APPENDIX DD
MOT/QUEUE ANALYSIS

M E M O R A N D U M

DATE: May 21, 2013

TO: Tom Seeman, PE
Project Manager
Indiana Department of Transportation

FROM: Lee E. Klieman, PE, PTOE
Transportation Engineer
Bernardin, Lochmueller and Associates, Inc.

SUBJECT: Maintenance of Traffic and Queue Analysis;

Transmitted, herein, is an analysis to evaluate potential future queuing in the I-69 corridor during construction of the I-69 facility. The purpose of this memorandum is to summarize our recommendations pertaining to queuing during maintenance of traffic during construction of Section 5 of I-69. The construction of I-69 will occur primarily on the existing facility of SR 37, which is a multi-lane facility. While construction occurs, it is presently planned that a minimum of two lanes would remain open to traffic. A three-lane section in urban Bloomington would be reduced to two lanes and two lanes in the rural portion would continue to be maintained during construction). Please see Appendix B of this memo for Maintenance of Traffic Typical Cross Sections. It is INDOT's maintenance of traffic policy preference to maintain the same number of lanes during construction as available before construction. It is under these assumptions that the analysis was completed.

Analysis Parameters

Future volumes from 2020 were used for the analysis. Daily volumes for 2020 were estimated using the existing counts and output from the Indiana Statewide Travel Demand Model (ISTDM) version 6.2. Daily volume output from the ISTDM for the I-69 corridor in the year 2020 were compared to base year (2010) outputs from the ISTDM to create a growth rate. The 2020 ISTDM traffic assignment was completed using the ISTDM 2020 TAZ layer combined with the 2015 network (this network includes I-69 Sections 1 through 4 open to traffic, and existing SR 37 north of the I-69/SR 37 interchange.) To calculate daily 2020 volumes, these growth rates were then applied to the existing counts taken on SR 37 which were performed for the I-69 Corridor Travel Model update. Traffic counts were performed in 2010 or 2011. Both overall volumes and truck volumes were calculated in this manner. The daily distribution of traffic volumes from the existing traffic counts was applied to the forecasted volumes to create the spread of traffic across twenty-four hours.

The hourly distribution of trucks was also calculated from the existing traffic counts and applied to the 2020 forecasted volumes. The truck percentage (of total traffic) for each hour was then calculated. Three locations were chosen for queuing analysis.

1) SR 37 north of 3rd Street – this section was chosen because it represents the most traffic in the urban section, where a three-lane section would be reduced to two lanes during construction.
2) SR 37 north of Walnut Street – this section was chosen because it represents the most traffic in the rural section, where a two-lane section would be increased to three lanes

in the permanent condition after construction.

3) SR 37 north of Sample Road – this section represents the most traffic in the rural section, where a two-lane section would be upgraded to an interstate facility.

Analysis Tool

The queuing analysis was performed using QuickZone 2.0 (officially the QuickZone Delay Estimation Guide). This program was developed for and with the Federal Highway Administration (FHWA). It's an Excel-based program that allows the user to input a number of work zone parameters. The inputs include traffic volumes, work zone duration, etc. The user also inputs the capacity for the roadways involved, both in the workzone and outside the workzone. For the purposes of the analysis, trucks were considered to be any single-unit or multi-unit truck. The capacities through the work zones were taken from default values found in the Highway Capacity Manual (2010). The HCM shows default capacity of 1,400 vehicles per lane for a long-term construction zone with a lane reduction from two lanes to one lane. The default capacity for a lane reduction from three lanes to two lanes is 1,450 vehicles per lane.

Analysis Results

1) SR 37 north of 3rd Street Analysis output from QuickZone indicates that there will be no sustained queuing during construction at this location for reductions from three lanes to two lanes.

2) SR 37 north of Walnut Street Analysis output from QuickZone indicates that there will be

no sustained queuing during construction at this location for maintaining two travel lanes.

3) SR 37 north of Sample Road Analysis output from Quickzone indicates that there will be no sustained queuing during construction at this location with two lanes open to traffic. A separate analysis (attached to this memo) was conducted at location 3 to test the effects of reducing the two-lane section to one lane during construction. The results indicate that there would be sustained queuing during construction at this location under these assumptions. The northbound flow results show sustained queuing from 2:00-7:00 PM with a maximum queue of around 4.1 miles. The southbound flow results show sustained queuing from 6:00-11:00 AM and from 3:00-6:00 PM, with a maximum queue of around 1.5 miles in the first queuing period (AM) and a maximum queue of around 0.6 miles in the second queuing period (PM). This analysis is based on 2020 traffic forecasts. As provided in the IDM, a benefit-cost (B/C) analysis was performed to compare added user delays and added construction costs for the southbound scenario. This B/C analysis found that the benefits of maintaining two southbound lanes during construction were significantly less than the costs. In other words, the increased construction cost of maintaining two lanes does not provide significant benefits to those who will use the facility.

Interpretation of Results

The workzone capacity of 1,400 vehicles per lane per hour (and 1,450 vehicles per lane per hour)

is below what QuickZone recommends for workzone capacities. QuickZone defaults to the HCM 2000 methodology which suggests a workzone capacity of 1,600 vehicles per lane per hour. However, the HCM 2010 differentiates between short-term construction zones (where the 1,600 vehicles per lane per hour capacity remains) and long-term construction zones (1,400 vehicles per lane per hour).

A general observation regarding the elasticity of results was made with regard to various input parameters. The truck percentages (which are used to calculate the passenger car equivalent factors) do not have a large impact on the queuing results. Queuing results are much more sensitive to the workzone capacity. The QuickZone tool does not permit specification of variations in geometric characteristics and their influence upon work zone capacity. Exhibit 10-14 in the HCM 2010 presents the long-term work zone default capacities. This exhibit also shows the observed workzone capacities from various studies around the country, from which the default values were derived. The observed capacities range from a low of 950 vehicles per hour to a high of 1,900 vehicles per hour. Although a range of workzone capacities was reported in the HCM, there is no indication of when the differing capacities would be applicable or what characteristics might have contributed to them. The HCM does include adjustment factors for free-flow speed (which are used to estimate capacity) on highways, but these adjustments are meant to decrease the capacity from an ideal state on a multi-lane highway.

Conclusions and Recommendations

The costs and impacts of construction of the Preferred Alternative assume that two travel lanes

would remain open for maintenance of traffic during construction. The results of the queuing analysis indicate that there would be no sustained queuing where two travel lanes remain open to traffic. However, sustained queuing would be observed in the Sample Road location under the alternative assumption that only one travel lane remains open to traffic.

As stated previously, it is INDOT's maintenance of traffic policy preference to maintain the same number of lanes during construction as available before construction. Section 5's Final EIS / ROD assumes two travel lanes will be maintained throughout the project. One exception could include strengthening shoulders during non-peak travel hours. If INDOT or its designer chooses to not maintain two travel lanes in each direction, the IDM contains methods to address instances when the preferred number of lanes is not maintained during construction. The methodology includes B/C analysis. Such an analysis is included in Appendix A of this memo. A B/C analysis is also discussed extensively in the following memo from Dustin Riechmann, BLA to Tom Seeman, INDOT. The highway design team may consider alternatives to the current maintenance of traffic assumptions. Any final determination would occur in design, with appropriate analytical justification.

M E M O R A N D U M

DATE: May 21, 2013

TO: Tom Seeman, PE, Project Manager, Indiana Department of Transportation

FROM: Dustin B. Riechmann, P.E., PTOE Traffic Engineering Manager
Bernardin, Lochmueller and Associates, Inc.

SUBJECT: Maintenance of Traffic: Benefit Cost Analysis

Transmitted, herein, is a benefit-cost analysis pertaining to maintenance of traffic options for the construction of the I-69 facility with Section 5. A memorandum was previously prepared that summarized findings pertaining to queuing of traffic during construction of Section 5 of I-69. That document provided the following conclusions:

1) **SR 37 north of 3rd Street**

   Analysis output from QuickZone indicates that there will be no sustained queuing during construction at this location for reductions from three lanes to two lanes.

2) **SR 37 north of Walnut Street**

   Analysis output from QuickZone indicates that there will be no sustained queuing during construction at this location because two lanes will be maintained at all times.

3) **SR 37 north of Sample Road**

   Analysis output from QuickZone indicates that there will be sustained queuing during construction at this location if only one lane is maintained instead of two. The northbound flow results show sustained queuing from 2:00-7:00 PM with a maximum queue of

approximately 4.1 miles. The southbound flow results indicate sustained queuing from 6:00-11:00 AM and from 3:00-6:00 PM, with a maximum queue of approximately 1.5 miles in the first queuing period and a maximum queue of approximately 0.65 miles in the second queuing period. A further analysis of this location was made in which a workzone was present but two lanes of travel would remain open to traffic. Under this scenario, there would be no sustained queuing at this location during construction.

