Technical Memorandum

Traffic Forecast Special Report

Manual Gravity Diversion Methodology

Prepared for:

Kentucky Transportation Cabinet

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EXECUTIVE SUMMARY

It is difficult to accurately predict the traffic volume that will use a new facility without the assistance of a travel demand model to demonstrate area travel patterns and anticipate traffic diversion to the new facility. However, many projects involving new roads occur in relatively rural areas where no travel demand model exists or the model is outdated or irrelevant. For this reason, Jordan, Jones and Goulding, Inc. (JJG) worked together with the Kentucky Transportation Cabinet (KYTC) to develop a standardized procedure for applying manual gravity diversion curves to more accurately forecast the future traffic volume on a new facility. The procedure is built around methodologies contained in NCHRP Report 387[1] and methodologies published by the California Department of Transportation. This report documents this procedure and outlines it use and limitations.

I. INTRODUCTION

Manual gravity diversion is a useful tool in generating traffic forecasts for a new facility when no travel demand model for the study area exists or the travel demand model is outdated or irrelevant. A manual gravity diversion is named for its parts. It is manual in that the diverted volumes are estimated using calculations simple enough to be performed by hand (but often simplified using a spreadsheet). It is a gravity diversion in that trips are diverted to the new route based on its attractiveness, expressed as a distance and travel time advantage over the existing route.

There are several data inputs required to perform a manual gravity diversion for a new facility. Default values are available for most inputs, but it is also noted that more generalized data inputs generate much less reliable traffic forecasts. The required input data are listed below:

- Traffic control data (posted speed, signal information, segment lengths, etc.)
- Physical characteristics (number of lanes, lane widths, turn bays, directional factors, etc.)
- Traffic characteristics (growth rate, K factor, peak hour factor, truck percentage, etc.)
- Base year no build ADT traffic volumes
- Future year no build ADT traffic volumes
- ADT turning movements at major intersections

There are five steps involved in performing a manual gravity diversion for a new facility. These steps form the body of this document. Section II presents the procedures used to estimate free-flow speed. Section III outlines the procedures used to calculate roadway capacity. Section IV reviews some of the concepts involved in generating the no build traffic forecasts, but is not to be considered an all-inclusive approach. Section V demonstrates the application of the BPR curve with some recent modifications to estimate congested travel speed. Section VI outlines the use of the California DOT diversion curves to determine the traffic volume diverted to the new facility. Section VII concludes the report and highlights some potential limitations to the procedure.

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[1] "*Planning Techniques to Estimate Speed and Service Volumes for Planning Applications,*" NCHRP Report 387, National Cooperative Highway Research Program, Richard Dowling, et al. Transportation Research Board, Washington, D.C., 1997, pp. 79-84.

II. FREE-FLOW SPEED

Free-flow speed can be determined in two ways. It is preferred to measure free-flow speed in the field under light traffic conditions. However, when this is not possible the free-flow speed can be estimated using one of the following equations.

Facilities without Signals

Facilities without signals are divided into two categories by posted speed limit as follows:

Speed Limit > 50 mph: S_f (mph) = $0.88 * S_p + 14$

Speed Limit < 50 mph: S_f (mph) = $0.79 * S_p + 12$

where:

S_p = posted speed limit (mph)

Signalized Facilities

The free-flow speed for signalized facilities is determined by the following equation:

S_f (mph) = $L / [\, L/S_{mb} + N * (D/3600)\,]$

where:

S_f = free-flow speed for urban interrupted facility (mph)

L = length of facility (miles)

S_{mb} = midblock free-flow speed (mph)

= $0.79 * S_p + 12$

N = number of signalized intersections on length, L, of facility

D = average delay per signal per the following equation:

$D = DF * 0.5 * C\,(1 - g/C)^2$

where:

D = total signal delay per vehicle (sec)

g = effective green time (sec)

C = cycle length (sec)

If signal timing data are not available, the following defaults can be used:

C = 120 sec

g/C = 0.45

DF = 0.6 for coordinated signals with highly favorable progression

0.9 for uncoordinated actuated signals

0.9 for coordinated signals with favorable progression

1.0 for uncoordinated fixed time signals

1.2 for coordinated signals with unfavorable progression

Example

US 460 is a two-lane highway through West Liberty, Kentucky. One segment of US 460 is 0.35 miles long, has a posted speed of 35 mph, and terminates at a traffic signal. For this segment, the midblock free-flow speed is 0.79 * 35 mph + 12 or 39.7 mph. The average delay for the signal (using defaults) is 0.9 (uncoordinated actuated) * 0.5 * 120 * $(1 – 0.45)^2$ or 16.3 seconds. Therefore, the free-flow speed of the facility is given as 0.35 miles / [(0.35 miles/39.7mph) + 1 signal * (16.3/3600)] or 26 mph.

III. ROADWAY CAPACITY

The Highway Capacity Manual is generally accepted as the standard of practice for determining the capacity of various types of roadways. However, the data requirements are often too extensive to make these procedures accessible for planning purposes. The following equations for four major facility types were obtained from NCHRP 387 and simplify the application of the HCM methods for use in planning applications.

Freeways

$Capacity\ (vph) = Ideal\ Cap * N * F_{hv} * PHF$

where:

Ideal Cap = 2,400 (pcphl) for freeways with 70 mph or greater FFS
= 2,300 (pcphl) for all other freeways
N = number of through lanes
F_{hv} = heavy vehicle adjustment factor
= 1.00 / (1.00 + 0.5 * HV) for level terrain
= 1.00 / (1.00 + 2.0 * HV) for rolling terrain
= 1.00 / (1.00 + 5.0 * HV) for mountainous terrain
HV = proportion of heavy vehicles. If unknown, use 0.05 as default.
PHF = peak-hour factor (ratio of the peak 15-min flow rate to the average hourly flow rate)
If unknown, use default of 0.90

Multilane Unsignalized Roads

$Capacity\ (vph) = Ideal\ Cap * N * F_{hv} * PHF$

where:

Ideal Cap = 2,200 (pcphl) for multilane rural roads with 60 mph FFS
= 2,100 (pcphl) for multilane rural roads with 55 mph FFS
= 2,000 (pcphl) for multilane rural roads with 50 mph FFS
N = number of through lanes
F_{hv} = heavy vehicle adjustment factor
= 1.00 / (1.00 + 0.5 * HV) for level terrain
= 1.00 / (1.00 + 2.0 * HV) for rolling terrain
= 1.00 / (1.00 + 5.0 * HV) for mountainous terrain
HV = proportion of heavy vehicles. If unknown, use 0.05 as default.
PHF = peak-hour factor (ratio of the peak 15-min flow rate to the average hourly flow rate)
If unknown, use 0.90 as default.

Two-Lane Unsignalized Roads

$Capacity\ (vph) = Ideal\ Cap * N * F_w * F_{hv} * PHF * F_{dir} * F_{nopass}$

where:

Ideal Cap = 1,600 (pcphl) for all two-lane rural roads
N = number of lanes
F_w = lane width and lateral clearance factor
= 1 + (W – 12) / 30
W is the lane width in feet
If W is unknown, use 0.8 if narrow lanes (<12 feet) and/or narrow shoulders (<3 feet)
Use 1.0 otherwise
F_{hv} = heavy vehicle adjustment factor
= 1.00 / (1.00 + 1.0 * HV) for level terrain
= 1.00 / (1.00 + 4.0 * HV) for rolling terrain
= 1.00 / (1.00 + 11.0 * HV) for mountainous terrain
HV = proportion of heavy vehicles. If unknown, use 0.02 as default.
PHF = peak-hour factor (ratio of the peak 15-min flow rate to the average hourly flow rate)

If unknown, use 0.90 as default.

F_{dir} = directional adjustment factor
= 0.71 * 0.58 * (1.00 – peak direction proportion)
If unknown, use 0.55 as default peak direction proportion.

