Memorandum

TO: Washington Metropolitan Council of Governments

FROM: Cambridge Systematics

DATE: September 19, 2016, Revised September 22, 2016

RE: **Task Order 16.2: Task #9, Revise Bus Speed Linkage to Highway Speeds**

1. Overview

CS has been tasked with making recommendations on improving the methodology of representing bus speeds in the MWCOG/TPB travel demand model. CS has addressed this mission by: 1) reviewing the state of the practice in regional travel demand models in the country's largest MPOs; 2) performing a corridor speed analysis using data provided by MWCOG/TPB; and 3) developing recommendations. These are all reported on within this report.

Since the Fiscal Year 2010 Task Report (Cambridge Systematics 2010) included a review of practice in this topic area, we began the latest effort by checking on changes in the regions looked at last time. This check confirmed there are still three main approaches being used: 1) bus speed curves, 2) regression models, and 3) highway time/speed with bus delay.

Each region exhibits unique characteristics that require agencies to adapt to their environments. So, no one-size-fits-all strategy exists with regard to modeling of transit speeds. The specific method used depends on how various elements of transit time are explicitly or implicitly represented, including:

- Auto travel speed/time on roadway network;
- Acceleration/deceleration of transit vehicles;
- Dwell time at stops/stations; and
- Recovery time at the end of each trip.

There are some variations on how the relationships between highway travel time and mixed-flow transit travel time are represented in the MPO models reviewed. For transit service operating on exclusive right-of-way, such as fixed guideway or dedicated bus lanes, it is state-of-the-practice to directly code the typical transit travel time or speed. For transit operating in mixed traffic, the MPO models reviewed contain a linkage between the highway travel time and the travel time of transit in the shared right-of-way.

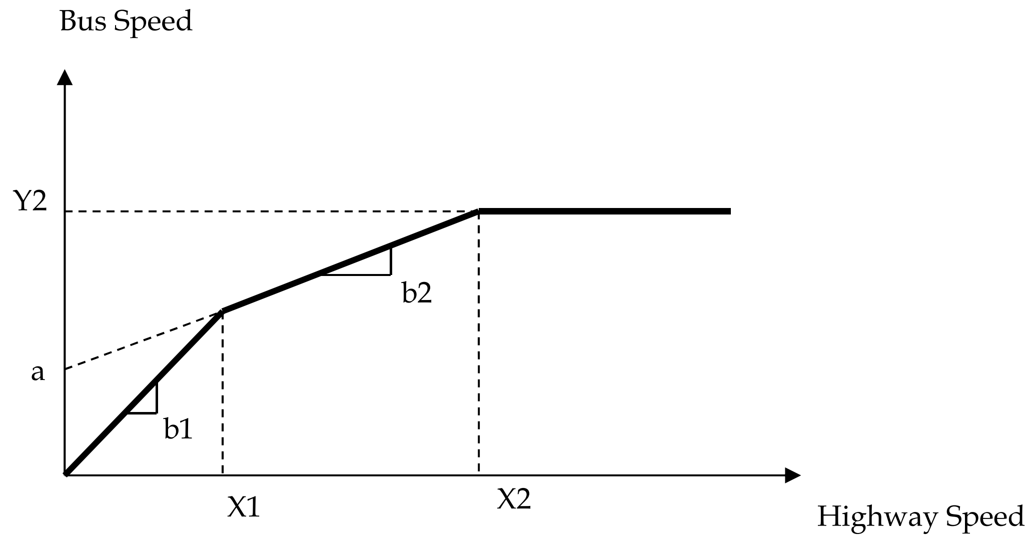
For this latest review, CS focused on adding examples from models updated since the last CS transit speed review was performed, representing incremental improvements to already existing transit speed modeling practices. The following subsections discuss the Triangle Regional Model (Raleigh, North Carolina), the Atlanta Regional Council Model, the Houston-Galveston Area Council Model, and the Baltimore Metropolitan Council Model.

