

**US-40 & Elk River Rd.
Steamboat Springs, CO**

Roundabout Analysis

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Introduction

The purpose of this memorandum is to document the preliminary roundabout analysis results at the intersection of US-40 and Elk River Rd. as a part of the West of Steamboat Springs, US Highway 40 NEPA Study.

Methodology

Since there is no single approach to conduct roundabout capacity analysis and specify geometric design parameters we have chosen an iterative process that utilizes several resources. The resources can be broadly broken into three categories:

- ▶ Design guidelines – these offer good principles of design but are not standards. (i. e. Roundabouts: An Informational Guide published by FHWA, June 2000)
- ▶ Computer models/software – RODEL software has been used to provide capacity analysis of various design parameters.
- ▶ Professional Experience – Technical Journals and conferences provide the opportunity for Roundabout designers to share experience and cutting edge techniques to analyze and design modern roundabouts.

The methodology used in this memorandum utilizes all three types of resources; FHWA design guidelines, RODEL, and Professional judgment.

Analysis Steps:

To reach the recommended design parameters we performed the following steps:

1. Convert the 2035 AM and PM peak hour turning movements into entering and circulating volumes for roundabouts.
2. Iteratively determine capacity and preliminary geometric design parameters by referring to following sources -
 - a) General guidelines provided in - Roundabouts: An Informational Guide, Publication No. FHWA-RD-00-067, U.S. Department of Transportation, FHWA, June 2000.
 - b) Capacity comparison of single lane and double lane roundabouts graph (Roundabouts: An Informational Guide, Exhibit 4-6, page 89, 2000).
 - c) Level of Service (LOS) criteria for Roundabouts listed in Highway Capacity Manual (HCM, Proposed Draft Chapter 17, Exhibit 17-43, 2006).
 - d) RODEL software analysis.
 - e) Recent experience as documented National Roundabout Conference 2008 presentations located at website www.teachamerica.com and other “Rules of Thumb”.

Base Data:

The following base data was utilized for the preliminary roundabout analysis:

1. Projected 2035 AM & PM peak hour turning movements at US-40 and Elk River Rd.
2. Design Vehicle - WB15 (WB-50)
3. Truck Percentage - 2% (based on existing vehicle counts)
4. Aerial Plan

Default Geometric Parameters assumed for RODEL Analysis:

Table 1: Default Geometric Parameters

Geometric/Other Parameter	Value
1. Half Width, V	12 feet (3.70-meters) each-lane
2. Entry Radius, R	80 feet (25-meters)
3. Entry Angle, N	30-degrees
4. Inscribed Circle Diameter (ICD)	160 feet (50-meters)
5. Circulating Roadway Width	Minimum 15 feet (4.67-meters) each lane, Truck Apron may be needed.
6. RODEL Confidence Level (CL) for Operational Characteristics Check	85%
7. Two lanes based on the identified preferred alternative.	

US-40 & Elk River Rd. 2035 AM Peak Analysis:

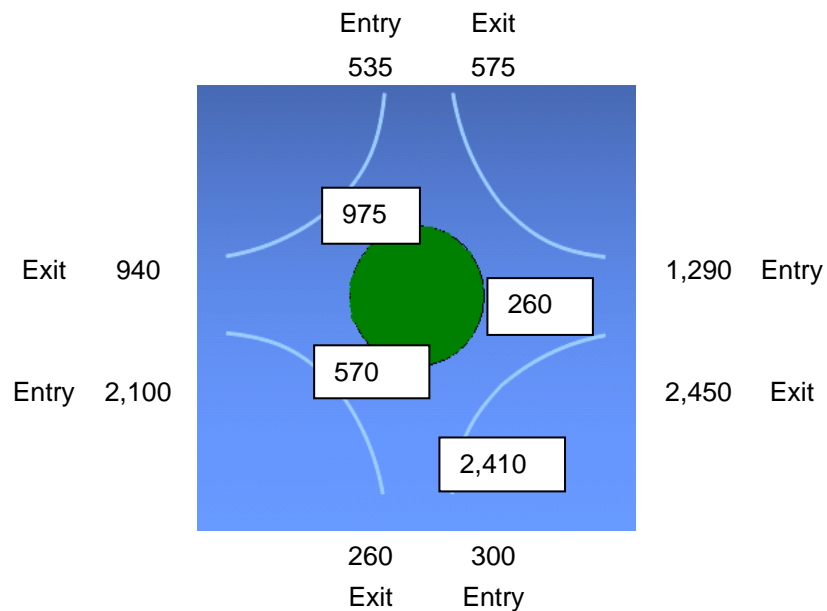
US-40 is assumed to have four lanes (two lanes in each direction) and Elk River Road is assumed to have four lanes (two lanes in each direction) on the southbound approach & two lanes (one lane in each direction) on the northbound approach. The projected 2035 AM peak turning movements at the intersection are listed below:

