PARSONS BRINCKERHOFF

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MEMORANDUM

Date: October 29, 2012

To: Elizabeth Caraker, AICP, City of Monterey

From: Sean Houck, P.E.

Subject: Intersection Operations and Emissions Comparative Analysis at Holman Highway 68 and Highway 1

Parsons Brinckerhoff (PB) has completed an evaluation of the performance of a proposed modern roundabout interchange at the intersection of State Route 68 (Holman Highway) and State Route 1 (Highway 1) southbound off-ramp and the intersection of 17 Mile Drive and Highway 1 southbound on-ramp in the city of Monterey, CA. The purpose of this analysis is to evaluate the operations and emissions of the proposed roundabout interchange based upon traffic forecasts in the new Del Monte Forest Plan (DMFP). The following analysis compares the existing intersection geometry and control to proposed roundabout intersection improvements.

A description of traffic forecast scenarios, methodology, intersection operations, and project phasing are described in the October 12, 2011 Memorandum: Roundabout Interchange Operations at Holman Highway 68 and Highway 1.

NOTE: The directionality used throughout this memo is based on Holman Highway having an east-west orientation and Highway 1 having a north-south orientation. Therefore, southbound Holman Highway as defined in the DMFP is the same as eastbound Holman Highway as used in this memo.

BASIS OF COMPARISON

Proposed roundabout intersection improvements were compared to existing intersection geometry and control for the 2011 (existing), 2015, and 2030 design year forecast volumes. Design year forecast volumes assumed DMFP Alternative 1.

Existing intersection control consists of a signalized intersection at the Holman Highway / Highway 1 intersection and a side-stop, stop control for vehicles exiting the Pebble Beach Gate. No improvements are contemplated at these intersections for the design year forecast volume increments.

Proposed roundabout intersection improvements are evaluated for phased construction. Phase 1 (interim condition) improvements were evaluated using the existing and 2015 design year forecast volumes. The Phase 2 (ultimate condition) was evaluated using the 2030 design year forecast volumes.

Intersection analysis for the existing and the proposed intersection control was performed using Sidra Intersection 5.1 (Sidra). Sidra was selected for this comparative analysis because of its ability to evaluate signal, stop, and roundabout intersection control using the same sequential drive cycle model. The drive cycle model considers the time, distance, speed, and emissions of a vehicle's modal operations at cruise speed, to deceleration, idling, acceleration, and back to cruise speed.

SIDRA PERFORMANCE MEASURES

Select intersection performance measures calculated by Sidra were evaluated to compare the performance of the proposed improvements against the existing conditions for the AM and PM peak hours of each design year. The intersections at Holman Highway / Highway 1 and 17 Mile Drive / Highway 1 on-ramp were each modeled separately. Due to the close proximity of the intersections within the project area, the results of the individual

intersection analysis were combined to create results for a single intersection for each alternative and design year. The performance measures evaluated and the calculation method used to combine the total intersection performance is as follows:

Performance Measure	Calculation Method
Control Delay - Average (s)	Sum
Control Delay – Worst Movement (s)	Maximum value
Practical Spare Capacity (%)	Minimum value
Effective Intersection Capacity (veh/h)	Weighted average of total demand flow for each intersection
95% Queue – Worst Lane (ft)	Maximum value
Proportion Queued	Weighted average of total demand flow for each intersection
Effective Stop Rate	Weighted average of total demand flow for each intersection
Travel Time – Average (s)	Sum
Travel Speed (mph)	Weighted average of average travel distance
Fuel Consumption (gal/h)	Sum
Carbon Dioxide (kg/h)	Sum
Hydrocarbons (kg/h)	Sum
Carbon Monoxide (kg/h)	Sum
NOx (kg/h)	Sum

Each performance measure is grouped into four primary performance areas:

1. Delay and Capacity: Control Delay – Average, Control Delay – Worst Movement, Practical Spare Capacity, and Effective Intersection Capacity.
2. Queue: 95% Queue – Worst Lane, Proportion Queued, and Effective Stop Rate.
3. Efficiency: Travel Time – Average, Travel Speed, Fuel Consumption.
4. Emissions: Carbon Dioxide, Hydrocarbons, Carbon Monoxide, Nitrogen Oxides (NOx)

COST EFFECTIVENESS

The cost effectiveness of the proposed roundabout intersection improvements were calculated based on the May 2005 California Air Resources Board (CARB) document *Methods to Find the Cost-Effectiveness of Funding Air Quality Projects.* The signal coordination method, using average speed, was the basis for estimating the cost effectiveness of the roundabout improvements in reducing the following three major pollutants:

- Reactive organic gasses (ROG)
- Nitrogen Oxides (NOx)
- Particulate Matter (PM10)

Average speeds through the study intersections were calculated using the Sidra model described above. Emission factors for ROG, NOx, and PM10 were calculated for the average vehicle speed of each study intersection. A capital recovery factor of 0.07 was applied based on a project life of 20 years.

Given that the PM peak hour models yielded lower intersection performance levels relative to the AM peak hour condition, cost effectiveness was calculated using travel demand for the PM peak hour in determining total vehicle miles traveled (VMT) through the study intersection.

RESULTS

Based on the results of the analysis, the proposed roundabout intersection improvements will significantly improve operations and emissions through the Holman Highway / Highway 1 project area.

As shown in Attachment 1, the proposed roundabout improvements exhibited superior performance measures for Delay and Capacity, Queue, and Efficiency. Emission performance measures were mixed but overall, favored the roundabout alternative. The proposed roundabout alternative produced fewer pollutant emissions for Carbon Dioxide and Hydrocarbons during all design year forecast volumes and for Carbon Monoxide and NOx during the 2030 design year analysis.

As shown in Attachment 2, cost effectiveness of funding the proposed roundabout intersection improvements per $1,000 invested results in a cost of $37 per ton for the 2015 design year and $15 per ton for the 2030 design year. The proposed roundabout improvements yielded significantly higher average vehicle speeds through the study intersection resulting in a significant reduction in PM10, NOX, and ROG emissions.

Refer to the attached documents for detailed performance measure comparisons and cost effectiveness calculations.