1.1 Triangle Regional Model

The Triangle Regional Model (TRM Version 5 and Version 6) algorithmically calculates the bus speed from the highway speed using local parameters (Triangle Regional Model Service Bureau 2012). In the TRM network, each link is assigned a facility type and a bus speed category according to the facility look up table. There are nine bus speed categories, one for each combination of area type (urban, suburban and rural) and facility type (freeway, arterial and local). Each bus speed category has two bus speed equations (18 bus speed equations in total), one for peak period (PK) and one for off-peak (OP). The equation information is stored in the file of "BusSpeed_Equations.bin" of the model. On transit only links, specific speed values are coded, instead of the calculated speed based on the equations.

A typical bus speed equation used in TRM is visualized in Figure 1. It consists of three line segments: at low highway speed, it is a line crossing the origin; at medium highway speed, it is a line with a certain intercept; and at high highway speed, it is horizontal and the bus speed is independent of the highway speed. For the peak periods, the highway speed refers to congested highway speed; and for off-peak, the highway speed refers to free-flow highway speed. A bus speed equation is defined by 6 parameters: $X1$, $X2$, $b1$, $b2$, $Y2$ and a (a can be negative), as shown in Figure 1, where $b1$ and $b2$ are slopes and a is an intercept. These parameters were obtained by conducting linear regressions to observed highway and bus speeds from the year-2000 data.

Figure 1. Visualization of Bus Speed Equations



1.2 Atlanta Regional Council Model

Documentation for the Atlanta Regional Council (ARC) model states that the MPO has developed an empirical model to relate bus speed to congested highway speed (Atlanta Regional Commission 2011). The previous model included a lookup table with a constant bus speed for each area type and facility type. These speeds were independent of highway speed. Their stated objective for updating this aspect of the model "was to add highway congested speed into the lookup table and change each cell of the table into a dynamic function." The constant speed was replaced with a curve for each area type and facility type combination relating bus speed to congested highway speed. They found this approach closely approximated observed operational speed. The resulting functions are linear, following the equation below:

Bus speed = a (congested highway speed) + b

Where both *a* and *b* are parameters closely related to bus cruise speed, frequency of stops, and dwell times at stations. This information was drawn from the MARTA and CCT bus schedules. The model took the factors as inputs allowing it to dynamically calculate bus speed based on the congested highway speed. The speeds therefore vary and "the model feedback loop is modified to reflect bus path building within every iteration." The values generated, including distance, time and speed, are output by bus route. The factors were calibrated by comparing the output to the matching bus line's schedule until the average error level was below five percent.

1.3 Houston-Galveston Area Council Regional Travel Model

The Houston-Galveston Area Council (HGAC) model uses a set of functions to calculate travel time on each link in the network (Houston-Galveston Area Council 2012). These use automobile travel time and type and location of transit service. The three types of functions are: 1) assumed constant speed, 2) proportion of auto speed, or 3) congested travel time estimation. The function used is based on the context and time period. Type 3 is not used in off peak, but all three are used in the peak period.

Type 1 is a universally set constant transit speed. Type 2 multiplies the auto time by a factor for transit time. The type 3 function uses a free flow transit time and a factor calculated using the v/c ratio and a location based constant. The general form of this function is:

$$t_c = t_{ff} \cdot \left(1 + \alpha \cdot \left({}^{v}/_{c}\right)\right)$$

Where t_{ff} is free-flow transit travel time, and α is a transit line specific factor. For equations applied to nonstop bus operations outside the CBD, $a = 0.15$, but in all other cases $a = 0.10$. The congested travel time is kept between a minimum (auto time) and a maximum (the time associated with 10 percent of the LOS E speed). This maximum time can put the bus speed at 3-5 mph for certain type of roads.

1.4 Baltimore Metropolitan Council Model

Baltimore Metropolitan Council (BMC) developed a formula process rather than route-specific data to simplify model development and to allow for use of dwell times to be calculated for new and rerouted bus lines (de Rouville 2009). They set out to see if "dwell times at stops would correlate to the density of the zone as measured by the area type variable used in the modeling process". It was assumed that high density areas tend to have heavier volumes of boarding and alighting passengers, while sparse areas had only light activities.

