the heartbeat of HAMPTON ROADS TPO
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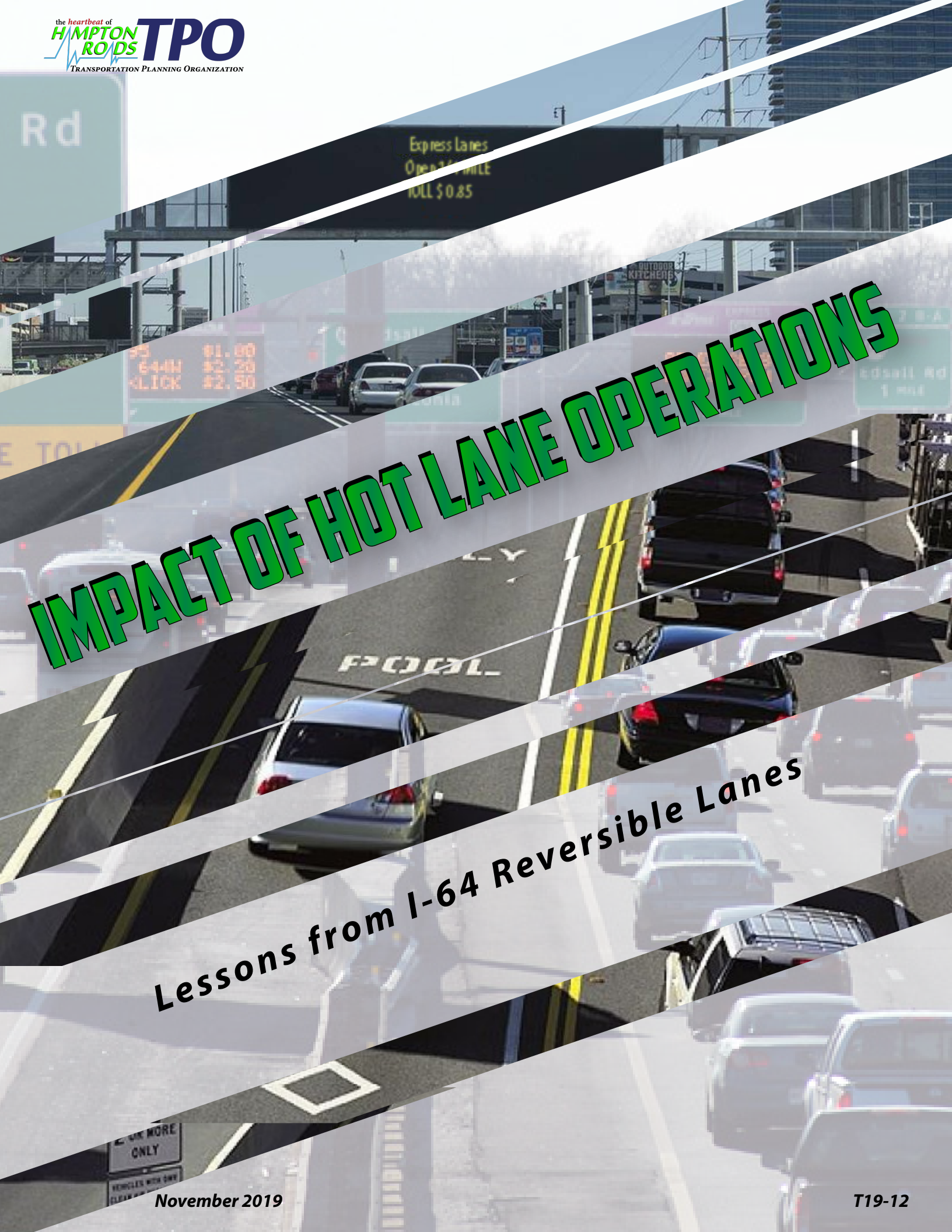

IMPACT OF HOT LANE OPERATIONS

Lessons from I-64 Reversible Lanes

November 2019

T19-12

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REPORT DOCUMENTATION

TITLE
Impact of HOT Lane Operations-
Lessons from I-64 Reversible Lanes

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REPORT DATE November 2019

ABSTRACT
The purpose of this analysis is to observe the impact of the January 10, 2018 change in the operation of the I-64 reversible lanes in Norfolk:

- during original managed hours: change from HOV operation to HOT operation
- during additional managed hours: change from unrestricted operation to HOT operation.

The analysis uses vehicle volumes and speeds to measure the impact of these changes.

ACKNOWLEDGMENT & DISCLAIMERS
Prepared in cooperation with the U.S. Department of Transportation (USDOT), Federal Highway Administration (FHWA), and Virginia Department of Transportation (VDOT). The contents of this report reflect the views of the Hampton Roads Transportation Planning Organization (HRTPO). The HRTPO is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the FHWA, VDOT or Hampton Roads Planning District Commission. This report does not constitute a standard, specification, or regulation. FHWA or VDOT acceptance of this report as evidence of fulfillment of the objectives of this planning study does not constitute endorsement/approval of the need for any recommended improvements nor does it constitute approval of their location and design or a commitment to fund any such improvements. Additional project level environmental impact assessments and/or studies of alternatives may be necessary.

Table of Contents

Introduction

The I-64 reversible lanes and general purpose (GP) lanes (on either side of the reversible lanes) operate as a system, i.e. drivers can choose one or the other:

- When the reversible lanes become **less restricted**, we expect more vehicles in the reversible lanes and therefore, fewer vehicles in the GP lanes.
- When the reversible lanes become **more restricted**, we expect fewer vehicles in the reversible lanes and therefore, more vehicles in the GP lanes.

Note that changing operations is not necessarily a "zero-sum game". In addition to shifting vehicles between the reversible and GP lanes, a change in operations may affect the *total* number of vehicles carried by the system.

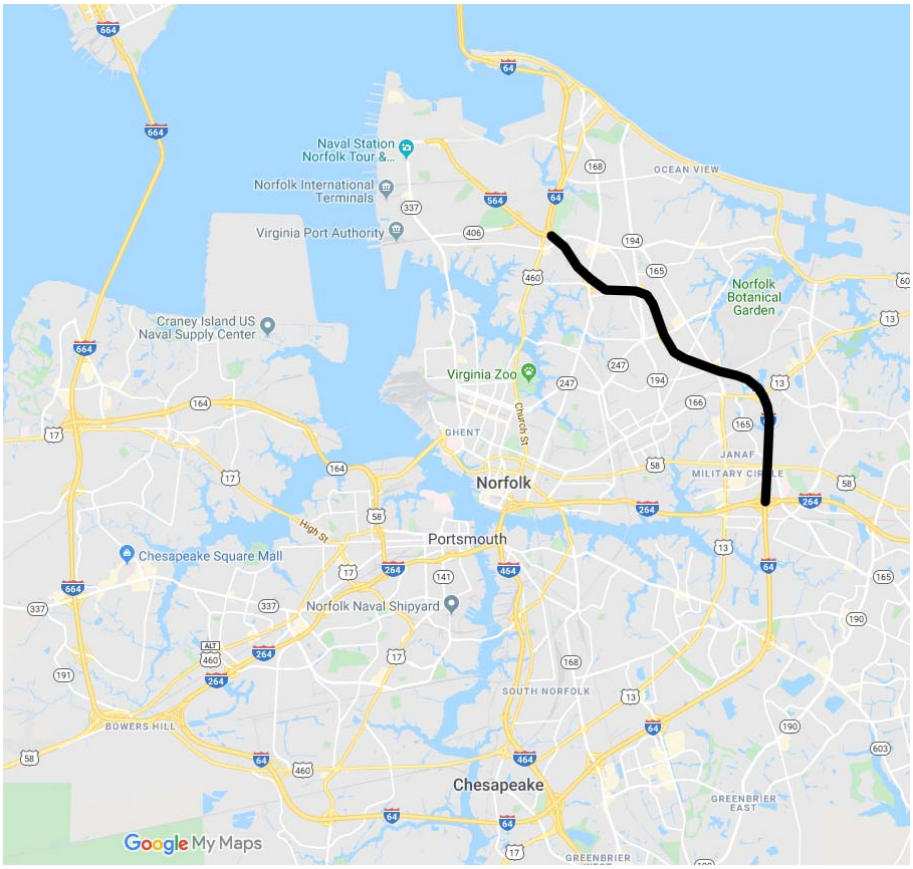


FIGURE 1 I-64 Reversible Lanes

Source: HRTPO via Google My Maps

Before January 10, 2018, VDOT operated the I-64 reversible lanes in Norfolk under "HOV operation" (only High-Occupancy Vehicles allowed) during four (4) weekday hours, 6-8am (westbound) and 4-6pm (eastbound). For HOV and HOT lanes in Hampton Roads, VDOT has defined "HOV" as vehicles with two or more (2+) occupants. Starting January 10, 2018, VDOT operated the reversible lanes under "HOT operation" (HOVs and Toll-paying Single-Occupancy Vehicles [SOVs] allowed) during eight weekday hours, 5-9am (westbound) and 2-6pm (eastbound). Because this involved both a new operations regime (HOT) and a change in managed hours, January 10, 2018 represents two changes:

1) during "**original managed hours**" (6-8am, 4-6pm) operations became **less restrictive**, changing from High-Occupancy Vehicle (HOV) operation (only HOVs allowed) to High-Occupancy/Toll (HOT) operation (HOVs and paying Single-Occupancy Vehicles [SOVs] allowed)
2) during "**additional managed hours**" (5-6am, 8-9am, 2-4pm) operations became **more restrictive**, changing from unrestricted operation (any vehicle allowed) to HOT operation.

The purpose of this analysis is to observe the impact of each of these two changes on **vehicle volumes, vehicle speeds, and lane usage**. These impacts were calculated from raw vehicle volume and speed data collected by VDOT. The details of the processing of the raw data is included as an appendix. The processed data—i.e. the impact of each of the two operations changes—is examined for **each change**, in turn, below.

HOT Operation vs. HOV Operation (original managed hours)

For the original managed hours (weekdays 6-8am and 4-6pm), on January 10, 2018 VDOT changed the operation of the I-64 reversible lanes **from HOV operation to HOT operation**. This chapter examines the volume and speed impacts of that change.

HOT operation being **less restrictive** than HOV operation (HOT operation allowing paying SOVs), it was expected that the January 10, 2018 change from HOV operation to HOT operation in the reversible lanes caused some drivers to shift from the GP lanes to the reversible lanes, as shown below. In addition, due to new vehicles filling the space provided in the GP lanes by vehicles shifting to reversible lanes, it is expected that the operations change caused the total system (reversible and GP) to carry more vehicles.

