

FEASIBILITY STUDY OF MOVABLE BARRIER SYSTEM ALONG INTERSTATE 70 IN COLORADO

PHASE 1 REPORT

(DRAFT - VERSION 2 UPDATED FROM JULY 1)

PREPARED FOR

COLORADO DEPARTMENT OF TRANSPORTATION

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EXECUTIVE SUMMARY

This technical report documents the work performed for the Colorado Department of Transportation (CDOT) in regards to the feasibility study of a movable barrier system (MBS) implementation along a 15-mile segment on Interstate 70 (I-70). The objective of the feasibility study was to determine possible traffic related issues and advantages in the implementation and operation of the MBS, and if the performance of the MBS is practical in terms of operations of corridor traffic. The feasibility study used a dynamic traffic assignment (DTA) and simulation network model called DynusT and VISSIM. The goals of this study are to demonstrate the advantages and disadvantages of the MBS along the 15-mile segment on I-70.

The overall analysis shows that there is a travel time improvement for all vehicles due to MBS operation with an average travel time savings of 34-36%. Restricting trucks from using the I-70 WB lanes provides a slightly higher savings because reduced amount of trucks in the traffic stream mix would normally facilitate acceleration/decelerate in a congested situation. This gives westbound non-truck traffic greater travel time savings along the 25-mile segment. Similar to the average network travel time, time savings percentage improvement for total vehicle hours traveled (VHT) reaches 34-37%.

Examining the travel conditions by direction, EB traffic that is currently experiencing severe congestion can indeed benefit from the MBS operations. Significant speed improvements are observed in all modeled scenarios. The East terminal exhibits certain speed drops due to merging of traffic. This is a rather normal situation for most freeway merging facilities. The MB lane is found to be considerably utilized. Traffic also slows down at the Idaho Spring area. This is expected in the situation when through and local traffic is interacted in this segment. The average travel time traversing the 25-mile corridor is improved to 25 minutes from the existing 60 minutes, equivalent to a nearly 60% improvement.

The WB traffic flows at free-flow speed in the current situation, but 3-5 miles slow moving queue is observed in all modeled MB scenarios due to lane drop. The existing travel time for the same corridor is 22 minutes but it is increased to 28 or 33 minutes with the MB operation. This statistics include the time waiting in the queue to enter the WB lane.



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1. INTRODUCTION

This technical report documents the work performed for the Colorado Department of Transportation (CDOT) in regards to the feasibility study of a movable barrier system (MBS) implementation along a 15-mile segment on Interstate 70 (I-70). The objective of the feasibility study was to determine possible traffic related issues and advantages in the implementation and operation of the MBS, and if the performance of the MBS is a practical traffic management strategy. The feasibility study used a dynamic traffic assignment (DTA) and simulation network model called DynusT and VISSIM. The work performed includes network model conversion, network cleanup and verification, traffic flow model calibration, origin-destination demand calibration, departure profile adjustments, simulation validation, and scenario development and analysis. Modeling methodologies include commercial truck restrictions on selected facilities.

Final results demonstrate the advantages and disadvantages of the MBS along the 15-mile segment on I-70. According to modeling results, implementation of the system is a benefit to the overall I-70 facility; however, there are operational issues that must be addressed to mitigate the likely event of traffic congestion on the terminal boundaries of the MBS. Analysis results are further presented and discussed in the later sections of this report.

1.1. Interstate 70 Congestion and Mitigation Strategy

Along the I-70 mountainous corridor between the towns of Georgetown, CO and Idaho Springs, CO there is significant travel in the winter months due to the ski season in Colorado as I-70 leads directly to the ski resorts in the area, including the towns of Vail, Breckenridge, Frisco, and ski resorts. Field traffic observations show I-70 experiences high levels of directional traffic congestion on Sunday afternoons as travelers make their way back from the mountain counties of Eagle, Summit and Clear Creek on the I-70 corridor towards the Denver metro area in the eastbound direction. The worst delays occur from Georgetown to the Twin Tunnels just east of Idaho Springs. In the summer months there is significant traffic in both the eastbound and westbound directions that cause large congestion; however, this study does not consider the summer months.

The mitigation strategy of concern is to employ a MBS along a 15-mile segment along the I-70 corridor in the eastbound direction from 2 miles east of Georgetown to Floyd Hill just west of the US 6 interchange, as shown in Figure 1.1: 15-mile MBS segment on I-70. The MBS would be operational on Sunday afternoons when the eastbound congestion is at its highest during the winter months. Since the I-70 segment is a divided highway, the MBS would be placed on the westbound direction of I-70, thereby reducing the WB capacity from two lanes to one lane, and increasing the eastbound capacity from two lanes to three lanes. Again, being a divided highway, there would be only one entry point (west terminal) for eastbound traffic and one exit point (east terminal); therefore, travelers who enter the additional eastbound lane must remain in that lane for the entire 15-mile segment.

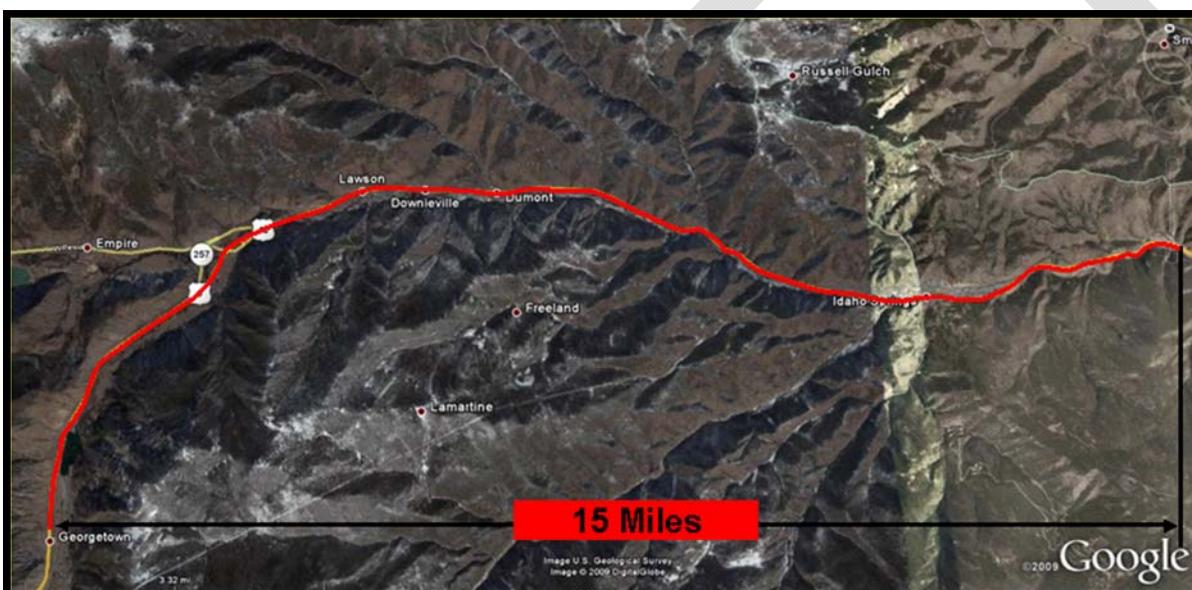


Figure 1.1: 15-mile MBS segment on I-70

Concerns of operational flaws in the employment of the MBS were brought to attention as to whether westbound traffic during the MBS operations would exceed acceptable congestion levels due to capacity reduction. Also, the question of whether implementing the MBS would provide acceptable benefit to the eastbound congestion as well as the entire network system. This feasibility study was aimed at answering these and other related questions.

1.2. Interstate 70 Regional Planning Model

The primary analysis tools chosen for this project are DynusT and VISSIM in a multi-resolution modeling framework. The CDOT I-70 regional planning model was used to export link characteristics such as

functional classes, link lengths, and number of lanes to convert into DynusT format. The CDOT I-70 model was developed for I-70 corridor studies. The model was provided to the UA team by the University of Colorado at Denver's (UCD) Dr. Bruce Janson. UCD received the planning model, including the GISDK script and data from CDOT. The TransCAD planning model, including a GISDK script and all network and demand information for the script were provided for network conversion. The regional model's network includes 749 Traffic Analysis Zones (TAZ), 15,387 links, and 10,843 nodes. An initial inspection and clean-up of the network, including removing links in the network that do not pertain to the DynusT modeling process, reduced the link and node count to 13,364 and 9,830, respectively.

1.2.1. Auto and Truck Demand Preparation

The original input files for the GISDK script used to execute the typical urban planning procedures to the UA team. It was expected that after running the script, the final product would be the origin-destination (OD) demand tables for both personal auto vehicle and commercial truck. However, after many attempts of running the script, the script was not in working condition. . It was determined the required input data for the GISDK was not available, as well as discovering script errors and bugs, thus acquiring the additional data would be difficult and still not produce the appropriate demand needed. The script errors were found in the transit assignment code of the mode choice module. Even when transit assignment code was disabled in the script, errors still occurred, thereby not allowing the script to complete. UCD confirmed their attempts ended with the same errors and results. As a result of the non-functioning GISDK script, the origin-destination (OD) trip matrices were not created. The trip matrices are the estimated vehicle trips from the travel forecasting model. Had the OD trip matrices been available from the planning model, the OD table would be converted to DynusT format and used for generation of vehicles to simulate in the DynusT. Nonetheless, DynusT would need OD trip matrices. It was decided to extract what information could be developed which were time-of-day production rates in the trip distribution module for a winter Sunday from the year 2000 from the trip distribution module of the GISDK script. This information was the most complete data that could be extracted from the model. It was anticipated that the OD demand for both auto vehicle and commercial truck would be calibrated in later DynusT development steps to mitigate what was so far extracted and developed. The calibration adjusted the OD demand to an acceptable level with given limited resources of traffic volumes provided by CDOT (traffic data resources are detailed in section 2.2). Details and results from the calibration procedure are reported in section 2.4 of this report.

1.3. Analysis Period

The analysis period of interest is the winter Sunday PM period from 1:00pm to 9:00pm. Within this time period, the MBS is proposed to begin operation at 1:00 PM at Floyd Hill (east terminal) moving toward the west terminal near Georgetown. The MBS would remain at the west terminal and begin its operation back toward the east terminal at 8:00 PM.

This required the DynusT model to extend the simulation period and demand period beyond the time boundaries of the actual analysis period in order to capture onset congestion before the analysis period of interest. The simulation period is the time period in which vehicles in the DynusT model travel the network. The demand period is the time period in which vehicles are entered into the network based upon the calibrated OD demand tables. The simulation period for the DynusT model would then begin at 12:00 PM as the “warm-up” period, the end of the simulation period would end at 10:00 PM. The demand period was also set to begin at 12:00 PM to 10:00 PM, thus represented by 10 one-hour time-dependent demand tables. Each 1-hr demand table has some hourly factor. Demand hourly factors were extracted from traffic data found within the input data of the I-70 regional planning model.

1.4. Interstate 70 Subarea Definition for Dynamic Traffic Assignment Model

Much of the regional model was not within the scope of this feasibility study as it focused on the 15-mile segment on I-70.; therefore, the UA team performed a subarea cut of the regional network. It was decided to keep majority of the I-70 corridor with the eastern boundary at C-470 and the western boundary near Vail, CO, as shown in Figure 1.2.

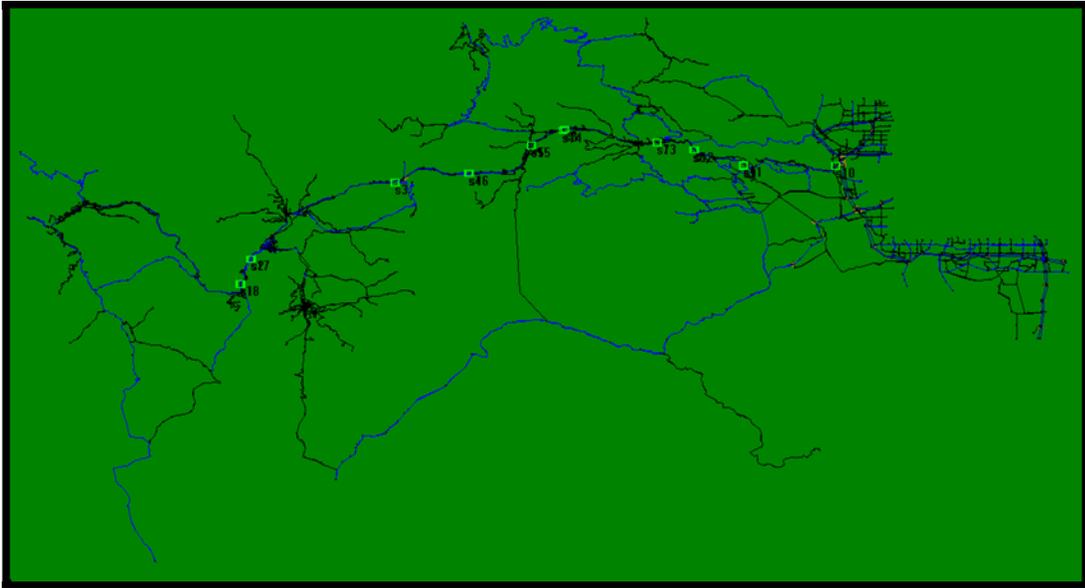


Figure 1.2: I-70 subarea in Dynust

The network included US 285 as this route was considered as an alternative route in some scenarios of this study.

In Dynust, a dynamic user equilibrium (DUE) condition is rigorously sought. The DUE condition can be stated as:

For each OD pair and particular departure time, the experienced travel time on all used routes is equal and minimal, and travelers cannot improve their experienced travel time by unilaterally switching to another route.¹

Once a dynamic user equilibrium (DUE) condition is met, all generated vehicles and their paths are stored in two separate files. During the subarea cut process, the original internal zones are retained but new external zones are created along the I-70 network boundary. From the regional network, vehicles traversing the I-70 network are processed to become an entry to the OD matrices by their location arriving at the I-70 network and the destination (either within the I-70 network or at one of the boundary nodes if this vehicles is a pass-by vehicle), and their arrival time.

¹ Chiu, Y.-C., J. Bottom, et al. (2010). A Primer for Dynamic Traffic Assignment. Washington, D.C., Transportation Research Board

Before the regional model was spatially reduced to a subarea for this analysis, care and caution needed to be exercised to define the boundary of the reduced network. The regional model was run DUE to simulate the all vehicles of the region, thus generating all vehicle trajectories through the corridor of interest so that the trip length for vehicles going through the corridor was preserved without being excessively shortened. This was to avoid introducing significant biasness to the modeling results. Given the defined boundary, the reduction of the network was performed in DynusT graphical user interface (GUI) by selecting and deleting the portion outside the defined boundary. In this process, the zones encompassed in the subarea network were retained whereas the zones that were cut through by this boundary are re-defined as external zones to this subarea network. In summary, this procedure ensures that (1) trip lengths were not excessively reduced, (2) all major possible diversion points and routes were included in the subarea network cut.

2. BASELINE NETWORK PREPARATION

Once the subarea network for the I-70 corridor was defined, a large amount of effort was placed into rectifying the network toward a suitable modeling network for the use of DTA. The model required network rectification to ensure correct connectivity, “cleaning” the network of links not typically used in DTA models, placement of localized intersection control at appropriate locations and highway grade.

2.1. Network Rectification

The following describes the level and of effort and fidelity of network rectification placed to bring the model up to a greater, realistic standard in an effort to replicate existing conditions of the I-70 corridor under the context of the DTA model. The performed rectification exercise was performed to assure the network connectivity was correct, lane counts on links were accurate, surrounding townships and parallel routes were appropriately represented, and all directional highway grade information (in particular I-70 segments) corresponded to existing conditions.

2.1.1. Network Alignment, Rectification, and Link Attribute Verification

Within the network boundaries described in section 1.4, the I-70 corridor and surrounding townships near the interstate was reviewed and verified using Google Earth aerial images as a side-by-side comparison with the converted DynusT network. Close attention was given to interchanges as to

whether the on/off ramps along I-70 were correctly positioned and connected. The number of lanes represented for links were verified using the aerial images.

2.1.2. Corridor-wide Ramp Control Device Verification

For the entire I-70 corridor within the given network boundaries, each on and off ramp were closely examined using Google Earth at each ramp location. This information was important to the DTA modeling because the model uses delay information and turning movements at intersections as part of the calculation of determining improvement routes. Control devices that were placed in the network were assumed to have a default actuated signal control. Actual signal control device information from the real signals was not input as there was not enough time and resources to gather such information. The signal times were assumed to be 45 seconds as max green time, 5 seconds as min green time, and 4 seconds as amber time. With such a large span of time between the max green and the min green, this allows the approaching flow to the intersection to regulate the operation of the actuated signal green time.

Majority of the on/off ramps control implementation were represented by 2-way stop signs and 4-way stop signs. Therefore, with ramp intersections that were determined to have a stop sign rather than a signal, the intersection node was updated. If a signal device was found to be the control device at an intersection, the default actuated signal control with default time was assumed the control device.