Figure 1: 2035 AM peak Hour Turning Movements

60	75	400	ELK RIVER RD.	^	400	
<<<<<	V	>>>>>		<<<<<	795	
	V			V	95	
	US 40					
	85	^		^		
	1,925	>>>>>		<<<<<	^	>>>>>
	90	V		85	90	125

2035 AM peak hour turning movements were then converted to roundabout volumes (entering and circulating) listed below: Entering volumes equal the total approach volumes unless a right turn bypass is provided. In that case the right turn volumes are removed from the calculation. For this initial analysis, no right turn bypass is assumed and all movements will enter the roundabout. Circulating volumes equal all vehicle passing the approach. This includes through movements and left turns from the approach immediately to the left of the subject approach in addition to the left turns from the opposite approach. For example for the SB Elk River Road approach entering volumes equals Right Turns + Through + Left Turns = 60 + 75 + 400 = 535. Circulating volumes for this approach equal WB US 40 Through + WB US 40 LT + NB Elk River Road LT = 795 + 95 + 85 = 975. The conflicting volumes are the total of the entering volumes plus the circulating volumes. Again using the SB Elk River Road leg as an example, the entering 535 vehicles conflict with 975 vehicles circulating past the entry point creating a total conflicting volume of 1,510.

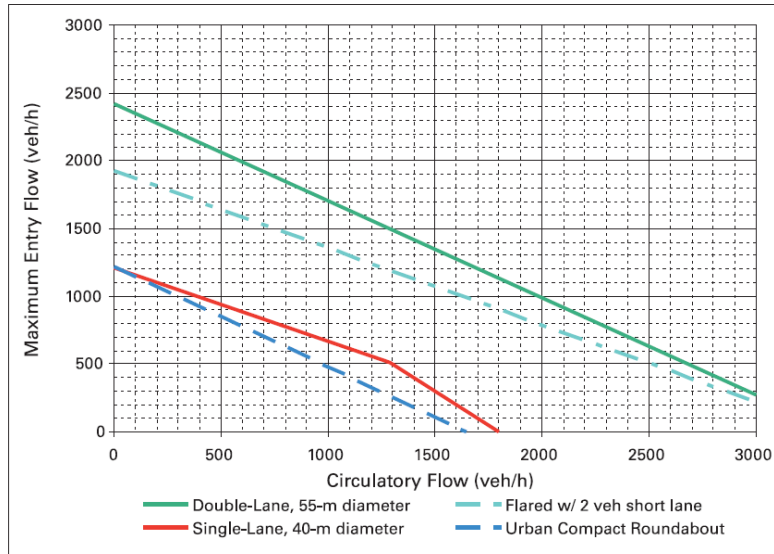
Figure 2: 2035 AM Peak Hour Roundabout Entering and Circulating Volumes



Capacity Analysis based on FHWA Guidelines:

The capacity at each entry is determined based on Exhibit 4-6 (Roundabouts - An Informational Guide, page 89). This analysis is based on the relationship between entry and circulating volumes shown in the referenced figure. **Figure 3** below reproduces the FHWA figure.