Parsons Brinckerhoff

Sean Houck, P.E.
Senior Supervising Civil Engineer

ATTACHMENTS

1. Performance Measures
2. Cost Effectiveness

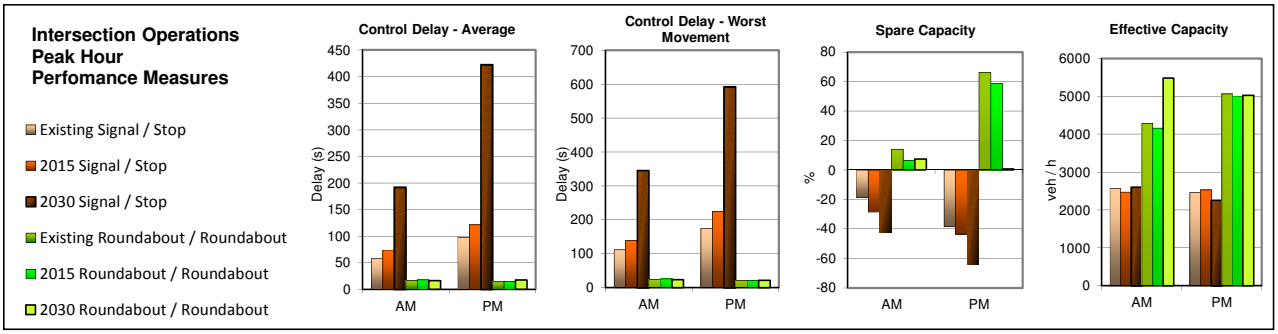
Attachment 1

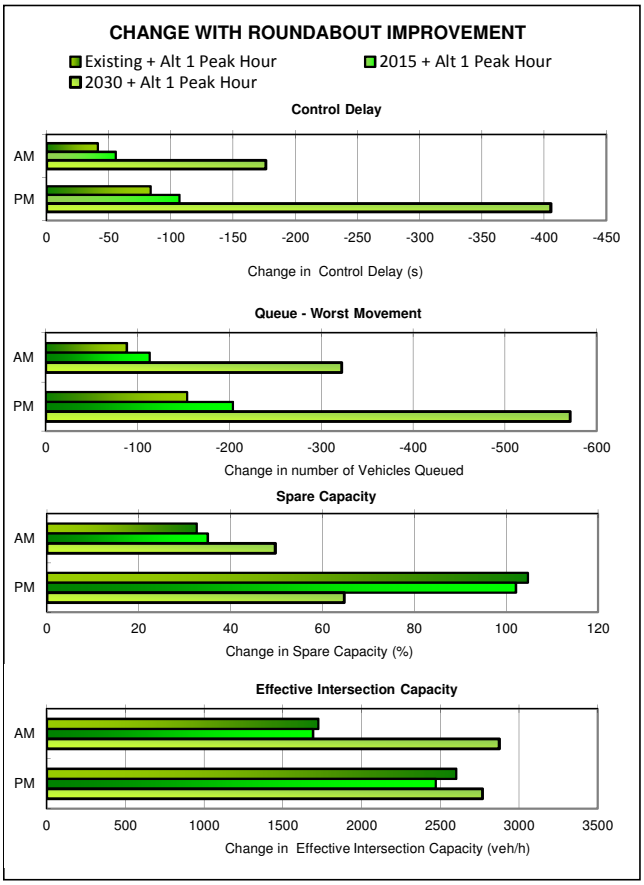
Performance Measures

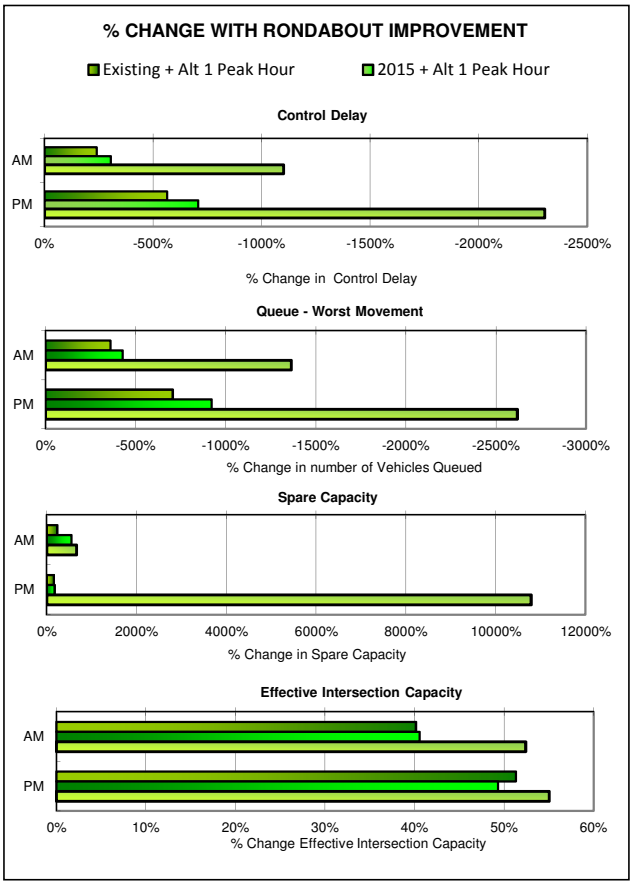
COMPARISON OF PERFORMANCE MEASURES
SIDRA PERFORMANCE MODEL

DELAY AND CAPACITY

Intersection Control	Control Delay - Average (s) AM	Control Delay - Average (s) PM	Control Delay - Worst Move (s) AM	Control Delay - Worst Move (s) PM	Spare Capacity (%) AM	Spare Capacity (%) PM	Effective Capacity (veh/h) AM	Effective Capacity (veh/h) PM
Existing Signal / Stop	58.3	98.4	113	176	-18.5	-38.5	2571	2468
2015 Signal / Stop	73.9	122.0	140	226	-28.6	-43.5	2479	2538
2030 Signal / Stop	192.2	422.9	346	593	-42.2	-64.1	2610	2260
Existing Roundabout / Roundabout	17.1	14.8	25	22	14.1	66.2	4296	5069
2015 Roundabout / Roundabout	18.2	15.1	27	22	6.4	58.6	4170	5008
2030 Roundabout / Roundabout	16.0	17.6	23.6	21.8	7.5	0.6	5484.00	5027
Change vs. Existing Control								
Existing + Alt 1 Peak Hour	-41.1	-83.6	-88.2	-153.8	32.6	104.7	1725.0	2601.0
2015 + Alt 1 Peak Hour	-55.7	-106.9	-113.2	-203.7	35.0	102.1	1691.0	2470.0
2030 + Alt 1 Peak Hour	-176.2	-405.3	-322.0	-570.8	49.7	64.7	2874.0	2767.0
% Change vs. Control								
Existing + Alt 1 Peak Hour	-240%	-565%	-360%	-706%	231%	158%	40%	51%
2015 + Alt 1 Peak Hour	-305%	-707%	-427%	-922%	547%	174%	41%	49%
2030 + Alt 1 Peak Hour	-1101%	-2303%	-1364%	-2618%	663%	10783%	52%	55%