2.1.3. Grade Input

Highway grade information was input along the I-70 corridor that existed in the subarea boundaries defined in section 1.4. Besides the I-70 corridor, other routes were also updated with grade information if the routes were considered as alternative routes including US 285. The simulation of DynusT is sensitive to the grade input on links, especially for commercial trucks simulated, as the passenger car equivalent (pce) value calculated for truck vehicles is updated when traveling along the mountainous corridor. The link grade information was provided by the CDOT DTD group which maintained a GIS layer of the entire state of Colorado. The GIS layer contained all interstate and state highway road information including grade. For links in the network that were considered long, meaning the link represented a long span of thousands of feet, and the actual grade of the link varied drastically along the represented link, the link was then broken down to several links with each link representing the changes of grade along the segment.

2.2. Traffic Data Collection

Traffic count data and speed data was provided to the UA team for traffic flow model calibration, OD demand calibration, as well as model simulation validation using volume and speed profiles. CDOT has implemented in the surrounding boundaries of the I-70 subarea network Automatic Traffic Recorders (ATR) in which traffic counts are recorded non-stop. Data from the ATR locations was first received starting on February 18, 2010. The traffic counts provided were for Saturdays and Sundays for 3 major locations along I-70 were provided. The earliest date of traffic data provided was December 5, 2009. The 3 major locations of the ATR data were:

- Site 106: I-70 Eisenhower tunnels EB/WB
- Site 107: I-70 east of Genesee Interchange EB/WB
- Site 120: I-70 at Twin Tunnels (Idaho Springs) EB/WB

Please note, the only location within the defined 15-mile modeling corridor of interest for this project (described more in section 3.2) was Site 120. The two other locations were within the subarea network and were used to adjust the model in calibration to match the overall traffic flows over the 10 hours of time interest (section 1.3). There were some dates in which data was not complete for certain directions of these three locations. It was explained that some of the devices were not in operation due to malfunctions or maintenance.

Other data was also provided from what will be termed “ITS” data. Several devices used for traveler information and traffic management devices such as ramp metering devices, remote traffic microwave sensors (RTMS), Doppler devices, and AVI devices. This data was provided by CDOT’s ITS group. According to the ITS group, the I-70 corridor is divided into several segments. Within each segment, there are a certain number of the listed 4 devices collecting data. Through data aggregation algorithms the data is compiled to average values of both traffic counts and speed information. For the most part, the purpose of these ITS devices are used for real-time traffic management, therefore, the information is used in majority for speed collection. It was later determined that traffic counts from the ITS devices were not reliable for the OD demand calibration, which is further described in section 2.4.

2.3. Traffic Flow Model Calibration

The simulation of the DynusT model must be calibrated to replicate real-world conditions. The simulation follows the rules of the mesoscopic traffic flow dynamics of speed, density, and flow. The flow model utilized in the simulation model is called the modified Greenshield's Model which follows the basic traffic engineering principle of the speed, density, and flow relationship:

$$q = kv \quad (2.1)$$

There are two types of traffic flow models identified in the DynusT simulation model. Type 1 better depicts freeway or major urban arterial traffic flow behavior because freeway links have greater capacity than other secondary arterials and can hold larger densities near free-flow speeds. Type 2 is more suited for secondary arterial-type links, of which the speeds are more sensitive to density changes. Both flow model types are shown in Figure 2.1: Modified Greenshield's Model. The modified Greenshield's model is shown in Equation (2.2).

$$v_i - v_0 = (v_f - v_0) \left(1 - \frac{k_i}{k_{jam}} \right)^\alpha \quad (2.2)$$

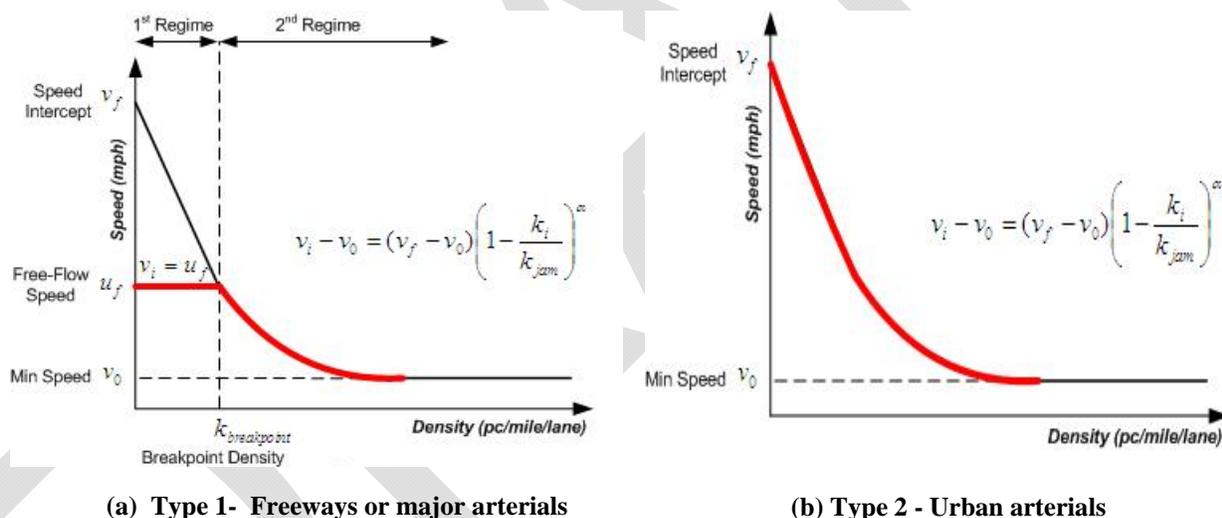


Figure 2.1: Modified Greenshield's Model

Free-flow speed v_f , minimum speed v_0 , density breakpoint $k_{breakpoint}$, and jam density k_{jam} are estimated based on the collected data. The unknown variable α is the shape term which gives the curvature of the speed-density curve as the density increases. By taking the natural log (ln) of Equation (2.2), the α can be estimated by performing a linear regression analysis of what is now a linear equation as shown in Equation (2.3):



$$\ln(v_t - v_0) = \ln(v_f - v_0) + \alpha \left(1 - \frac{k_t}{k_{jam}} \right) \tag{2.3}$$

Because of the mountainous terrain of the I-70 corridor, the highway grade affects the traffic dynamics and certain segment dynamics should be accurately captured. There were 4 different type-1 traffic flow models applied to matching segments with similar traffic dynamics captured by the available traffic data collected. Due to the high sensitivity to density of such a mountainous corridor, the modified Greenshield’s model is further adjusted to depict the corridor dynamics as shown in Equation (2.4):

$$v_t - v_0 = (v_f - v_0) \left(1 - \left(\frac{k_t}{k_{jam}} \right)^\beta \right)^\alpha \tag{2.4}$$

The additional shape term β gives a much better fit to the α shape term. The α shape term provides the sensitivity of the traffic flow model’s experienced speed relative to the experienced density. The β shape term adjusts the α shape term position to represent the greater drop in speed due to higher density changes. Figure 2.2: Alpha and Beta Shape Term Calibration shows the differences in different traffic flow models of optimizing the combination of α and β shape terms. The optimization operation was performed by a MATLAB script developed by the UA team.

Traffic Flow Model Comparison

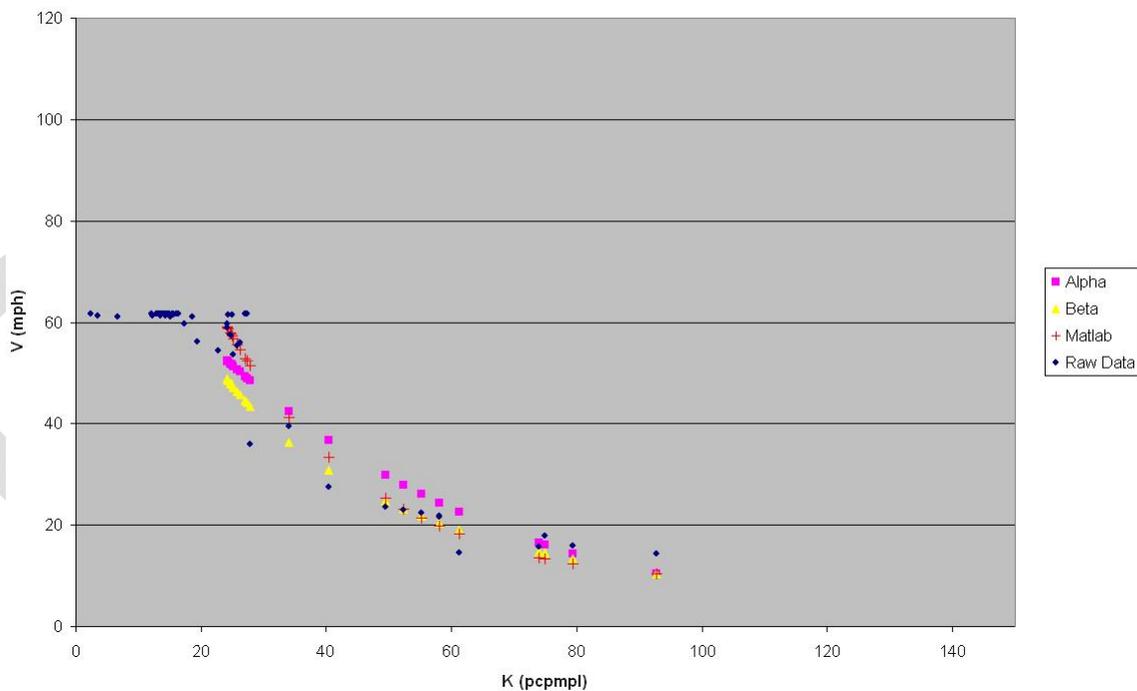


Figure 2.2: Alpha and Beta Shape Term Calibration

The four traffic flow models were calibrated to be the following:

Table 2.1: Traffic Flow Model Properties

Parameter	Steep Grades (>4%)	Mild Grades (1-4%)	Negative/No Grade
v_0 (mph)	5	2	5
v_f (mph)	1355	400	1631
$k_{breakpoint}$ (vpmp)	16	25	21
k_{jam} (vpmp)	151	120	98
α shape term	2.05	1.00	1.79
β shape term	0.09	0.22	0.11

For all other links that are not calibrated due to lack of facility data, the default traffic flow model data was applied, including arterial links as the arterial links follow the type 2 model.

2.4. Time-Dependent Origin-Destination Demand Calibration

The OD demand calibration methodology developed by the UA team is a two-step approach (Figure 2.3), in which the first step is to systematically match the total link volumes/counts over the entire analysis period (extended peak hours) by adjusting the OD entries through the optimization model, while the second step is to properly represent the speed profile through the demand-supply concept based on the calibrated OD. There are several advantages in this approach. First, it reduces the problem to be in a manageable size; second, it has a satisfactory convergence behavior.

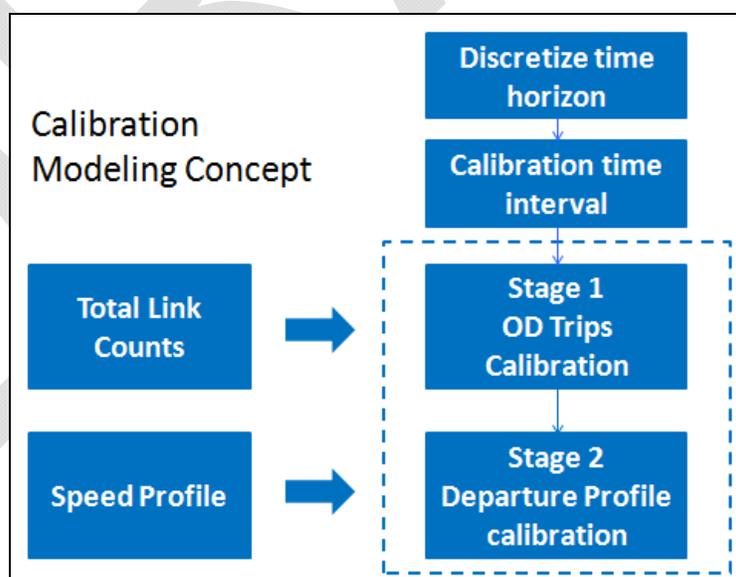


Figure 2.3: Two-stage Dynamic Calibration Framework

The OD calibration process attempts to match simulated time-varying link volumes with observed link traffic counts collected from the field such that the difference between the simulated link volumes and observed link volumes is minimal. The calibration procedure is a bi-level optimization problem. The upper level is the one-norm linear program optimization problem minimizing total link count deviation, and the lower level is the DUE problem solved by DynusT.

This procedure calls for iterative interplays of DynusT and the calibration program. DynusT is executed with the given demand and run to DUE. A post-processing program is called to evaluate vehicle-based output data and accumulate information of vehicles (and their associated OD pair) whose paths traversed through any link being evaluated. At this point, the link volumes are known. OD pairs that were found to have vehicles traveling through evaluated links are considered affected OD pairs. All these data are then fed into a one-norm LP formulation and solver to solve for the OD matrices that aims to minimize the deviations of simulated and observed link counts. The total amount of adjusted OD trips are then distributed to the time-dependent OD matrices according to the weighted ratios of each affected OD pair. The time-dependent OD demand tables are then rebuilt to reflect the changes, and the demand is fed into DynusT and re-run to DUE through another inner-loop to evaluate the new demand. In this nested algorithmic process, each outer loop is called the OD iteration, within which each DynusT run include multiple iterations until convergence.

As further depicted in Figure 2.4, at each DUE iteration, mesoscopic simulation (network loading) is run to the end of the analysis period. The necessary information is then passed to the time-dependent shortest path and then the assignment algorithm to update the assignment of vehicles for each origin destination and departure time to the corresponding path set. This procedure is repeated for multiple iterations until the minimal gap value is reached. The OD iterations continue until the maximum number of OD iteration is reached, or a pre-specified stopping criterion is met.

As discussed above, the convergence is measured by the relative gap which is the sum of the difference between the experienced travel time for the used paths and the time-dependent shortest path for each origin, destination and departure time. The typical definition of the total relative gap is:

$$rel_{gap} = \frac{\sum_t \sum_{i \in I} \sum_{k \in K_i} f_k^t \tau_k^t - \sum_t \sum_{i \in I} d_i^t w_i^t}{\sum_t \sum_{i \in I} d_i^t w_i^t} \quad (2.5)$$

t is an index for an assignment interval or a departure time interval, i is an index for an origin-destination pair and k is an index for a path. Index i represents the set of origin-destination pairs and K_i denotes the set of paths connecting the origin-destination pair i . f_k^t represents the flow on path k departing at assignment interval t . τ_k^t is the travel time on path k for assignment interval t . d_i^t denotes the demand (total flow) for origin-destination pair i at time interval t and w_i^t is the shortest path travel time for origin-destination pair i and departure time interval t .

Note that at perfect equilibrium, the travel times on all used paths are equal to the time-dependent shortest path time and hence the value of relative gap is to zero. Since the travel time on all used paths will always be greater than or equal to the shortest path, the value of relative gap will never be negative. In most DTA applications, the solution is assumed to have converged to an equilibrium solution when the relative gap is less than a pre-specified tolerance level (1% to 10% is the commonly reported convergence level for existing DTA models).

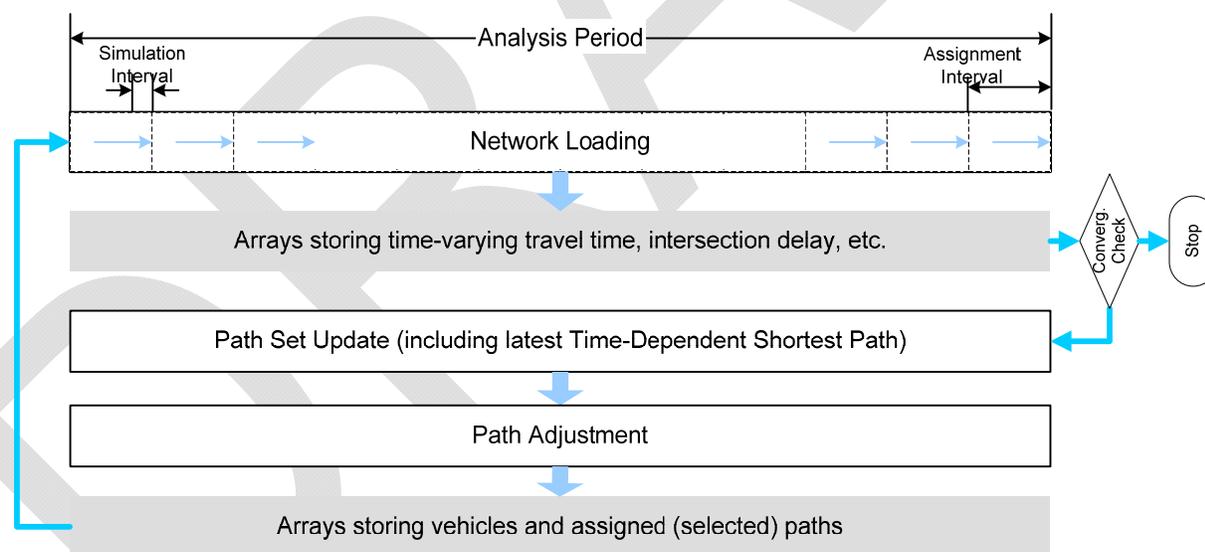


Figure 2.4: DynusT Algorithmic Procedure

2.4.1. Low-Volume Day Calibration

The first round of calibration was based on the date of February 14, 2010. This date was the most considered the most consistent and spatially complete data. This means the traffic counts extracted from the ATR and ITS data, there were a total of 27 data points in which the calibration procedure could

be used to match the simulation results. For the truck demand, 4 data points could be used as the only information of vehicle type classification was provided by 2 ATR locations within the study area.