Figure 3: FHWA Capacity Comparison of Single-lane and Double-lane Roundabouts



Roundabouts are designed to operate at no more than 85% of their estimated capacity. Beyond this threshold delays and queues vary significantly from their mean values and can break down.

Table 2 below depicts the V/c analysis for a double-lane roundabout with a 160 foot inscribed circle diameter (ICD). The analysis indicates that the eastbound US-40 entry will operate over capacity with a V/c ratio of 1.05 (>0.85) during the AM peak hour.

Table 2: Capacity Analysis

Leg	Circulating Volume (vph)	Entering Flow (vph)	Capacity of Entry* (vph)	V/C Ratio	Remarks
Eastbound US-40	570	2,100	2,000	1.05	>0.85, over capacity
Northbound Elk River Rd.	2,410	300	700	0.43	
Westbound US-40	260	1,290	2,200	0.59	
Southbound Elk River Rd.	975	535	1,700	0.31	

*Capacity of the Entry varies based on Circulating volumes as shown in figure __ above.

Conflicting Volumes

The total circulating and entering volume on the eastbound and northbound approaches exceed the normal range (2,000 to 2,200 vehicles per hour) for a double lane roundabout. **Table 3** shows the total conflicting volumes on each approach. Capacity varies as shown in the FHWA figure shown earlier.

Table 3: Circulating and Entering Volumes

Leg	Circulating + Entering Volume (vph)
Eastbound US-40	2,670
Northbound Elk River Rd.	2,710
Westbound US-40	1,550
Southbound Elk River Rd.	1,510

A three-lane approach and a third eastbound lane within roundabout will be required to accommodate and improve the capacity during the AM peak hour. The FHWA guide however does not provide guidance for analyzing three lane roundabouts. Analysis of a three lane roundabout will need be conducted with RODEL only.

RODEL Analysis:

Based on the default geometric parameters listed earlier, RODEL was used to determine the roundabout Level of Service (LOS) based on average vehicle delay graded A-F (similar to reporting of other intersection types). A two-lane roundabout (160 foot ICD) was analyzed based on the preferred alternative recommendation of four lanes on US 40. The RODEL analysis indicates that the roundabout will operate at LOS F during the AM peak period in 2035. The traffic volumes at the eastbound US-40 and northbound Elk River Rd. entries will exceed capacity. Significant delay and queuing will occur at these entries.

Figure 4: RODEL Analysis Results: AM - Two Lane Roundabout

```

C:\WINDOWS\system32\cmd.exe
5:10:09 US40 & ELK RIVER 2035 AM REVISED 61
E (m) 10.00 10.00 10.00 10.00 TIME PERIOD min 90
L' (m) 100.00 50.00 100.00 100.00 TIME SLICE min 15
U (m) 7.40 7.40 7.40 7.40 RESULTS PERIOD min 15 75
RAD (m) 25.00 25.00 25.00 25.00 TIME COST $/hr 15.00
PHI (d) 30.00 30.00 30.00 30.00 FLOW PERIOD min 15 75
DIA (m) 50.00 50.00 50.00 50.00 FLOW TYPE pcu/veh UEH
GRAD SEP 0 0 0 0 FLOW PEAK am/op/pm AM

LEG NAME PCU FLOWS <1st exit 2nd etc...U> FLOF CL FLOW RATIO FLOW TIME
EB US40 1.03 90 1925 85 0 1.00 85 0.75 1.125 0.75 15 45 75
NB ELK RVR 1.03 125 90 85 0 1.00 85 0.75 1.125 0.75 15 45 75
WB US40 1.03 400 795 95 0 1.00 85 0.75 1.125 0.75 15 45 75
SB ELK RVR 1.03 60 75 400 0 1.00 85 0.75 1.125 0.75 15 45 75

MODE 2
FLOW veh 2346 335 1441 598
CAPACITY veh 2089 714 2360 1747
AUE DELAY mins 3.91 0.15 0.07 0.05
MAX DELAY mins 8.20 0.22 0.10 0.07
AUE QUEUE veh 188 1 2 1
MAX QUEUE veh 291 1 2 1
AUDEL $ 118.8
L O $ F
UEH HRS 155.7
COST $ 2335.1

F1mode F2direct F3peak CtrlF3rev F4fact F6stats F8econ F9prnt F10run Esc
Ins
  
```

At least a third eastbound entering lane and a third circulating lane within the roundabout will be required at this intersection during the AM peak in 2035 to operate at an acceptable LOS. Since the directional split on US 40 is so pronounced (60/40) the PM analysis was reviewed to determine the roundabout geometry to accommodate the 2035 PM volumes.

