I-95 CORRIDOR COALITION

MEMORANDUM

To: Vehicle Probe Project Arterial Data Quality Committee

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Date: November 2, 2010

Subject: ***I-95 Vehicle Probe Project –Arterial Data White Paper***

The purpose of this document is to provide a summary of the issues and concerns that have surfaced related to the ability to provide quality traffic data on arterials as part of the I-95 Corridor Coalition's Vehicle Probe Project (VPP). This information is a compilation from (1) lessons learned from freeway monitoring, (2) information gleaned from limited validation performed on arterials, (3) discussions with project stakeholders, and (4) comments and feedback obtained from the July 14, 2010 webinar with the Arterial Data Quality sub-committee that was formed to help guide this effort.

EXECUTIVE SUMMARY

The scope of the I-95 Corridor Coalition's Vehicle Probe Project (VPP) included providing traffic data on major arterials that acted as alternate routes and connecting links between major freeways. Such arterial links were included in the RFP and in the initial deployment that began in July 2008. INRIX donated traffic data on about 1000 miles of arterials during the initial three years of the VPP (scheduled to end in June of 2011). (See the map in Figure 1 for an overview of the original freeway and arterial coverage.) The Coalition's goal during the initial three years was to investigate the quality of donated arterial data so that appropriate quality specifications and value could be assessed prior to project renewal in 2011. In late 2009, after the first 18 months of validation activities which concentrated primarily on freeways, the Coalition turned its attention to arterial data quality; the team began collecting data on arterials as part of the monthly validation process, and formed a committee of interested Coalition members to review and guide the process. Data collected on arterials has revealed several issues, and a conference call with the committee in July 2010 identified further concerns, however, it also re-affirmed the need for quality traffic data on arterials similar to that available for freeways through the VPP. The issues and concerns are summarized below (the body of the white paper provides samples and additional detail, as well as other minor issues.)

'Arterials' as referred to in the initial VPP request for proposal (RFP) included any road category that was not a limited access freeway. Arterials of interest and for which quality traffic data may by attainable in the near term encompass high-volume, multi-lane arterials that can serve as diversion routes during incidents and link major freeways. Such arterials exhibit sparse signal spacing, and medium to low mid-block friction.

Traffic flow on arterials is more diverse than on freeways, requiring a higher sampling rate to attain the same level of data quality. This high variance is induced primarily by the influence of signalized intersections, but increased turning opportunities and mid-block access to goods and services contribute as well.

In addition to **higher overall variance in speeds**, traffic signals tend to divide traffic in pulsed flows, with two or more distinct travel times. The faster travel time corresponds to the portion of traffic that progressed through on green, while the slower travel times reflect the portion stopped on red and forced to wait through the next signal cycle. These bi-modal flows are the largest technical challenge to obtaining and effectively using arterial traffic data.

Volumes on arterials are generally half that of freeways for the same geometric configuration (number of lanes). Due to the variance issues described above, larger sample sizes are required to achieve levels of accuracy comparable to that of freeways within the VPP. The combined effect significantly increases the difficulty of delivering quality traffic data on arterials. This impacts not only INRIX's ability to provide quality data, but also limits validation opportunities.

Congested flow on arterials is difficult to discern from free-flow. Whereas congested flow on freeways can be identified with a simple speed threshold, differing travel times on arterials occur due to different signal timing plans in effect throughout the day. The assessment of data quality on freeways concentrated on the performance of the system during congested periods. A similar approach with arterials will be more difficult to design.

It is uncertain whether the **commercial traffic data standard** used to define roadway segments, called Traffic Message Channel (or TMC) codes, are adequate to reflect the complexity of arterial networks. The method used to reflect turning movements within intersections requires additional investigation.

Despite the challenges described above, the demand for arterial data continues to grow. Applications for which arterial data is needed are similar to that of freeways. Traveler information services are expanding to include alternate routes that encompass parallel arterials, travel time on signs and on web maps incorporate arterials to connect to end destinations, and as diversion routes during incidents. Local commute patterns and transit frequently require arterial travel time data to support scheduling and other services. So in spite of the difficulties in providing quality travel time data on arterials, the need for the data is not diminished, but is growing.

Specific recommendations for trial implementation are identified in the conclusions of this white paper. Unlike freeway traffic data in which many applications, uses, and quality metrics are available to draw upon, arterial traffic monitoring is not as mature. Definitions, specifications, and methods will need to remain flexible as more data and additional experience is obtained.

ORGANIZATION AND OVERVIEW OF WHITE PAPER

This white paper is divided into three sections and an appendix.

Section 1, titled *Introduction*, reviews the original vision of the Vehicle Probe Project, and initial scope of implementation which included about 1000 miles of arterials. Arterial data quality was to be investigated over the initial three years of the VPP in order appropriately specify and measure arterial data quality.

Section 2, titled *Arterial Traffic Data – Issues and Challenges*, isolates and summarizes the primary concerns that impact the ability to provide quality data on arterials. Sample validation data are presented that exemplify the issues.

Section 3, titled *Conclusions and Action Items*, presents suggested specifications and validation methods, identifies further action items, and emphasizes the need to remain flexible moving forward.

Appendix, titled *Lessons Learned from Freeways*, provides an overview of the reporting measures and quality specifications of the VPP as originally designed. This freeway perspective is critical because it forms the backdrop from which arterial data quality was initially analyzed. By comparing and contrasting with freeways, the challenges of quality traffic monitoring on arterials comes into clear focus.

INTRODUCTION

The scope of the I-95 Corridor Coalition's Vehicle Probe Project included major arterials that provided alternate routes and connecting links between major freeways.