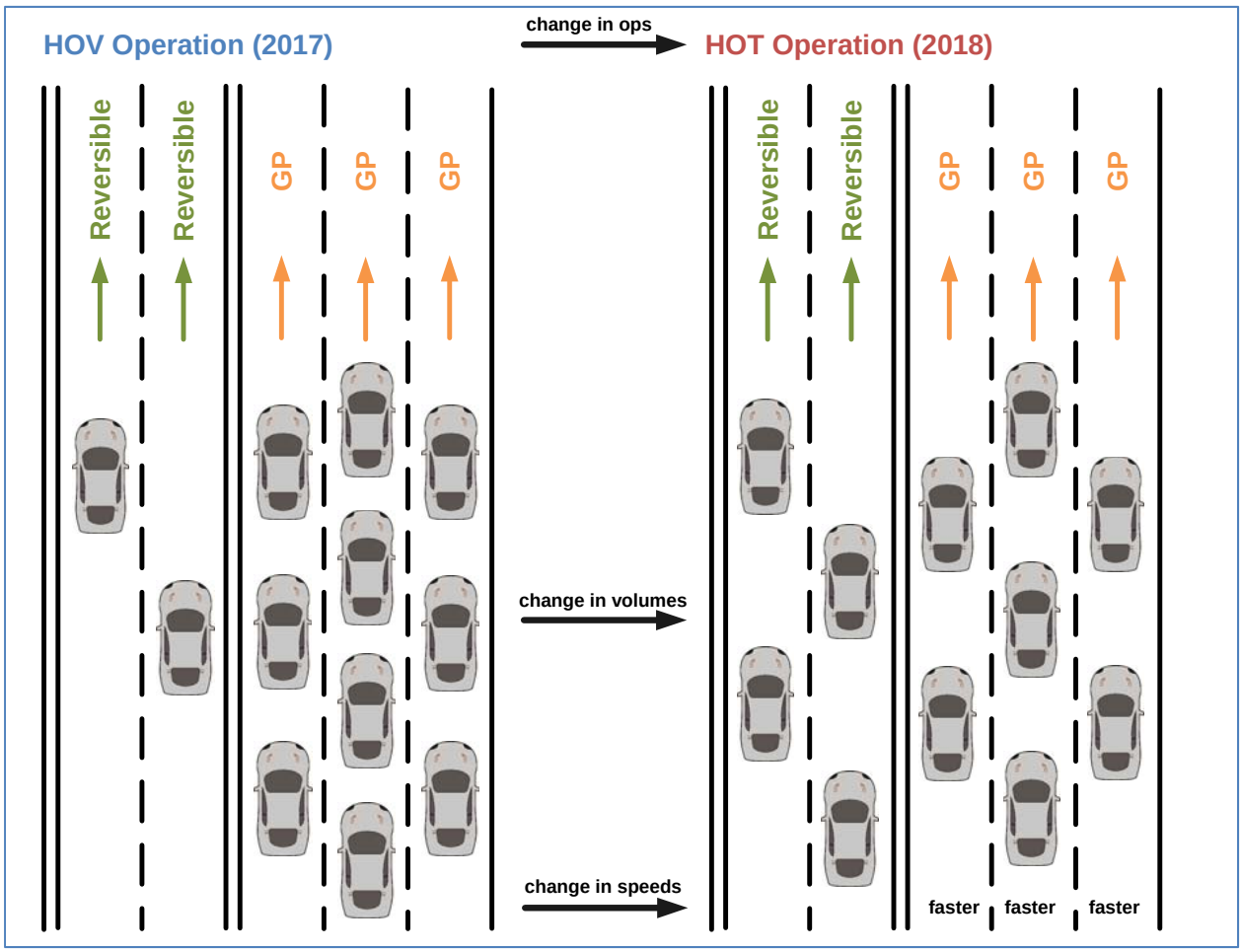


FIGURE 2 Expectation for the Original Managed Hours

Source: HRTPO- HOV to HOT w gray cars.vsd

First, staff examined the change in volumes in the reversible lanes.

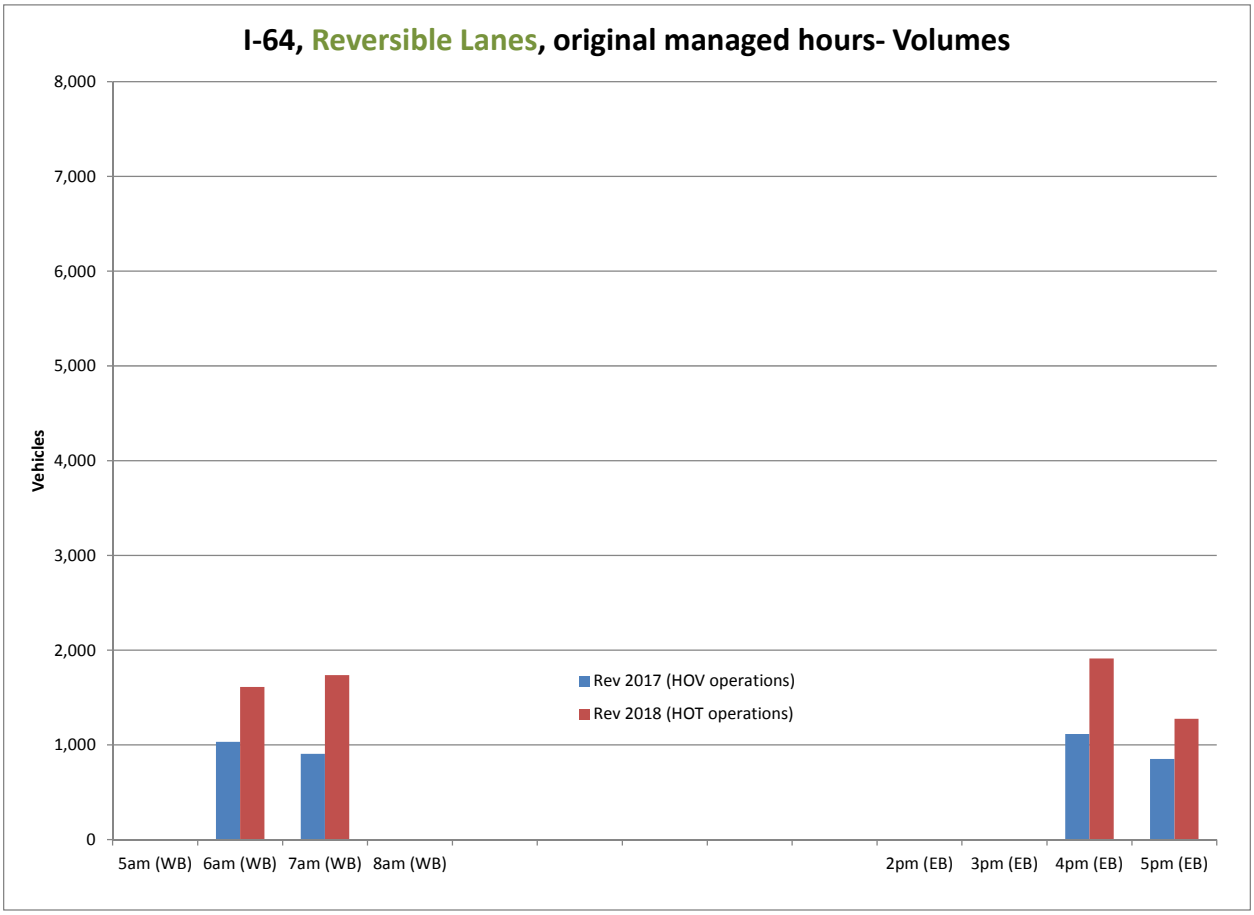


FIGURE 3 I-64 between Chesapeake Blvd & Norview Ave- Vehicle Volume, per hour
Source: HRTPO processing of VDOT data- volume data.xlsx

As expected, **volumes increased significantly in the reversible lanes** following the reduction in restriction.

Next, staff examined the speed impact of the above increase in volumes in the reversible lanes.

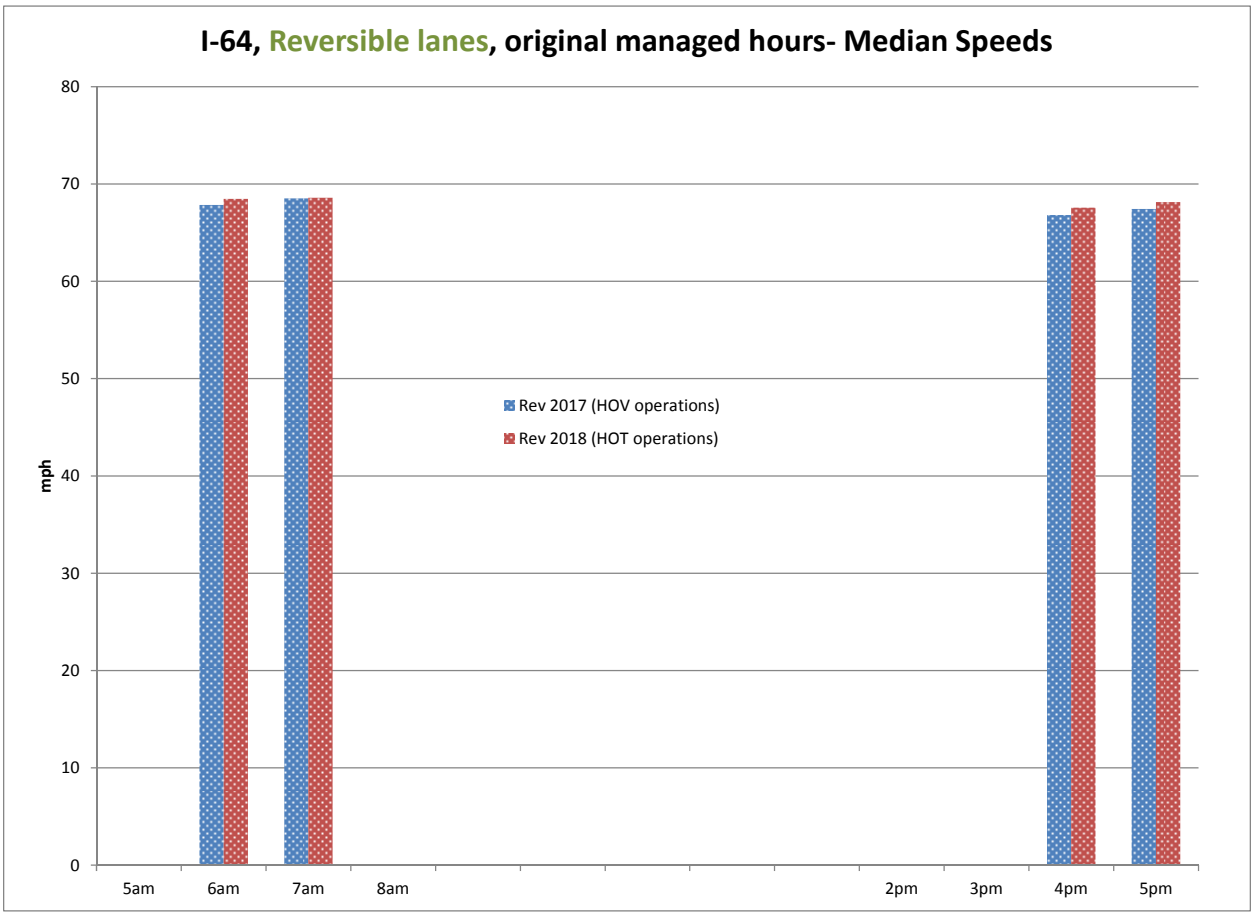


FIGURE 4 I-64 between Chesapeake Blvd & Norview Ave- Vehicle Speed, by hour
Source: HRTPO processing of VDOT data- Speed_150112.xlsx

Even with the increase in volumes (shown on the previous page), **high speeds** were maintained **in the reversible lanes**, likely due to VDOT's ability to raise toll rates "in real time" as volumes rise.