F_{nopass} = no-passing zone factor
= 1.00 for level terrain
= 0.97 – 0.07 * (*NoPass*) for rolling terrain
= 0.91 – 0.13 * (*NoPass*) for mountainous terrain
NoPass is the proportion of length of the facility for which passing is prohibited.
If unknown, use 0.6 for rolling terrain and 0.8 for mountainous terrain

Signalized Arterials (and one-way streets)[2]

$Capacity\ (vph) = Ideal\ Sat * N * F_w * F_{hv} * PHF * F_{park} * F_{bay} * F_{CBD} * g/C$

where:

Ideal Sat = ideal saturation flow rate (vehicles per lane per hour green)
= 1,900

N = number of lanes

F_w = lane width and lateral clearance factor
= 1 + (W – 12) / 30
W is the lane width in feet
If W is unknown, use 0.8 if narrow lanes (<12 feet) and/or narrow shoulders (<3 feet)
Use 1.0 otherwise

F_{hv} = heavy vehicle adjustment factor
= 1.00 / (1.00 + HV) for level terrain
HV = proportion of heavy vehicles. If unknown, use 0.02 as default.

PHF = peak-hour factor (ratio of the peak 15-min flow rate to the average hourly flow rate
If unknown, use 0.90 as default.

F_{park} = on-street parking adjustment factor
= 0.9 if on-street parking is present and parking time limit is 1 hour or less
= 1.0 otherwise

F_{bay} = left turn bay adjustment factor
= 1.1 if exclusive left turn lanes are present, or for one-way streets
= 1.0 otherwise

F_{CBD} = central business district (CBD) adjustment factor
= 0.9 if located in CBD
= 1.0 elsewhere

g/C = ratio of effective green time per cycle
If no data are available, use the following defaults:
= 0.4 if protected left turn phase is present
= 0.45 if protected left turn phase is not present

Example

The same segment of US 460 in West Liberty, Kentucky, has the following physical characteristics: 11-foot lanes, 7.9 percent heavy vehicles, no on-street parking, no left-turn bays, and it is outside the CBD. Using the default g/C ratio and a local PHF of 0.88, the capacity of the segment is given as 1900 * 2 lanes * 0.97 (F_w) * 0.93 (F_{hv}) * 1.0 (F_{park}) * 1.0 (F_{bay}) * 1.0 (F_{CBD}) * 0.45 (g/C) * 0.88 (PHF), or 1,347 vph.

[2] For one-way streets, use 1.1 for the left turn bay adjustment factor (F_{bay}).

IV. TRAFFIC VOLUMES

No build ADT traffic volumes for both the base year and design year of the facility need to be determined, along with turning movements at the major intersections in the study area. The base year traffic volumes are best determined from traffic counts, but can be estimated by analyzing the historical count data for a given roadway segment and inflating the last count by a growth rate. The traffic growth rate will also be applied to the base year traffic volumes to determine the future no build traffic volumes. Traffic growth rates are best determined by statistical analysis of historical count data (linear regression, regression analysis using Box-Cox transformations, etc.). Traffic growth rates should also consider observed trends in socioeconomic growth and anticipated developments in the study area that may impact travel patterns.

Turning movements at the major intersections are also best determined from traffic count data. In the absence of count data, they can be estimated from the approach ADTs using a program that produces reasonable estimates of turning volumes such as the *turns.bat* program. If the turns are estimated using this approach, they should be verified and/or adjusted to accurately reflect local travel patterns. Turning movements must be generated for both the base year and design year ADT traffic volumes.

Example

The base year for a project is 2002, and the design year is 2026. At a given traffic count station in the study area, the following historical count data were observed (growth rate as compared to oldest count):

Year	ADT Count	Growth Rate
2001	12,400	2.8%
1996	11,600	3.2%
1990	9,200	2.8%
1984	7,650	2.4%
1980	6,960	N/A

A linear regression analysis is performed on this data and the Box-Cox transformations of this data to determine the curve of best fit to the count data, as presented below. For this segment, it was determined that the best curve was created using a beta value of 0.2; this value generated a growth rate of 2.6 percent per year. Assuming that the socioeconomic data does not reveal any surprising trends and there are no major developments scheduled that would change affect this analysis, this growth rate would be applied to the 2001 volume at this location to determine both the 2002 base year traffic volume and the 2026 no build design year traffic volume.

		Box-Cox Transformations					
		Log Trans.	Beta Transformations				
YEAR	COUNT	Log(Count)	0.1	0.15	0.2	0.25	0.3
2001	12,400	4.0934	15.665	20.744	27.935	38.210	53.018
1996	11,600	4.0645	15.494	20.471	27.498	37.512	51.902
1990	9,200	3.9638	14.910	19.544	26.026	35.175	48.191
1984	7,650	3.8837	14.455	18.829	24.902	33.409	45.417
1980	6,960	3.8426	14.225	18.470	24.342	32.535	44.054
R^2 value:	0.98281	0.98546	0.98554	0.98555	0.98555	0.98552	0.98547

Projected Volumes*

	YEAR	2002	2006	2026	GR ('02-'28)
	Count	12800	13900	19500	1.8%
	Log(cnt)	13200	14800	26500	2.9%
Beta Values	0.1	13100	14700	25300	2.8%
	0.15	13100	14600	24700	2.7%
	0.2	13100	14600	24200	2.6%
	0.25	13100	14500	23800	2.5%
	0.3	13000	14500	23300	2.5%

*Best Estimate determined from R^2 value is highlighted in YELLOW

This spreadsheet fits a STRAIGHT LINE to either given or transformed count data and then uses that line to find estimated counts for the current, build, and design years. A Growth rate is then calculated from the build year estimate based on the equation:

$$\text{NewCount} = \text{OldCount} * (1 + \text{GR})^{\text{Yrs.}}$$

The Box-Cox beta transformations use the equation: $Y_\beta = (Y^\beta - 1) / \beta$

V. CONGESTED SPEED

Congested speeds are calculated for each segment along the existing route, for both the base year and design year traffic volumes, using the following modified BPR equation:

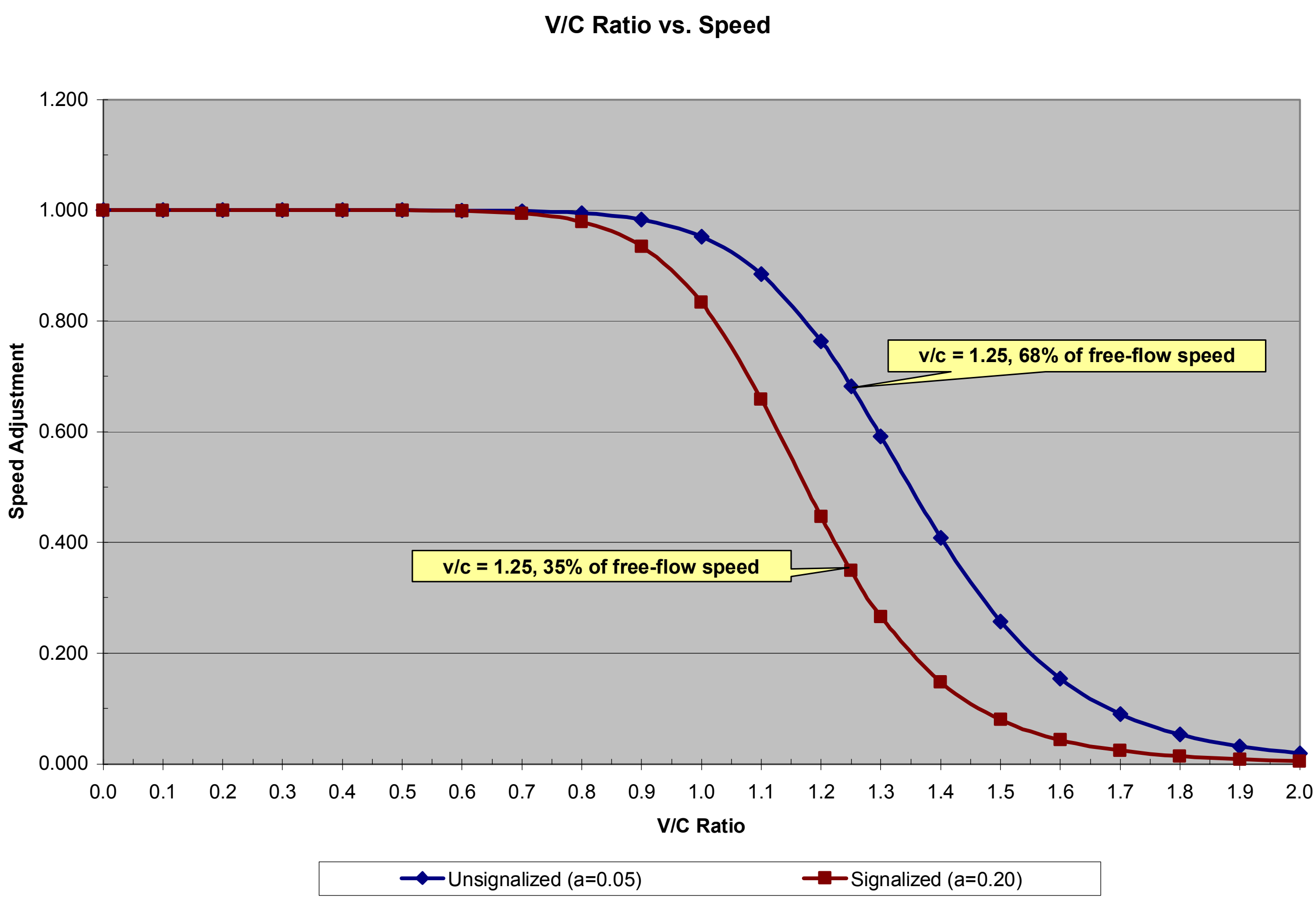
$$S = S_f / [\ 1 + a * (v/c)^b\ ]$$

where:

S = congested speed (mph)
S_f = free-flow speed (mph)
v = generalized hourly volume (vph, using ADT and default K factor of 10 percent)
= ADT * 0.10
c = segment capacity (vph)
a = 0.05 for facilities with signals spaced 2 miles apart or less
= 0.2 for all other facilities
b = 10

Note: A maximum v/c ratio of 1.25 was established to prevent the BPR curve from overestimating delay due to traffic congestion. At this point, the congested speed is adjusted to 35 percent of free-flow for signalized facilities and 68 percent for unsignalized facilities, as presented in **Exhibit A**. With congestion beyond this point, peak traffic begins spreading to multiple hours and the relationships used in the equation are no longer valid.

Exhibit A. Modified BPR Curve



Example

The same 0.35-mile segment of US 460 in West Liberty, Kentucky, has a free-flow speed of 26 mph, an ADT in 2002 of 13,400 which equates to a peak hour volume of 1,340, and a capacity of 1,350 vph. Because it is a signalized facility, a = 0.20. From the modified BPR curve, the congested speed is calculated as 26 mph / $[1 + 0.2 * (1340/1350)^{10}]$ or 22 mph.

VI. DIVERSION ANALYSIS

The following list details the procedure that is followed to apply the manual diversion analysis to each origin-destination (OD) pair in the study area that may use the new bypass facility. This procedure is applied to both the base year and design year volumes.

1. Determine the volume of traffic moving between a given OD pair. This volume is determined by starting with the ADT at the origin and reducing it by the percentages of through trips from the estimated turning movements until the destination is reached. The volume moving between the OD pair may also be reduced to account for changes in the ADT along the segment due to local destinations. The procedure is repeated in the opposite direction (starting at the destination) and the two resultant volumes are averaged to determine an approximate volume of traffic moving between the given OD pair.
2. Determine the distance between the OD pair using the existing route (d_e) and the best available route (d_b) using the new facility. The distance saved, Δd, is $d_b - d_e$.
3. Determine the travel times between the OD pair using the existing route (t_e) and the best available route (t_b) using the new facility, using the *congested travel speeds* to determine travel times. The time saved, Δt, is $t_b - t_e$.
4. Calculate the percentage of diverted traffic using the following equation developed by the California Department of Transportation:
$$P = 50 + 50 * (\Delta d + 0.5 * \Delta t) / \mathrm{SQRT}[(\Delta d - 0.5 * \Delta t)^2 + 4.5]$$
5. Multiply the OD volume by P and assign this volume to the bypass; assign the balance to the existing route.
6. Repeat steps 1-5 for every OD pair that may use the new bypass facility.
7. For the design year analysis, increase the volume assigned to the new facility by 20 percent to account for observed trends in induced traffic on a new facility. This volume increase is generally observed in the through trips rather than any in-town traffic that may use the facility.

Modlin Comparison

NCHRP Report 365[3] references a procedure developed by D.G. Modlin, Jr. in conjunction with the State of North Carolina. The study evaluated travel patterns in several small urban areas and ultimately produced a single regression equation to determine the percentage of through trips on a given highway. The equation is based on four independent variables: functional class of the highway, the ADT at the external station, the percentage of trucks (excluding vans and pickups), the percentage of vans and pickups, and the population of the study area. The equation for estimating the percent through trips at an external station is:

$$Y_i = 76.76 + 11.22*I - 25.74*PA + 42.18*MA + 0.00012*ADT_i + 0.59*PTKS_i - 0.48*PPS_i - 0.000417*POP$$

where:

Y_i = percentage of the ADT at external station *i*, that are through trips

[3] "*Travel Estimation Techniques for Urban Planning,*" NCHRP Report 365, National Cooperative Highway Research Program, William A. Martin, Nancy A. McGuckin, et al. Transportation Research Board, Washington, D.C., 1998, pp. 49-50.

I = interstate (0 or 1)
PA = principal arterial (0 or 1)
MA = minor arterial (0 or 1)
ADT_i = average daily traffic at external station *i*
$PTKS_i$ = percentage of trucks excluding vans and pickups at external station *i*
PPS*i* = percentage of vans and pickups at external station *I*
POP = population of the study area

The application of this procedure in calculating the traffic diverted to a new facility is to assume that all of the through trips would be diverted to the new route. Obviously this procedure varies a great deal from the manual gravity diversion analysis. The Modlin equation was developed from observed travel trends in the 1970s and 1980s, for a limited number of study areas. It also weighs heavily on functional class, which may not be a good measure to analyze the diverted traffic to a new bypass of a small town where the primary route through town is a minor arterial.

By contrast, the manual gravity diversion uses recent count data and estimates of turning movements through town to determine travel patterns and percentages of through trips. The manual method is based on link speeds and capacities, and takes into account traffic congestion in its calculation of timesavings. For this reason, the manual method is also able to account for trips within town that might choose to use the new facility because of congestion on the main route in town.

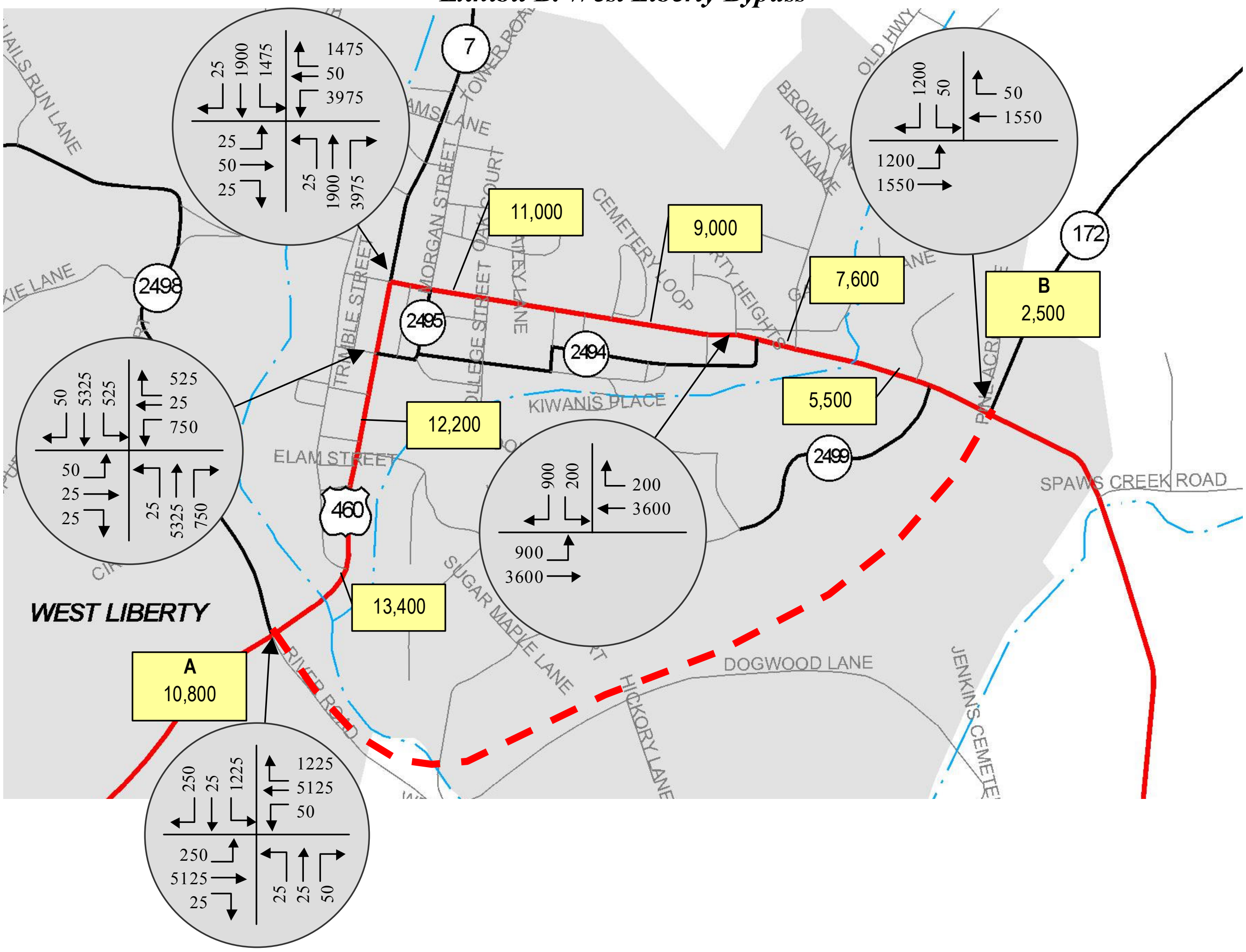
The Modlin equation may be used for comparative purposes, to determine if the through traffic it predicts is similar to the volume of through traffic shown by the turning movement estimates. When making this comparison, caution should be used in revising the turning movements to better match the Modlin through traffic volume. Finally, due to the differences already identified, the Modlin equation should not be used to validate the total volume of traffic diverted by the manual gravity method.