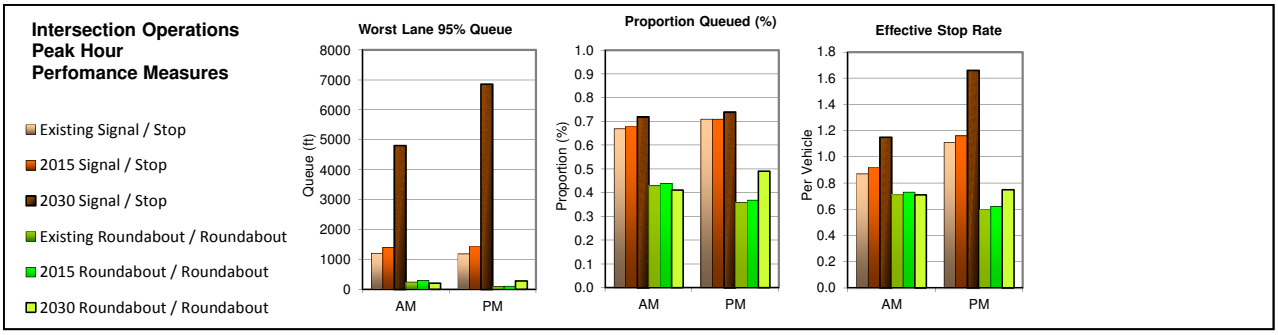


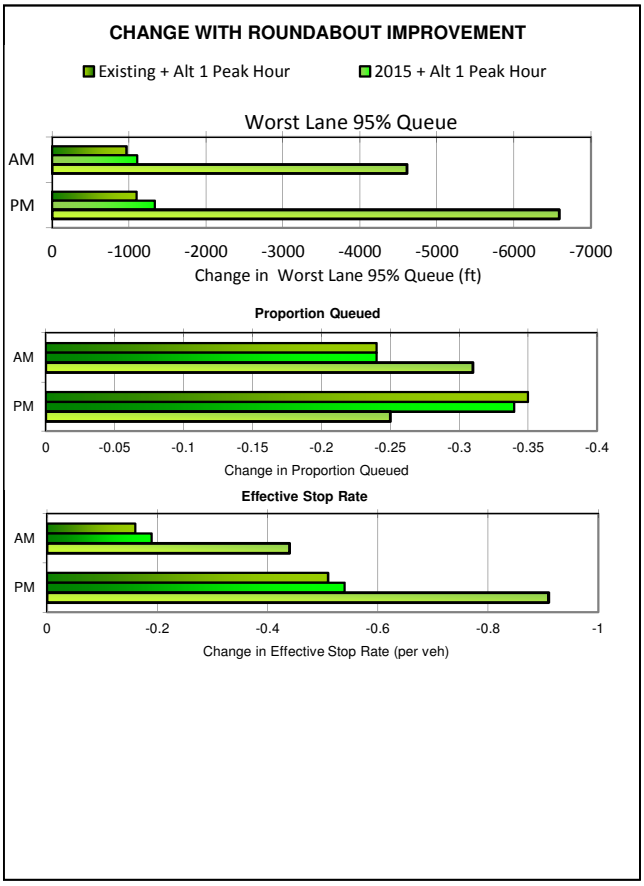


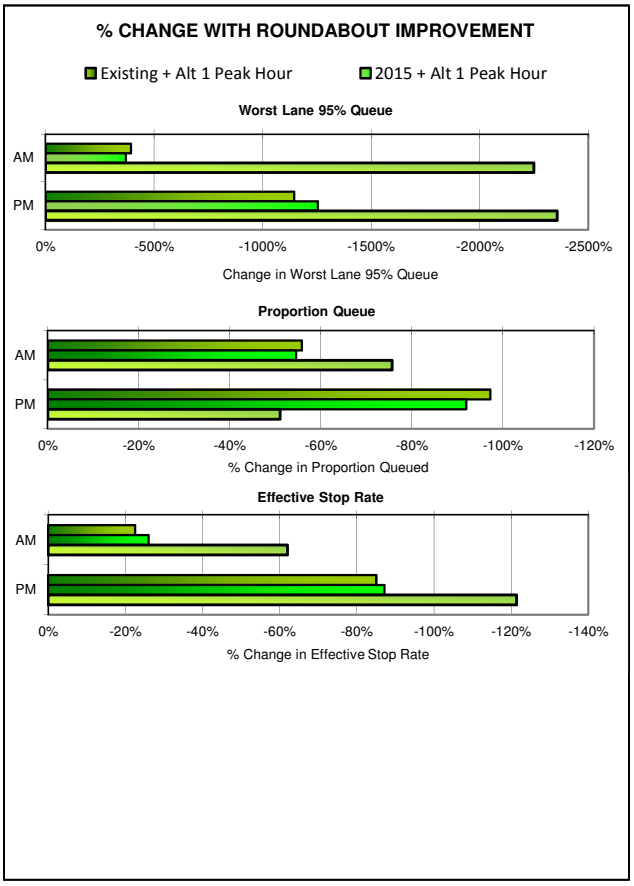
COMPARISON OF PERFORMANCE MEASURES
SIDRA PERFORMANCE MODEL

QUEUE

Intersection Control	Worst Lane 95% Queue (ft) AM	Worst Lane 95% Queue (ft) PM	Proportion Queued AM	Proportion Queued PM	Effective Stop Rate (per veh) AM	Effective Stop Rate (per veh) PM		
Existing Signal / Stop	1213.2	1193.7	0.67	0.71	0.87	1.11		
2015 Signal / Stop	1405.7	1442.8	0.68	0.71	0.92	1.16		
2030 Signal / Stop	4816.4	6869.2	0.72	0.74	1.15	1.66		
Existing Roundabout / Roundabout	246.3	95.9	0.43	0.36	0.71	0.60		
2015 Roundabout / Roundabout	299.6	106.6	0.44	0.37	0.73	0.62		
2030 Roundabout / Roundabout	205.1	279.8	0.41	0.49	0.71	0.75		
Change vs. Existing Control								
Existing + Alt 1 Peak Hour	-966.9	-1097.8	-0.2	-0.4	-0.2	-0.5		
2015 + Alt 1 Peak Hour	-1106.1	-1336.2	-0.2	-0.3	-0.2	-0.5		
2030 + Alt 1 Peak Hour	-4611.3	-6589.4	-0.3	-0.3	-0.4	-0.9		
% Change vs. Control								
Existing + Alt 1 Peak Hour	-393%	-1145%	-56%	-97%	-23%	-85%		
2015 + Alt 1 Peak Hour	-369%	-1253%	-55%	-92%	-26%	-87%		
2030 + Alt 1 Peak Hour	-2248%	-2355%	-76%	-51%	-62%	-121%		