The original vision of the Vehicle Probe Project is reflect in the RFP when describing the monitoring network as follows –

"In 2006 the I-95 Corridor Coalition conceived of a Corridor Wide Traffic Monitoring System that spanned the Eastern Seaboard from Maine to Florida providing real-time traffic information to support inter-corridor movements. The monitoring system was envisioned to include a network consisting of I-95 and major parallel freeways; beltways and cross-linking freeways; and major arterials that provided alternative routes.

Data from the system was to support multiple applications such as operations, 511, traveler Information systems, performance measure, planning, travel times on signs and incident management."

Arterials were included in the RFP and in the initial deployment which began in July 2008. The VPP became operational on July 1, 2008 with roughly 1500 miles of freeway spanning from New Jersey to North Carolina. In addition to the freeway mileage, INRIX donated data for approximately 1000 miles of arterials during the first three years of the project. The arterial data was made available on July 1, 2008 as well. (See the map in Figure 1 below for an overview of the original freeway and arterial coverage.) The Coalition goal was to monitor and study the quality of donated arterial data, so that by the time of contract renewal in 2011 arterial data quality could be adequately specified as well as an appropriate dollar value assigned relative to freeway traffic data.

The 1000 miles of donated arterials coverage included a variety roadway types such as city streets in urban areas, multi-lane limited-access facilities with very sparse signalized intersections in suburban areas, well as two-lane state highways. The common factor, and probably a more fitting definition for the arterials in the initial I-95 VPP is that an arterial included any roadway type other than limited-access freeways.

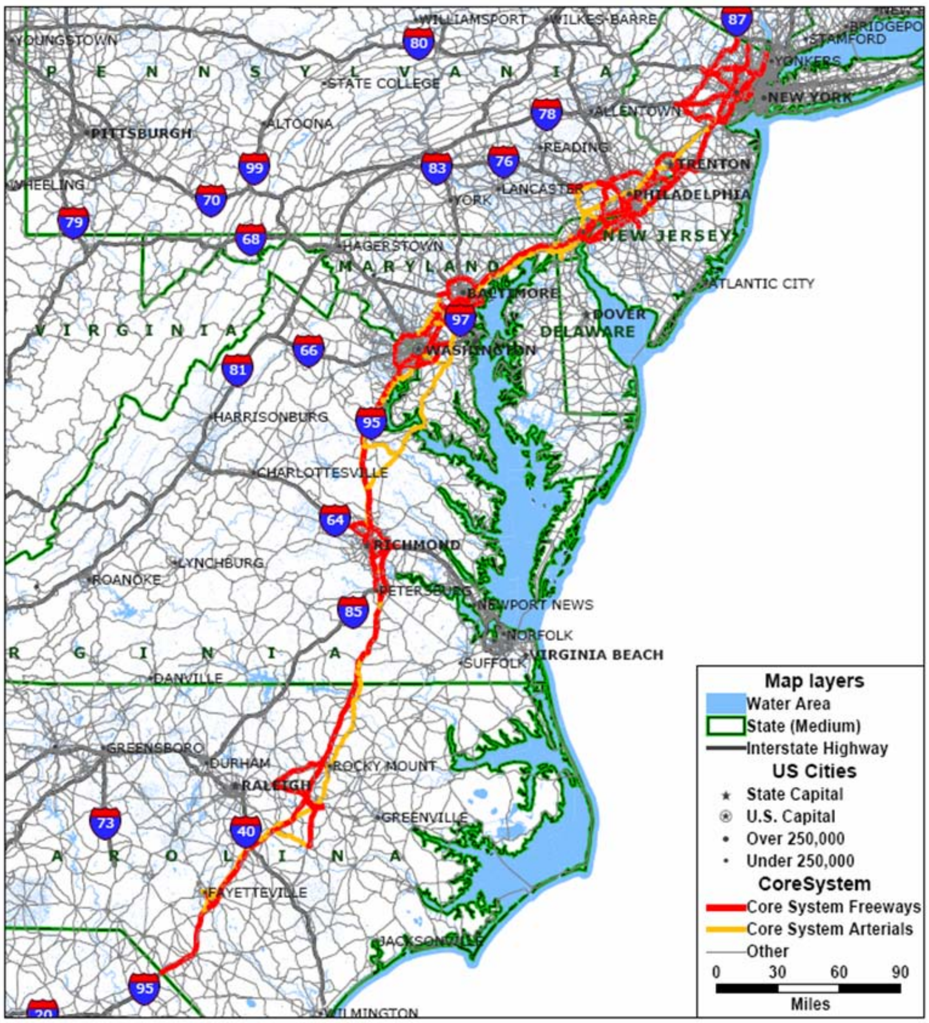

Figure 1 - Freeway and Arterial Network as envisioned, and implemented in 2008 as part of the I-95 Corridor Coalition's Vehicle Probe Project

Future Vision: Where we are going --At the time of this writing, the I-95 Corridor Coalition is planning an additional year of support for the VPP. The plan will expand freeway coverage from Maine to Florida using a cost-sharing concept to encourage additional states to participate. The I-95 Corridor Coalition through the VPP is leading the nation in infrastructure-less traffic monitoring with significant benefits that include cost, coverage, standards, and ubiquity. Some of the remaining challenges are to investigate data quality on arterials for the purposes stated above, to determine the types of arterial facilities to be included, and to establish the appropriate quality specifications for those facilities.

ARTERIAL DATA – ISSUES AND CHALLENGES

As previously mentioned, INRIX donated 1000 miles of arterial data beginning in July 2008. At that time, the specifications were undefined and the quality of the arterial data donated to the project was unknown. Since late 2009, validation data samples have been systematically collected on arterials with the aim to appropriately assess quality and establish specifications. Four primary challenges have emerged as a result of analyzing data on arterials and discussing the application of the data within the committee. These challenges are summarized and discussed topically as the following questions.