BMC used published Maryland Department of Transportation/Maryland Transit Administration (MDOT/MTA) transit schedules from year 2008 to compare with peak and off-peak travel times estimated by the model. In addition to a general overview, several urban and suburban bus routes were selected for a more detailed comparison in peak and off-peak times. Sections were selected and travel times were compared to highway travel time using the time-period specific estimated speed inputs.

Highway links were matched with a variable marking the area type of its location. This area type reflected a composite of residential and employment density, from the lowest to highest. Link-level precision was not possible due to too little data. Their solution was to take longer sections, applying an average area type and calculating an average delay per stop. This exercise showed little relationship between area type and delay per stop.

As a result of this process, BMC estimated a single average dwell time per stop for each time period for all area types. The dwell times are shown in Table 1.

Table 1. Average Dwell Time per Stop

	Peak	Off-Peak
Local Bus	0.673	0.652
QuickBus[1]	1.417	1.420

Due to the limited difference between peak and off-peak, model inputs were simplified to a dwell time per stop of 0.65 minutes for local buses and 1.4 minutes for limited stop services for all time periods.

1.5 Latest Considerations

For representation of bus travel times on roadway links shared with autos, current practice focuses on use of some functional relationship to the model-produced auto travel times on those links. Unfortunately, these approaches are somewhat dependent on a travel model's ability to reasonably predict auto travel times, which can be a challenge, particularly on arterial streets with lots of signalized intersections (where some streets have better signal coordination than others), or where local buses are making frequent stops to load/unload passengers.

An alternative state-of-the-art approach is to use the actual scheduled bus travel times between stops via General Transit Feed Specification (GTFS) files to represent existing transit service over any specified time-of-day period, and a model-produced prediction of the changes in auto travel times to predict the future changes in transit travel times. Transit times include the moving-in-traffic times plus the extra time associated with making passenger stops, so the "change over time" relationship might not be directly proportional, and an increase in the model-predicted auto travel times may be necessary to compensate for that percent increase.

Growing access to "Big Data" sources (actual auto travel times and GTFS-based scheduled transit times) creates a potential to identify the relationship of changes in actual auto and actual transit travel times over time, as well as the differences between the actual versus scheduled transit travel times. This may result in additional approaches to linking bus speeds and highway speeds being available in the future.

