips at these locations. The levels of service corresponding to these new traffic volumes were calculated, and the effectiveness of TDM strategies was assessed. In addition to

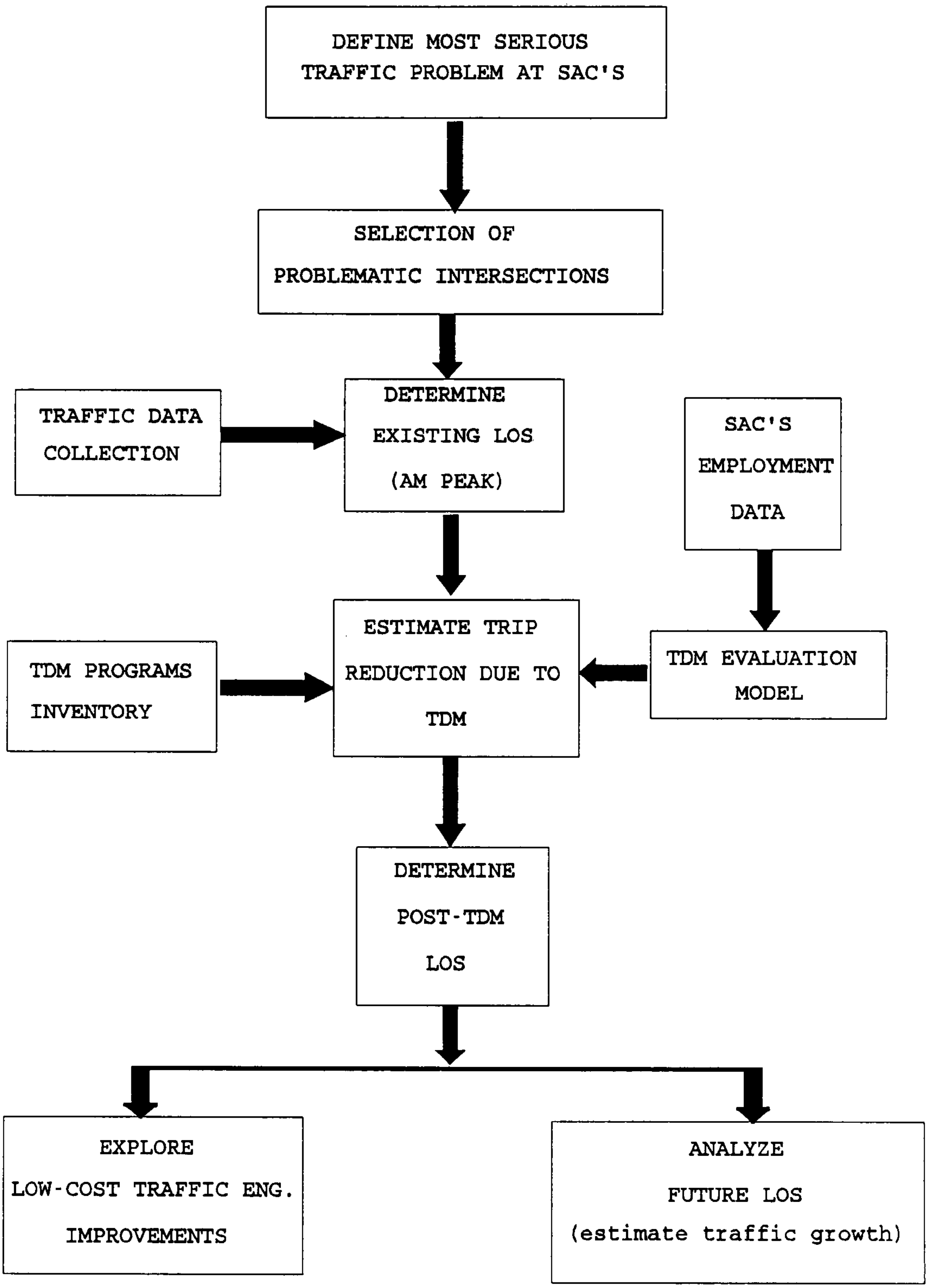

Figure 1 - STUDY METHODOLOGY: FLOW DIAGRAM

examine TDM strategies, the effectiveness of different signal timing schemes at these intersections were evaluated in terms of their impact on the level of service. Furthermore, low cost improvements on the intersections layouts such as the addition of a traffic lane were also tested as one possible traffic engineering related strategy.

In addition to analyzing the existing situation, the study examined the future situation. The growth of traffic at these locations was analyzed, and probable future problems were examined. Detailed descriptions of these analyses are presented in Chapter IV - Analysis Procedure.

CHAPTER II

TDM PROGRAMS

Since the end of World War II until the recent years, the primary goal of transportation planning was to accommodate traffic growth by constructing facilities which would have adequate capacity to handle the travel demand. Although it was known that land use and economic development were the sources of traffic, hardly any attention was devoted to regulate them in order to control traffic growth. Developers usually were not held responsible for the impacts of their projects on the transportation system (Ferguson 1990a).

This situation has changed during the past few years. Increasing growth and traffic congestion, coupled with limited transportation budgets, and increasing social and environmental concerns, have led to the conclusion that capital intensive expansion of the transportation system to accommodate increasing travel demand may not be either appropriate or feasible in many cases. Planners have realized that "we cannot build our way out of congestion problems". The need to manage congestion through more efficient use of available facilities gave rise to what is called

Transportation System Management (TSM). TSM strategies strive to augment capacity through low-capital-cost approaches such as traffic signal synchronization, reversible lanes, and reserved lanes for high occupancy vehicles (Blanckson & Wachs 1989). This part of the short-range planning process involving low-cost transportation improvements is considered as a versatile means of resolving specific problems, improving operational efficiency, or accommodating anticipated near-term growth and development.

In recent years another new approach is gaining in popularity. This approach is a subset of TSM programs, and it is known as Travel Demand Management. TDM strategies/programs differ from commonly used TSM actions in that their focus is exclusively on travel demand rather than on transportation supply. These strategies strive to reduce peak period trip-making either through discouraging solo driving or shifting the time of travel to less congested time periods. According to COMSIS (1990a), TDM involves not only the actions that affect travel time, cost, and other factors that influence travel behavior, but also the ways of implementing these actions utilizing innovative legal and institutional approaches. TDM actions can be grouped into three categories (COMSIS 1990a):

- **Improved Alternatives for Travel** - providing competitive alternatives to driving alone such as transit services, carpooling, vanpooling, etc.;

- **Incentives and Disincentives** - implementing measures to increase the attractiveness of ridesharing modes, and to decrease advantages of the single-occupancy auto mode, such as HOV lanes, preferential parking for HOV's at destinations, discounted transit fares or "inverted" parking rates, etc.;
- **Work Hours Management** - shifting trips to time periods with less demand through strategies such as flextime, staggered work hours, and modified work schedules.

One important aspect of TDM programs is that they usually require that both public and private sectors share responsibilities during the implementation process. The participation and support of developers and employers are important to assure the effectiveness of TDM actions by controlling individual travel decisions at their source. Difficulties in establishing this mutual cooperation with employers would reduce the likelihood of success for many TDM strategies.

Some new institutional arrangements have provided a favorable environment for program implementation (Jewell, Ellis & Oram 1990). Included among these institutional arrangements are transportation management associations (TMA's), trip reduction ordinances (TRO's), and negotiated agreements. These and similar arrangements are intended to promote greater cooperation between private and public sectors. TMA's have been of great importance not only in promoting and operating TDM programs such as ridesharing, variable work hours, and preferential parking and subsidies for pool vehicles, but also in providing a forum for debate in which land development and business interests can reach consensus on needs for new facility improvements or land use planning issues (Lin 1990). TRO's are gaining recognition in areas with serious problems such as the Los Angeles area where auto travel must be reduced for improving air quality (Blanckson & Wachs 1989).

Evaluation of Existing TDM Programs

As TDM programs gained importance and were implemented in a wide range of situations throughout the country, there appeared a need to evaluate them and determine their effectiveness in meeting the objectives, and to identify their scope of refinement and improvement (Pilgrim 1991). Furthermore, it was recognized that the development of a standardized evaluation methodology would be crucial to produce performance parameters which can be transferred to predict the results of new TDM programs.

In the last few years, several studies were performed to assess the effectiveness of ongoing TDM programs (COMSIS 1990a, Dunphy & Lin 1990, Higgins 1989, Beroldo 1990, Turnbull et al 1990, Giuliano 1990, Ferguson 1990b, etc.). Their major findings are presented below:

- TDM programs can reduce low-occupancy vehicle trips at a site, in a corridor, or within a subarea. However, the range of their effectiveness is wide. The successful programs usually are found where large employers are involved.
- Parking related pricing strategies appear to be a major contributor to the effectiveness of TDM programs.
- It may be easier to shift trips to time periods with less demand rather than to reduce solo driving during peak hours, especially where parking related pricing strategies are not employed. The results also suggest that flextime may reduce the effectiveness of high-occupancy vehicle strategies, when both measures are applied simultaneously.
- TDM programs take considerable time to become effective and are susceptible to declines in effectiveness over time.
- To guarantee a successful TDM program, either some type of legal pressure is necessary, or there must be a strong commitment by the parties

involved to adopt the proposed measures, specifically the individual firms/employers.

For this study the available literature on TDM programs was examined carefully to compile quantitative information on the effectiveness of TDM programs. The documents that were reviewed included cases from a variety of states and localities. For each case, the conditions prevailing before the implementation of TDM strategies were summarized, including the size of employment, transit availability, parking constraints, the existence of institutional measures, and other important characteristics of the sites. The strategies implemented in each case were listed, and the percentages of mode usage after implementation were compared to the corresponding figures for a control group representing the 'before' situation. Where the same companies' pre-TDM conditions were not known, the 'before' data were estimated based on conditions at similar companies or regional average values. The percentage of vehicle trip reduction observed in each case was calculated. The findings are presented in Table 1. It can be noticed that more attention was given to programs implemented by employers with a large number of employees. The reason was the greater likelihood of success of large-employer-based programs. Since the main interest is to define the reasonable maximum reduction in peak

Table 1 - INVENTORY OF TDM PROGRAMS

SITE/COMPANY	CHARACTERISTICS OF SITE: SIZE OF EMPLOYM	CHARACTERISTICS OF SITE: EXISTING CONDITIONS	ACTIONS	RESULTS MODE SPLIT: DRIVE ALONE	RESULTS MODE SPLIT: CAR/VAN POOL	RESULTS MODE SPLIT: TRANSIT	% VEH. TRIP REDUCT.	NOTES
1) HARTFORD, CT								Regional CBD
a) Travelers Insurance	10000	Relatively constrained parking Proximity to good transit service (Local & Express)	Parking pricing(below market rates) Vanpool & Transit subsidies	33.2 (48.0)	27.4 (21.0)	36.2 (31.0)	25.4%	Post-TDM Control:(Pre-TDM)
b) Hartford Steam Boiler	1100	Relatively constrained parking Maximum use of nearby transit	Locational & pricing incentive parking for HOV vehicles Vanpool & Transit subsidies	39.9 (48.0)	22.2 (21.0)	35.9 (31.0)	13.6%	Post-TDM Control:(Pre-TDM)
2) MONTGOMERY, MD								Suburban Activity Center
a)Nuclear Regulat. Comission	1400	Presence of TMA, Urban & Parking Districts	Fee parking at market rates Transit discounts Matching Service Flextime Transit Shuttle	42.0 (89.5) {54.0}	27.0 (6.5) {25.0}	28.0 (4.0) {11.0}	 41.6% 16.6%	Post-TDM (North Bethesda) {Pre-relocation}
b)Rock Spring Park	12000	8 major employers, from 100 to 3600 per employer Ample & free parking	Center & Company coordinators Ridematching Preferential parking Vanpool & Transit subsidies Bicycle Club	-	-	-	(*)	*Modest results: Boost in carpool/transit up to 10%; Less 220 peak hour trips.

Table 1 - (Continued)

SITE/COMPANY	CHARACTERISTICS OF SITE SIZE OF EMPLOYM	EXISTING CONDITIONS	ACTIONS	RESULTS MODE SPLIT DRIVE ALONE	CAR/VAN POOL	TRANSIT	% VEH. TRIP REDUCT.	NOTES
3)MINNEAPOLIS, MN a)I-394 HOV lane (interim)	3630 person-trips	Single reversible lane (median) Two segments HOV: minimum of 2 pass.	Free parking for car-poolers at downtown Express bus service Extensive marketing High fines for HOV violations	48.7 (61.9)	32.8 (20.2)	18.4 (17.9)	9.4%	Radial Corridor Post-lane (Pre-lane)
b)MN Rideshare Free Parking Program	2750 regist.		Free parking privileges for registered car & vanpoolers at downtown fringe lots	-	-	-	15.0%	Regional CBD
4)ST.PAUL, MN a)3M Company	12700		Staggered work hours Subscription buses Car/vanpool programs Safety/capacity improvements	82.7 (91.6)	21.9 (13.0)	1.7 (0.6)	9.7%	Suburban Business Park Post-TDM Control: (3M in 1970, before TDM)
5) BELLEVUE, WA a)Downtown Bellevue (Areawide)	24000	Small employers located in multi tenant office bldgs. & retail businesses Restrained parking conditions Focused transit service	Employee transportation coordinators Vanpool subsidies Ride home programs HOV lanes Transit improvements	63.2 (81.8)	19.2 (11.8)	10.9 (3.3)	17.8%	Suburban Activity Center Post-TDM Control:(Regional Control sites)

Table 1 - (Continued)

SITE/COMPANY	CHARACTERISTICS OF SITE SIZE OF EMPLOYM	EXISTING CONDITIONS	ACTIONS	RESULTS MODE SPLIT DRIVE ALONE	CAR/VAN POOL	TRANSIT	% VEH. TRIP REDUCT.	NOTES
b)US WEST	1150		Parking mngt.techniques -inverted pricing -free parking for HOV Carpool incentives Flextime Transp. Coordinator	25.7 (81.8)	46.5 (11.8)	12.8 (3.3)	47.6%	Post-TDM Control:(Regional Control sites)
c)Puget Power	830	Lottery parking system	Free parking for HOV Transit subsidies Transp. Coordinator	76.6 (81.8)	15.0 (11.8)	8.4 (3.3)	12.6%	Post-TDM Control:(Regional Control sites)
d) CH2M Hill	400	Restricted parking	Transit subsidies Free parking for carpoolers Transp. allowance	54.8 (81.8)	12.0 (11.8)	17.0 (3.3)	31.2%	Post-TDM Control:(Regional Control sites)
e)Bellevue City Hall	450	Tight parking	Coordinator Ridematching City fleet vehicles for poolers Free transit passes Free carpool parking	58.0 (75.0)	-	-	-	Post-TDM Control: (Before pay parking)
f)Bellevue,I-90, Bel-Red,Overlake	52000	52 small to large companies	Wide range of programs with range of densities, transit serv. and TSM/PM strategies	-	-	-	(*)	(*)No significant results

Table 1 - (Continued)

SITE/COMPANY	CHARACTERISTICS OF SITE SIZE OF EMPLOYM	EXISTING CONDITIONS	ACTIONS	RESULTS MODE SPLIT DRIVE ALONE	CAR/VAN POOL	TRANSIT	% VEH. TRIP REDUCT.	NOTES
6)CONTRA COSTA, CA								Sub.Business Park
a)Bishop Ranch (Areawide)	14000	Low density area Professional,white collar emp.center Nearest BART stat. at 11 miles away Shuttle buses to stations Formal trip reduction requirement	Computerized ridematch Transit discounts & information Vanpool assistance Shopper shuttle Flextime	70.2 (90.0)	25.0 (5.5)	3.2 (2.0)	 16.6%	Post-TDM Control:(Two similar locations) (Walnut Creek and Santa Rosa)
b)Pacific Bell	6900	Massive relocation of employees in 6 months	Ridematching Transp. Coordinator Vanpool program Shuttle service to BART stations Flextime Strict parking supply	63.0 (73.0) {80.0}	33.0 (23.0) {15.0}	2.0 (2.0) { 4.0}	 8.7% 17.0%	Post-TDM (Company B) {Rest of park}
7)PLEASANTON, CA								
a)City-wide	22000	TSM ordinance tied to both peak hour trip reduction & intersection LOS goals (applies to new and existing employers)	Transp. Coordinator Flexible work hours	-	-	-	(*)	(*)45% reduction in peak trips. This result was achieved by temporal shift rather than HOV usage increase
b)Hacienda Business Park (areawide)	7770	TSM task force	Computerized ridematch Shuttle service to BART stations Noon-time interval circulation system Flextime programs	78.7 (84.3) {90.0}	17.7 (11.5) { 5.5}	2.3 (1.6) { 2.0}	 3.9% 8.4%	Post-TDM (Pleasanton) {Two similar locations}

Table 1 - (Continued)

SITE/COMPANY	CHARACTERISTICS OF SITE SIZE OF EMPLOYM	EXISTING CONDITIONS	ACTIONS	RESULTS MODE SPLIT DRIVE ALONE	CAR/VAN POOL	TRANSIT	% VEH. TRIP REDUCT.	NOTES
c)AT&T	3890		Ridematching Preferential parking for poolers Flextime (arrivals between 5:00/9:00am	71.3 (84.3)	25.0 (11.5)	2.4 (1.6)	9.3%	Post-TDM (Pleasanton)
d)Sun Diamond Growers	128			77.2 (84.3)	21.9 (11.5)	- (1.6)	3.9%	Post-TDM (Pleasanton)
e)Payco General Credits	112	Majority of empls. live 16 miles or more from work		49.5 (84.3)	33.0 (11.5)	17.7 (1.6)	28.5%	Post-TDM (Pleasanton)
f)Clorox Technical Center	450			78.5 (84.3)	19.6 (11.5)	0.2 (1.6)	2.8%	Post-TDM (Pleasanton)
8)LOS ANGELES, CA								Suburban Activity Center
a)UCLA	52000	Traffic is severely congested 20000 university-controlled park spaces Very efficient transit service Internal shuttle system Commuter buses Large bicycle use	Collection of traffic mitigation impact fees ($5200/pm peak trip generated) Parking fees Preferential parking for HOV (3 or +) Commuter Assistance Rideshare office-CAR Guaranteed ride home	74.4 (75.0) {85.1}	15.1 (7.0) { 6.7}	6.2 (11.4) { 0.6}	 -1.0% 10.2%	Post-TDM (Pre-TDM/1980) {CSUN}