Based on these results, it was determined that additional analysis was needed to evaluate the appropriateness of maintaining one lane of traffic during construction for SR 37 north of Sample Road. The purpose of this memorandum is to summarize the benefit-cost analysis completed for this section of the construction staging.

According to INDOT guidelines found in Chapter 81 of the Indiana Design Manual, a cost evaluation should be performed to assess the appropriateness of a construction staging plan when queuing is expected as a result of the workzone. Therefore, a benefit-cost analysis was performed to evaluate the economic impacts to users of the facility.

Northbound Maintenance of Traffic

Based on the queuing analysis, peak queues of up to 4.1 miles are expected for northbound traffic within this section of the construction zone if only one lane of traffic remains open. Given that these queues are excessive and could impact operations at adjacent intersections to the south near Bloomington, it was concluded that two lanes of traffic must be maintained for northbound

traffic during construction for SR 37 north of Sample Road. This would eliminate any sustained queuing, and a benefit-cost analysis was therefore not necessary.

Southbound Maintenance of Traffic

Given that southbound queuing would be much less extensive, yet still significant, it was necessary to prepare a benefit-cost analysis. The purpose of this analysis is to compare anticipated User Costs incurred due to queuing within the construction zone to the additional Construction Costs necessary to reduce these queues.

The User Cost analysis was performed using QuickZone 2.0 (officially the QuickZone Delay Estimation Guide). This program was developed for the Federal Highway Administration (FHWA). In addition to analyzing queues, this tool provides an estimate of User Costs due to workzone delays. The FHWA confirmed the appropriateness of applying QuickZone for completing tradeoff analyses between construction costs and delay costs as recently as December 2011 in their publication "Work Zone Road User Costs – Concepts and Applications."

Since QuickZone was originally developed in 2005, it was necessary to update the unit costs for various motorist impacts to reflect current estimates. Therefore, the following unit costs were updated based upon the most current data available from the respective sources cited by FHWA, which are noted below:

- Average Vehicle Occupancy (2009 National Household Travel Survey, USDOT)

- Average Wage Rates for All Employees and Truck Operators (U.S. Department of Labor Bureau of Labor Statistics 2012 Q1)
- Vehicle Operating Costs for Trucks, Light Duty Trucks and Cars (AAA "Your Driving Costs" 2012)
- Value of Freight (2002 Commodity Flow Survey by Bureau of Transportation Statistics)
- Discount Rate (Wall Street Journal, September 2012)

Using this updated data, QuickZone calculates a Cost per Vehicle-Hour of Delay for both trucks and passenger vehicles. When combined with the total User Delay estimated based upon expected workzone queuing, the User Costs incurred under a given maintenance of traffic plan are calculated.

Based upon an assumed workzone duration of six months, it was estimated that the provision of one southbound travel lane (versus two lanes) would result in total User Costs of approximately $4.06 million.

The anticipated Construction Costs of maintaining a second southbound travel lane were evaluated next. Based upon preliminary engineering, it would be necessary to provide an additional 11 feet of temporary widening and 4 feet of permanent over-widening for a length of approximately 51,500 linear feet in order to maintain two travel lanes throughout construction. The estimated cost of this additional widening is $12 million.

The additional Construction Costs of approximately $12 million would not be justified to avoid anticipated User Costs of approximately $4.06 million. The resulting benefit-cost ratio would be approximately 0.34.

Conclusions and Recommendations

Section 82-5.01 Traffic-Capacity Analysis of INDOT's Design Manual states a desire to maintain the same number of travel lanes during construction that currently exists on a roadway. For instance, if a road has two travel lanes, then INDOT desires to have two travel lanes open during construction. This assumption was used for Section 5's Final EIS in order to provide a more conservative environmental footprint. It also represents a more desirable design standard. However, based on anticipated User Costs and additional Construction Costs, it could be possible to maintain one southbound travel lane during construction for SR 37 north of Sample Road. A Maintenance of Traffic scheme will be finalized in the design phase of the project.

APPENDIX A
Benefit-Cost A ıalysis

Summary of QuickZone Inputs and Outputs - SR 37 North of Sample Road

QuickZone Network Summary

F1 | Link Information

Return to Main

Link #	A Node	B Node	Lanes	Capacity (VPL)	Length (Miles)	FreeFlow Speed (mph)	Jam Density (Vlm/L)	I or O	Type	Position	Description
1	1	2	2	2000	10	55	210	I	M	1	NB Highway Approaching WZ
2	2	3	1	2000	5	55	210	I	WZ	1	NB WorkZone
3	3	4	2	2000	10	55	210	I	M	1	NB Highway Departing WZ
4	2	1	2	2000	10	55	210	O	M	2	SB Highway Departing WZ
5	3	2	1	2000	5	55	210	O	WZ	2	SB WorkZone
6	4	3	2	2000	10	55	210	O	M	2	SB Highway Approaching WZ
7											

Truck Percentages (Inbound = Northbound; Outbound = Southbound)

Inbound - Truck Percentages

	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Weekday	19.00%	24.00%	30.00%	30.00%	24.00%	17.00%	9.00%	12.00%	16.00%	16.00%	20.00%	21.00%	14.00%	18.00%	14.00%	13.00%	8.00%	6.00%	6.00%	10.00%	8.00%	9.00%	10.00%	19.00%
Weekend	19.00%	24.00%	30.00%	30.00%	24.00%	17.00%	9.00%	12.00%	16.00%	16.00%	20.00%	21.00%	14.00%	18.00%	14.00%	13.00%	8.00%	6.00%	6.00%	10.00%	8.00%	9.00%	10.00%	19.00%

Outbound - Truck Percentages

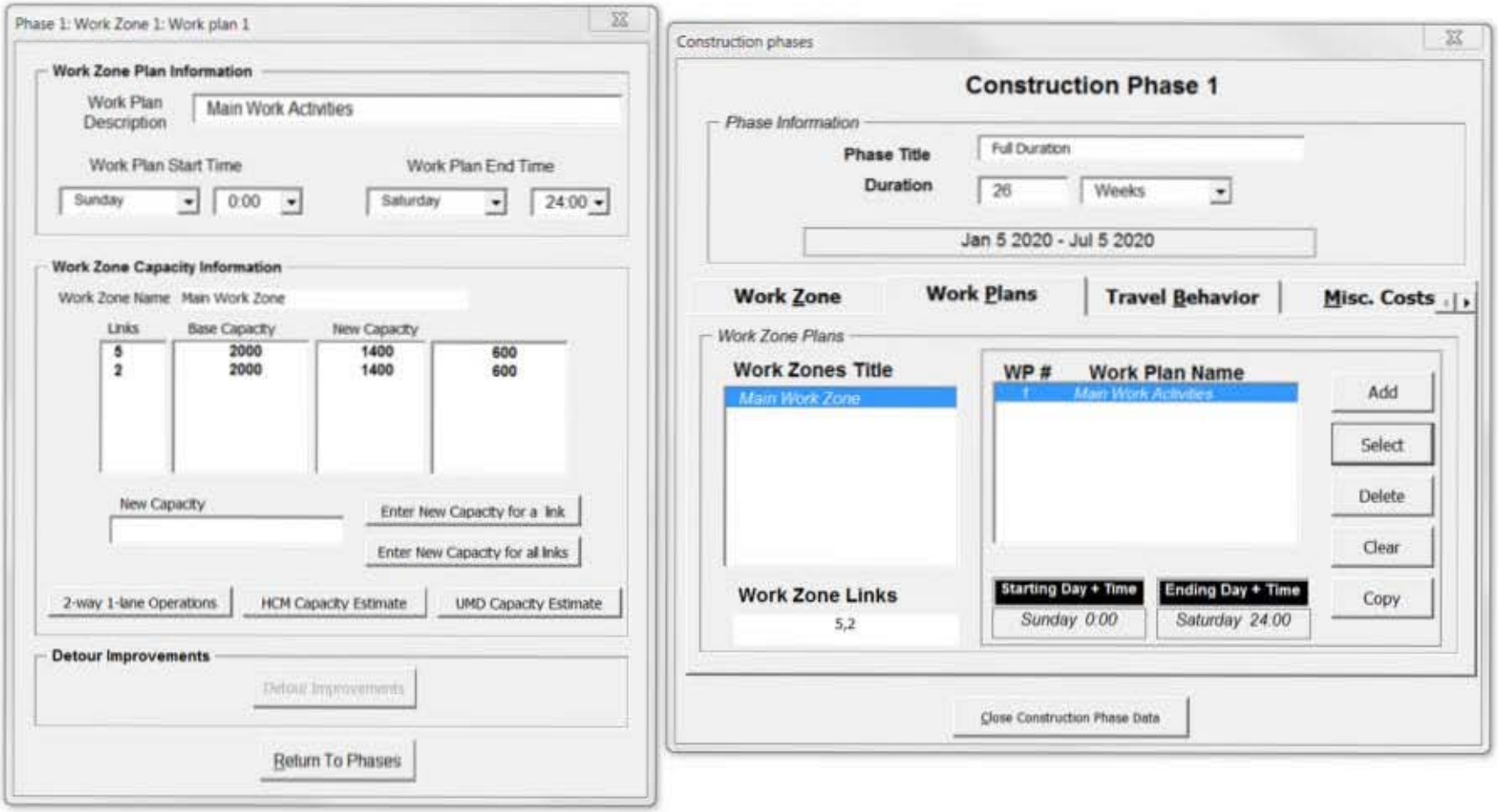
	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Weekday	13.00%	16.00%	32.00%	37.00%	30.00%	23.00%	12.00%	13.00%	17.00%	16.00%	15.00%	18.00%	17.00%	19.00%	12.00%	13.00%	9.00%	5.00%	5.00%	7.00%	8.00%	7.00%	9.00%	14.00%
Weekend	13.00%	16.00%	32.00%	37.00%	30.00%	23.00%	12.00%	13.00%	17.00%	16.00%	15.00%	18.00%	17.00%	19.00%	12.00%	13.00%	9.00%	5.00%	5.00%	7.00%	8.00%	7.00%	9.00%	14.00%