- WHAT IS AN ARTERIAL?
- WHAT APPLICATIONS WILL THE DATA SUPPORT?
- WHAT DATA QUALITY SPECIFICATIONS ARE ADEQUATE FOR ARTERIALS?
- ARE THERE ANY UNUSUAL CHALLENGES?

WHAT IS AN ARTERIAL?

While the term 'arterials' from the original RFP encompasses any road that is not a limited-access multi-lane freeway. Through discussion with the arterial data quality committee, and influenced by validation data, the definition of 'arterials' within the context of the VPP is narrowed to reflect higher volume arterials, typically multi-lane facilities that serve major corridor movements. These are typically found in suburban environments and link major freeway facilities or provide alternative parallel paths of sufficient capacity to be used during major incidents as alternative routes. The density of signals is medium to sparse, and mid-block friction caused by access to goods and services is light compared to the through movement traffic. Examples of such roadways include Route 1 between Washington DC and Baltimore, and Route 17 in Northern Virginia.

While the operating characteristics of freeways are homogeneous from region to region and facility to facility, the operating characteristics of arterials (as defined above) are quite broad. These varying operating characteristics present challenges not only in the accurate monitoring of traffic data, but also in the appropriate use of the data in applications. Table 1 attempts to contrast the operating characteristics of freeways versus arterials (with the definition of arterials narrowed as discussed in the previous paragraph.)

Table 1 contrasts arterials with freeways

	Freeways	Arterials
Volume	2200 vphpl	1400 vphpl on green
Speed Range	20-70 mph	10-45 mph
Freeflow	65 mph	Unknown, determined by signal timing
Congestion Types	Recurring / Non-recurring	Cycle Failure / Mid-Block Friction
Congestion Signature / Incident	Slowdowns < 55 mph	Difficult to recognize
Flow characteristic	Uniform	Higher Variance, Frequently Bi-Modal

WHAT APPLICATIONS WILL ARTERIAL DATA SUPPORT?

Since late 2009 validation data samples have been systematically collected on arterials with the aim to appropriately assess quality and establish specifications. This has led to questions of what quality is adequate to support intended applications, and what are the intended applications.

From discussion with the Arterials Committee, a list of target applications was assembled. Several of the intended applications were similar to that of Freeways. These applications included 511 systems, web maps, travel times on signs and operations performance measures (similar to freeways).

However, several potential applications were identified that were unique to the arterial environment. These included traffic signal assessment, transit planning (busses) and optimal routing of transit and inputs into signal analysis software such as Synchro.

WHAT DATA QUALITY SPECIFICATIONS ARE ADEQUATE FOR ARTERIALS?

At this point, the lessons learned from freeways pointed toward several challenges in arterial data as presented here.

Defining and Observing Congestion - Whereas free flow within the freeway environment has common characteristics such as speeds greater than 60MPH, free flow is more difficult to define in terms of speed and travel time for arterials. Each arterial will be unique based on signal timing plans. Furthermore, even on the same arterial, the free flow speed will be different at different times of the day depending on the signal timing plan in effect. In short, the nature of flow on arterials is most dependent on intersection operations, which is highly variable by facility and time of day. As a result, congestion also will be more difficult to identify.

Variations in Flow within Arterials - Even though freeways occasionally exhibit variations in traffic flow in which two distinct speeds are observed, such instances are general treated as abnormalities during validation of freeway data quality. Whenever the traffic flow exhibit two distinct travel time patterns (referred to as bi-modal flow) in the validation data, it was excluded from the validation data because no true mean existed in the ground-truth data. Also, a confidence interval referred to as the SEM band was introduced to account for times during which a large variance in speed was observed (as well as times when ground truth samples were at a minimum) in order to fairly score INRIX accuracy.
In contrast to freeways, large variances and bi-modal flows appears frequently in Arterial data as evidenced from the data gathered to date from the VPP data validation effort on arterials. Figure 5 and Figure 6 show two examples of this.