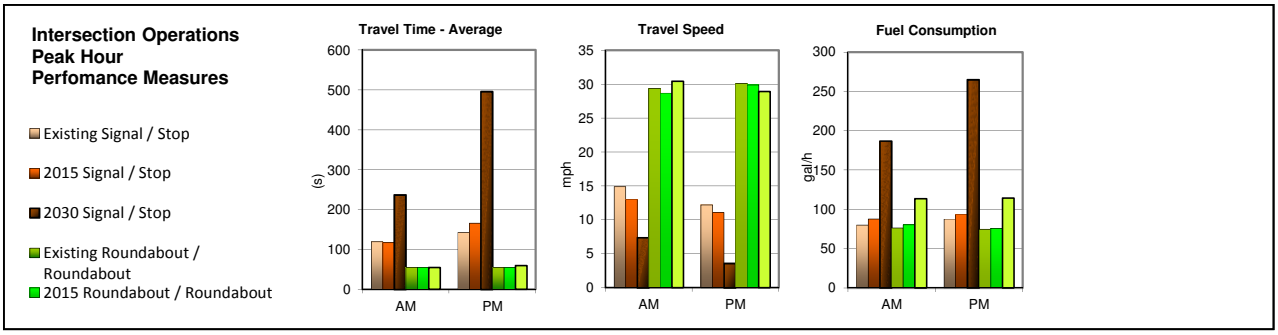


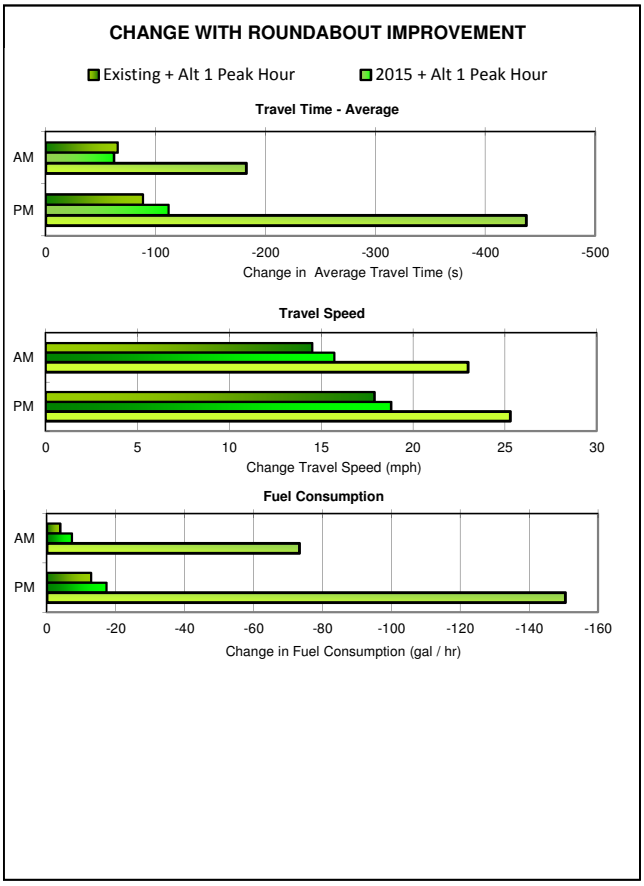


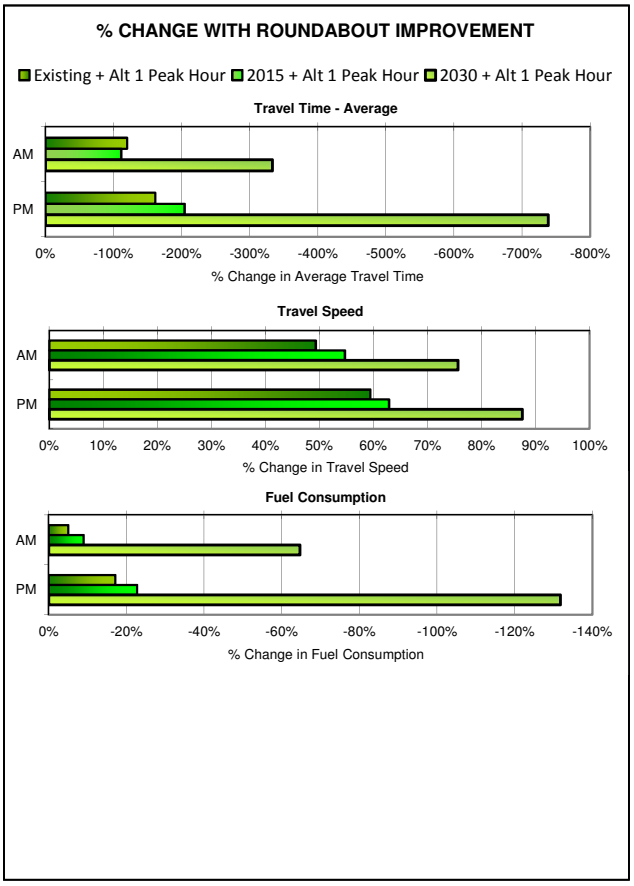
COMPARISON OF PERFORMANCE MEASURES
SIDRA PERFORMANCE MODEL

EFFICIENCY

Intersection Control	Travel Time - Average (s) AM	Travel Time - Average (s) PM	Travel Speed (mph) AM	Travel Speed (mph) PM	Fuel Consumption (gal/h) AM	Fuel Consumption (gal/h) PM	AM	PM
Existing Signal / Stop	120.1	143.2	15	12	80.0	87.4		
2015 Signal / Stop	117.8	166.5	13	11	87.5	93.1		
2030 Signal / Stop	237.2	496.4	7	4	186.6	264.7		
Existing Roundabout / Roundabout	54.6	54.8	29	30	76.1	74.6		
2015 Roundabout / Roundabout	55.7	54.7	29	30	80.3	75.8		
2030 Roundabout / Roundabout	54.7	59.2	30.4	28.9	113.3	114.2		
Change vs. Existing Control								
Existing + Alt 1 Peak Hour	-65.5	-88.4	14.5	17.9	-3.8	-12.8		
2015 + Alt 1 Peak Hour	-62.1	-111.8	15.7	18.8	-7.2	-17.3		
2030 + Alt 1 Peak Hour	-182.5	-437.2	23.0	25.3	-73.3	-150.5		
% Change vs. Control								
Existing + Alt 1 Peak Hour	-120%	-161%	49%	59%	-5%	-17%		
2015 + Alt 1 Peak Hour	-111%	-204%	55%	63%	-9%	-23%		
2030 + Alt 1 Peak Hour	-334%	-739%	76%	88%	-65%	-132%		