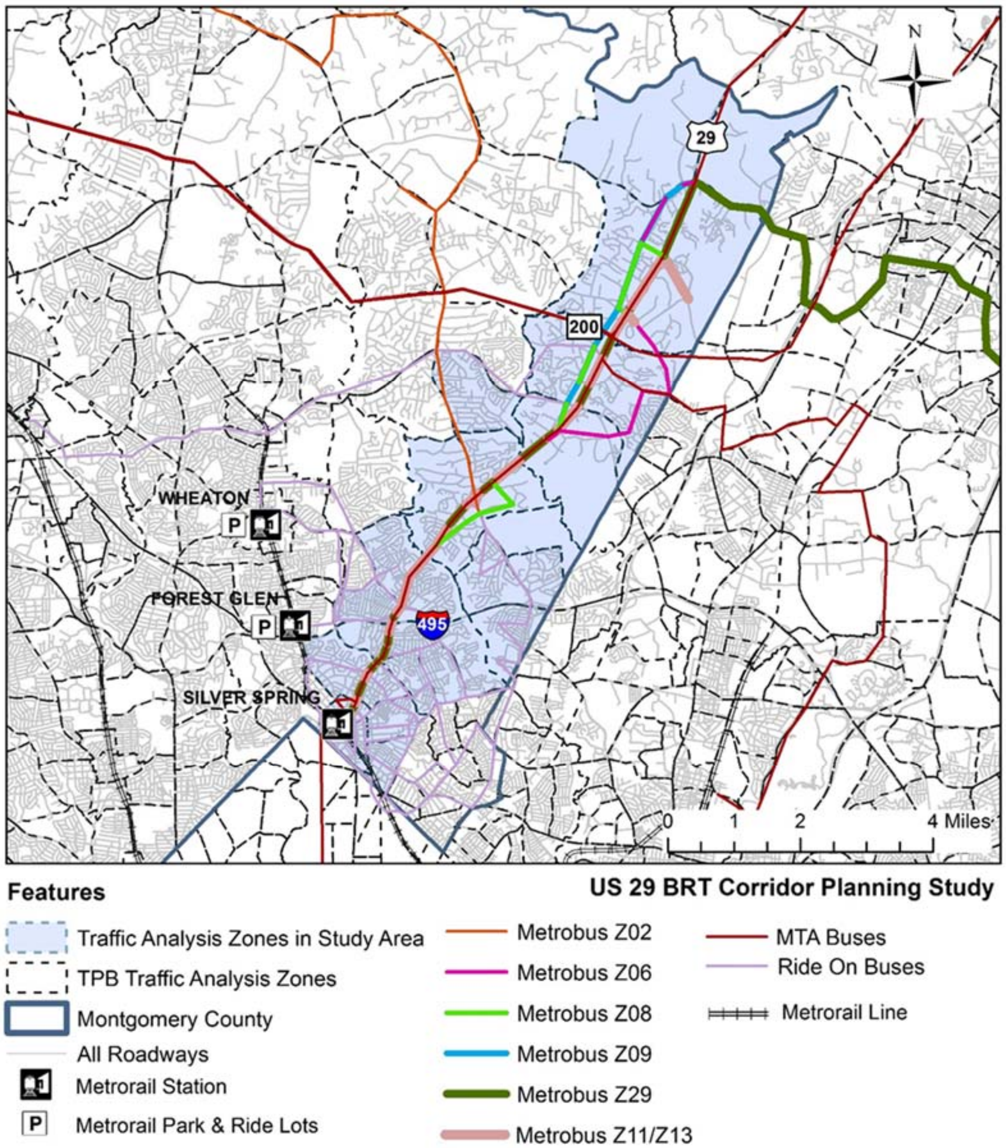
2. Corridor Transit Speed Analysis in D.C. Region

As part of the model enhancement exercise, CS looked at existing bus and highway service information from available INRIX data and WMATA timepoint data for a specified time period for a selected corridor. The study team decided to test the U.S. 29 BRT project corridor in Montgomery County, Maryland as shown in Figure 2. The portion of the U.S. 29

[1] MTA bus service with limited stops.

BRT corridor that the team looked at lies between the Burtonsville Park-and-Ride lot and the Silver Spring Transit Center, with a total length of approximately 14 miles. Metrobus, Montgomery Ride-On, and MTA commuter buses operate along and near U.S. 29. Figure 2 displays the boundaries of the studied U.S. 29 corridor.

Figure 2. U.S. 29 BRT Corridor Planning Study Area



Prior to this CS analysis of bus travel times on the U.S. 29 corridor, MWCOG/TPB put a substantial effort into examining existing bus and highway service information from the regional travel demand model (for the year 2015) at the transit line level of analysis and presented a memorandum to CS summarizing their observations (dated April 21, 2016). In the memo, MWCOG/TPB staff presented comparisons of transit and highway times and speeds for each bus line in the regional transit network. The transit information used reflects published schedule information extracted mostly from recent GTFS sources. The highway information is taken directly from the morning peak and midday restrained speeds developed through the standard highway assignment process.

The MWCOG/TPB staff analysis indicated that scheduled bus run times are generally longer than travel times derived from estimated/restrained highway speeds, except for longer bus routes (highway minutes greater than 100), which appeared to exhibit scheduled bus times that are less than the restrained highway times. MWCOG/TPB staff examined these specific observations and discovered that these faster buses are express/commuter bus services that use special facilities such as the Inter-County Connector (ICC) in Maryland or the I-95 HOT lanes in Virginia. However, it is not known whether these seemingly faster buses result from inaccurate schedules, inaccurate restrained highway speeds from the assignment, or a combination of both.