US-40 & Elk River Rd. 2035 PM Peak Analysis:

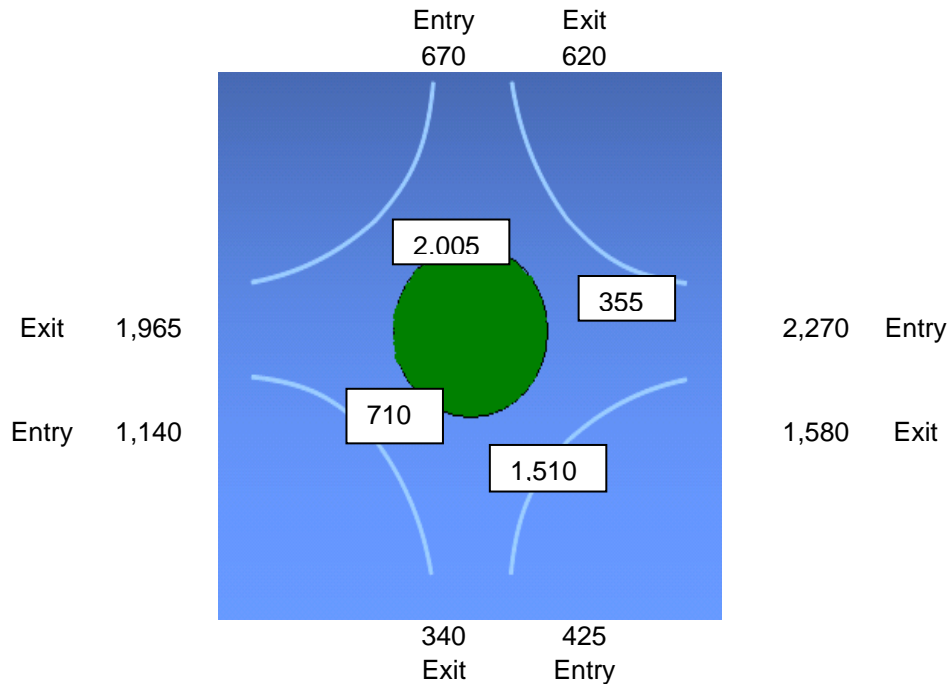
The preferred alternative for US-40 will have four lanes (two lanes in each direction) and Elk River Road is assumed to have four lanes (two lanes in each direction) on the southbound approach & two lanes (one lane in each direction) on the northbound approach. The projected 2035 PM peak turning movements at the intersection are listed below:

Figure 5: 2035 PM Peak Hour Turning Movements

95	100	475	ELK RIVER RD.	^	425
<<<<<	V	>>>>>		<<<<<	1,710
	V			V	135
	US 40				
	95	^		^	
	940	>>>>>		<<<<<	^ >>>>>
	105	V		160	100 165

2035 PM peak hour turning movements were then converted to roundabout volumes (entering and circulating) listed below:

Figure 6: 2035 PM Peak Hour Roundabout Entering and Circulating Volumes



Capacity Analysis based on FHWA Guidelines:

The V/c analysis assuming a double-lane roundabout with a 160 foot inscribed circle diameter (ICD) indicates the westbound US-40 entry will operate over capacity with a V/c ratio of 1.06 during the PM peak hour.