It was determined there were three locations in which the traffic count data were giving inconsistent results in relation to neighboring points such as doubling the amount of traffic relative to the closest neighboring point. This resulted in unstable OD demand results. It was determined the data from the three points were of devices that were not reporting correct counts, and then dropped from the dataset. Figure 2.5 and Figure 2.6 show the final results of the OD demand calibration after 20 full calibration iterations. The y-axis is the simulation counts, while the x-axis is the actual traffic counts collected by ATR and ITS devices. The blue dots show the original OD demand counts; this shows the instability of the demand that was extracted from the travel demand model (see section 1.2). The red dots show after 20 iterations are lying along the 45 degree line, meaning the simulation counts and the actual traffic counts are nearly the same, meaning the OD demand has reached convergence in matching the actual traffic counts. The percent error between the actual counts and simulated counts for the auto demand calibrated 54% of all counts were within +/- 1%, while 75% of all counts were within +/- 2%, and 100% of all counts were within +/- 5%. For truck demand calibrated, 50% were within +/- 2% and 100% of all counts were within +/- 12%.

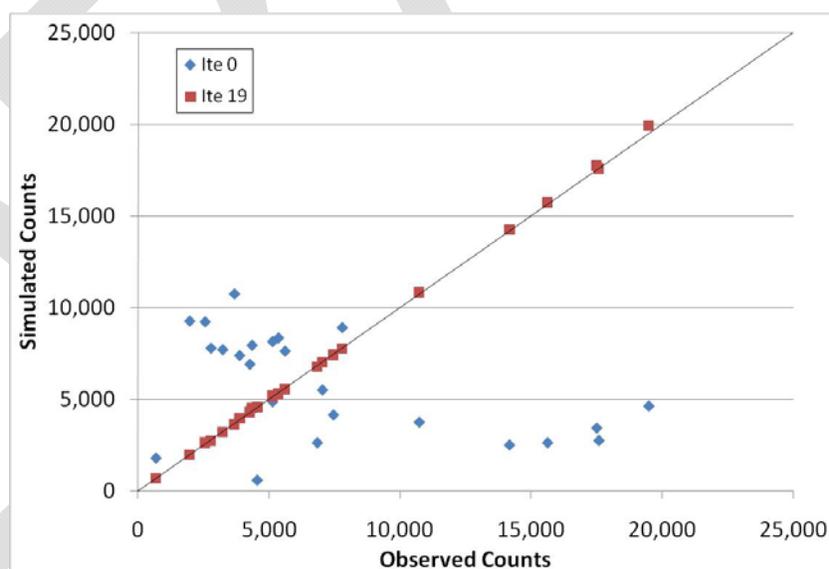


Figure 2.5: Low-volume OD Auto Demand Calibration

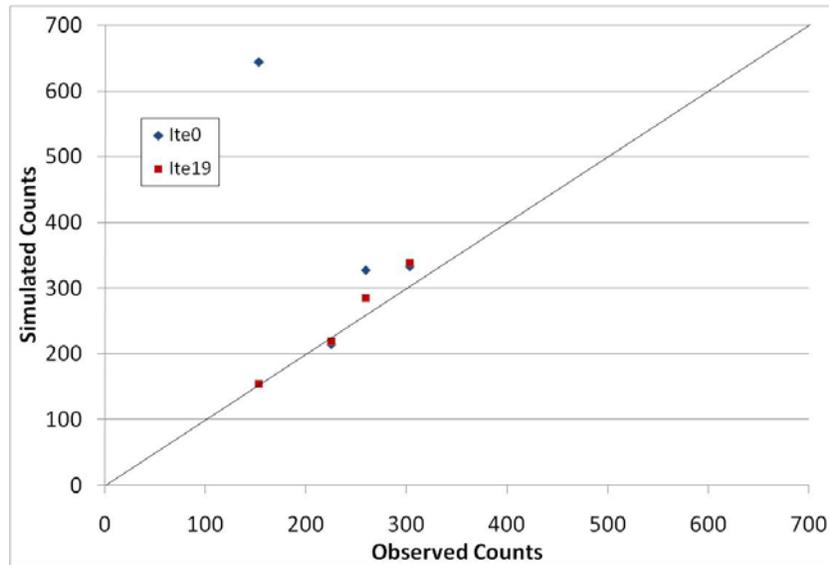


Figure 2.6: Low-volume OD Truck Demand Calibration

After review, the OD calibration performed to this point was considered low demand. This was determined by examining the low congestion in the EB. The high peak congestion time period within the study period (12pm-1pm) was only experiencing just over 1800 veh/hr, which is low for the eastbound direction. Although the calibration was not to the level that represents normally higher congestion periods, by results of this calibration provided a good starting point in which the OD demand patterns were much more stable and could be better calibrated to a higher demand much easier. The next step was to continue in the calibration to a higher congestion condition.

2.4.2. High-Volume Day Calibration

To calibrate toward the high congestion period, all available Sunday traffic counts were examined. January 31, 2010 was found to be a date with high eastbound demand. The calibration for high-volume was started from the results of the low-volume calibration. It was discovered that the ITS data was not as reliable as traffic counts from the ATR data. It was decided to not use the ITS data and use only the ATR data. This meant there would be less data to use which reduced the total number of calibration points from 24 to 12. Figure 2.7 shows the increase in demand from the low-volume to high-volume condition. 10 calibration iterations were performed as 42% of all counts were within +/- 1%, and 100% of all counts were within +/- 5%.

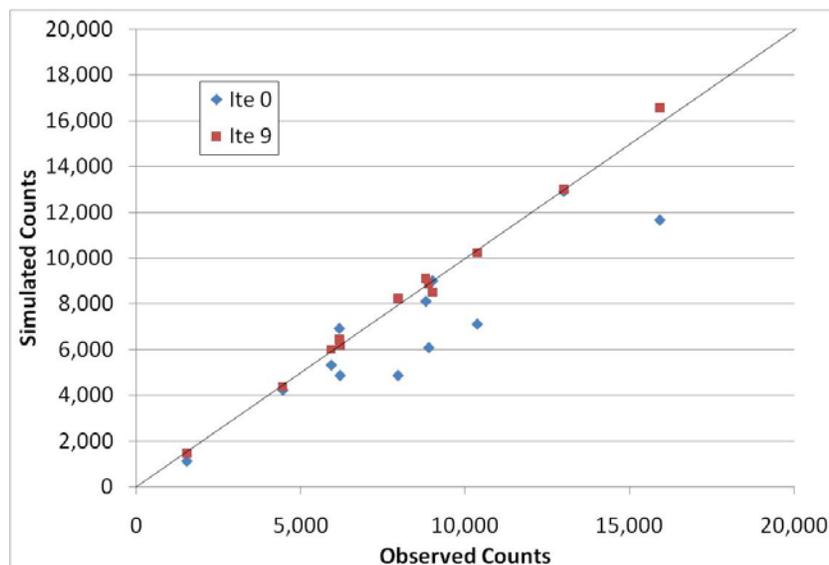


Figure 2.7: High-volume OD Auto Demand Calibration

2.5. Time-Dependent Departure Profile Adjustment

After the Stage 1 calibration (OD demand calibration; Figure 2.3), the total simulated and actual link counts may match well at the analysis period level, but the congestion pattern (e.g. speed or density figures) may still exhibit distinct discrepancies. The purpose of the Stage 2 calibration is to adjust the departure pattern based on the Stage 1 calibrated OD matrices so that, after calibration, the total link counts over the analysis period would remain unchanged, but the OD matrices departure pattern would be updated such that after the simulation, the simulated and field observed speed profiles become comparable. The basic concept of the Stage 2 calibration is that under congestion, the observed flow rate is actually lower than demand because the observed flow rate is subject to the reduced capacity as shown in Figure 2.8. Here *demand* is defined as amount of trips wanting to arrive at the link at a certain time instance, but the actual throughput would be less than demand if demand exceeds capacity of this link. In reality, once this demand/supply imbalance occurs, the speed decreases (and density increases). However, such demand is unobservable as the traffic data is the observed traffic condition subject to the constraint of the available capacity. The main contribution of this proposed method is to devise an intuitive and theoretically sound approach based on shockwave theory and mapping matrix between the OD and link traffic through DTA – DynusT. In other words, the proposed Stage 2 calibration method is aimed at estimating the demand arriving at the location of interest where bottleneck is observed, and then map such link arriving demand to departing trips, thus updating the time-dependent OD matrices.

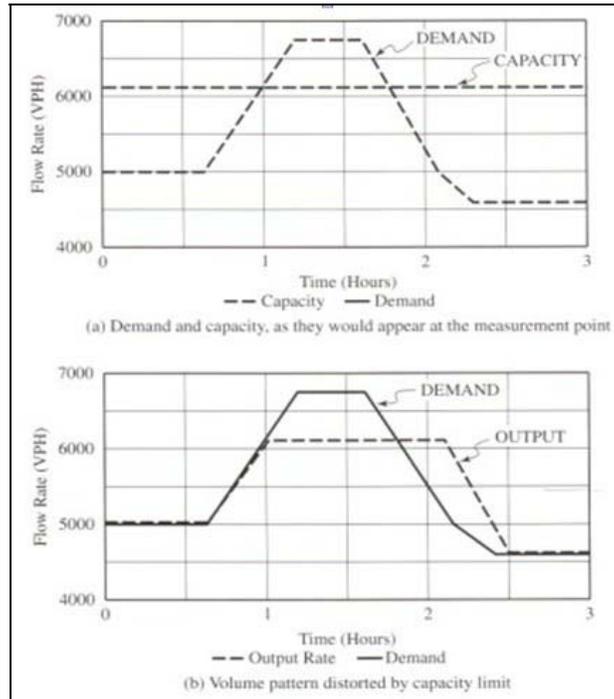


Figure 2.8: Relationship between demand, capacity and observed flow²

The speed profile calibration is based on the concept of back casting the temporal demand pattern based on the observed traffic data. The temporal pattern of the demand curve is then used to adjust the temporal pattern in the vehicle and path file generated from the simulation run using the calibrated OD table. This speed profile calibration method has been shown to generate satisfactory speed profile calibration results, as shown in the example figure below for the eastbound Eisenhower Tunnel for January 31, 2010.

² Roess, R. P., E. S. Prassas, et al. (2004). Traffic Engineering

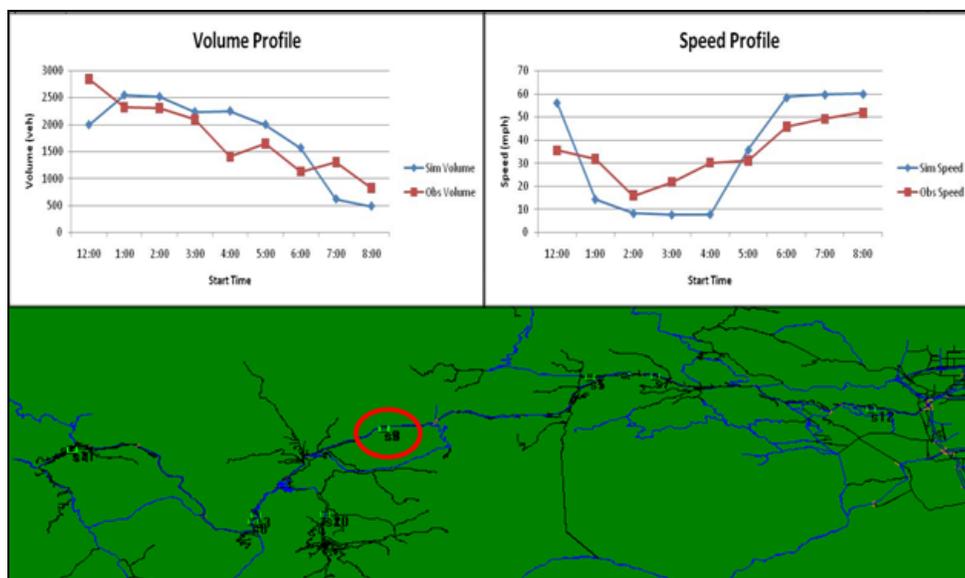


Figure 2.9: Example of departure profile adjustment at Eisenhower Tunnel EB

3. ALTERNATIVE SCENARIO MODELING

The subarea calibrated to the existing conditions of a common, high-volume Sunday between the hours of 12 PM to 10 PM. The scenario modeling was performed to evaluate various mitigation strategies that would improve the congested traffic conditions of the eastbound I-70 corridor between Georgetown and Floyd Hill by increasing the capacity from 2 lanes to 3 lanes using a movable barrier system (MBS). Increasing the capacity of the eastbound means removing capacity of the westbound from 2 lanes to 1 lane; therefore the primary objective of the study was to determine to what extent of disruption the westbound direction of the study area would possibly experience. The various strategies defined were designed to minimize the effect of the westbound operation when westbound capacity is reduced. This evaluation was to determine if there was any “fatal flaw” in the design of the proposed mitigation strategies.

3.1. Scenario Definitions

There were 4 modeled scenarios for this study.

Table 3.1 Study Scenario Description

Scenario #	Scenario Title	Description
1	Baseline	Existing Conditions, no strategy



2	Truck in MB Lane	EB truck allowed in GP or MB lane, no WB strategy
3	Truck not in MB Lane	EB truck restricted from MB lane, no WB strategy
4	WB Truck Restriction	EB truck restricted from MB lane, WB truck restricted from traveling on I-70

The assumptions for the movable barrier system are as follows:

- The MBS operates at 10 mph
- The MBS begins operation at 1:00 PM
 - Travels from Floyd Hills at 1:00 PM and reaches 2 miles east of Georgetown at 2:20 PM
 - Traffic can use the MB lane at east terminal at 2:20 PM
- The MBS closure begins operations at 8:00 PM
 - Travels from 2 miles east of Georgetown at 8:00 PM and reaches Floyd Hill at 9:20 PM
 - Traffic stops use of MB lane at west terminal at 8:00 PM

3.1.1. Tolling Scenarios

Tolling scenarios were performed for this Phase I task order. The tolling scenarios were based upon a congestion-responsive pricing scheme in which the regulation of tolling prices were based upon the congestion experienced between the tolled facility and the non-tolled, general purpose lanes. In the case of this Phase I work the tolled facility was the eastbound MB lane.

The objective of the congestion-responsive tolling is to maximize throughput. The tolling logic aims at maximizing throughput by maintaining speed above a defined threshold. Typically, the speed threshold is set to 45mph which would allow the maximum throughput. As volumes increase for the general purpose lanes, more drivers would be willing to pay a price to avoid congestion. However, as volumes increase in the tolled facility, the price will increase as well in order to ensure a certain level of service of driving no less than 45mph.

Based upon the current Phase I models and the entering volumes of the eastbound 15-mile segment of I-70, the congestion is not severe enough to receive full usability of a tolled facility as now demand does not exceed capacity (from 2 to 3 lanes). This is under the assumption of the same level of demand and does not assume any adjustments to the demand due to corridor improvements. Due to these

assumptions, it was decided not to include the preliminary simulation results of the tolled scenarios until further investigation of directional demand levels are tried to determine network and toll sensitivity is performed and understood. This is scheduled to be completed for Phase II of this current study.

3.2. 25-mile Segment Analysis Results

The defined I-70 corridor begins in the west from Silver Plume, CO to the CO Rd 65 interchange in the east. This is approximately a 25-mile stretch which includes the 15-mile I-70 segment in which the movable barrier would be operational, beginning in the west just 2 miles east of the town of Georgetown. The 15-mile segment ends in the east along I-70 at Floyd Hill. A 25-mile segment which included the 15-mile movable barrier segment was used in order to allow an additional 5 miles on either end of the 15-mile segment to capture traffic conditions before and exiting the 15-mile segment.

From the DynusT simulation, travel time estimations and experienced travel speed profiles of the 25-mile segment were recorded for each of the 5 scenarios. Travel statistics were generated for 3 routes along the 25-mile segment:

- Route 1: 25-mile segment, westbound I-70 general purpose (GP) lane(s)
- Route 2: 25-mile segment, eastbound I-70 GP lanes
- Route 3: 25-mile segment, eastbound I-70 movable barrier lane (when in operation)

Note, routes 2 and 3 both started and ended at the same locations. This allowed vehicles who travel route 3 to experience the same congestion as those traveling route 2 at the same time of travel before entering the movable barrier lane.

The following analyses presented range from the network level of improvements, the corridor-level average time-varying speeds, to the departure-based corridor-level statistics of the 25-mile segment.