For the CS effort, the average workday data from WMATA and INRIX were provided from the second half of 2015. Data comparisons of transit and highway times and speeds were performed to establish the relationship between the two sources of observed data. Figures 3 and 4 reflect peak times and speeds, and Figures 5 and 6 reflect off-peak times and speeds. The transit information was derived from published scheduled and observed information extracted from timepoint data for the routes running on the U.S. 29 corridor.

The scheduled times were then compared with actual bus and highway run times. Peak observed and scheduled transit times and speeds (Figures 3 and 4) indicated that times derived from schedules were generally shorter than actual run times, and therefore scheduled speeds were higher than actual bus running speeds. Overall, the correlations between scheduled and observed bus speeds were low, however, suggesting that scheduled bus speeds do not replicate observed running speeds precisely.

The same analysis for the off-peak period (Figures 5 and 6) yielded better results for speeds, although a few outliers still existed. Data variation for speeds was lower than that found in the peak period.

Figure 3. 2015 Peak Transit Line Running Times: Schedule versus Actual

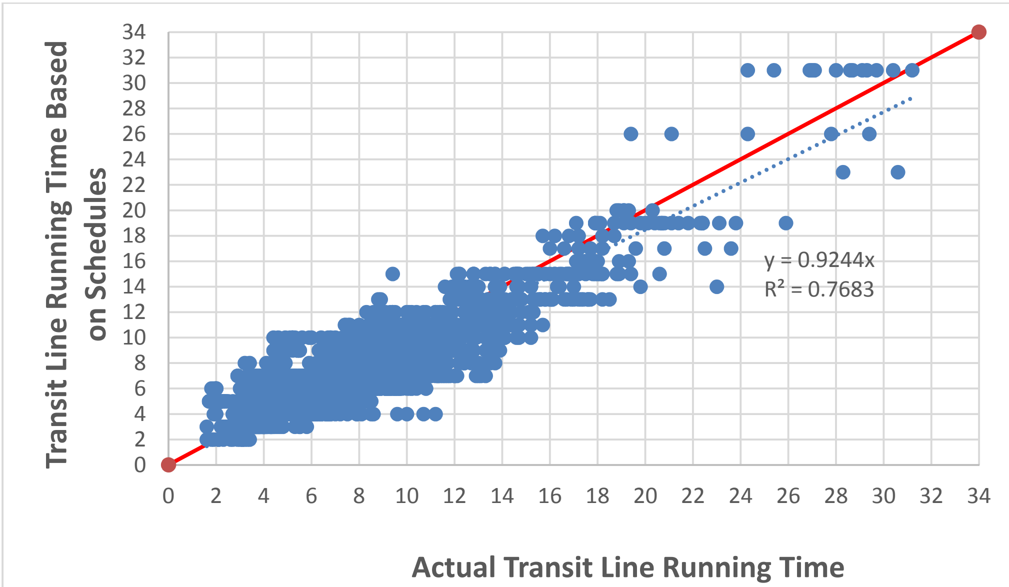


Figure 4. 2015 Peak Transit Line Running Speed: Schedule versus Actual

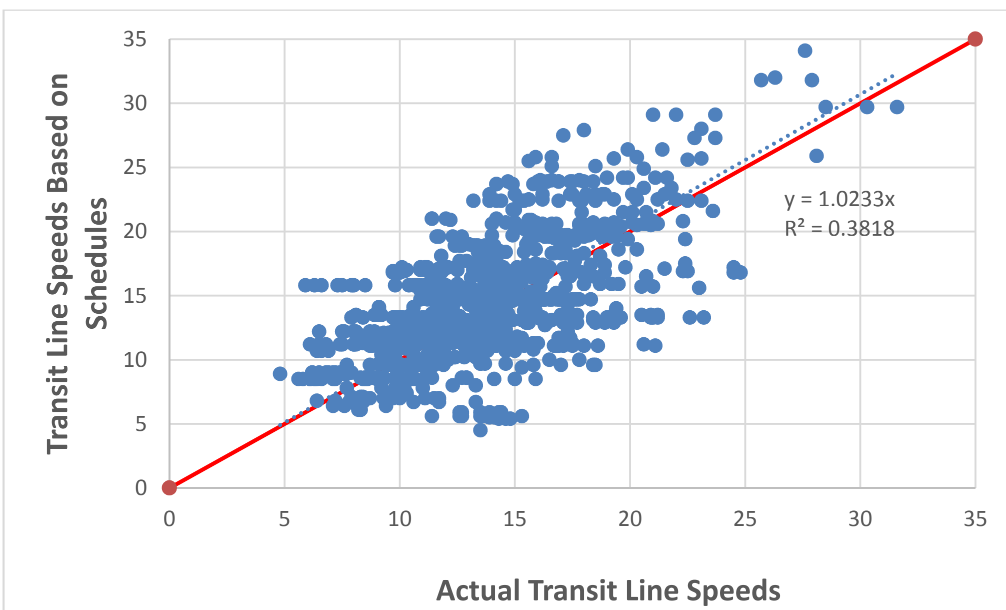


Figure 5. 2015 Off-Peak Transit Line Running Times: Schedule versus Actual

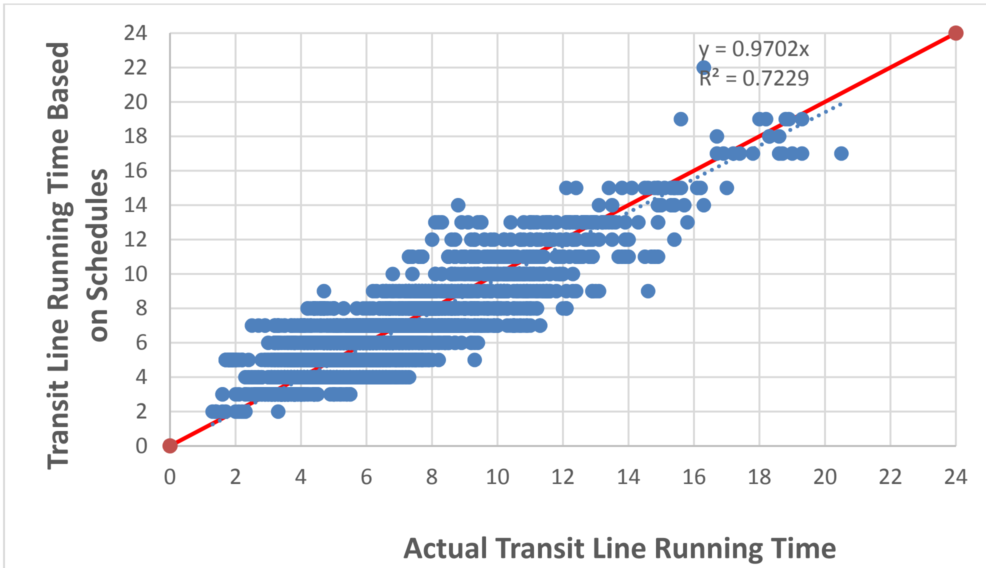
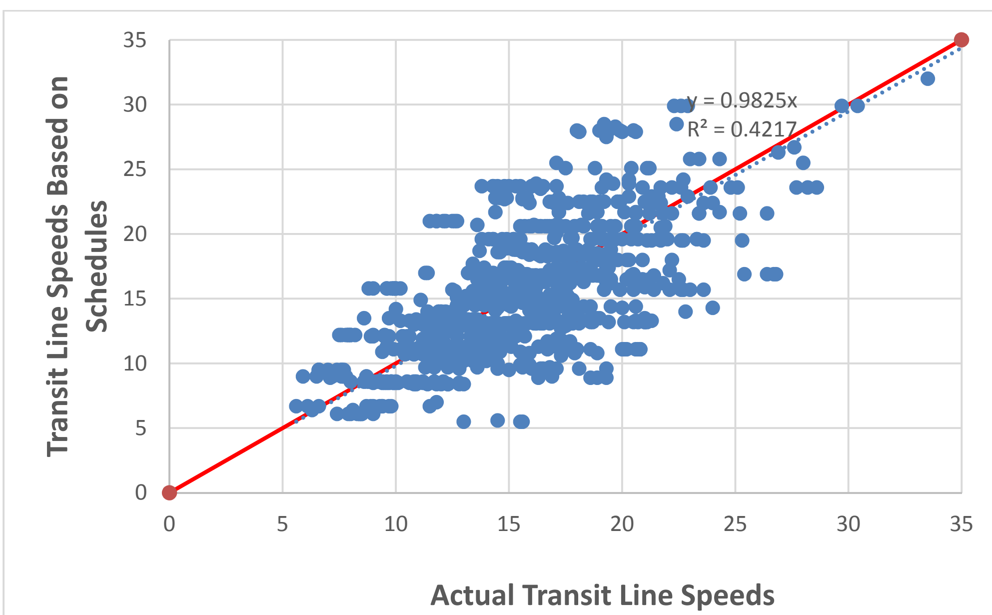