Example

Exhibit B presents the critical turning movements and traffic volumes for the West Liberty Bypass. The diverted volume between points A and B is calculated as follows:

1. Location A has a 2002 ADT of 10,800. Location B has a 2002 ADT of 2,500. The volume of traffic moving from A to B is:
   10,800 * (5125/5400) * (12200/13400) * (5325/6100) * (3975/5900) * (9000/11000) * (3600/4500) * (5500/7600) * (1200/2750) = 1,100
   The volume of traffic moving from B to A is:
   2,500 * (1200/1250) * (5500/7600) * 3600/3800) * (9000/11000) * 3975/5500) * 5325/5900) * 12200/13400) * 5125/6400) = 640
   Therefore, the traffic volume for OD pair A-B used in the analysis is (1100 + 640) / 2 = 887 (900)
2. The existing distance between A-B is 1.6 miles; the new distance is 1.4 miles, giving a distance savings of 0.2 miles.
3. The existing congested time between A-B is 5.4 minutes; the new time is 1.9 minutes, giving a time savings of 3.5 minutes.
4. The percentage of diverted traffic is therefore calculated to be:
   $P = 50 + 50 * (0.2 + 0.5 * 3.5) / SQRT[(0.2 – 0.5 * 3.5)^2 + 4.5] = 87$ percent
5. Therefore, the volume from OD pair A-B that will use the new bypass is 900 * 0.87 or 774 (800) vehicles, and the volume remaining on the existing route is 100 vehicles.

Exhibit B. West Liberty Bypass



VII. CONCLUSION

The manual gravity diversion methodology is a reasonable approach to forecast the traffic on a new facility in the absence of a travel demand model. The obvious limitations lie in the accuracy of the input data; poor data used to generate the segment capacities will lead to inaccurate congested speeds, poor turning movement data will lead to inaccurate diversion volumes, and poor estimation of traffic growth will lead to inaccurate design year volumes. With these concessions, the manual gravity procedure as stated in this report is an excellent manual approach to determine base year and design year traffic volumes for a new facility.

In order to demonstrate the application of the manual gravity diversion, an evaluation of the traffic diverted to the proposed West Liberty, Kentucky bypass (US 460) is presented in the **Appendix**.