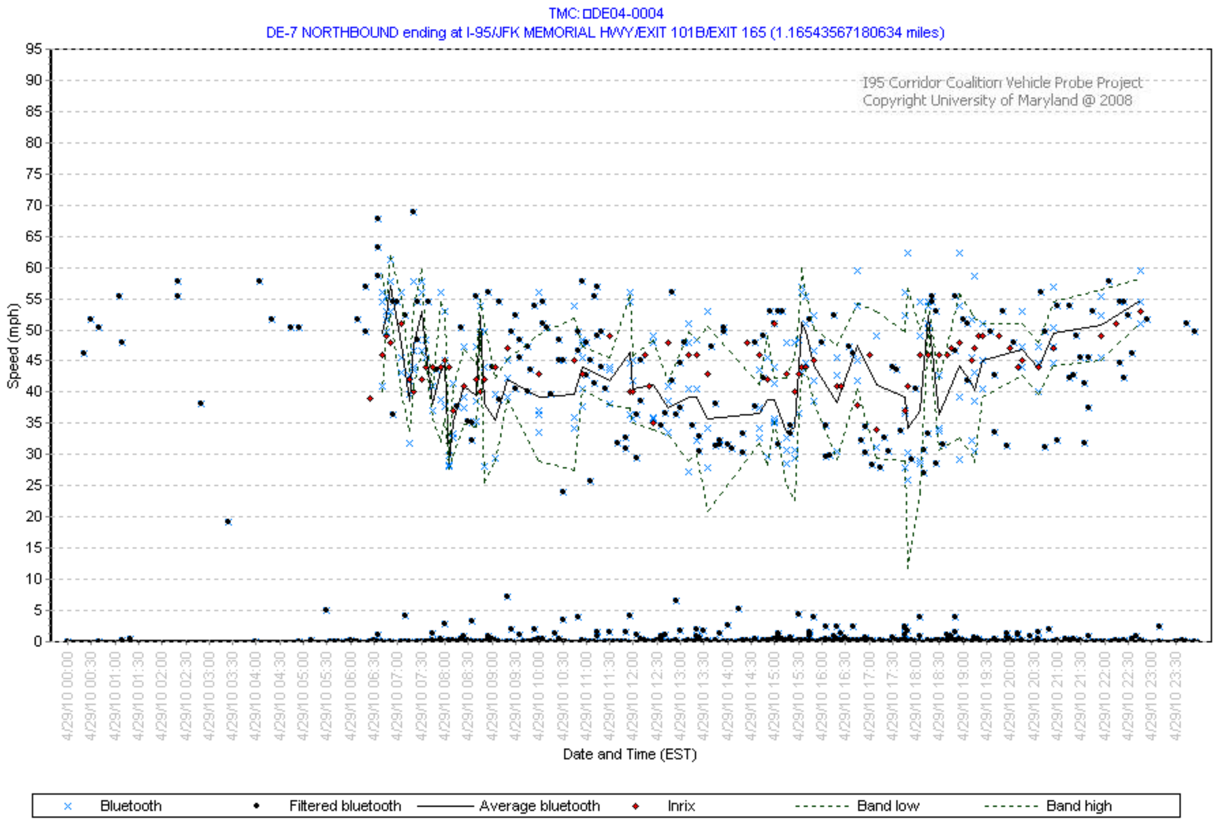

Figure 5 Sample data taken from Route 7 Northbound in Delaware showing two distinct travel time patterns induced by signal operations

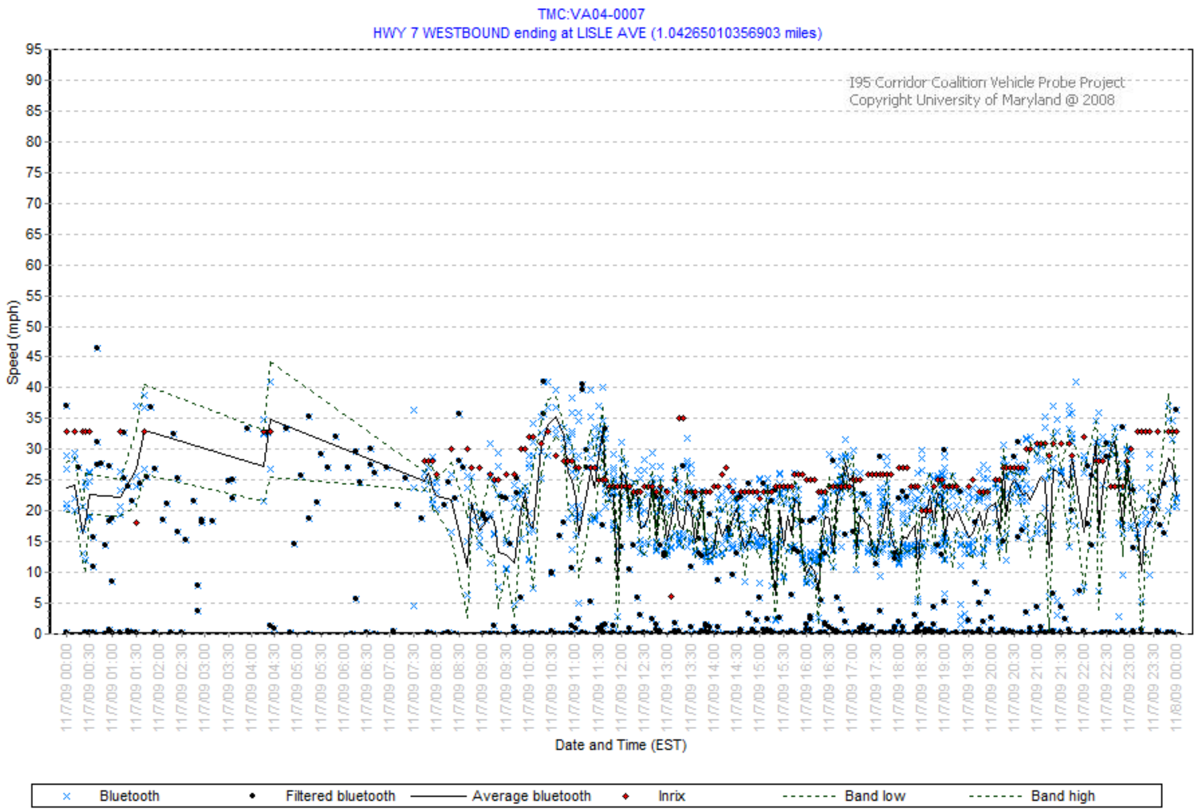

Figure 6 Sample data taken from Highway 7 Westbound in Virginia showing two distinct travel time patterns induced by signal operations.

Note that in Figure 5 and 6, not only were the travel time patterns disperse and bi-modal, but there was also no indication on whether the flow observed was congested or normal for that facility. Speeds were much slower as compared to freeways, and the variation in speed much greater relative to the mean speed. The bi-modal distributions are not unexpected on arterials due to the nature of traffic signal operations in which a portion of vehicles progress through on green and a portion are stopped on red and wait through the cycle for the next green phase.

Temporal Reporting Requirements - While temporal reporting requirements were set at a minimum of five-minute updates, with an eight-minute data lag, indications are that arterial traffic patterns many need to be analyzed and observed over larger time windows in order to adequately characterize the nature of the traffic flow. As a result, minimum reporting intervals of ten minutes may be more appropriate. Validation that is currently summarized to five-minute time intervals on freeways may be more appropriately summarized over a ten- or 15-minute time interval on arterials. It is not expected that the minimum reporting interval will be changed from that of freeways, however, use of the data for applications may need to take into account timing constraints induced by traffic signals.

Lessons Learned

The nature of traffic flow on arterials is fundamentally different creating significant challenges as below.