Figure 6. 2015 Off-Peak Transit Line Speeds: Schedule versus Actual



The team looked at the relationship between observed bus speeds from WMATA data and average observed speeds from INRIX data. Data were assessed at the segment level to allow direct comparison. The U.S. 29 corridor was divided into segments of major intersections or attraction centers. The INRIX data were summarized into segments by average weekday speed for a segment. The WMATA data were also summarized into segments and the average dwell time and running time and speed data was derived by segment. Figures 7 and 8 show fairly weak relationships between observed transit speed and INRIX road traffic speeds, but the number of observations was quite small.

Figure 7. Peak Observed Transit Speed versus INRIX Speed

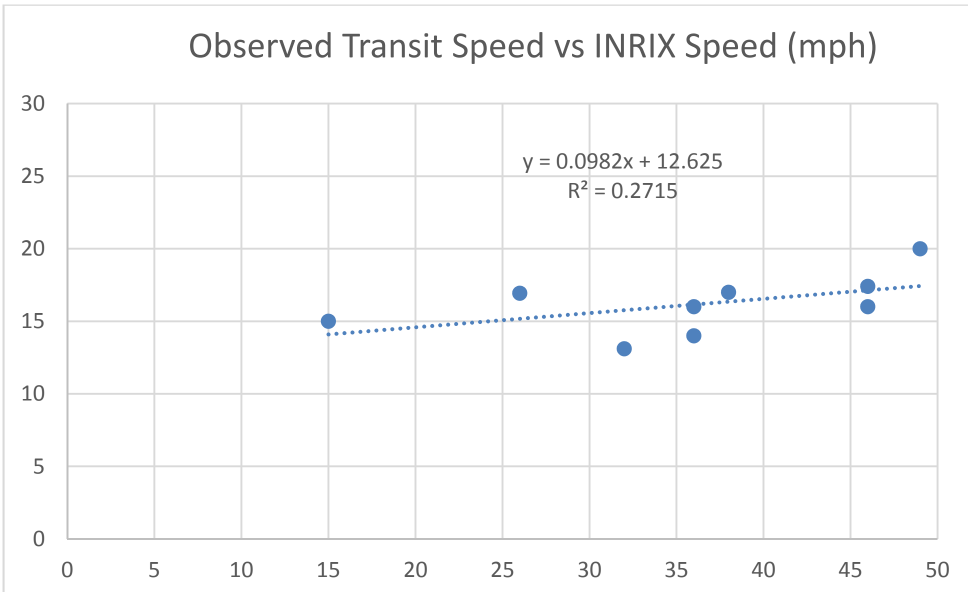
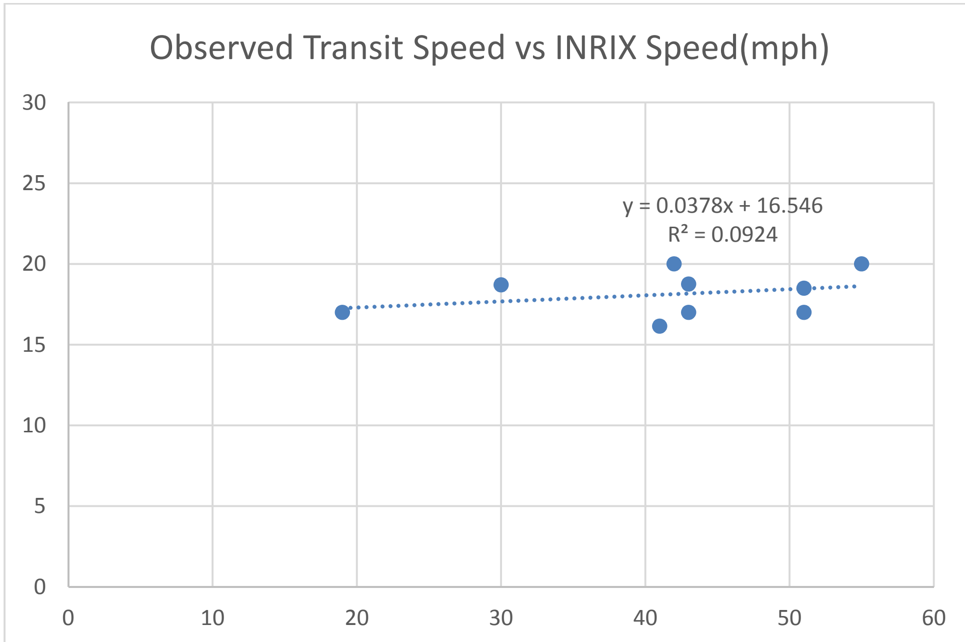


Figure 8. Off-Peak Observed Transit Speed versus INRIX Speed



The main observations we derive from this analysis are:

- Given the complexity of fitting various data sources into one format, it is a challenging task to build a model using observed highway and transit speeds. In addition, it is challenging to update the model on the basis of scheduled times and traffic assignment-based speeds, as evidenced from the peak and off-peak transit/highway time comparisons.
- Given the variations in the figures from the analysis we did perform, it seems that no single regression model can easily reflect actual bus times for all bus routes in the system.
- When updating the model, it is important to make sure that transit network coding is adjusted to accommodate the modeling approach. In the case where a bus speed model differentiates between freeways and arterials, transit line files would need to be prepared such that freeway segment running times are distinguished from arterial segment running times. Thus, the modeling approach influences network coding.
- A bus speed model will require thresholds governing the degree to which congestion degrades bus speeds.

3. Findings and Recommendations

No state of the practice consensus exists among transportation practitioners regarding the best methods for calculating transit speeds in regional models. A review of the state of the practice for transit speed estimation in several MPOs revealed no major advancements with regard to transit modeling over the past six years. Linking transit travel time/speed to highway travel time/speed in one way or another is the general practice in regional models of large MPOs, but the method used varies.

Given current practices and challenges, and considering the desirability to make improvements in the short term, it is recommended that the MWCOG/TPB consider the following refinements:

- Improve representation of the base-year bus run time/speed through analysis of scheduled run time/speed versus observed run time/speed;
- For future years, calculate bus run time/speeds based on the base year bus run time/speed and the changes in modeled roadway speeds between base and future years;
- In implementing changes in modeled roadway speeds, use degradation factors segmented by area types/facility types (rather than a global factor), with certain thresholds governing the degree to which congestion degrades bus speeds. These factors would be confirmed using local-data case reviews such as the ones described in Section 2, above, coupled with professional judgment.

References

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