3.2.1. Traffic Diversion

The DTA model pursues the adaptive learning behavior of drivers in response to network changes. Based upon this assumption, after many DynusT running iterations of the simulation, drivers begin to adapt to the network based on previous knowledge and experience as previous knowledge and experience is from previous iterations of the simulation.

Diversion, in the context of the data presented in this section, is defined as the number of vehicles that travel a defined segment length under existing conditions, but may travel to another route due to changes to the network. In other words, the total number of vehicles from the baseline (existing conditions) case who travel from the start of a defined segment length and exit from the end of the defined segment length are considered as the base comparison. For an alternative case, the total number of vehicles are then counted who enter and exit the same defined segment length. The relative difference between the base comparison and alternative case is considered the diversion rate. Not only does this method determine whether vehicles divert from the segment length of interest, but this method may also capture those vehicles who may divert to the segment length. This would infer that vehicles may have attracted to the segment length as a result of corridor improvement relative to the existing conditions model. The segment length of interest is the 25-mile segment which encompasses the 15-mile MBS segment. The diversion rates are reported for eastbound and westbound directions in relation to each defined scenario. Therefore, those vehicles who enter and exit the 25-mile segment are counted. The following tables present the diversion rates in comparison to the baseline or existing conditions model.

For the eastbound direction, the number of vehicles traveling through the entering link of the 15-mile segment changes quite a bit in comparison to the baseline conditions. The 15-mile segment is looked at because the entering link of the eastbound between the MB lane and GP lanes were examined. The total volumes were directly a result due to diversion either to the GP lanes or away from the GP lanes. For both eastbound scenarios examined (truck in MB lane; truck not in MB lane), both scenario volumes were closely matching, but were larger volumes in comparison to baseline conditions. The improvements to the eastbound direction allowed more vehicles to travel along I-70 in the eastbound direction with a 23% increase of volume entering relative to the baseline. The increase in interim capacity allowed for diversion back to the I-70 eastbound main lanes. Diversions to the I-70 eastbound stemmed from the volumes experienced from the parallel frontage roads along the 15-mile corridor.

For the westbound direction, the congestion that incurs from the drop of 2 lanes to 1 lane shows that vehicles are willing to divert to alternative routes. The volume changes between the two alternative scenarios (WB Truck Allowed; WB Truck Restriction) were relatively similar; however, when compared to the baseline conditions, the WB volumes diverted to alternative paths by approximately 11%.

Intuitively, one would determine the reason for diversion is the bottleneck created by the MBS in reducing the capacity from 2 lanes to 1.

3.2.2. Space-Time Diagrams

The space-time diagram is a corridor-based graphical representation of the experienced speed for vehicles traveling the 25-mile corridor distance over time for the complete study period. The RGB color map depicting the varying dynamic traffic conditions along the specified corridor. This provides a great deal of performance information pertaining to corridor scenarios, and the dynamic variations in traffic conditions in response to scenario adaption along a spatio-temporal stage.

The horizontal direction is the distance along the 25-mile distance. For eastbound travel, the graphs are read from left to right, while for westbound travel, the graphs are read from right to left. The vertical axis is the time dimension read from top to bottom starting from 12 PM to 10 PM. The RGB image represents the increase and decrease of travel speed in response to time-varying congestion as dark red symbolizes low speeds, and blue represents high speeds.

- Scenario 1: Baseline

The existing conditions of the eastbound show significant congestion within the 25-mile corridor where the MBS would be implemented (15-mile boundary of the MBS is shown by blue diamonds of the I-70 map). Congestion begins downstream of the network near Idaho Springs and begins to build in slowing congestion moving west along the general purpose (GP) lanes. The repetition of dark red/orange/yellow stripes shows the segments that experience the fluctuation of reduced speed. The darker red that occurs near the US 40 interchange from Empire shows the junction of traffic starting in the 3pm hour until 5:30pm. The light blue stripe east of the 15-mile segment represents the portion of I-70 that is reduced in the speed limit from 65 mph to 55 mph for that short segment.

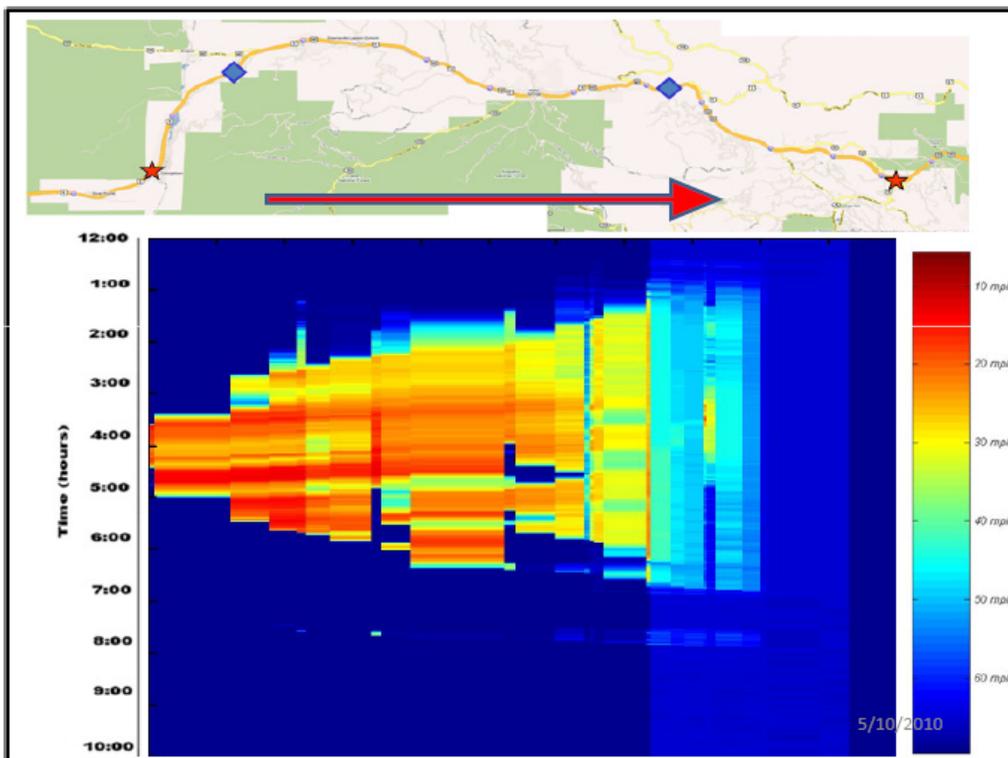


Figure 3.1: Scenario 1 - EB GP lanes

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The westbound shows the free-flow conditions of traffic traveling the 25-mile segment. There are some slight speed drops near the east boundary, but is due to the demand pattern of some late evening traffic, but is not significant.

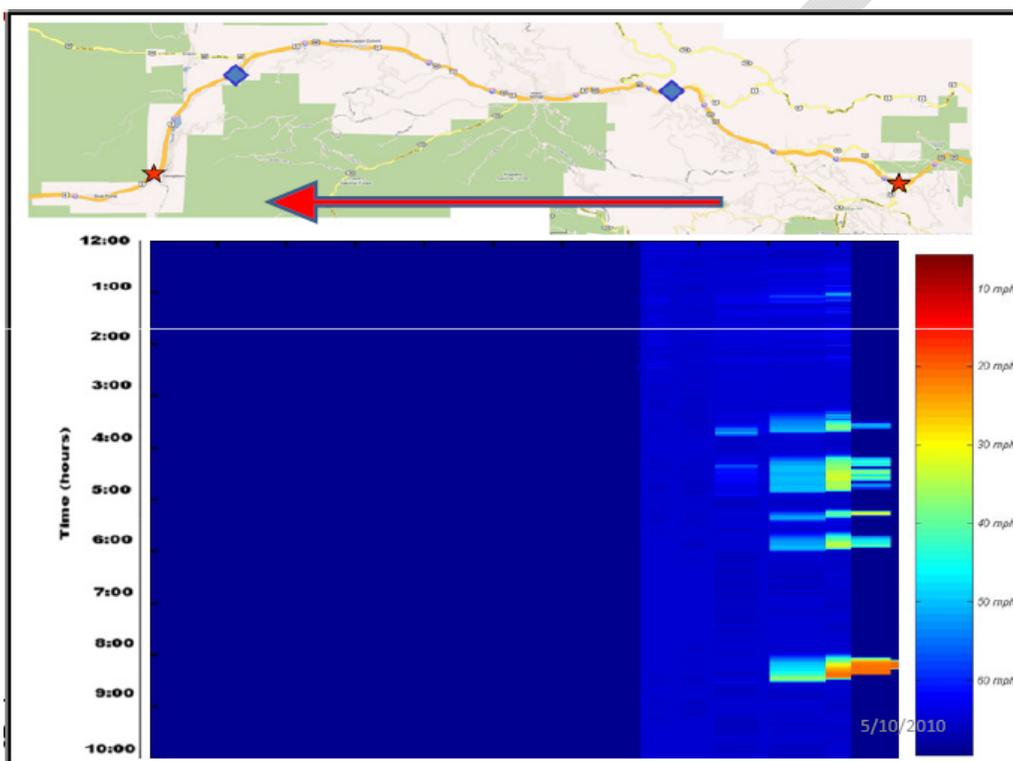


Figure 3.2: Scenario 1 - WB GP lanes

- Scenario 2 - Truck in MB Lane

The first alternative scenario includes the MBS in operation and allows commercial trucks to travel in the MB lane. The figure below shows the operation of the MB lane once the lane is open at 2:20 PM. When travelers approach near the area in which the MB lane terminates, there is some speed reduction due to merging of the MB lane traffic and GP lane traffic.

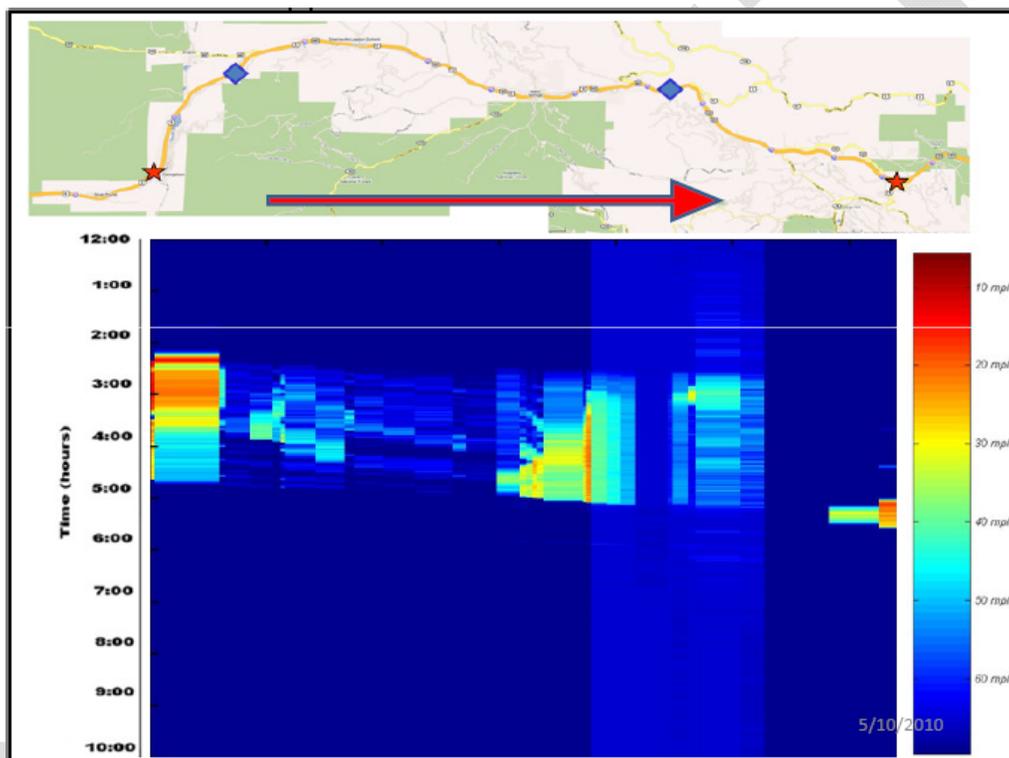


Figure 3.3: Scenario 2 - EB MB lane

Congestion builds up near the east of the 15-mile segment, however, when the MB lane opens for eastbound traffic, the overall operations of the eastbound traffic improved as the MB reached the west terminal at 2:20 PM. Shown near the west terminal where traffic enters the MB lane is congestion and spillback due to the merging area. Although there is some speed reduction, those who travel in the GP lanes experience higher speeds for the 15-mile segment.

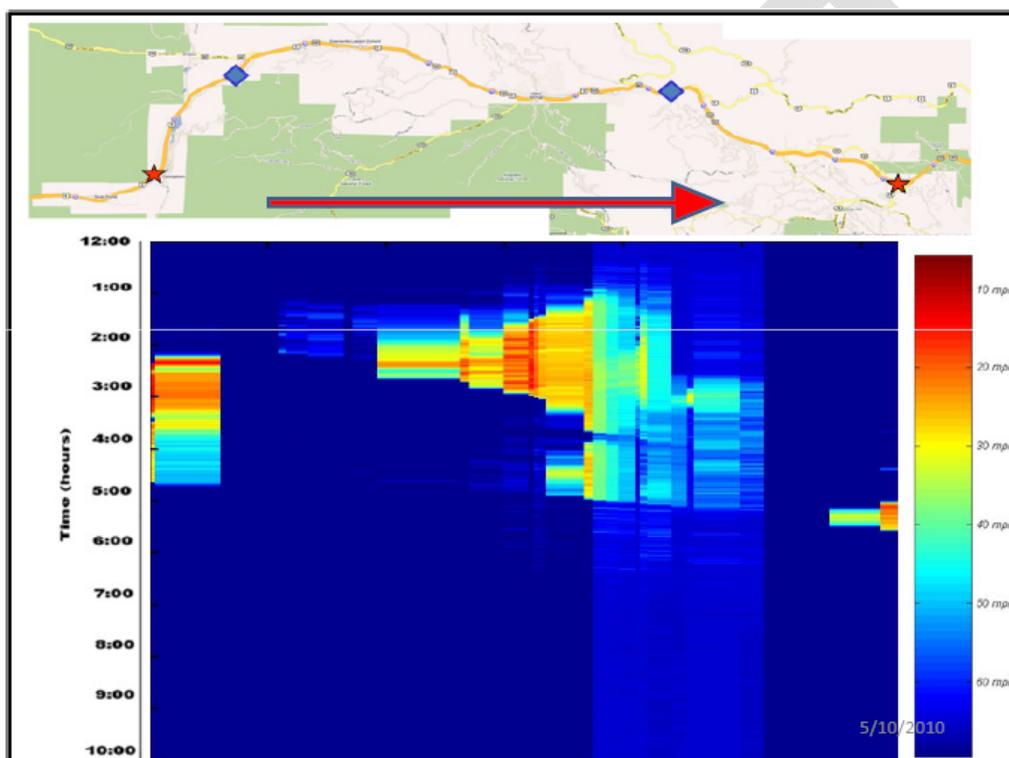


Figure 3.4: Scenario 2 - GP lanes

The westbound traffic is no longer traveling at free-flow conditions. This is due to the capacity reduction from 2 lanes to 1 lane. What is significant to note is the congestion that is experienced from the east terminal of the MB lane while in operation. Intuitively, as the 15-mile segment is reduced from 2 lanes to 1 lane, a bottleneck of merging would be created. The dark red vertical stripe in the figure below shows the speed drop due to the bottleneck. This is consistent through all alternative scenarios. The simulation results show consistent speed reduction moving east upstream from the east terminal for those traveling westbound, and spills back as far as approximately 3 miles under largest congested condition.