APPENDIX:
WEST LIBERTY BYPASS

Exhibit A: Site Visit Notes and Proposed Alignment

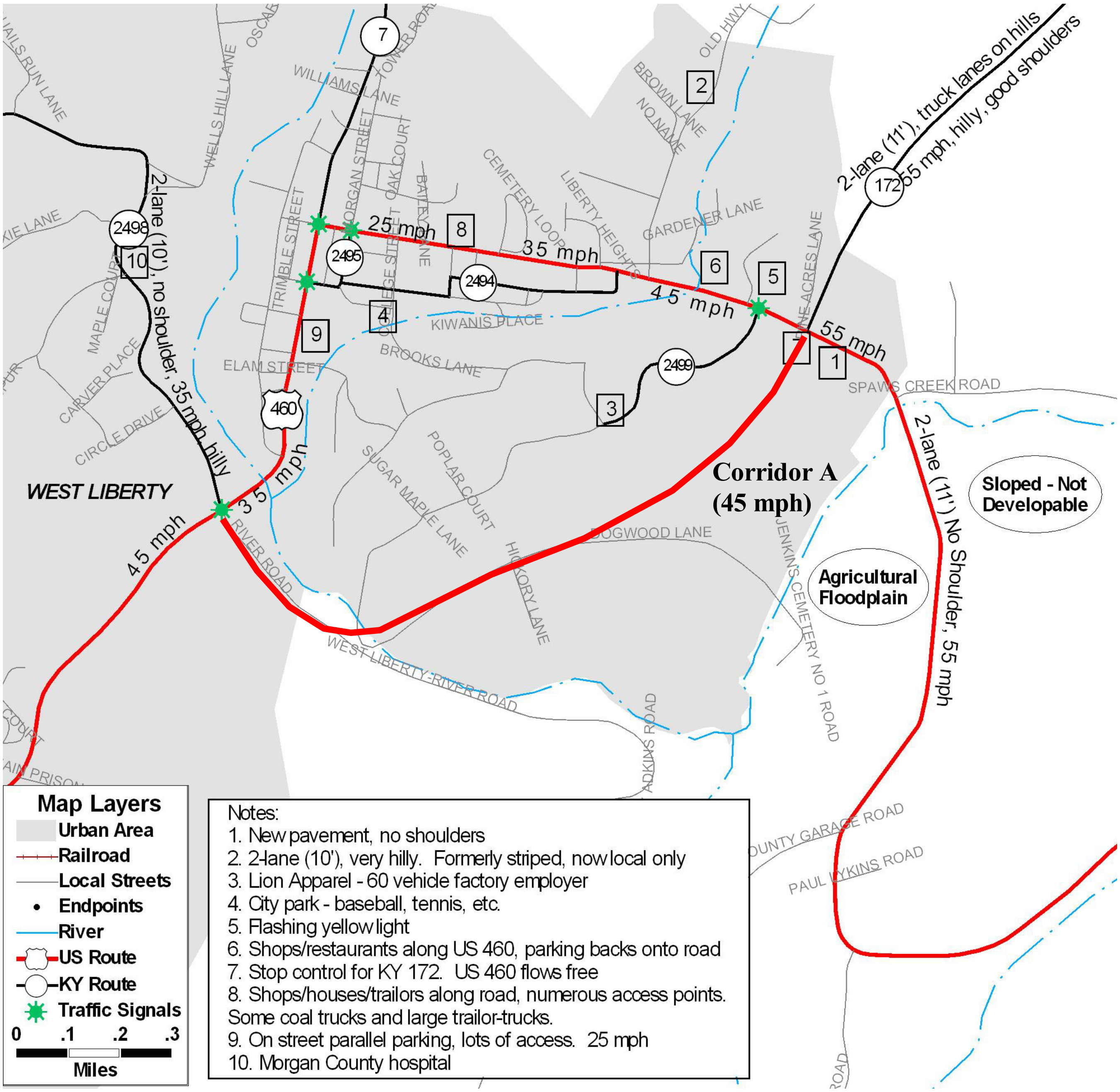
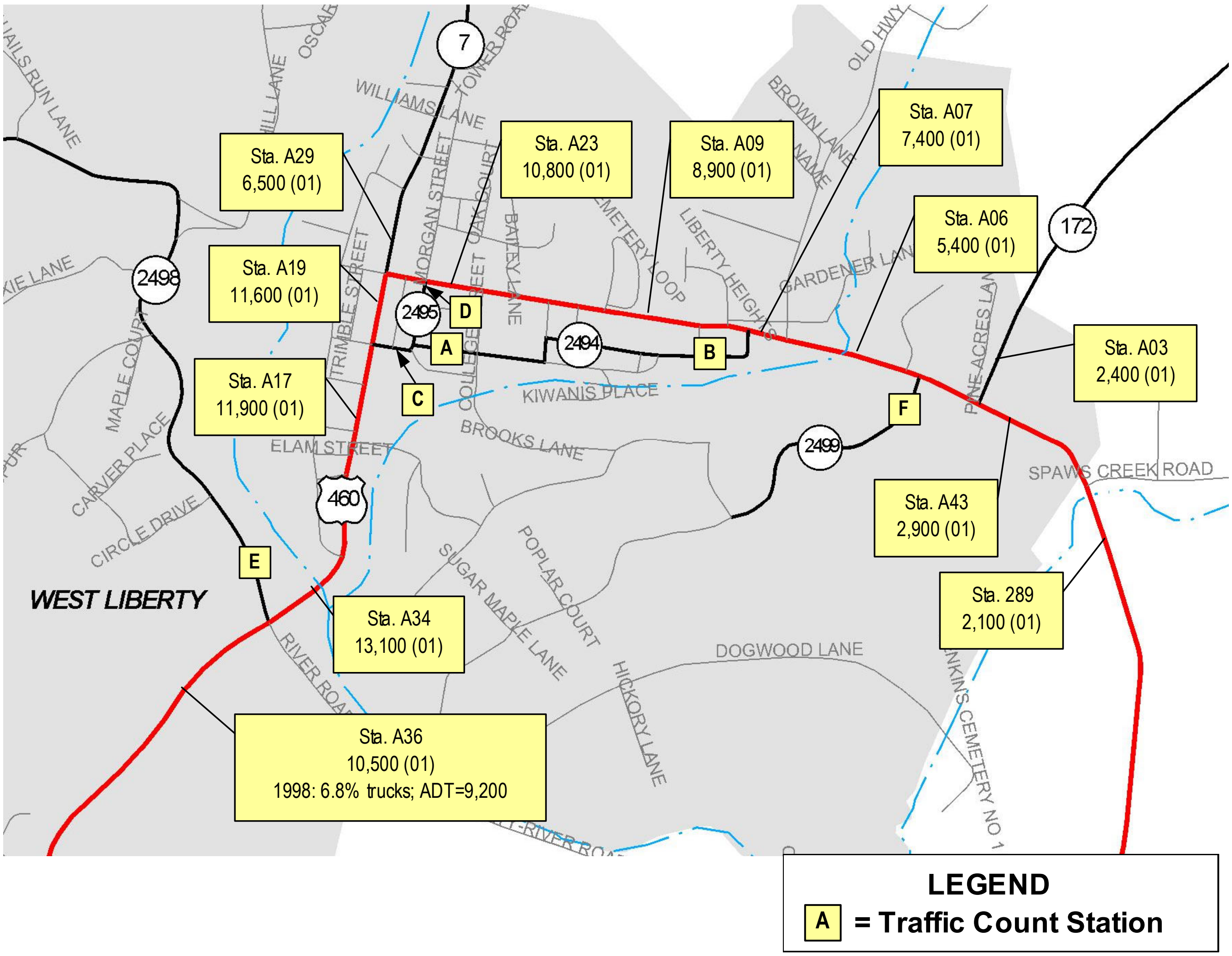
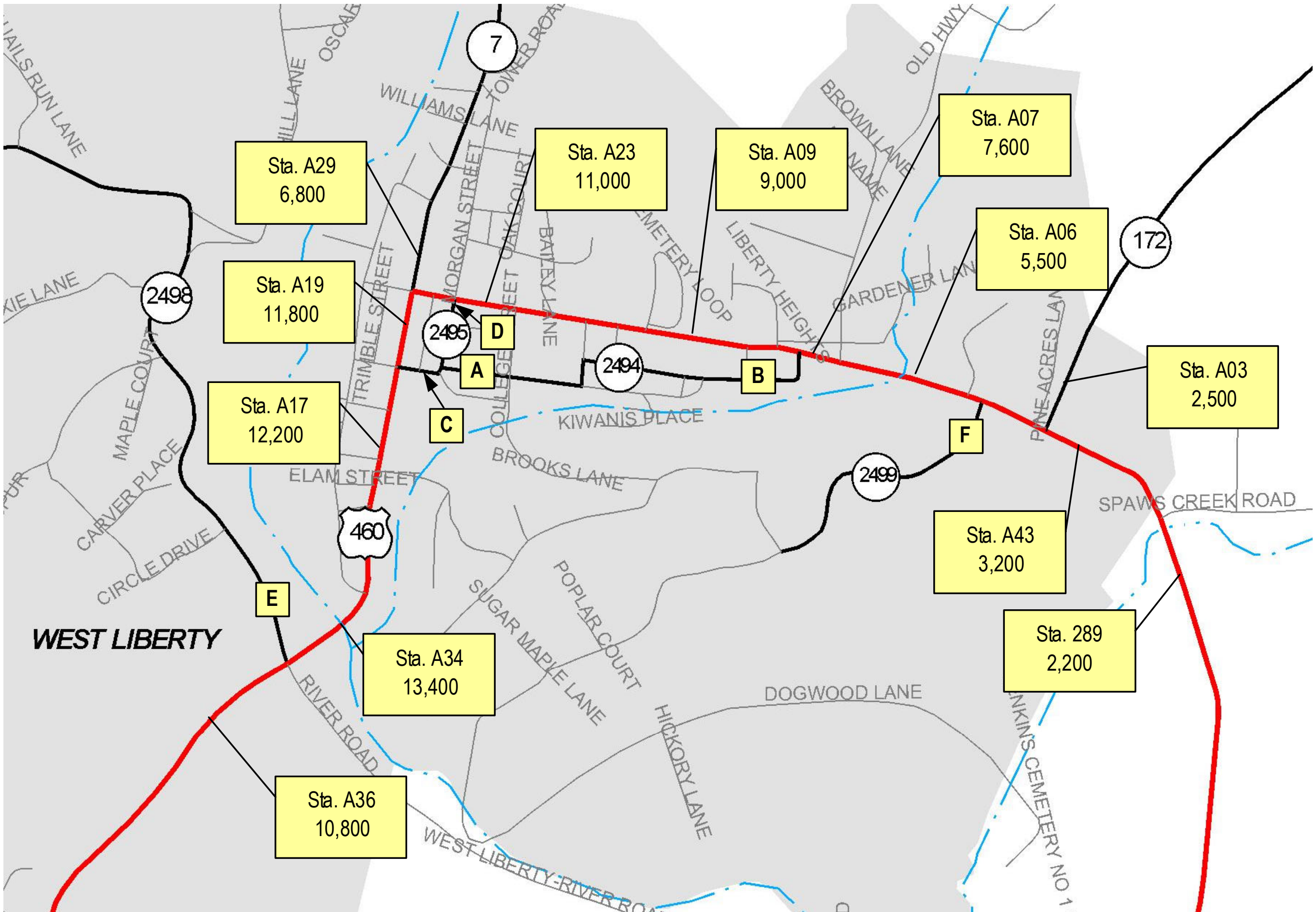


Exhibit B: Historical Traffic Count Data



Location	Station	Route	Count	Year
A	A15	KY 2494	1,900	2001
B	A08	KY 2494	600	1999
C	A18	KY 2495	2,500	2001
D	A24	KY 2495	2,000	1998
E	A40	KY 2498	2,900	2001
F	A42	KY 2499	900	2001

Exhibit C: 2002 No Build Traffic Volumes (after growth rate is applied)