Following the above look at reversible lanes, staff examined changes in the GP lanes.

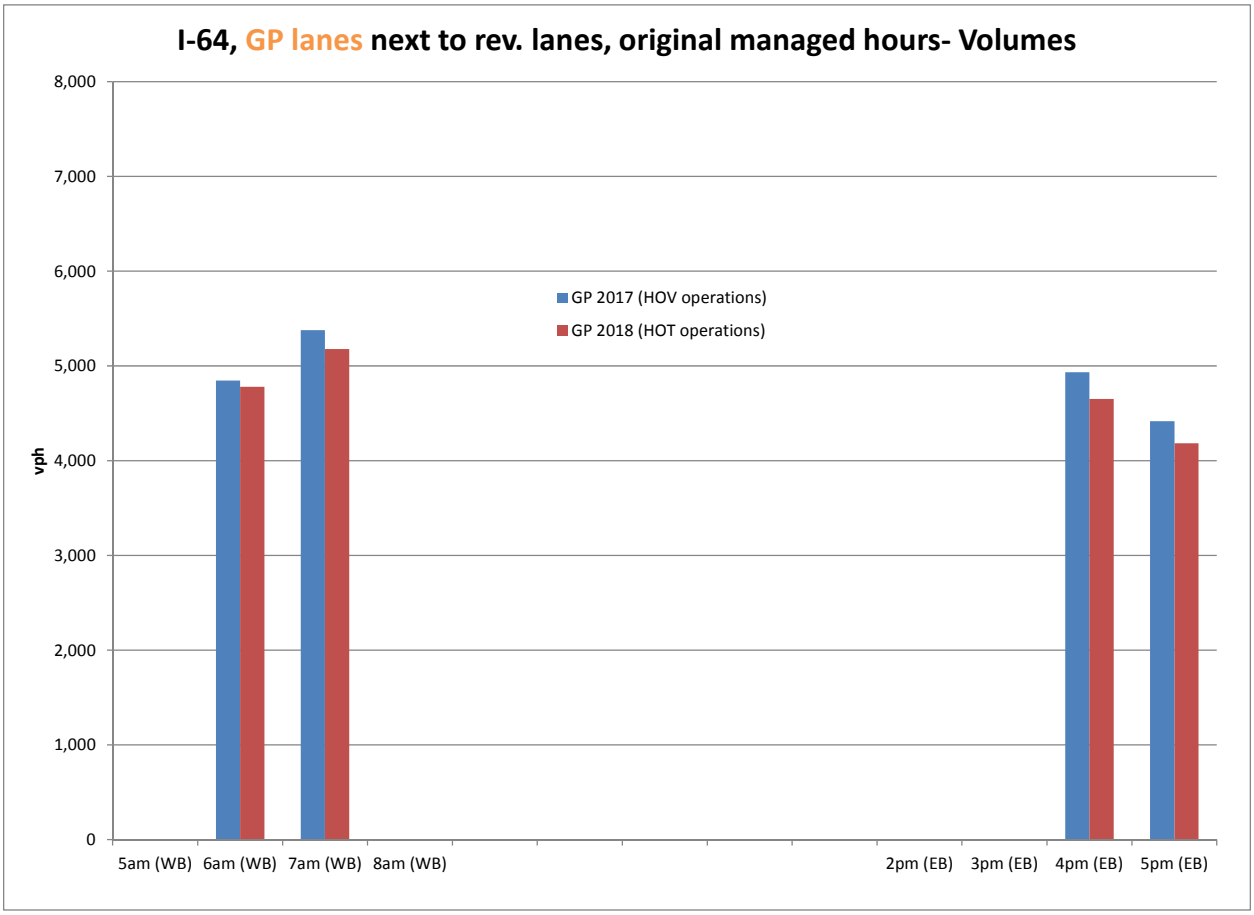


FIGURE 5 I-64 between Chesapeake Blvd & Norview Ave- Vehicle Volume, per hour
Source: HRTPO processing of VDOT data- volume data.xlsx

As expected, following the reduction in restriction in the reversible lanes, **volumes decreased in the GP lanes**. This reduction in GP volumes was less than the increase in reversible volumes, indicating that new vehicles joined the system.

Next, staff examined the speed impact of the above reduction in volumes in the GP lanes.

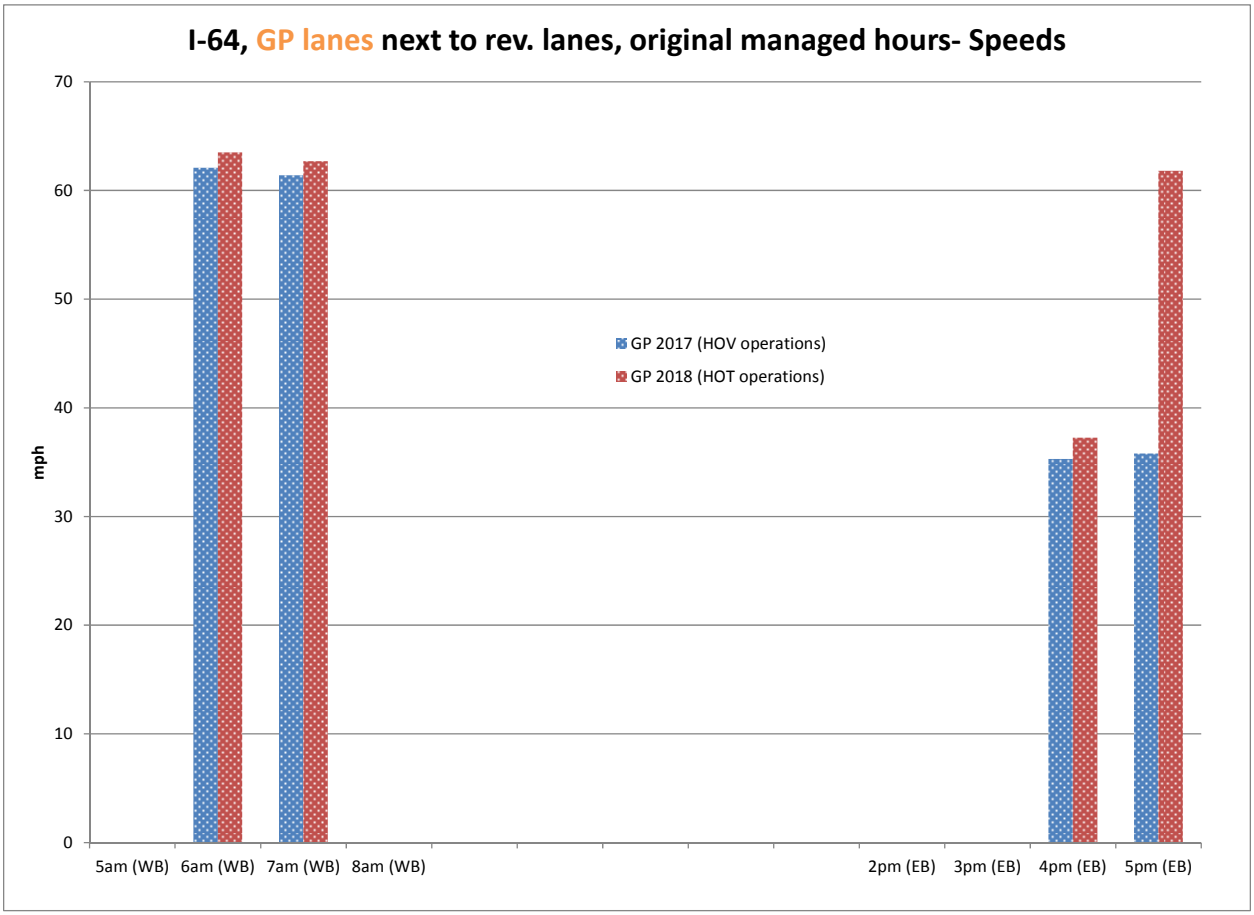


FIGURE 6 I-64 between Chesapeake Blvd & Norview Ave- Vehicle Speed, by hour
Source: HRTPO processing of VDOT data- summary of speeds.xlsx

As expected, the reduction in volumes shown on the previous page was accompanied by **higher speeds in the GP lanes**, particularly in the 5pm hour. The relationship between volume and speed being non-linear, the change in operations apparently lowered the GP volume below the congestion "tipping point" in the 5pm hour.

Then staff calculated the change in **total** volume, reversible plus GP.

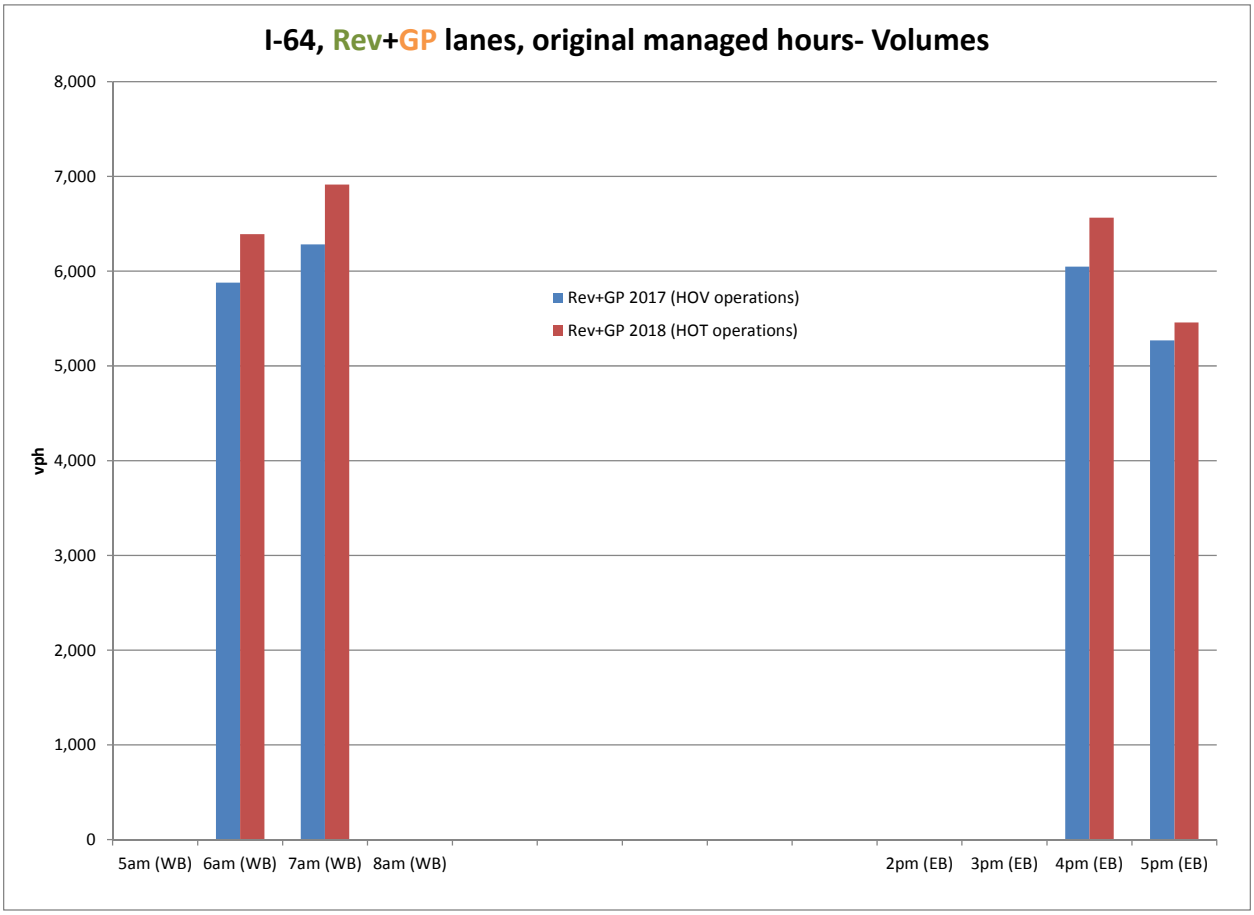


FIGURE 7 I-64 between Chesapeake Blvd & Norview Ave- Vehicle Volume, per hour
Source: HRTPO processing of VDOT data- volume data.xlsx

The increase in reversible volumes exceeding the decrease in GP volumes, the **total system volume increased**, as expected.