Traffic Demand by Hour (Inbound = Northbound; Outbound = Southbound)

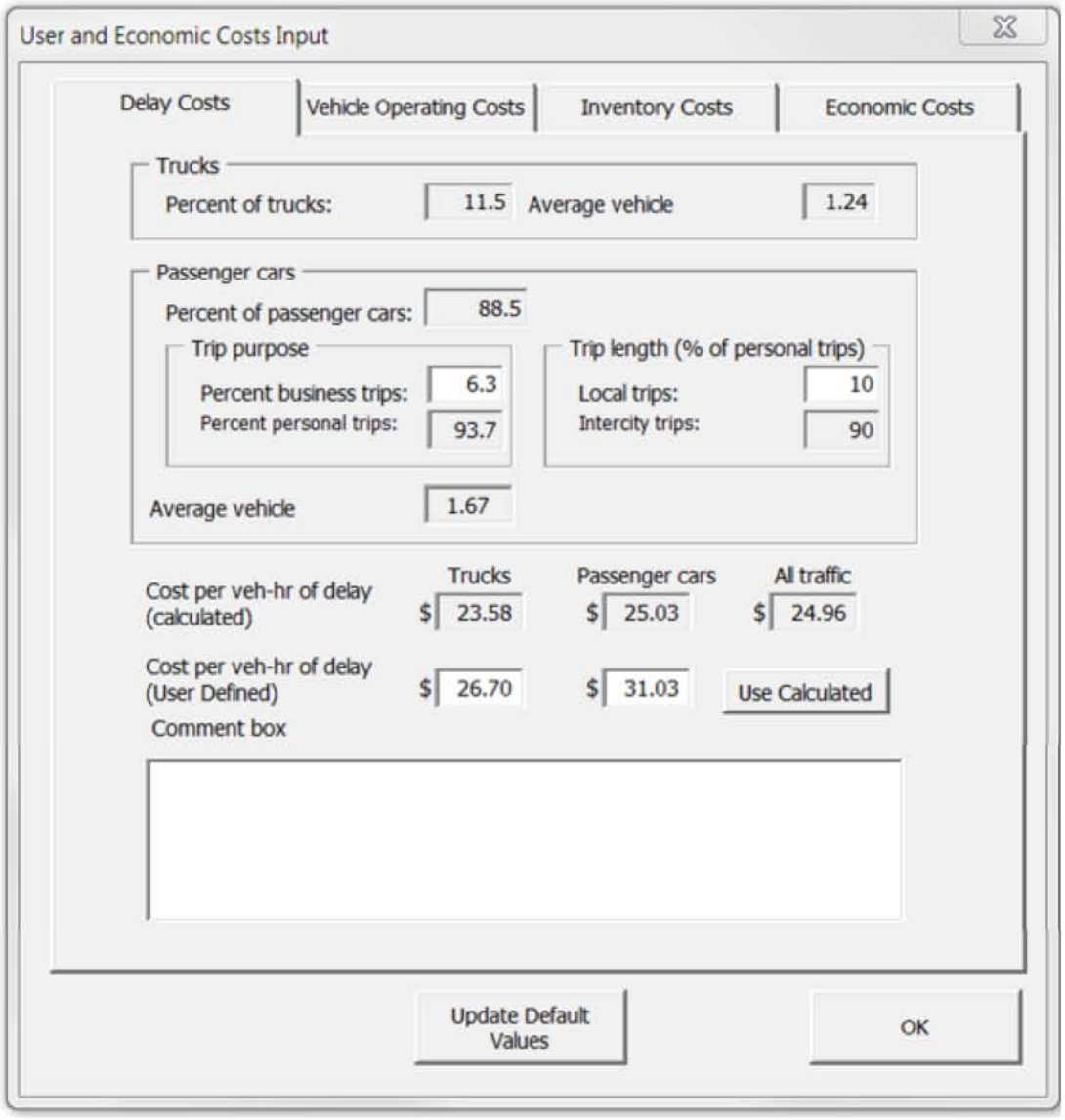
Tuesday

Link	I or O	AADT	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1	I		94	61	52	85	144	382	795	994	1033	823	899	1006	1086	1131	1203	1387	1517	1614	993	711	563	398	250	159
2	I		94	61	52	85	144	382	795	994	1033	823	899	1006	1086	1131	1203	1387	1517	1614	993	711	563	398	250	159
3	I		94	61	52	85	144	382	795	994	1033	823	899	1006	1086	1131	1203	1387	1517	1614	993	711	563	398	250	159
4	O		186	104	64	41	117	269	718	1276	1328	1076	1045	951	1045	942	933	1039	1298	1393	1145	743	600	460	367	241
5	O		186	104	64	41	117	269	718	1276	1328	1076	1045	951	1045	942	933	1039	1298	1393	1145	743	600	460	367	241
6	O		186	104	64	41	117	269	718	1276	1328	1076	1045	951	1045	942	933	1039	1298	1393	1145	743	600	460	367	241