Table 1 - (Continued)

SITE/COMPANY	CHARACTERISTICS OF SITE SIZE OF EMPLOYM	EXISTING CONDITIONS	ACTIONS	RESULTS MODE SPLIT DRIVE ALONE	CAR/VAN POOL	TRANSIT	% VEH. TRIP REDUCT.	NOTES
b)ARCO(Downtown LA)	2000	Parking constraint	Carpool incentives Company sponsored vanpooling Buspooling Transit inform. and pass sales Commuter rail Telecommuting Compressed work weeks Guaranteed ride home Parking subsidies for poolers	46.0 (60.0)	34.0 (19.0)	20.0 (21.0)	19.0%	Regional CBD Post-TDM (CBD average)
9)ORANGE COUNTY, CA (South Coast Metro) a)State Farm	980	No rapid transit or radially-oriented hwy system Dispersed residential and emp. patterns HOV lanes in all freeways Limited parking TDM as marketing tool	Direct subsidy for commute alternatives (coupon system) Subsidized van service Flexible work hours	66.0 (78.0)	33.0 (21.0)	-	22.0%	Suburban Activity Center Post-TDM Control:(Pre-TDM) (one month int.)
b)Allergan Company	1300		Coordinator Ridematching Vanpools Preferential parking	80.0 (86.0)	19.0	-	-	Results contrast with 86% solo countywide

Table 1 - (Continued)

SITE/COMPANY	CHARACTERISTICS OF SITE SIZE OF EMPLOYM	EXISTING CONDITIONS	ACTIONS	RESULTS MODE SPLIT DRIVE ALONE	CAR/VAN POOL	TRANSIT	% VEH. TRIP REDUCT.	NOTES
c)Irvine Spectrum	17000	39 employers over 100 employees each	TMA and coordinator Ridematching Transit promotion Cycling Flextime,staggered hrs. Vanpool subsidy	82.0 (86.0)	-	-	-	40% leave out of pm peak (program 3 yrs. in operation)
10)LIVERMORE, CA a)Lawrence Livermore Labs.	7200		Coordinator Ridematching Preferential Parking Express buses Vanpools BART feeder bus Company bicycles	36.0 (85.0)	-	-	-	Decrease in solo driving over 5 years
11)WEST SAN FERNANDO, CA a)Twentieth Century Corp(Warner Ctr.)	1150		Coordinator Transit passes Ridematching Priced parking Free carpool parking	65.0 (90.0)	31.0 (6.0)	-	-	Carpools percent went up after parking pricing started
12)PALO ALTO, CA a)Varian	5000	Tight parking	Coordinator Ridematching Subsidized transit passes Bicycle lockers/ showers	63.0 (82.0)	-	-	-	Result maintained since 1984

Table 1 - (Continued)

SITE/COMPANY	CHARACTERISTICS OF SITE SIZE OF EMPLOYM	EXISTING CONDITIONS	ACTIONS	RESULTS MODE SPLIT DRIVE ALONE	CAR/VAN POOL	TRANSIT	% VEH. TRIP REDUCT.	NOTES
13)SAN JOSE, CA a)FMC Corporation	5000		Coordinator Ridematching Preferential parking Subsidized bus passes Shuttle to Caltrain	79.0 (85.0)	-	-	-	Results due to carpooling
14)CONCORD, CA		25 employers 50-3300 emp./ company	Company coordinators Ridematching Transit passes Bike racks Flextime,staggered hrs.	-	-	-	-	Results:increase in solo driving at most emplys. up to 8%, with some declines up to 4%
15)GOLDEN, CO a)Coors Company	6000		Coordinator Ridematching Vanpools Preferential parking Transit information	84.0 (90-95)	-	-	-	Comparison with areawide rates (results have declined since 1984)
16)LAKEWOOD, CO a)Cobe Labs.	1300		Coordinator Ridematching Shuttle between bldgs. Preferential parking Flextime	80.0 (90-95)	-	-	-	Comparison with areawide rates
17)OVERLAND PK, KS a)Employees Reassurance Corp.	575		Coordinator Vanpool	83.0 (90-95)	-	-	-	Comparison with areawide rates (operating since late 70's)

Table 1 - (Continued)

SITE/COMPANY	CHARACTERISTICS OF SITE SIZE OF EMPLOYM	CHARACTERISTICS OF SITE EXISTING CONDITIONS	ACTIONS	RESULTS MODE SPLIT DRIVE ALONE	RESULTS MODE SPLIT CAR/VAN POOL	RESULTS MODE SPLIT TRANSIT	% VEH. TRIP REDUCT.	NOTES
18)BALTIMORE, MD a)Baltimore-Washington Int. Airport(BWI) Area	50000 users	Rail station providing both AMTRAK and MARC commuter rail service Free parking	Personalized computer matching County ridesharing coordinator Transit fares subsidy New public bus routes Flextime Parking incentives for pools	89.0	13.0	1.0	-	

hour vehicle trips that can be expected in other/new TDM programs, such emphasis is justifiable.

The results summarized in Table 1 suggest that vehicle trip reductions over 20% can be achieved only when restrictive parking policies are implemented along with other TDM strategies. Therefore, it is very unlikely that such high levels of trip reduction would occur in the cases of Cedar Bluff and Maryland Farms areas, where parking is ample and free. Nevertheless, these high values may be considered in an analysis representing a situation with a 100% level of employer participation and with all possible TDM strategies implemented.

CHAPTER III

STUDY AREA DESCRIPTION

Cedar Bluff Suburban Activity Center

Located approximately 10 miles west of Downtown Knoxville, around the intersection of Cedar Bluff Road and Interstate 40/75 (Figure 2), the Cedar Bluff area is considered to be one of the major and fastest growing suburban area in Knox County. The annual population increase and buildings permits issued in this area are routinely among the highest in this county. The area's land use is dominated by office and retail space, comprising a wide range of activities such as several general and single office buildings, one hospital, three drive-in banks, medical/dental office buildings, a variety of fast food restaurants, four hotels, shopping centers, service stations, etc. Residential areas surround the commercial development.

Interstate 40 and Kingston Pike (US 70/11) are the major east-west continuous routes serving the Cedar Bluff SAC. Middlebrook Pike, which is located on the north side of the area, also provides access to the area from the east and west directions. Cedar Bluff Road running north and south links

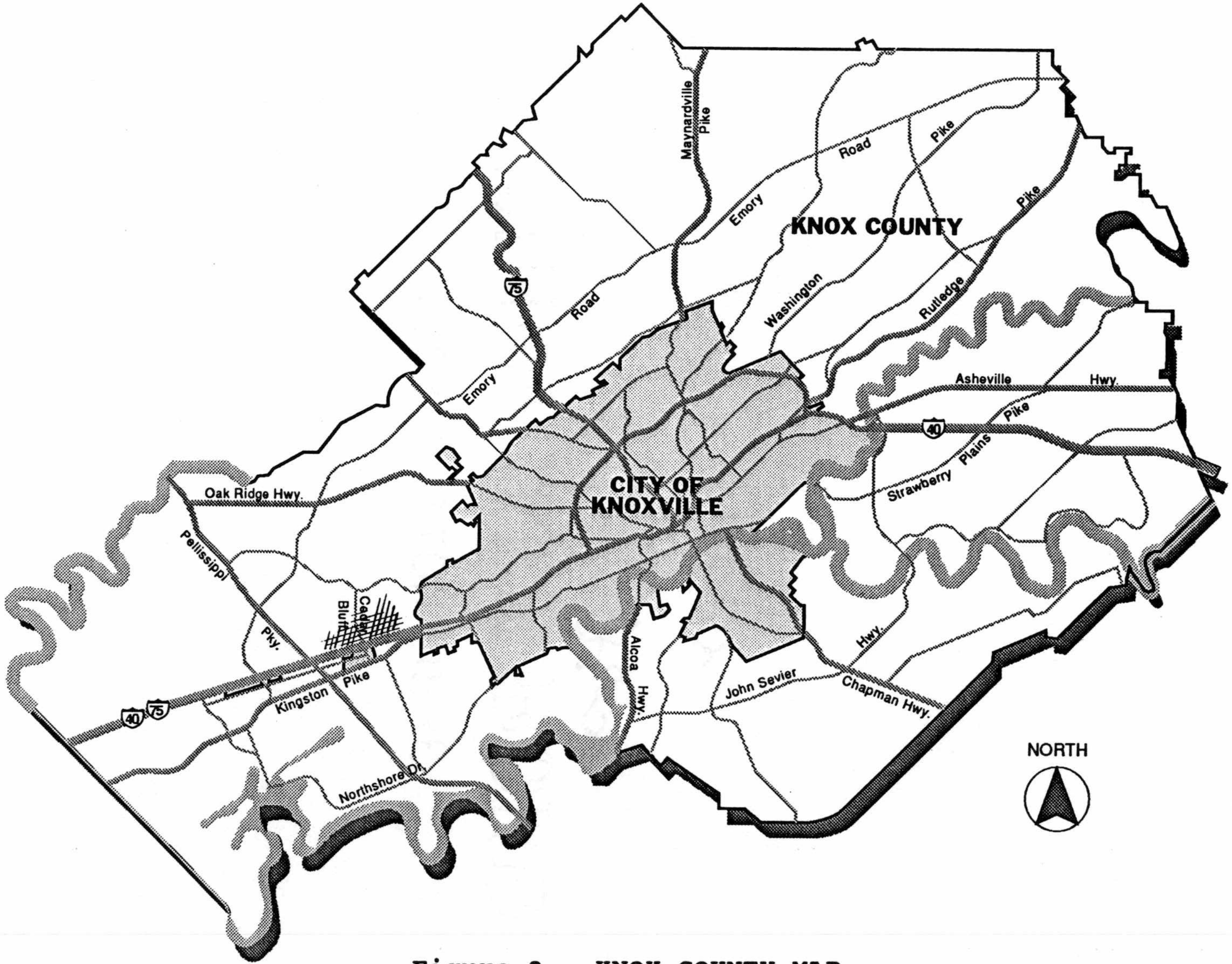

Figure 2 - KNOX COUNTY MAP

these three parallel arterials. Since this is the only route which crosses I-40 in the SAC, it carries high volumes of north-south traffic. The Cedar Bluff SAC is also served by a fixed route bus service operated by the Knoxville Transit Authority. This service is provided six days a week, Monday through Saturday, from 6:45 a.m. to 5:35 p.m. (Saturday service begins approximately one hour later and ends at 5:10 p.m.). The buses operate on an hourly schedule. This route links the SAC with downtown Knoxville, the University of Tennessee, and a few other major business concentrations along Kingston Pike, such as West Town Mall.

The majority of commercial development for which the Cedar Bluff area is now known for has occurred in the past twenty years. The initial development in the area was primarily single family housing. The construction of a planned development containing several hundred thousand square feet of office space and a shopping center followed. The development was named Executive Park. The construction of several multi-family housing complexes, more retail stores, and a 325 bed hospital was completed next. Directly following that development were restaurants and more office space. Most recently four shopping centers with a total of over 800,000 square feet of leasable space have opened within the SAC. There also has been a proliferation of motels in the area near the freeway interchange.

With such changes in urban development patterns, accompanied by the fact that the SAC is surrounded by large areas of residential development and located close to a major interstate interchange, it is not surprising that Cedar Bluff has become a synonym of traffic jams and accidents, destroying its image of an attractive and growing center, and preventing its further expansion. To solve the congestion problem, the interchange at I-40/75 is being modified. A new configuration of ramps is being built and new intersection controls will be installed. The Cedar Bluff Road will be widened near the interchange. But, how long will it take for travel demand to exceed the network capacity again? The answer for this question is very complex since it involves different variables with almost unpredictable behavior patterns. The economic development of the region and possible land use changes will dictate how soon traffic congestion will become once again a major problem.

For the purpose of this study, only the area on the north side of Interstate 40 was analyzed (Figure 3). The highway improvements that are under implementation were disregarded. Only the present conditions observed at the study site were considered. The intersections between Cedar Bluff Road and West Park Drive, and Cedar Bluff Road and Executive Park Drive, located both north of the interstate, were selected for level-of-service analysis. A survey was performed to determine the proportion of employees that work for

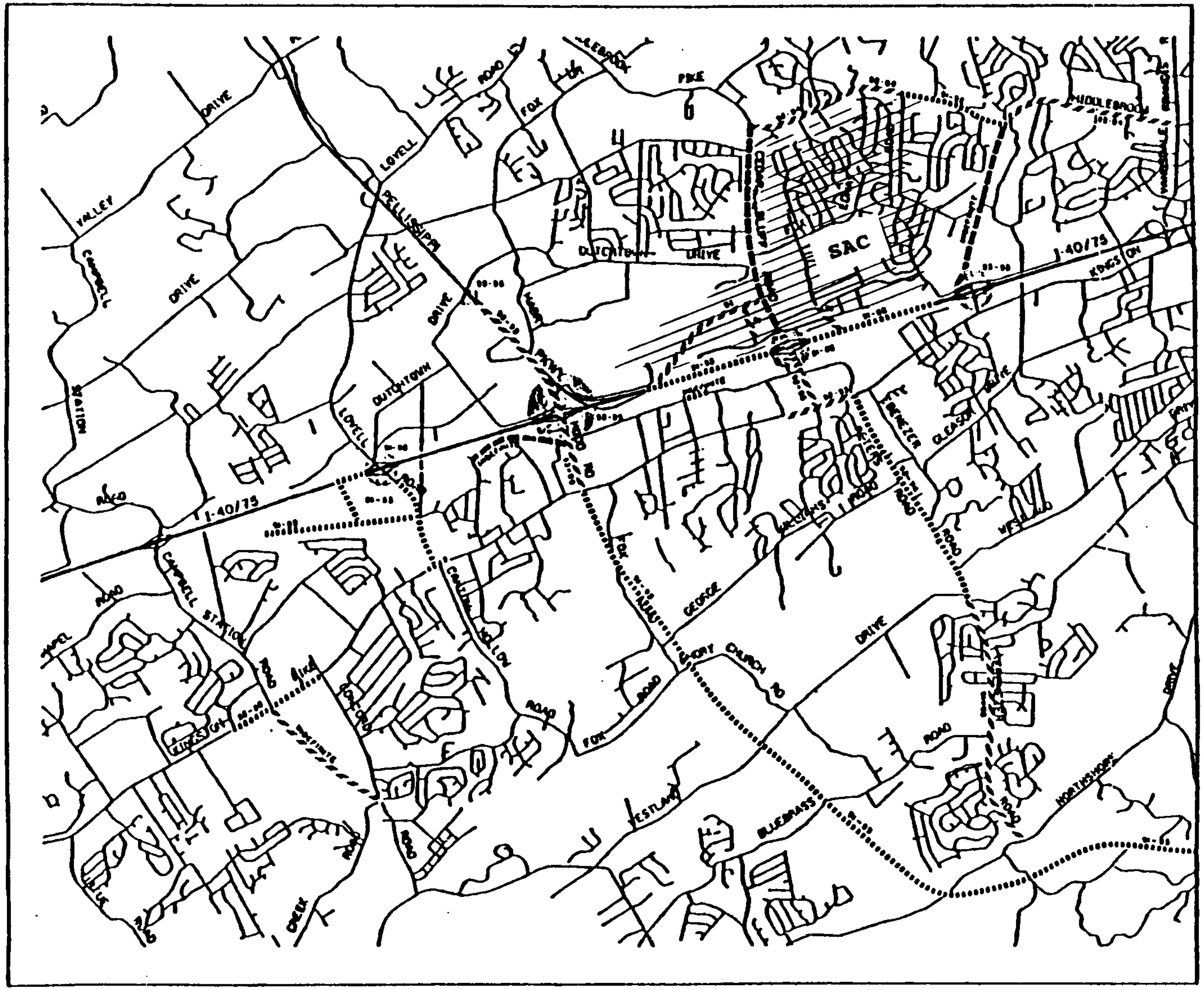

Figure 3 - CEDAR BLUFF SAC: LOCATION

companies with less than 50, between 50 and 100, between 100 and 500, and more than 500 employees. The employers were categorized because past experiences revealed that the effectiveness of TDM programs varies according to the size of employment. The specific thresholds of employment categories were selected to match those used in the COMSIS TDM Software (Comsis 1990b). For the cases in where the number of employees was not available, the employment was estimated based on the rates provided by the Trip Generation Manual (ITE 1990). The survey was performed only for employers located at north of the interstate, that is, the ones inside the area of influence of the selected intersections. In Table 2, a list of employers and office buildings is presented, with their respective floor area (sq. ft.), rate of employees per 1000 sq. ft., and number of employees.