Finally, staff examined the fullness of the individual lanes, 3 GP lanes (in each direction) and 2 reversible lanes, during the subject hours.

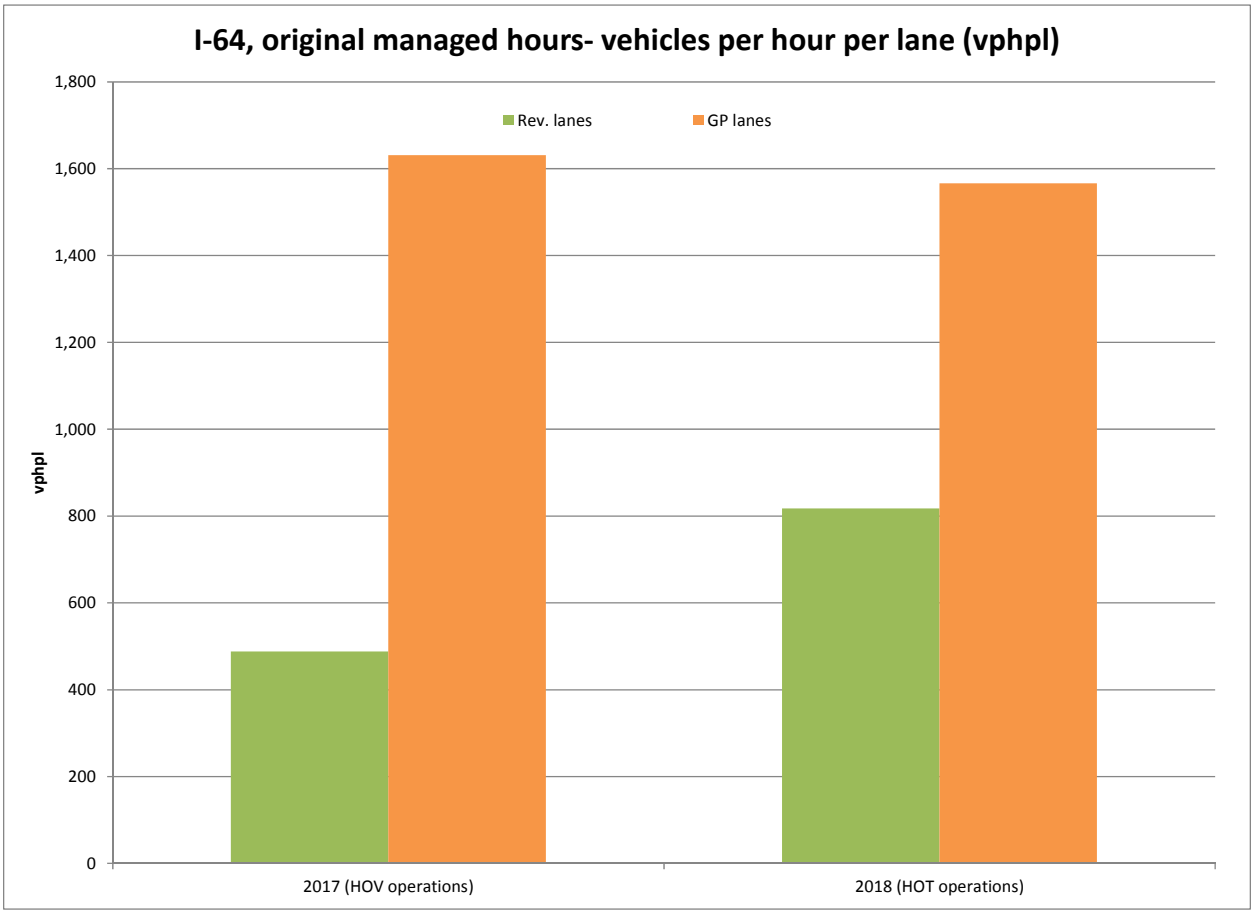


FIGURE 8 I-64 between Chesapeake Blvd & Norview Ave- Fullness of Lanes

Source: HRTPO processing of VDOT data- volume data.xlsx

Under HOV operations (2017), the reversible lanes were less than one-third as full as the GP lanes. In 2018, HOT operation 1) added vehicles to the reversible lanes, significantly increasing their fullness—from approx. 500 vehicles per hour per lane (vphpl) to approx. 800 vphpl—and 2) removed some vehicles from the GP lanes. With HOT operations, the reversible lanes are now half as full as the GP lanes.

In summary, as compared to HOV operation, HOT operation:

- significantly increased the usage of the reversible lanes
- maintained high speeds in the reversible lanes
- reduced volume and congestion in the GP lanes
- enabled the total system to carry more vehicles
- resulted in the reversible lanes being half as full as the GP lanes

HOT Operation vs. Unrestricted Operation (additional managed hours)

For the additional managed hours (weekdays 5-6am, 8-9am, and 2-4pm), on January 10, 2018 VDOT changed the operation of the I-64 reversible lanes **from unrestricted operation to HOT operation**. This chapter examines the volume and speed impacts of that change.

HOT operation (allowing HOVs and paying SOVs) being **more restrictive** than unrestricted operation (allowing any vehicles), it was expected that the January 10, 2018 change from unrestricted operation to HOT operation in the reversible lanes would cause some drivers to shift from the reversible lanes to the GP lanes, as shown below. Given lower usage of the reversible lanes, and the limited ability of congested GP lanes to receive many vehicles from the reversible lanes, it is expected that the change in operations caused the total system (reversible lanes and GP lanes) to carry fewer vehicles.

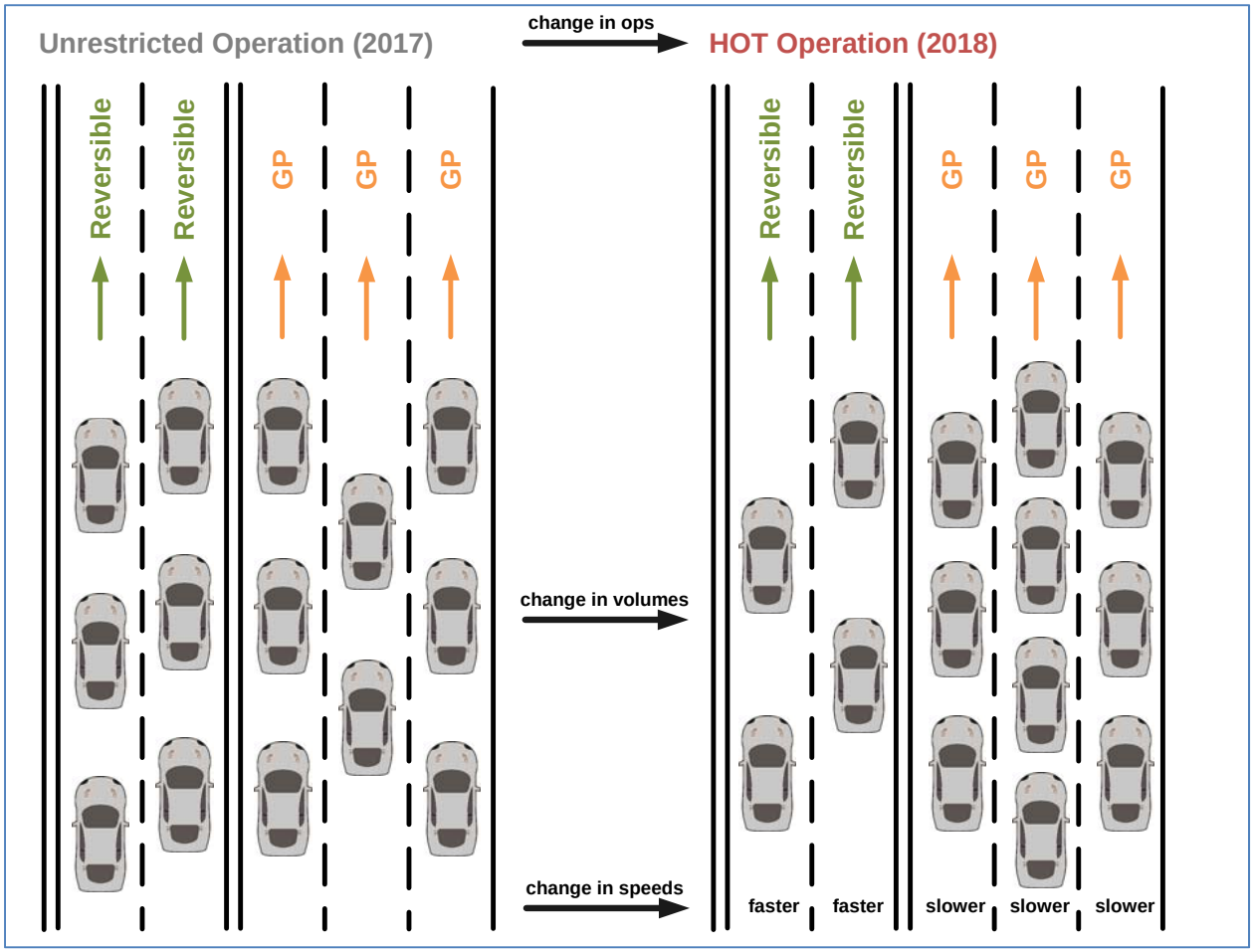


FIGURE 9 Expectation for the Additional Managed Hours

Source: HRTPO- UnRe to HOT w gray cars.vsd

First, staff examined the change in volumes in the reversible lanes.

FIGURE 10 I-64 between Chesapeake Blvd & Norview Ave- Vehicle Volume, per hour
Source: HRTPO processing of VDOT data- volume data.xlsx

As expected, **volumes decreased significantly in the reversible lanes** following the restrictions applied to them.

Next, staff examined the speed impact of the above decrease in volumes in the reversible lanes.