Table 4: Capacity Analysis

Leg	Circulating Volume (vph)	Entering Flow (vph)	Capacity of Entry* (vph)	V/C Ratio	Remarks
Eastbound US-40	710	1,140	1,900	0.54	
Northbound Elk River Rd.	1,510	425	1,300	0.33	
Westbound US-40	355	2,270	2,150	1.06	>0.85, over capacity
Southbound Elk River Rd.	2,005	670	1,000	0.67	

*Capacity of the Entry varies based on Circulating volumes as shown in figure __ above.

Conflicting Volumes

The total circulating and entering volume on the westbound and southbound approaches exceed the normal range (2,000 to 2,200 vehicles per hour) for a double lane roundabout, hence, at least a three-lane approach and a third southbound and westbound lane within roundabout will be required to improve the capacity during the PM peak hour.

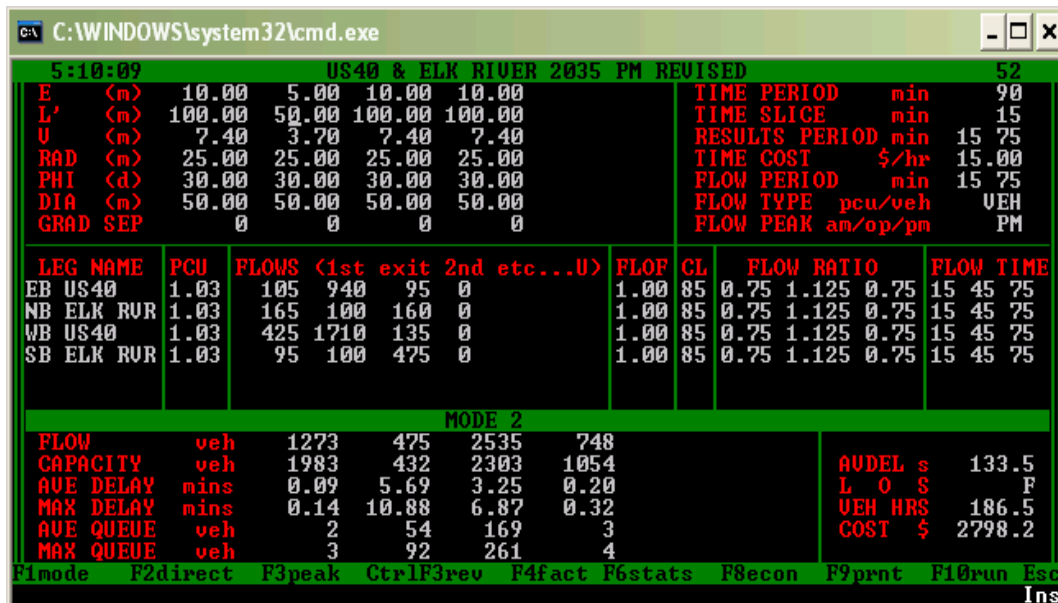
Table 5: Circulating and Entering Volumes

Leg	Circulating + Entering Volume (vph)
Eastbound US-40	1,850
Northbound Elk River Rd.	1,935
Westbound US-40	2,625
Southbound Elk River Rd.	2,675

RODEL Analysis:

Based on the default geometric parameters listed earlier, RODEL was used to determine the roundabout Level of Service (LOS) based on average vehicle delay graded A-F (similar to reporting of other intersection types). A two-lane roundabout (160 foot ICD) was analyzed based on the preferred alternative recommendation of four lanes on US 40. The RODEL analysis indicates that the roundabout will operate at LOS F during the PM peak period in 2035. The traffic volumes at the westbound US-40 entry will exceed capacity. Significant delay and queuing will occur at these entries.

Figure 7: RODEL Analysis Results: PM – Two Lane Roundabout



Because of the heavy westbound right turn volumes during the PM peak hour, a westbound right-turn bypass lane on US-40 is considered. With this improvement the intersection will operate at LOS E.