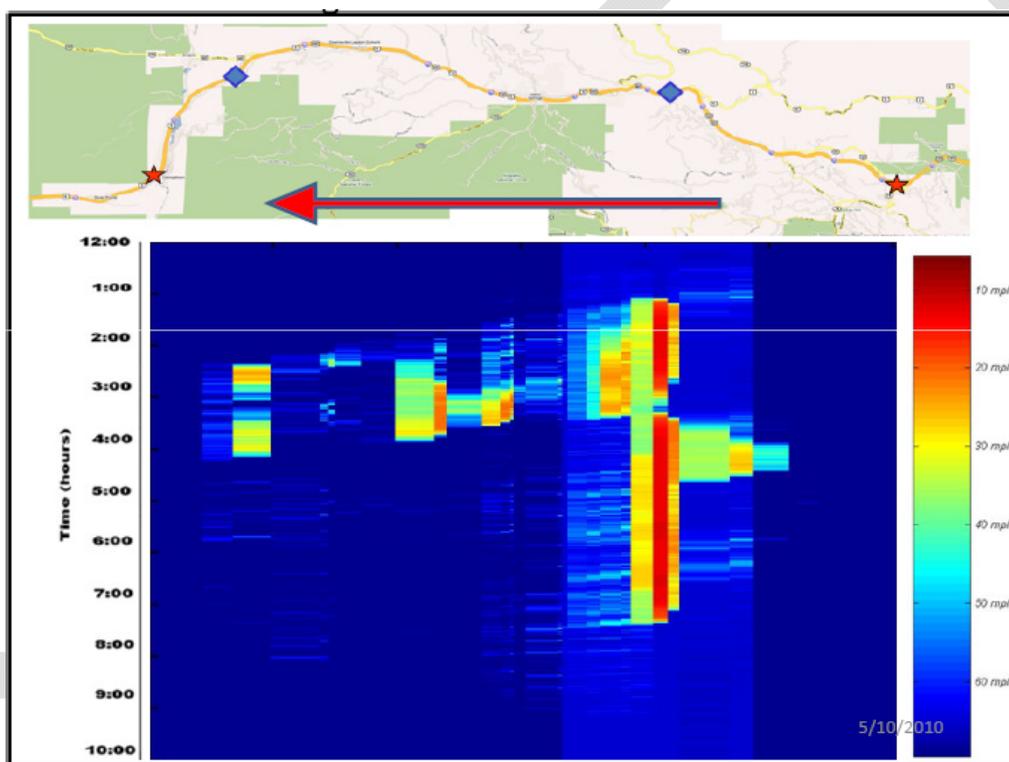


Figure 3.5: Scenario 2 - WB GP lane(s)

- Scenario 3 – Truck not in MB Lane

For the following scenario, EB commercial trucks are restricted from traveling in the MB lane. The allowance of truck traffic in the MB lane is not only a safety issue in terms of truck breakdowns and merging/weaving areas, but from this study's modeling standpoint, this improves the operation of the MB lane as shown in the figure below. There is still an experience of speed reductions at the merging area near the west terminal; however, the little spurts of speed reduction within the MB lane have improved from scenario 1. The merging area downstream toward the east terminal has improved from scenario 1 as commercial trucks do not pose a significant issue in terms of merging. The simulation model is sensitive in characterizing commercial truck as a higher passenger car equivalent (pce) value.

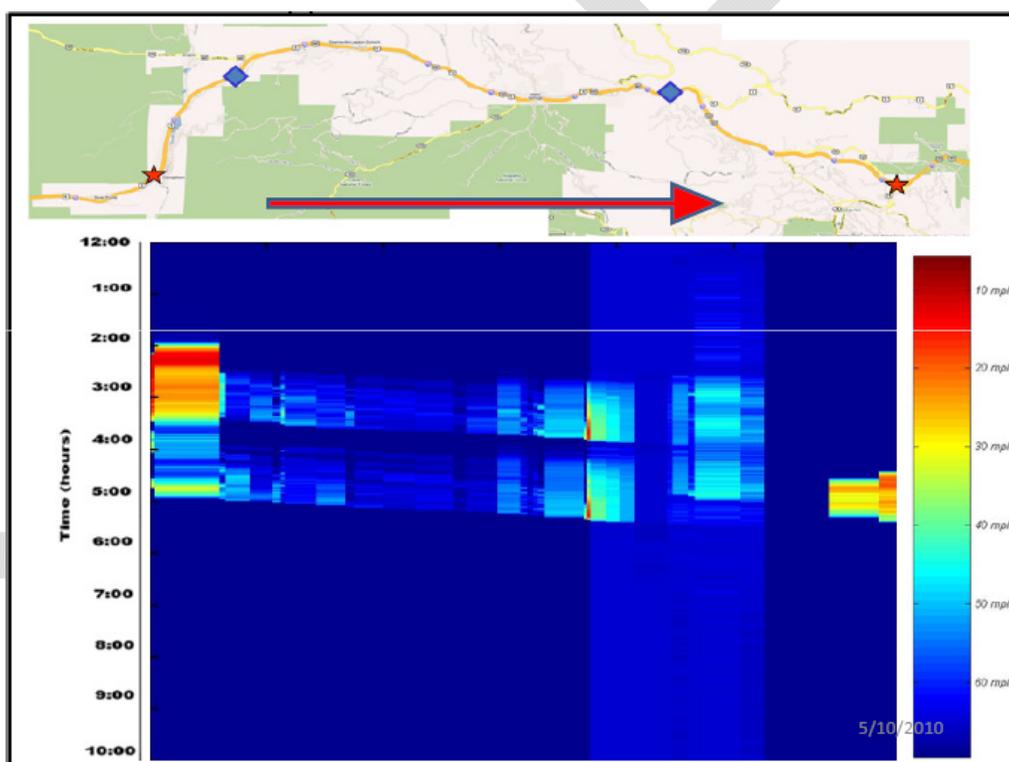


Figure 3.6: Scenario 3 - EB MB lane

The spatial stretch of speed reductions in the figure below have improved from scenario 1, meaning the speeds improve and not as extended west as compared to the previous scenario. There is a difference in time length of speed reduction near the east terminal which could be due to the change in travel pattern and traffic patterns from the assignment changes of traffic from one scenario improvement to the next.

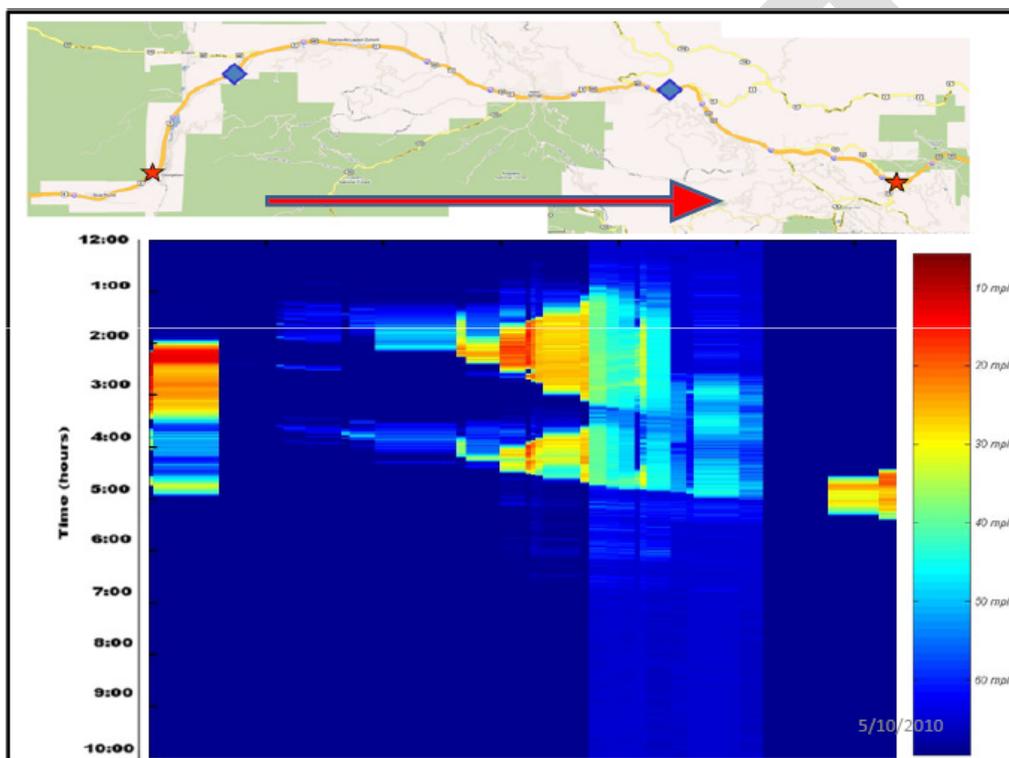


Figure 3.7: Scenario 3 - EB GP lane

Westbound traffic is not significantly different from the previous scenario 2 as the modeling operation for westbound traffic was not changed.

- Scenario 4 - WB Truck Restriction

Scenario 4 was built from the previous scenario 3 for the eastbound strategy of restricting commercial truck from entering the MB lane. Scenario 4 was focused on implementing strategy for the westbound traffic; scenario 4 restricts commercial truck from traveling the 15-mile segment on I-70. The commercial truck traffic is diverted to other routes which may potentially be US 285 south of I-70. This improves the operational safety of the westbound in case of an incident, but from the modeling point of view, this improved the bottleneck merging area at the east terminal. There was no dark red vertical stripe at the terminal point which improves the spill back length.

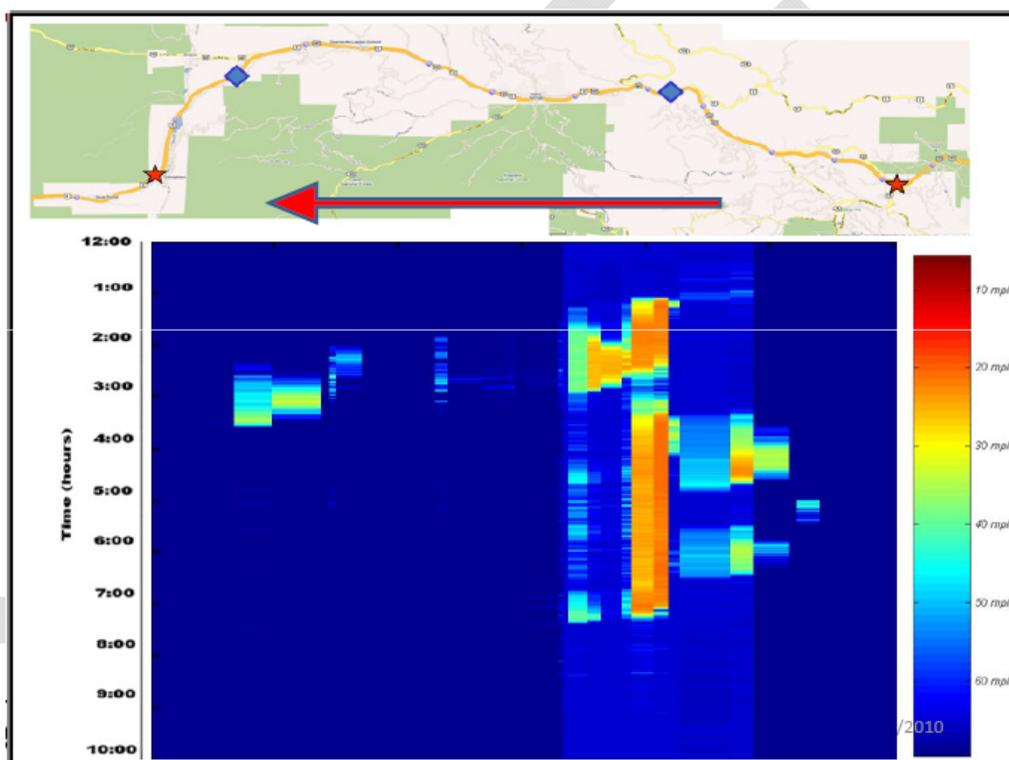


Figure 3.8: Scenario 4 - WB GP lane(s)



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3.2.3. Experienced Travel Speed Profiles

In order to capture the time-varying congestion of each route, sets of vehicles were assigned to each route with each vehicle traveling at different times of the day. For routes 1 and 2, vehicles traveled the 25-mile segment from 1:00pm to 9:00pm at 15-minute intervals. For route 3, vehicles traveled the 25-mile segment from 2:30pm to 9:00pm. Route 3 starts at a later time due to the operation of the movable barrier and the time it reaches the west terminal of the movable barrier lane which is approximately 2:20pm. For the vehicles that were synthesized as described above, the travel speed was recorded to show the experienced speed at various locations along the 25-mile corridor. In the following graphs, every line in the graph represents the experienced average speed of a vehicle entering the 25-mile segment at the specified time. The horizontal axis is displayed in conjunction with the Google map to relate the speed to the actual location. Note, “WB Truck Allowed” for figures referring to westbound traffic represents the average speed of scenarios 2 and 3 as the operations of the two scenarios are identical.

- 1:00pm

Figure 3.9 shows the experienced average speed for a vehicle entering the corridor at 1pm under the three scenarios: baseline, WB truck allowed and WB truck restricted. One can see that in the baseline case, the average experience speeds are mostly at free-flow speed except some slight speed drops before entering the Idaho Spring area. When MBS is in operation, obvious speed drops can be observed at upstream and downstream of the East terminal. The upstream speeds however still maintain at about 50 mph.

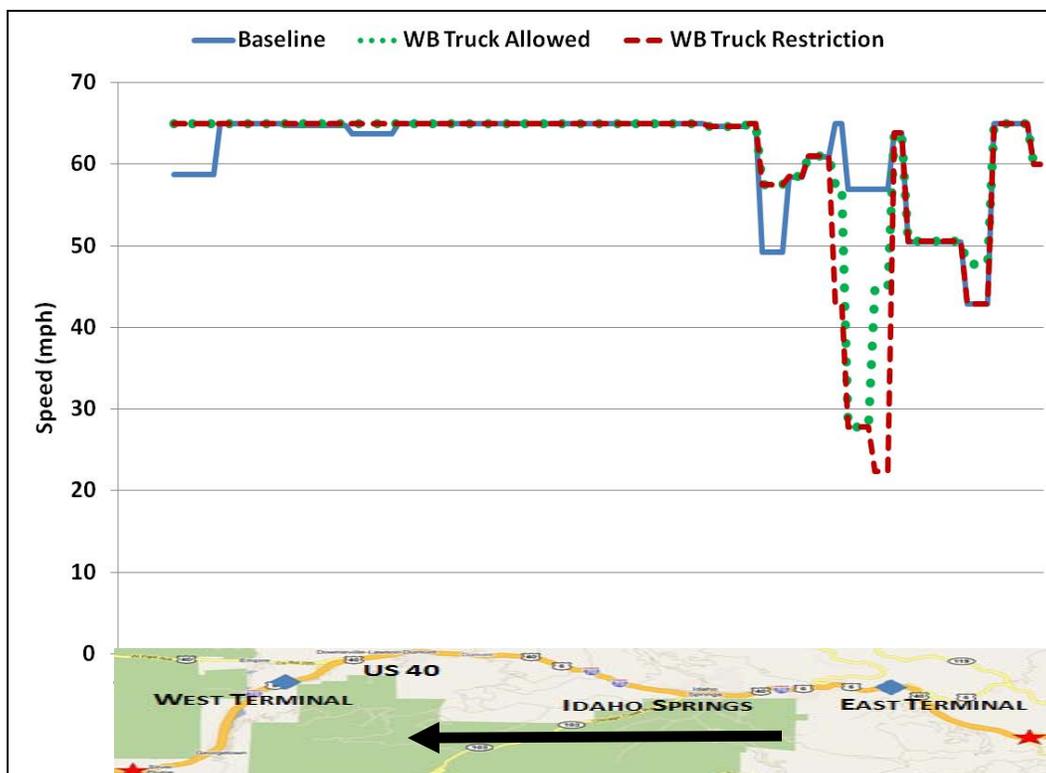


Figure 3.9: 1:00pm westbound

Figure 3.10 shows that when the vehicle enters the corridor at 1pm, it experiences about free-flow condition until approaching the Idaho Spring area, in which the speed drops to 20-30 mph range. The situation gradually recovers once passing the Idaho Spring area to the 40+ mph level.

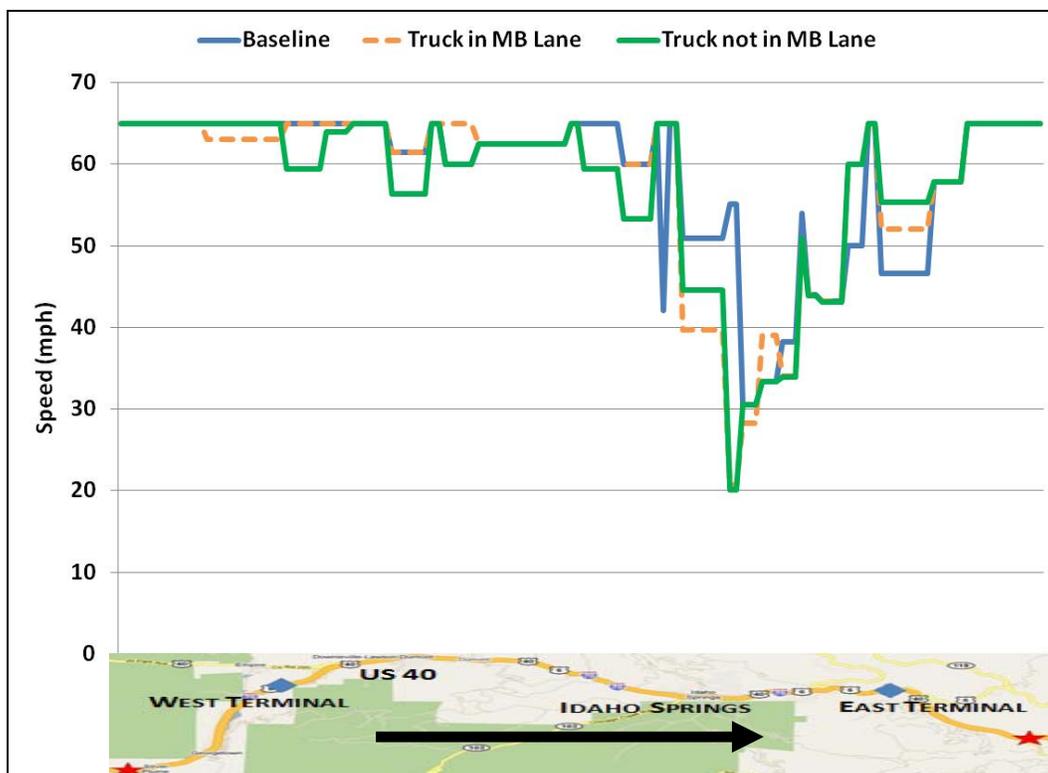


Figure 3.10: 1:00pm eastbound

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- 2:00pm

At WB experienced travel time at 2pm appear to be significantly reduced in the MBS operation scenario, although the baseline case shows rather normal free-flow condition. The speed reduction immediately entering the corridor drops to below 10 mph and the speed drops for both allowing and restricting trucks appear to be similar at the vicinity of the East terminal. However, it is clearly seen that when truck is allowed, the experienced speeds fluctuate considerably more than not allowing trucks. This indicates that truck in the corridor may cause irregular speed disturbance and unsmooth traffic flow.