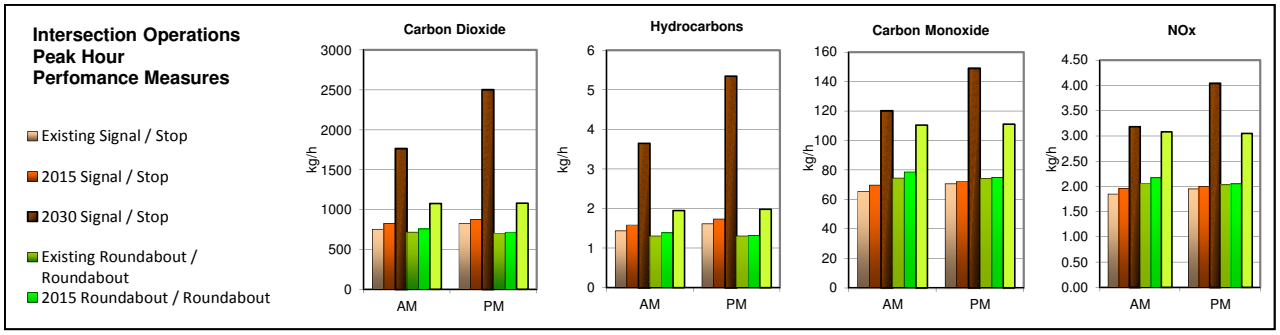


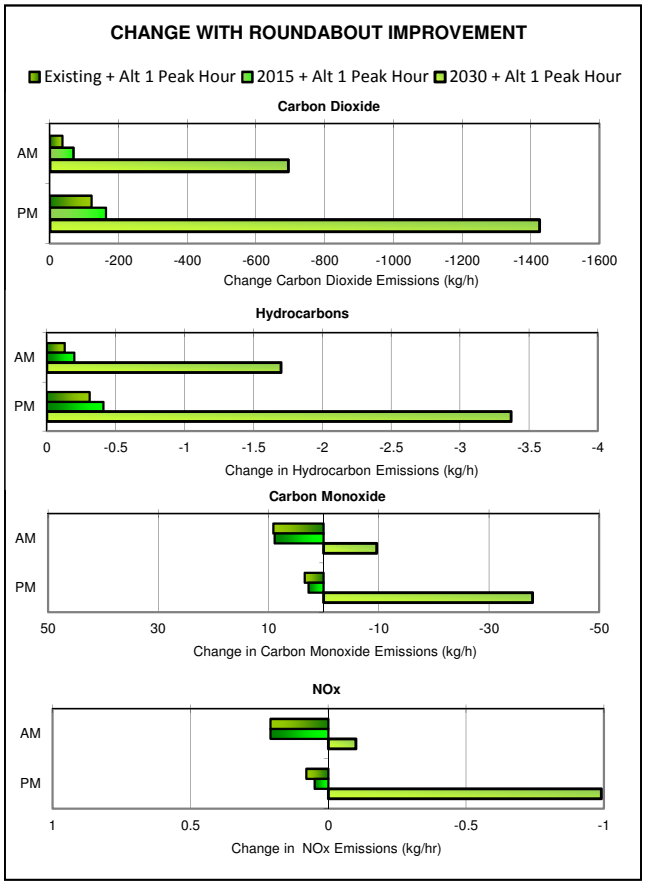


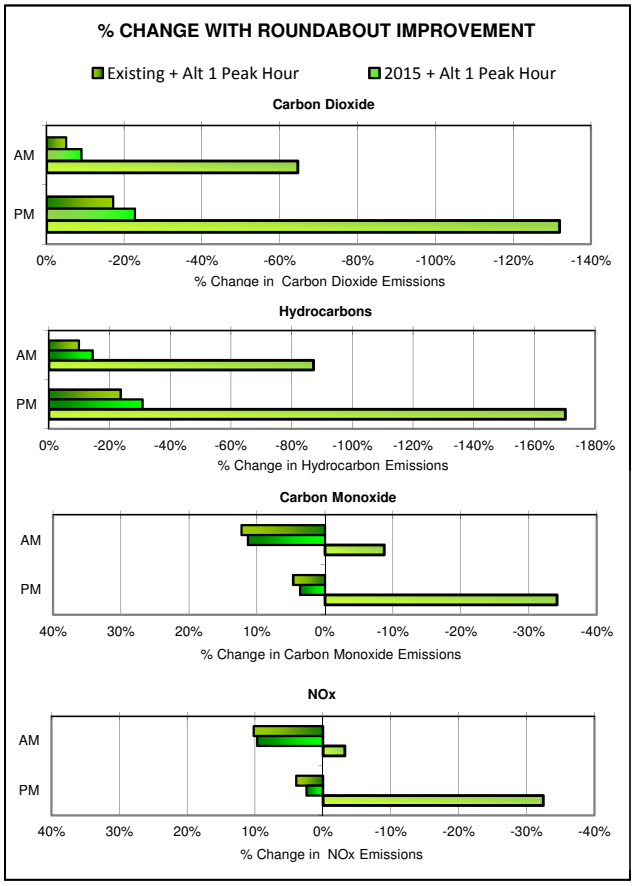
COMPARISON OF PERFORMANCE MEASURES
SIDRA PERFORMANCE MODEL

EMISSIONS

Intersection Control	Carbon Dioxide (kg/h) AM	Carbon Dioxide (kg/h) PM	Hydrocarbons (kg/h) AM	Hydrocarbons (kg/h) PM	Carbon Monoxide (kg/h) AM	Carbon Monoxide (kg/h) PM	NOx (kg/h) AM	NOx (kg/h) PM
Existing Signal / Stop	757.45	827.08	1.44	1.62	65.32	70.66	1.85	1.95
2015 Signal / Stop	828.74	881.08	1.59	1.74	69.71	72.24	1.96	2.00
2030 Signal / Stop	1767.00	2505.60	3.65	5.35	120.10	148.91	3.18	4.04
Existing Roundabout / Roundabout	721.14	705.94	1.31	1.31	74.47	74.12	2.06	2.03
2015 Roundabout / Roundabout	760.18	717.70	1.39	1.33	78.63	74.99	2.17	2.05
2030 Roundabout / Roundabout	1073.40	1080.70	1.95	1.98	110.46	111.01	3.08	3.05
Change vs. Existing Control								
Existing + Alt 1 Peak Hour	-36.3	-121.1	-0.1	-0.3	9.2	3.5	0.2	0.1
2015 + Alt 1 Peak Hour	-68.6	-163.4	-0.2	-0.4	8.9	2.8	0.2	0.0
2030 + Alt 1 Peak Hour	-693.6	-1424.9	-1.7	-3.4	-9.6	-37.9	-0.1	-1.0
% Change vs. Control								
Existing + Alt 1 Peak Hour	-5%	-17%	-10%	-24%	12%	5%	10%	4%
2015 + Alt 1 Peak Hour	-9%	-23%	-14%	-31%	11%	4%	10%	2%
2030 + Alt 1 Peak Hour	-65%	-132%	-87%	-170%	-9%	-34%	-3%	-32%