Maryland Farms Office Park

The second study site is located in Brentwood, Tennessee, eight miles south of Nashville in the northern portion of Williamson County (Figure 4). With an appealing location, close to downtown Nashville, to major interstate highways, to the international airport and to Greater Nashville's executive housing corridor, Brentwood has attracted, over the past decade, a large number of major companies including Comdata Holdings Corp., with 1,100 employees; South Central Bell, with 798; Service Merchandise,

Table 2 - CEDAR BLUFF SAC: EMPLOYMENT DATA

LAND USE	BUSINESS	FLOOR AREA	RATE OF EMPLOYEES	No.OF EMPLS
General Office				
	Gilbert Commonwealth	25,643	3.39	87
	Financial Plaza	56,000	3.39	190
	9040 Building	50,283	3.39	170
	Corporate Square	93,733	3.39	318
	Executive Plaza	82,387	3.39	280
	Executive Park	27,200	3.39	92
	Executive Square	32,000	3.39	108
	Cross Park Plaza	91,176	3.39	309
	Executive Tower I	79,054	3.39	268
	Executive Tower II	50,858	3.39	172
	Parker Building	7,250	3.39	25
	Pitney Bowes	10,350	3.39	35
Single Tenant				
	IT Corporation	82,820	3.39	280
	State Farm Insurance	9,144	3.39	31
Medical/Dental				
	Cedar Bluff	12,204	4.83	59
	Park 40 Plaza	19,684	4.83	95
	Boulevard Bldg.	12,480	4.83	60
	Westside Medical	17,750	4.83	86
	Park West Physicians	21,013	4.83	102
	Cedar Bluff Med.	37,680	4.83	182
Hotel		(Rooms)		
	Holiday Inn	223	0.90	200
	Hampton Inn	120	0.90	108
	Roadway Inn	178	0.90	160
	Scottish Inn	118	0.90	106
Drive-in Bank				
	First American	4,048	3.64	15
	First Tennessee	2,025	3.64	7
	Charter Federal	3,710	3.64	14

Table 2 - (continued)

LAND USE	BUSINESS	FLOOR AREA	RATE OF EMPLOYEES	No.OF EMPLS
Fast Food				
	KY Fried Chicken	2,660	10.90	29
	Burger King	3,827	10.90	42
	Wendy's	2,450	10.90	27
	Long John Silvers	2,845	10.90	31
	Craker Barrel	9,035	10.90	98
	Pizza Hut	2,924	10.90	32
	Arby's	3,431	10.90	37
	McDonald's	4,368	10.90	48
Shopping				
	Cedar Bluff S.C.	90,000	1.82	164
	C.B.Crossing S.C.	47,187	1.82	86
	Pekadees	4,050	1.82	7
	Cedar Square	7,124	1.82	13
	Comer Drug Bldg.	5,900	1.82	11
Hospital				
	Fort Sanders Hosp.			1200

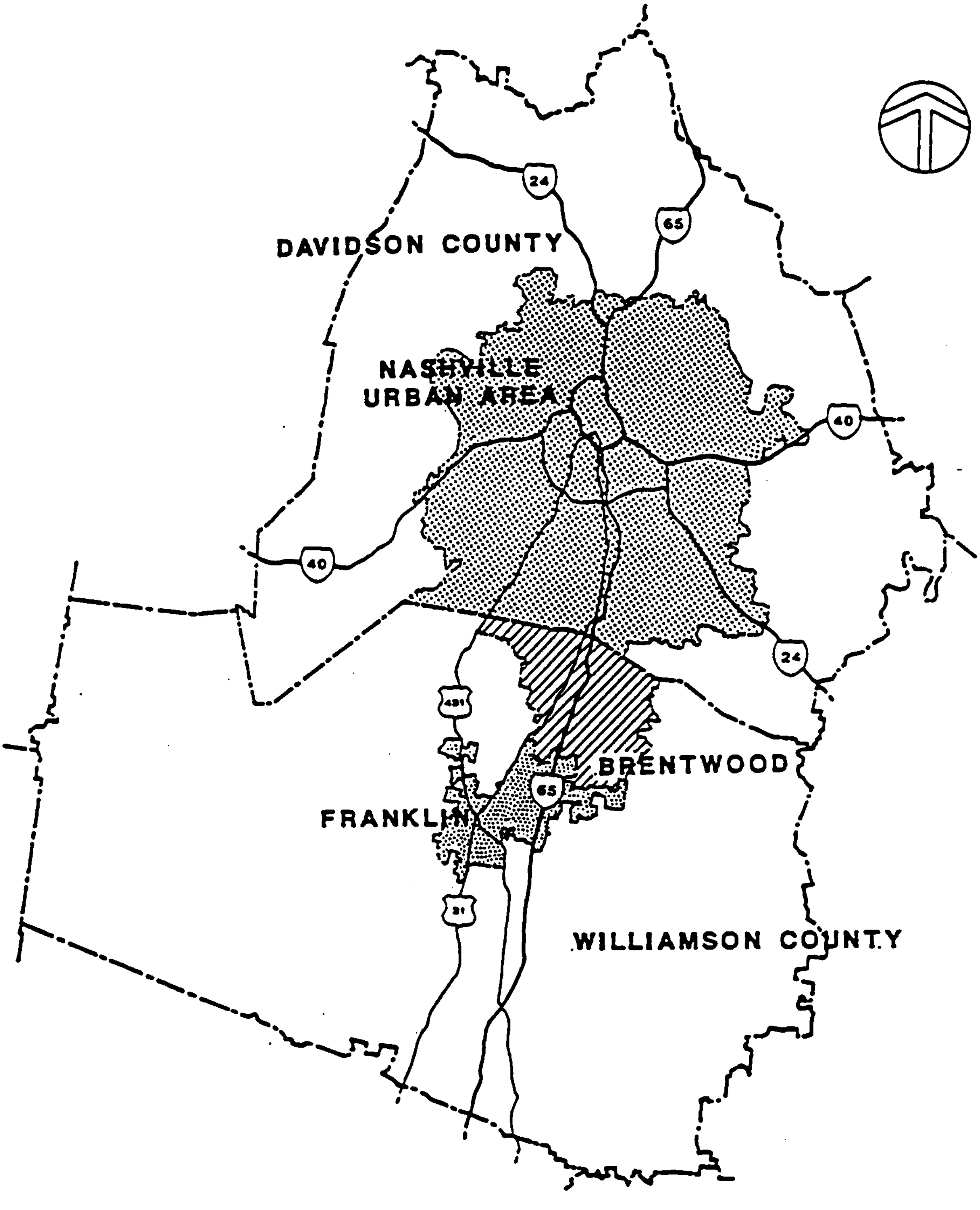

Figure 4 - WILLIAMSON COUNTY MAP

with 610; FISI-Madison Financial Corporation, with 280; and Murray Ohio Manufacturing, with 260; as well as a number of smaller, equally impressive businesses. According to the last edition of the *Brentwood* magazine, since 1980 the number of workers coming into Brentwood each day has increased 280 percent. The city's population has grown 46 percent during the last decade, and the present estimate is that its population will double by 1999 (Brentwood 1991).

The Maryland Farms Office Park is the major constituent of the area defined as the Brentwood SAC shown in Figure 5, which includes locations on both the east and west sides of I-65 and is bounded by Old Hickory Boulevard on the north. In the early 1970's, the Brentwood SAC area underwent a rapid change from being primarily a farm land to becoming a bedroom community for Nashville as a huge number of single family homes were built. Later during the decade, a shift from residential to office development occurred. Now, the dominant land use in the Brentwood SAC is medium density office space with over 1,500,000 sq. ft. of leasable space in the Maryland Farms Office Park alone. There is also a 135,000 square foot country club, approximately 10,000 sq. ft. of child care facilities, 73,000 sq. ft. of medical office space, 71,000 sq. ft. of municipal space, and over 175,000 sq. ft. of hotel space in Maryland Farms.

The major highways serving the Brentwood SAC include Interstate 65 and U.S. Highway 31 (Franklin Pike) running

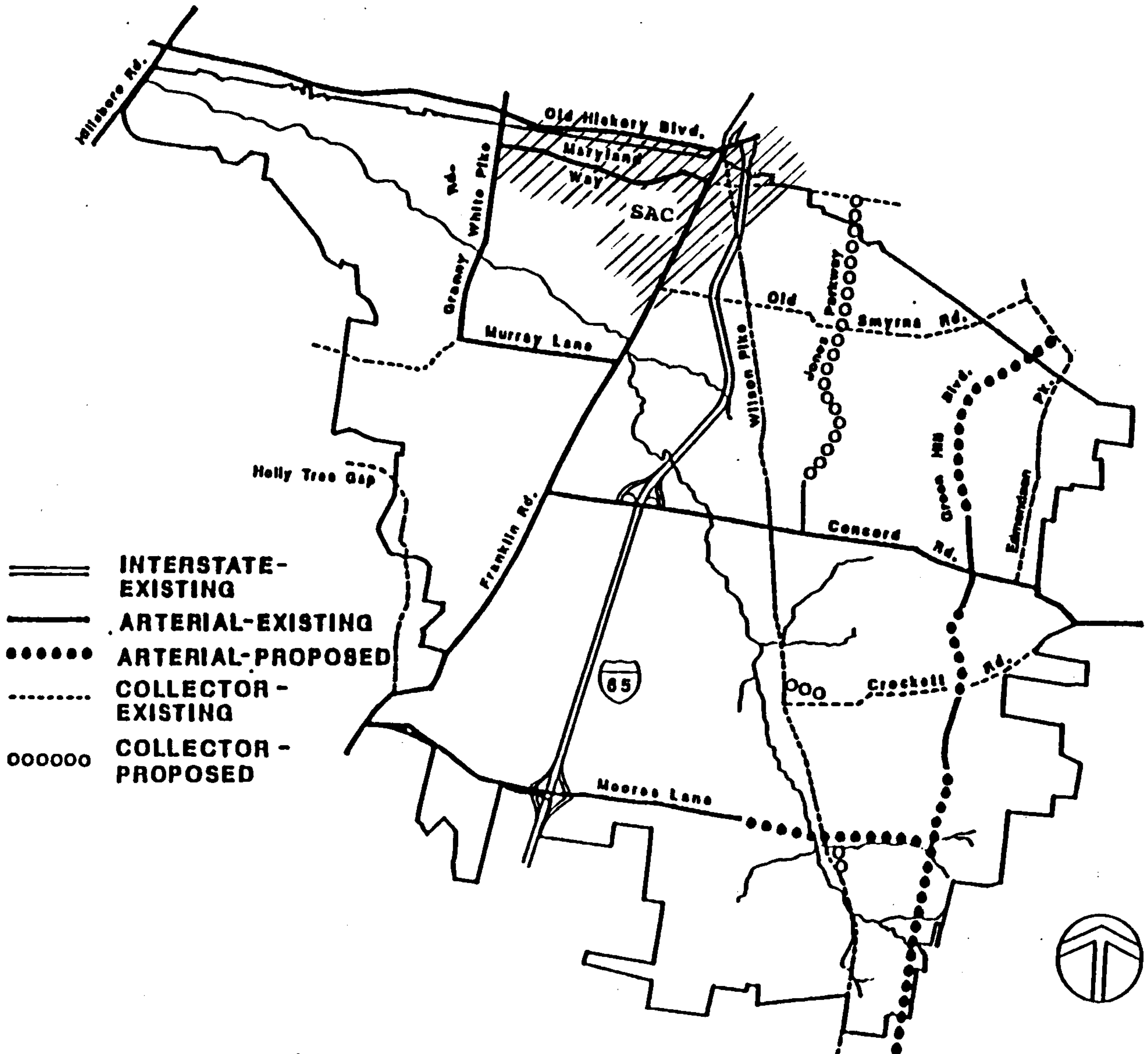

Figure 5 - BRENTWOOD SAC: LOCATION

north to south, and Old Hickory Boulevard running east to west. The Old Hickory Boulevard serves as an internal linkage between the portions of the SAC that are divided by I-65, and it also provides external access to the area. No mass transit routes currently serve the SAC. The city of Brentwood does not currently have a transit system in operation.

The Brentwood area may have lost some of its attractiveness as a beautiful place for living due to its present high traffic volume levels. To address transportation and mobility issues, the Brentwood Area Transportation Management Association (BATMA) was created in 1987, and now it involves more than 40 employers in the area. Despite the intensive effort of this organization, the TDM measures so far implemented have not been very successful in reducing rush hour traffic. This result may be attributable to the nonavailability of transit alternatives and insufficient institutional support for the TDM actions, as well as the large amount of free parking spaces available at the site. Free parking is not conducive to a change in the commuter travel behavior.

For the purpose of this study, the TDM programs already implemented in Brentwood by BATMA were disregarded. The Maryland Farms Office Park was selected as a representative subarea of the Brentwood activity center. The intersection of Maryland Way / Church St., and Franklin Pike, which is located adjacent to a major entrance to the study area, was chosen for a detailed level-of-service analysis. A list of all the buildings within the Maryland Farms Office Park was prepared, with their respective usage classification (office or non-office) and occupied floor area (sq. ft.). Some office buildings, although not located within the Maryland Farms Office Park, were also included in the analysis, because of their proximity to the selected intersection, and also due to their importance on generating trips that go through this intersection. The number of employees in each building was estimated using the rates of employees per 1000 sq. ft., provided in the Trip Generation Manual (ITE 1990). For the cases for which employee data were available, the actual number of employees was used and these values are indicated beside the estimated figure. The list of office buildings is presented in Table 3.

Table 3 - MARYLAND FARMS OFFICE PARK: EMPLOYMENT DATA

BUILDING	USE	FLOOR AREA	RATE OF EMPLOYEES	No. OF EMPLYS
One Maryland Farms	Office	26,191	3.39	89
Two Maryland Farms	Office	53,340	3.39	181
Three Maryland Farms	Office	56,791	3.39	193
Maryland F. Raquet Club	Non/office	135,000	-	- /180
Andrews Cadillac	Non/office	41,000	-	- / 71
Park Lane	Office	94,140	3.39	319
West Park	Office	95,000	3.39	322
The Historic Horse Barn	Office	12,400	3.39	42
The 101 Bldg (Winners)	Office	26,085	3.39	88
Chappel	Office	22,857	3.39	77
Kindercare	Non/office	5,000	2.20	11
Westwood	Office	24,000	3.39	81
Paddock Office Condo I	Office	29,000	3.39	98
Paddock Office Condo II	Office	25,910	3.39	88
Paddock Off. Condo III	Office	18,650	3.39	63
Harpeth on the Green I	Office	45,150	3.39	153
Harpeth on the Green II	Office	46,072	3.39	156
Harp. on the Green III	Office	73,991	3.39	251
Harpeth on the Green IV	Office	78,000	3.39	264
Harbours	Non/office	17,000	4.83	82
Churchill	Office	31,000	3.39	105
Medical Center	Non/office	56,000	4.83	270
CA Garden	Office	44,000	3.39	149
Mitzell Riggs	Office	14,550	3.39	49
United Cities Gas	Office	41,000	3.39	139/150
Continental Life Bldg.	Office	31,743	3.39	108
Kinder Care Add.	Non/office	4,300	2.20	9
Mariott Courtyard	Non/office	175,000	-	- / 50
Center Court	Office	50,767	3.39	172
Library	Non/office	14,500	0.92	13
Brentwood Municipal	Office	56,500	3.39	192
First American Bank	Office	600	3.64	2
Raintree Bldg.	Office	67,500	3.39	229
State Farm Insurance	Office	14,000	3.39	48/ 68

Table 3 - (continued)

BUILDING	USE	FLOOR AREA	RATE OF EMPLOYEES	No. OF EMPLYS
Maryland Manor	Office	26,000	3.39	88
Sovran Bank	Office	27,523	3.64	100
Comdata Holdings	Office	133,000	3.39	451/1100
Inacomp Computer	Office	11,000	3.39	37
Financial Plaza	Office	96,400	3.39	327
James Town	Office	17,464	3.39	59
NCR	Office	23,200	3.39	79/ 75
Tennessee Baptist	Non/office			- /105
Murray Ohio	Non/office			- /285
South Central Bell	Office			- /798

CHAPTER IV

ANALYSIS PROCEDURE

The methodology adopted for analyzing the effectiveness of TDM strategies in reducing peak traffic congestion comprised two distinct phases. First, for each study area, a TDM evaluation model (COMSIS 1990b) was employed to calculate the increase in HOV mode share, and the consequent reduction in peak period vehicle trips attributable to selected TDM strategies. Second, the Highway Capacity Software (McTrans 1987) was used to determine the existing level of service (LOS) of the study intersections, and then estimate at what LOS those intersections would be expected to operate after the implementation of selected TDM strategies. In the following sections, a detailed description of the procedures used for these two analytical phases is presented.

TDM Evaluation Model

The Travel Demand Management Evaluation Model, developed by COMSIS Corporation, consists of a system of computer spreadsheets where the user can enter the specifications of TDM strategies that are to be evaluated and obtain the expected results of the strategies. The model can be run on a standard, IBM-compatible microcomputer (386 level), and it offers the user the opportunity to examine a wide range of TDM strategies, alone or in combination, which may be implemented in different types of situations with regard to area coverage, level of employer participation, and the stringency of participation requirement. The computer program is designed to prompt the different strategies, and the user simply indicates which particular strategy is of interest, and at what level it should be tested.

Other input data for the TDM model include trip tables taken from conventional planning software packages, such as MINUTP, TRANPLAN and EMME/2. The trip tables provide the number of person trips and vehicle trips by origin and destination within the impact area selected for the study. For each selected scenario, information is generated on modal split, vehicle trips (absolute number and percentage change from base conditions), and vehicle miles of travel. Moreover, the software produces a revised set of trip tables for each examined scenario, which may be used as input to the external planning software (MINUTP, TRANPLAN, etc.) for network level traffic analysis.

The TDM software estimates the impact of TDM strategies on existing travel characteristics through a combination of theoretical models and empirical findings. At the core of the theoretical model is a disaggregate logit mode choice model, which is similar to mode split models used in most regional planning packages. The mode choice model is used for assessing the impacts of TDM policies that affect travel time and travel cost of commuters. For other types of strategies, which involve institutional participation such as employer supported ridesharing programs or variable work hours programs, impacts are estimated using empirical data gathered from case studies in different areas.

In the case of this study no trip tables were available for the study areas. However, since this study is concerned with individual sites, and specific intersections, trip tables were not necessary. The empirical data on the effectiveness of TDM strategies that are included in the TDM model were utilized using the following steps:

1) Three employer-based strategies were identified as most appropriate for the conditions of the study areas. These are: a)ridesharing programs (carpools); b)vanpool programs; c)variable work hours programs.
2) Based on the available employment data for each SAC, the percentages of employees by work place categories were developed;
3) The levels of employer involvement and support that were selected for different TDM strategies were relatively high. For the case of carpooling, which in the Comsis TDM Model is referred to as

"ridesharing", four levels of employer effort are considered, ranging from little or no effort (level 1) to a "significant" effort (level 4). It was assumed for this analysis that a "significant" effort would be expected from the employers taking part in the ridesharing program. For the case of vanpool programs, an index value of 6, in a 1-10 scale, was considered appropriate for describing the level of effort to be devoted by the employers. Index values higher than 6 would lead to reductions not compatible with what has been observed from past experience on TDM programs.