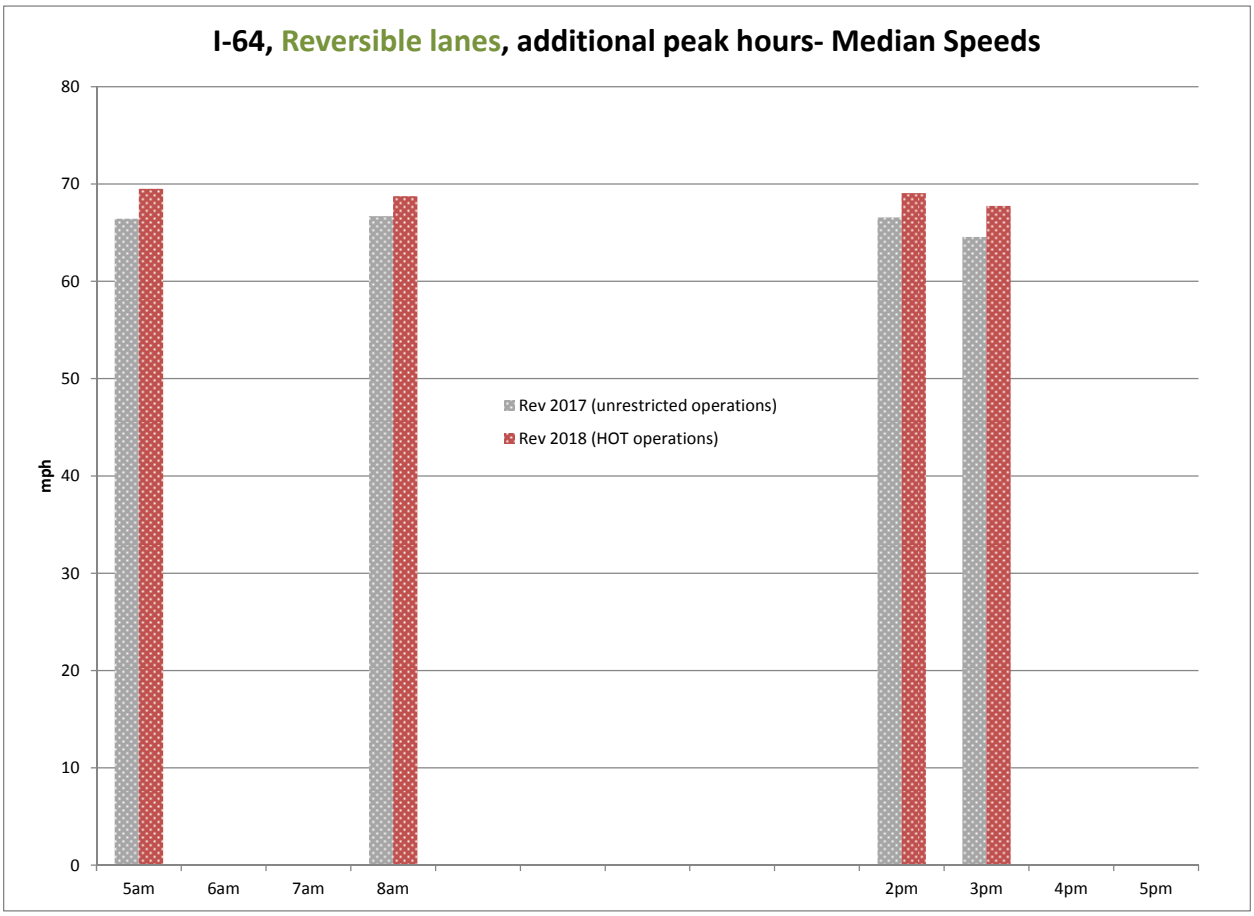


FIGURE 11 I-64 between Chesapeake Blvd & Norview Ave- Vehicle Speed, by hour
Source: HRTPO processing of VDOT data- speed_150112.xlsx

As expected, the decrease in volumes (shown on the previous page) was accompanied by **higher speeds in the reversible lanes**. The speeds being fairly high under unrestricted operations, the increase in speeds under HOT operation was slight.

Following the above look at reversible lanes, staff examined changes in the GP lanes.

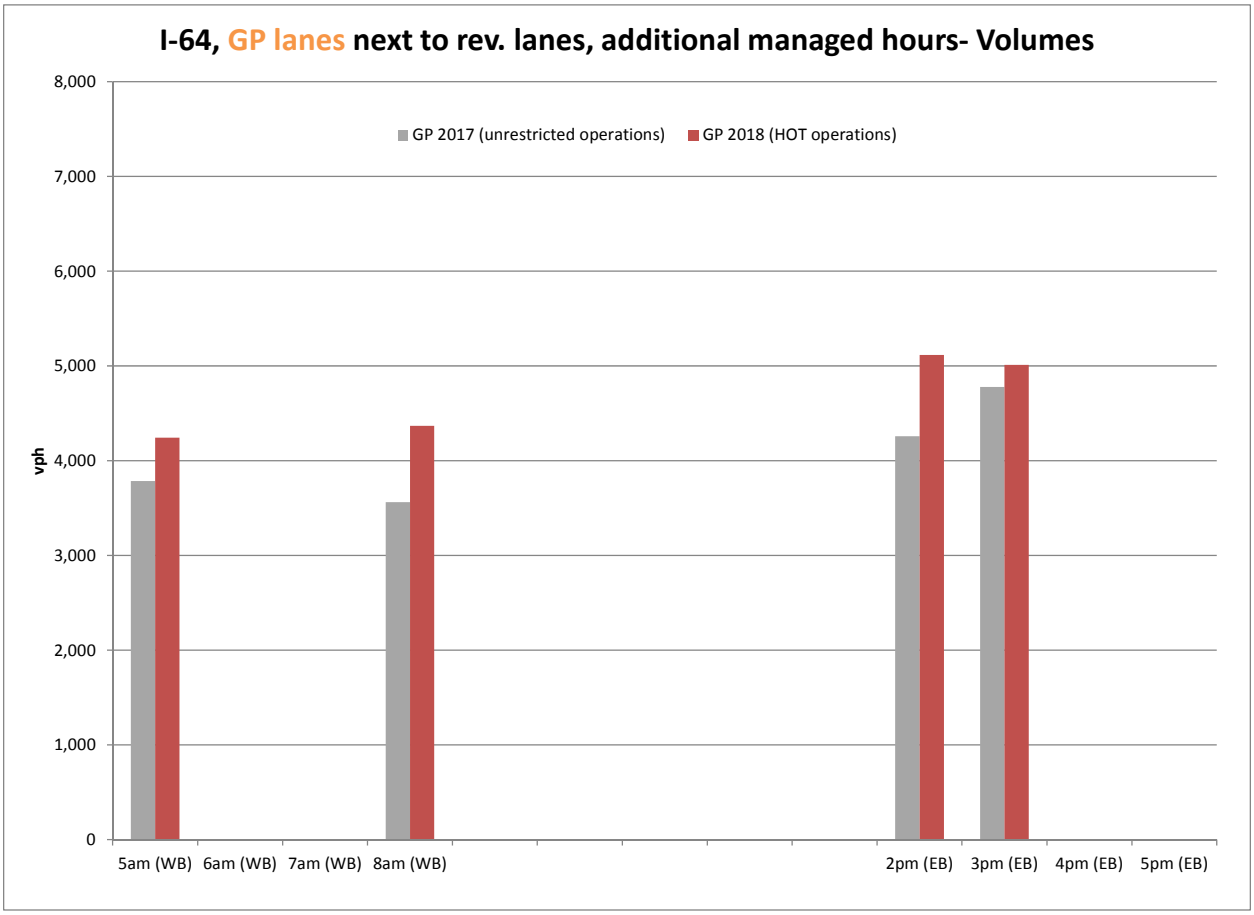


FIGURE 12 I-64 between Chesapeake Blvd & Norview Ave- Vehicle Volume, per hour
Source: HRTPO processing of VDOT data- volume data.xlsx

As expected due to restriction in the reversible lanes, **volumes increased in the GP lanes**. Although these increases were significant, they were less than the decreases in the reversible lanes, indicating that some vehicles left the system.

Next, staff examined the speed impact of the above increase in volumes in the GP lanes.

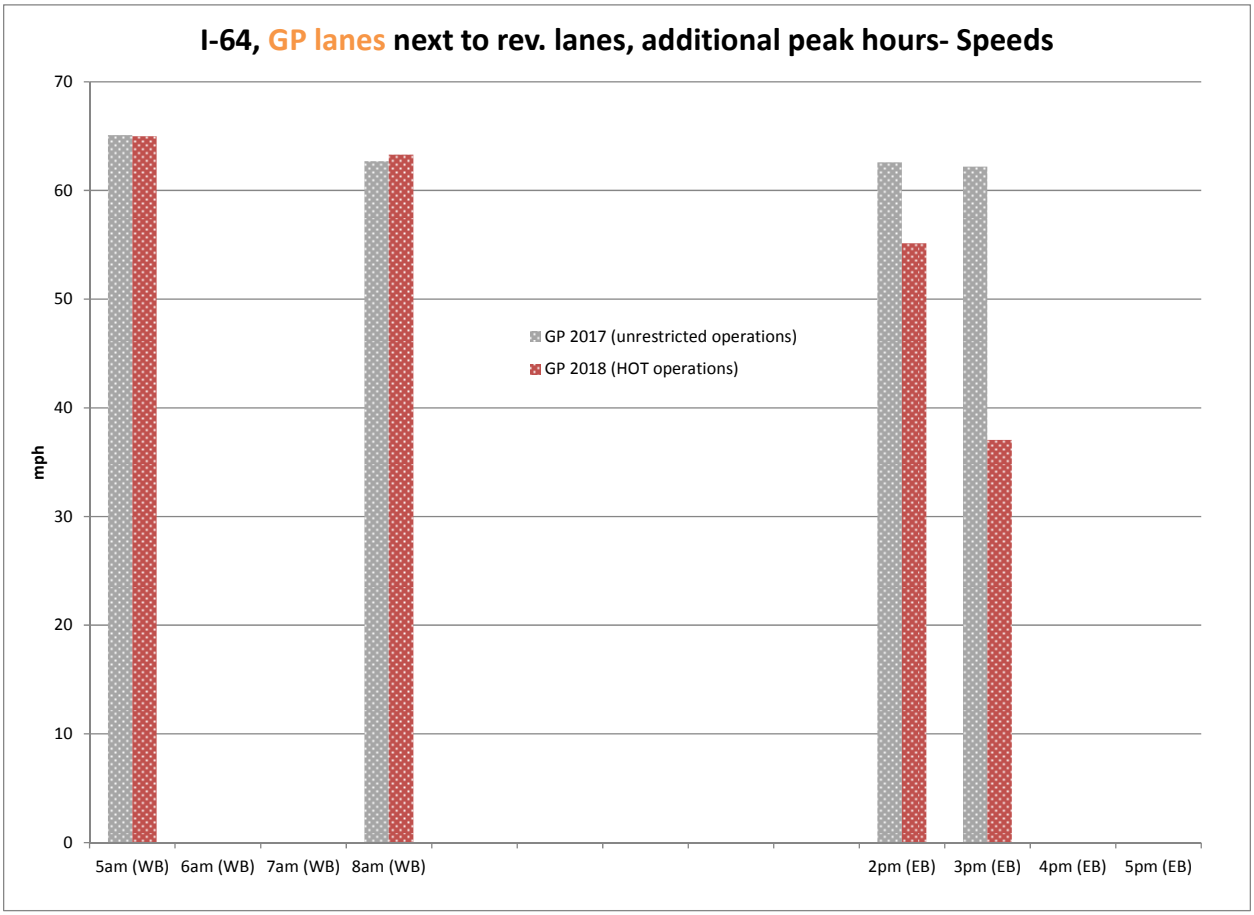


FIGURE 13 I-64 between Chesapeake Blvd & Norview Ave- Vehicle Speed, by hour
Source: HRTPO processing of VDOT data- summary of speeds.xlsx

As expected, the increase in volumes shown on the previous page was accompanied by **lower speeds in the GP lanes**, particularly in the 3pm hour. The relationship between volume and speed being non-linear, the change in operations apparently raised the GP volume above the congestion "tipping point" in the 2pm and 3pm hours.