Figure 8: RODEL Analysis Results: PM - Two Lane Roundabout w/ Bypass

LEG NAME	PCU	FLOWS (1st exit 2nd etc...U)	FLOP	CL	FLOW RATIO	FLOW TIME
EB US40	1.03	105 940 95 0	1.00 85	0.75	1.125 0.75	15 45 75
NB ELK RVR	1.03	165 100 160 0	1.00 85	0.75	1.125 0.75	15 45 75
WB US40	1.03	0 1710 135 0	1.00 85	0.75	1.125 0.75	15 45 75
SB ELK RVR	1.03	95 100 475 0	1.00 85	0.75	1.125 0.75	15 45 75

MODE 2						
FLOW	veh	1273	475	2061	748	
CAPACITY	veh	1972	432	2303	898	AUDEL s 55.0
AUE DELAY	mins	0.09	5.19	0.37	1.13	L O S E
MAX DELAY	mins	0.13	10.51	0.76	2.60	UEH HRS 69.6
AUE QUEUE	veh	2	50	13	14	COST \$ 1043.8
MAX QUEUE	veh	3	81	24	35	

To provide adequate capacity in the PM, at a minimum a two lane roundabout with a westbound right turn bypass would be necessary. Since this configuration would essentially be operating at capacity, a third entering lane and third circulating lane are preferable for WB US 40 traffic.

Revised Geometry

Based on the above presented analysis, two revised roundabout geometries were tested in RODEL to determine their capacity to handle AM and PM peak volumes.

The first is a roundabout with three circulating lanes in each direction on US-40 and a two circulating lanes for south and north bound traffic. Given this geometry the RODEL analysis indicates that the intersection will operate at LOS B during the AM peak hour & LOS C during the PM peak hour in 2035.

Figure 9: RODEL Analysis Results: AM – Three Circulating Lanes EB and WB

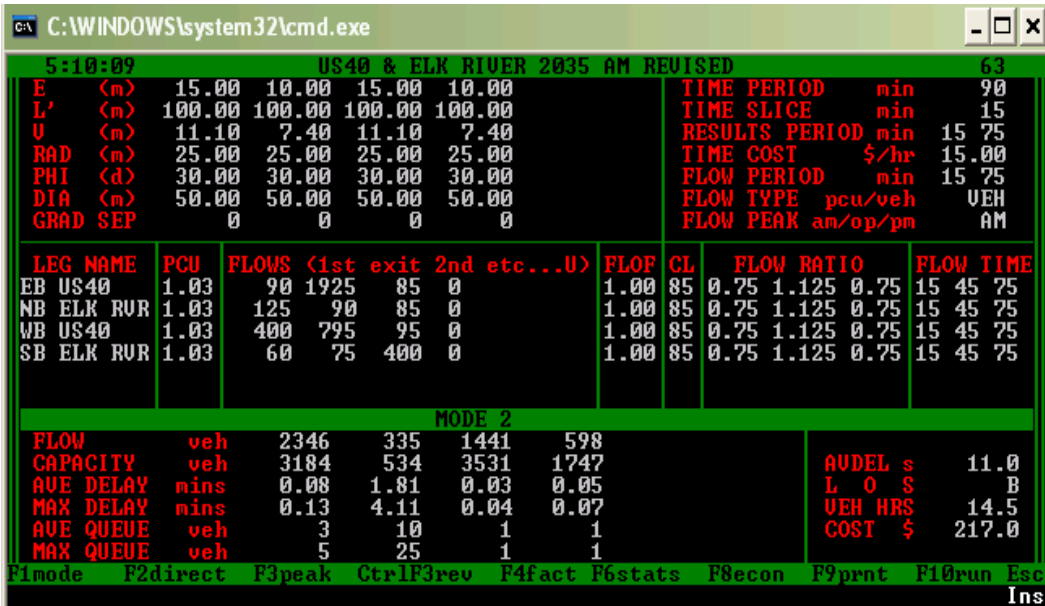
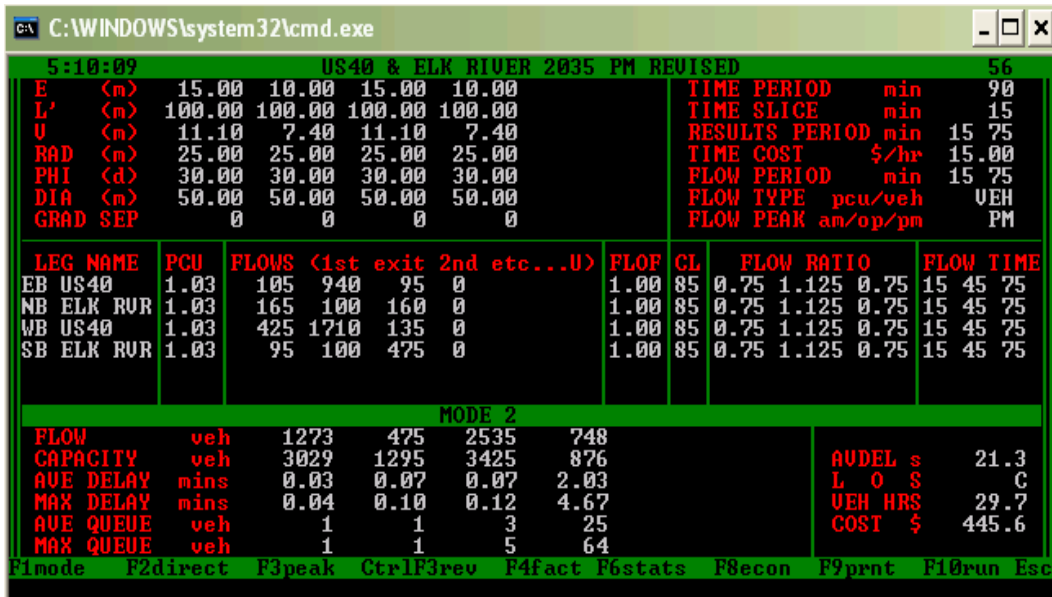