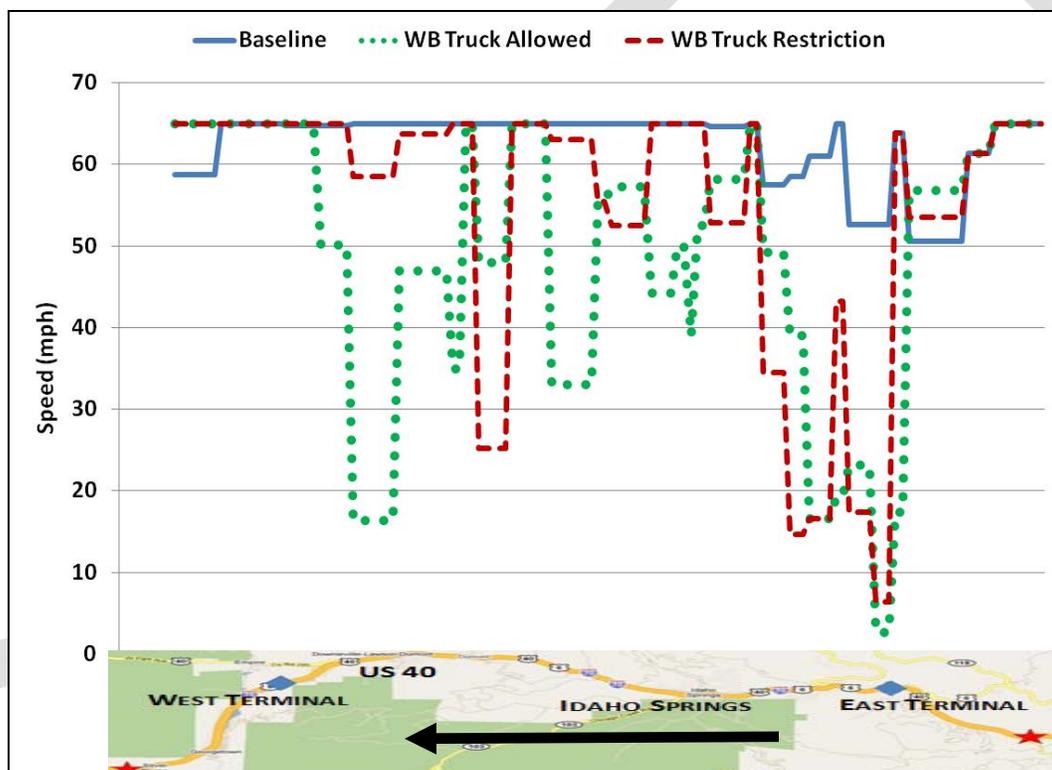


Figure 3.11: 2:00pm westbound

For someone entering the corridor at this time, his/her speed quickly reduces to 10+ mph after passing the US40 interchange. He/she drives at the “crawling” speed until passing the Idaho Spring area, from which the speed starts to gradually recover. This 10-mile segment appears to be under severe congestion starting at 2pm. It is also noted that for all MBS scenarios, there appears to be some congestion spillback from the East terminal. This is likely as vehicles may perform certain weaving actions upon reaching at the east terminal where the MB lane merges with the generalized purpose



lane. These merging actions cause capacity reduction and subsequently backward shockwaves traveling WB.

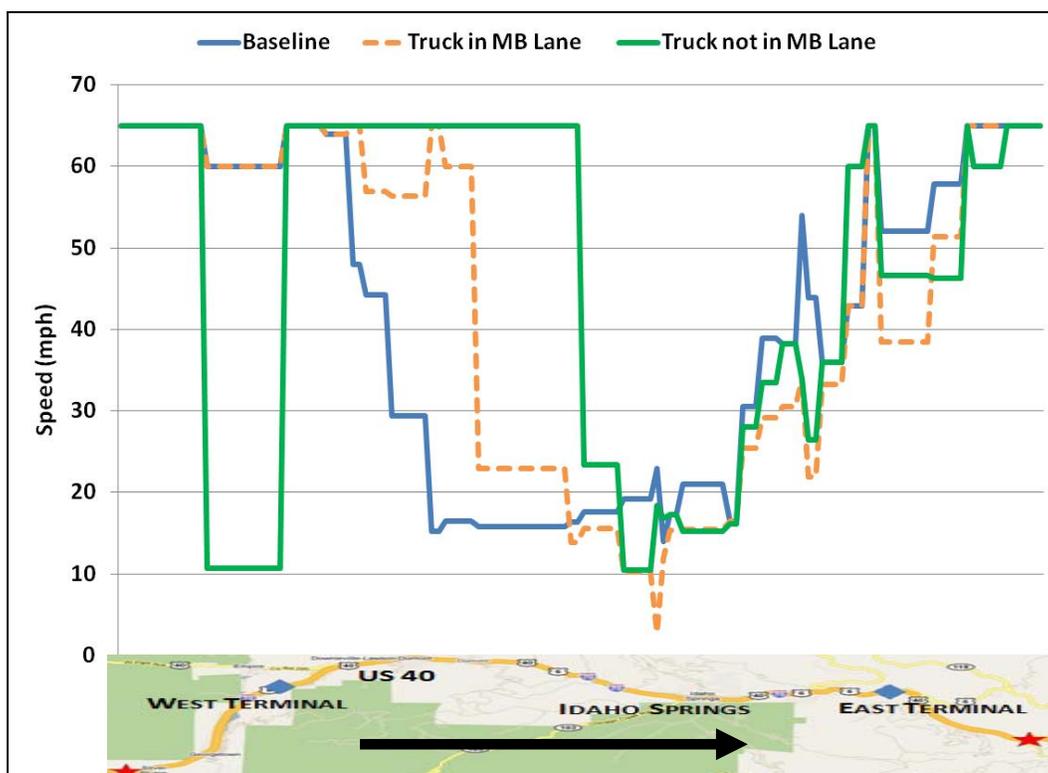


Figure 3.12: 2:00pm eastbound

- 3:00pm

The WB traffic in the baseline case remains relatively free-flow when entering the corridor at 3pm. However, due to the MBS operation, both truck allowed and truck restricted scenarios exhibit obvious speed reduction. Notably, allowing trucks in the WB direction not only give rise severe congestion at the East terminal, but also severe speed fluctuation at various locations along the WB corridor. It appears that restricting trucks in the WB direction help improve the traffic flow.

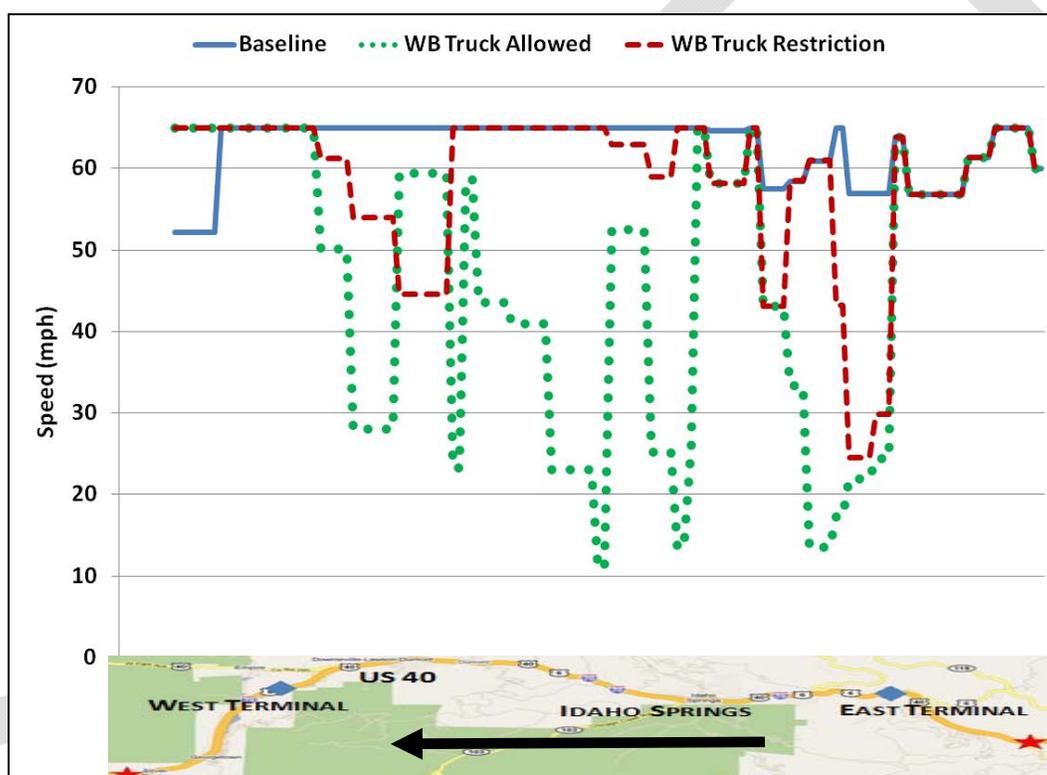


Figure 3.13: 3:00pm westbound

For someone entering the corridor at 3pm, in the baseline case without MBS, he/she would experience 10+ mph and at times below 10 mph speed from George Town to the Idaho Spring area. The speed gradually recovers once he/she passes the Idaho Spring area. With MBS operation, for all 3 examined scenarios, the experienced speed maintains mostly at free-flow speed in spite of mild speed drop to 50 mph. For all MBS scenarios, the speed reduction at the East terminal is also observed. The speed slightly reduces to 40+ mph levels.

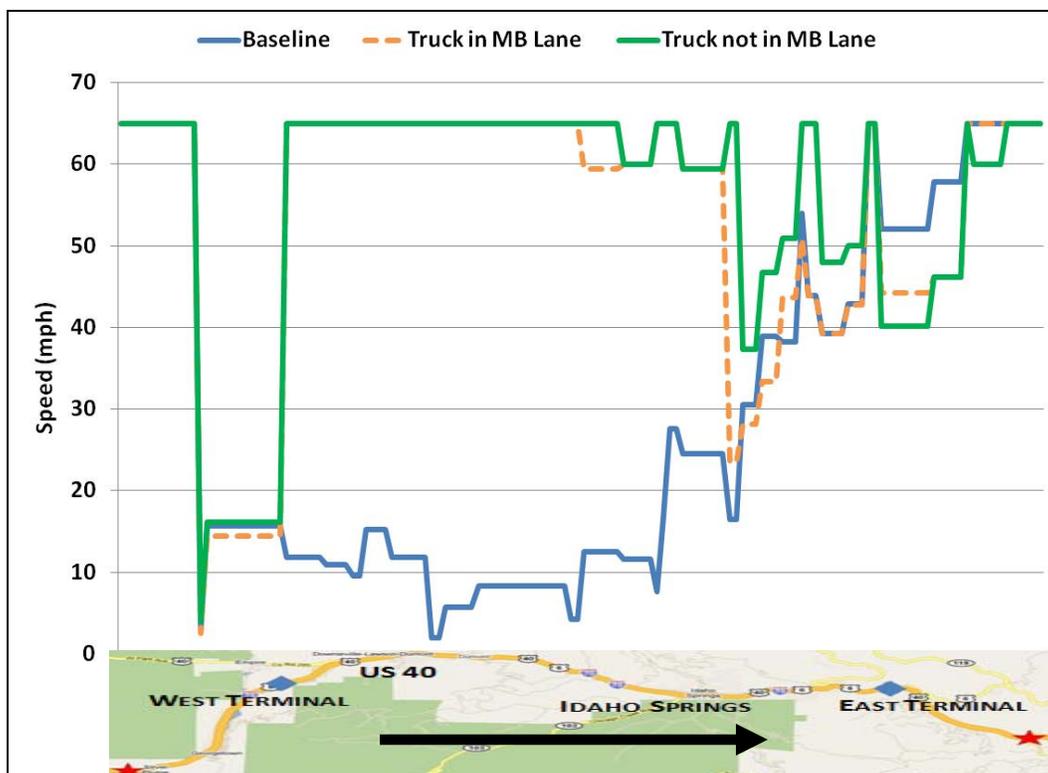


Figure 3.14: 3:00pm eastbound

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By this time, vehicles traveling in the MB lane at 3pm appear to be able to maintain mostly 40 mph+ speed before reaching Idaho Spring. The drivers would then experience relatively more speed fluctuations between Idaho Spring and the East terminal. The speed fluctuates between 30+ mph to 60+ mph. All three tested scenarios have similar performance at this time.

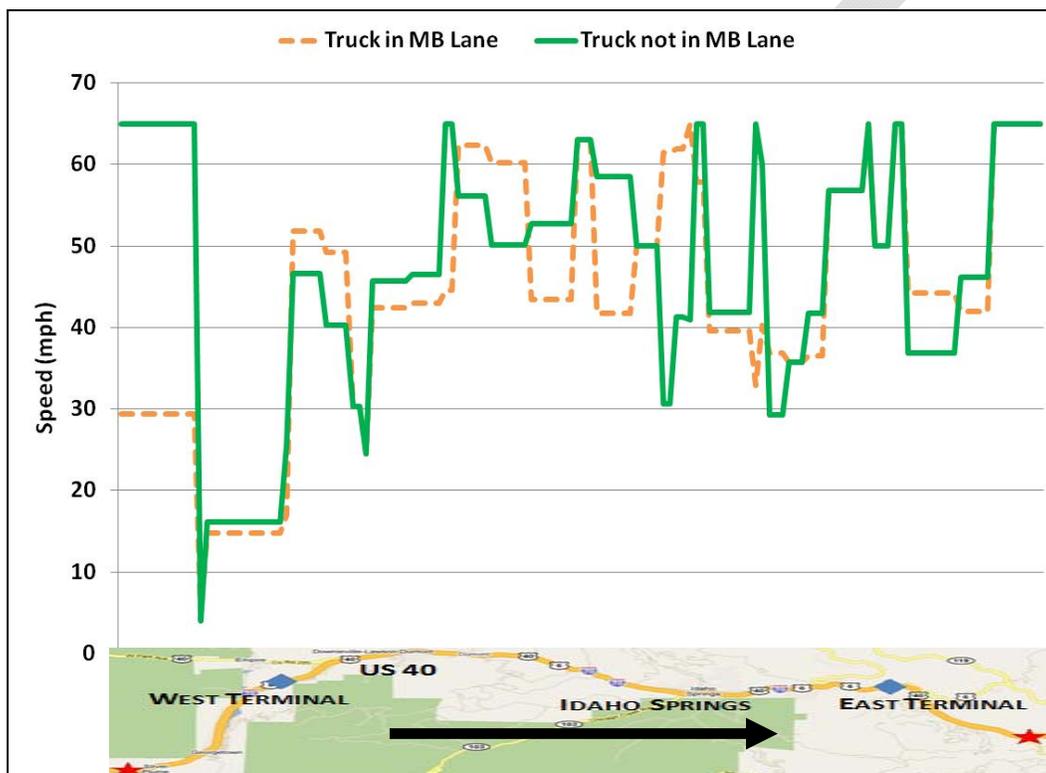


Figure 3.15: 3:00pm movable barrier lane

- 4:00pm

Vehicles attempting to traverse the corridor at 4pm appear to experience the lower speed upstream of the East terminal with MBS in operations. For both truck allowed and restricted cases, the speed drops starts about 5 miles upstream of the East terminal and speed drops could reach below 5 mph. This is the indication that the vehicle is crawling within the queue formed from the lane drop at the East terminal. Notable speed fluctuation within the queue is rather common. Speed recovers to the range of 40+ and mostly 50+ mph after passing the East terminal.