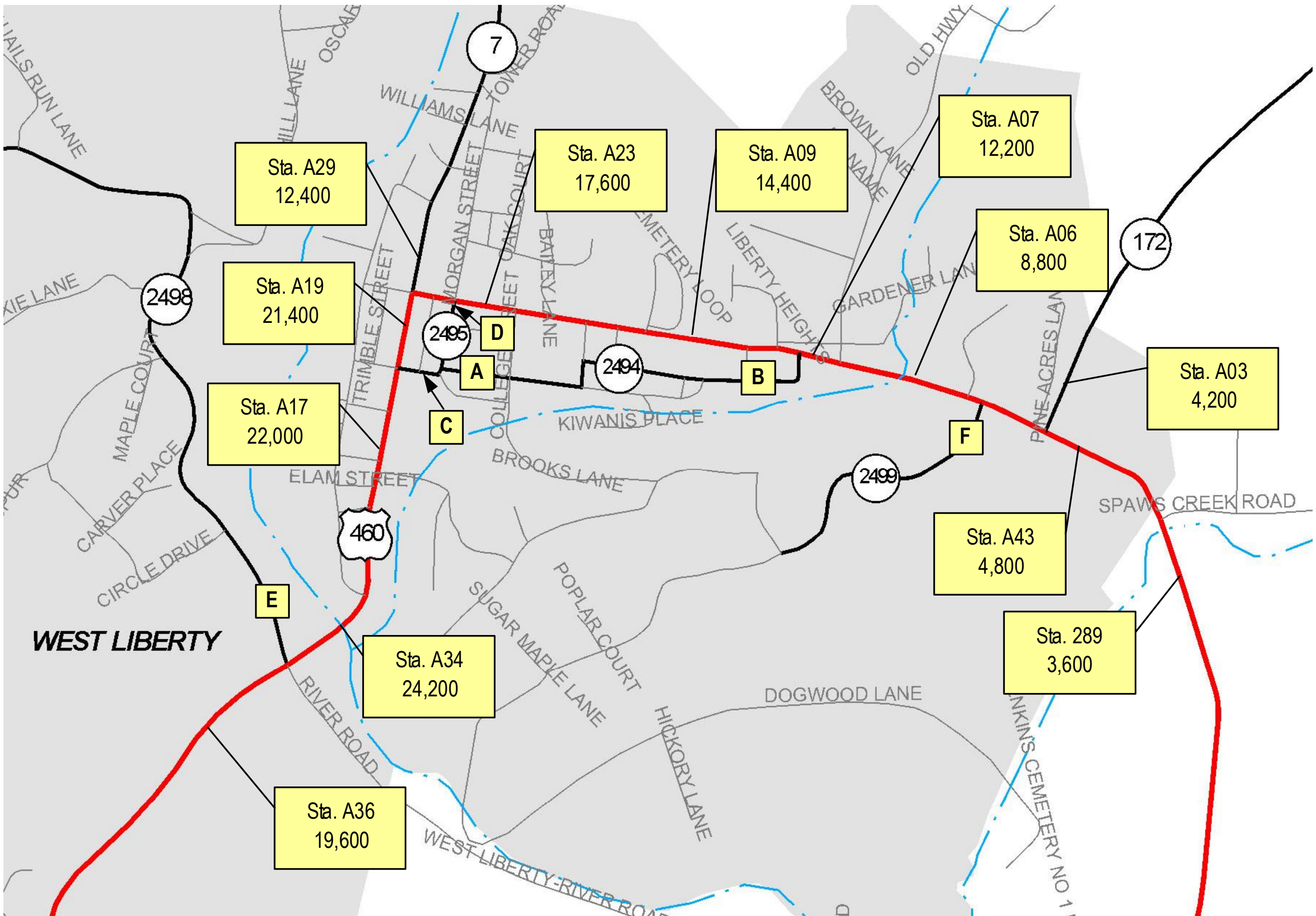


Location	Station	Route	2002 Vol
A	A15	KY 2494	2,000
B	A08	KY 2494	700
C	A18	KY 2495	2,600
D	A24	KY 2495	2,200
E	A40	KY 2498	3,000
F	A42	KY 2499	1,000

LEGEND

A = Traffic Count Station

Exhibit D: 2026 No Build Traffic Volumes (after growth rate is applied)



Location	Station	Route	2026 Vol
A	A15	KY 2494	3,200
B	A08	KY 2494	1,200
C	A18	KY 2495	4,200
D	A24	KY 2495	3,600
E	A40	KY 2498	5,400
F	A42	KY 2499	1,600