4) Two program levels were considered reflecting the stringency of implementation environment. The percentage of peak hour vehicle trip reduction was calculated, first, for a "voluntary" program, meaning that there would be no legal requirements compelling the participation of employers. Then, the trip reduction was estimated for a "mandatory" program, meaning that there would be legal requirements for participation applicable to all employers within each study area. For each level of program, a "percentage of employers participating" was assigned, corresponding to the default values used by the TDM Model, according

to each work place category. These percentages under the "voluntary" program ranged from 4 to 37 percent. Under the "mandatory" program, the participation rate varied from 76 to 100 percent.

5) Using the values included in TDM tables of the software for the assumed levels of employer involvement and implementation requirements, the increase in the use of each mode was calculated for each work place category. For variable work hours, there is a default 4 percent reduction in peak hour vehicle trips for all employers who participate at all.

6) The increase in the usage of each mode was multiplied by the employer participation rate for each work place category.

7) The results of step 6 were multiplied by the percentages of employees in each work place category.

8) The results of step 7 were summed up for all work place categories to get the composite values for the increase in the share of each rideshare mode.

9) The number of vehicle trips for a specific mode, after the TDM measures have been applied, was determined by first multiplying the total number of employees by the mode share percentage of each mode found in step 8, and then dividing that

number by the average occupancy rate for the respective modes. The following average occupancy rates were used in the calculations:

a) Drive-alone = 1.0 person/vehicle;

b) Rideshare (carpool) = 2.5 persons/vehicle;

c) Vanpool = 12.0 persons/vehicle.

The total number of vehicle trips was calculated by adding up the vehicle trips by each mode.

10) The number of peak hour vehicle trips was calculated by taking the total number of vehicle trips calculated in step 9 and reducing it by 4 percent due to the assumed variable work hours program.

11) The percentage of reduction in peak hour vehicle trips was determined assuming that, before the implementation of the TDM strategies, all employees would drive alone, and that all trips would be made during the peak hour. These assumptions are in favor of TDM strategies, considering the existing conditions at the study sites.

The data presented in Tables 4 & 5 summarize how the employee population is broken down into different work place categories. For both Cedar Bluff and Maryland Farms areas, accurate employment data were gathered for employers with more than 50 employees. For the rest of the employers, the number

Table 4 - EMPLOYEES IN CEDAR BLUFF SAC

WORK PLACE CATEGORY	No. OF EMPLOYEES	% OF EMPLOYEES
Office		
1 - 49 employees	2,387	44.34%
50 - 99 employees	144	2.67%
100 - 499 employees	454	8.43%
+ 500 employees	-	-
Subtotal	**2,985**	**55.44%**
Non-office		
1 - 49 employees	427	7.93%
50 - 99 employees	198	3.68%
100 - 499 employees	574	10.66%
+ 500 employees	1,200	22.29%
Subtotal	**2,399**	**44.56%**
TOTAL	5,384	100.00%

Table 5 - EMPLOYEES IN MARYLAND FARMS OFFICE PARK

WORK PLACE CATEGORY	No. OF EMPLOYEES	% OF EMPLOYEES
Office		
1 - 49 employees	3,394	46.40%
50 - 99 employees	319	4.36%
100 - 499 employees	530	7.25%
+ 500 employees	1,898	25.95%
Subtotal	**5,343**	**83.96%**
Non-office		
1 - 49 employees	352	4.81%
50 - 99 employees	121	1.65%
100 - 499 employees	700	9.58%
+ 500 employees	-	-
Subtotal	**1,173**	**16.04%**
TOTAL	7,314	100.00%

of employees working in each office or non-office building was estimated considering its total occupied floor area. Since what is important for the application of the TDM model is only the proportion of employees in each work place category, such procedure is justifiable.

To display the outputs of the calculations performed in steps 1 through 11, one spreadsheet was developed, using the LOTUS 123 package. Table 6 presents the percentage of employees in each work place category for the Cedar Bluff SAC along with the increase in mode usage after the application of the selected TDM actions, and the expected percentage of employers participating in the program for a "voluntary" and a "mandatory" institutional environments. The percent of employees using each mode, and the percent of employees that would switch from the morning peak hour due to flextime policies are also presented. The table also shows the final reduction in peak hour vehicle trips for each program level. The data for the Maryland Farms SAC, corresponding to that for the Cedar Bluff SAC, are presented in Table 7.

A sample calculation to help a better understanding of Tables 6 and 7 is presented below for a "mandatory" program at Maryland Farms SAC:

a) Calculating the percentage of employees shifting to vanpooling in the work place category of "old office" with to 100-499 employees:

Table 6 - RESULTS OF TDM MODEL: CEDAR BLUFF SAC

Work Place Category			% Increase in Mode Usage		% of Employers Participating		% of Employees Using The Mode				% Reduction in PHV due to Variable Work Hours	
Type	Size	% of Employees	Rideshare	Vanpool	Voluntary (1)	Mandatory (2)	Rideshare (1)	Rideshare (2)	Vanpool (1)	Vanpool (2)	(1)	(2)
Old Office	1- 49	44.34	7	10	4	76	0.12	2.36	0.18	3.37	0.07	1.35
	50- 99	2.67	7	11	4	100	0.01	0.19	0.01	0.29		0.11
	100-499	8.43	12	12	37	100	0.37	1.01	0.37	1.01	0.12	0.34
	500+		14	12	37	100						
Old Non-Office	1- 49	7.93	2	6	4	76	0.01	0.12	0.02	0.36	0.01	0.24
	50- 99	3.68	2	7	4	100		0.07	0.01	0.26	0.01	0.15
	100-499	10.66	4	8	37	100	0.16	0.43	0.32	0.85	0.16	0.43
	500+	22.29	5	8	37	100	0.41	1.11	0.66	1.78	0.33	0.89
							1.08	5.29	1.57	7.92	0.70	3.51

% Vehicle Trip Reduction in Peak Hour:

(1) Voluntary program: 2.8%

(2) Mandatory program: 13.6%

Table 7 - RESULTS OF TDM MODEL: MARYLAND FARMS SAC

Work Place Category			% Increase in Mode Usage		% of Employers Participating		% of Employees Using The Mode				% Reduction in PHV due to Variable Work Hours	
Type	Size	% of Employees	Rideshare	Vanpool	Voluntary (1)	Mandatory (2)	Rideshare (1)	Rideshare (2)	Vanpool (1)	Vanpool (2)	(1)	(2)
Old Office	1- 49	46.40	7	10	4	76	0.13	2.47	0.19	3.53	0.07	1.41
	50- 99	4.36	7	11	4	100	0.01	0.31	0.02	0.48	0.01	0.17
	100-499	7.25	12	12	37	100	0.32	0.87	0.32	0.87	0.11	0.29
	500+	25.95	14	12	37	100	1.34	3.63	1.15	3.11	0.38	1.04
Old Non-Office	1- 49	4.81	2	6	4	76		0.07	0.01	0.22	0.01	0.15
	50- 99	1.65	2	7	4	100		0.03		0.12		0.07
	100-499	9.58	4	8	37	100	0.14	0.38	0.28	0.77	0.14	0.38
	500+		5	8	37	100						
							1.94	7.76	1.97	9.10	0.72	3.51

% Vehicle Trip Reduction in Peak Hour:

(1) Voluntary program: 3.7%

(2) Mandatory program: 16.1%

% Vanpool (Mandatory) = (% employees in the work place category) x (% increase in vanpool usage) x x (% employers participating) x 100 =

= (7.25%) x (12%) x (100%) x 100 =

= 0.87%

The same procedure described above was used to determine the percentage of employees shifting to carpooling (rideshare) and the percentage of employees switching out of the peak hour due to flextime. Then, the same calculations were accomplished for the other work place categories and the results summed up for each mode.

b) Calculating the percentage of peak hour vehicle trip reduction:

- Number of trips that will be generated by the employees using each mode:

Carpooling = (7.76% employees) ÷ (2.50 persons/veh.)

= 3.10 veh.trips per 100 employees

Vanpooling = (9.10% employees) ÷ (12.00 persons/veh.)

= 0.76 veh.trips per 100 employees

Driv.Alone = (100% - 7.76% - 9.10%) ÷ (1.0 person/veh.)

= 83.14 veh.trips per 100 employees

- Total veh.trips = (3.10 + 0.76 + 83.14) per 100 empls.

= 87.00 veh.trips per 100 employees.

- Number of peak hour veh.trips (deducting the shift due to variable work hours) = (100% - 3.51%) x 87.00

= 83.9 PHV trips/100 empl.

- Reduction in PHV trips (considering that before the TDM program all employees were driving alone) = 100 - 83.9

= **16.1%**

Intersection Analysis

The second phase of the analysis involved the application of the Highway Capacity Software (McTrans 1987) to determine the levels of service (LOS's) at which the selected intersections are currently operating, and to assess at what LOS's they may be expected to operate if peak hour vehicle trips are reduced by the amounts estimated by the TDM model as described above.

The Highway Capacity Software (HCS) was developed by the Federal Highway Administration to assist users with the application of procedures included in the 1985 Highway Capacity Manual (TRB 1985). The software operates on IBM PC, XT, AT or compatible machines with at least 384k of memory. In this study, only the part of the software that deals with signalized intersections was used.

Pre-TDM Conditions

After the selection of the study intersections at each site, traffic counts were made to determine the approach volumes during the morning peak hour. Counts were taken for a three-hour period for defining exactly when the morning peak hour occurred, and how the traffic was spread over that period.

For the case of Cedar Bluff area, the two adjacent "T" intersections were combined to make up one four-leg intersection. This was done to simplify the capacity analysis procedure considering that the intersections are located less than 200 feet apart and that their signal phasing and timing are synchronized (Figure 6). Average phase lengths were used since the signals have a traffic actuated type of control, and the software takes into account such an adjustment by multiplying the calculated stopped delay by a reduction factor. To make the application of the software feasible, the westbound right-turn volume (35 vehicle/hour) was assumed to use the red phase, and the two westbound approach lanes were treated as two exclusively left-turn lanes. For unknown reasons, the software could not accept the actual lane configuration, that is, a left-right shared lane. Also, an adjustment on the northbound left-turn volume was made. It was assumed that approximately 3 to 4 vehicles would turn left during each permitted phase. This assumption was based on field observations. The number of permitted left turns during the peak hour (121 vehicles/hour) was subtracted from the total volume (486 veh./hour), allowing the software to run with the "assign no left turns to the permitted phase" option.

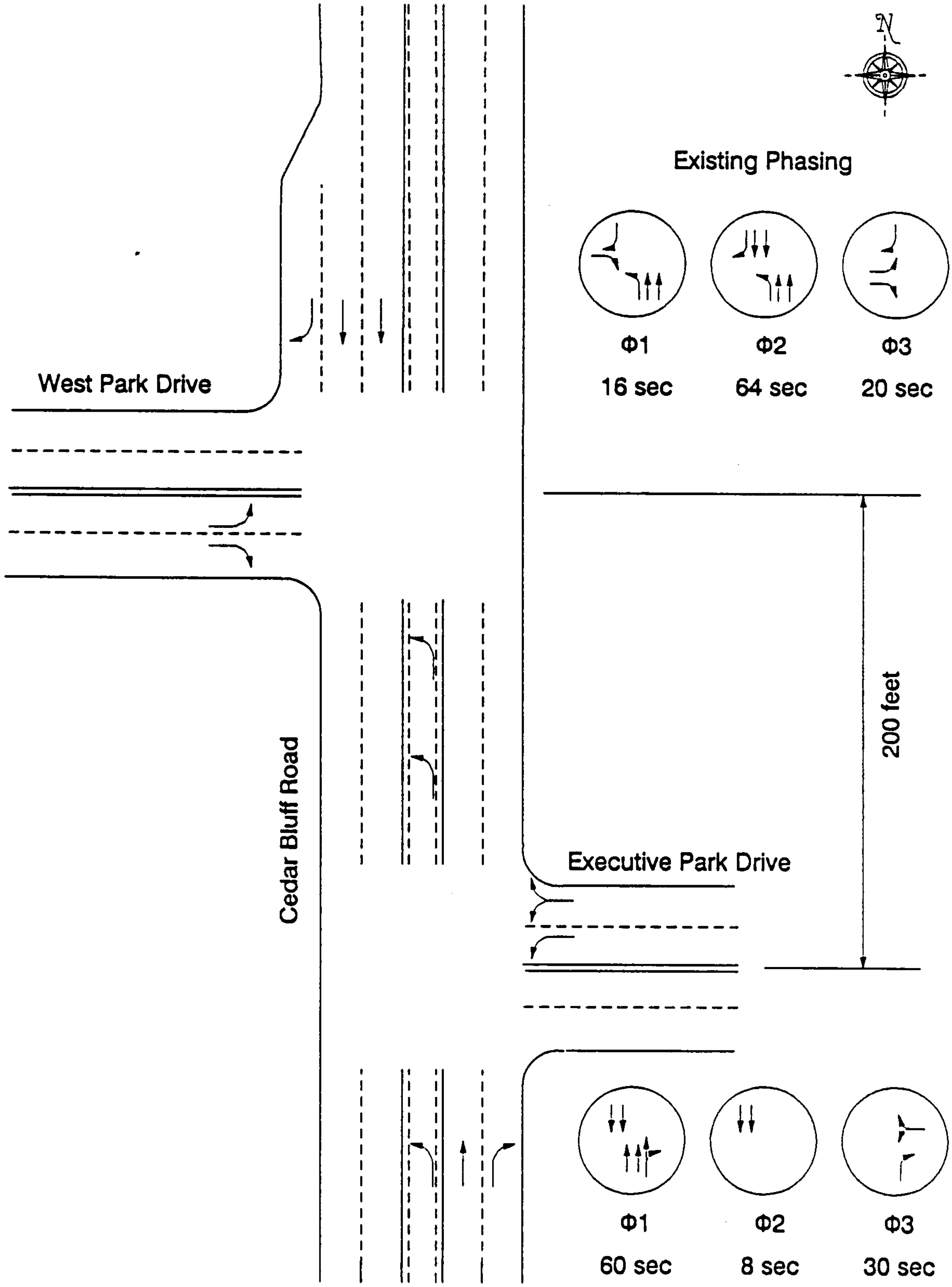

Figure 6 - INTERSECTIONS AT CEDAR BLUFF

This was also done because of operational reasons. The morning peak hour volumes are shown on Figure 7.

For the case of Maryland Farms Office Park, no adjustments were necessary. The present LOS was calculated for the 7:30 to 8:30 AM peak hour. For the left-turn movements, it was considered that the number of vehicles using the permitted/yield phase is equal to the value that would result in equal v/c ratios for the permitted and protected phases. The other two options provided by the software - "assign no left turns to the permitted phase" and "assign the maximum number of left turns to the permitted phase" - were found to result in numbers of vehicles using the permitted phase that differed considerably from the values observed during field observations. For the right-turn movements, two different treatments were applied: the north-south direction was assumed to present no right turns during the red phase, and the east-west direction was considered as having 75 percent of the eastbound right turns and 25 percent of the westbound right turns on red. These figures were selected based on field observations. As in the case of the Cedar Bluff intersection, average phase lengths were determined to represent the actuated signal operation at the Maryland Farms intersection. Figures 8 and 9 show the intersection layout, the present signal timing and phasing, and the approach volumes.

The printouts obtained from the Highway Capacity Software are presented in the Appendix I. For each analyzed

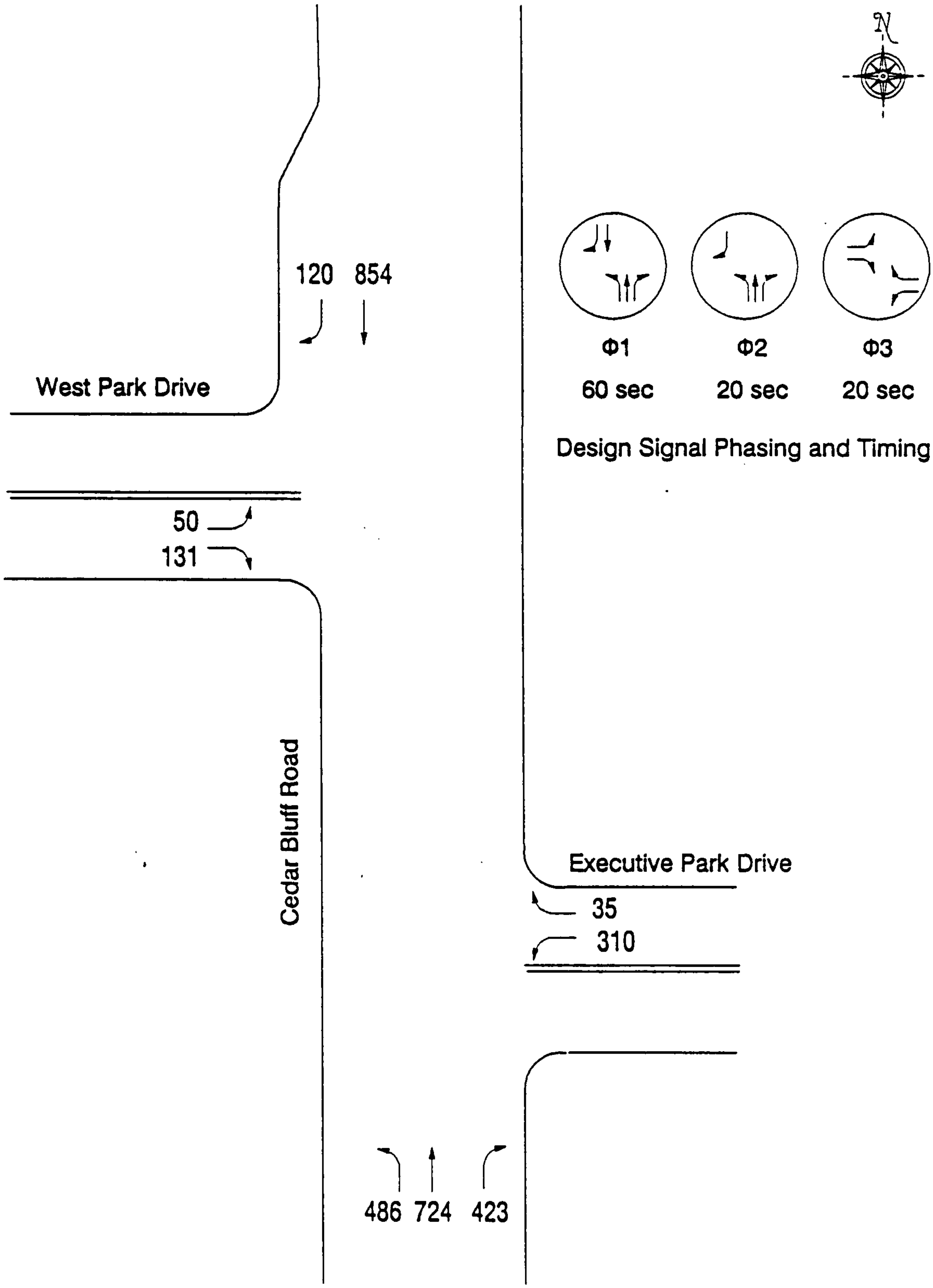

Figure 7 - TRAFFIC VOLUMES AT CEDAR BLUFF DURING 8:00 A.M. TO 9:00 A.M.