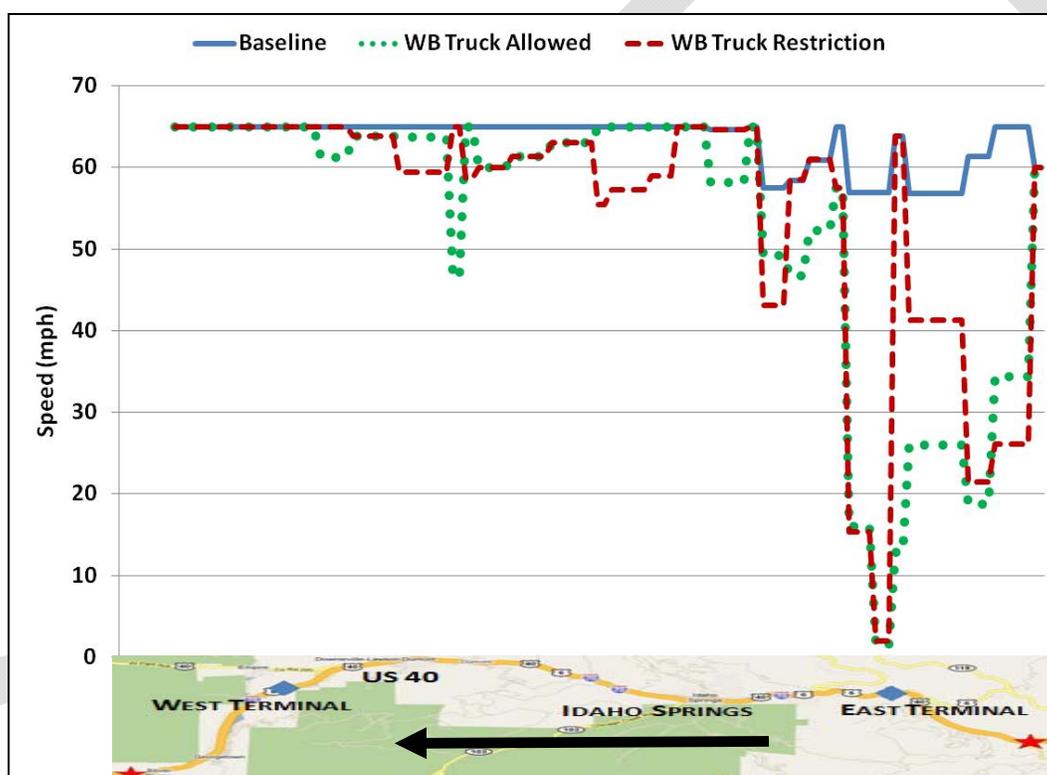


Figure 3.16: 4:00pm westbound

At the same time for the EB traffic, the baseline case without MBS show severe congestion and spillback all the way to Georgetown, in which speeds are mostly at 20-30 mph range. With MBS, vehicles would travel at free-flow speeds after passing the Georgetown area. The traveling speeds later differ in the truck allowed in and truck restricted cases in that when trucks are allowed in the MB lane, the GP lane speed is higher than the case in which truck is restricted from the MB lane. Allowing trucks in MB lane reduces truck mixes in the GP lane, consequently improves the GP lane speed.

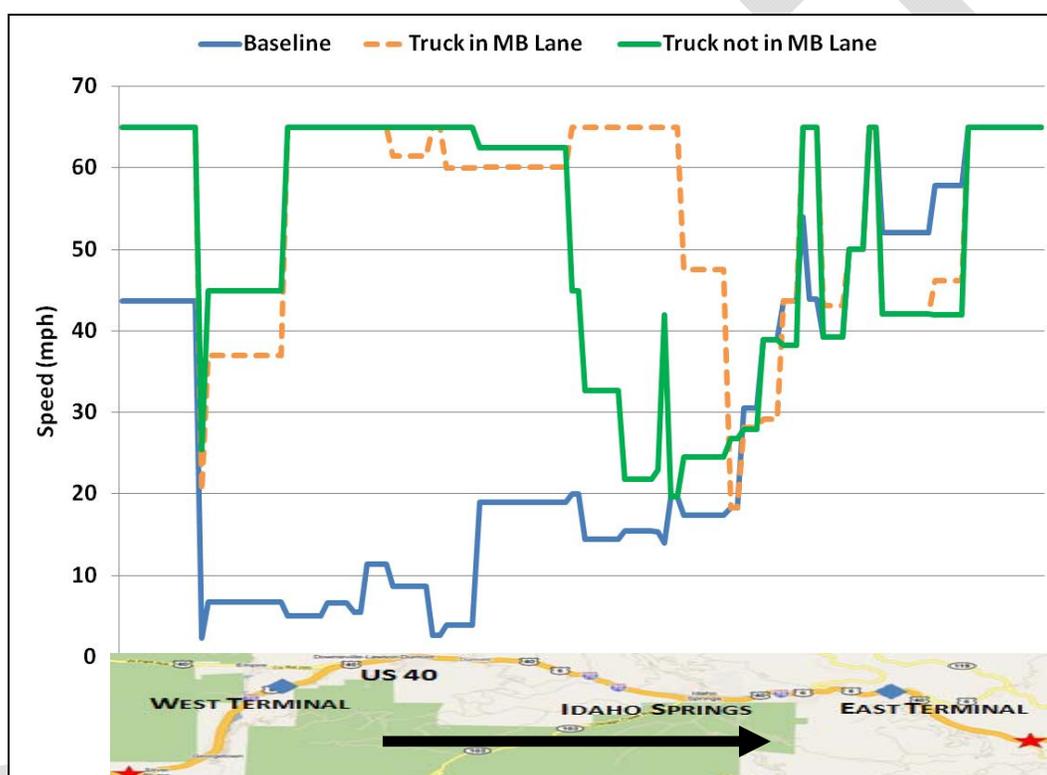


Figure 3.17: 4:00pm eastbound



Intuitively, from the MB lane operation standpoint, restricting trucks in MB lane provides better LOS than allowing trucks in the MB lane. In the truck restricted case, the traveling speeds maintain at 50+ mph range, whereas the speeds for the truck allowed case exhibit 3-5 miles of speed spillback from the East terminal merging point. In a signal-lane operation, once speeds starts to decrease, it is considerably difficult for trucks to accelerate, causing further capability and traveling speed reduction.

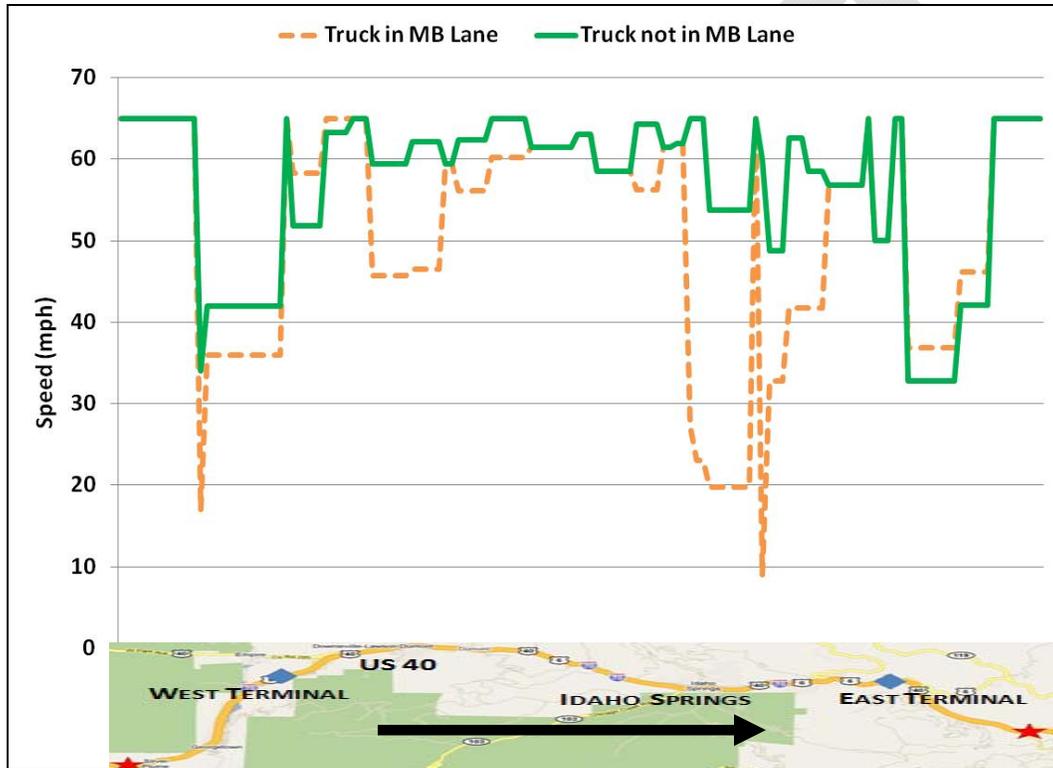


Figure 3.18: 4:00pm movable barrier lane

- 5:00pm

Entering the corridor WB at 5pm one would experience 1-2 miles queue within which the speeds briefly drop to below 10 mph, but the severity of congestion and length of the queue is dissipating. This is due to the reduced WB demand at this time. Allowing trucks in the WB lane leads to mild speed fluctuation, but generally the speeds can be maintained at 50+ mph level for both truck allowed and truck restricted cases.

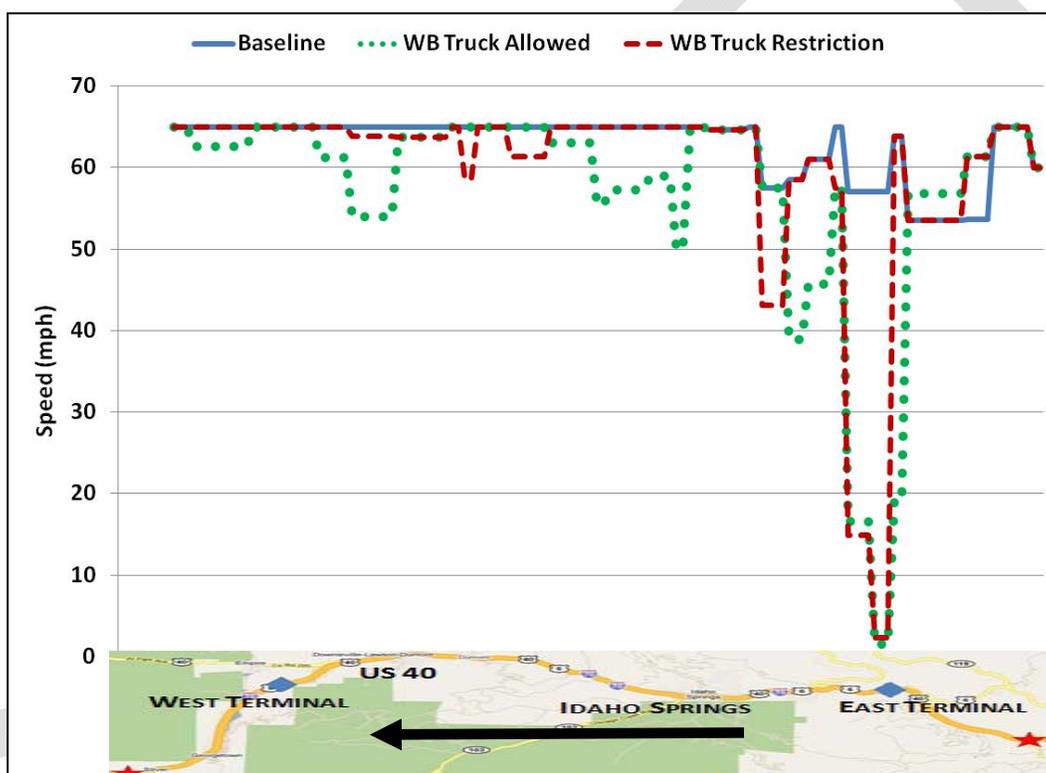


Figure 3.19: 5:00pm westbound



In the meanwhile, the EB traffic in the baseline case continues to stay at stop-and-go level. Entering the corridor at 5pm would experience 20 mph or lower speed between Georgetown and Idaho Spring, in site that the speeds gradually increase further approaching the East terminal and the eventually recover to free-flow condition within 5 miles east of the terminal.

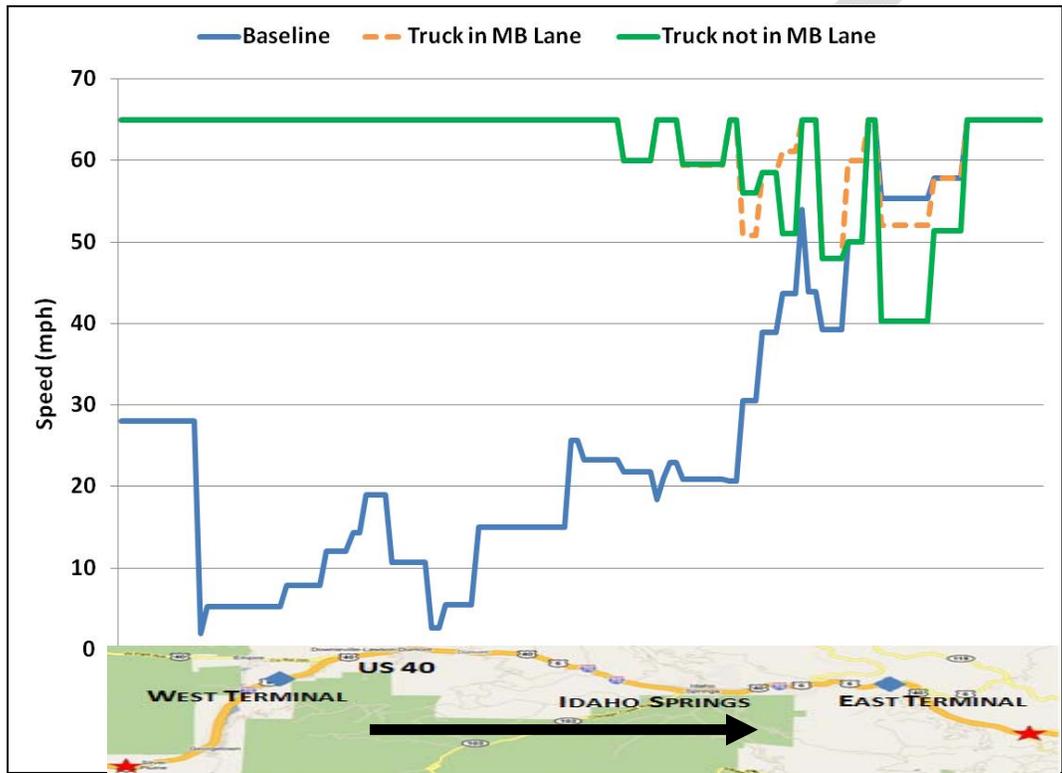


Figure 3.20: 5:00pm eastbound

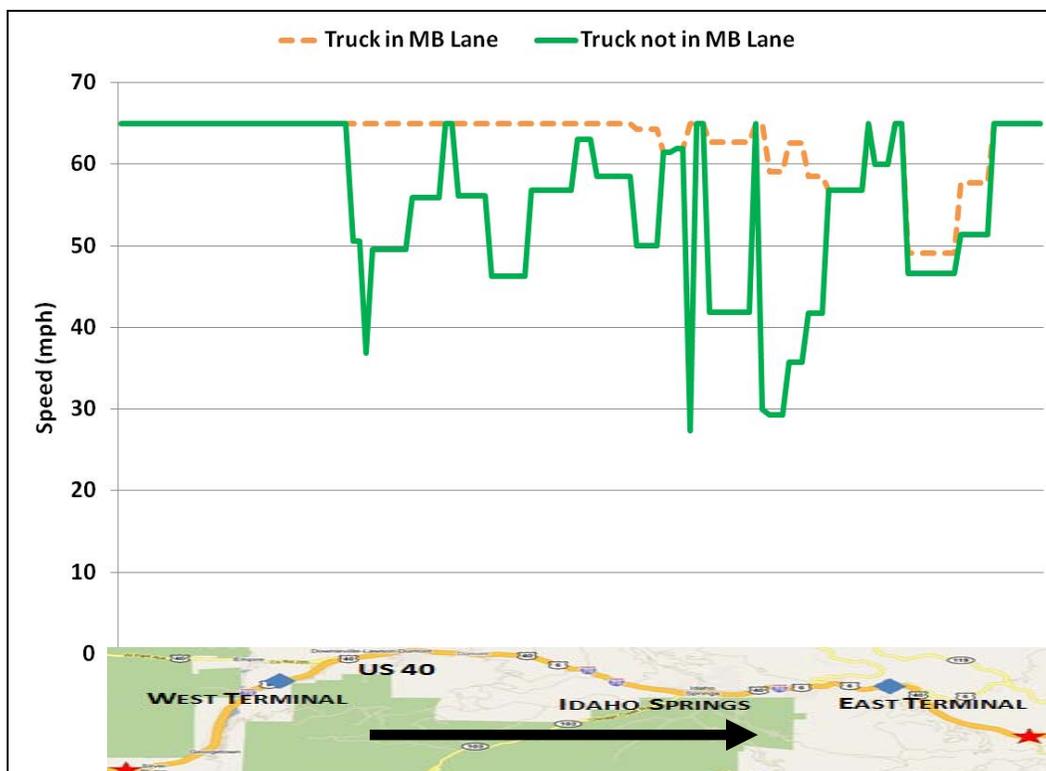


Figure 3.21: 5:00pm movable barrier lane

- 6:00pm

At 6 PM, queues still present at the East terminal. Although speed may briefly dropped to below 10 mph, most speeds fluctuate between 30 and 40 mph, indicating a recovered traffic.