Figure 10: RODEL Analysis Results: PM - Three Circulating Lanes EB and WB



The second geometry option included a roundabout with two circulating lanes for north south, and west bound traffic and three circulating lanes for eastbound traffic. For this configuration to work, a westbound right-turn bypass lane is provided. This configuration will operate at LOS B during the AM peak hour & LOS D during the PM peak hour in 2035.

Figure 11: RODEL Analysis Results: AM – WB RT Bypass, Three Circulating Lanes EB

C:\WINDOWS\system32\cmd.exe													
5:10:09 US40 & ELK RIVER 2035 AM REVISED 65													
E	(m)	15.00	10.00	10.00	10.00	TIME PERIOD	min	90					
L'	(m)	100.00	100.00	100.00	100.00	TIME SLICE	min	15					
U	(m)	11.10	7.40	7.40	7.40	RESULTS PERIOD	min	15	75				
RAD	(m)	25.00	25.00	25.00	25.00	TIME COST	\$/hr	15.00					
PHI	(d)	30.00	30.00	30.00	30.00	FLOW PERIOD	min	15	75				
DIA	(m)	50.00	50.00	50.00	50.00	FLOW TYPE	pcu/veh	VEH					
GRAD SEP		0	0	0	0	FLOW PEAK	am/op/pm	AM					
LEG NAME	PCU	FLOWS (1st exit 2nd etc...U)				FLOF	CL	FLOW RATIO		FLOW TIME			
EB US40	1.03	90	1925	85	0	1.00	85	0.75	1.125	0.75	15	45	75
NB ELK RVR	1.03	125	90	85	0	1.00	85	0.75	1.125	0.75	15	45	75
WB US40	1.03	0	795	95	0	1.00	85	0.75	1.125	0.75	15	45	75
SB ELK RVR	1.03	60	75	400	0	1.00	85	0.75	1.125	0.75	15	45	75
MODE 2													
FLOW	veh	2346	335	994	598						AUDEL s	12.2	
CAPACITY	veh	3184	534	2351	1747						L O S	B	
AVE DELAY	mins	0.08	1.81	0.04	0.05						VEH HRS	14.5	
MAX DELAY	mins	0.13	4.11	0.06	0.07						COST \$	217.7	
AVE QUEUE	veh	3	10	1	1								
MAX QUEUE	veh	5	25	1	1								
F1mode F2direct F3peak CtrlF3rev F4fact F6stats F8econ F9prnt F10run Esc													