- Large variance and bi-modal flow are frequent and the methods currently used for freeways are inadequate for arterials.
- Detecting congestion versus normal or planned operations is more difficult, speed categorization used for freeways does not (or may not) separate flow into congestion levels.
- Lower volumes and compressed speed ranges enhance the difficulty of specifying and validating quality metrics.
- The temporal reporting requirements for arterials should be less stringent than freeways (or may need to be taken into account when used in applications).

ARE THERE ANY UNUSUAL CHALLENGES?

Traffic Message Channel (TMC) codes are currently used by INRIX, as well as by most commercial traffic data suppliers, to define roadway segments. These TMC codes, which are maintained as a proprietary industry standard, define the geographic extents upon which speed and travel time are reported. The segmentation based on TMC codes are used to build logical reporting segments. For example several TMC segments may comprise the freeway between two major interchanges. The individual travel times of the TMC segments are combined (sometimes with special algorithms) to develop a travel time estimated for a freeway corridor between major interchanges or landmarks, referred to here as a path. This is needed to enable applications such as reporting travel times on freeway message signs. For freeways, the speeds and travel times reported in the VPP are interpreted for through movements. When a travel time is needed for a path that encompasses more than one freeway, the delay at an interchange connecting the respective freeways is ignored, with little impact. (Note, at the present freeway ramps are not included in the VPP, though they are anticipated to be available for freeway to freeway interchanges within the next year.) Even though reporting using TMC codes does not include ramps at present, it does include a fine grain resolution within interchanges so that various turning movements onto ramps can be somewhat isolated.

The method used to define arterial segments emerged as a special challenge in light of the use of TMC codes. The adequacy of TMC codes to reflect arterial traffic flow is unknown at this time. Specific to arterials, TMC knowledge and concerns include:

- TMC segments typically reflect roadway segments between intersections of major arterials or between a major arterial intersection and access to a freeway.
- The method employed by TMC codes to model turning movements internal to the intersection is not well understood. It is unclear whether TMC codes reflect turning movements at all, and if they do, how it is coded. This is more critical in arterials because delay at intersections contributes to the overall travel time more than ramp movements do on freeways.
- Current reporting of travel time on freeways using TMC codes indicates travel time between interchanges. Does the travel time include queue delays at the upstream interchange? At the downstream interchange? This reporting impacts the method of validation.
- Are travel times that are currently reported for arterials only reflecting through movement at the intersection? Can or should they be combined together to form path travel times similar to freeways when the path includes rights turn and left turns?

- How are segment lengths for TMC codes defined, particularly if the segments are internal to the intersection?

In summary, several issues related to TMC codes were identified and discussed during the Webinar on July 14, 2010 as shared above. The adequacy of TMCs to capture the arterial network logic is not well understood, and continues to be studied. A general consensus emerged from the committee to continue to investigate, with INRIX volunteering to investigate the issues raised.

CONCLUSIONS AND ACTION ITEMS

As a result of the investigations and collaboration to date, a list of recommendations for moving forward with arterial traffic monitoring has been developed. In many respects these recommendations are given as a first guess until additional information or knowledge is gained. These 'strawman' data quality specifications and validation methods are intended to evoke further debate, investigation, and discussion. Also highlighted are areas for further investigation.

Definition of Arterials

Arterial traffic monitoring within the VPP is limited to higher volume arterials, typically multi-lane facilities that serve major corridor movements, within low signal density and low to medium mid-block friction.

Measures to be Reported

Similar to the freeways, traffic monitoring will include:

- Travel Time (Space-mean speed)
- Confidence Value

In contrast to freeways, the following parameters are suggested or emphasized:

*Historical / 85th Percentile***:** Already provided in the freeway data, these parameters will be more critical in order to detect congestion or incidents.

A measure of variance or dispersion: The large variation in flow observed in sample data suggests that some type of variance measure may be needed to characterize traffic flow.

A flag to indicate type of flow (for example bi-modal flow). In conjunction with or as a compliment to the suggested variance measure, an indicator of bimodal or other unusual is needed.

Suggested Quality Specifications

- Retain the 10mph AASE / 5mph bias at present
- Use a speed bin scheme as follows: >45 mph; 30-45mph; 15-30mph; <15mph
- Temporal Requirement:
    - Data Lag – eight minutes

  - Minimum reporting interval : once every 5 minutes
  - Validation will aggregate data into 10 minute bins for accuracy assessment.
  - Minimum Flow Requirement: > 500 vph flow

Segment Definition

- Continued research on how TMC codes reflect arterial network logic. INRIX volunteered this as an action item for future reporting.
- Travel time for a TMC segment is defined as departure from the upstream intersection to departure from the downstream intersection (includes downstream queue delay but not upstream queue delay)

Definitions, specifications, and methods will need to remain flexible as more data and experience using the data is obtained. Unlike freeway traffic data in which many mature applications were available from which to define data quality specifications, arterial traffic monitoring and its associated applications are not as mature. As such, the data quality specifications, and methods of implementation outlined above will need to be remain pliable as experience and knowledge grow in this area.

APPENDIX - LESSONS LEARNED FROM FREEWAYS

The original data quality specifications in the VPP were developed primarily for freeway traffic data in order to support various anticipated applications. Although developed primarily with freeway applications in mind, these specifications and the methodology for validation form the default lens through which arterial data is initially investigated and analyzed. By reviewing the freeway specifications and lessons learned, the challenges of monitoring arterials are brought into sharp focus.

Requirements were characterized both objectively and subjectively in the RFP. When possible, specifications were explicitly stated (such as accuracy and data-lag). In other cases the quality concerns were described subjectively in the RFP, and vendors were directed to respond with solutions that may be customized to their approach (such as the need for a confidence measures). The data items and related specification for the Vehicle Probe Project are below.