Then staff calculated the change in **total** volume, reversible plus GP.

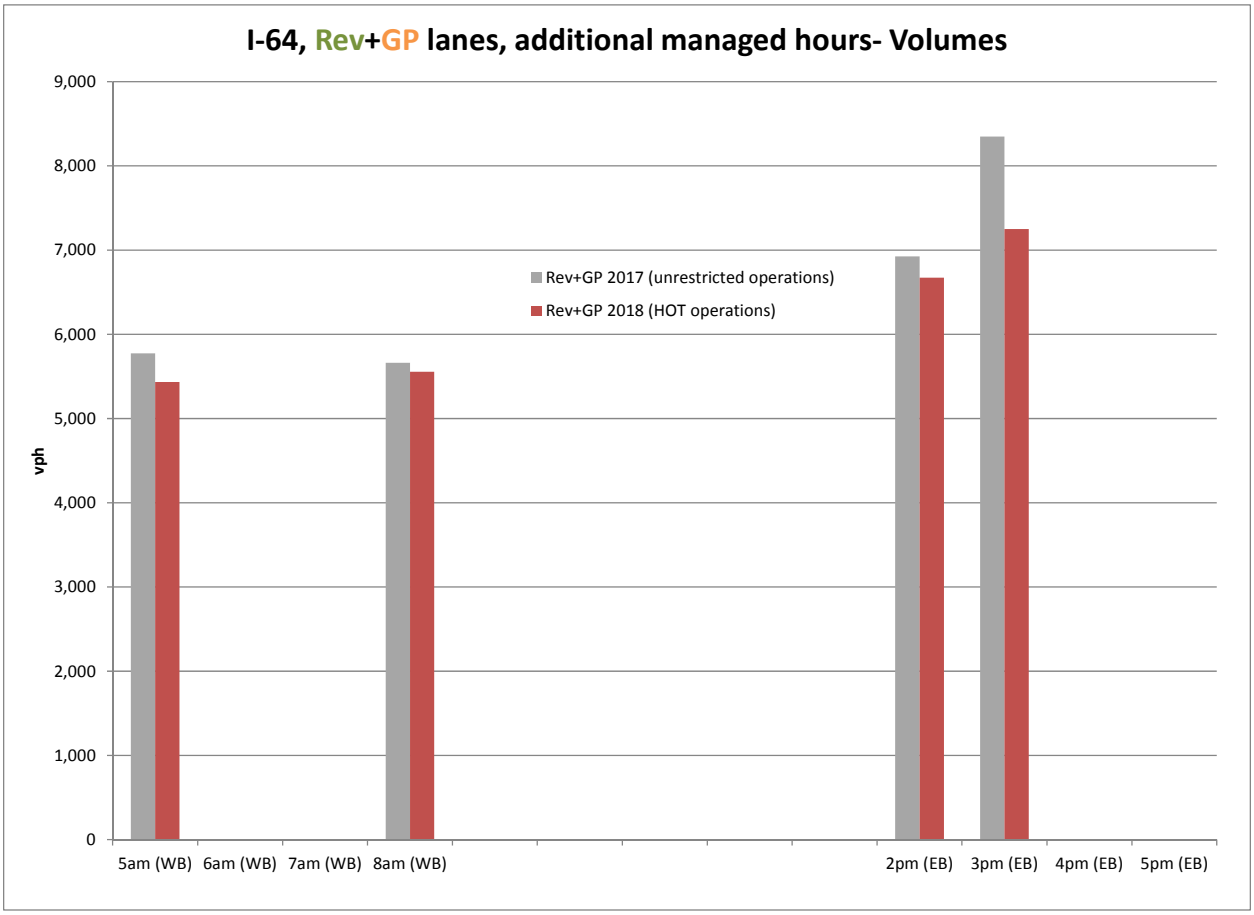


FIGURE 14 I-64 between Chesapeake Blvd & Norview Ave- Vehicle Volume, per hour
Source: HRTPO processing of VDOT data- volume data.xlsx

As expected, the decrease in reversible volumes exceeding the increase in GP volumes, the **total system volumes decreased**. Note that this decrease was particularly significant in the 3pm hour.

As shown above, changing from unrestricted to HOT operation reduced the total number of *vehicles* served by the system, but—due to HOV formation—did this operational change also reduce the number of *persons* served? To answer this question, staff estimated the number of persons served before and after the operations change.

First, staff processed available vehicle transponder data from VDOT to calculate the portion of vehicles which are HOV (i.e. which have transponder switch turned to "HOV" to avoid paying toll) under HOT operation.

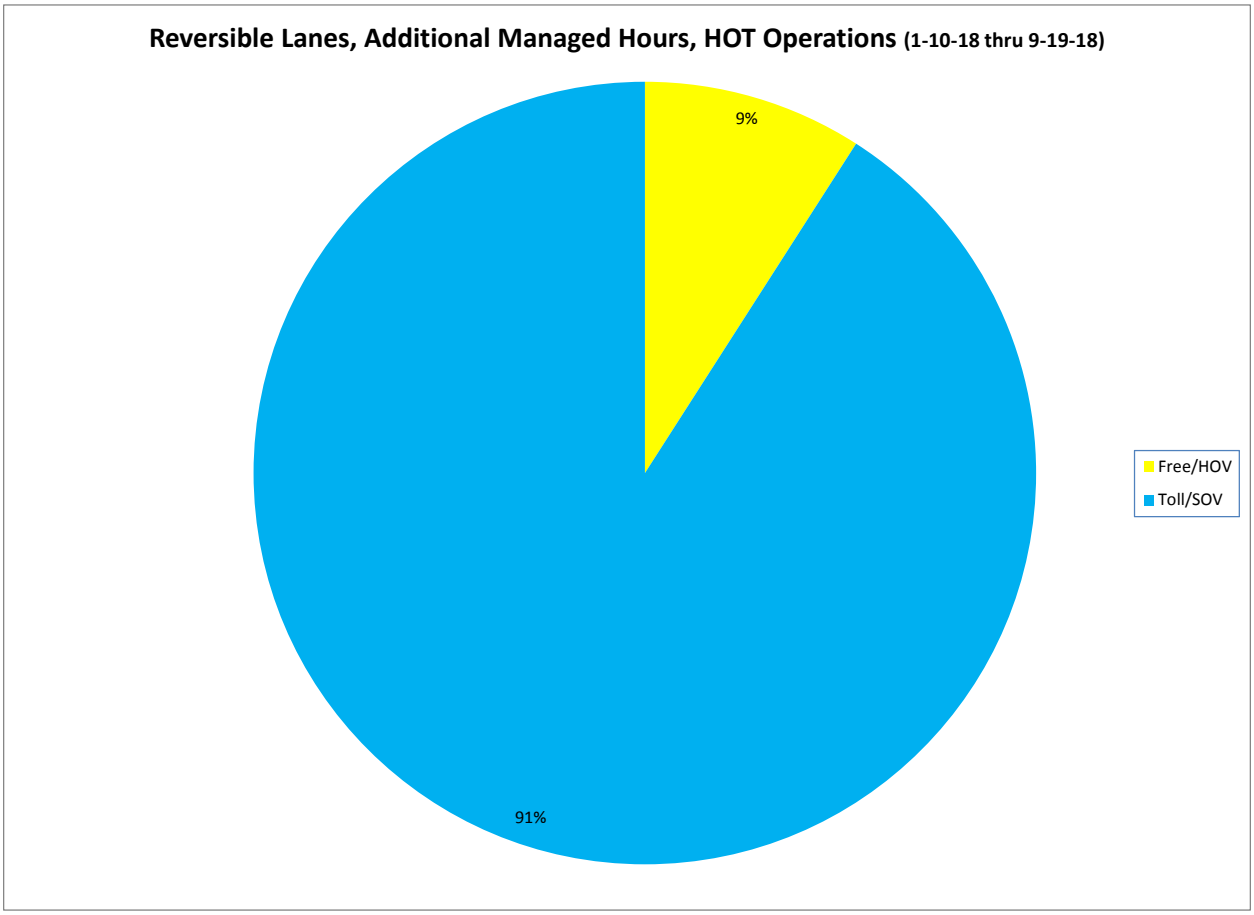


FIGURE 15 I-64 Reversible Lanes- HOV vs. SOV

Source: HRTPO processing of VDOT data- volume data.xlsx

As shown above, under HOT operation, 9% of the vehicles in the reversible lanes are HOV.

Assuming that *all* of these HOVs represent carpools of two persons newly formed due to HOT operation renders the following persons calculation.

	5am (WB)	8am (WB)	2pm (EB)	3pm (EB)
Rev 2017 (unrestricted operations), vehicles	1,991	2,098	2,670	3,571
occupancy, assumed	1.0	1.0	1.0	1.0
Rev 2017 (unrestricted operations), persons	1,991	2,098	2,670	3,571
GP 2017 (unrestricted operations), vehicles	3,784	3,563	4,257	4,779
occupancy, assumed	1.0	1.0	1.0	1.0
GP 2017 (unrestricted operations), persons	3,784	3,563	4,257	4,779
Rev+GP 2017 (unrestricted operations), persons	**5,775**	**5,661**	**6,926**	**8,350**
Rev 2018 (HOT operations), vehicles	1,192	1,186	1,558	2,239
% HOV	10%	8%	8%	9%
Rev 2018 (HOT operations), HOV vehicles	123	99	125	212
occupancy, assumed	2.0	2.0	2.0	2.0
Rev 2018 (HOT operations), persons in HOV vehicles	247	198	251	425
Rev 2018 (HOT operations), vehicles	1,192	1,186	1,558	2,239
% SOV	90%	92%	92%	91%
Rev 2018 (HOT operations), SOV vehicles	1,068	1,087	1,433	2,026
occupancy, assumed	1.0	1.0	1.0	1.0
Rev 2018 (HOT operations), persons in SOV vehicles	1,068	1,087	1,433	2,026
Rev 2018 (HOT operations), persons	1,315	1,285	1,683	2,451
GP 2018 (HOT operations), vehicles	4,244	4,370	5,116	5,013
occupancy, assumed	1.0	1.0	1.0	1.0
GP 2018 (HOT operations), persons	4,244	4,370	5,116	5,013
Rev+GP 2018 (HOT operations), persons	**5,559**	**5,654**	**6,799**	**7,464**

FIGURE 16 I-64 between Chesapeake Blvd & Norview Ave- Persons Calculation

Source: HRTPO processing of VDOT data- volume data.xlsx

The above calculation of persons rendered the following results.

FIGURE 17 I-64 between Chesapeake Blvd & Norview Ave- Persons

Source: HRTPO processing of VDOT data- volume data.xlsx

In addition to serving fewer *vehicles* (as shown earlier), the operational change apparently caused the system to **serve fewer *people***, particularly in the 3pm hour.

Finally, staff examined the fullness of the individual lanes, 3 GP lanes (in each direction) and 2 reversible lanes, during the subject hours.