Attachment 2

Cost Effectiveness

Emission Worksheet

2015

Cost Effectiveness of Funding Dollars for Proposed Project: **$ 37.00** ***per ton per $1000***

Before Condition: Signal at Holman Highway / Highway 1
Side Stop at Pebble Beach Gate

After Condition: Roundabout at Holman Highway / Highway 1 (Phase 1)
Roundabout at Pebble Beach Gate

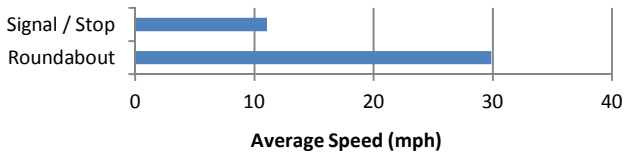
Vehicle Miles Traveled Calculations

Vehicles		
2015 PM Peak Hour Volume	3,041	veh/hr
Daily Traffic in PM Peak Hour	10%	
2015 Volume	30,410	veh/day

Vehicle Miles Traveled (VMT)		
Length of roadway	2,300	feet
	0.44	miles
2015 Vehicles	30,410	veh/day
Daily	13,247	mi/day
Days per Year	365	days/year
Annual VMT	4,835,075	mi/year

Average Vehicle Speed (2015)		
Roundabout	30	MPH
Signal / Stop	11	MPH

2015 Peak Hour Volume	
Approach	**Vehicles**
PB Gate	526
WB Holman Hwy	473
SB Off-Ramp	994
EB Holman Hwy	1048
Total	*3041*



Emission Calculations

Emission Factors by Speed* (grams/mile)				
Emission	**Before (g)**	**After (g)**	**Δ (g)**	**Δ (lb)**
ROG	0.53	0.19	0.34	0.000749572
NOX	1.18	0.85	0.33	0.000727525
PM10	0.07	0.03	0.04	8.81849E-05

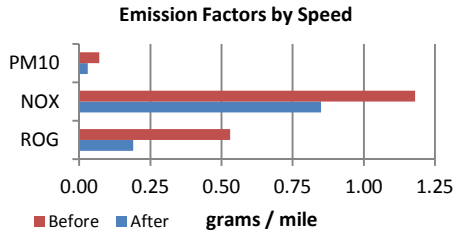
Emissions (pounds/year)				
Emission	**reduction**	**Δ (lb)**	**VMT**	**Total (lb/yr)**
ROG	0.5	0.00075	4,835,075	1,812
NOX	0.5	0.000728	4,835,075	1,759
PM10	0.5	8.82E-05	4,835,075	213
		Annual Emission Reduction		***3,784***

Notes

** Source: Methods to Find the Cost-Effectiveness of Funding Air Quality Projects, May 2005. Table 4 - Emission Factors by Speed (Analysis Period 6-10 years)*

Cost Effectiveness Calculations

Cost Effectiveness of Funding Dollars per $1000 Increment			
Funding Dollars	$	1,000	
Effectiveness Period		20	years
Capitol Recovery Factor (CRF)		0.07	
Annual Emission Reduction		3,784	lb/year
	$	***0.02***	***per pound***
COST EFFECTIVENESS	***$***	***37.00***	***per ton***



Emission Worksheet

2030

Cost Effectiveness of Funding Dollars for Proposed Project: **$ 14.97** *per ton per $1000*

Before Condition: Signal at Holman Highway / Highway 1
Side Stop at Pebble Beach Gate

After Condition: Roundabout at Holman Highway / Highway 1 (Phase 2)
Roundabout at Pebble Beach Gate

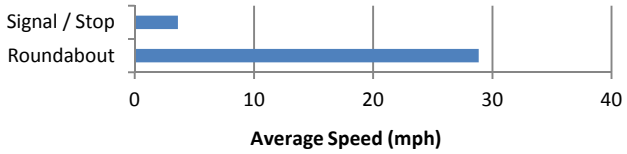
Vehicle Miles Traveled Calculations

Vehicles		
2030 PM Peak Hour Volume	4,104	veh/hr
Daily Traffic in PM Peak Hour	10%	
2030 Volume	41,040	veh/day

Vehicle Miles Traveled (VMT)		
Length of roadway	2,300	feet
	0.44	miles
2030 Vehicles	41,040	veh/day
Daily	17,877	mi/day
Days per Year	365	days/year
Annual VMT	6,525,205	mi/year

Average Vehicle Speed (2030)		
Roundabout	29	MPH
Signal / Stop	4	MPH

2030 Peak Hour Volume	
Approach	**Vehicles**
PB Gate	578
WB Holman Hwy	545
SB Off-Ramp	1209
EB Holman Hwy	1772
Total	*4104*



Emission Calculations

Emission Factors by Speed* (grams/mile)				
Emission	**Before (g)**	**After (g)**	**Δ (g)**	**Δ (lb)**
ROG	0.84	0.2	0.64	0.001410958
NOX	1.44	0.85	0.59	0.001300727
PM10	0.1	0.03	0.07	0.000154324

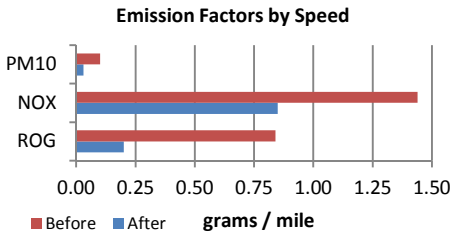
Emissions (pounds/year)				
Emission	**reduction**	**Δ (lb)**	**VMT**	**Total (lb/yr)**
ROG	0.5	0.001411	6,525,205	4,603
NOX	0.5	0.001301	6,525,205	4,244
PM10	0.5	0.000154	6,525,205	503
		Annual Emission Reduction		***9,351***

Notes

** Source: Methods to Find the Cost-Effectiveness of Funding Air Quality Projects, May 2005. Table 4 - Emission Factors by Speed (Analysis Period 6-10 years)*