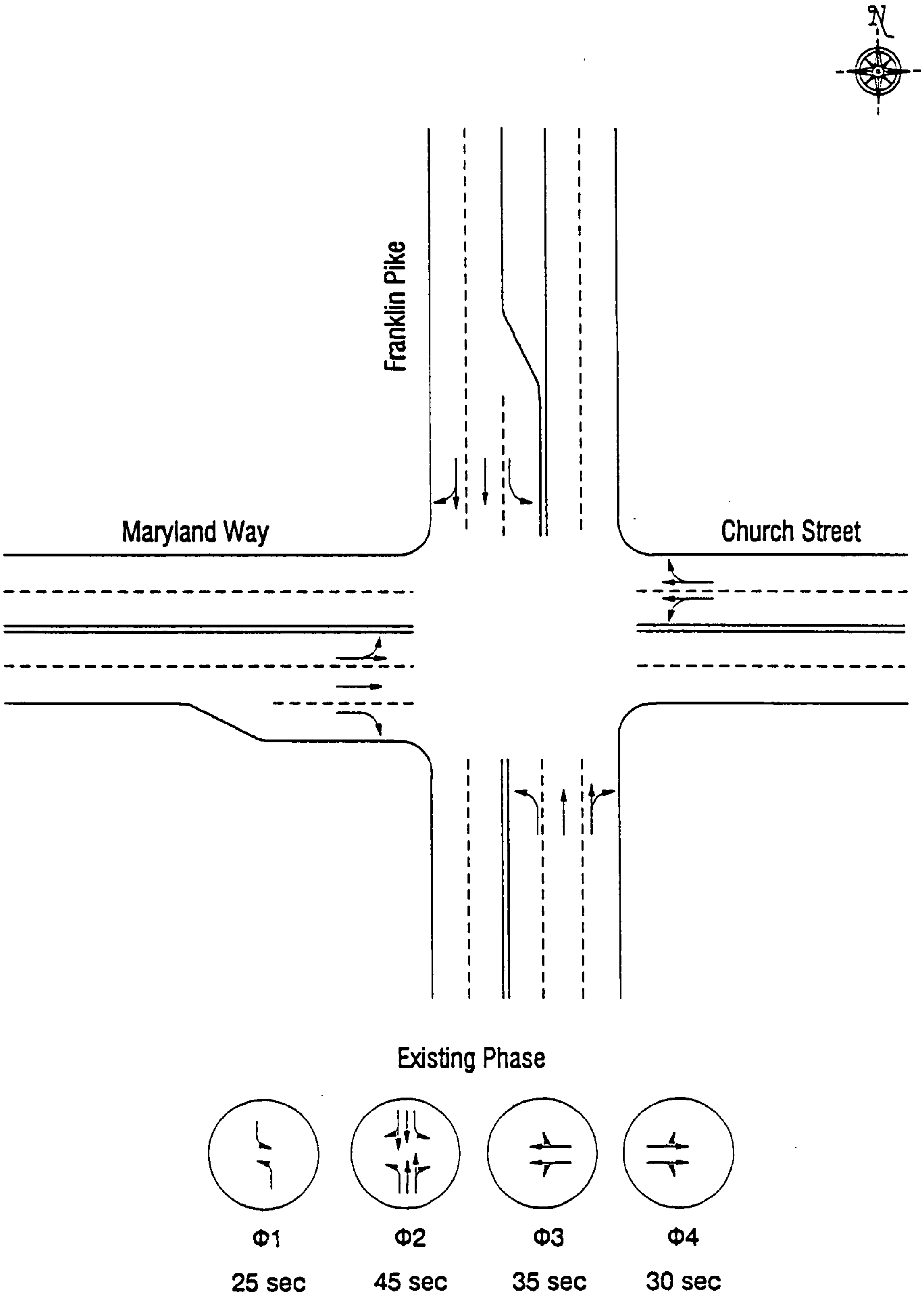

Figure 8 - INTERSECTION AT MARYLAND FARMS

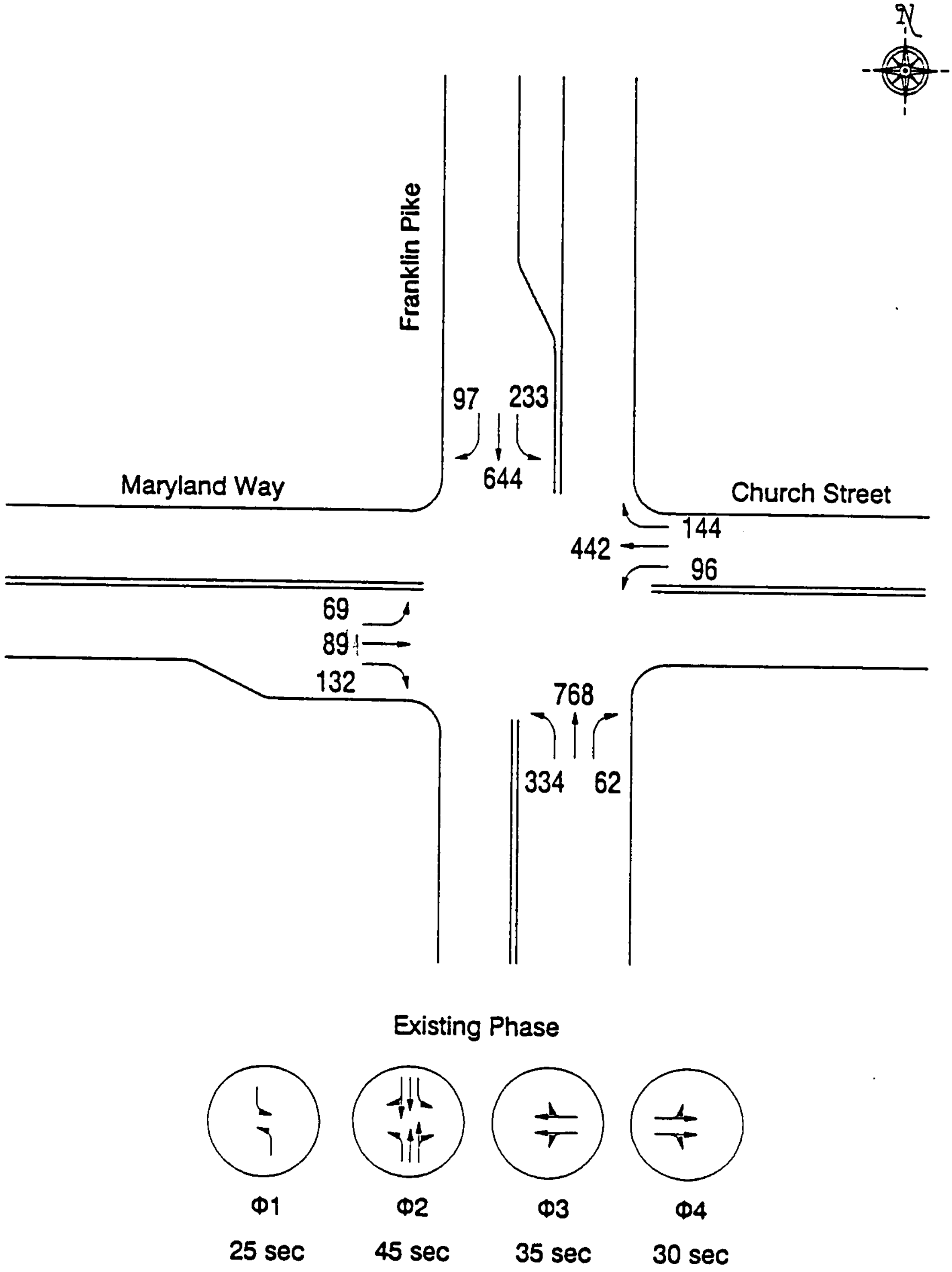

Figure 9 - TRAFFIC VOLUMES AT MARYLAND FARMS INTERSECTION DURING 7:30 A.M. TO 8:30 A.M.

intersection, these show the approach volumes, the intersection geometry, the adjustment factors applied during the lane capacity determination, and the signal settings. There are also four worksheets in which the outputs from the calculation process are displayed. At the end, the levels of service by approach and the overall intersection LOS are calculated, based on the corresponding delay values.

Post-TDM Conditions

As reported in the previous section, the percentages of reduction in peak hour vehicle trips were determined for two different TDM program levels - a "voluntary" and a "mandatory" level of regulation. The "voluntary" case assumes that there is no supportive institutional measures. In the case of "mandatory level", it is assumed that regulatory actions will be taken to achieve the maximum possible level of employer participation. In the latter case it was assumed that 100 percent of employers would participate in the program for all size of employments, except those with less than 50 employees.

Besides those two specific situations, a third assumption was considered. Based on a search of literature, the findings of which are summarized in Table 1, a value that would represent an "extremely successful" program was selected. This value is a **25 percent** reduction in peak hour vehicle trips. This value represents a program that would involve all possible travel demand control measures, including different forms of transit and parking restrictions. It was also assumed that employers would be compelled to participate through institutional mechanisms. This value represents an average of the best results observed throughout the country under this comprehensive TDM scenario. It is important to point out that most of the better results relate to employer-based programs. Since for the cases of Cedar Bluff and Maryland Farms a site analysis is been performed, the extrapolation of those figures is per se a very optimistic assumption.

The next step was to reduce the approach traffic volumes at each intersection using the estimated percentage reductions. The distinction between "local" traffic - that produced and attracted by the SAC generators - and "through" traffic was recognized. In the case of Cedar Bluff, it was assumed that all vehicles coming in and going out from West Park Dr., and all vehicles entering Executive Park Dr. are local traffic. The inclusion of vehicles leaving the SAC through West Park Dr. as part of "local traffic" is justified by the fact that the morning peak hour matches with Park West Hospital's shift change. Moreover, it was also assumed that ten percent of the traffic going through the intersection is generated by the businesses located on Cedar Bluff Road, and is of "local" nature. This last figure was estimated based on the differences of traffic volumes between the number of approaching vehicles at the intersections and the traffic volumes measured by the Tennessee DOT at two count stations (St.127 and St.350) located at the north and south sides of the study intersection on Cedar Bluff Road. The westbound approach volume on Executive Park Dr. was considered to be through traffic entirely because commuters who live in the residential areas situated in the northeast part of the activity center use that road.

For the Maryland Farms' intersection, "local" traffic was defined as all vehicles coming into Maryland Way plus 80 percent of the vehicles going southbound along Franklin Pike. Although a portion of the traffic coming into Maryland Way may be "through" traffic, it was considered to be very small. The estimated figure of 80 percent for the "local" traffic on Franklin Pike (southbound) was derived from traffic counts at the study site.

Based on the reduced approach volumes at the intersections, the new levels of service were calculated considering the "voluntary", the "mandatory", and the "extremely successful" TDM programs. The software printouts corresponding to the analysis of each alternative are presented in Appendix II.

It should be pointed out that the proportion of "through" traffic with respect to total traffic using each of the two intersections was fairly high. In the case of the Cedar Bluff intersection 38 percent of the northbound approach volume was "through" traffic, and 78 percent of the southbound approach volume was "through" traffic. These values represent the traffic pattern during the morning peak hour. In the case of the Maryland Farms intersection, the estimated "through" traffic represents about 50 percent of the intersection approach volume. Therefore, one-half of the morning trips going through the intersection was not subjected to TDM impacts, since these trips are not related to SAC business establishments.

CHAPTER V

RESULTS

TDM Strategies

The results of the analysis for the Cedar Bluff area differ substantially from those for the Maryland Farms Office Park. In the case of the Cedar Bluff SAC, it was found that even a "voluntary" TDM program would result in some improvement in the operational level of service of the study intersection. Although no change would occur in the level of service of any individual approach, the overall LOS of the intersection would improve under a "voluntary" program from the current "D" level to a "C" level. More specifically there would be a 4-second reduction of the average delay at the intersection. The "mandatory" TDM program and the "extremely successful" TDM case would both result in the intersection's level of service to improve to the "B" level. This significant gain with respect to congestion mitigation is mainly due to reductions in the northbound left-turn approach volumes. The left-turn movement has currently been the main cause of the intersection's traffic problem during the morning peak hour. Under the present conditions, the HCS software estimated an average delay of 152 seconds (level of service equal "F") for the northbound left turn lane, indicating that cycle failures have been occurring on this lane. The "mandatory" TDM program would reduce such delay to 42 seconds, while the "extremely successful" case would reduce it even more, to 14 seconds. The lack of balance among the levels of services of the different phases suggests that an optimization of the signal phasing and/or timing might be necessary. This issue will be considered in the next section.

In the case of Maryland Farms, none of the TDM programs would result in significant changes in the intersection's LOS. For both "voluntary" and "mandatory" programs, the LOS's would still remain at the "D" status, with small reductions in delay of 1.0 second and 2.9 seconds, respectively. Even an "extremely successful" TDM program would be able to reduce the intersection delay by only 3.7 seconds, keeping the operation at the current level of service "D". By analyzing each approach separately, it can be noticed that the major problem is related to the westbound approach. Since this is the only two-lane approach of the intersection, an additional lane might be helpful in enhancing the intersection's operation. This prospective improvement as well as changes in the signal timing and phasing will be taken into consideration in the analysis presented in the following section. The results presented above are summarized in

Table 8. The software printouts corresponding to the analysis of each alternative are included in Appendix II.

Traffic Engineering Strategies

In order to determine if any low cost traffic engineering strategy can reduce the traffic congestion at the study sites, an analysis of the current cycle lengths for signal-timing was performed using the computer software, Signal Operations Analysis Package (SOAP). This package is a traffic signal optimizing tool which enables the user to design the signal timing for isolated intersections through the determination of the optimum cycle length and phase pattern. In the case of this study, the lane capacity values were obtained from the HCS results for the existing conditions at each intersection. The traffic volumes used in the analysis represented the existing situation. The respective optimum cycle lengths and signal timings were determined by SOAP considering the same signal phasing as being used now. The levels of service were recalculated by HCS using the new optimum signal timings.

For both intersections the optimum cycle lengths generated by SOAP were different from the existing ones. In the case of Cedar Bluff, it was found that the optimal cycle length should be 60.0 seconds, in contrast to the present length of 100.0 seconds. With a 60.0 second cycle the intersection operation can be improved from the current LOS

Table 8 - LEVEL OF SERVICE ANALYSES

Program Status (Expectation)	Cedar Bluff			Maryland Farms		
	% Reduction in veh.trips	LOS	Delay(sec.)	% Reduction in veh.trips	LOS	Delay(sec.)
Existing Condition	-	D	25.9	-	D	32.8
Voluntary (Expected)	2.8%	C	21.7	3.7%	D	31.8
Mandatory (Very Positive)	13.6%	B	12.5	16.1%	D	29.9
Extremely Successful	25.0%	B	9.6	25.0%	D	29.1

"D" to a LOS "B". This improvement would represent a reduction of 17.8 seconds in the average delay at the intersection. Regarding Maryland Farms' intersection, a reduction in the cycle length from the present 135.0 seconds to 60.0 seconds would improve the LOS from "D" to "C", and would cut the average intersection delay by 16.0 seconds.

It should be pointed out that for this study, the intersection level of service constitutes the only measure of effectiveness of TDM programs. The fact that the intersections are not currently operating with optimum cycle lengths may conceal the real impacts of a reduction in vehicle trips due to the implementation of TDM strategies. To assess the impact of the estimated vehicle trip reductions on the intersections' LOS under the optimum cycle lengths, the approach volumes (local traffic only) were reduced by percentages corresponding to the implementation of a "mandatory" TDM program, and the new LOS's were determined using the optimum cycle lengths. For Cedar Bluff intersection, the reduction in average delay time was not significant enough to produce any further improvement in the level of service "B". For Maryland Farms intersection, a 2-second delay reduction was obtained, improving the intersection LOS from "C" to "B".

These findings suggest that, for the two study cases, improvements in the operation of traffic controls would be, per se, more effective in reducing congestion than TDM actions at the SAC's. By merely changing the cycle length at the

Maryland Farms intersection, a more significant improvement in the operational levels could be achieved than with the assumed results of a "mandatory" TDM program with 100 percent employer participation. Moreover, after adopting the optimum cycle lengths and signal timings, the impacts of TDM programs would have an even smaller effect on the reduction of the intersections' delay values.

To explore further how effective other low cost traffic engineering strategies would be in improving the intersections' operation, two other alternatives were taken into consideration: new signal phasings and additional lanes. This analysis was performed only for Maryland Farms intersection, since the major ongoing constructions at the Cedar Bluff SAC will certainly result in significant changes in the travel pattern at that site after their completion. First, an overlap phase was designed for the east-west movements. Since the westbound volumes are much higher than the eastbound volumes, an overlap-phase alternative seems to be the most appropriate to increase capacity at the westbound approach. No changes were accomplished for the north-south movements. Once again the SOAP software was employed for determining the optimum cycle length and signal timing. The proposed signal phasing and timing are displayed on Figure 10.