Construction Zone Capacity and Duration Inputs



Delay Costs Input



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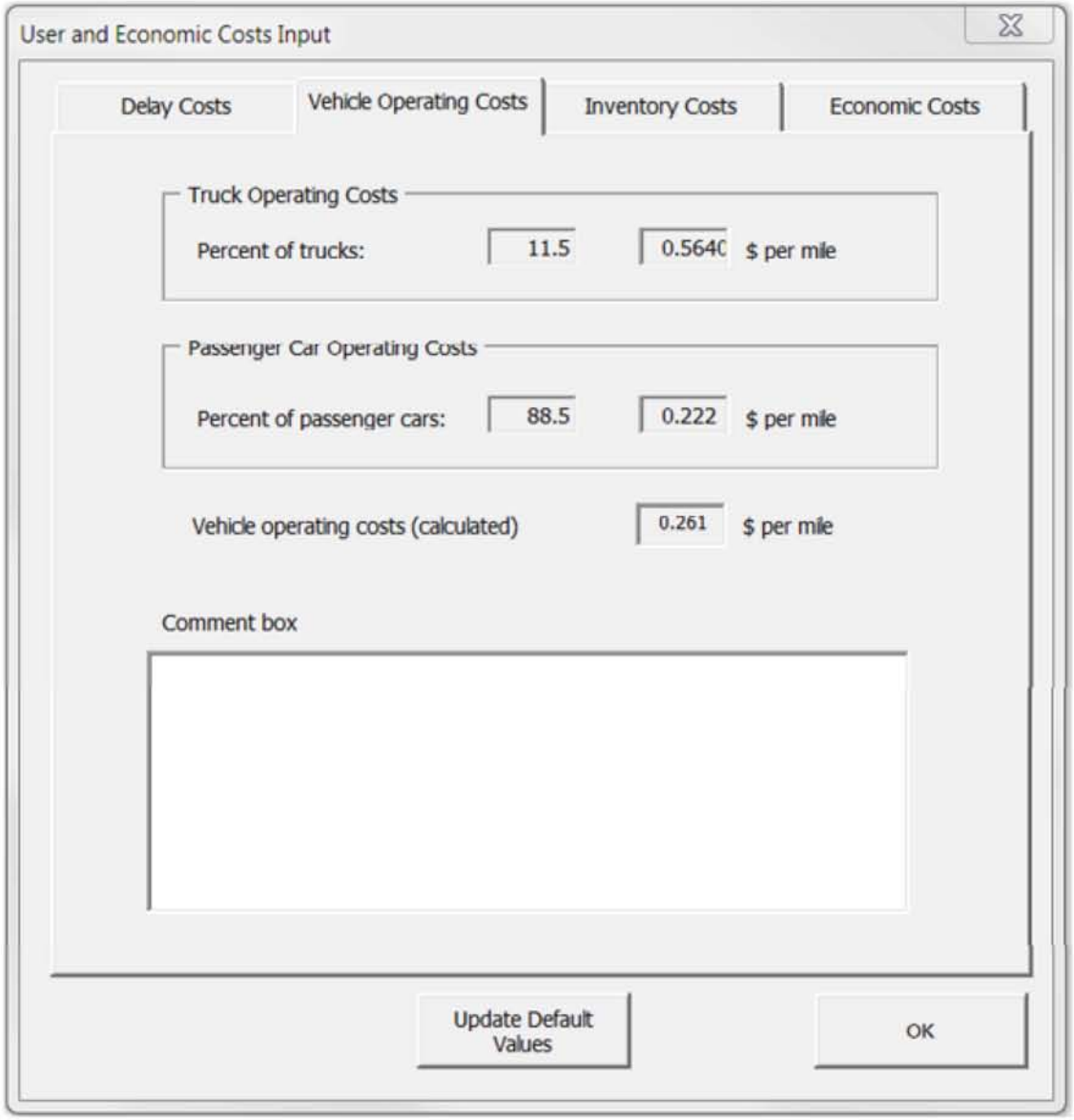
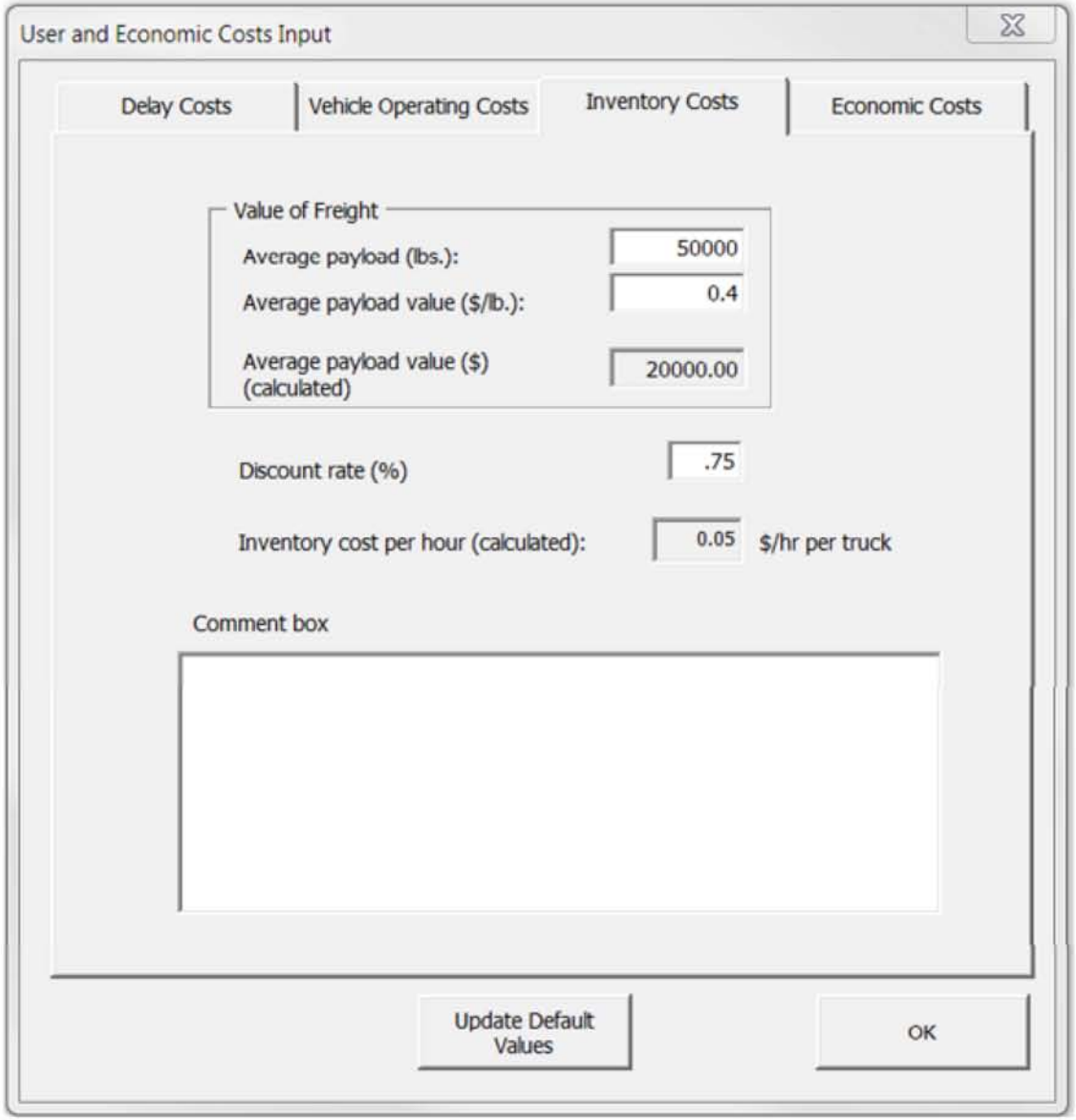
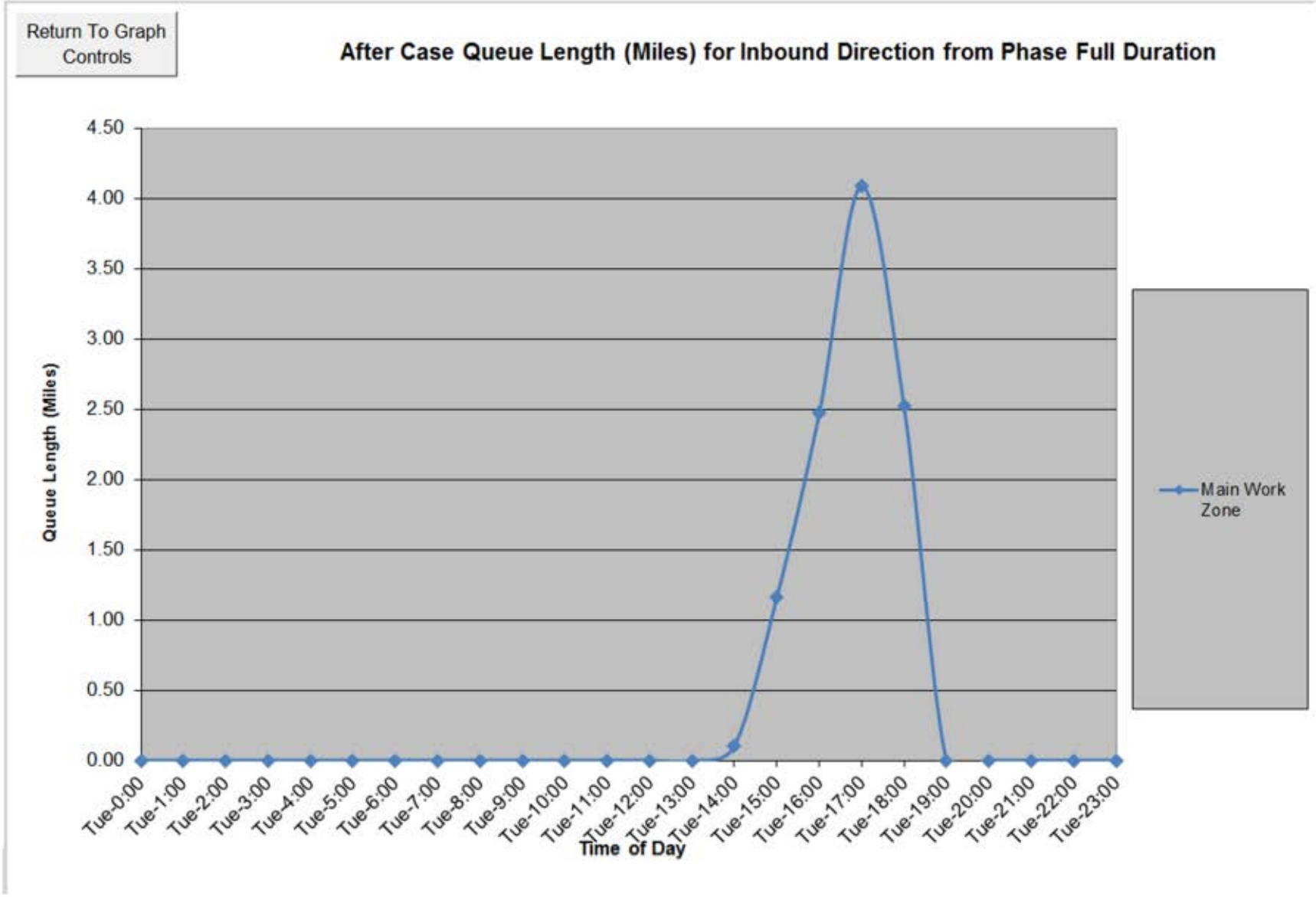