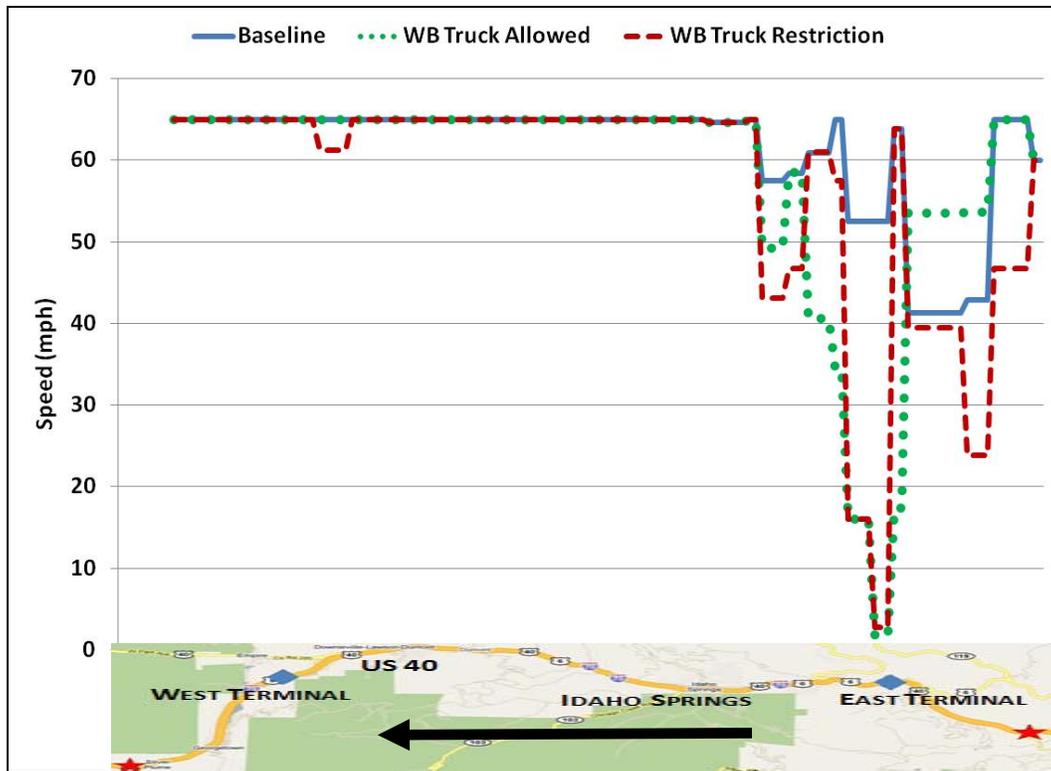


Figure 3.22: 6:00pm westbound

The EB baseline case traffic is also recovering at 6pm, but the result is the relatively volatile speed fluctuation within the corridor. This is a typical traffic dynamics when traffic is transiting from severely congested situation to free-flow conditions. However, with the MB lane operation, the EB traffic is almost at the free-flow conditions by this time. One can attribute this quicker recovery to MB lane providing higher capacity so traffic can flow through the corridor faster and by 6pm, there is much less residual traffic remained in the corridor.

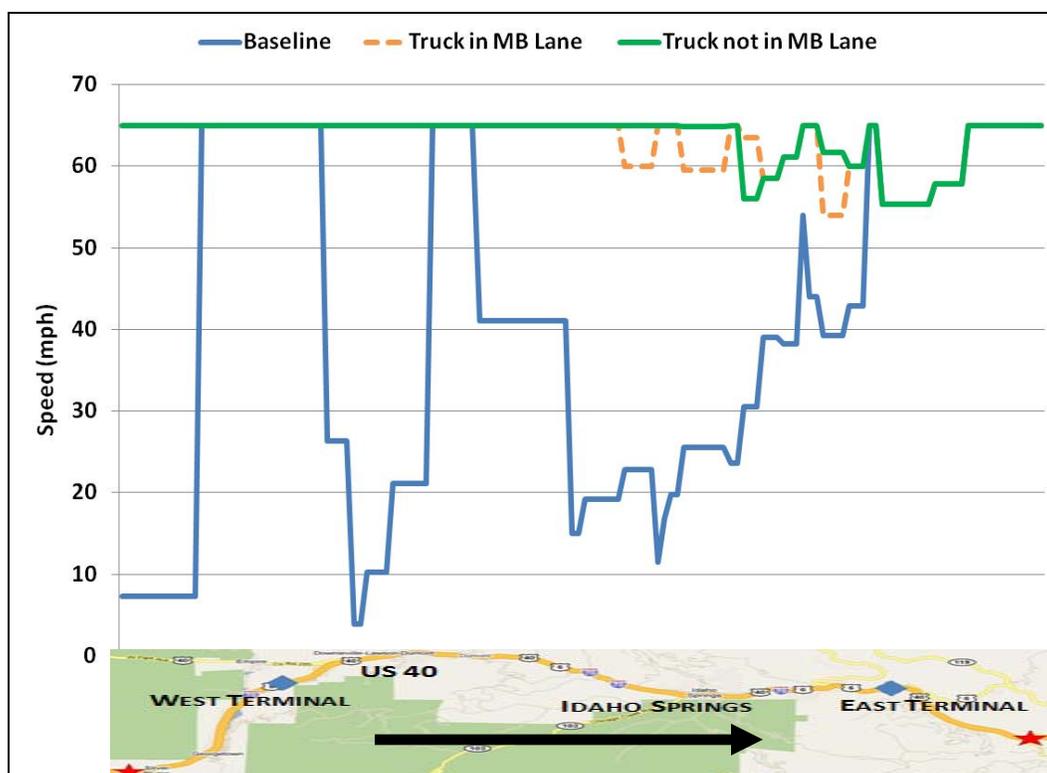


Figure 3.23: 6:00pm eastbound

In the meanwhile, the MB lane operation reaches mostly free-flow condition in the corridor. Mile speed drops can also be observed upon arriving at the East terminal, which is expected due to merging. Nonetheless, speeds are mostly at 55 mph+ level.

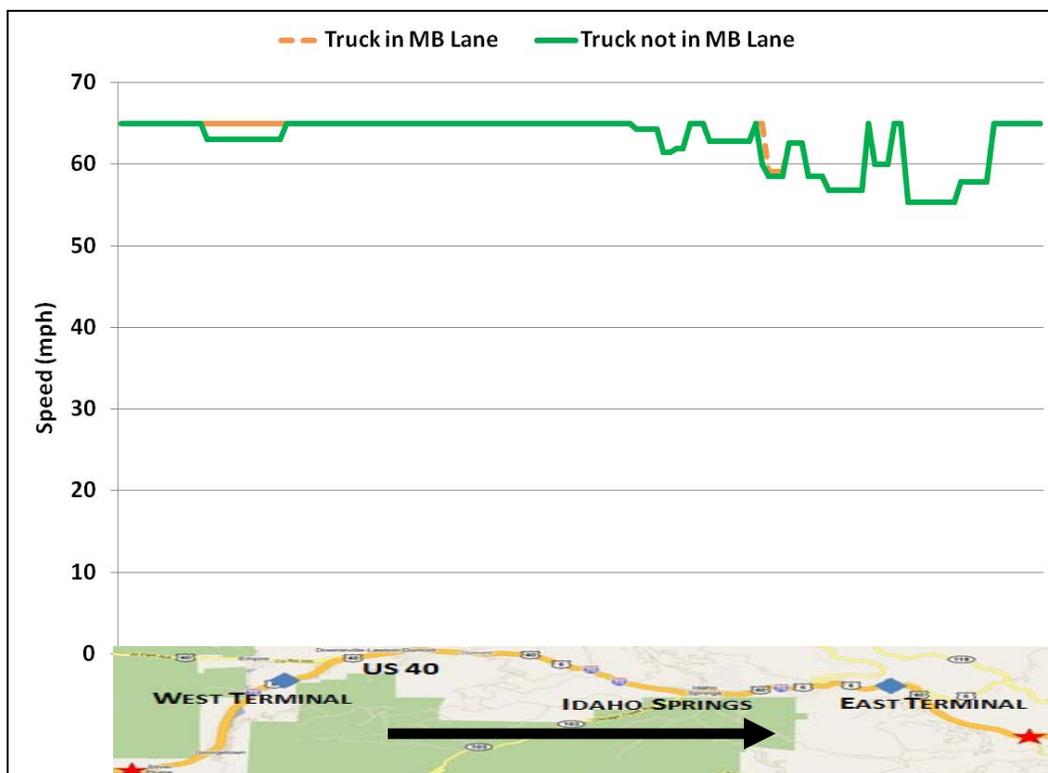


Figure 3.24: 6:00pm movable barrier lane

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- 7:00pm

The 7 PM EB situation is similar to 6pm with the extent of queue and speed reduction continues to improve for both MBS scenarios.

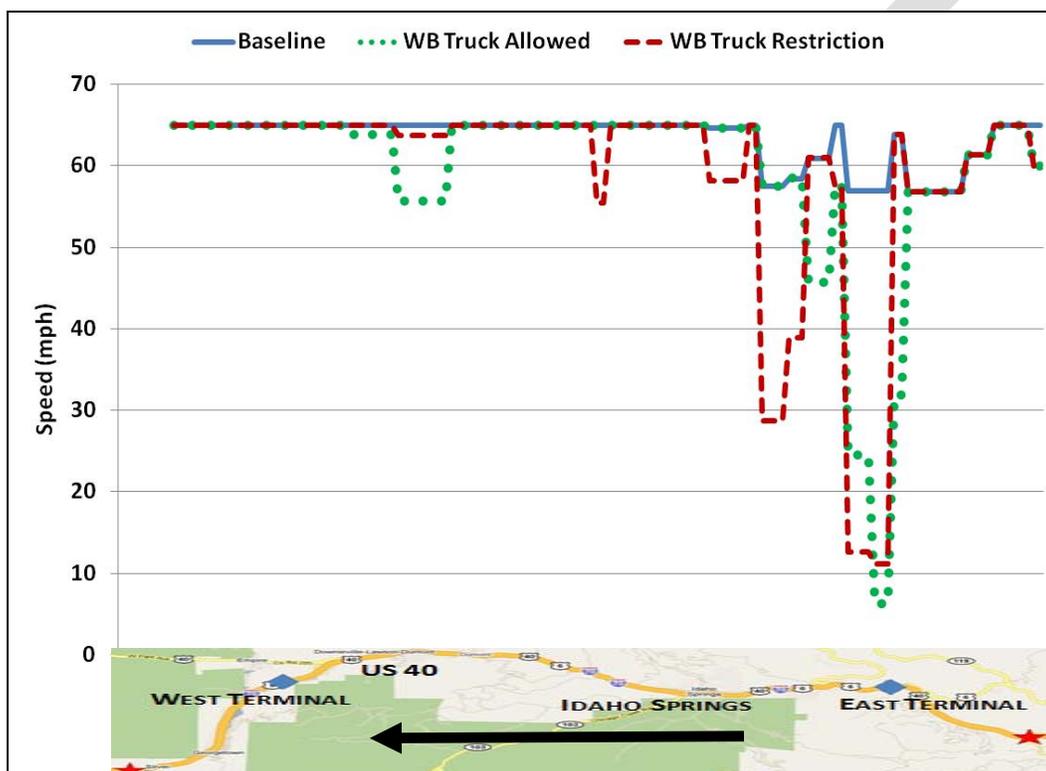


Figure 3.25: 7:00pm westbound

In the same time, the EB operation continue to recovers with mild speed reduction observed in the baseline case, and free-flow conditions observed for both MBS scenarios.

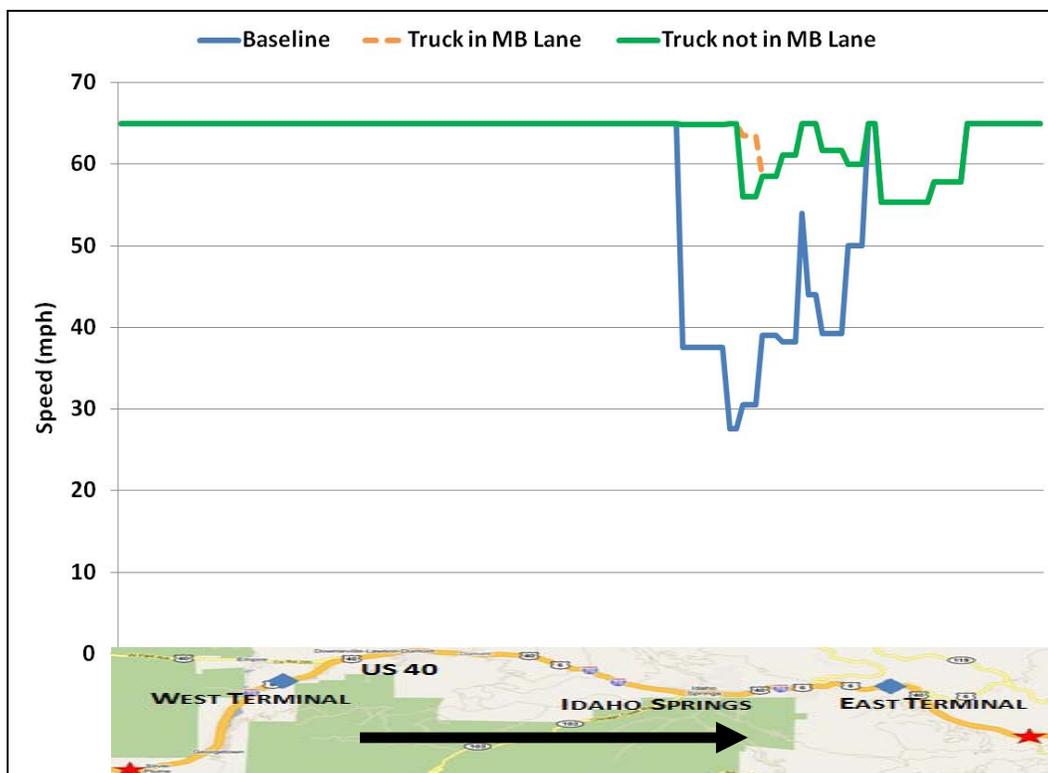


Figure 3.26: 7:00pm eastbound

The MB lane also exhibit free-flow condition by 7pm.

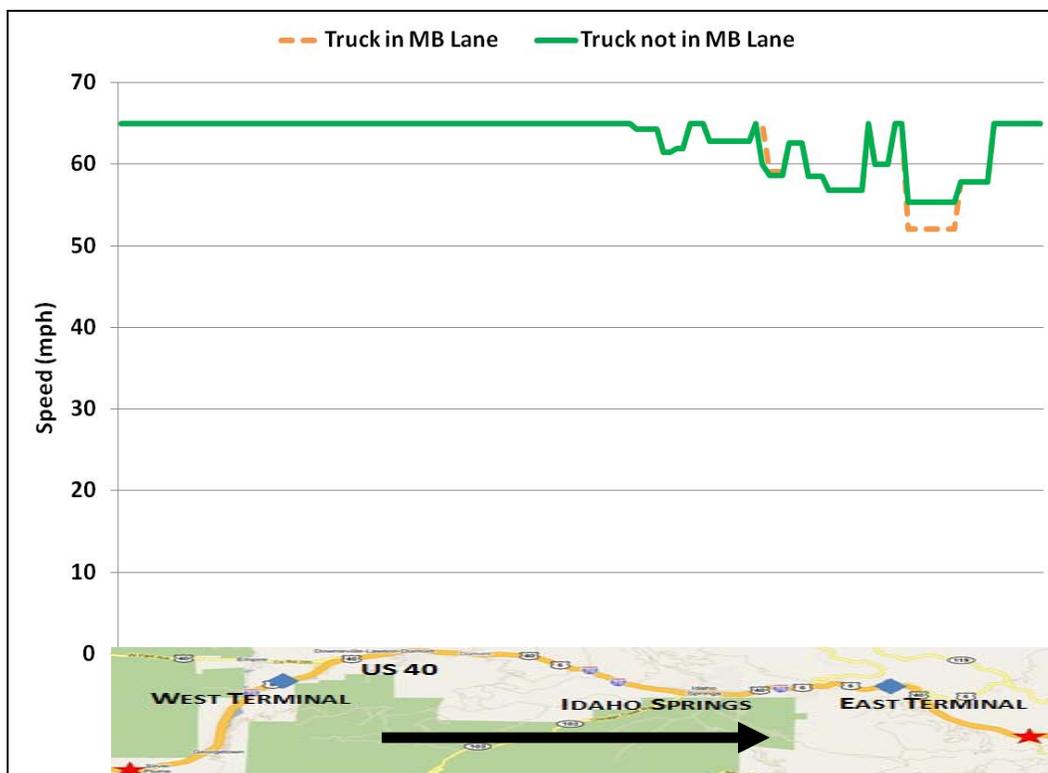


Figure 3.27: 7:00pm movable barrier lane

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