Figure 12: RODEL Analysis Results: PM – WB RT Bypass, Three Circulating Lanes EB

C:\WINDOWS\system32\cmd.exe													
5:10:09 US40 & ELK RIVER 2035 PM REVISED 58													
E	(m)	15.00	10.00	10.00	10.00	TIME PERIOD	min	90					
L'	(m)	100.00	100.00	100.00	100.00	TIME SLICE	min	15					
U	(m)	11.10	7.40	7.40	7.40	RESULTS PERIOD	min	15	75				
RAD	(m)	25.00	25.00	25.00	25.00	TIME COST	\$/hr	15.00					
PHI	(d)	30.00	30.00	30.00	30.00	FLOW PERIOD	min	15	75				
DIA	(m)	50.00	50.00	50.00	50.00	FLOW TYPE	pcu/veh	VEH					
GRAD SEP		0	0	0	0	FLOW PEAK	am/op/pm	PM					
LEG NAME	PCU	FLOWS (1st exit 2nd etc...U)				FLOF	CL	FLOW RATIO		FLOW TIME			
EB US40	1.03	105	940	95	0	1.00	85	0.75	1.125	0.75	15	45	75
NB ELK RVR	1.03	165	100	160	0	1.00	85	0.75	1.125	0.75	15	45	75
WB US40	1.03	0	1710	135	0	1.00	85	0.75	1.125	0.75	15	45	75
SB ELK RVR	1.03	95	100	475	0	1.00	85	0.75	1.125	0.75	15	45	75
MODE 2													
FLOW	veh	1273	475	2061	748						AUDEL s	29.1	
CAPACITY	veh	3030	1295	2271	878						L O S	D	
AVE DELAY	mins	0.03	0.07	0.55	1.33						VEH HRS	36.9	
MAX DELAY	mins	0.05	0.11	1.24	3.05						COST \$	553.4	
AVE QUEUE	veh	1	1	19	17								
MAX QUEUE	veh	1	1	41	42								
F1mode F2direct F3peak CtrlF3rev F4fact F6stats F8econ F9prnt F10run Esc													

Conclusion

A two lane roundabout will not provide adequate service given the projected volumes at this intersection. To adequately meet the intersection demands the roundabout at US-40 &

Elk River Road intersection will require one of the following geometric configurations to operate at an acceptable LOS in 2035.

1. A roundabout with three circulating lanes in eastbound and westbound direction on US-40 and two circulating lanes for the north and south bound traffic.

OR

2. A roundabout with a westbound right-turn bypass lane, two circulating lanes for all directions except eastbound which will require three circulating lanes

This analysis shows that, to operate at an acceptable level of service, at least three lanes must be provided in some locations within the roundabout. Three lane roundabouts do not exhibit the same safety benefits as smaller roundabouts, especially in the off peak hours as vehicles can cut across the circulating lanes to limit their change in direction. This allows vehicles to maintain higher speeds through larger roundabouts. Many of the safety benefits of roundabouts are due to the reduced entry and circulating speeds.

In addition, professional experience shows that roundabouts work best when the volumes on the approaches are roughly balanced. In this case US 40 volumes are many times the approach volumes on Elk River Road. In such situations, the large volume approaches are likely to dominate the roundabout causing significant side street delay. The three lanes in addition to the large US 40 volumes will combine so that the Elk River Road approaches will operate more as a stop condition than as a yield necessary for successful roundabout operations.

Based on this analysis a three lane roundabout was screened from consideration as an alternative for the US 40 and Elk River Road intersection. Because a two lane roundabout does not have adequate capacity to handle the projected volumes two lane and smaller roundabouts at this intersection were also screened from consideration.

J:_Transportation\WVXV4800 Steamboat\Transportation Analysis\RODEL\RA_Elk River_Revised_10-12-09_fb.doc