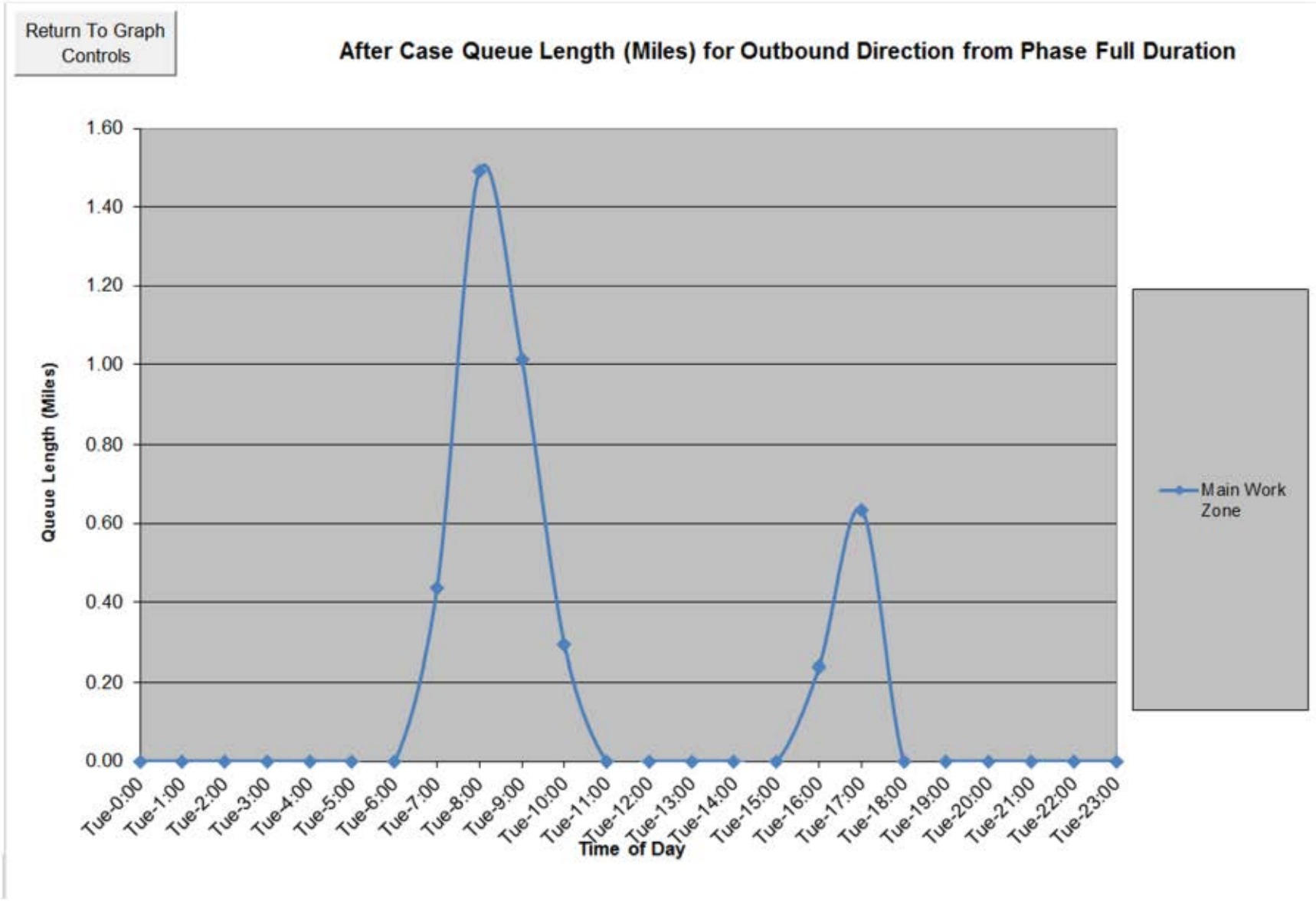
Inventory Costs Input



Projected Northbound Queuing with One Lane Open in Construction Zone



Projected Southbound Queuing with One Lane Open in Construction Zone



Projected User Costs for Northbound Direction with One Lane Open in Construction Zone

Return to Main

Summary Type

Project Summary

Period with highest delay in After Case

Phase	1 - Full Duration
Direction	Inbound
Day/Time	Sunday 17:00

			Total Project User Cost ($)				
	Max Queue (Miles)	Max Delay (min)	Passenger Cars	Truck	Detour	Econ/Misc	Total
Baseline	0	0	$0	$0	$0	$0	$0
After	4.09	36.77	$13,935,231	$1,211,809	$0	$0	$15,147,040
Total	4.09	36.77	$13,935,231	$1,211,809	$0	$0	$15,147,040

Projected User Costs for Southbound Direction with One Lane Open in Construction Zone

Return to Main

Summary Type

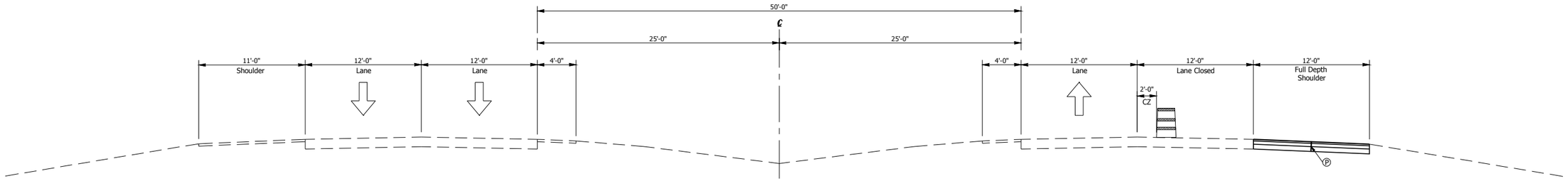
Project Summary

Period with highest delay in After Case

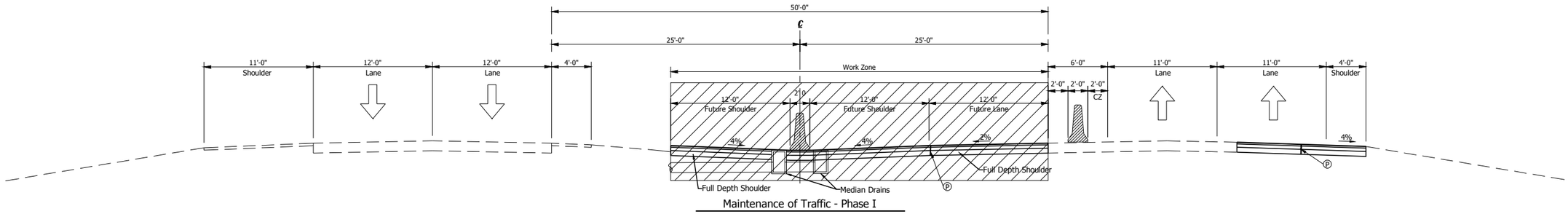
Phase	1 - Full Duration
Direction	Outbound
Day/Time	Sunday 8:00

			Total Project User Cost ($)				
	Max Queue (Miles)	Max Delay (min)	Passenger Cars	Truck	Detour	Econ/Misc	Total
Baseline	0	0	$0	$0	$0	$0	$0
After	1.49	13.42	$3,550,101	$511,209	$0	$0	$4,061,310
Total	1.49	13.42	$3,550,101	$511,209	$0	$0	$4,061,310