Defined data items provided by the Traffic Monitoring System

Mean Travel Time (space-mean speed) - The primary traffic data item is the mean travel time and speed on a segment. The speed was explicitly defined as the space mean speed. This was originally included to clarify how the system would be validated. Speed comparison for validation purposes were obtained by direct measures of travel time converted to speed.

Confidence Measure – (Score and Value) - The Coalition anticipated a need for a metric that reflected the relative confidence of the travel time / speed estimate. At the time of the RFP, several vendors and several different technologies were competing. As most technologies were sampled (either from fleet GPS, or cell phones, or other electronic means), the Coalition anticipated that there would be times in which the traffic volumes would be insufficient to provide a sampled travel time with any degree of confidence. The RFP required a confidence value to reflect the uncertainty in the travel time estimate, so that ultimately this could be used in applications to determine when and if to use the data (such as posting travel time on signs.) When INRIX was awarded the contract in 2007, the Coalition worked with INRIX to define an appropriate measure (Score), this was later amended to include another confidence measure (C-Value). The reader is referred to the I-95 Vehicle Probe Project Interface Guide for further details on the definition of these measures. A similar approach is anticipated for some of the special challenges with arterials.

The RFP also invited vendors to include additional measures. Historical & Expected Travel Time were suggested and provided by INRIX as part of the contract. These measures have proved beneficial in the overall data system in order to determine when traffic flow is deviating substantially from normal conditions. *(The reader is referred to the I-95 Vehicle Probe Project Interface Guide for further details on these metrics.)* It is anticipated that these measures (or similar measures) will prove invaluable for arterials due to the difficulty of identifying congested flow as explained later.

Overview of Quality specifications

The RFP called out specific quality specifications with freeway traffic monitoring in mind. The following summarizes these specifications. Full details are available in the RFP and resulting contract.

Average Absolute Speed Error - 10 mph maximum - The primary accuracy specification for travel time/ speed data is the Average Absolute Speed Error (AASE). The average allowed maximum deviation is 10 MPH. Previous work typically had specified a percentage based accuracy, such as 5 percent or 10 percent error. Upon review, most targeted applications were for the detection and assessment of congestion. Ten percent speed error during congested freeway flows when traffic slows to less than 30MPH would allow for an error of three mph, while free-flow at 60 mph would allow for six mph error. An overall absolute speed error rather than percentage based was chosen to better reflect application needs. When applied to the speed bins, as described below, this approach has proven critical in monitoring the quality of the data feed over time and isolating the performance of the system during congested periods.

Speed Error Bias (+/-5mph) - In order to assure that the data feed did not consistently over estimate or underestimate the traffic flow, a maximum speed error bias (SEB) was also specified. It was also applied in all four speed categories similar to the AASE.
Application of Quality Metrics in Four Flow Regimes (speed bins) - At the time of implementation, several demonstrations of non-intrusive technologies had been performed. From those demonstrations it was learned that applying any accuracy metric across all time did not adequately reflect the ability of the system to accurately characterize traffic flow. Rather than apply the AASE and SEB to all data, the data was first grouped into four speed bins as described below. The philosophy was that in grouping the data into four speed categories, the performance of the system during congested periods would be isolated by observing the performance in the lower two speed bins (that is speeds less than 45 MPH). Without breaking data into these categories, the relative quantity of free-flow data during off-peak hours (times when it is easiest to estimate travel time and speed) compared to data from congestion periods would be so great that it would mask any quality issues in the accuracy statistics. The four speed bins are presented here.

<30mph	Severe congestion
30-45mph	Congestion
45-60mph	Maximum capacity
>60mph	Free-flow

More than two years of validation experience on freeways has confirmed this approach. A similar approach for arterials is required. The speed bins can be adjusted appropriately for arterials, however arterials differ in that speed thresholds cannot be used universally to identify congested flow. A 20mph average speed on one arterial may indicate free-flow on one facility, while it indicates congestion on another, or congestion on the same facility, but at a different time of day when a different traffic signal plan is in effect.

Temporal Requirements - The RFP specified the maximum delay between the time when a slow-down occurs on the roadway and the time when it is reflected on the data feed of eight minutes (eight minutes Data Lag). The data feed was to supply speed and travel time estimates at intervals no longer than five minutes (five minute update (1 min update in practice)).

Volume Requirements (In effect for flows >500 vph) - The quality specifications are in effect only when vehicle flows exceed 500 vehicles per hour per direction. This clause was added to account for the sampling nature of most non-intrusive technologies. In brief, it relieved the contractor from monitoring freeway flows in the middle of the night with only token freeway traffic. This is also critical for arterials where volume flows are about half that of freeways with a similar number of lanes.

Critical Lessons Learned from Freeway Traffic Monitoring

Accuracy during abnormal flow is primary indicator of system performance - The validation process uses Bluetooth Traffic Monitoring (BTM) technology to capture ground truth data and compare to the data feed. These validation exercises are performed monthly. Typically they capture the flow pattern from eight to ten freeway segments for a period of seven to ten days. The data from each segment is scrutinized to determine if the INRIX data feed responded adequately during congestion events (recurring congestion, incidents, and road construction). Graphs of the data from congestion events provide a visual indication of quality. The performance of the lower two speed bins provide an objective measure of the performance of the data feed during congestion events. See sample freeway chart in Figure 2.

<30mph & 30-45mph bins reflect ability to capture congestion while monthly validation ensures quality and flag data abnormalities.