The HCS results indicate a level of service "B" for the new intersection configuration with a 13.3-second average overall delay. This finding attests to the potential power of

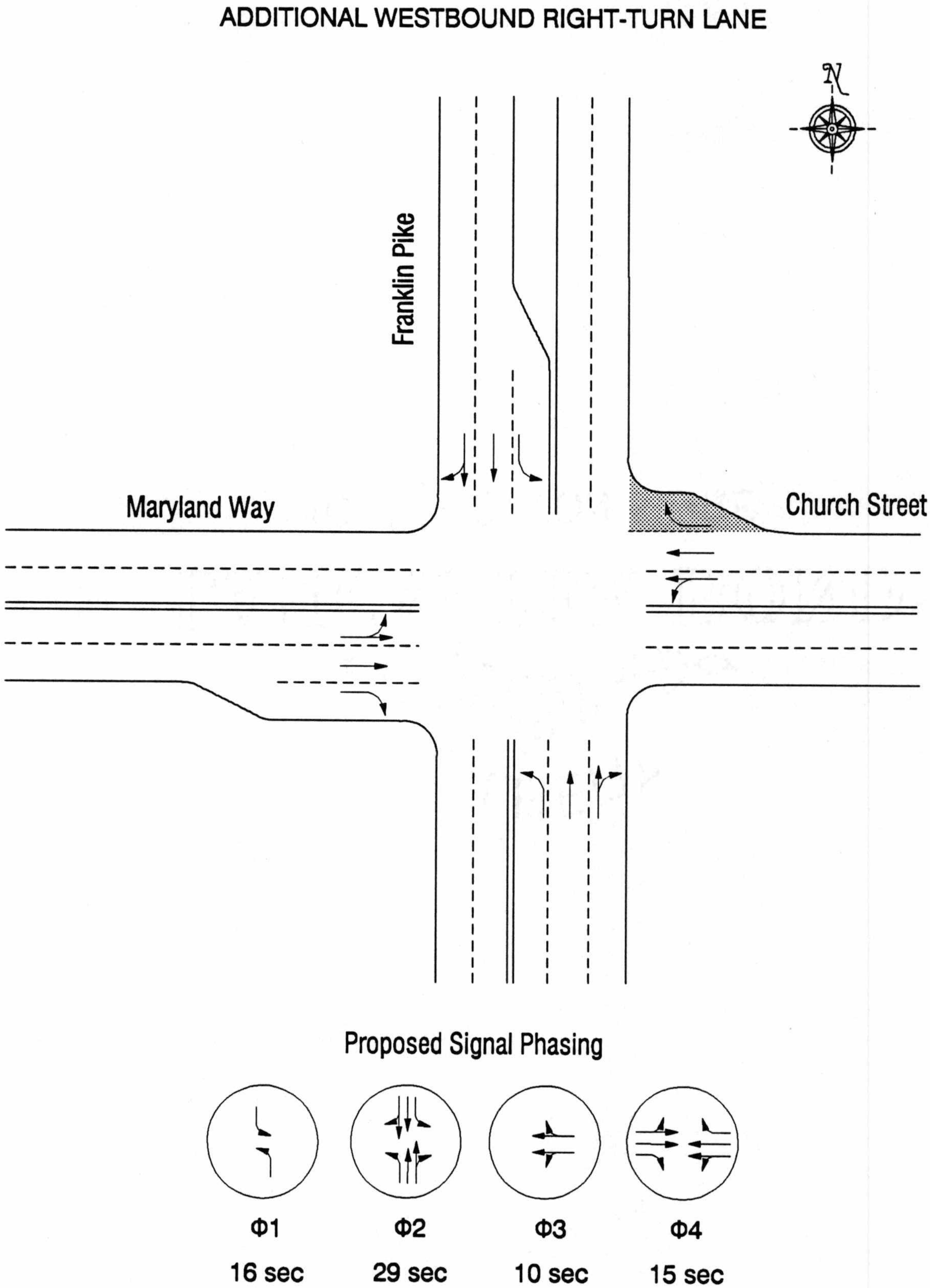

Figure 10 - PROPOSED LAYOUT AND SIGNAL PHASING FOR MARYLAND FARMS INTERSECTION

signal timing optimization for congestion mitigation. In the case of Maryland Farms intersection this strategy would reduce the intersection delay by almost 20 seconds.

The second alternative considered was the addition of one exclusive right-turn lane for the westbound approach (Figure 10). Together with the optimum signal phasing and timing, this improvement would reduce the intersection delay by 0.6 seconds, keeping its operation at a LOS equal to "B" (intersection delay equal to 12.7 seconds).

It is important to notice that, if a 16.1 percent reduction in peak hour vehicle trips ("mandatory" program) was assumed for this "optimized" intersection, the new overall average delay would be equal to 12.2 seconds, still corresponding to a LOS "B".

The results presented above are summarized in Table 9. The outputs generated by HCS for the alternatives described above are included in Appendix II.

Future Growth of Traffic

Traffic management should be a continuous process, and transportation planners must consider the future growth of traffic in developing TSM and/or TDM strategies. Planners should have a clear idea regarding how long a TDM strategy may be effective in the future. Therefore, the growth trend of traffic in the vicinity of Cedar Bluff and Maryland Farms

Table 9 - IMPACT OF TRAFFIC ENGINEERING STRATEGIES

Traffic Engineering Improvement	Cedar Bluff		Maryland Farms	
	LOS	Delay(sec.)	LOS	Delay(sec.)
Existing Condition	D	25.9	D	32.8
Optimum Cycle Length	B	8.1	C	16.8
Optimum Cycle + "Mandatory" Program	B	7.3	B	14.7
New Signal Phasing	-	-	B	13.3
New Phasing + Additional Lane	-	-	B	12.7
New Phasing + Lane + "Mandatory" Prog.	-	-	B	12.2

SAC's was analyzed with traffic volume data for the past several years.

In the case of the Cedar Bluff SAC, there was one location (Station 127) on the Cedar Bluff Road very near the SAC for which Average Daily Traffic (ADT) data were available for several years. This Station 127 is located at the north side of the intersection that was analyzed. In the case of Maryland Farms SAC, there was also one traffic count station located close to the study intersection for which historic ADT data were available. This Station 261 is located on Franklin Pike on the north side of the intersection.

The past growth of traffic at Station 127 and Station 261 was analyzed in a variety of manners. First, the traffic volumes were plotted. The graph, presented in Figure 11, shows that the growth trend during these past years can be associated to a linear pattern. A linear growth results in a fixed amount increase in traffic every year. The fixed increase can be expressed as a percentage/proportion with respect to the ADT of any reference year, and the value of this percent growth will be different depending on which reference year is chosen. Using the last year of the analysis period, which is 1990, the percent growth at Station 127 was found to be 2.3 percent, and that at station 261 was 4.7 percent.

In order to recognize the possibility of a compounding growth pattern of traffic volumes, the ADT growth rates were

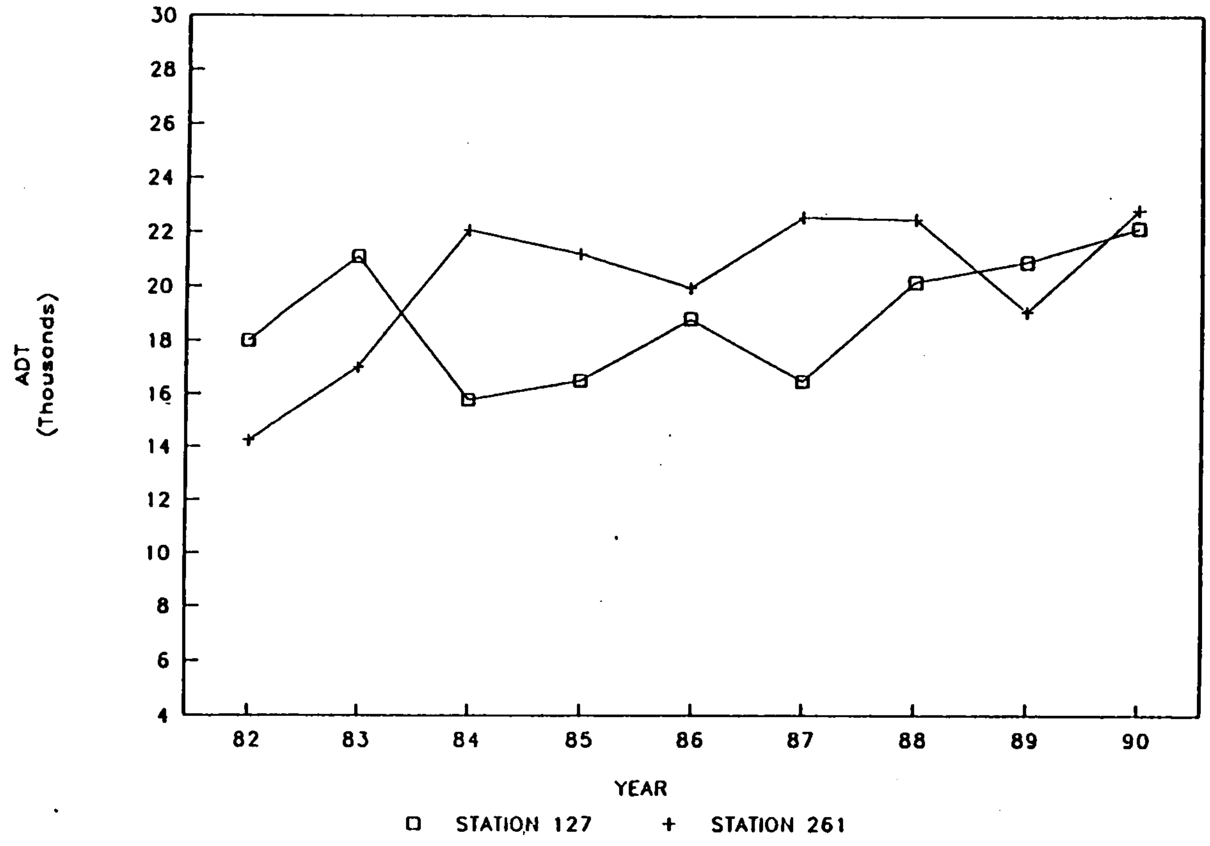

Figure 11 - ADT TREND ANALYSIS

calculated on a year by year basis, as shown in Table 10 and 11, not only for Stations 127 and 261, but also for other stations located close to the intersections. An analysis of these rates shows that for most of the count stations the rates have a decreasing trend over the analysis period. The average annual growth rate was calculated to be 3.8 percent for Station 127, and 7.1 percent for Station 261.

Another procedure was used to derive compounded growth rates (r) for the 1982/1990 period at Stations 127 and 261. The following equation was utilized:

$$ADT(1990) = ADT(1982) \times (1 + r)^{(1990 - 1982)}$$

Based on this equation, the compounded growth rates were found to be 2.6 percent per year at Station 127, and 6.1 percent per year at Station 261.

To estimate the increase in ADT at both study sites in the future years, say five and ten years from today, a linear regression model was developed for each data set. The regression model was used in lieu of the calculated compounded growth rates because these rates would lead to very high ADT values. Since, as stated before, the growth rates were found to have a decreasing trend over the analysis period, a compounded growth rate was considered to be unrealistic in these cases. The ADT values for the years 1991, 1996, and 2001

Table 10 - ADT ANALYSIS: CEDAR BLUFF AREA

YEAR	ST.127 ADT	ST.127 AGR	ST.350 ADT	ST.350 AGR	ST.253 ADT	ST.253 AGR	ST.164 ADT	ST.164 AGR	ST.128 ADT	ST.128 AGR	ST.369 ADT	ST.369 AGR
82	18000				67791		61237		16104			
83	21105	17.3	13735		55598	-18.0	54566	-10.9	15771	-2.1		
84	15780	-25.2	14337	4.4	76967	38.4	63162	15.8	19585	24.2		
85	16501	4.6	17552	22.4	62000	-19.4	55000	-12.9	19906	1.6		
86	18812	14.0	13359	-23.9	74187	19.7	68518	24.6	19600	-1.5	8695	
87	16490	-12.3	12817	-4.1	82953	11.8	81023	18.3	22569	15.1	8538	-1.8
88	20168	22.3	11301	-11.8	90851	9.5	84512	4.3	23481	4.0	9371	9.8
89	20910	3.7	10592	-6.3	89354	-1.6	89030	5.3	23029	-1.9	9000	-4.0
90	22163	6.0	10417	-1.7	91998	3.0	89132	0.1	24175	5.0	10517	16.9
	AVE =	3.778	AVE =	-2.98	AVE =	5.413	AVE =	5.566	AVE =	5.557	AVE =	5.211

Obs.: 1) AGR = ANNUAL GROWTH RATE (%);
2) ST.127 & ST.350 - Minor Arterial (Cedar Bluff Rd.);
3) ST.253 & ST.164 - Freeway (I-40);
4) ST.128 - Major Arterial (Kingston Pike);
5) ST.369 - Collector (Peters Rd.).

Table 11 - ADT ANALYSIS: MARYLAND FARMS AREA

	ST.261		ST.133		ST.212		ST.213		ST.132	
YEAR	ADT	AGR	ADT	AGR	ADT	AGR	ADT	AGR	ADT	AGR
82	14240		8400		14290		22190		12770	
83	17022	19.5	9162	9.1	16746	17.2	25278	13.9	12454	-2.5
84	22075	29.7	11154	21.7	20113	20.1	29122	15.2	14444	16.0
85	21200	-4.0	11358	1.8	20073	-0.2	29903	2.7	16489	14.2
86	19957	-5.9	11986	5.5	23511	17.1	29600	-1.0	16493	0.0
87	22567	13.1	12638	5.4	21115	-10.2	32751	10.6	22060	33.8
88	22500	-0.3	12444	-1.5	22000	4.2	32000	-2.3	20000	-9.3
89	19071	-15.2	13041	4.8	22250	1.1	32500	1.6	16449	-17.8
90	22828	19.7	11305	-13.3	24918	12.0	34054	4.8	24182	47.0
	AVE =	7.079	AVE =	4.195	AVE =	7.668	AVE =	5.685	AVE =	10.16

Obs.: 1) AGR = ANNUAL GROWTH RATE (%);
2) ST.261 & ST.133 - Major Arterial (Franklin Pike);
3) ST.212, ST.213 & ST.132 - Minor Arterial (Old Hickory Blvd.).

were calculated, based on the following equations. The results are displayed in Table 12.

a) Cedar Bluff Area - St. 127 ($R^2 = 0.237$):

ADT = 413.9*(YEAR) - 803,058.2

b) Maryland Farms Area - St. 261 ($R^2 = 0.439$):

ADT = 711.9*(YEAR) - 1,393,737.4

The estimated growth of ADT values during the next 10 years was used to assess the impacts of the reductions in vehicle trips due to TDM programs in the year 2001. The purpose was to determine if the results obtained for the present conditions would be valid in a future scenario, that is, whether the increase in traffic volumes would offset the benefits of TDM strategies with respect to the improvement of intersection LOS. For both Cedar Bluff and Maryland Farms intersections the new approach volumes corresponding to year 2001 were calculated based on the percent increases of ADT values obtained from the regression equations (Table 12). The reductions of peak hour vehicle trips corresponding to a "mandatory" TDM program were then applied to those approach volumes (local traffic only) and the future levels of service were determined.

The results indicate that, for both study sites, if no actions were taken to control traffic growth, the intersections will face serious congestion problems in the future. For some approaches the calculated V/C ratios were

Table 12 - ADT FORECASTS (LINEAR MODEL)

YEAR	Cedar Bluff (St.127)		Maryland Farms (St.261)	
	ADT (Predicted)	% Increase from 1991	ADT (Predicted)	% Increase from 1991
1991	21,017	-	23,656	-
1996	23,086	9.8%	27,216	15.0%
2001	25,156	19.7%	30,775	30.1%

over 1.2 for year 2001. Such a high value of V/C ratio is practically not feasible, what makes meaningless the determination of the intersection LOS. However, such calculated values indicate severe congestion problems. Thus according to the analysis, even a "mandatory" TDM program alone would be unable to prevent the intersections from operating at a LOS "F" in the future. The HCS printouts corresponding to these results are included in Appendix II.

It should be pointed out that based on the estimated traffic growth rates generated by the regression model, the Maryland Farms' intersection will be operating at a LOS "E" by the year 1995. A LOS "E" is considered to be an unstable situation, which is vulnerable to severe congestion. If, on the other hand, a "mandatory" TDM program be implemented at the activity center, the LOS "E" will be reached only in 1997. Although, for this case, TDM programs can not be viewed as a definitive solution for congestion problems, this finding attests to the important role of these programs in helping to manage traffic congestion.

CHAPTER VI

CONCLUSIONS

The analysis of the effectiveness of TDM programs at Cedar Bluff and Maryland Farms SAC's led to some interesting findings and suggestions. The two cases show that TDM can not be viewed as a panacea for traffic congestion problems. The results of this study reveal that the ability of TDM measures focused on the employees of a SAC to alleviate the traffic congestion problems of developing suburban activity centers may be limited. A large portion of traffic using the congested intersections near the analyzed SAC's is not related to the local development, and thus TDM measures focused solely on the SAC have little impact on this traffic. Areawide TDM measures would be necessary to affect a larger portion of traffic and to achieve significant reductions in travel. Another important aspect already emphasized in recent studies (Orski 1991) regards the fact that about three out of every four overall trips are nonwork trips. In addition, over 25 percent of work trips are, on average, made outside of peak periods. Thus, measures that target peak-period commuters will be affecting a very small share of travel. However, the role of TDM actions as a long term strategy can not be neglected. These actions can complement other strategies designed to change the way americans relate to solo driving.

One point that appears to be very important is that, if we really want to mitigate congestion by concentrating efforts on commuter trips, it would be necessary to control the trip generation process in addition to shifting some of trips to high occupancy modes or to time periods other than peak hours. Private decisions on development must be coordinated with public decisions on transportation infrastructure investment. Moreover, means of involving the private sector in the financing process should be taken into consideration.

At this point, it has to be emphasized that the characteristics of suburban activity centers vary widely in terms of their land use and travel patterns. Thus, the conclusions drawn from this study deserve special attention when different SAC's are to be considered. Singularities inherent to certain locations may considerably affect the expectations about TDM actions. For instance, the fact that all retail activities at Maryland Farms are located on the borders of the SAC, resulting in a extremely high volume of midday trips, may work against the ridesharing programs. Therefore, special care should be devoted to the analysis of all particularities involved in each location where a TDM program is being taken into consideration.