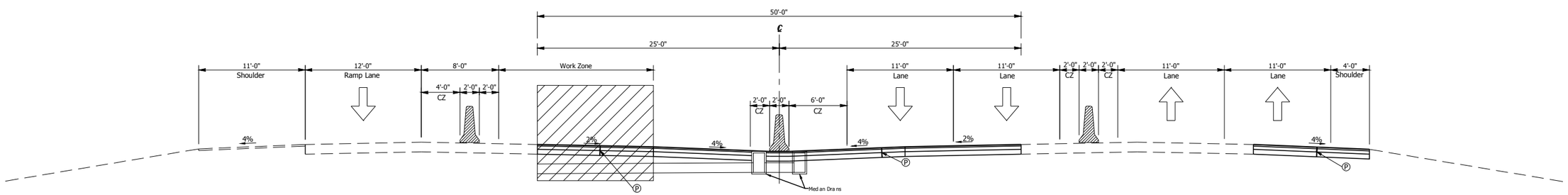
APPENDIX B
Maintenance of Traffic Typical Cross Sections



Maintenance of Traffic
Pre-Construction Shoulder Strengthening



Maintenance of Traffic - Phase I



Maintenance of Traffic - Phase II-A

Ⓣ Temporary Pavement
Ⓟ Permanent Pavement

RECOMMENDED FOR APPROVAL
DESIGN ENGINEER DATE

DESIGNED: DRAWN:
CHECKED: CHECKED:

INDIANA DEPARTMENT OF TRANSPORTATION

MAINTENANCE OF TRAFFIC
REFINED PREFERRED ALTERNATIVE
URBAN SECTION

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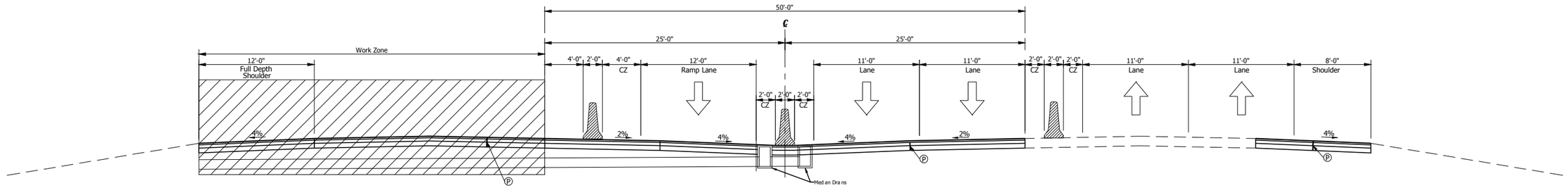
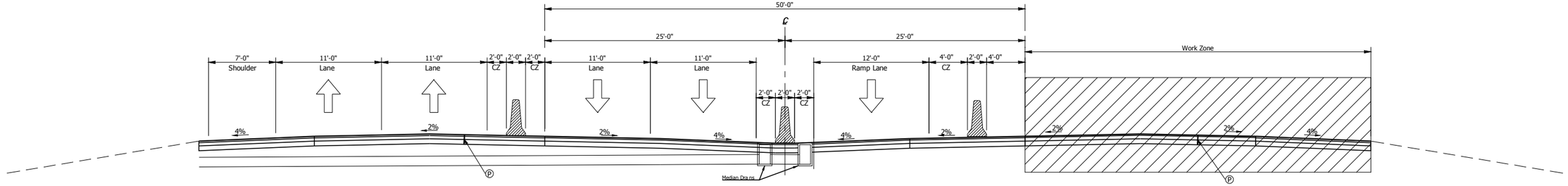


Maintenance of Traffic - Phase II-B



Maintenance of Traffic - Phase III

Ⓣ Temporary Pavement
Ⓟ Permanent Pavement

RECOMMENDED FOR APPROVAL
DESIGN ENGINEER DATE

DESIGNED: DRAWN:

CHECKED: CHECKED:

INDIANA DEPARTMENT OF TRANSPORTATION

MAINTENANCE OF TRAFFIC
REFINED PREFERRED ALTERNATIVE
URBAN SECTION

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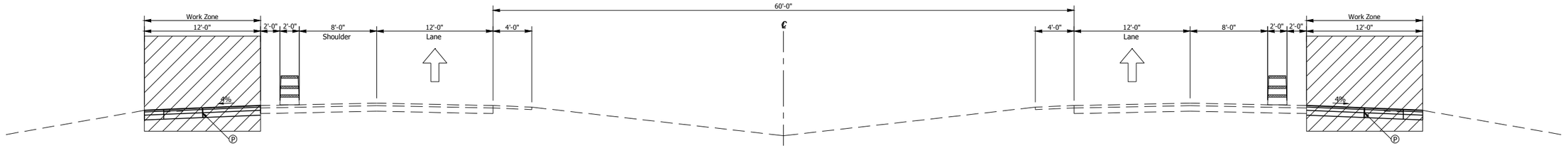
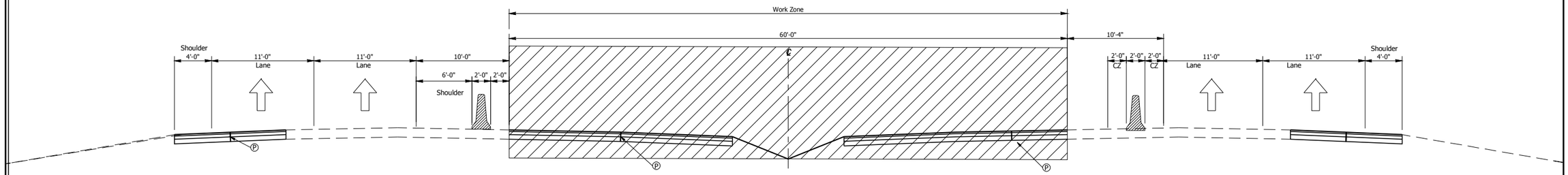
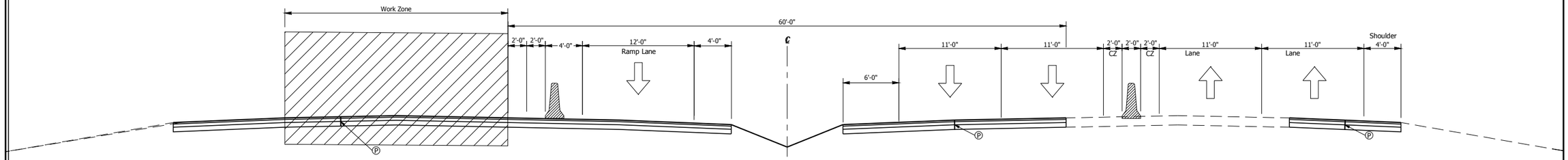


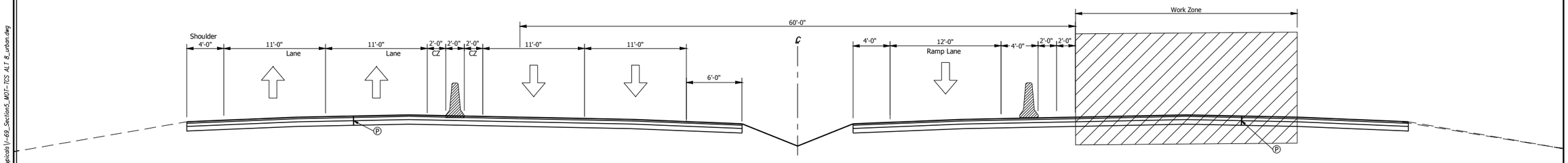
Maintenance of Traffic
Pre-Construction Shoulder Strengthening



Maintenance of Traffic - Phase I



Maintenance of Traffic - Phase II



Maintenance of Traffic - Phase III

Ⓣ Temporary Pavement
Ⓟ Permanent Pavement

RECOMMENDED FOR APPROVAL
DESIGN ENGINEER DATE

DESIGNED: DRAWN:
CHECKED: CHECKED:

INDIANA DEPARTMENT OF TRANSPORTATION

MAINTENANCE OF TRAFFIC
REFINED PREFERRED ALTERNATIVE
Suburban–0.5 mi N. of SR46 to Sample

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	of
CONTRACT	PROJECT
R-31871	