LEGEND

A = Traffic Count Station

Exhibit E: 2002 Turning Movement Estimates

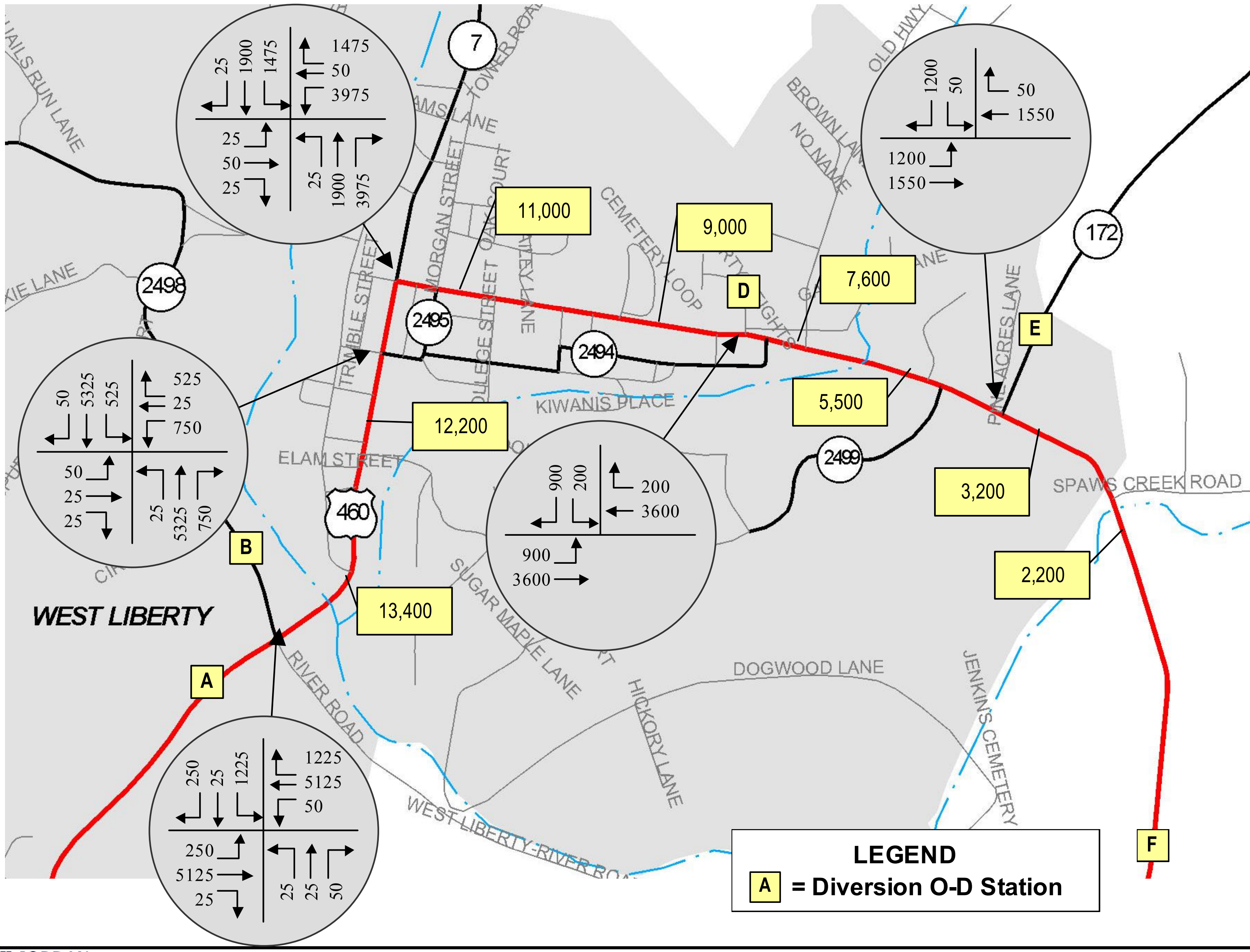


Exhibit F: 2026 Turning Movement Estimates

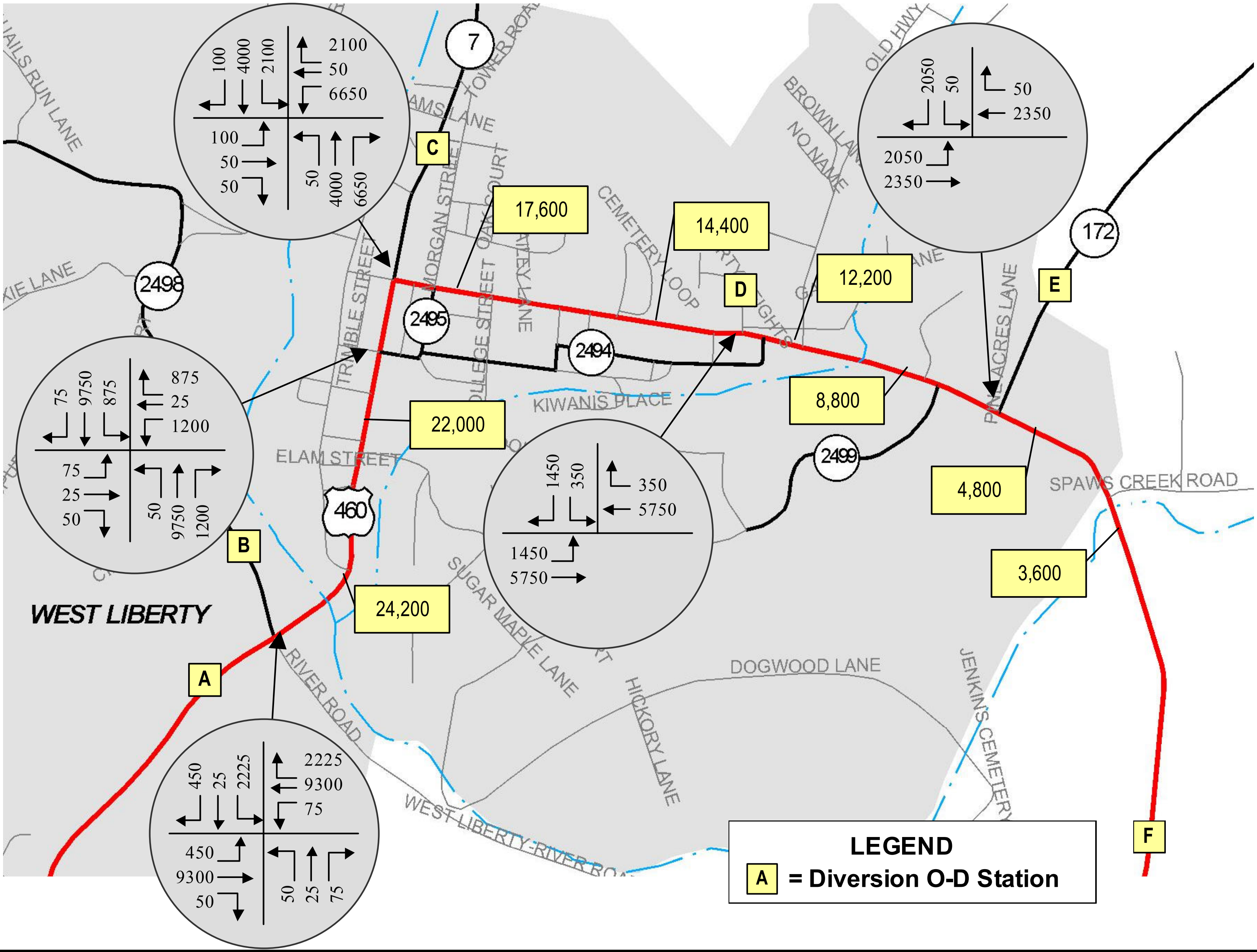


Exhibit G: Capacity Restraint Segments

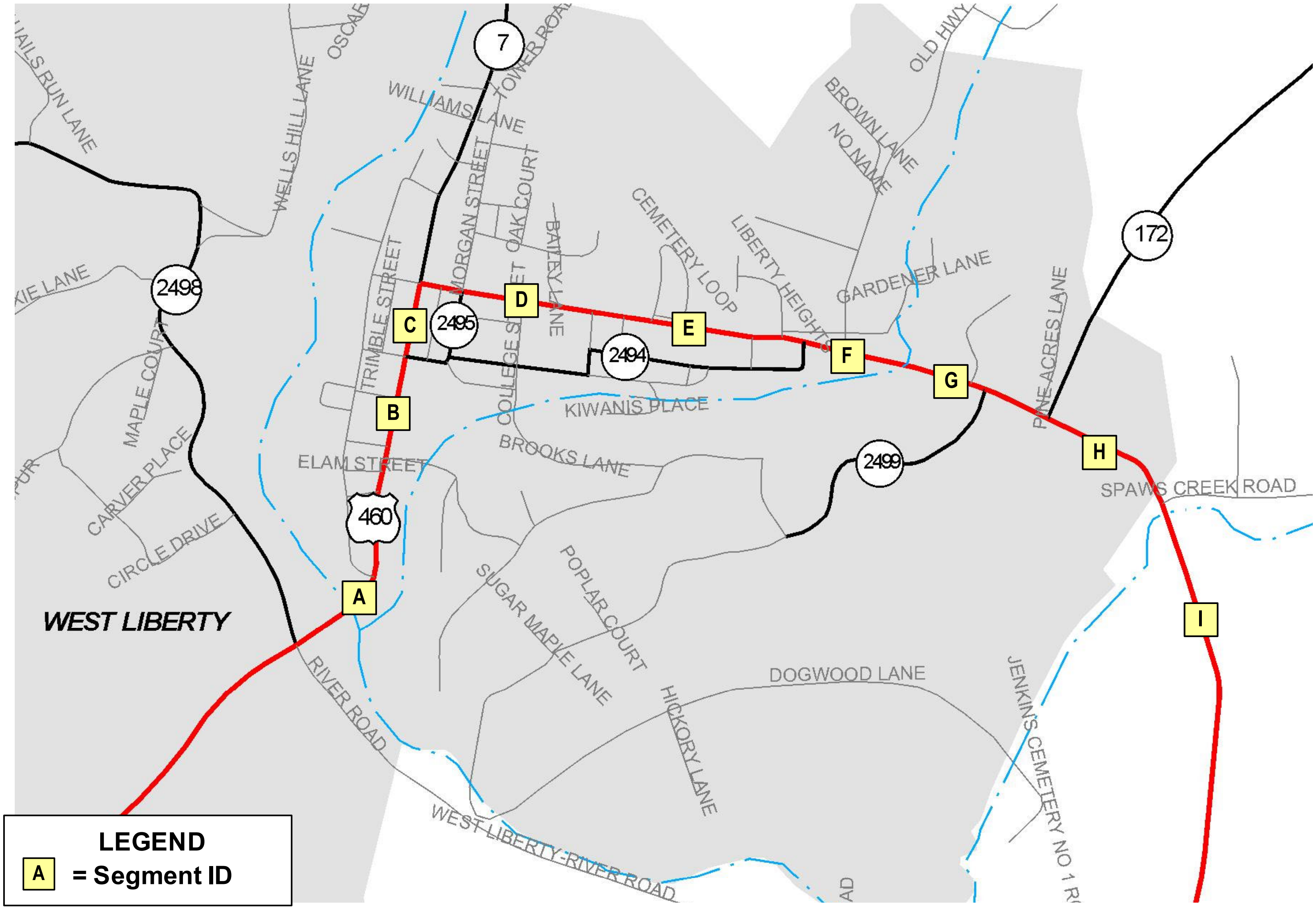


Exhibit H: Free-flow Speed, Capacity, and Congested Speed Calculations

Segment	A	B	C	D	E	F	G	H	I
Distance (miles)	0.35	0.18	0.12	0.16	0.43	0.16	0.23	0.23	1.14
Posted Speed (mph)	35	25	25	25	35	45	45	55	55
Midblock Speed (mph)	40	32	32	32	40	48	48	62	62
Number of Signals	1	1	1	2	0	0	1	0	0
Ave. Signal Delay (D)	16.3	16.3	16.3	16.3	N/A	N/A	16.3	N/A	N/A
Free-flow Speed (mph)	**26**	**18**	**14**	**11**	**40**	**48**	**25**	**62**	**62**
Uncongested Time (min)	0.8	0.6	0.5	0.9	0.6	0.2	0.6	0.2	1.1
Ideal Sat. Flow (vph)	1900	1900	1900	1900	1400	1400	1900	1400	1400
Number of Lanes	2	2	2	2	2	2	2	2	2
F_w	0.97	0.97	0.90	0.97	0.90	0.90	0.90	0.90	0.90
F_{hv}	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
F_{park}	1.00	0.90	0.90	0.90			1.00		
F_{bay}	1.00	1.00	1.00	1.00			1.00		
F_{CBD}	1.00	0.90	0.90	0.90			1.00		
F_{dir}					0.97	0.97		0.97	0.97
F_{nopass}					1.00	1.00		0.93	0.93
g/C	0.45	0.45	0.45	0.45			0.45		
PHF	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Capacity (vph)	**1348**	**1092**	**1017**	**1092**	**1996**	**1996**	**1255**	**1852**	**1852**
2002 AADT (vpd)	13400	12200	11800	11000	9000	7600	5500	3200	2200
2002 Vol (vph)	1340	1220	1180	1100	900	760	550	320	220
V/C Ratio	0.99	1.12	1.16	1.01	0.45	0.38	0.44	0.17	0.12
Cong. Spd (mph)	**22**	**11**	**7**	**9**	**40**	**48**	**25**	**62**	**62**
Cong. Time (min)	**1.0**	**1.0**	**1.0**	**1.1**	**0.6**	**0.2**	**0.6**	**0.2**	**1.1**
2026 AADT (vpd)	24200	22000	21400	17600	14400	12200	8800	4800	3600
2026 Vol (vph)	2420	2200	2140	1760	1440	1220	880	480	360
V/C Ratio	1.80	2.01	2.10	1.61	0.72	0.61	0.70	0.26	0.19
Cong. Spd (mph)	**9**	**6**	**5**	**4**	**40**	**48**	**25**	**62**	**62**
Cong. Time (min)	**2.3**	**1.8**	**1.4**	**2.4**	**0.6**	**0.2**	**0.6**	**0.2**	**1.1**