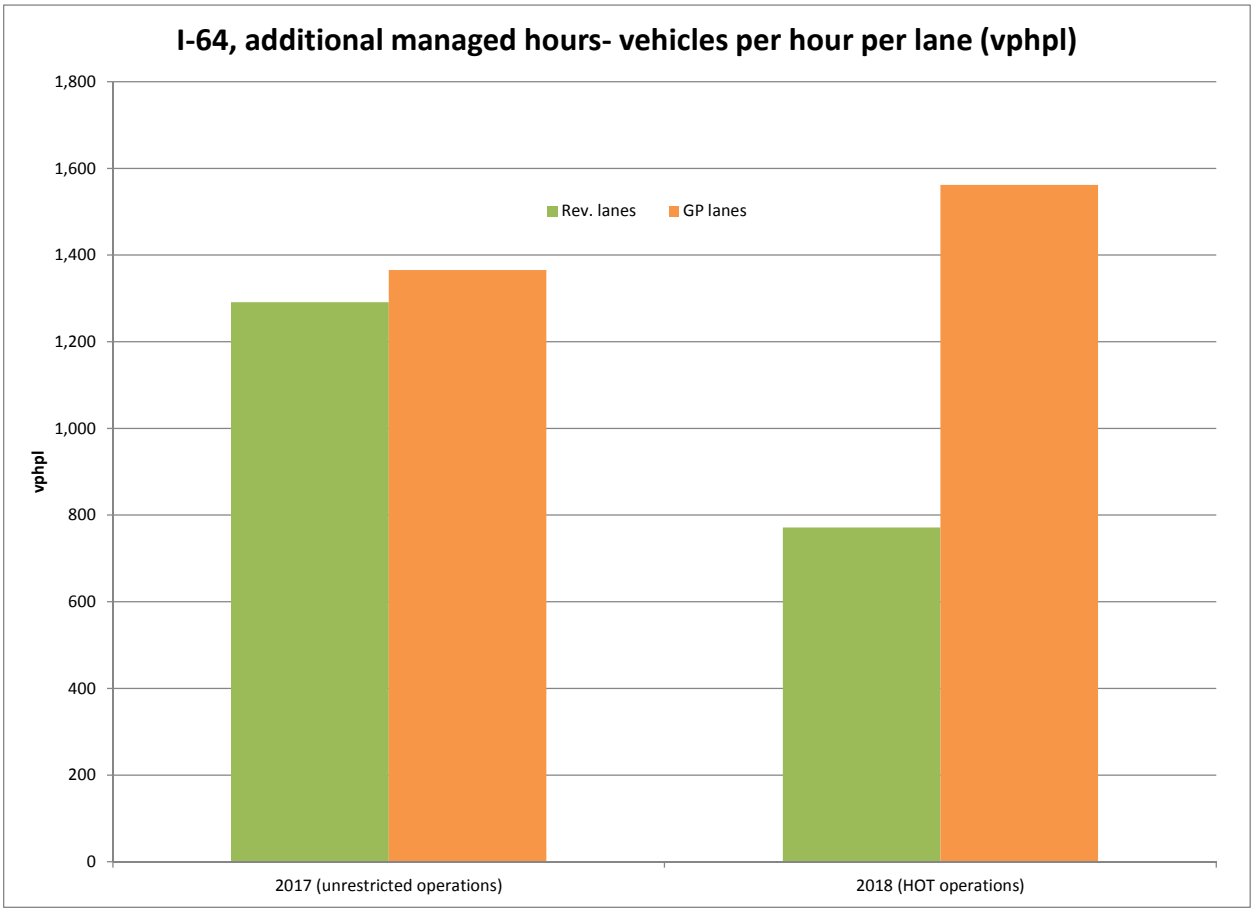


FIGURE 18 I-64 between Chesapeake Blvd & Norview Ave- Fullness of Lanes
Source: HRTPO processing of VDOT data- volume data.xlsx

Under unrestricted operations (2017), the reversible lanes were almost as full as the GP lanes. In 2018, HOT operation 1) removed vehicles from the reversible lanes, significantly decreasing their fullness—from approx. 1,300 vehicles per hour per lane (vphpl) to approx. 800 vphpl—and 2) added some vehicles from the GP lanes. With HOT operations, the reversible lanes are half as full as the GP lanes.

In summary, as compared to unrestricted operation, HOT operation:

- significantly decreased the usage of the reversible lanes
- slightly increased reversible lane speeds
- significantly increased volume and congestion in the GP lanes
- caused the total system to carry fewer vehicles and persons
- resulted in the reversible lanes being half as full as the GP lanes

Summary

The impacts of the January 10, 2018 changes in the operation of the I-64 reversible lanes resulted in the following volume, speed, and lane usage impacts:

1) during "**original managed hours**" (6-8am, 4-6pm) operations became **less restrictive**, changing from HOV operation to HOT operation

As compared to HOV operation, HOT operation:

- significantly increased the usage of the reversible lanes
- maintained high speeds in the reversible lanes
- reduced the volume and congestion in the GP lanes
- enabled the total system to carry more vehicles
- resulted in the reversible lanes being half as full as the GP lanes

2) during "**additional managed hours**" (5-6am, 8-9am, 2-4pm) operations became **more restrictive**, changing from unrestricted operation to HOT operation

As compared to unrestricted operation, HOT operation:

- significantly decreased the usage of the reversible lanes
- slightly increased reversible lane speeds
- significantly increased volume and congestion in the GP lanes
- caused the total system to carry fewer vehicles and persons
- resulted in the reversible lanes being half as full as the GP lanes

Appendix: Data Collection and Processing

Staff limited the analysis to weekdays and non-holidays. For the "before" analysis, staff used 2017 data; for the "after" analysis, staff used 2018 data. Given that the change in operations occurred January 10, 2018, data during the first few days of 2018 was ignored.

The collection and processing of the two types of data used in the analysis—vehicle volume and vehicle speed—are discussed, in turn, below.

I. Volume

Staff used volume data from the following VDOT count stations:

- reversible lanes station 150112
- GP lanes westbound station 150066 **between Norview Ave. & Ches. Blvd.**
- GP lanes eastbound station 050306 **between Ches. Blvd. & Norview Ave.**

Given that directional labels were incorrect for the second half of 2018, for that half staff assumed—based on the following chart for the first half of 2019—that midnight to 11am volumes were westbound (WB) and 11am to midnight volumes were eastbound (EB).

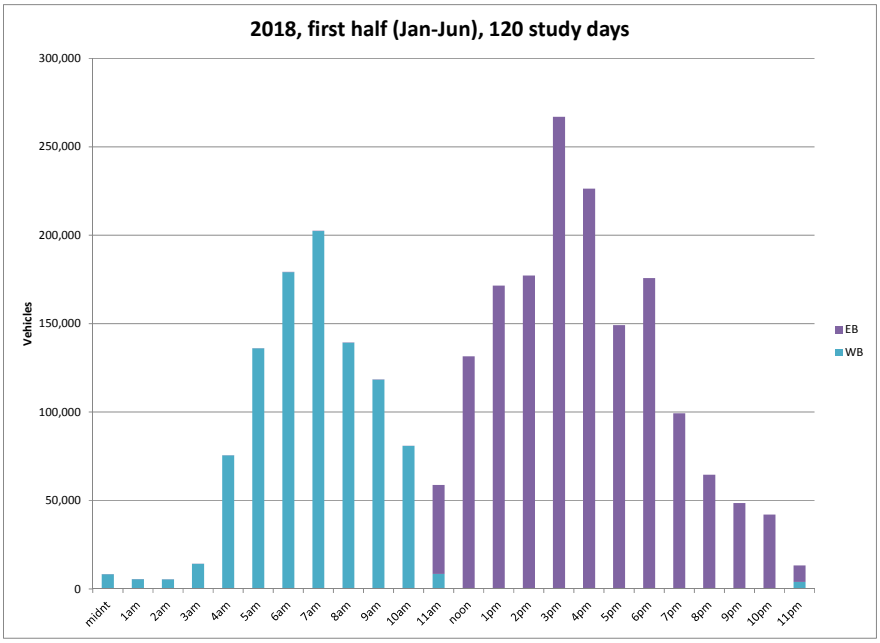


FIGURE A1 I-64 Reversible Lanes Vehicle Volumes

Source: HRTPO processing of VDOT data- volume data.xlsx

To check whether differences between 2017 and 2018 data (e.g. changes in general purpose [GP] lane hourly volumes) may reasonably be attributed to the January 10, 2018 change in operations, staff compared the total daily volumes (GP + reversible), as shown below.

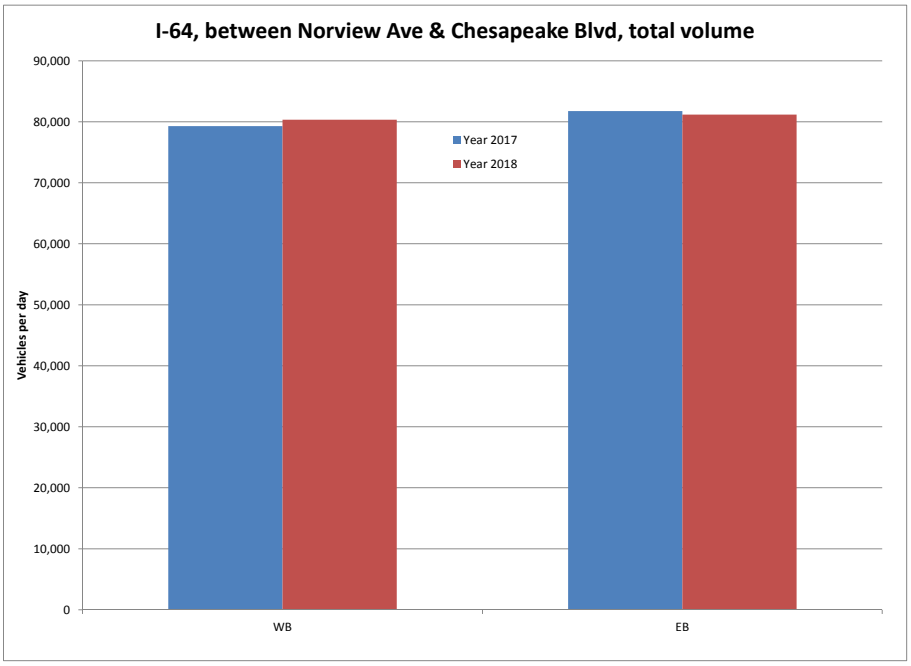


FIGURE A2 I-64 Vehicle Volumes

Source: HRTPO processing of VDOT data- volume data.xlsx

Given that there was no significant change in total daily volumes (e.g. due to the economy), staff assumed that any differences in GP or reversible hourly volumes and speeds found in this report may reasonably be attribute to the January 10, 2018 change in operations.

When summarizing volumes for each subject year, staff calculated **average** volumes (as opposed to median volumes).

II. Speed

For the reversible lanes, staff used data from VDOT's 1500112 loop detector. For the years analyzed (2017 and 2018) the "Speed Quality" averaged 4.85 (maximum 5.00).

To reduce the undesirable impact of outlying speeds, when summarizing speeds for each subject year, staff calculated **median** speeds (as opposed to average speeds).