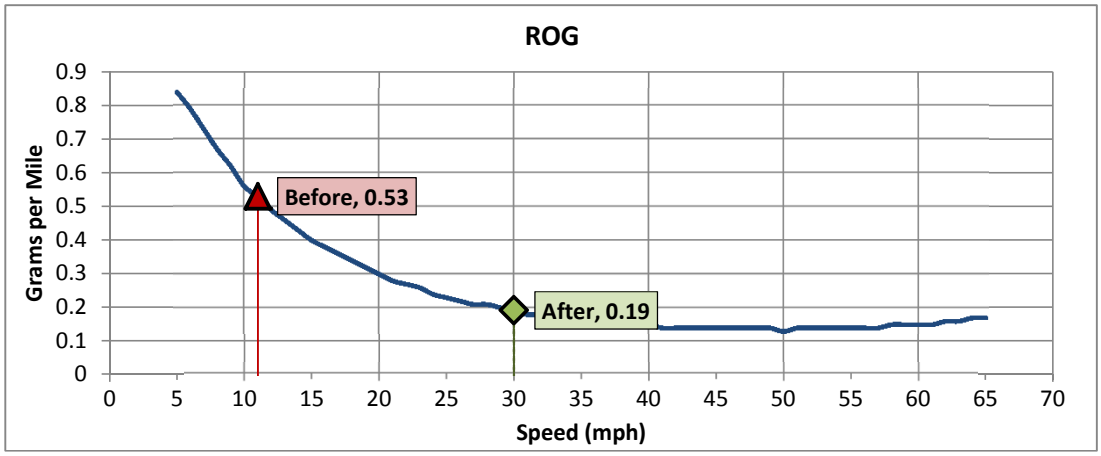
Cost Effectiveness Calculations

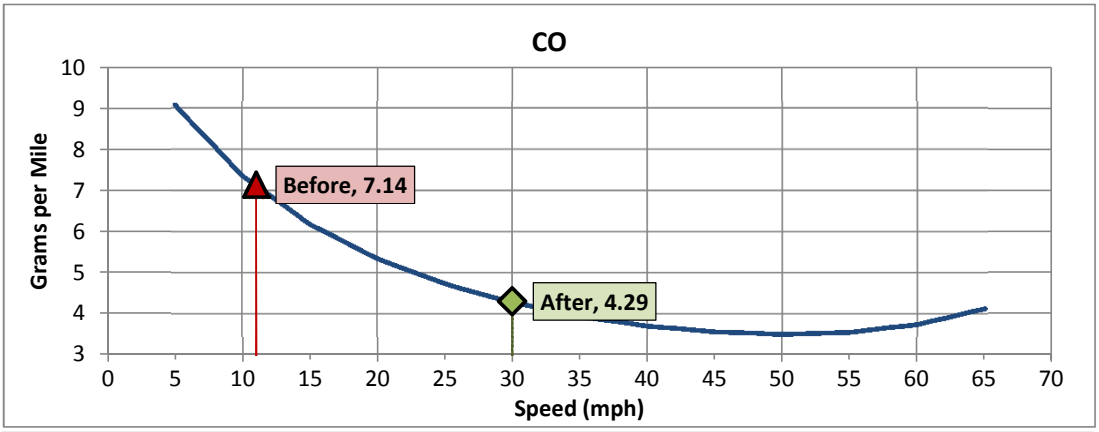
Cost Effectiveness of Funding Dollars per $1000 Increment			
Funding Dollars	$	1,000	
Effectiveness Period		20	years
Capitol Recovery Factor (CRF)		0.07	
Annual Emission Reduction		9,351	lb/year
	$	***0.01***	***per pound***
COST EFFECTIVENESS	***$***	***14.97***	***per ton***