Exhibit I: 2002 Manual Gravity Diversion Calculations

O-D Volumes

O-D Pair	ADT	Medium Trucks	Heavy Trucks	Int. 1	Int. 2	Int. 3	Int. 4	Int. 5	Int. 6	Int. 7	Int. 8	Int. 9	Vol_Exist	Medium Truck_Exist	Heavy Truck_Exist
A-D	10800	497	281	0.95	0.91	0.87	0.67	0.82	0.20				898	41	23
A-E	10800	497	281	0.95	0.91	0.87	0.67	0.82	0.80	0.72	0.44		1134	52	29
A-F	10800	497	281	0.95	0.91	0.87	0.67	0.82	0.80	0.72	0.56	0.69	1007	46	26
B-D	3000	171	96	0.82	0.91	0.87	0.67	0.82	0.20				215	12	7
B-E	3000	171	96	0.82	0.91	0.87	0.67	0.82	0.80	0.72	0.44		271	15	9
B-F	3000	171	96	0.82	0.91	0.87	0.67	0.82	0.80	0.72	0.56	0.69	241	14	8
C-F	6800	435	218	0.43	0.82	0.80	0.72	0.56	0.69				541	35	17

Reverse O-D Pair	ADT	Medium Trucks	Heavy Trucks	Int. 1	Int. 2	Int. 3	Int. 4	Int. 5	Int. 6	Int. 7	Int. 8	Int. 9	Vol_Exist	Medium Truck_Exist	Heavy Truck_Exist
D-A	2200	44	22	0.82	0.82	0.72	0.90	0.91	0.80				700	14	7
D-B	2200	44	22	0.82	0.82	0.72	0.90	0.91	0.19				167	3	2
E-A	2500	128	73	0.96	0.72	0.95	0.82	0.72	0.90	0.91	0.80		640	33	19
E-B	2500	128	73	0.96	0.72	0.95	0.82	0.72	0.90	0.91	0.19		153	8	4
F-A	2200	119	66	0.69	0.97	0.72	0.95	0.82	0.72	0.90	0.91	0.80	391	21	12
F-B	2200	119	66	0.69	0.97	0.72	0.95	0.82	0.72	0.90	0.91	0.19	93	5	3
F-C	2200	119	66	0.69	0.97	0.72	0.95	0.82	0.27				220	12	7

Diversion Analysis

O-D Pair	Volume	Medium Trucks	Heavy Trucks	Existing Dist.	Existing Time	New Dist.	New Time	Change Dist.	Change Time	CA Div %	% Diverted	Vehicles Diverted	Med. Trucks Diverted	Hvy. Trucks Diverted
A-D	799	28	15	1.2	4.7	1.8	2.9	-0.6	1.8	56.07	56	448	16	15
A-E	887	42	24	1.6	5.4	1.4	1.9	0.2	3.5	87.29	87	774	37	24
A-F	699	34	19	3.0	6.8	2.8	3.3	0.2	3.5	87.29	87	610	29	19
B-D	191	8	4	1.2	4.7	1.8	2.9	-0.6	1.8	55.77	56	107	4	4
B-E	212	12	7	1.6	5.4	1.4	1.9	0.2	3.5	87.29	87	185	10	7
B-F	167	9	5	3.0	6.8	2.8	3.3	0.2	3.5	87.11	87	145	8	5
C-F	381	23	12	2.3	3.8	3.4	7.2	-1.1	-3.4	-13.26	0	0	0	12
											Total	**2269**	**104**	**86**
											Percentage		**4.6%**	**3.8%**

Exhibit J: 2026 Manual Gravity Diversion Calculations

O-D Volumes

O-D Pair	ADT	Medium Trucks	Heavy Trucks	Int. 1	Int. 2	Int. 3	Int. 4	Int. 5	Int. 6	Int. 7	Int. 8	Int. 9	Vol_Exist	Medium Truck_Exist	Heavy Truck_Exist
A-D	19600	1294	725	0.95	0.91	0.89	0.62	0.82	0.20				1533	101	57
A-E	19600	1294	725	0.95	0.91	0.89	0.62	0.82	0.80	0.72	0.47		2046	135	76
A-F	19600	1294	725	0.95	0.91	0.89	0.62	0.82	0.80	0.72	0.53	0.75	1759	116	65
B-D	5400	437	248	0.82	0.91	0.89	0.62	0.82	0.20				367	30	17
B-E	5400	437	248	0.82	0.91	0.89	0.62	0.82	0.80	0.72	0.47		490	40	23
B-F	5400	437	248	0.82	0.91	0.89	0.62	0.82	0.80	0.72	0.53	0.75	421	34	19
C-F	12400	1128	570	0.34	0.82	0.80	0.72	0.53	0.75				793	72	36

Reverse O-D Pair	ADT	Medium Trucks	Heavy Trucks	Int. 1	Int. 2	Int. 3	Int. 4	Int. 5	Int. 6	Int. 7	Int. 8	Int. 9	Vol_Exist	Medium Truck_Exist	Heavy Truck_Exist
D-A	3600	104	50	0.81	0.82	0.76	0.91	0.91	0.80				1191	35	17
D-B	3600	104	50	0.81	0.82	0.76	0.91	0.91	0.19				285	8	4
E-A	4200	307	172	0.98	0.72	0.94	0.82	0.76	0.91	0.91	0.80		1145	84	47
E-B	4200	307	172	0.98	0.72	0.94	0.82	0.76	0.91	0.91	0.19		274	20	11
F-A	3600	277	155	0.75	0.98	0.72	0.94	0.82	0.76	0.91	0.91	0.80	738	57	32
F-B	3600	277	155	0.75	0.98	0.72	0.94	0.82	0.76	0.91	0.91	0.19	177	14	8
F-C	3600	277	155	0.75	0.98	0.72	0.94	0.82	0.24				351	27	15

Diversion Analysis

O-D Pair	Volume	Medium Trucks	Heavy Trucks	Existing Dist.	Existing Time	New Dist.	New Time	Change Dist.	Change Time	CA Div %	% Diverted	Vehicles Diverted	Med. Trucks Diverted	Hvy. Trucks Diverted
A-D	1362	68	37	1.2	8.6	1.8	3.1	-0.6	5.5	77.22	77	1052	52	37
A-E	1596	109	61	1.6	9.4	1.4	1.9	0.2	7.5	97.79	98	1560	107	61
A-F	1249	86	48	3.0	10.7	2.8	3.3	0.2	7.4	97.68	98	1220	84	48
B-D	326	19	10	1.2	8.6	1.8	3.1	-0.6	5.5	77.11	77	251	15	10
B-E	382	30	17	1.6	9.4	1.4	1.9	0.2	7.5	97.79	98	374	29	17
B-F	299	24	13	3.0	10.7	2.8	3.3	0.2	7.4	97.65	98	292	23	13
C-F	572	50	26	2.3	5.1	3.4	7.8	-1.1	-2.7	-7.01	0	0	0	26
											Total	**4749**	**310**	**213**
											Percentage		**6.5%**	**4.5%**
											Inflated by 20%	**5700**	**370**	**260**
											Percentage		**6.5%**	**4.6%**