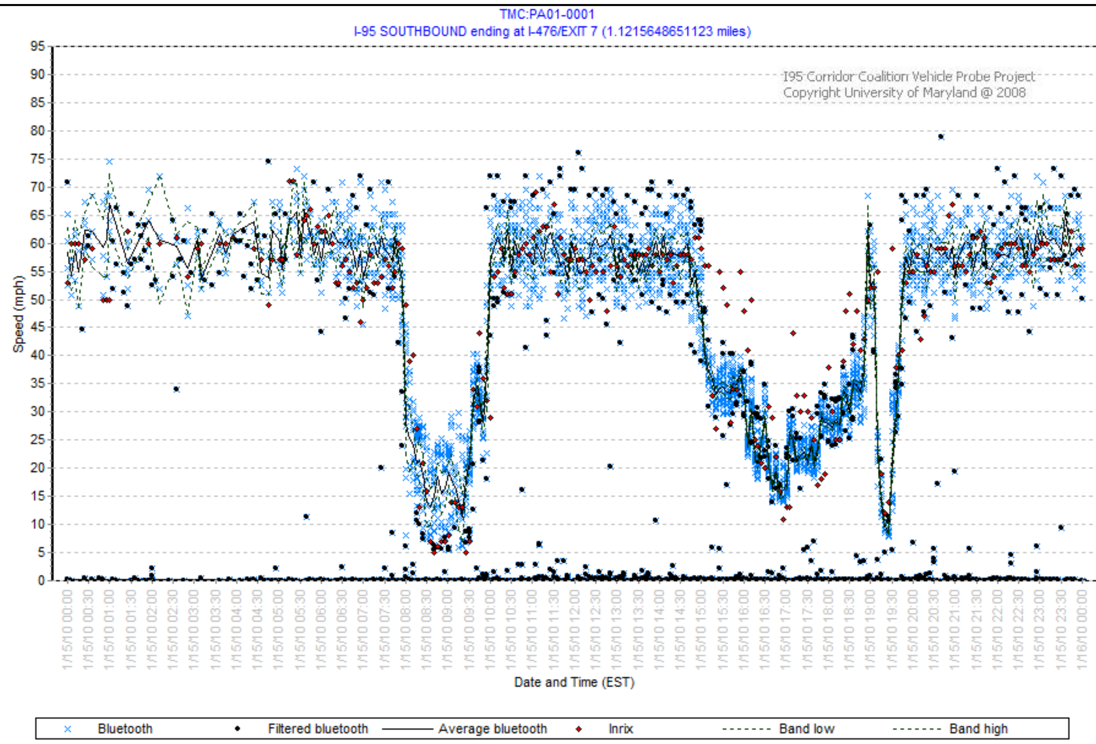

Figure 2 Sample of a comparison of INRIX data (shown in red) with BTM ground truth (shown in Blue) over a 24 hour period with AM and PM congestion

The variation in Travel Time and Speed is larger than anticipated **-** BTM is a re-identification technology that samples the travel time of approximately one in twenty vehicles. This provides a sample large enough to observe both the mean and variance of the traffic flow and to estimate volume of flow. As a result of the validation activities with BTM, the Coalition has been able to observe the performance of the INRIX data feed in relation to large and small variations in traffic flow. An example of the fluctuations in the variance of travel time is illustrated in Figure 3. As a result of the ability to assess traffic flow variance, the validation methodology was amended to account for large variations in travel time in the ground truth data. A Standard Error Measure (SEM) band was defined that captures the interval about the mean of the validation data that provides a 95% confidence interval of the actual mean travel time.

Lessons learned:
- Travel time variation was larger than expected on freeways
- Data quality specification and validation methods must account for such variations

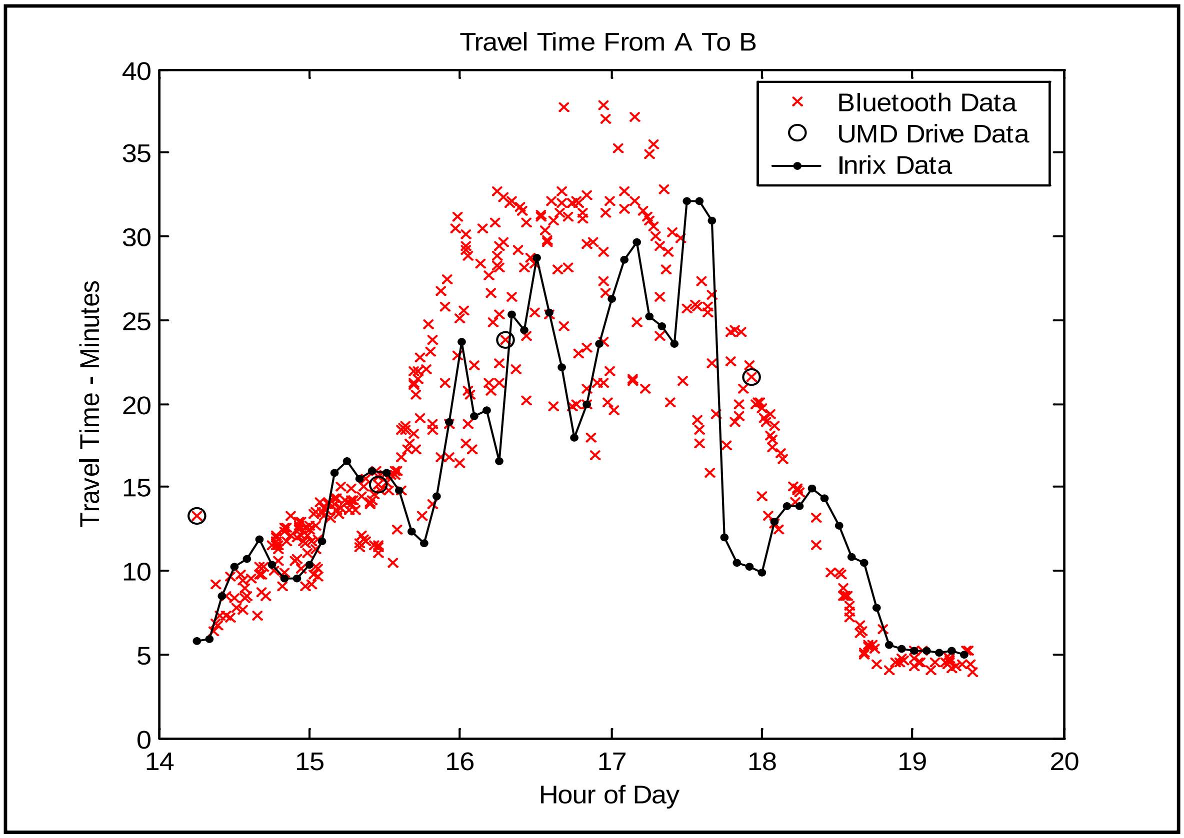

Figure 3 - Comparison of pre-production INRIX data to BTM data on a section I-495 during a congestion event.