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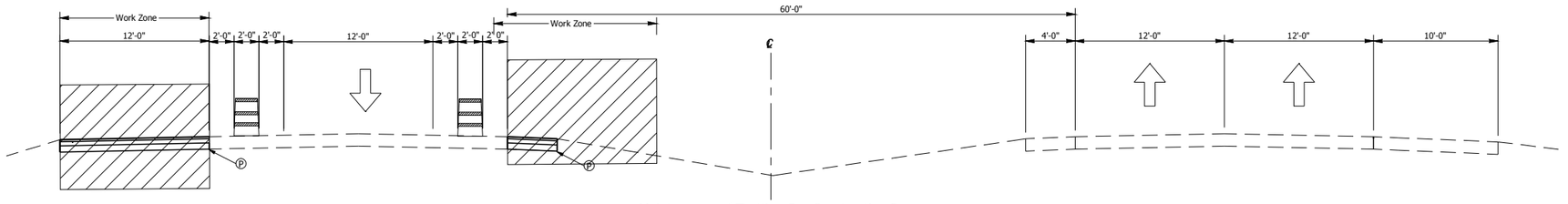
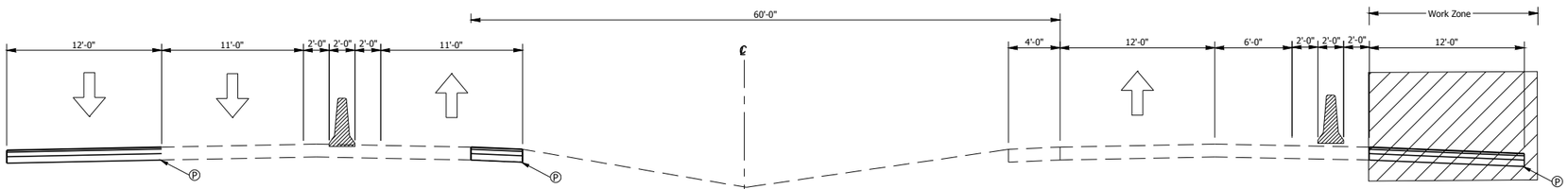
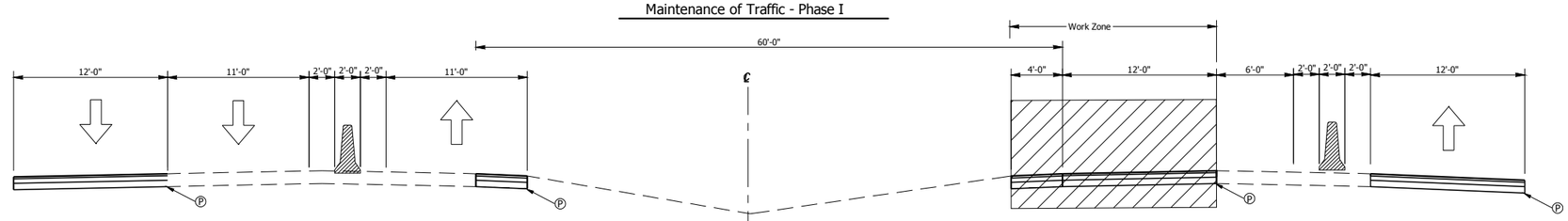


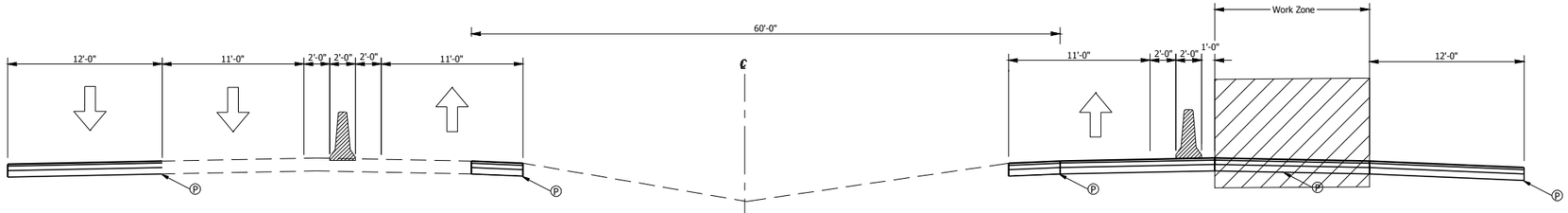
Maintenance of Traffic - Pre-Construction Phase
Non-Peak Temporary Restriction- Shoulder Strengthening



Maintenance of Traffic - Phase I



Maintenance of Traffic - Phase II



Maintenance of Traffic - Phase III

Ⓣ Temporary Pavement
Ⓟ Permanent Pavement

RECOMMENDED FOR APPROVAL
DESIGN ENGINEER DATE

DESIGNED: DRAWN:
CHECKED: CHECKED:

INDIANA DEPARTMENT OF TRANSPORTATION

MAINTENANCE OF TRAFFIC
Refined Preferred Alternative
Rural

HORIZONTAL SCALE	BRIDGE FILE
"='	–
VERTICAL SCALE	DESIGNATION
"='	0810498
SURVEY BOOK	SHEETS
	of
CONTRACT	PROJECT
R-31871	

Date: May 17, 2013 1:10pm User Name: Mehrens
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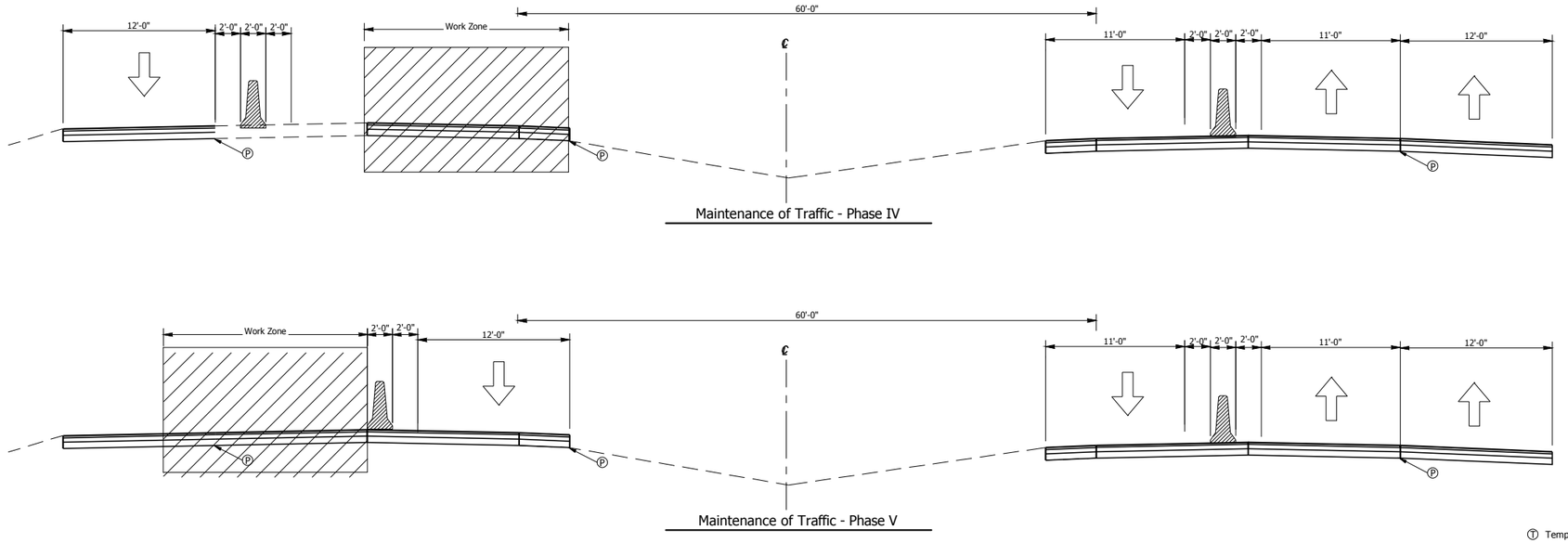

Ⓣ Temporary Pavement
Ⓟ Permanent Pavement

RECOMMENDED FOR APPROVAL _____ DESIGN ENGINEER DATE

DESIGNED: _____ DRAWN: _____

CHECKED: _____ CHECKED: _____

INDIANA DEPARTMENT OF TRANSPORTATION

MAINTENANCE OF TRAFFIC
Refined Preferred Alternative
Rural

HORIZONTAL SCALE	BRIDGE FILE
_"=_'	–
VERTICAL SCALE	DESIGNATION
_"=_'	0810498
SURVEY BOOK	SHEETS
	of
CONTRACT	PROJECT
R-31871	