For the GP lanes, staff tried several sources of speed data before finding a reliable source:

A. StreetLight personal vehicle data
B. StreetLight commercial vehicle data
C. VDOT Radar Spot Speeds near Azalea Garden Rd
D. VDOT Radar Spot Speeds between Chesapeake Blvd & Norview Ave

Each is discussed in turn on the following pages.

A. StreetLight Personal Vehicle Data

Staff tried *personal* vehicle travel time data from StreetLight, checking its reasonableness as shown below.

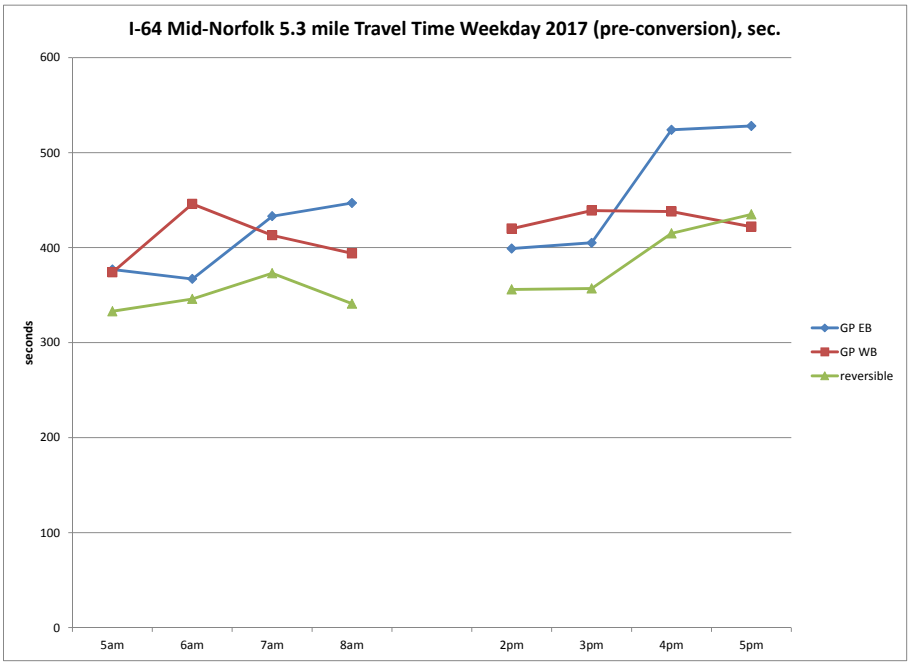


FIGURE A3 I-64 Travel Time between Lake Taylor High School and MacDonald Rd

Source: HRTPO processing of StreetLight data- I_64_mid_Nor_2017_3469_zone_seg_counts_all.xlsx

Given that the reversible lane travel time was higher during the managed (HOV operations) period (4-6pm) than during the unrestricted period (2-4pm) according to StreetLight data, staff assumed that StreetLight travel time data is unreliable along this segment (likely due to StreetLight difficulty differentiating between the GP and reversible lanes).

B. StreetLight Commercial Vehicle Data

Staff tried *commercial* vehicle travel time data from StreetLight, checking its reasonableness as shown below.

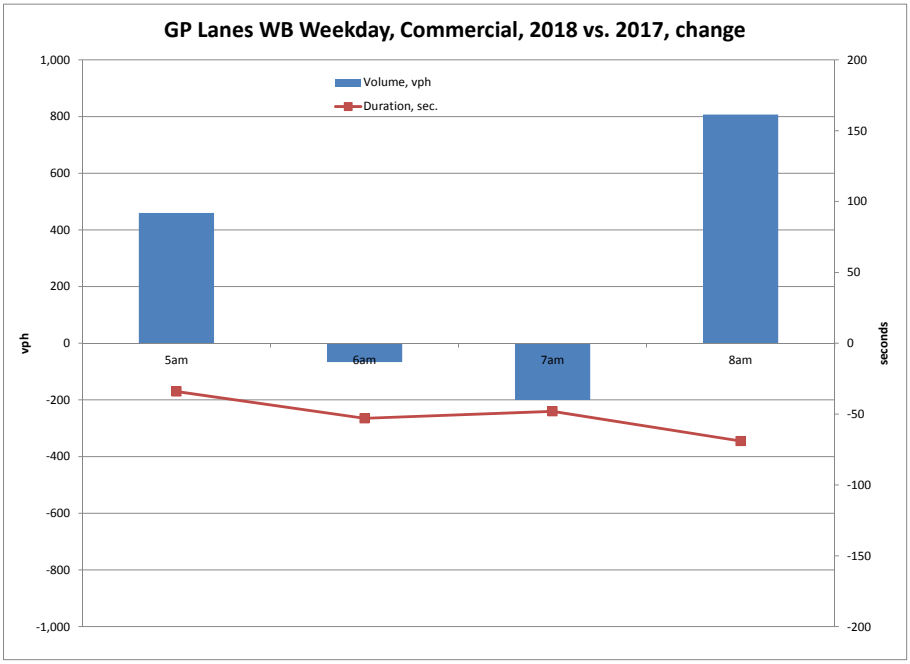


FIGURE A4 I-64 Volume & Travel Time between Lake Taylor HS and MacDonald Rd

Source: HRTPO processing of StreetLight data- I_64_mid_Nor_2017_3158_zone_seg_counts_commercial.xlsx

Given that the reversible lane travel time improved (2018 HOT operation vs. 2017 HOV operation) regardless of whether the volume increased (5am and 8am) or decreased (6am and 7am), staff assumed that StreetLight commercial vehicle travel time data is unreliable along the segment (likely due to StreetLight difficulty differentiating between the GP and reversible lanes).

C. VDOT Radar Spot Speeds near Azalea Garden Rd

Staff downloaded spot speed data via VDOT's Performance Measurement System (PeMS) for stations near Azalea Garden Road:

- Eastbound station 64046121
- Westbound station 64046241

Finding abnormalities in the data, staff checked "data quality" as shown below.

Parameter	Value
Quantity	Speed
Data	216,000 Lane Points
Data Quality	4.5% Observed
Segment Type	VDS
Segment Name	**Mainline Station 64046121 - 64EB before Azalea Garden Rd E**
start date	01/01/2018 00:00:00
end date	12/31/2018 23:59:59
Day of Week	Mo,Tu,We,Th,Fr
Granularity	hour

FIGURE A5 I-64 Speed Station 64046121

Source: VDOT- reversible HOT work space.pptx

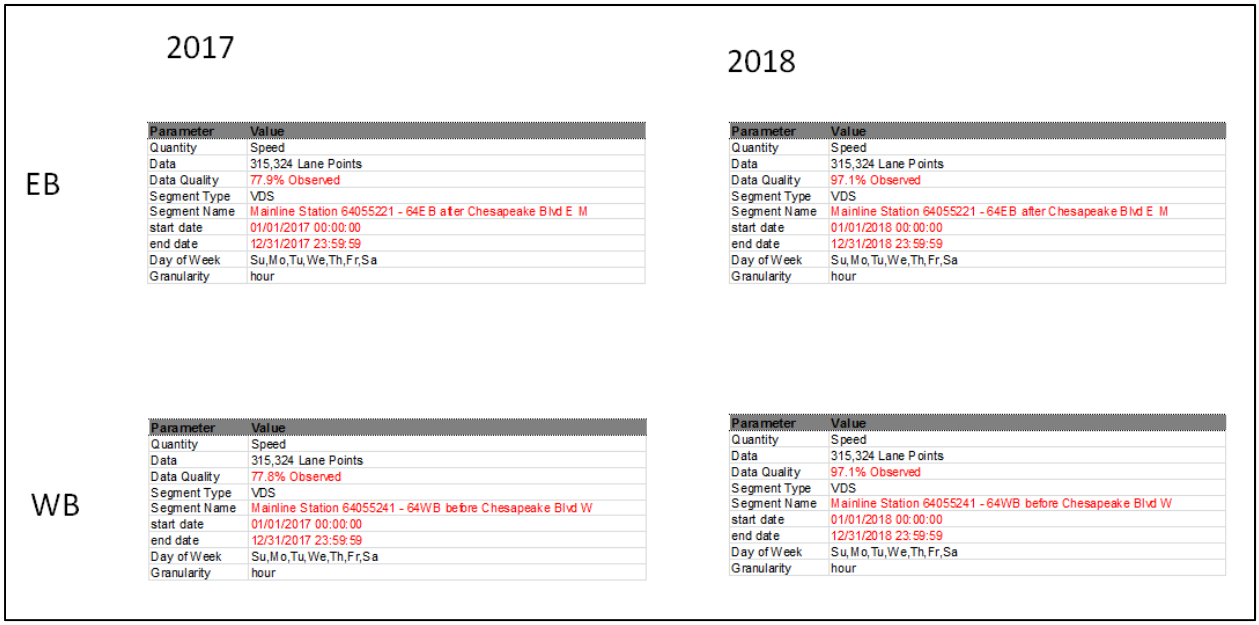
Given that only 4.5% of the EB 2018 data was observed, staff rejected this source of speed data.

D. VDOT Radar Spot Speeds between Chesapeake Blvd & Norview Ave

Finally, staff downloaded spot speed data via VDOT's Performance Measurement System (PeMS) for stations between Chesapeake Blvd & Norview Ave:

- Eastbound station 64055221
- Westbound station 64055241

Having found poor data quality in the previous data set, staff checked "data quality" for this set as shown below.



Parameter	Value
Quantity	Speed
Data	315,324 Lane Points
Data Quality	77.9% Observed
Segment Type	VDS
Segment Name	Mainline Station 64055221 - 64EB after Chesapeake Blvd E M
start date	01/01/2017 00:00:00
end date	12/31/2017 23:59:59
Day of Week	Su,Mo,Tu,We,Th,Fr,Sa
Granularity	hour

Parameter	Value
Quantity	Speed
Data	315,324 Lane Points
Data Quality	97.1% Observed
Segment Type	VDS
Segment Name	Mainline Station 64055221 - 64EB after Chesapeake Blvd E M
start date	01/01/2018 00:00:00
end date	12/31/2018 23:59:59
Day of Week	Su,Mo,Tu,We,Th,Fr,Sa
Granularity	hour

Parameter	Value
Quantity	Speed
Data	315,324 Lane Points
Data Quality	77.8% Observed
Segment Type	VDS
Segment Name	Mainline Station 64055241 - 64WB before Chesapeake Blvd W
start date	01/01/2017 00:00:00
end date	12/31/2017 23:59:59
Day of Week	Su,Mo,Tu,We,Th,Fr,Sa
Granularity	hour

Parameter	Value
Quantity	Speed
Data	315,324 Lane Points
Data Quality	97.1% Observed
Segment Type	VDS
Segment Name	Mainline Station 64055241 - 64WB before Chesapeake Blvd W
start date	01/01/2018 00:00:00
end date	12/31/2018 23:59:59
Day of Week	Su,Mo,Tu,We,Th,Fr,Sa
Granularity	hour

FIGURE A6 I-64 Speed Stations between Chesapeake Blvd & Norview Ave
Source: VDOT- reversible HOT work space.pptx

Given the high percentages observed (above) and the logicalness of the data (as shown in the report body), staff accepted this speed data as reliable.

To reduce the undesirable impact of outlying speeds, when summarizing speeds for each subject year, staff calculated **median** speeds (as opposed to average speeds).