Some remarks are necessary regarding the methodology applied in this study. The approach used to assess the effectiveness of TDM actions in mitigating traffic congestion problems can be contested. The TDM model's default values for trip reductions are based on cases that are larger than the Cedar Bluff and Maryland Farms SAC's. The trip reduction estimates, therefore, are likely to be higher than what really would occur in these areas. Since the conclusions on the effectiveness of the TDM strategies are not optimistic despite the probable overestimation of trip reductions, the conclusions are valid. Another important point to be considered is that TDM actions usually take a certain period of time to start showing results. It will not be realistic to assume that the entire reduction in peak hour vehicle trips would occur at once. Therefore, the evaluation of the effectiveness of TDM programs based on current traffic volumes alone is not adequate. For a realistic assessment traffic growth should be taken into consideration.

Finally, it is important to emphasize that this study strived to evaluate the effectiveness of TDM actions only on the mitigation of traffic congestion problems. No environmental or fuel savings consequences were taken into consideration. Therefore, the results provide no reason for disregarding TDM strategies when those aspects are of considerable priority.

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APPENDICES

APPENDIX I - HCS PRINTOUTS

1985 HCM: SIGNALIZED INTERSECTIONS Page-1

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IDENTIFYING INFORMATION

NAME OF THE EAST/WEST STREET.........EXECUTIVE/WEST PARK DR.

NAME OF THE NORTH/SOUTH STREET.......CEDAR BLUFF RD.

AREA TYPE............................OTHER

NAME OF THE ANALYST..................FELIPE LOUREIRO

DATE OF THE ANALYSIS.................05/23/91

TIME PERIOD ANALYZED.................8 AM - 9 AM

OTHER INFORMATION:

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	50	310	365	0
THRU	0	0	724	854
RIGHT	131	0	423	120
RTOR	0	0	0	0

(RTOR volume must be less than or equal to RIGHT turn volumes.)

INTERSECTION GEOMETRY Page-2

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NUMBER OF LANES PER DIRECTION INCLUDING TURN BAYS:
EASTBOUND = 2   WESTBOUND = 2   NORTHBOUND = 3   SOUTHBOUND = 3

	EB		WB		NB		SB	
LANE	TYPE	WIDTH	TYPE	WIDTH	TYPE	WIDTH	TYPE	WIDTH
1	L	12.0	L	12.0	L	12.0	T	12.0
2	R	12.0	L	12.0	T	12.0	T	12.0
3		12.0		12.0	TR	12.0	R	12.0
4		12.0		12.0		12.0		12.0
5		12.0		12.0		12.0		12.0
6		12.0		12.0		12.0		12.0

L - EXCLUSIVE LEFT LANE
LT - LEFT/THROUGH LANE
LR - LEFT/RIGHT ONLY LANE
LTR - LEFT/THROUGH/RIGHT LANE
T - EXCLUSIVE THROUGH LANE
TR - THROUGH/RIGHT LANE
R - EXCLUSIVE RIGHT LANE

ADJUSTMENT FACTORS

==

	GRADE (%)	HEAVY VEH. (%)	ADJACENT PKG Y/N	(Nm)	BUSES (Nb)	PHF
EASTBOUND	0.00	2.00	N	0	0	0.90
WESTBOUND	0.00	2.00	N	0	0	0.90
NORTHBOUND	0.00	2.00	N	0	0	0.90
SOUTHBOUND	0.00	2.00	N	0	0	0.90

Nm : number of parking maneuvers/hr; Nb : number of buses stopping/hr

	CONFLICTING PEDS (peds/hour)	PEDESTRIAN BUTTON (Y/N)	(min T)	ARRIVAL TYPE
EASTBOUND	0	N	20.5	3
WESTBOUND	0	N	20.5	3
NORTHBOUND	0	N	14.5	3
SOUTHBOUND	0	N	14.5	3

min T = minimum green time for pedestrians

SIGNAL SETTINGS - OPERATIONAL ANALYSIS Page-3

ACTUATED LOST TIME/PHASE = 3.0 CYCLE LENGTH = 100.0

EAST/WEST PHASING

	PHASE-1	PHASE-2	PHASE-3	PHASE-4
EASTBOUND				
LEFT	X			
THRU				
RIGHT	X			
PEDS				
WESTBOUND				
LEFT	X			
THRU				
RIGHT				
PEDS				
NORTHBOUND RT	X			
SOUTHBOUND RT	X			
GREEN	16.0	0.0	0.0	0.0
YELLOW + ALL RED	4.0	0.0	0.0	0.0

NORTH/SOUTH PHASING

	PHASE-1	PHASE-2	PHASE-3	PHASE-4
NORTHBOUND				
LEFT	X	X		
THRU	X	X		
RIGHT	X	X		
PEDS				
SOUTHBOUND				
LEFT				
THRU	X			
RIGHT	X	X		
PEDS				
EASTBOUND RT		X		
WESTBOUND RT				
GREEN	56.0	16.0	0.0	0.0
YELLOW + ALL RED	4.0	4.0	0.0	0.0

VOLUME ADJUSTMENT WORKSHEET Page-4

	MVT. VOL.	PHF	ADJ. VOL.	LANE GRP.	LANE GRP. VOL.	NO. LN	LANE UTIL. FACT.	GROWTH FACT.	ADJ. GRP. VOL.	PROP LT	PROP RT
EB											
LT	50	0.90	56	L	56	1	1.000	1.000	56	1.00	0.00
TH	0	0.90	0								
RT	131	0.90	146	R	146	1	1.000	1.000	146	0.00	1.00
WB											
LT	310	0.90	344	L	344	2	1.050	1.000	362	1.00	0.00
TH	0	0.90	0								
RT	0	0.90	0								
NB											
LT	365	0.90	406	L	406	1	1.000	1.000	406	1.00	0.00
TH	724	0.90	804	TR	1274	2	1.050	1.000	1338	0.00	0.37
RT	423	0.90	470								
SB											
LT	0	0.90	0								
TH	854	0.90	949	T	949	2	1.050	1.000	996	0.00	0.00
RT	120	0.90	133	R	133	1	1.000	1.000	133	0.00	1.00

* Denotes a Defacto Left Turn Lane Group

SATURATION FLOW ADJUSTMENT WORKSHEET Page-5

	IDEAL SAT. FLOW	NO. LNS	f W	f HV	f G	f P	f BB	f A	f RT	f LT	ADJ. SAT. FLOW
EB											
L	1800	1	1.000	0.990	1.000	1.000	1.000	1.000	1.000	0.950	1693
R	1800	1	1.000	0.990	1.000	1.000	1.000	1.000	0.850	1.000	1515
WB											
L	1800	2	1.000	0.990	1.000	1.000	1.000	1.000	1.000	0.920	3279
NB											
L	1800	1	1.000	0.990	1.000	1.000	1.000	1.000	1.000	0.950	1693
TR	1800	2	1.000	0.990	1.000	1.000	1.000	1.000	0.945	1.000	3367
SB											
T	1800	2	1.000	0.990	1.000	1.000	1.000	1.000	1.000	1.000	3564
R	1800	1	1.000	0.990	1.000	1.000	1.000	1.000	0.850	1.000	1515

CAPACITY ANALYSIS WORKSHEET Page-6

	ADJ. FLOW RATE (v)	ADJ. SAT. FLOW RATE (s)	FLOW RATIO (v/s)	GREEN RATIO (g/C)	LANE GROUP CAPACITY (c)	v/c RATIO
EB						
L	56	1693	0.033	0.170	288	0.193
R	146	1515	0.096	0.340	515	0.283
WB						
L	362	3279	0.110	0.170	557	0.649 *
NB						
Lperm.	0					
Lprot.	406	1693	0.240	0.200	339	1.198 *
TR	1338	3367	0.397	0.770	2592	0.516
SB						
T	996	3564	0.280	0.570	2031	0.490 *
R	133	1515	0.088	0.940	1424	0.094

Cycle Length, C = 100.0 sec. Sum (v/s) critical = 0.629
Lost Time Per Cycle, L = 6.0 sec. X critical = 0.670

LEVEL-OF-SERVICE WORKSHEET Page-7

	v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB											
L	0.193	0.170	100.0	27.1	288	0.0	1.00	27.1	D	18.8	C
R	0.283	0.340	100.0	18.3	515	0.1	0.85	15.6	C		
WB											
L	0.649	0.170	100.0	29.4	557	1.9	1.00	31.3	D	31.3	D
NB											
L	1.198	0.770	100.0	25.9	339	125.9	1.00	151.8	F	37.6	D
TR	0.516	0.770	100.0	3.3	2592	0.2	0.85	3.0	A		
SB											
T	0.490	0.570	100.0	9.8	2031	0.2	0.85	8.4	B	7.4	B
R	0.094	0.940	100.0	0.2	1424	0.0	0.85	0.1	A		

Intersection Delay = 25.9 (sec/veh) Intersection LOS = D

1985 HCM: SIGNALIZED INTERSECTIONS Page-1
****

IDENTIFYING INFORMATION
::

NAME OF THE EAST/WEST STREET.........MARYLAND WAY / CHURCH STREET

NAME OF THE NORTH/SOUTH STREET.......FRANKLIN PIKE

AREA TYPE............................OTHER

NAME OF THE ANALYST..................FELIPE LOUREIRO

DATE OF THE ANALYSIS.................05/29/91

TIME PERIOD ANALYZED.................7:30 AM - 8:30 AM

OTHER INFORMATION:
BRENTWOOD SAC

TRAFFIC VOLUMES
::

	EB	WB	NB	SB
LEFT	69	96	334	233
THRU	89	442	768	644
RIGHT	132	144	62	97
RTOR	99	36	0	0

(RTOR volume must be less than or equal to RIGHT turn volumes.)

INTERSECTION GEOMETRY

NUMBER OF LANES PER DIRECTION INCLUDING TURN BAYS:
EASTBOUND = 3 WESTBOUND = 2 NORTHBOUND = 3 SOUTHBOUND = 3

	EB		WB		NB		SB	
LANE	TYPE	WIDTH	TYPE	WIDTH	TYPE	WIDTH	TYPE	WIDTH
1	LT	12.0	LT	12.0	L	12.0	L	12.0
2	T	12.0	TR	12.0	T	12.0	T	12.0
3	R	12.0		12.0	TR	12.0	TR	12.0
4		12.0		12.0		12.0		12.0
5		12.0		12.0		12.0		12.0
6		12.0		12.0		12.0		12.0

L - EXCLUSIVE LEFT LANE
LT - LEFT/THROUGH LANE
LR - LEFT/RIGHT ONLY LANE
LTR - LEFT/THROUGH/RIGHT LANE
T - EXCLUSIVE THROUGH LANE
TR - THROUGH/RIGHT LANE
R - EXCLUSIVE RIGHT LANE

ADJUSTMENT FACTORS

	GRADE (%)	HEAVY VEH. (%)	ADJACENT PKG Y/N	(Nm)	BUSES (Nb)	PHF
EASTBOUND	0.00	2.00	N	0	0	0.90
WESTBOUND	0.00	2.00	N	0	0	0.90
NORTHBOUND	0.00	2.00	N	0	0	0.90
SOUTHBOUND	0.00	2.00	N	0	0	0.90

Nm : number of parking maneuvers/hr; Nb : number of buses stopping/hr

	CONFLICTING PEDS (peds/hour)	PEDESTRIAN BUTTON (Y/N)	(min T)	ARRIVAL TYPE
EASTBOUND	0	N	20.5	3
WESTBOUND	0	N	20.5	3
NORTHBOUND	0	N	17.5	3
SOUTHBOUND	0	N	17.5	3

min T : minimum green time for pedestrians

ACTUATED LOST TIME/PHASE = 3.0 CYCLE LENGTH = 135.0

EAST/WEST PHASING

	PHASE-1	PHASE-2	PHASE-3	PHASE-4
EASTBOUND				
LEFT	X			
THRU	X			
RIGHT	X			
PEDS				
WESTBOUND				
LEFT		X		
THRU		X		
RIGHT		X		
PEDS				
NORTHBOUND RT				
SOUTHBOUND RT				
GREEN	26.0	31.0	0.0	0.0
YELLOW + ALL RED	4.0	4.0	0.0	0.0

NORTH/SOUTH PHASING

	PHASE-1	PHASE-2	PHASE-3	PHASE-4
NORTHBOUND				
LEFT	X	X		
THRU		X		
RIGHT		X		
PEDS				
SOUTHBOUND				
LEFT	X	X		
THRU		X		
RIGHT		X		
PEDS				
EASTBOUND RT				
WESTBOUND RT				
GREEN	21.0	41.0	0.0	0.0
YELLOW + ALL RED	4.0	4.0	0.0	0.0

VOLUME ADJUSTMENT WORKSHEET Page-4

	MVT. VOL.	PHF	ADJ. VOL.	LANE GRP.	LANE GRP. VOL.	NO. LN	LANE UTIL. FACT.	GROWTH FACT.	ADJ. GRP. VOL.	PROP LT	PROP RT
EB											
LT	69	0.90	77	*L	77	1	1.000	1.000	77	1.00	0.00
TH	89	0.90	99	T	99	1	1.000	1.000	99	0.00	0.00
RT	132	0.90	37	R	37	1	1.000	1.000	37	0.00	1.00
WB											
LT	96	0.90	107								
TH	442	0.90	491	LTR	718	2	1.050	1.000	754	0.15	0.17
RT	144	0.90	120								
NB											
LT	334	0.90	371	L	371	1	1.000	1.000	371	1.00	0.00
TH	768	0.90	853	TR	922	2	1.050	1.000	968	0.00	0.07
RT	62	0.90	69								
SB											
LT	233	0.90	259	L	259	1	1.000	1.000	259	1.00	0.00
TH	644	0.90	716	TR	823	2	1.050	1.000	865	0.00	0.13
RT	97	0.90	108								

* Denotes a Defacto Left Turn Lane Group

SATURATION FLOW ADJUSTMENT WORKSHEET Page-5

	IDEAL SAT. FLOW	NO. LNS	f W	f HV	f G	f p	f BB	f A	f RT	f LT	ADJ. SAT. FLOW
EB											
L	1800	1	1.000	0.990	1.000	1.000	1.000	1.000	1.000	0.950	1693
T	1800	1	1.000	0.990	1.000	1.000	1.000	1.000	1.000	1.000	1782
R	1800	1	1.000	0.990	1.000	1.000	1.000	1.000	0.850	1.000	1515
WB											
LTR	1800	2	1.000	0.990	1.000	1.000	1.000	1.000	0.975	0.993	3449
NB											
L	1800	1	1.000	0.990	1.000	1.000	1.000	1.000	1.000	0.950	1693
TR	1800	2	1.000	0.990	1.000	1.000	1.000	1.000	0.989	1.000	3524
SB											
L	1800	1	1.000	0.990	1.000	1.000	1.000	1.000	1.000	0.950	1693
TR	1800	2	1.000	0.990	1.000	1.000	1.000	1.000	0.980	1.000	3494

CAPACITY ANALYSIS WORKSHEET Page-6

===

	ADJ. FLOW RATE (v)	ADJ. SAT. FLOW RATE (s)	FLOW RATIO (v/s)	GREEN RATIO (g/C)	LANE GROUP CAPACITY (c)	v/c RATIO
EB						
L	77	1693	0.045	0.200	339	0.226
T	99	1782	0.055	0.200	356	0.277 *
R	37	1515	0.024	0.200	303	0.121
WB						
LTR	754	3449	0.219	0.237	818	0.922 *
NB						
Lperm.	135					
Lprot.	236	1693	0.139	0.185	314	0.753 *
TR	968	3524	0.275	0.311	1096	0.883 *
SB						
Lperm.	83					
Lprot.	176	1693	0.104	0.185	314	0.560
TR	865	3494	0.247	0.311	1087	0.795

Cycle Length, C = 135.0 sec. Sum (v/s) critical = 0.688
Lost Time Per Cycle, L = 9.0 sec. X critical = 0.737

LEVEL-OF-SERVICE WORKSHEET Page-7

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	v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB											
L	0.226	0.200	135.0	34.4	339	0.1	1.00	34.5	D	31.2	D
T	0.277	0.200	135.0	34.8	356	0.1	0.85	29.6	D		
R	0.121	0.200	135.0	33.6	303	0.0	0.85	28.6	D		
WB											
LTR	0.922	0.237	135.0	38.2	818	11.4	0.85	42.1	E	42.1	E
NB											
L	0.753	0.496	135.0	20.8	314	6.7	1.00	27.5	D	32.1	D
TR	0.883	0.311	135.0	33.6	1096	6.2	0.85	33.8	D		
SB											
L	0.560	0.496	135.0	18.0	314	1.7	1.00	19.7	C	27.6	D
TR	0.795	0.311	135.0	32.3	1087	2.9	0.85	30.0	D		

Intersection Delay = 32.8 (sec/veh) Intersection LOS = D

APPENDIX II - LOS WORKSHEETS

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	49	310	352	0
THRU	0	0	722	852
RIGHT	127	0	411	117

<RET> RETAINS VALUE; <ESC> TO EXIT

Cedar Bluff: "Voluntary" Program

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.189	0.170	100.0	27.0	288	0.0	1.00	27.1	D	18.8	C
	R	0.274	0.340	100.0	18.3	515	0.1	0.85	15.6	C		
WB	L	0.649	0.170	100.0	29.4	557	1.9	1.00	31.3	D	31.3	D
NB	L	1.155	0.770	100.0	18.2	339	100.6	1.00	118.7	F	29.4	D
	TR	0.509	0.770	100.0	3.3	2595	0.1	0.85	2.9	A		
SB												
	T	0.489	0.570	100.0	9.7	2031	0.2	0.85	8.4	B	7.5	B
	R	0.091	0.940	100.0	0.1	1424	0.0	0.85	0.1	A		

Intersection Delay = 21.71 sec./veh.　　　Intersection LOS = C

HIT <RETURN> TO CONTINUE

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	43	310	300	0
THRU	0	0	714	842
RIGHT	113	0	365	104