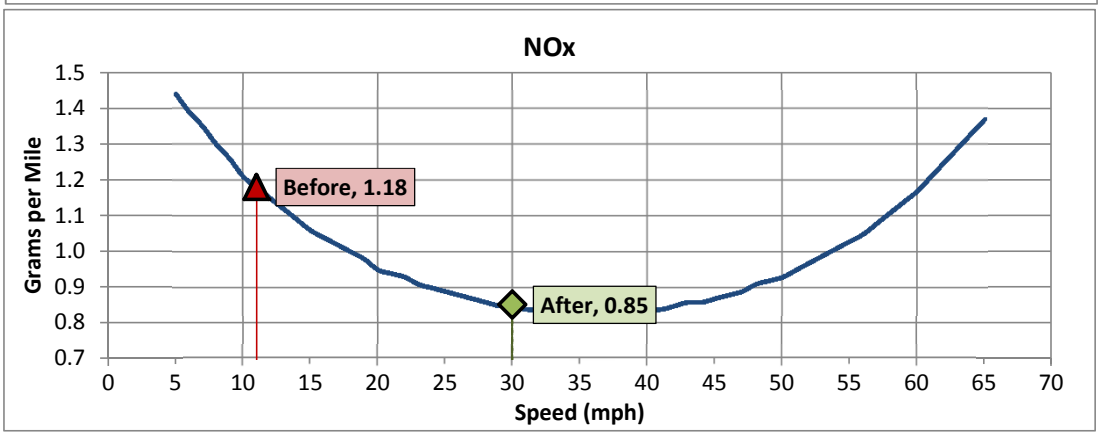


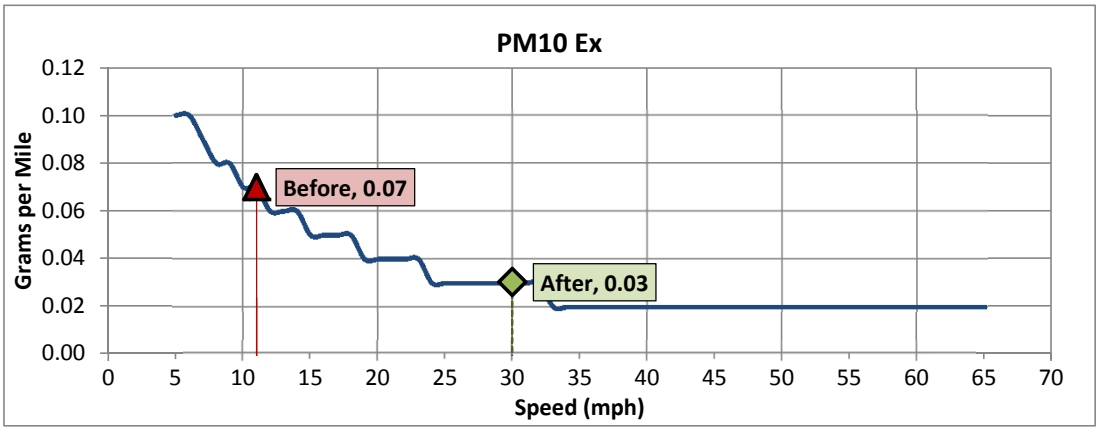
2015

Emission Factors by Speed

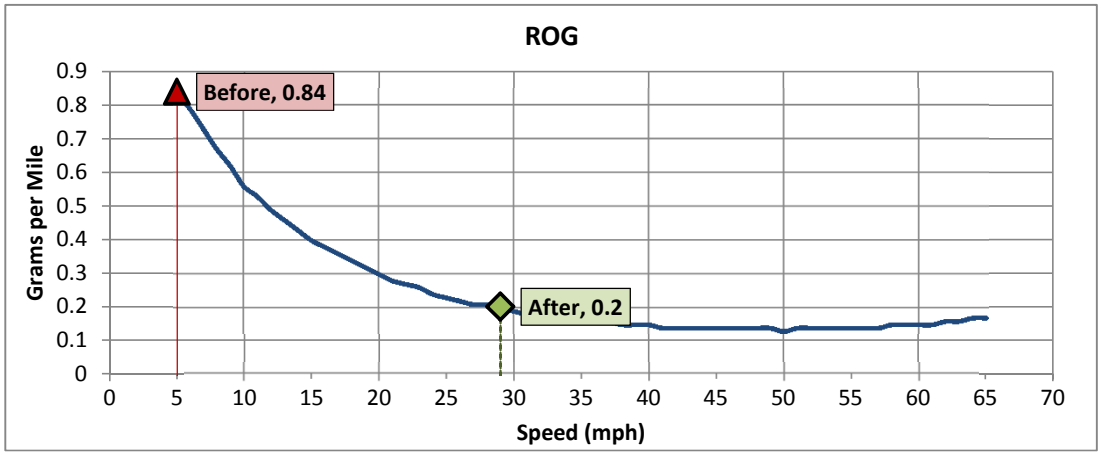


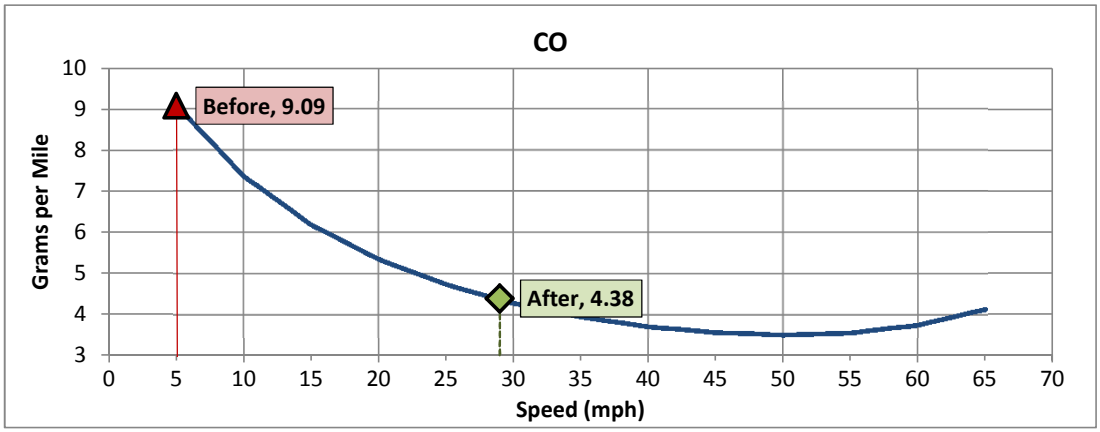


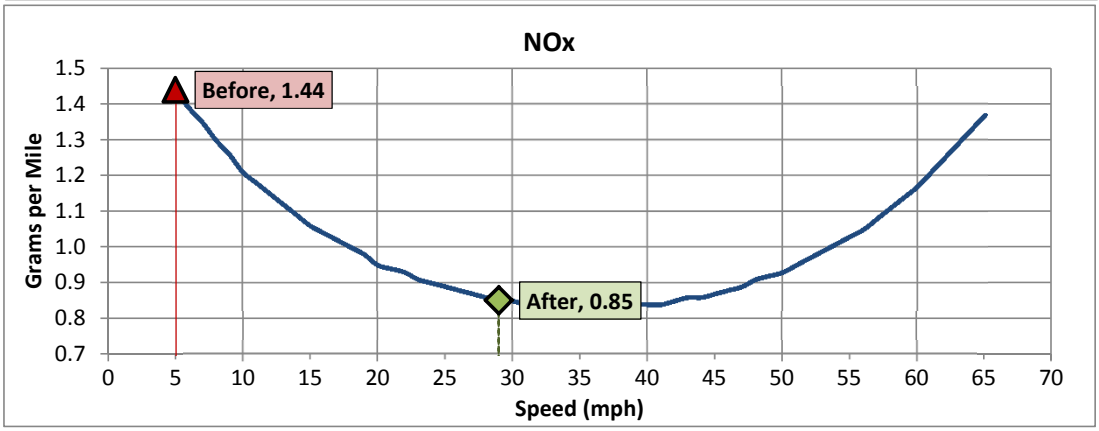


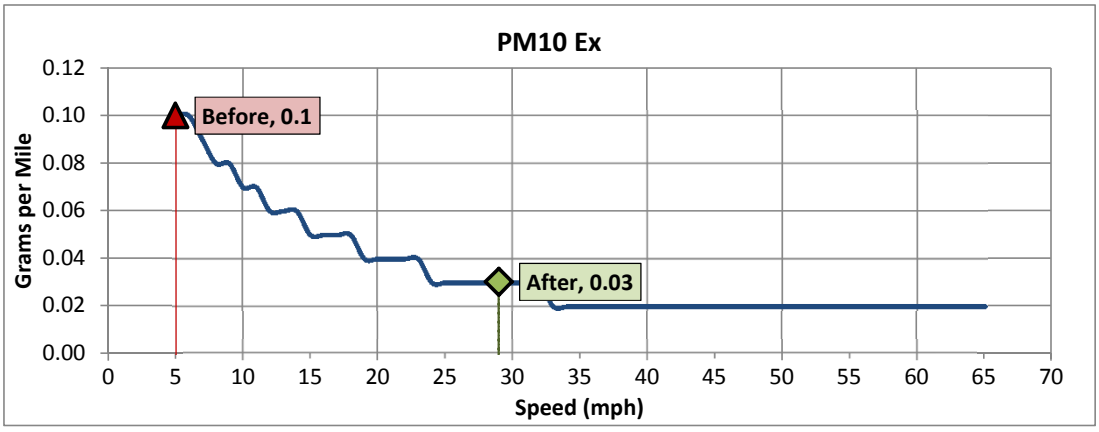


2030


ROG
Grams per Mile
Speed (mph)
Before, 0.84
After, 0.2


CO
Grams per Mile
Speed (mph)
Before, 9.09
After, 4.38


NOx
Grams per Mile
Speed (mph)
Before, 1.44
After, 0.85


PM10 Ex
Grams per Mile
Speed (mph)
Before, 0.1
After, 0.03