As shown in Figure 3, the Bluetooth data (shown in red) reflects the large variation in travel time experienced by drivers during the congestion event. This takes on greater significance on arterial data when variance has been observed that is larger than that of freeways.

Non-Uniform flow patterns - Unusual or non-standard traffic flow characteristics were observed in the freeway validation data on occasion. These flow patterns were typically associated with the presence of one or more of the following: Local / Express Lanes / HOV / Truck lanes / Weigh Stations / Steep Grades / Exit Ramp Queues. The validation data at such times reflected two distinct travel time patterns in which a portion of traffic moved at a slower speed than the rest of the traffic flow. See Figure 4 for an example. These travel-time patterns, referred to as bi-modal distributions, were omitted from the validation when observed. Non-uniform flows were omitted because the calculated mean travel time did not reflect a central tendency of the bi-modal traffic stream, but was only a statistical abstraction. Uniform flow was typical for freeways, even during congestion. Non-uniform flow was monitored and omitted from validation results

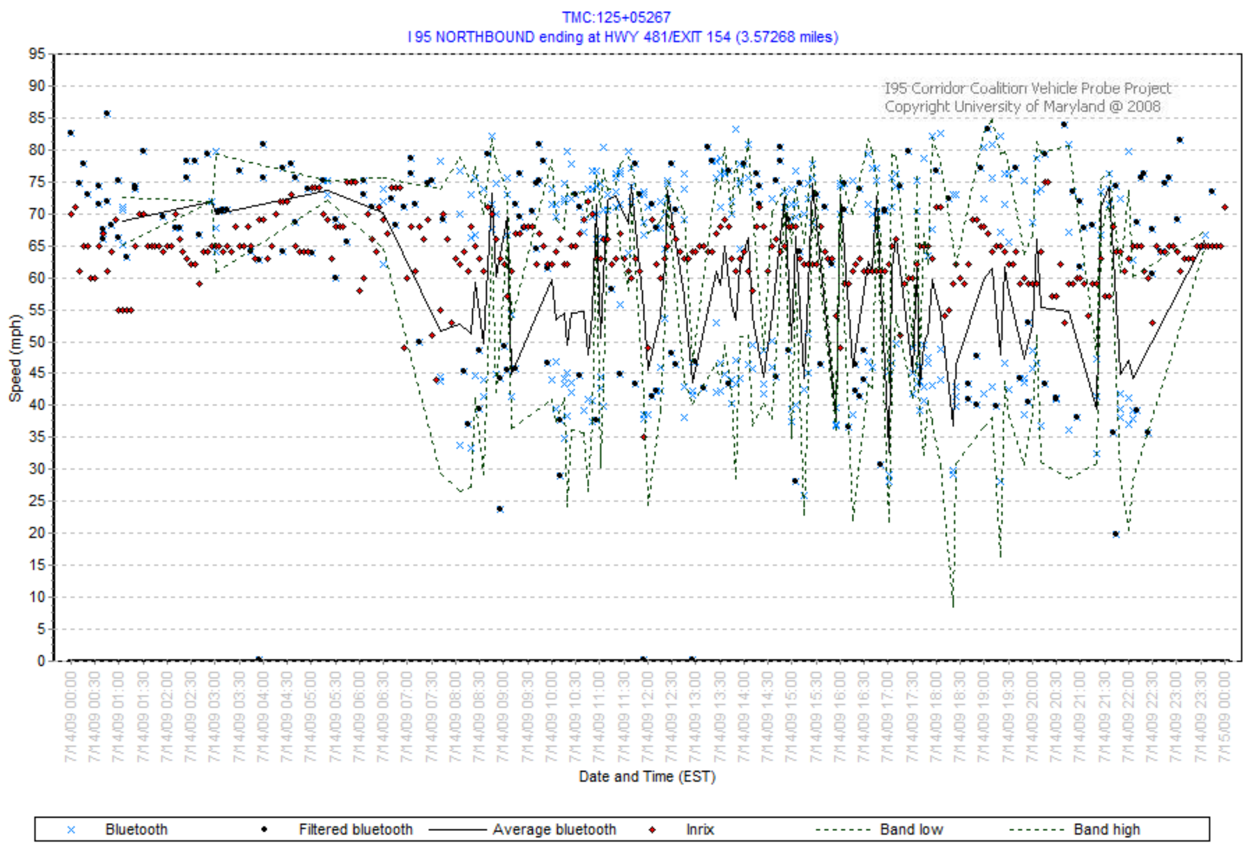

Figure 4 - An example of non-uniform flow.

As presented in Figure 4, a weigh station is present on this validation segment. Two distinct travel time patterns are evident from 8AM to 10PM, reflecting the use of the weight station by trucks as opposed to passenger vehicles on the main line. The validation data from arterials collected to date indicates a high prevalence of bi-modal flow due to the effect of signalization. In freeway segments it appears that only a modest percentage of segments have bimodal flow effects, while on arterials bimodal effects are more the norm.