<RET> RETAINS VALUE; <ESC> TO EXIT

Cedar Bluff: "Mandatory" Program

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.166	0.170	100.0	26.9	288	0.0	1.00	27.0	D	18.6	C
	R	0.244	0.340	100.0	18.0	515	0.1	0.85	15.4	C		
WB	L	0.649	0.170	100.0	29.4	557	1.9	1.00	31.3	D	31.3	D
NB	L	0.985	0.770	100.0	8.3	339	33.7	1.00	42.0	E	11.0	B
	TR	0.483	0.770	100.0	3.2	2605	0.1	0.85	2.8	A		
SB												
	T	0.484	0.570	100.0	9.7	2031	0.1	0.85	8.4	B	7.5	B
	R	0.081	0.940	100.0	0.1	1424	0.0	0.85	0.1	A		

Intersection Delay = 12.50 sec./veh. Intersection LOS = B

HIT <RETURN> TO CONTINUE

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	38	310	245	0
THRU	0	0	706	833
RIGHT	98	0	317	90

<RET> RETAINS VALUE; <ESC> TO EXIT

Cedar Bluff: "Extremely Successful" Program

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.147	0.170	100.0	26.8	288	0.0	1.00	26.9	D	18.5	C
	R	0.211	0.340	100.0	17.8	515	0.0	0.85	15.2	C		
WB	L	0.649	0.170	100.0	29.4	557	1.9	1.00	31.3	D	31.3	D
NB	L	0.804	0.770	100.0	5.3	339	9.0	1.00	14.3	B	4.9	A
	TR	0.456	0.770	100.0	3.1	2617	0.1	0.85	2.7	A		
SB												
	T	0.478	0.570	100.0	9.7	2031	0.1	0.85	8.3	B	7.6	B
	R	0.070	0.940	100.0	0.1	1424	0.0	0.85	0.1	A		

Intersection Delay = 9.62 sec./veh. Intersection LOS = B

HIT <RETURN> TO CONTINUE

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	50	310	365	0
THRU	0	0	724	854
RIGHT	131	0	423	120

<RET> RETAINS VALUE; <ESC> TO EXIT

Cedar Bluff: Optimal Clycle Length

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.164	0.200	60.0	15.1	339	0.0	1.00	15.1	C	9.2	B
	R	0.222	0.433	60.0	8.1	656	0.0	0.85	6.9	B		
WB	L	0.552	0.200	60.0	16.4	656	0.8	1.00	17.2	C	17.2	C
NB	L	0.846	0.700	60.0	5.0	480	9.1	1.00	14.1	B	5.7	B
	TR	0.568	0.700	60.0	3.4	2357	0.2	0.85	3.1	A		
SB												
	T	0.671	0.417	60.0	10.8	1485	0.8	0.85	9.9	B	8.7	B
	R	0.098	0.900	60.0	0.3	1363	0.0	0.85	0.2	A		

Intersection Delay = 8.09 sec./veh. Intersection LOS = B

HIT <RETURN> TO CONTINUE

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	43	310	300	0
THRU	0	0	714	842
RIGHT	113	0	365	104

<RET> RETAINS VALUE; <ESC> TO EXIT

Cedar Bluff: Optimal Clycle Length + "Mandatory" Program

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.141	0.200	60.0	15.0	339	0.0	1.00	15.0	C	9.1	B
	R	0.191	0.433	60.0	8.0	656	0.0	0.85	6.8	B		
WB	L	0.552	0.200	60.0	16.4	656	0.8	1.00	17.2	C	17.2	C
NB	L	0.695	0.700	60.0	4.0	480	3.0	1.00	7.0	B	3.8	A
	TR	0.532	0.700	60.0	3.3	2368	0.2	0.85	2.9	A		
SB												
	T	0.662	0.417	60.0	10.7	1485	0.8	0.85	9.8	B	8.8	B
	R	0.085	0.900	60.0	0.2	1363	0.0	0.85	0.2	A		

Intersection Delay = 7.27 sec./veh. Intersection LOS = B

HIT <RETURN> TO CONTINUE

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	60	371	462	0
THRU	0	0	867	1023
RIGHT	157	0	507	144

<RET> RETAINS VALUE; <ESC> TO EXIT

Cedar Bluff: Operation in Year 2001

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.232	0.170	100.0	27.3	288	0.1	1.00	27.3	D	19.2	C
	R	0.339	0.340	100.0	18.7	515	0.2	0.85	16.0	C		
WB	L	0.777	0.170	100.0	30.2	557	4.7	1.00	34.9	D	34.9	D
NB	L	1.516	0.770	100.0	*	339	*	1.00	*	*	*	*
	TR	0.618	0.770	100.0	3.8	2592	0.3	0.85	3.5	A		
SB												
	T	0.588	0.570	100.0	10.6	2031	0.3	0.85	9.3	B	8.2	B
	R	0.112	0.940	100.0	0.2	1424	0.0	0.85	0.1	A		

Intersection Delay : * sec./veh. Intersection LOS : *

* Delay and LOS not meaningful when v/c is greater than 1.2

HIT <RETURN> TO CONTINUE

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	52	371	386	0
THRU	0	0	856	1009
RIGHT	136	0	440	125

<RET> RETAINS VALUE; <ESC> TO EXIT

Cedar Bluff: Year 2001 + "Mandatory" Program

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.201	0.170	100.0	27.1	288	0.0	1.00	27.2	D	18.9	C
	R	0.293	0.340	100.0	18.4	515	0.1	0.85	15.7	C		
WB	L	0.777	0.170	100.0	30.2	557	4.7	1.00	34.9	D	34.9	D
NB	L	1.267	0.770	100.0	*	339	*	1.00	*	*	*	*
	TR	0.581	0.770	100.0	3.6	2605	0.2	0.85	3.3	A		
SB												
	T	0.579	0.570	100.0	10.5	2031	0.3	0.85	9.2	B	8.2	B
	R	0.098	0.940	100.0	0.2	1424	0.0	0.85	0.1	A		

Intersection Delay = * sec./veh. Intersection LOS = *

* Delay and LOS not meaningful when v/c is greater than 1.2

HIT <RETURN> TO CONTINUE

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	69	93	322	233
THRU	81	426	768	625
RIGHT	128	144	62	93

<RET> RETAINS VALUE; <ESC> TO EXIT

Maryland Farms: "Voluntary" Program

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.226	0.200	135.0	34.4	339	0.1	1.00	34.5	D	31.2	D
	T	0.253	0.200	135.0	34.6	356	0.1	0.85	29.5	D		
	R	0.116	0.200	135.0	33.6	303	0.0	0.85	28.6	D		
WB												
	LTR	0.895	0.237	135.0	37.9	817	8.9	0.85	39.8	D	39.8	D
NB	L	0.714	0.496	135.0	20.2	314	5.1	1.00	25.3	D	31.5	D
	TR	0.883	0.311	135.0	33.6	1096	6.2	0.85	33.8	D		
SB	L	0.560	0.496	135.0	18.0	314	1.7	1.00	19.7	C	27.0	D
	TR	0.770	0.311	135.0	32.0	1087	2.4	0.85	29.3	D		

Intersection Delay = 31.83 sec./veh.   Intersection LOS = D

HIT <RETURN> TO CONTINUE

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	69	84	280	233
THRU	81	371	768	561
RIGHT	115	144	62	81

<RET> RETAINS VALUE; <ESC> TO EXIT

Maryland Farms: "Mandatory" Program

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.226	0.200	135.0	34.4	339	0.1	1.00	34.5	D	31.2	D
	T	0.253	0.200	135.0	34.6	356	0.1	0.85	29.5	D		
	R	0.105	0.200	135.0	33.5	303	0.0	0.85	28.5	D		
WB												
	LTR	0.807	0.237	135.0	36.9	814	4.2	0.85	35.0	D	35.0	D
NB	L	0.590	0.496	135.0	18.4	314	2.1	1.00	20.5	C	30.6	D
	TR	0.883	0.311	135.0	33.6	1096	6.2	0.85	33.8	D		
SB	L	0.560	0.496	135.0	18.0	314	1.7	1.00	19.7	C	25.5	D
	TR	0.689	0.311	135.0	31.0	1088	1.3	0.85	27.4	D		

Intersection Delay = 29.90 sec./veh. Intersection LOS = D

HIT <RETURN> TO CONTINUE

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	69	72	251	233
THRU	81	332	768	515
RIGHT	106	144	62	73

<RET> RETAINS VALUE; <ESC> TO EXIT

Maryland Farms: "Extremely Successful" Program

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.226	0.200	135.0	34.4	339	0.1	1.00	34.5	D	31.3	D
	T	0.253	0.200	135.0	34.6	356	0.1	0.85	29.5	D		
	R	0.095	0.200	135.0	33.5	303	0.0	0.85	28.5	D		
WB												
	LTR	0.735	0.237	135.0	36.2	812	2.4	0.85	32.8	D	32.8	D
NB	L	0.511	0.496	135.0	17.4	314	1.2	1.00	18.6	C	30.4	D
	TR	0.883	0.311	135.0	33.6	1096	6.2	0.85	33.8	D		
SB	L	0.560	0.496	135.0	18.0	314	1.7	1.00	19.7	C	24.6	C
	TR	0.630	0.311	135.0	30.3	1088	0.8	0.85	26.5	D		

Intersection Delay = 29.12 sec./veh. Intersection LOS = D

HIT <RETURN> TO CONTINUE

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	69	96	334	233
THRU	81	442	768	644
RIGHT	132	144	62	97

<RET> RETAINS VALUE; <ESC> TO EXIT

Maryland Farms: Optimal Cycle Length

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.388	0.117	60.0	18.6	198	0.7	1.00	19.3	C	17.5	C
	T	0.433	0.117	60.0	18.7	208	0.9	0.85	16.7	C		
	R	0.207	0.117	60.0	18.2	177	0.1	0.85	15.6	C		
WB												
	LTR	0.874	0.250	60.0	16.4	862	7.0	0.85	19.9	C	19.9	C
NB	L	0.798	0.483	60.0	9.9	282	10.1	1.00	20.0	C	17.8	C
	TR	0.868	0.317	60.0	14.7	1116	5.3	0.85	17.0	C		
SB	L	0.597	0.483	60.0	8.6	282	2.5	1.00	11.0	B	13.5	B
	TR	0.781	0.317	60.0	14.1	1106	2.6	0.85	14.2	B		

Intersection Delay = 16.84 sec./veh. Intersection LOS = C

HIT <RETURN> TO CONTINUE

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	69	84	280	233
THRU	81	371	768	561
RIGHT	115	144	62	81

<RET> RETAINS VALUE; <ESC> TO EXIT

Maryland Farms: Optimal Cycle Length + "Mandatory" Program

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.388	0.117	60.0	18.6	198	0.7	1.00	19.3	C	17.5	C
	T	0.433	0.117	60.0	18.7	208	0.9	0.85	16.7	C		
	R	0.180	0.117	60.0	18.2	177	0.1	0.85	15.5	C		
WB												
	LTR	0.765	0.250	60.0	15.9	859	2.9	0.85	15.9	C	15.9	C
NB	L	0.623	0.483	60.0	8.7	282	3.0	1.00	11.7	B	15.7	C
	TR	0.868	0.317	60.0	14.7	1116	5.3	0.85	17.0	C		
SB	L	0.597	0.483	60.0	8.6	282	2.5	1.00	11.0	B	12.1	B
	TR	0.676	0.317	60.0	13.5	1107	1.2	0.85	12.5	B		

Intersection Delay = 14.72 sec./veh.   Intersection LOS = B

HIT <RETURN> TO CONTINUE

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	90	125	435	303
THRU	105	575	999	838
RIGHT	172	187	81	126

<RET> RETAINS VALUE; <ESC> TO EXIT

Maryland Farms: Operation in Year 2001

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.295	0.200	135.0	34.9	339	0.1	1.00	35.0	D	31.7	D
	T	0.327	0.200	135.0	35.1	356	0.2	0.85	30.0	D		
	R	0.159	0.200	135.0	33.9	303	0.0	0.85	28.8	D		
WB												
	LTR	1.199	0.237	135.0	41.7	818	111.9	0.85	130.6	F	130.6	F
NB	L	1.162	0.496	135.0	30.8	314	106.4	1.00	137.1	F	110.0	F
	TR	1.149	0.311	135.0	37.9	1096	79.3	0.85	99.6	F		
SB	L	0.896	0.496	135.0	23.4	314	18.6	1.00	42.0	E	52.9	E
	TR	1.035	0.311	135.0	35.9	1087	30.1	0.85	56.1	E		

Intersection Delay = 91.12 sec./veh. Intersection LOS = F

HIT <RETURN> TO CONTINUE

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	90	109	365	303
THRU	105	482	999	730
RIGHT	150	187	81	106

<RET> RETAINS VALUE; <ESC> TO EXIT

Maryland Farms: Year 2001 + "Mandatory" Program

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.295	0.200	135.0	34.9	339	0.1	1.00	35.0	D	31.8	D
	T	0.327	0.200	135.0	35.1	356	0.2	0.85	30.0	D		
	R	0.134	0.200	135.0	33.7	303	0.0	0.85	28.7	D		
WB												
	LTR	1.047	0.237	135.0	39.7	814	37.7	0.85	65.8	F	65.8	F
NB	L	0.882	0.496	135.0	23.1	314	16.7	1.00	39.9	D	85.1	F
	TR	1.149	0.311	135.0	37.9	1096	79.3	0.85	99.6	F		
SB	L	0.896	0.496	135.0	23.4	314	18.6	1.00	42.0	E	36.6	D
	TR	0.897	0.311	135.0	33.8	1088	7.1	0.85	34.7	D		

Intersection Delay = 62.14 sec./veh. Intersection LOS = F

HIT <RETURN> TO CONTINUE

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	69	96	334	233
THRU	81	442	768	644
RIGHT	132	144	62	97

<RET> RETAINS VALUE; <ESC> TO EXIT

Maryland Farms: New Signal Phasing

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.753	0.171	70.0	21.0	102	17.3	1.00	38.3	D	23.5	C
	T	0.295	0.171	70.0	19.2	305	0.2	0.85	16.5	C		
	R	0.068	0.357	70.0	11.3	541	0.0	0.85	9.6	B		
WB												
	LTR	0.718	0.314	70.0	16.2	1050	1.7	0.85	15.2	C	15.2	C
NB	L	0.617	0.600	70.0	6.8	387	2.1	1.00	8.9	B	12.3	B
	TR	0.740	0.371	70.0	14.5	1309	1.6	0.85	13.7	B		
SB	L	0.459	0.600	70.0	5.9	387	0.6	1.00	6.5	B	11.2	B
	TR	0.666	0.371	70.0	14.0	1298	0.9	0.85	12.7	B		

Intersection Delay = 13.26 sec./veh. Intersection LOS = B

HIT <RETURN> TO CONTINUE

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	69	96	334	233
THRU	81	442	768	644
RIGHT	132	144	62	97

<RET> RETAINS VALUE; <ESC> TO EXIT

Maryland Farms: New Phasing + Additional Lane

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.753	0.171	70.0	21.0	102	17.3	1.00	38.3	D	23.5	C
	T	0.295	0.171	70.0	19.2	305	0.2	0.85	16.5	C		
	R	0.068	0.357	70.0	11.3	541	0.0	0.85	9.6	B		
WB												
	LT	0.587	0.314	70.0	15.3	1069	0.6	0.85	13.6	B	12.4	B
	R	0.158	0.500	70.0	7.2	757	0.0	0.85	6.1	B		
NB	L	0.617	0.600	70.0	6.8	387	2.1	1.00	8.9	B	12.3	B
	TR	0.740	0.371	70.0	14.5	1309	1.6	0.85	13.7	B		
SB	L	0.459	0.600	70.0	5.9	387	0.6	1.00	6.5	B	11.2	B
	TR	0.666	0.371	70.0	14.0	1298	0.9	0.85	12.7	B		

Intersection Delay = 12.65 sec./veh. Intersection LOS = B

HIT <RETURN> TO CONTINUE

TRAFFIC VOLUMES

	EB	WB	NB	SB
LEFT	69	84	280	233
THRU	81	371	768	561
RIGHT	115	144	62	81

<RET> RETAINS VALUE; <ESC> TO EXIT

Maryland Farms: New Phasing + Lane + "Mandatory" Program

LEVEL-OF-SERVICE WORKSHEET

		v/c RATIO	g/C RATIO	CYCLE LEN.	DELAY d 1	LANE GROUP CAP.	DELAY d 2	PROG. FACT.	LANE GRP. DELAY	LANE GRP. LOS	DELAY BY APP.	LOS BY APP.
EB	L	0.753	0.171	70.0	21.0	102	17.3	1.00	38.3	D	23.8	C
	T	0.295	0.171	70.0	19.2	305	0.2	0.85	16.5	C		
	R	0.059	0.357	70.0	11.2	541	0.0	0.85	9.5	B		
WB												
	LT	0.497	0.314	70.0	14.8	1067	0.3	0.85	12.9	B	11.6	B
	R	0.158	0.500	70.0	7.2	757	0.0	0.85	6.1	B		
NB	L	0.485	0.600	70.0	6.0	387	0.8	1.00	6.8	B	12.0	B
	TR	0.740	0.371	70.0	14.5	1309	1.6	0.85	13.7	B		
SB	L	0.459	0.600	70.0	5.9	387	0.6	1.00	6.5	B	10.4	B
	TR	0.577	0.371	70.0	13.4	1299	0.5	0.85	11.8	B		

Intersection Delay = 12.16 sec./veh.   Intersection LOS = B

HIT <RETURN> TO CONTINUE

VITA

Carlos Felipe G. Loureiro was born in Fortaleza, Brazil on March 28, 1968. He attended elementary and high schools in its own hometown and graduated from high school in December, 1984. The following March he entered The Federal University of Ceara, Brazil, and in February, 1990 received the degree of Bachelor of Science in Civil Engineering. In August, 1990 he entered the University of Tennessee, Knoxville and in December, 1991 received a Master of Science degree in Civil Engineering with concentration in Transportation Engineering.

He is presently working on his Doctor of Philosophy degree at the University of Tennessee, Knoxville.