Date: May 17, 2013 1:10pm User Name: JAndrews
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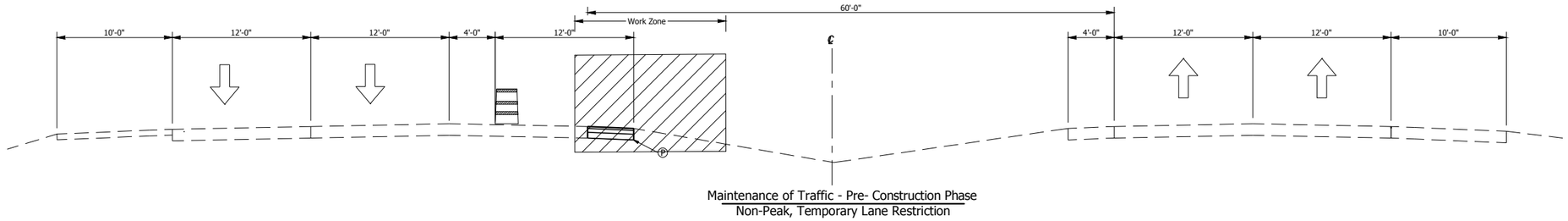
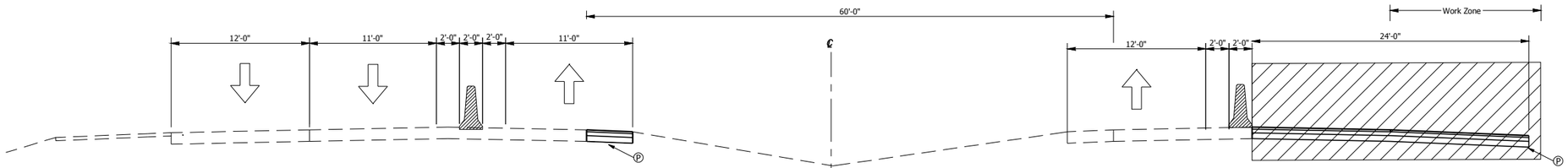
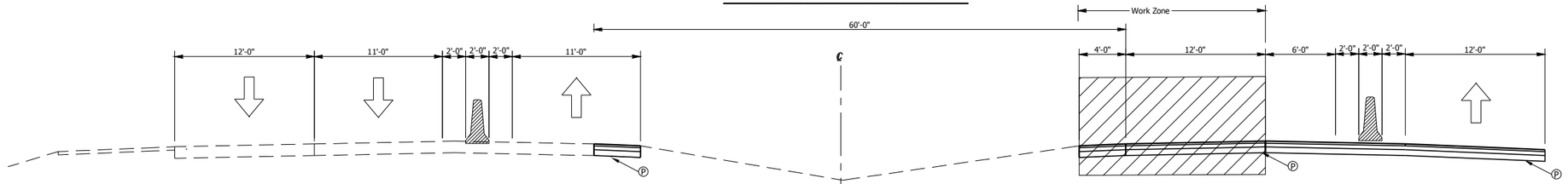


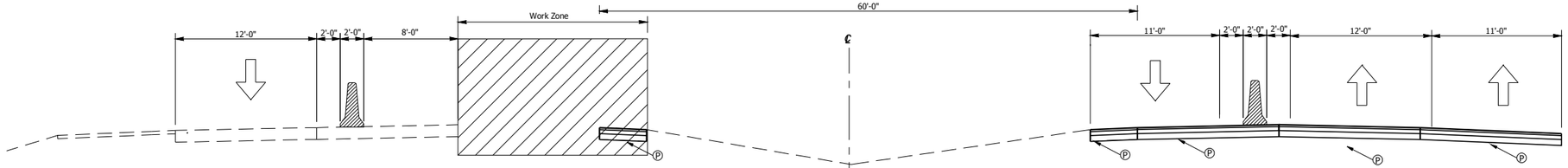
Maintenance of Traffic - Pre- Construction Phase
Non-Peak, Temporary Lane Restriction



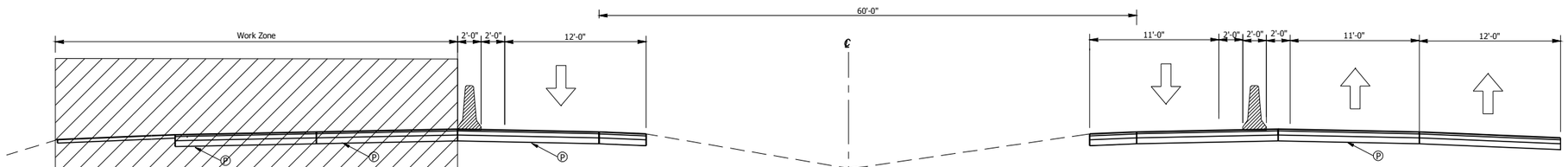
Maintenance of Traffic - Phase I



Maintenance of Traffic - Phase II



Maintenance of Traffic - Phase III



Maintenance of Traffic - Phase IV

Ⓣ Temporary Pavement
Ⓟ Permanent Pavement

RECOMMENDED FOR APPROVAL
DESIGN ENGINEER DATE

DESIGNED: DRAWN:

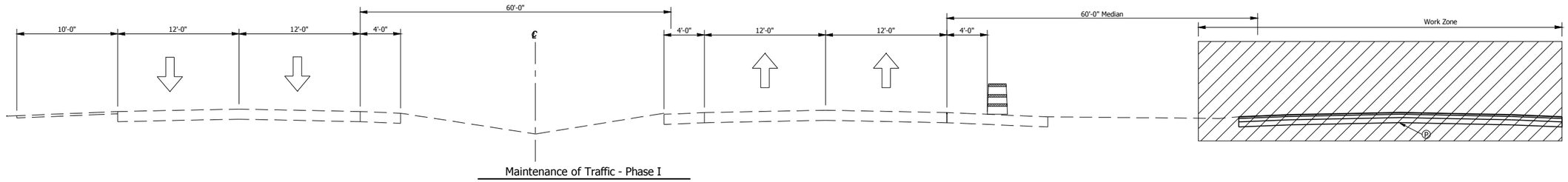
CHECKED: CHECKED:

INDIANA DEPARTMENT OF TRANSPORTATION

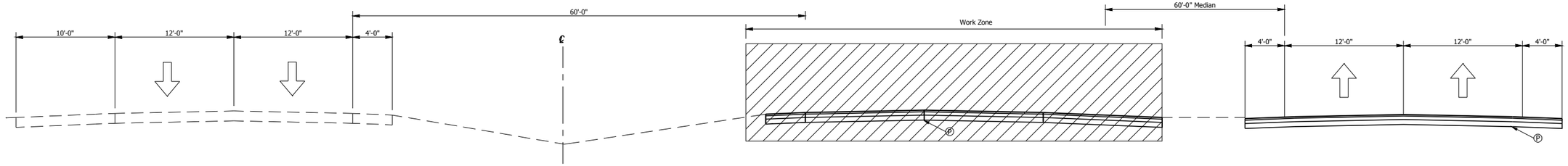
MAINTENANCE OF TRAFFIC
REFINED PREFERRED ALTERNATIVE
Rural with Truck Climbing Lane

HORIZONTAL SCALE	BRIDGE FILE
_"=_'	_
VERTICAL SCALE	DESIGNATION
_"=_'	0810498
SURVEY BOOK	SHEETS
	of
CONTRACT	PROJECT
R-31871	

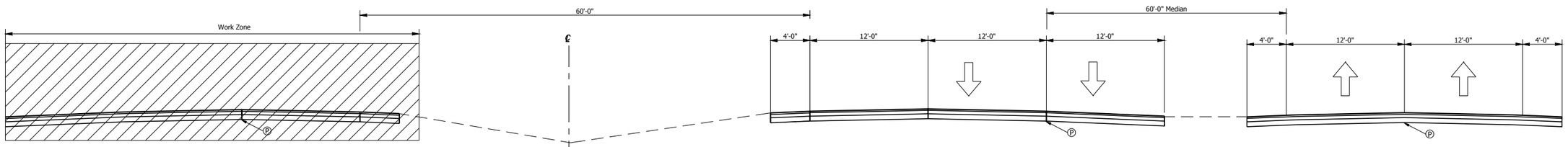
Date: May 17, 2013 1:10pm User Name: JAndrews
File: S:\Projects\103-0001\Section_5\Engineering\MOT Typicals\I-69_Section5_MOT-TCS ALT B_Rural.dwg



Maintenance of Traffic - Phase I



Maintenance of Traffic - Phase II



Maintenance of Traffic - Phase III

Ⓣ Temporary Pavement
Ⓟ Permanent Pavement

RECOMMENDED FOR APPROVAL _____ DESIGN ENGINEER DATE

DESIGNED: _____ DRAWN: _____

CHECKED: _____ CHECKED: _____

INDIANA DEPARTMENT OF TRANSPORTATION

MAINTENANCE OF TRAFFIC
REFINED PREFERRED ALTERNATIVE
Rural with Adjacent Access Road

HORIZONTAL SCALE	BRIDGE FILE
"='	-
VERTICAL SCALE	DESIGNATION
"='	0810498
SURVEY BOOK	SHEETS
	of
CONTRACT	PROJECT
R-31871	

Date: May 17, 2013, 1:10pm User Name: JAndrews
File: S:\Projects\103-10011\Section_5\Engineering\MOT Typicals\I-69_Section5_MOT- TCS ALT 8_Rural.dwg